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Habitat Assessment and Salmon Life-Cycle Models for the Chehalis Basin Aquatic Species Restoration Plan: Summary of Research Products

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1. Introduction

A key element of the Aquatic Species Restoration Plan (ASRP) for the Chehalis Basin is habitat restoration for anadromous salmonids of economic and cultural significance, including spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead (*O. mykiss*), and chum salmon (*O. keta*). To assist with development of the Chehalis River basin Aquatic Species Restoration Plan (ASRP), the National Oceanic and Atmospheric Administration (NOAA) Northwest Fisheries Science Center developed a suite of analyses and life-cycle models to (1) assess habitat changes from historical (pre-Euro-American settlement or natural potential) conditions to present, (2) evaluate which types of habitat changes most limit rebuilding of salmon populations within the Chehalis Basin, and (3) model future restoration scenarios for the ASRP. The identification of habitat restoration potential using diagnostic scenarios was intended to help identify key restoration actions for salmon populations in the basin, and the restoration scenario analysis was intended to estimate potential benefits of proposed restoration actions.

This final report summarizes the suite of products from the NOAA watershed assessment and life-cycle model, focusing on products that support the Aquatic Species Restoration Plan. (NOAA was also contracted to assist with federal and state Environmental Impact Statements, which are summarized in separate reports.) We note that throughout development of the Phase 1 and Phase 2 products for the ASRP, this suite of assessments and models was referred to as the NOAA Model. Once those products were completed and we focused on producing peer-reviewed journal articles to support the ASRP, the suite of models was modified to include stochasticity in stream flow and temperature and renamed the Habitat Assessment and Restoration Planning Model, or HARP Model.

We first provide an overview of the model development (Section 2), including a model change log documenting the model development (Beechie et al. 2021b). We then summarize the Phase 1 and Phase 2 NOAA Model report products (Section 3), including (1) the Phase 1 contract report summarizing results of the NOAA Model Version 13 (Beechie et al. 2021b), (2) the Phase 2 contract report summarizing the chum salmon model that was part of the NOAA Model Version 14 (Beechie et al. 2021c), and (3) one journal article describing the riparian assessment and shade-temperature model (Seixas et al. 2018). The HARP Model report products (Section 4) include (1) two journal articles summarizing results of the watershed assessment and diagnostic life-cycle model analysis (Jorgensen et al. 2021, Beechie et al. 2021a), (2) two journal articles summarizing results of climate change analyses for increasing peak flow and increasing stream temperature (Nicol et al. 2022, Fogel et al. 2022), and (3) one journal article examining the potential for habitat restoration to increase resilience of Chehalis basin salmon populations to climate change (Beechie et al. 2023). We also produced a number of data products that are publicly available, including data sets that support NOAA Model Version 13 and the ASRP model results, and data sets and model code that support the HARP Model and journal articles (Section 5).

2. Overview of Model Development

We began the model development in late 2015, with much of the effort over the first two years focused on assessing current and historical habitat conditions and beginning development of the life cycle model. Model development continued in late 2017 and into 2018, and in mid-2018 the Life-cycle Model Workgroup was formed to review model components and provide feedback on the model structure and functions. We worked with the Workgroup through the end of 2019 to finalize Version 13 of the NOAA Model, which was used to run all Phase 1 analyses including the diagnostic model runs and the ASRP/climate change model runs for coho salmon (*Oncorhynchus kisutch*), spring- and fall-run Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*). The Phase 1 report was completed in January of 2020. Once Phase 1 was complete, we developed the Phase 2 chum salmon model (Version 14 of the NOAA Model), and finalized the chum model and report in July of 2020. Both reports have since been published as NOAA contract reports (Beechie et al. 2021b, 2021c).

Planned Phase 3 model updates were not requested by the Chehalis Basin Science Review Team, so we focused our attention on refining model functions and completing the remaining contract tasks. The remaining tasks included incorporating additional climate change effects on peak flow and low flow and incorporating stochasticity in flow and temperature metrics into the model. Those elements were developed in late 2020 and the model was renamed the HARP Model. The HARP Model is capable of running scenarios with stochastic annual variations in peak flow, low flow, and summer stream temperature, and the model can be run with or without stochastic effects. The HARP Model was used in the analyses for the five journal manuscripts that were published from 2021 to 2023.

2.1 Model Concept and Structure

The NOAA Model and HARP Model have the same underlying concept and structure. Briefly, the habitat assessments and life-cycle models are founded on a process-based conceptual model that links landscape processes to habitat conditions, and then habitat conditions to salmon populations (vertical direction in Figure 1). The analysis itself evaluates how habitat-forming processes, habitats and salmon populations have changed from historical to current conditions, and how climate change and future habitat restoration may influence salmon populations in the future (horizontal direction in Figure 1). The key questions we address with this suite of analyses are

1. How have past habitat changes affected salmon populations?
2. What are the causes of past habitat changes?
3. Which restoration actions will most benefit salmon populations and increase salmon resilience to climate change?

