Pacific Salmon & Steelhead 2015-2020

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Background & Scope

In 2019 NOAA announced 5-year reviews of 28 species listed under the Endangered Species Act. The listed species comprise 17 evolutionarily significant units of Pacific salmon (Oncorhynchus spp.) and 11 distinct population segments of steelhead (Oncorhynchus mykiss). The purpose of these reviews is to ensure the accuracy of their listing classifications. The 5-year reviews are based on the best scientific and commercial data available at the time of the reviews and this bibliography was developed in support of the Endangered Species Division of the Office of Protected Resources, National Marine Fisheries Service. The scope of literature contained in this bibliography is as follows, publication dates: 2015-2020 with select materials from the latter half of 2014; Literature types: peer reviewed journal articles, select government documents including federal, state, tribal, etc., and NGO reports. Materials including theses, select government documents such as Biological Opinions, datasets, websites, blogs, and news articles are contained in the EndNote library associated with this project, but are not included in this annotated bibliography. The bibliography is broken into thirteen sections with a focus on recovery domains and sub-domains, which cover common watershed and geographic boundaries. Literature in each section is organized alphabetically by author.

Section I – California Central Valley

This section contains literature relevant to the California Central Valley Recovery Domain. This Domain contains three ESA-listed salmon and steelhead species: Central Valley spring-run Chinook salmon, Sacramento River winter-run Chinook salmon, and California Central Valley steelhead.

Section II – South-Central & Southern California Coast

This section contains literature relevant to the South-Central/Southern California (SCSC) Recovery Domain. This Domain contains two ESA-listed salmon and steelhead species: South-Central California Coast steelhead, and Southern California Coast steelhead.

Section III – North Central California Coast

This section contains literature relevant to the North Central California Coast Recovery Domain. This Domain contains a five ESA-listed salmon and steelhead species: California Coastal Chinook salmon, Northern California steelhead, Central California Coast steelhead, Central California Coast coho salmon, and Southern Oregon and Northern California Coast (SONC) coho salmon. Due to the overlap with the SONC Domain, literature on the SONC coho is found in section 4.

Section IV – Southern Oregon & Northern California Coast

This section contains literature relevant to the Southern Oregon and Northern California Coast (SONC) Recovery Domain. This Domain contains a single ESA-listed salmon and steelhead species: Southern Oregon/Northern California Coast coho salmon. The SONC domain overlaps with the North-Central California Coast (NCCC) Recovery Domain, which covers two ESA-listed species. This section contains only literature on the SONC coho salmon.

Section V – Oregon Coast
This section contains literature relevant to the Oregon Coast Recovery Domain. This Domain contains a single ESA-listed salmon and steelhead species: Oregon Coast coho salmon.

Section VI – Upper Willamette River
This section contains literature relevant to the Willamette River Recovery Sub-domain, which is one of two sub-domains comprising of the Willamette/Lower Columbia Salmon Recovery Domain. This sub-domain contains two ESA-listed salmon and steelhead species: Upper Willamette River Chinook salmon, and Upper Willamette River steelhead.

Section VII – Puget Sound
This section contains literature relevant to the Puget Sound Recovery Domain. This Domain contains a three ESA-listed salmon and steelhead species: Puget Sound Chinook salmon, Hood Canal Summer-run Chum salmon, and Puget Sound steelhead.

Section VIII – Washington Coast
This section contains literature relevant to the Washington Coast Recovery Domain. This Domain contains a single ESA-listed salmon and steelhead species: Lake Ozette Sockeye salmon.

Section IX – Lower Columbia River
This section contains literature relevant to the Lower Columbia River recovery sub-domain, which is one of two sub-domains comprising of the Willamette/Lower Columbia Salmon Recovery Domain. This sub-domain contains four ESA-listed salmon and steelhead species: Lower Columbia River Chinook salmon, Lower Columbia River coho salmon, Columbia River chum, and Lower Columbia River steelhead.

Section X – Middle Columbia River
This section contains literature relevant to the Middle Columbia River Recovery Sub-domain, which is one of three sub-domains comprising the Interior Columbia River Recovery Domain. This sub-domain contains a single ESA-listed salmon and steelhead species: Middle Columbia River steelhead.

Section XI – Upper Columbia River
This section contains literature relevant to the Upper Columbia River Recovery Sub-domain, which is one of three sub-domains comprising the Interior Columbia River Recovery Domain. This sub-domain contains two ESA-listed salmon and steelhead species: Upper Columbia River spring-run Chinook salmon and Upper Columbia River steelhead.

Section XII – Snake River

This section contains literature relevant to the Snake River Recovery Sub-domain, which is one of three sub-domains comprising the Interior Columbia River Recovery Domain. This sub-domain contains four ESA-listed salmon and steelhead species: Snake River sockeye salmon, Snake River spring/summer Chinook salmon, Snake River fall-run Chinook salmon, and Snake River steelhead.

Section XIII – Multispecies Resource

This section is unique in its scope as it contains literature that is relevant to multiple species across multiple Recovery Domains and Sub-domains (Snake River, California Central Valley, etc.), as citations are not duplicated between sections. This sections contains literature on all 17 ESUs of Pacific salmon and 11 DPS of steelhead.

Sources Reviewed

The following database were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; Lexis Advanced; ProQuest's Science and Technology including Aquatic Science and Fisheries Abstracts; JSTOR; EBSCO's Academic Search Complete, Environment Complete and EconLit; NOAA's Institutional Repository; Science.gov, the Biodiversity Heritage Library, Elsevier's Science Direct, Wiley's Online Library, Digital Science's Dimensions.ai, BioOne, and Google Scholar. Beyond the open and subscribed databases listed above, extensive searching of state, local, and tribal websites was conducted. Only English language materials were included.

Section I: California Central Valley

Abadía-Cardoso, A., Brodsky, A., Cavallo, B., Arciniega, M., Garza, J. C., Hannon, J., & Pearse, D. E. (2019). Anadromy Redux? Genetic Analysis to Inform Development of an Indigenous American River Steelhead Broodstock. *Journal of Fish and Wildlife Management, 10*(1), https://doi.org/10.3996/072018-jfwm-063

The construction of dams and water diversions has severely limited access to spawning habitat for anadromous fishes. To mitigate for these impacts, hatchery programs rear and release millions of juvenile salmonids, including steelhead, the anadromous ecotype of the species Oncorhynchus mykiss. These programs sometimes use nonindigenous broodstock sources that may have negative effects on wild populations. In California, however, only one anadromous fish hatchery program currently uses nonnative broodstock: the steelhead program at Nimbus Fish Hatchery on the American River, a tributary of the Sacramento River in the California Central Valley. The goal of this study was to determine if potentially appropriate sources to replace the broodstock for the Nimbus Hatchery steelhead program exist in the Upper American River, above Nimbus and Folsom dams. We show that all Upper American River O. mykiss sampled share ancestry with other populations in the Central Valley steelhead distinct population segment, with limited introgression from out-of-basin sources in some areas. Furthermore, some Upper American River populations retain adaptive genomic variation associated with a migratory life history, supporting the hypothesis that these populations display adfluvial migratory behavior. Together, these results provide insights into the evolution of trout populations above barrier dams. We conclude that some Upper American River O. mykiss populations represent genetically appropriate sources from which fisheries managers could potentially develop a new broodstock for the Nimbus Hatchery steelhead program to reestablish a native anadromous population in the Lower American River and contribute to recovery of the threatened Central Valley steelhead distinct population segment.

Acierto, K. R., Israel, J., Ferreira, J. O. E., & Roberts, J. (2014). Estimating Juvenile Winter-Run and Spring-Run Chinook Salmon Entrainment onto the Yolo Bypass over a Notched Fremont Weir. *California Fish & Game, 100*(4) Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=99272

In this study, a proposed notching of the Fremont Weir was analyzed compared to existing conditions using empirical data to estimate the proportion of juvenile Sacramento River winter-run and Central Valley spring-run Chinook salmon (Oncorhynchus tshawytscha) entrained onto the Yolo Bypass. Using historic flow and rotary screw trap data from water years 1997-2011, we found that entrainment of listed juvenile salmon onto the Yolo Bypass was higher on average across all water year types under evaluated notch conditions than occurred under existing conditions. We found that notching the weir resulted in increased listed juvenile salmon entrainment onto the Yolo Bypass in the months of November through March, but not in April. Our results indicate that lowering the required river stage for Sacramento River flows to enter the Yolo Bypass by notching the Fremont Weir is likely to increase entrainment of listed juvenile salmon onto the bypass for the majority of the listed juvenile salmon emigration seasons.