Functionally, the model analysis sequence includes a spatial analysis, a habitat analysis, and the life-cycle models (Figure 2). The spatial analysis includes GIS analyses (primarily

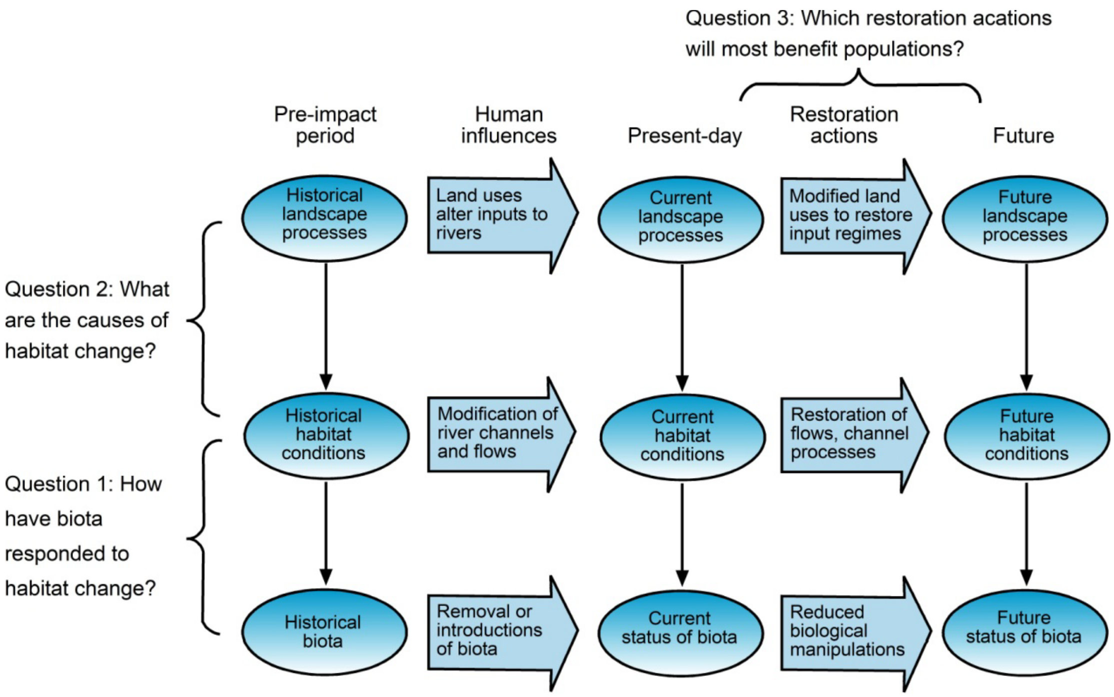

Figure 1. Schematic diagram of process linkages and analysis questions that guide our analysis. Figure from modified from Beechie et al. (2010). Note that present to future (Question 3) also includes future climate change effects.

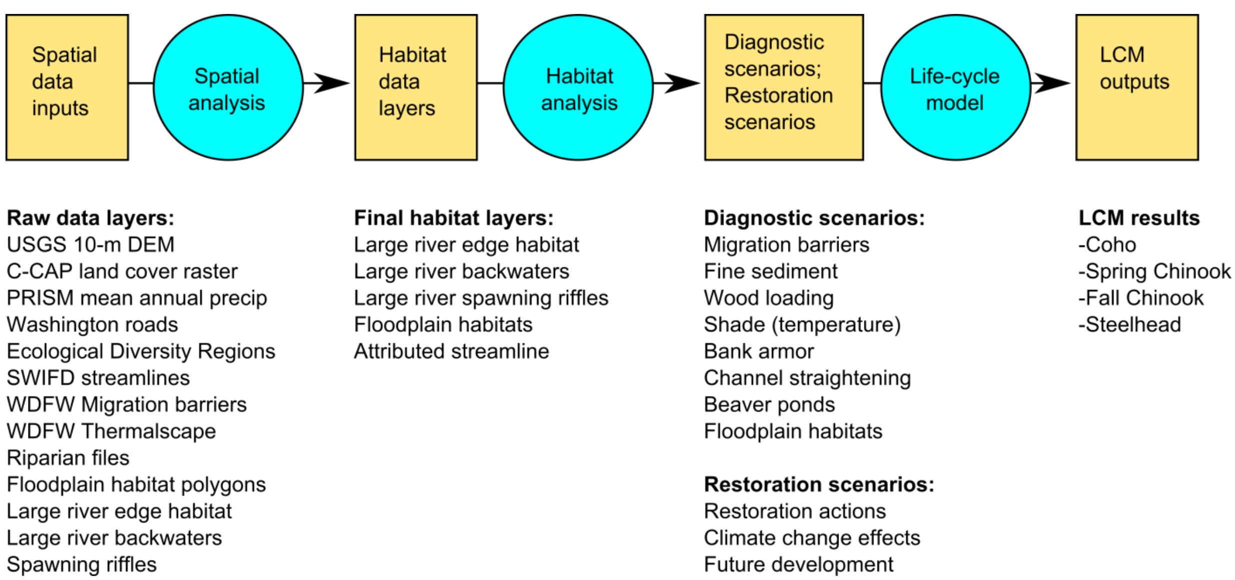

Figure 2. Illustration of the analysis steps, proceeding from the raw data layers, to habitat data layers, to habitat scenarios, and finally to the life-cycle model (LCM) outputs. C-CAP is NOAA's Coastal Change Analysis Program; SWIFD is the State-Wide Integrated Fish Distribution from the Washington Department of Fish and Wildlife (WDFW).

Python code) that import raw data layers and produce a set of five habitat data layers that become the inputs to the habitat analysis. The habitat analysis (primarily R code) uses the five habitat data layers and other information to produce historical and current habitat conditions for each reach in the basin, which are then used to produce (1) up to eight individual diagnostic habitat scenarios, (2) one climate change scenario for the mid- and late-century time periods, and (3) three future restoration scenarios. Finally, the life cycle models (R code) run each diagnostic and future scenario to estimate which habitat restoration actions are most likely to increase spawner abundance and increase resilience to climate change for each modeled species (coho salmon, spring-run Chinook salmon, fall-run Chinook salmon, steelhead, and chum salmon). The model concept and structure are detailed in Beechie et al. (2021b).

2.2 Development of the NOAA Model: Versions 13 and 14

The NOAA Model was developed with the substantial involvement of the Life-cycle Model Workgroup. Responses to queries from the Workgroup and model changes were documented in a change log so the Workgroup could track differences among the model versions (Beechie et al. 2021b). In general, the Workgroup first focused on development of the coho salmon model, followed by the spring- and fall-run Chinook models, the steelhead model, and finally, the chum salmon model. The Workgroup aimed to ensure that the life cycle structure and life stage parameters were realistic representations of each species' life cycle, and that habitat condition estimates were accurate reflections of habitat conditions in the basin. These models were deterministic, and only included fixed estimates of changes in future stream temperature and low flow in the restoration scenarios. The models were used to evaluate diagnostic scenarios that illustrated how natural habitat potential and past habitat changes determine restoration potential for each action type, as well as to run future climate change and restoration scenarios to inform development of the ASRP (Beechie et al. 2021b). The final NOAA Model data, reports, and code are available at https://www.fisheries.noaa.gov/resource/tool-app/chehalis-watershed-assessment-and-salmon-life-cycle-modeling.

2.3 Transition to the Habitat Assessment and Restoration Planning (HARP) Model

Once we completed the Phase 1 and 2 analyses for each species, we focused on refinement of V13/14 model components, as well as adding climate change and stochastic effects to meet the remaining contract obligations. We focused on four model refinements for peer review: (1) simplifying the stream temperature model to one model only (Thermalscape) (Winkowski and Zimmerman 2018), (2) refining the coho salmon temperature response to be more consistent with the scientific literature, (3) changing the form of the egg capacity function from hockey-stick to Beverton-Holt, and (4) standardizing the method for estimating spawning capacity in small streams across species. The net effect of the combined changes was small, although each individual effect could increase or decrease in spawner abundance on its own. We renamed this version of the model the Habitat Assessment and Restoration Planning (HARP) Model. These changes are reflected in the first two journal articles we produced, which describe the habitat analysis and life cycle models for the diagnostic scenarios (Jorgensen et al. 2021, Beechie et al. 2021a). These model runs were deterministic (no stochasticity), and they only addressed effects of past habitat changes on restoration potential.

We subsequently added stochastic variation in peak flow, low flow, and stream temperature to the HARP Model. We first analyzed the individual potential effects of increasing peak flows and stream temperatures in separate manuscripts (Nicol et al. 2022, Fogel et al. 2022), and later analyzed the combined stochastic effects of increasing peak flow, increasing temperature, and decreasing low flow, as well as the potential for habitat restoration to increase salmon resilience to climate change (Beechie et al. 2023). The HARP Model products are summarized in Section 4 of this report. The final HARP Model data, publications, and code are available at https://www.fisheries.noaa.gov/resource/tool-app/salmon-habitat-restoration-planning-harp-model.