Aslund, M. W., Breton, R. L., Padilla, L., Winchell, M., Wooding, K. L., Moore, D. R. J., . . . Whatling, P. (2017). Ecological Risk Assessment for Pacific Salmon Exposed to Dimethoate in California. *Environmental Toxicology and Chemistry, 36*(2), https://doi.org/10.1002/etc.3563

A probabilistic risk assessment of the potential direct and indirect effects of acute dimethoate exposure to salmon populations of concern was conducted for 3 evolutionarily significant units (ESUs) of Pacific salmon in California. These ESUs were the Sacramento River winter-run chinook, the California Central Valley spring-run chinook, and the California Central Valley steelhead. Refined acute exposures were estimated using the Soil and Water Assessment Tool, a river basin-scale model developed to quantify the impact of land-management practices in large, complex watersheds. Both direct effects (i.e., inhibition of brain acetylcholinesterase activity) and indirect effects (i.e., altered availability of aquatic invertebrate prey) were assessed. Risk to salmon and their aquatic invertebrate prey items was determined to be de minimis. Therefore, dimethoate is not expected to have direct or indirect adverse effects on Pacific salmon in these 3 ESUs.

Barkstedt, J., Castle, C., Giannetta, G., & Kirsch, J. (2017). Adult Spring-Run Chinook Salmon Return Monitoring During 2016 within the San Joaquin River, California. Retrieved from https://www.fws.gov

The main stem San Joaquin River historically supported naturally self-sustaining populations of fall-run and spring-run Chinook Salmon Oncorhynchus tshawytscha. The construction of Friant Dam and subsequent water management practices led to the extirpation of salmon runs within the San Joaquin River above the confluence with the Merced River. As a result of NRDC et al. v. Kirk Rodgers et al lawsuit, a Stipulation of Settlement (Settlement) was reached that established a framework for accomplishing the Restoration and Water Management goals that will require environmental review, design, and construction of projects over a multiple-year period. The Settlement created the San Joaquin River Restoration Program (Program) with the goal to restore and maintain fish populations in "good condition" from Friant Dam to the confluence with the Merced River. To facilitate the reestablishment of spring-run Chinook Salmon into the San Joaquin River, the Program implemented direct releases of approximately 60,000 juvenile spring-run Chinook Salmon from Feather River hatchery stock into the San Joaquin River beginning in 2014. The Program hypothesized that an estimated total of 21 (±4) adult spring-run salmon would return to the Restoration Area as early as the spring of 2016 based on the numbers of juveniles released and historical hatchery fish return data. We conducted real-time adult spring-run salmon return monitoring during 2016 to determine the survival, distribution, and habitat use of adult spring-run salmon returning to the restoration area that were released by the Program in 2014. We passively monitored returning adult spring-run salmon using a Vaki Riverwatcher Fish Counter paired with a V-shaped net weir from March through June at Hills Ferry located at the most downstream section of the restoration area just above the confluence of the Merced River. The Vaki Riverwatcher Fish Counter consisted of two infrared scanner plates and produced at least one silhouette image of each passing fish with a body depth greater than or equal to 4 cm. The Vaki Riverwatcher Fish Counter and net weir were checked 3–5 times each week throughout the sampling period to ensure stability and proper function. If adult spring-run returns are detected, a fyke trap will be installed and checked daily to capture individuals passing through the Vaki unit. Captured adult spring-run would be transported to Reach 1 of the Restoration Area. More than 1,700 fish were scanned during the sampling period, but Chinook Salmon were not detected. To ensure that salmon were not misidentified, we evaluated the identification accuracy of our observers using Vaki Riverwatcher Fish Counter silhouettes of known fish species collected in other rivers within the Central Valley. In addition, our identification of fish using silhouette data was verified by other local Vaki Riverwatcher Fish Counter experts and users. In general, we postulate that our lack of adult spring-run salmon detections may be the result of no returning adults passed this location during the monitoring period? We recommend that the Program continue monitoring returning adult spring-run salmon in subsequent years using our methods along with gear efficiency calibration tests.

Baumsteiger, J., & Moyle, P. B. (2017). Assessing Extinction. *BioScience, 67*(4), https://doi.org/10.1093/biosci/bix001

Most extinction literature focuses on prevention and prediction, not assessment. Determination of extinction can be surprisingly complicated, with diverse approaches and terminology, leading to a gray area within extinction assessment. A series of five gray-extinction categories (mitigated, regional, native range, wild, and apparent) are provided to address these ambiguities and highlight how extant lineages may be effectively extinct. For reference, we use freshwater fishes, a group in serious decline throughout the world. Categories are interwoven into a decision tree to ensure a practical assessment of extinction and maximize conservation effectiveness. To prevent premature declarations, a waiting period based on generation time (versus a fixed number of years) is proposed. We also explain how extinction is tied to multilineage and lineage-specific anthropogenic effects and how dependence on artificial selection equates to a form of extinction. Finally, we touch on the resurrection of lineages and the impact of artificial hybridization and propagation on the extinction process.

Bourret, S. L., Caudill, C. C., & Keefer, M. L. (2016). Diversity of Juvenile Chinook Salmon Life History Pathways. *Reviews in Fish Biology and Fisheries, 26*(3), https://doi.org/10.1007/s11160-016-9432-3

Life history variability includes phenotypic variation in morphology, age, and size at key stage transitions and arises from genotypic, environmental, and genotype-by-environment effects. Life history variation contributes to population abundance, productivity, and resilience, and management units often reflect life history classes. Recent evidence suggests that past Chinook salmon (Oncorhynchus tshawytscha) classifications (e.g., 'stream' and 'ocean' types) are not distinct evolutionary lineages, do not capture the phenotypic variation present within or among populations, and are poorly aligned with underlying ecological and developmental processes. Here we review recently reported variation in juvenile Chinook salmon life history traits and provide a refined conceptual framework for understanding the causes and consequences of the observed variability. The review reveals a broad continuum of individual juvenile life history pathways, defined primarily by transitions among developmental stages and habitat types used during freshwater rearing and emigration. Life history types emerge from discontinuities in expressed pathways when viewed at the population scale. We synthesize recent research that examines how genetic, conditional, and environmental mechanisms likely influence Chinook salmon life history pathways. We suggest that threshold models hold promise for understanding how genetic and environmental factors influence juvenile salmon life history transitions. Operational life history classifications will likely differ regionally, but should benefit from an expanded lexicon that captures the temporally variable, multi-stage life history pathways that occur in many Chinook salmon populations.

An increased mechanistic awareness of life history diversity, and how it affects population fitness and resilience, should improve management, conservation, and restoration of this iconic species.

Bowen, H. L., & Marchetti, M. P. (2015). Ecomorphological Plasticity of Juvenile Fall-Run Chinook Salmon (Oncorhynchus tshawytscha) in Perennial and Ephemeral Streams. *Environmental Biology of Fishes, 99*(1), https://doi.org/10.1007/s10641-015-0454-9

In the Central Valley of California, environmental characteristics differ between perennial and ephemeral stream types and therefore present different challenges for rearing salmonids with respect to water discharge, water temperature, food availability, and habitat complexity. Body shape of juvenile fall-run Chinook salmon (Oncorhynchus tshawytscha) reared in a perennial stream environment was compared to juveniles reared in an ephemeral stream environment. Using geometric morphometrics and multivariate analyses, this study presents morphological differences of rearing juvenile Chinook salmon both within and between ephemeral and perennial stream types. We found that shape differences between stream types were primarily associated with expansion of the mid-body region relative to differences in body length. Specifically, juvenile Chinook salmon reared in the ephemeral stream expressed increased body depth dominated by dorsal-ventral elongation of the dorsal, adipose, and anal fins. Eye position and gill opercula-body insertion points also were anteriorly shifted in the juvenile body shape of the ephemeral stream. Our findings support that juvenile Chinook salmon are morphologically flexible and can express habitat-specific developmental differences.