3. NOAA Model Phase 1 and 2 Products

The primary products of the NOAA Model were the Phase 1 Report to support development and refinement of the ASRP, the Phase 2 Chum salmon model report, and one journal article describing our lidar based assessment of riparian shade and stream temperature (Seixas et al. 2018).

3.1 Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-cycle Model

Timothy J. Beechie, Colin Nicol, Caleb Fogel, Jeff Jorgensen, Jamie Thompson, Gus Seixas, Josh Chamberlin, Jason Hall, Britta Timpane-Padgham, Peter Kiffney, Spencer Kubo, Jenna Keaton. 2021. NOAA Contract Report NMFS-NWFSC-CR-2021-01. NOAA Fisheries, Seattle, Washington.

The Phase 1 Contract Report includes the complete description of the NOAA Model Version 13, as well as results that were relevant to the Chehalis basin Aquatic Species Restoration Plan. The report includes eight sections and twelve appendices. Each is summarized briefly here.

1. Introduction

The Introduction describes the purpose of the project and the context of this project relative to the Chehalis Basin Aquatic Species Restoration Plan (ASRP). It also includes a brief overview of the model and analyses.

2. A Process-based Assessment Approach

The NOAA Model approach is based on four process-based principles for restoring river ecosystems (Beechie et al. 2010). These principles gave rise to the restoration questions we answered in this study (described in Section 2.1, above), and helped define the range of watershed process assessments, habitat assessments, and life-cycle models needed to answer them.

3. Overview of the NOAA Model

The NOAA Model components (illustrated in Figure 2 above) include the spatial analyses used to produce the habitat data sets needed to estimate life-stage capacities and productivities, the habitat analyses that produce the diagnostic and restoration scenario input data for the life-cycle models, and the life-cycle models that calculate spawner abundance for each species and subbasin under each scenario.

4. Life-cycle Model and Scenario Descriptions

The life-cycle model chapter provides much greater detail on each species' life-cycle model, including diagrams of the life cycle, descriptions of the life stages, density and productivity parameters for each life stage and habitat type, and descriptions of the diagnostic scenarios.

5. Diagnostic Scenario Results

Diagnostic scenario results at the basin scale illustrate which types of restoration actions are likely to most benefit each species, indicating that coho salmon may most benefit from restoration of floodplain and beaver pond habitats, spring-run Chinook may most benefit from shade, wood, and floodplain restoration, and fall-run Chinook and steelhead may most benefit from wood and floodplain restoration. Diagnostic results also vary by subbasin for each species, indicating that some areas have much higher restoration potential for each action type.

6. Potential Restoration Options

The diagnostic analysis indicates that floodplain and wood restoration are likely to benefit all four species, whereas beaver pond restoration primarily benefits coho salmon and temperature reduction (shade and floodplain restoration) most benefits spring-run Chinook. Barrier removal is locally important for coho and steelhead, but does not provide a large benefit for any species at the basin scale. Although the model results indicate that all species are very sensitive to fine sediment levels, we do not have sufficient fine sediment data to know if and where fine sediment levels are high, nor do we have sufficient information on sources of fine sediment to recommend sediment reduction actions and locations. An inventory of fine sediment levels and sources in the basin is a logical next step.

7. Restoration Scenario Results

The climate change and restoration scenario results indicate that spring-run Chinook salmon are most sensitive to increasing stream temperatures, and that even with ASRP Scenario 3 restoration effort, spring-run Chinook may decline from current levels. Nonetheless, Scenario 3 restoration effort will substantially improve late-century spring-run Chinook abundance over the no-action scenario. Coho and steelhead are only slightly less sensitive to temperature increase, and Scenario 3 restoration effort could maintain coho and steelhead abundance above current spawner returns into late century. Fall-run Chinook are least sensitive to climate induced temperature increases in the NOAA Model, but are also less responsive to the modeled restoration actions.

8. Model Uncertainty and Sensitivity

Model uncertainties include model form uncertainty, parameter uncertainty, and scenario uncertainty. We discuss the implications of each form of uncertainty for the model results. Model form uncertainty refers to uncertainties in model structure, including how functions are written and which functions are included or not included. Parameter uncertainties include measurement error, extrapolation error, and natural variation. Scenario uncertainties include uncertainties in prediction of future climate or human development, as well as uncertainties in projected restoration actions. We also describe the results of the sensitivity analysis, which indicates which life-stage capacities and productivities most influence the model results.

Appendix A. Riparian Assessment

The riparian assessment appendix describes methods for estimating wood recruitment potential, canopy opening angle, and effect of canopy opening angle on stream temperature. The results indicate that most of the basin is moderately impaired for wood recruitment, but a relatively small proportion of the stream length is impaired for canopy opening angle and increased summer stream temperature. However lower elevation reaches in the basin tend to have very high temperature naturally (i.e., not as a result of shade loss or floodplain disconnection).

Appendix B. Hydrologic Assessment

The hydrologic assessment primarily used the metrics and analysis methods of Indicators of Hydrologic Alteration (Richter et al. 1996), which can identify step changes in flow metrics due to flow regulation by dams or long-term trends in flow metrics. The assessment identified step changes in low flow metrics in the lower Wynoochee and Skookumchuck Rivers when dams were constructed in those rivers. We only identified a significant increasing trend in flood flows at the Newaukum gage. Although the Chehalis River near Doty also showed an increasing trend, that trend appeared to be driven by a single large flood in 2007. Trends in peak and low flows were generally correlated with changes in precipitation.

Appendix C. Fine Sediment Supply Assessment

There were very few fine sediment samples in the basin, and several were in very low energy reaches with very high percentages of fine sediment. There was no clear correlation with potential drivers such as land use or stream power. We therefore used a model that predicted fine sediment as a function of unpaved road density in high energy reaches, and modeled uniformly high fine sediment in low energy reaches based on the local data.

Appendix D. Migration Barrier Assessment

The migration barrier assessment used barrier data from the Washington Department of Fish and Wildlife (WDFW) to create cumulative passage ratings above barriers, which ultimately reduced spawning or rearing capacities above barriers in the life-cycle models.

Appendix E. Small Stream and Large River Habitat Assessment

Habitat assessments were conducted separately for small streams (<20m bankfull width) and large rivers (>20 m bankfull width). Current small stream habitat conditions were estimated by extrapolating habitat data from 339 habitat surveys conducted by WDFW across the basin. Survey data were stratified by slope and land cover classes, and mean conditions from each class were extrapolated to all similarly classified reaches in the basin. Historical conditions were estimated by extrapolating a reference condition to all similarly classified reaches. Current large river habitat conditions were digitized from aerial imagery. Historical conditions were estimated with reference conditions for sinuosity and side channel length, as well as reclassifying all armored banks to natural banks.

Appendix F. Floodplain Habitat Assessment

We mapped historical floodplain habitats using General Land Office survey maps and notes dating from 1853 to 1901, and current floodplain habitats were primarily from the National Hydrography Dataset. Approximately 90% of floodplain habitats have been lost or degraded since the time of the historical surveys.

Appendix G. Delta Habitat Assessment

We mapped historical delta habitats using General Land Office survey maps and notes dating from 1853 to 1901, and current delta habitats were primarily from the National Hydrography Dataset. Bay and tidal channel habitats were mapped from current aerial imagery and bathymetry data. Overall, habitat loss was small in the delta (<25%) compared to floodplain habitat losses.

Appendix H. Estimating Life-stage Capacities and Productivities

Summary of methods and data used to estimate baseline habitat capacity and productivity for each habitat type.

Appendix I. Estimating Changes in Habitat Capacity and Productivity

Description of the model functional relationships that calculate changes in habitat capacity and productivity based on changes in habitat type or quality.

Appendix J. Modeling Future Development and Climate Change

We modeled future changes in developed land area, future stream temperature (a function of climate change, shade, and floodplain connectivity), future low flows, and future peak flows. This appendix describes the methodology for each future scenario.

Appendix K. Study Area

Geology, physiography, climate, and land use in the Chehalis River basin.

Appendix L. Record of Model Changes in the Life-cycle Model Workgroup

List of major model changes made between May 2018 and January 2020.

3.2 Chum Salmon Life-cycle Model Description and Results for the Chehalis River Basin

Timothy J. Beechie, Colin Nicol, Caleb Fogel, Jeff Jorgensen, Britta-Timpane-Padgham. 2021. NOAA Contract Report NMFS-NWFSC-CR-2021-02. NOAA Fisheries, Seattle, Washington.

The Phase 2 Contract Report includes a complete description of the NOAA Model's chum salmon (*O. keta*) life-cycle model. The report includes six sections, which are summarized briefly here.

1. Introduction

The chum salmon model fulfills a contract obligation to model the potential for restoration of chum salmon in the Chehalis River basin.

2. Chum Salmon Life-cycle Model

The chum salmon model has a very simple freshwater life-cycle structure, with all juveniles outmigrating as fry. Adults return at ages 3 to 5 years. The model was calibrated by choosing a target spawner abundance and a target intrinsic productivity from existing data, and then tuning the current condition model to those targets by adjusting fry colonization capacity and productivity, as well as juvenile rearing productivity.