Brodsky, A., Zeug, S. C., Nelson, J., Hannon, J., Anders, P. J., & Cavallo, B. J. (2020). Does Broodstock Source Affect Post-Release Survival of Steelhead? Implications of Replacing a Non-Native Hatchery Stock for Recovery. *Environmental Biology of Fishes, 103*(5), https://doi.org/10.1007/s10641-020-00951-2

Steelhead trout (Oncorhynchus mykiss) reared at the Nimbus Fish Hatchery (NFH) and released into the Lower American River (LAR) in California are not part of the native California Central Valley Distinct Population Segment (CCVDPS); listed as threatened under the Endangered Species Act (ESA), and therefore cannot contribute to recovery. In response to this situation, we evaluated the potential of using a CCVDPS stock from the Coleman National Fish Hatchery (CNFH) to aid in recovery. Steelhead from the CNFH were reared in 2015 at NFH along with NFH-origin steelhead. Smolts from both stocks were implanted with acoustic transmitters and released into the LAR. This study assessed: 1) reach-specific, post-release survival ofeach stock from release to the ocean; 2) the degree to which either stock residualized; and 3) the spatial distribution of post-release mortality in the LAR. Multistate mark-recapture models were constructed to estimate reach-specific survival and entrainment into alternate migration routes. Four models were constructed to test hypothesized relationships between survival and covariates. Covariates included: 1) broodstock origin; 2) release date; 3) fork length; and 4) no covariates. Fork length was the best predictor of reach-specific survival and exhibited a positive relationship with survival in each reach. Juveniles from both stocks emigrated quickly, did not residualize, and exhibited similar survival while emigrating to the ocean. Results suggested the need for additional research to further evaluate CNFHorigin steelhead performance at NFH-origin during additional life stages to support recovery of CCVDPS Steelhead.

Butte County Association of Governments. (2019). *Butte Regional Conservation Plan.* Retrieved from http://www.buttehcp.com/BRCP-Documents/Final-BRCP/index.html

The Butte Regional Conservation Plan (BRCP or Plan) will provide a comprehensive, coordinated, and efficient program to conserve ecologically important resources in the lowland and foothill region of Butte County (the "Plan Area"), including endangered, threatened, and other at-risk species and their habitats; natural communities and the ecological processes that support them; biodiversity; streams and ponds and the watersheds that support them; wetlands and riparian habitats; and ecological corridors. Important to the success of the BRCP is the continued ecological and economic function of working landscapes, including certain farming and ranching practices, and the preservation of open space. The BRCP addresses regulatory compliance with state and federal laws that protect species, wetlands, and streams for Butte County, cities within the Plan Area, water/irrigation districts within the Plan Area, the Butte County Association of Governments (BCAG),1 and the California Department of Transportation.

Caldwell, J., Rajagopalan, B., & Danner, E. (2015). Statistical Modeling of Daily Water Temperature Attributes on the Sacramento River. *Journal of Hydrologic Engineering, 20*(5), https://doi.org/10.1061/(asce)he.1943-5584.0001023

The Sacramento River is the largest river in California, and an important source of water for agricultural, municipal, and industrial users. Input to the Sacramento River comes from Shasta Lake and is controlled by operators of Shasta Dam, who are challenged with meeting the competing needs of these users while also maintaining a cold water habitat for Endangered Species Act (ESA) listed winter-run Chinook salmon. The cold water habitat goals are constrained by the volume of cold water storage in the lake, which operators attempt to selectively deploy throughout the critical late summer/fall window. To make informed decisions about the release of this limited cold water resource, skillful forecasts of downstream water temperature attributes at the seasonal time scale are crucial. To this end, we offer a generalized linear modeling (GLM) framework with a local polynomial method for function estimation, to provide predictions of a range of daily water temperature attributes (maximum daily water temperature, daily temperature range, number of hours of threshold exceedance, and probability of threshold exceedance/nonexceedance). These attributes are varied in nature (i.e.,discrete, continuous, categorical, etc.), and the GLM provides a general framework to modeling all of them. A suite of predictors that impact water temperatures are considered, including current and prior day flow, water temperature of upstream releases, air temperature, and precipitation. A two-step model selection is proposed. First, an objective method based on Bayesian Information Criteria (BIC) is used in a global model to select the best set of predictors for each attribute; then the parameters of the local polynomial method for the selected best set of predictors are obtained using generalized cross validation (GCV). Daily weather ensembles from stochastic weather generators are coupled to the GLM models to provide ensembles of water temperature attributes and consequently, the probability distributions to obtain risk estimates. We demonstrate the utility of this approach by modeling water temperature attributes for a temperature compliance point on the Sacramento River below Shasta Dam. Regulations on the dam depress the water temperature forecasting skill; to show this, we present skillful results from applying the approach to an unregulated location in the Pacific Northwest. The proposed method is general, can be ported across sites, and can be used in climate change studies.

California Bureau of Reclamation. (2014). *San Joaquin River Restoration Program Annual Report 2014*. Retrieved from www.restoresjr.net

This San Joaquin River Restoration Program (SJRRP or Program) Annual Report describes Program activities and accomplishments and planned activities moving forward. The SJRRP was established upon court acceptance of a Stipulation of Settlement (Settlement) in Natural Resources Defense Council, et al., v. Kirk Rodgers, et al., in October 2006 on litigation related to the renewal of long-term water supply contracts in the Friant Division of the Central Valley Project, California. The San Joaquin River Restoration Settlement Act (Settlement Act), in Public Law 111-11, authorizes and directs the Secretary of the Interior to implement the Settlement.

California Bureau of Reclamation. (2016). *San Joaquin River Restoration Program Annual Report 2015-2016*. Retrieved from http://www.restoresjr.net/

This San Joaquin River Restoration Program (SJRRP or Program) Annual Report describes Program activities and accomplishments and planned activities moving forward. The SJRRP was established upon court acceptance of a Stipulation of Settlement (Settlement) in Natural Resources Defense Council, et al., v. Kirk Rodgers, et al., in October 2006 on litigation related to the renewal of long-term water supply contracts in the Friant Division of the Central Valley Project, California. The San Joaquin River Restoration Settlement Act (Settlement Act), in Public Law 111-11, authorizes and directs the Secretary of the Interior to implement the Settlement.

California Department of Fish and Wildlife. (2016). *Instream Flow Evaluation of Upstream Spring-Run Chinook Salmon Passage in Butte Creek, California*. California Retrieved from http://www.buttecreek.org/documents/Butte%20Creek%20Study%20Technical%20Report.pdf

Passage conditions for adult spring-run Chinook salmon (SRCS) (Oncorhynchus tshawytscha) through a bedrock formation (River Mile or RM 43) and depth sensitive, natural, low gradient, alluvial critical riffles (RM 36) were investigated in Butte Creek, California from 2012 – 2013. Passage conditions for adult SRCS were evaluated using River2D, a two-dimensional hydraulic and habitat model (Steffler and Blackburn 2002) and the California Department of Fish and Wildlife critical riffle analysis protocol (CDFW 2012). Quantitative passage criteria included species and life stage-specific depth. River2D was used to predict the amount of channel width meeting the minimum depth criteria for adult SRCS over a range of simulated flows. The data and analysis generated by the study and this report will be used by the CDFW Instream Flow Program to develop flow criteria for adult SRCS migrating upstream through Lower Butte Creek to reach summer holding and spawning habitat in upper Butte Creek.

California Department of Fish and Wildlife. (2017). *Assessment and Recommendations for Using the Progeny of Captive Broodstock to Benefit the Conservation of Sacramento River Winter-Run Chinook Salmon*. Retrieved from https://www.fws.gov/

The purpose of this document is to propose a strategy for using the progeny of Sacramento River Winter-run Chinook Salmon (SRWCS) Oncorhynchus tshawytscha captive broodstock at the Livingston Stone National Fish Hatchery (LSNFH) to contribute to the conservation of the SRWCS Evolutionarily Significant Unit (ESU). The recovery strategy developed by the National Marine Fisheries Service (NMFS) for Central Valley Chinook Salmon and steelhead is "to secure all extant populations and to reintroduce populations into historic habitat such that each salmonid diversity group in the Central Valley supports viable populations" (NMFS 2014). In alignment with the NMFS recovery strategy, consideration is given to two potential conservation uses of SRWCS captive broodstock progeny: (1), increasing the size and scope of the existing SRWCS supplementation program in the Sacramento River, and (2) jump-starting the process of reintroducing SRWCS to Battle Creek. This document recommends a strategy for using the progeny of SRWCS captive broodstock from Brood Year (BY) 2017 that will advance the conservation strategy developed by NMFS, and describes the issues and considerations that lead to the recommendation of this strategy. Lastly, this document recommends some specific management approaches that will increase the likelihood of achieving the stated conservation goals and promote effective monitoring.