3. Diagnostic and Restoration Scenarios

This section describes the diagnostic and restoration scenarios that were developed for the Phase 1 report and repeated for the chum salmon model.

4. Chum Salmon Model Results

Model results indicated that chum salmon were most likely to respond to fine sediment reduction, and only modestly responsive to increasing wood abundance or floodplain habitat area. Chum salmon were not sensitive to climate change in this model (no peak flow effect on incubation survival included in the model), and the restoration scenarios only produced a small increase in modeled spawner abundance.

5. Discussion

The model has several significant model form uncertainties, including lack of redd scour during peak flows, lack of delta-bay habitat change affecting estuary rearing capacity or productivity (a significant life stage for chum salmon), and lack of variation in marine survival.

6. Conclusions

The model result showing that fine sediment was the most important habitat parameter for chum salmon was robust to a variety of model parameterizations, suggesting that restoration actions targeting the incubation stage may have the largest influence on chum salmon.

3.3. Historical and Future Stream Temperature Change Predicted by a Lidar-based Assessment of Riparian Condition and Channel Width

Seixas, G. B., T. J. Beechie, C. Fogel, and P. M Kiffney. 2018. Historical and future stream temperature change predicted by a lidar-based assessment of riparian condition and channel width. Journal of the American Water Resources Association 54:974–991.

Abstract

Riparian forests attenuate solar radiation, thereby mediating an important component of the thermal budget of streams. Here, we investigate the relationship between riparian degradation, stream temperature, and channel width in the Chehalis River Basin, Washington State. We used lidar data to measure canopy opening angle, the angle formed between the channel center and trees on both banks; we assumed historical tree heights and calculated the change in canopy angle relative to historical conditions. We then developed an empirical relationship between canopy angle and water temperature using existing data, and simulated temperatures between 2002 and 2080 by combining a tree growth model with climate change scenarios from the NorWeST regional prediction. The greatest change between historical and current conditions (~7°C) occurred in developed portions of the river network, with the highest values of change predicted at channel widths less than ~40 m. Tree growth lessened climate change increases in maximum temperature and the length of river exceeding biologically critical thresholds by ~50%–60%. Moreover, the maximum temperature of channels with bankfull widths less than ~50 m remained similar to current conditions, despite climate change increases. Our findings are consistent with a possible role for the riparian landscape in explaining the low

sensitivity of stream temperatures to air temperatures observed in some small mountain streams.

4. HARP Model Products

There were five manuscripts produced using the HARP model (Jorgensen et al. 2021, Beechie et al. 2021a, 2023, Nicol et al. 2022, Fogel et al. 2022). They are listed here along with their abstracts to provide a brief summary of each article.

4.1 A Process-based Assessment of Landscape Change and Salmon Habitat Losses in the Chehalis River Basin, USA.

Timothy J. Beechie, Caleb Fogel, Colin Nicol, Britta Timpane-Padgham. 2021a. A process-based assessment of landscape change and salmon habitat losses in the Chehalis River basin, USA. PLOS ONE 16:e0258251.

Abstract

Identifying necessary stream and watershed restoration actions requires quantifying natural potential habitat conditions to diagnose habitat change and evaluate restoration potential. We used three general methods of quantifying natural potential: historical maps and survey notes, contemporary reference sites, and models. Historical information was available only for the floodplain habitat analysis. We used contemporary reference sites to estimate natural potential habitat conditions for wood abundance, riparian shade, main channel length, and side channel length. For fine sediment, temperature, and beaver ponds we relied on models. We estimated a 90% loss of potential beaver pond area, 91% loss of side-channel length, and 92% loss or degradation of floodplain marshes and ponds. Spawning habitat area change due to wood loss ranged from -23% to -68% across subbasins. Other changes in habitat quantity or quality were smaller—either in magnitude or spatial extent—including rearing habitat areas, stream temperature, and accessible stream length. Historical floodplain habitat mapping provided the highest spatial resolution and certainty in locations and amounts of floodplain habitat lost or degraded, whereas use of the contemporary reference information provided less site specificity for wood abundance and side-channel length change. The models for fine sediment levels and beaver pond areas have the lowest reach-specific certainty, whereas the model of temperature change has higher certainty because it is based on a detailed riparian inventory. Despite uncertainties at the reach level, confidence in subbasin-level estimates of habitat change is moderate to high because accuracy increases as data are aggregated over multiple reaches. Our results show that the largest habitat losses were floodplain and beaver pond habitats, but use of these habitat change results in salmon life-cycle models can illustrate how the potential benefits of alternative habitat restoration actions varies among species with differing habitat preferences.

4.2 Identifying the Potential of Salmon Habitat Restoration with Life-cycle Models

Jorgensen, J., C. Nicol, C. Fogel, and T. Beechie. 2021. Identifying the potential of anadromous salmonid habitat restoration with life cycle models. PLOS ONE 16(9):e0256792.

Abstract

An investigation into the causes of species decline should include examination of habitats important for multiple life stages. Integrating habitat impacts across life stages with life-cycle models (LCMs) can reveal habitat impairments inhibiting recovery and help guide restoration efforts. We developed LCMs for four populations of three species of anadromous salmonids (*Oncorhynchus kisutch*, *O. tshawytscha*, and *O. mykiss*), and ran diagnostic scenarios to examine effects of barrier removal, fine sediment reduction, wood augmentation, riparian shade, restoration of the main channel and bank conditions, beaver pond restoration, and floodplain reconnection. In the wood scenario, spawner abundance for all populations increased moderately (29-48%). In the shade scenario spring Chinook salmon abundance increased the most (48%), and fall Chinook salmon and steelhead were much less responsive. Coho responded strongly to the beaver pond and floodplain scenarios (76% and 54% increase, respectively). The fine sediment scenario most benefitted fall and spring Chinook salmon (32-63%), whereas steelhead and coho were less responsive (11-21% increase). More observations are needed to understand the locations and sources of high fine sediment and its impacts. Our LCMs were region-specific, and we identified places where habitat actions had the highest potential effects. For example, the increase in spring Chinook salmon in the wood scenario was driven by the Cascade Mountains Ecological Region. And, although the overall response of coho salmon was small in the barrier removal scenario (6% increase at the scale of the entire Chehalis River Basin), barrier removals had important sub-regional impacts. This analysis revealed basin-wide and regional population-specific potential benefits by action types, and could be used to develop restoration strategies and guide population rebuilding. An important next step will be to ground-truth our findings with robust empirically-based estimates of life stage-specific survivals and abundances.

4.3 Spatially Overlapping Salmon Species Have Varied Population Response to Early Life History Mortality from Increased Peak Flows

Nicol, C., C. Fogel, J. Jorgensen, and T. Beechie. 2022. Spatially overlapping salmon species have varied response to early life history mortality from increased peak flows. Canadian Journal of Fisheries and Aquatic Sciences. DOI: 10.1139/cjfas-2021-0038.

Abstract

In the Pacific Northwest, USA, climate change is expected to result in a shift in average hydrologic conditions and increased variability. The relative vulnerabilities to peak flow changes among salmonid species within the same basin have not been widely evaluated. We assessed the impacts of predicted increases in peak flows on four salmonid populations in the Chehalis River basin. Coupling observations of peak flows, emissions projections, and multi-stage Beverton-Holt matrix-type life-cycle models, we ran 100-year simulations of spawner abundance under baseline, mid-century, and late-century climate change scenarios. Coho (*Oncorhynchus kisutch*) and spring Chinook salmon (*O. tshawytscha)* shared the highest projected increase in interannual variability (sd = ±15%). Spring Chinook salmon (-13% to -15%) had a greater reduction in median spawner abundance, followed by coho and fall Chinook salmon (-7% to -9%), then steelhead (*O. mykiss)* (-4%). Our results show that interspecies and life history variability within a single basin is important to consider and that species with diverse age structures are partially buffered from population variability, which may increase population resilience to climate change.

4.4 How Riparian and Floodplain Restoration Modifies the Effects of Increasing Temperature on Adult Salmon Spawner Abundance in the Chehalis River, WA

Caleb B. Fogel, Colin L. Nicol, Jeffrey C. Jorgensen, Gustav Seixas, Timothy J. Beechie, Britta Timpane-Padgham, Peter Kiffney, John Winkowski. 2022. How riparian and floodplain restoration actions mitigate future increases in stream temperature. PLOS ONE 17(6): e0268813.

Abstract

Stream temperatures in the Pacific Northwest are projected to increase with climate change, placing additional stress on anadromous salmonids. In the Chehalis River Basin, Washington, USA, peak summer stream temperatures are predicted to increase by as much as 3°C by late century. In this study we assessed the impact of increased stream temperatures on four anadromous salmonid populations (spring-run and fall-run Chinook salmon *Oncorhynchus tshawytscha,* coho salmon *O. kisutch*, and steelhead *O. mykiss*) in the Chehalis River Basin. Using habitat assessment and life cycle models, we estimated the potential consequences of increased stream temperature due to climate change on these populations using species- and life-stage-specific relationships between temperature and productivity. Additionally, we assessed the potential for habitat restoration, including floodplain reconnection and increased stream shading through riparian planting and growth, to offset the effects of future temperature increases. We applied a temperature effect on rearing survival for all populations, however the magnitude of the effect varied among populations. Coho and steelhead rear in streams throughout the entire summer, and therefore experience the warmest summer temperatures, however steelhead are more tolerant of higher temperatures than coho. Juveniles of both runs of Chinook salmon migrate out of fresh water before summer temperatures reach their peak, therefore temperature had a diminished effect on rearing survival for these two populations. Spring-run Chinook salmon are the only population with adults holding in the river during the