California Department of Fish and Wildlife. (2017). *Trinity River Basin Salmon and Steelhead Monitoring Project: Chinook and Coho Salmon and Fall-Run Steelhead Run-Size Estimates Using Mark-Recapture Methods 2016-17 Season*. Retrieved from https://www.wildlife.ca.gov/Conservation/Fishes/Chinook-Salmon/Anadromous-Assessment

California Department of Fish and Wildlife's Trinity River Project conducted tagging and recapture operations from July 2016 through March 2017 to produce run-size, angler harvest, and spawner escapement estimates of spring- and fall-run Chinook Salmon (Oncorhynchus tshawytscha), Coho Salmon (O. kisutch), and fall-run steelhead (O. mykiss) in the Trinity River basin. Monitoring results informs the Trinity River Restoration Program's (TRRP) adaptive management decision making process and help evaluate progress toward achieving fundamental objectives outlined in the Integrated Assessment Plan (TRRP 2009). Additionally, run-size estimates are used in annual fishery management decisions, feeding into the Pacific Fishery Management Council's Klamath River basin fishery regulation and quota determination process. Using a Petersen mark-recapture methodology, we estimated 3,904 (95% CI 3,013 – 5,158) spring-run Chinook Salmon migrated into Trinity River basin upstream of Junction City weir. The run was comprised of an estimated 1,337 natural-origin adults, 178 natural-origin jacks, 2,022 hatchery-produced adults and 367 hatchery-produced jacks. Using tags returned by anglers we estimate 216 spring Chinook were harvested, yielding an escapement of 3,688 fish. Escapement of 1,258 natural-origin adult spring Chinook is 21.0% of the TRRP goal of 6,000. An estimated 6,196 (95% CI 5,007 – 7,823) fall-run Chinook Salmon migrated upstream of Willow Creek weir (WCW). The run was comprised of an estimated 2,987 naturalorigin adults, 1,022 natural-origin jacks, 1,548 hatchery-origin adults and 639 hatcheryorigin jacks. We estimated that 40 fall Chinook were harvested by anglers, yielding a total escapement of 6,156 fish. Escapement of 3,592 natural-origin adult fall Chinook is 5.8% of the 62,000 fish TRRP goal. Coho Salmon run-size, estimated by linear regression of returns to the Trinity River Hatchery, was 1,325 (95% CI 1,183 – 1,484). Because no Coho were reported as harvested, estimated escapement was also 1,325. Using a Peterson mark-recapture methodology we estimated 4,540 (95% CI 3,903 – 5,229) adult fall-run steelhead returned to the Trinity River basin upstream of WCW. Anglers harvested an estimated 96 adult fall-run steelhead upstream of the weir, leaving 4,444 (1,972 natural-origin and 2,568 hatchery-origin) fish as potential spawners. Escapement of 1,944 natural-origin adult steelhead is 4.9% of the 40,000 fish TRRP goal.

California Natural Resources Agency. (2017). *Sacramento Valley Salmon Resiliency Strategy*. Retrieved from http://resources.ca.gov/docs/Salmon-Resiliency-Strategy.pdf

he Sacramento Valley Salmon Resiliency Strategy (Strategy) is a science-based document that has been prepared by the State of California (State) to address specific near- and long-term needs of Sacramento River winter-run Chinook salmon (winter-run), Central Valley spring-run Chinook salmon (spring-run), and California Central Valley steelhead (steelhead). The Strategy mirrors the approach taken with the Delta Smelt Resiliency Strategy developed by the State in 2016: science-driven, focused, and designed to provide resource agencies, the public, Congress, and the California State Legislature with information critical to collaborative approaches to species resiliency. The Strategy relies heavily on the National Marine Fisheries Service Final Recovery Plan for winter-run, spring-run, and steelhead (NMFS 2014), and is guided by conceptual models of factors driving winter-run population dynamics at key life stages developed by the salmon and sturgeon assessment of indicators by life-stage (SAIL) teams (Johnson et al. 2016; Heublein et al. 2017). The actions are also supported, where indicated, by other salmonid recovery planning documents and efforts The Strategy is an aggressive approach to improving species viability and resiliency by implementing specific habitat restoration actions. The State will take leadership roles in each action, although in all cases federal and local agency leadership, coordination, and partnerships are required for success. Recent successful restoration efforts led by local agencies and landowners demonstrate the importance and value of these collaborative partnerships. State agencies that could implement this Strategy include the California Natural Resources Agency, the Department of Water Resources (DWR) and the Department of Fish and Wildlife (DFW). The U.S. Bureau of Reclamation (Reclamation) will be a primary partner in many of the actions.

California Natural Resources Agency Department of Water Resources. (2017). *San Joaquin River Restoration Program Fish Passage Evaluation Plan*. Retrieved from http://www.restoresjr.net/wpfb-file/fish_passage_evaluation_vol-1_alternative-concepts_final_3-30-17-pdf/

This technical memorandum describes the final phase (Task 3) of the Fish Passage Evaluation Plan performed for the San Joaquin River Restoration Program (SJRRP). The purpose of the Fish Passage Evaluation Plan is to inform the SJRRP of fish passage improvement conceptual designs for structures that have been identified as fish passage barriers. Task 3 focuses on site-specific projects that will support the reintroduction of Chinook salmon to the San Joaquin River. The structures evaluated as a part of Task 3 are divided into two groups – Group 1 (higher priority) and Group 2 (lower priority). Structure priority was based on the severity of the barrier, and the established priorities of the SJRRP

Chapman, E. D., Hearn, A. R., Singer, G. P., Brostoff, W. N., LaCivita, P. E., & Klimley, A. P. (2014). Movements of Steelhead (Oncorhynchus mykiss) Smolts Migrating through the San Francisco Bay Estuary. *Environmental Biology of Fishes, 98*(4), https://doi.org/10.1007/s10641-014-0341-9

We used acoustic telemetry to monitor the out-migration of1,000 steelhead smolts (Oncorhynchus mykiss) through the San Francisco Bay Estuary during spring of2009 and 2010. The smolts transited the estuary rapidly (2–4 days) and utilized flows in the main channel during their migration. Fewer smolts were detected in marinas, tributaries and other shallow areas surrounding the estuary. Many of the smolts made repeated upriver and downriver movements that were related to the tidal flow, moving upstream during flood tides and downstream during ebb tides. These results show that steelhead smolts migrating from the Sacramento River transit rapidly through the lower reaches and do not use the estuary for feeding, rearing, or smoltification purposes.

Clancey, K., Saito, L., Hellmann, K., Svoboda, C., Hannon, J., & Beckwith, R. (2017). Evaluating Head-of-Reservoir Water Temperature for Juvenile Chinook Salmon and Steelhead at Shasta Lake with Modeled Temperature Curtains. *North American Journal of Fisheries Management, 37*(5), https://doi.org/10.1080/02755947.2017.1350223

Loss of historical spawning and rearing habitat in the rivers and tributaries of California's Central Valley is one of the factors that led to the listing of Chinook Salmon Oncorhynchus tshawytscha and steelhead O. mykiss under the Endangered Species Act. To recover these salmonid populations, an interagency committee is developing a plan to reintroduce fish to tributaries upstream of Shasta Dam and provide juvenile fish passage downstream past the dam. One downstream fish passage alternative involves the collection and transport of juvenile fish from head-ofreservoir locations. A hydrodynamic and water quality model (CE-QUAL-W2) of Shasta Lake and its main tributaries was used to assess where and when water temperatures were favorable for juvenile salmonid collection on the McCloud River arm of the lake under different hydrologic scenarios. The application of anchored and floating temperature curtains (i.e., flexible fabric flow barriers) was examined to assess whether they could be used to improve temperature conditions for juvenile fish by reducing temperatures to within an optimal range. Model results indicated that head-of-reservoir conditions without a temperature curtain were suitable for spring-run Chinook Salmon, fall-run Chinook Salmon, and steelhead but not for winter-run and late-fall-run Chinook Salmon. However, permanent or temporary use of temperature curtains, especially a long floating curtain, may improve conditions for juvenile winter-run and late-fall-run Chinook Salmon by reducing or eliminating lethal water temperatures.