warmer summer months, and therefore they are the only population for which peak temperatures affect prespawn survival, one of the most sensitive parameters in our life cycle model. Results from the life cycle models indicated that increased summer temperatures produce significant declines in spawner abundance for coho, steelhead, and spring-run Chinook salmon, and smaller decreases for fall-run Chinook salmon. When the life cycle model included proposed habitat restoration actions, there were opportunities to mitigate the negative impacts of future increases in temperature

4.5 How Does Habitat Restoration Increase Resilience of Salmon Population to Climate Change?

Timothy J. Beechie, Caleb Fogel, Colin Nicol, Jeff Jorgensen, Britta Timpane-Padgham, Peter Kiffney. 2023. How does habitat restoration increase resilience of salmon populations to climate change? Ecosphere 14(2): e4402.

Abstract

A pressing question for managing recovery of depressed or declining species is: “Can habitat restoration increase resilience to climate change?” We addressed this question for salmon populations with varying life histories, where resilience is defined as maintaining or increasing population size despite climate change effects. Previous studies indicate that several interrelated mechanisms may influence salmon resilience to climate change, including improving either habitat capacity or productivity, and ameliorating climate change effects on flood flow, low flow, or stream temperature. Using the Habitat Assessment and Restoration Planning (HARP) Model, we first examined the relative importance of each mechanism for increasing salmon population resilience by comparing projected salmon spawner abundance for seven individual restoration action types under current and projected mid- and late-century climates. We found that restoring habitats with the greatest restoration potential most increased resilience for all species, but the most beneficial restoration actions varied among species. Increasing habitat capacity and productivity both contributed to resilience, and ameliorating climate change effects was important in a few subbasins where the restoration opportunity was widespread. Cool-water climate refuges contributed to resilience of some subpopulations by reducing late-century declines in spawner abundance even without restoration. We also modeled more complex habitat restoration strategies comprised of several restoration action types at varying restoration intensities, and found that the restoration action types and level of restoration effort needed to increase resilience varied among species. Less vulnerable species such as coho salmon responded well to four restoration actions (floodplain reconnection, wood augmentation, increased shade, increased beaver ponds) applied at low restoration intensity and over a large area. More vulnerable species such as spring Chinook responded to fewer action types (floodplain reconnection, wood augmentation, increased shade), but at much higher intensity and over a much smaller area. The analysis also identified important locations for each restoration action type for each species, which helps focus habitat restoration effort on areas that are likely to provide the largest increases in resilience.

5. Data Products

This project required that we generate a number of datasets, which we have made available on two separate websites. The data products consist of seven ArcGIS shapefiles for each model. The data sets for each model have the same names and descriptions (Table 1), but some habitat data were revised between the NOAA Model runs and the HARP Model runs (e.g., stream temperature data). Therefore, data sets and code for each model are posted separately. The NOAA Model Chehalis Assessment website is https://www.fisheries.noaa.gov/resource/tool-app/chehalis-watershed-assessment-and-salmon-life-cycle-modeling.

The HARP Model website is https://www.fisheries.noaa.gov/resource/tool-app/salmon-habitat-restoration-planning-harp-model. A link to the HARP Model code is also available on the HARP Model website.

Table 1. Names and descriptions of data layers available on the NOAA Model Chehalis Assessment website and on the HARP Model website.

Data layer	Description
Attributed stream line	Modified NHD+ stream layer with geomorphic and habitat quantity and quality attributes by 200-m segment
Backwater habitats	Polygon layer of large river (>20 m bankfull width) backwater habitats digitized from aerial imagery
Floodplain habitats	Historical and current floodplain marshes, ponds and lakes
GLO floodplain feature notes	Detailed data and descriptions of floodplain habitats noted along GLO survey lines, corresponding to floodplain habitat polygons
Large river edge habitat	Line layer of large river (>20 m bankfull width) bank and bar edge habitats, including armored bank designations from aerial imagery
Large river riffle habitats	Large river (>20 m bankfull width) riffle polygons digitized from aerial imagery
NOAA subbasins	Subbasin boundaries that define subpopulation habitat ranges

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