Cowan, W. R., Rankin, D. E., & Gard, M. (2017). Evaluation of Central Valley Spring-Run Chinook Salmon Passage through Lower Butte Creek Using Hydraulic Modelling Techniques. *River Research and Applications, 33*(3), https://doi.org/10.1002/rra.3098

River2D was used to develop a hydraulic model of an upstream passage impediment for adult spring-run Chinook salmon (Oncorhynchus tshawytscha) on Butte Creek, Tehama County, California. Topographic data were collected by using a total station, survey-grade real-time kinematic global positioning system, and terrestrial light detection and ranging. Stage-discharge relationships were developed at the upstream and downstream ends of the site to use as boundary conditions and to calibrate the 2D model. A pressure transducer was installed at the downstream boundary of the site to provide a time series of flow and water temperatures. Parameters of the hydraulic model were examined to assess upstream passage including minimum thalweg depth along the least width-limiting pathway, velocity, and water surface elevation above and below a jump, and flow partitioning between a split in the main flow paths through the site. The results of the River2D model were used to identify flow levels that met the minimum depth and width thresholds needed for adult spring-run Chinook salmon (SRCS) to migrate upstream through the study reach. A minimum passage depth criterion of 0.27m was used for adult SRCS. Site-specific passage width criteria were derived from the literature for the study site and ranged from 0.3 to 0.9 m. Model results indicated that a flow of 3.40 cms met the depth criterion and the lower bound of the width criterion. A flow level of 6.8 cms met the depth criterion and the upper bound of the width criterion. Data from the VAKI Riverwatcher fish passage counting device installed just upstream of the study site were related to the stage/passage limiting width and water temperature monitoring data. The monitoring data and results of the predictive modelling will be used by the California Department of Fish and Wildlife to recommend flow criteria that protect migrating adult SRCS. Copyright © 2016 John Wiley & Sons, Ltd.

Dudley, P. N. (2019). Insights from an Individual Based Model of a Fish Population on a Large Regulated River. *Environmental Biology of Fishes, 102*(8), https://doi.org/10.1007/s10641-019-00891-6

On regulated rivers, managers must understand how drivers they can influence interact with the system to affect the health of resident fish populations. One potential way to gain insight into how these drivers interact or act in insolation is with individual based models (IBM), which can take numerous environmental drivers as inputs and mechanistically simulate their effects on the individuals in the system. This paper uses inSALMO, a spatially explicit IBM for salmon freshwater life stages, to examine how eight different drivers affect nine response variables for winter run Chinook salmon on the Sacramento River, CA. This paper examines the effects spawner numbers, spawner timing, water temperature, flow rate, turbidity, habitat cover, gravel area, and food concentration on superimposition, temperature induced egg mortality, predation, stranding, poor condition mortality, age at out-migration, length at out-migration, number of out-migrants, and juvenile size distribution. Notable results included: flow's lack of effect on juvenile stranding and small effect on final out-migrant count, the degree to which flow affects superimposition risk, temperature having the largest effect on final juvenile out-migrant count, the interaction between predation and temperature induced egg mortality which produces a constantly decreasing out-migration count with temperature, and the level at which gravel additions would not have added benefits for superimposition mortality. While this method uses simulations, and thus will not have perfectly fidelity to the system, it is a cost-effective and quick method for gaining a mechanistically derived understanding of the complex relationships between numerous drivers and response variables.

Dusek Jennings, E., & Hendrix, A. (2020). Spawn Timing of Winter-Run Chinook Salmon in the Upper Sacramento River. *San Francisco Estuary and Watershed Science, 18*(2), https://doi.org/10.15447/sfews.2020v18iss2art5

Spawn timing in anadromous Pacific salmon may be especially sensitive to environmental cues such as river temperature and flow regimes. In this study, we explored correlations between peak spawn timing and water temperature in endangered Sacramento River winter-run Chinook Salmon. In recent drought years, rising water temperatures during egg incubation have negatively affected the winter-run Chinook Salmon population. This paper seeks to understand how winter-run spawn timing may be affected by temperatures during the staging period prior to spawning, and how water releases from Shasta Dam might affect these dynamics. We fit a proportional-odds logistic regression model to evaluate annual spawn timing as a function of average temperatures in April and May below Keswick Dam. While the start date of spawning remains relatively constant from year to year, the timing of peak spawning varies

Evans, M. L., Shry, S. J., Jacobson, D. P., Sard, N. M., & O'Malley, K. G. (2015). Functional Gene Diversity and Migration Timing in Reintroduced Chinook Salmon. *Conservation Genetics, 16*(6), https://doi.org/10.1007/s10592-015-0753-x

Reintroductions are used to reestablish populations to historical habitats from which they were extirpated. The long-term success of these efforts will depend on genetic diversity and the ability of reintroduced individuals to adapt to ecological change. We examined variation at circadian clock (OtsClock1b and OmyFbxw11) and reproductive timing (Ots515NWFSC)-associated genes in two threatened spring-run Chinook salmon (Oncorhynchus tshawytscha) populations that are undergoing restoration to historical habitats above dams. We also tested for an association between the genes and individual variation in arrival time to the spawning grounds. Our findings indicate that levels of genetic diversity in reintroduced individuals are similar to those found in previously studied spring, summer, fall and winter-run Chinook salmon populations. Captive-rearing programs established following dam construction and the more recent reintroduction efforts thus appear to have maintained diversity at these genes. We observed temporal (between run-years) and spatial (between populations) patterns of genetic differentiation, but little evidence that selection underlies these differences. However, there was a relationship between the circadian-associated gene, OmyFbxw11, and arrival time to the spawning grounds, and in one year of the study, "early" and "late" arrivers to the spawning grounds were more differentiated at the gene than at neutral markers. Taken together, these findings suggest that reintroduced salmon may be capable of an evolutionary response to ecological shifts that alter the adaptive landscape between fitness and arrival timing to the spawning grounds.

Fiechter, J., Huff, D. D., Martin, B. T., Jackson, D. W., Edwards, C. A., Rose, K. A., . . . Wells, B. K. (2015). Environmental Conditions Impacting Juvenile Chinook Salmon Growth Off Central California: An Ecosystem Model Analysis. *Geophysical Research Letters, 42*(8), https://doi.org/10.1002/2015gl063046

A fully coupled ecosystem model is used to identify the effects of environmental conditions and upwelling variability on growth of juvenile Chinook salmon in central California coastal waters. The ecosystem model framework consists of an ocean circulation submodel, a biogeochemical submodel, and an individual-based submodel for salmon. Simulation results indicate that years favorable for juvenile salmon growth off central California are characterized by particularly intense early season upwelling (i.e., March through May), leading to enhanced krill concentrations during summer near the location of ocean entry (i.e., Gulf of the Farallones). Seasonally averaged growth rates in the model are generally consistent with observed values and suggest that juvenile salmon emigrating later in the season (i.e., late May and June) achieve higher weight gains during their first 90 days of ocean residency.

Garrigan, D., & Hedrick, P. W. (2001). Class I Mhc Polymorphism and Evolution in Endangered California Chinook and Other Pacific Salmon. *Immunogenetics, 53*(6), https://doi.org/10.1007/s002510100352

Twelve MHC class I exon 2 sequences were uncovered in a sample from the endangered Sacramento River winter-run Chinook salmon in the central valley of California. Phylogenetic analysis of the 12 sequences indicates that the alleles descend from two of six major allelic lineages found among four Pacific salmon species. Nine of the 12 alleles belong to an allelic lineage that began diversifying 8 million years ago, just prior to the estimated time of Chinook speciation. The most recent common ancestor of all 12 winter-run alleles is estimated to be 15 million years ago, approximately 5 million years before the radiation of the Pacific salmon species. The average nonsynonymous distance among the peptide binding-region codons of exon 2 for the 12 alleles is significantly higher than the average synonymous distance in these codons. We estimate the symmetrical overdominant selection coefficient against homozygotes for this exon to be 0.038. Thus, strong positive and balancing selection has maintained functional diversity in the peptide-binding region of the exon over millions of years and this variation has not yet been substantially eliminated by increased genetic drift due to the recent dramatic decline in abundance of this Chinook salmon population.

Hamda, N. T., Martin, B., Poletto, J. B., Cocherell, D. E., Fangue, N. A., Van Eenennaam, J., . . . Danner, E. (2019). Applying a Simplified Energy-Budget Model to Explore the Effects of Temperature and Food Availability on the Life History of Green Sturgeon (Acipenser medirostris). *Ecological Modelling, 395*, https://doi.org/10.1016/j.ecolmodel.2019.01.005

In highly regulated systems, like large dammed rivers, conservation legislation requires that systems are managed, in part, to avoid adverse impacts on endangered species. However, multiple endangered species can occur in the same system, and management actions that benefit one species may be detrimental to another species. The current water management strategies in the Sacramento River basin are an example of this conflict. Cold-water releases from Shasta Reservoir during the summer and fall months are aimed at protecting Sacramento River winter-run Chinook (SRWRC) salmon by providing suitable incubation temperatures for their eggs. However, the effects of these regulated water temperature releases on another threatened species, green sturgeon, are less well understood. In this study, we applied a simplified dynamic energy budget (DEB) model (aka DEBkiss) to explore the effect of food limitation and water temperature on the growth rates of green sturgeon. This model captures these effects and able to predict the growth of green sturgeon at different food levels and temperature conditions. We then linked the DEB model with a physically-based water temperature model. We applied the DEB - water temperature linked model for green sturgeon along with a temperature-dependent egg to fry survival model for SRWRC salmon to quantify the consequences of managing water temperatures to improve salmon eggs survival on the growth rate of green sturgeon. We found that mean temperature-dependent egg-to-fry survival of salmon increased across a modeled environmental gradient from critically dry to wet water year types, while the fractional growth rate of juvenile green sturgeon showed the opposite trend, and decreased as water years transitioned from dry to wet conditions. We also found a non-linear negative correlation between temperaturedependent mean growth rate of green sturgeon and mean temperature-dependent egg-to-fry survival of salmon, which indicated there is a river temperature related trade-off between early growth rate of green sturgeon and embryonic stage survival of salmon. However, the relatively small gains in the growth rate of green sturgeon achieved in years when temperature criteria for SRWRC salmon eggs were not met came at the cost of large reduction in temperature-dependent egg-to-fry survival of salmon. Thus, we concluded the current Sacramento River water-temperature management for the eggs of the endangered SRWRC salmon eggs have a relatively small impact on the growth rate of green sturgeon.

Herbold, B., Carlson, S. M., & Henery, R. (2018). Managing for Salmon Resilience in California's Variable and Changing Climate. *San Francisco Estuary and Watershed Science, 16*(2), https://doi.org/10.15447/sfews.2018v16iss2art3

California's salmonids are at the southern limits of their individual species' ranges, and display a wide diversity of strategies to survive in California's highly variable climate. Land use changes after statehood in 1850 eliminated important habitats, or blocked access to them, and reduced the abundance, productivity, and distribution of California's salmon. Habitat simplification, fishing, hatchery impacts, and other stressors led to the loss of genetic and phenotypic (life history, morphological, behavioral, and physiological) diversity in salmonids. Limited diversity and habitat loss left California salmon with reduced capacity to cope with a variable and changing climate. Since 1976, California has experienced frequent droughts, as were common in the paleo-climatological record, but rare in the peak dam-building era of 1936–1976. Increasing temperatures and decreasing snowpacks have produced harsher conditions for California's salmon in their current habitats than they experienced historically. The most likely way to promote salmon productivity and persistence in California is to restore habitat diversity, reconnect migratory corridors to spawning and rearing habitats, and refocus management to replenish the genetic and phenotypic diversity of these southernmost populations.

Holmes, E. J., Saffarinia, P., Rypel, A. L., Bell-Tilcock, M. N., Katz, J. V., & Jeffres, C. A. (2020). Reconciling Fish and Farms: Methods for Managing California Rice Fields as Salmon Habitat. In *bioRxiv preprint*. Retrieved from https://www.biorxiv.org/content/biorxiv/early/2020/08/03/2020.08.03.234054.full.pdf

The rearing habitat for juvenile Chinook Salmon (Oncorhynchus tshawytscha) in California, the southernmost portion of their range, has drastically declined throughout the past century. Recently, through cooperative agreements with diverse stakeholders, winter-flooded agricultural rice fields in California's Central Valley have emerged as promising habitat for rearing juvenile Chinook Salmon. From 2013 to 2016, we conducted a series of experiments examining methods for rearing fall-run Chinook Salmon on winter-flooded rice fields in the Yolo Bypass, a modified floodplain of the Sacramento River in California. These included: 1) influence of field substrate differences from previous season rice harvest; 2) effects of depth refugia from avian predators (trenches); 3) field drainage methods to promote efficient egress of fish; and 4) in-field salmon survivorship over time. Zooplankton (fish food) in the winter-flooded rice fields were 53-150x more abundant when directly compared to the adjacent Sacramento River. Correspondingly, somatic growth rates of juvenile hatchery-sourced fall-run Chinook Salmon stocked in rice fields were two to five times greater versus fish in the adjacent Sacramento River. Post-harvest field substrate treatments had little effect on the lower trophic food web and had an insignificant effect on growth rates of in-field salmon. Though depth refugia did not directly increase survival, it buffered maximum water temperatures in the trenches and facilitated outmigration from fields during draining. Rapid field drainage methods yielded the highest survival and were preferable to drawn-out drainage methods. High initial mortality immediately after stocking was observed in the survival over time experiment with stable and high survival after the first week. In-field survival ranged 7.4–61.6% and increased over the course of the experiments. Despite coinciding with the most extreme drought in California's recorded history, which elevated water temperatures and reduced the regional extent of adjacent flooded habitats which concentrated avian predators, the adaptive research framework enabled incremental improvements in design to increase survival. The abundance of food resources and exceptionally high growth rates observed during these experiments illustrate the benefits associated with reconciling off-season agricultural land use with fish conservation practices. Without any detriment to flood control or agricultural yield, there is great promise for reconciliation ecology between agricultural floodplains and endangered fish conservation where minor alterations to farm management practices could greatly enhance the effectiveness of fish conservation outcomes.

Holmes, R. W., Rankin, D. E., Ballard, E., & Gard, M. (2016). Evaluation of Steelhead Passage Flows Using Hydraulic Modeling on an Unregulated Coastal California River. *River Research and Applications, 32*(4), https://doi.org/10.1002/rra.2884

Passage and habitat connectivity flows for steelhead Oncorhynchus mykiss through depth sensitive natural, low gradient, critical riffle sites were investigated in the unregulated Big Sur River, California. The River2D two-dimensional hydraulic habitat model, along with quantitative passage metrics and species-specific and lifestage-specific depth criteria, were used to evaluate and compare predicted fish passage flows with flows derived by a traditional empirical critical riffle fish passage method. Passage flows were also compared with historical unimpaired natural hydrology patterns to assess the frequency and duration of suitable passage flows under the naturally variable flow regimes characteristic of Central California coastal rivers. A strong relationship (r2 = 0.93) was observed between flows predicted by hydraulic modeling and flows identified by the empirical critical riffle method. River2D provided validation that the flows derived using the traditional critical riffle methodology provided for contiguous passable pathways of suitable hydraulic (depth and velocity) conditions through complex cobble-dominated riffle sites. Furthermore, steelhead passage flows were spatially and temporally consistent between lagoon and upstream riffles for adults, and were generally indicative of a river system in equilibrium with a naturally variable flow regime and associated intact ecological processes. An analysis of 25 years of continuous flow data indicated sufficient flows for upstream passage by young-of-year and juvenile steelhead were produced between 37% and 100% and between 1% and 95% of the time, respectively. September and October are the most challenging months for natural flows to meet young-of-year and juvenile passage and habitat connectivity flows. Careful consideration of seasonal and interannual flow variability dynamics, therefore, are critical components of an effective flow management strategy for the maintenance and protection of passage and habitat connectivity flows between lagoon and upriver habitats. Published 2015. This article is a U.S. Government work and is in the public domain in the USA.

IFC International. (2016). *Battle Creek Winter-Run Chinook Salmon Reintroduction Plan.* California Department of Fish and Wildlife Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=129504

The purpose of the Reintroduction Plan is to describe the issues, considerations, and steps necessary to reestablish a population of Sacramento River winter-run Chinook Salmon in North Fork Battle Creek (NF

Battle Creek), which will contribute to the recovery of the Sacramento River winter-run Chinook Salmon (NMFS 2014a). The NMFS recovery strategy for California's Central Valley salmon and steelhead is to secure existing populations and reintroduce salmon to historically occupied or suitable habitats (NMFS 2014a). Specifically for winter-run Chinook Salmon, the strategy calls for the establishment of three populations at low risk of extinction. Battle Creek presents a reasonable option for reestablishment of an independent population because the Battle Creek Salmon and Steelhead Restoration Project (BCRP) (USBR 2008) is expected to restore unencumbered access to quality spring-fed spawning habitat in NF Battle Creek by 2017. This document describes the process for reintroducing winterrun Chinook Salmon to its historical spawning and rearing habitat in NF Battle Creek, assuming successful implementation of the BCRP.

Johnson, R. C., Garza, J. C., MacFarlane, R. B., Grimes, C. B., Phillis, C. C., Koch, P. L., . . . Carr, M. H. (2016). Isotopes and Genes Reveal Freshwater Origins of Chinook Salmon Oncorhynchus tshawytscha Aggregations in California's Coastal Ocean. *Marine Ecology Progress Series, 548*, https://doi.org/10.3354/meps11623

The ability of salmon to navigate from the ocean back to their river of origin to spawn acts to reinforce local adaptation and maintenance of unique and heritable traits among salmon populations. Here, the extent to which Chinook salmon Oncorhynchus tshawytscha from the same freshwater breeding groups associate together in the ocean at regional and smaller-scale aggregations prior to homeward migration is evaluated. Natural variation in salmon otolith daily growth bands, strontium isotopes (Sr-87/Sr-86), and microsatellite DNA were used as intrinsic tags to link the distributions of fish caught in the ocean with their freshwater origins. Adults were caught from vessels by hook and line in small aggregations (7-18 ind.) at the same geographic location (1-24 km of coastline) and time (4-36 h) from 3 ocean regions along central California, USA. Salmon caught together in aggregations were from the same genetic group, and to a lesser extent, of the same natal origin (individual rivers or hatcheries). However, at regional scales, adult salmon mixed. Central Valley winter-run Chinook salmon caught together in the ocean varied in the duration of freshwater rearing for up to 2-3 mo prior to seaward migration, suggesting associations within the group were not established in freshwater or maintained over the lifetime of the fish. Our findings are consistent with coarser information indicating stocks are distributed differently in time and space, but larger sample sizes are required to evaluate the consistency of patterns at smaller spatial scales. This study uncovers freshwater associations prior to homeward migration, a principle and undocumented prerequisite of the collective navigation hypothesis.

Johnson, R. C., Windell, S., Brandes, P. L., Conrad, J. L., Ferguson, J., Goertler, P. A. L., . . . Swart, B. G. (2017). Science Advancements Key to Increasing Management Value of Life Stage Monitoring Networks for Endangered Sacramento River Winter-Run Chinook Salmon in California. *San Francisco Estuary and Watershed Science, 15*(3), https://doi.org/10.15447/sfews.2017v15iss3art1

A robust monitoring network that provides quantitative information about the status of imperiled species at key life stages and geographic locations over time is fundamental for sustainable management of fisheries resources. For anadromous species, management actions in one geographic domain can substantially affect abundance of subsequent life stages that span broad geographic regions. Quantitative metrics (e.g., abundance, movement, survival, life history diversity, and condition) at multiple life stages are needed to inform how management actions (e.g., hatcheries, harvest, hydrology, and habitat restoration) influence salmon population dynamics. The existing monitoring network for endangered Sacramento River winterrun Chinook Salmon (SRWRC, Oncorhynchus tshawytscha) in California's Central Valley was compared to conceptual models developed for each life stage and geographic region of the life cycle to identify relevant SRWRC metrics. We concluded that the current monitoring network was insufficient to diagnose when (life stage) and where (geographic domain) chronic or episodic reductions in SRWRC cohorts occur, precluding within- and among-year comparisons. The strongest quantitative data exist in the Upper Sacramento River, where abundance estimates are generated for adult spawners and emigrating juveniles. However, once SRWRC leave the upper river, our knowledge of their identity, abundance, and condition diminishes, despite the juvenile monitoring enterprise. We identified six system-wide recommended actions to strengthen the value of data generated from the existing monitoring network to assess resource management actions: (1) incorporate genetic run identification; (2) develop juvenile abundance estimates; (3) collect data for life history diversity metrics at multiple life stages; (4) expand and enhance real-time fish survival and movement monitoring; (5) collect fish condition data; and (6) provide timely public access to monitoring data in open data formats. To illustrate how updated technologies can enhance the existing monitoring to provide quantitative data on SRWRC, we provide examples of how each recommendation can address specific management issues.

Johnston, M., Frantzich, J., Espe, M. B., Goertler, P., Singer, G., Sommer, T., & Klimley, A. P. (2020). Contrasting the Migratory Behavior and Stranding Risk of White Sturgeon and Chinook Salmon in a Modified Floodplain of California. *Environmental Biology of Fishes, 103*(5), https://doi.org/10.1007/s10641-020-00974-9

While navigating through the same migratory corridor, different species may experience differing reproductive success due the interaction of speciesspecific movement behavior with habitat configuration. We contrasted the migratory behavior of White Sturgeon Acipenser transmontanus and fall-run Chinook Salmon Oncorhynchus tshawytscha, two native fishes in Central Valley ofCalifornia. These species co-occur in the region's Yolo Bypass floodplain seasonally, but they represent disparate reproductive strategies: White Sturgeon are iteroparous, spawning multiple times throughout their lifespan, while Chinook Salmon are semelparous, spawning only once in their lifespan. Except for briefwindows when the Yolo Bypass connected to the Sacramento River during flood conditions, migrating White Sturgeon and Chinook Salmon that entered the Bypass from 2012 to 2018 had to turn around and exit it in order to complete a successful spawning migration up the Sacramento River. This "exit behavior" was critical to migratory success when the Bypass was not flooded. Between March 2012 and May 2018, the

Klimley, A. P., Agosta, T. V., Ammann, A. J., Battleson, R. D., Pagel, M. D., & Thomas, M. J. (2017). Real-Time Nodes Permit Adaptive Management of Endangered Species of Fishes. *Animal Biotelemetry, 5*(1), https://doi.org/10.1186/s40317-017-0136-9

Background: Currently acoustic tag-detecting autonomous receivers must be visited periodically to download the files of tag detections. Hence, the information about the whereabouts of tagged fishes is not available to make prompt regulatory decisions to reduce entrainment. In contrast, real-time receivers can detect the signal from a transmitter on a passing fish and immediately transmit its identity and time of detection to a website, where they can be viewed on either a computer or cellular telephone. Real-time nodes can aid regulatory biologists in making important decisions. This is a powerful new tool for resource managers and conservation biologists. Results: We describe a network of real-time, fish-tracking nodes on the Sacramento River, California. Two case studies illustrate the value of the nodes. The first entails detecting the arrival of migrating winter-run Chinook salmon near a water diversion and alerting regulatory biologists to keep the diversion closed to increase the migratory success. The second study involves the detection of green sturgeon at potential stranding sites, alerting biologists of the need to transport them from that site to the main channel of the river so they can continue their upstream migration to their spawning sites.

Meek, M. H., Baerwald, M. R., Stephens, M. R., Goodbla, A., Miller, M. R., Tomalty, K. M. H., & May, B. (2016). Sequencing Improves Our Ability to Study Threatened Migratory Species: Genetic Population Assignment in California's Central Valley Chinook Salmon. *Ecology and Evolution, 6*(21), https://doi.org/10.1002/ece3.2493

Effective conservation and management of migratory species requires accurate identification of unique populations, even as they mix along their migratory corridors. While telemetry has historically been used to study migratory animal movement and habitat use patterns, genomic tools are emerging as a superior alternative in many ways, allowing large-scale application at reduced costs. Here, we demonstrate the usefulness of genomic resources for identifying single-nucleotide polymorphisms (SNPs) that allow fast and accurate identification of the imperiled Chinook salmon in the Great Central Valley of California. We show that 80 well-chosen loci, drawn from a pool of over 11,500 SNPs developed from restriction site-associated DNA sequencing, can accurately identify Chinook salmon runs and select populations within run. No other SNP panel for Central Valley Chinook salmon has been able to achieve the high accuracy of assignment we show here. This panel will greatly improve our ability to study and manage this ecologically, economically, and socially important species and demonstrates the great utility of using genomics to study migratory species.

Munsch, S. H., Greene, C. M., Johnson, R. C., Satterthwaite, W. H., Imaki, H., & Brandes, P. L. (2019). Warm, Dry Winters Truncate Timing and Size Distribution of Seaward-Migrating Salmon across a Large, Regulated Watershed. *Ecological Applications, 29*(4), https://doi.org/10.1002/eap.1880

Ecologists are pressed to understand how climate constrains the timings of annual biological events (phenology). Climate influences on phenology are likely significant in estuarine watersheds because many watersheds provide seasonal fish nurseries where juvenile presence is synched with favorable conditions. While ecologists have long recognized that estuaries are generally important to juvenile fish, we incompletely understand the specific ecosystem dynamics that contribute to their nursery habitat value, limiting our ability to identify and protect vital habitat components. Here we examined the annual timing of juvenile coldwater fish migrating through a seasonally warm, hydrologically managed watershed. Our goal was to (1) understand how climate constrained the seasonal timing of water conditions necessary for juvenile fish to use nursery habitats and (2) inform management decisions about (a) mitigating climate-mediated stress on nursery habitat function and (b) conserving heat-constrained species in warming environments. Cool, wet winters deposited snow and cold water into mountains and reservoirs, which kept the lower watershed adequately cool for juveniles through the spring despite the region approaching its hot, dry summers. For every 1°C waters in April were colder, the juvenile fish population (1) inhabited the watershed 4?7 d longer and (2) entered marine waters, where survival is size selective, at maximum sizes 2.1 mm larger. Climate therefore appeared to constrain the nursery functions of this system by determining seasonal windows of tolerable rearing conditions, and cold water appeared to be a vital ecosystem component that promoted juvenile rearing. Fish in this system inhabit the southernmost extent of their range and already rear during the coolest part of the year, suggesting that a warming climate will truncate rather than shift their annual presence. Our findings are concerning for coldwater diadromous species in general because warming climates may constrain watershed use and diminish viability of life histories (e.g., late springtime rearing) and associated portfolio benefits over the long term. Lower watershed nurseries for coldwater fish in warming climates may be enhanced through allocating coldwater reservoir releases to prolong juvenile rearing periods downstream or restorations that facilitate colder conditions.

Munsch, S. H., Greene, C. M., Johnson, R. C., Satterthwaite, W. H., Imaki, H., Brandes, P. L., & O'Farrell, M. R. (2020). Science for Integrative Management of a Diadromous Fish Stock: Interdependencies of Fisheries, Flow, and Habitat Restoration. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(9), https://doi.org/10.1139/cjfas-2020-0075

Fish face many anthropogenic stressors. Authorities in marine, estuarine, and freshwater realms often share interdependent fisheries management goals, but address singular stressors independently. Here, we present a case study suggesting that coordinating stressor relief across management realms may synergize conservation efforts, especially to actualize restoration benefits. Major efforts are underway to restore juvenile salmon habitat across California's Central Valley landscape, but it is unclear how fisheries and flow management will influence juvenile salmon occupancy of restored sites. Leveraging monitoring data, we find that for juvenile salmon (<55 mm) to actualize benefits of restored habitats will likely require maintaining spawner abundances and flows at or above intermediate values, especially in less-connected portions ofthe landscape. Furthermore, restoration efforts may prioritize more connected regions to promote use of restored areas, considering that less connected areas are often uninhabited when water and spawners are scarcer. This ecosystem-based framework that evaluates interdependencies ofmanagement decisions may be applied to realize natural productivity and enhance conservation in many systems.

National Marine Fisheries Service. (2014). *Life Cycle Modeling Framework for Sacramento River Winter-Run Chinook Salmon*. (NOAA-TM-NMFS-SWFSC-530). Retrieved from https://repository.library.noaa.gov/view/noaa/4738

In this document, we describe a strategy for quantitatively evaluating how Federal Central Valley Project (CVP) and California State Water Project (SWP) management actions affect Central Valley Chinook salmon populations. Examples of management actions include changes in water project operations, addition or removal of barriers, and a variety of habitat restoration initiatives. The analytical framework consists of linking and applying hydrological, hydraulic, water quality, and salmon population models.

National Marine Fisheries Service. (2016). *5-Year Review : Summary and Evaluation of Central Valley Spring-Run Chinook Salmon Evolutionarily Significant Unit*. Portland, OR Retrieved from https://repository.library.noaa.gov/view/noaa/17018

Many West Coast salmon and steelhead (Oncorhynchus sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. 2 These factors collectively led to NMFS listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under Section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent status reviews for West Coast salmon and steelhead occurred in 2010, and prior to that in 2005 and 2006. This document summarizes NMFS's 5-year review of the ESA-listed Central Valley (CV) spring-run Chinook salmon Evolutionarily Significant Unit (ESU).

National Marine Fisheries Service. (2016). *5-Year Status Review: Summary and Evaluation of Sacramento River Winter-Run Chinook Salmon Esu*. Retrieved from https://repository.library.noaa.gov/view/noaa/17014

Many west coast salmon and steelhead (Oncorhynchus sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors, among others, led to NOAA's National Marine Fisheries Service (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under Section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The term "threatened species" is defined under the ESA as any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. An "endangered species" under the ESA is any species which is in danger of extinction throughout all or a significant portion of its range. The most recent listing determinations for west coast salmon and steelhead occurred in 2005 and 2006. NMFS previously completed a 5-year status review in 2011 and concluded that the status of the Sacramento River (SR) winter-run Chinook salmon Evolutionarily Significant Unit (ESU) should remain as endangered. This document summarizes NMFS's current 5-year review of the ESA-listed SR winter-run Chinook salmon ESU.

National Marine Fisheries Service. (2016). *Winter-Run Chinook Salmon 5-Year Action Plan*. Retrieved from https://repository.library.noaa.gov/view/noaa/10746

The 5-year action plan is part of a strategy to marshal resources on species listed under the Endangered Species Act of 1973 (ESA) for which immediate, targeted efforts are vital for stabilizing their populations and preventing their extinction. Eight species were identified by the National Marine Fisheries Service (NMFS) as among the most at-risk of extinction: Atlantic Salmon Gulf of Maine Distinct Population Segment (DPS), Central California Coast Coho Evolutionarily Significant Unit (ESU), Cook Inlet Beluga Whale DPS, Hawaiian Monk Seal, Pacific Leatherback Sea Turtle, Sacramento River Winter-run Chinook ESU,Southern Resident Killer Whale DPS, White Abalone.

National Marine Fisheries Service. (2017). *Scientific Framework for Assessing Factors Influencing Endangered Sacramento River Winter-Run Chinook Salmon (Oncorhynchus tshawytscha) across the Life Cycle*. https://doi.org/10.7289/V5/TM-SWFSC-586

California's Central Valley Interagency Ecology Program (IEP) formed multi-agency Salmon and Sturgeon Assessment of Indicators by Life Stage (SAIL) synthesis teams to develop a scientific framework for evaluating existing information on endangered Sacramento River winter-run Chinook salmon (SRWRC; Oncorhynchus tshawytscha), green sturgeon (Acipenser medirostris), and white sturgeon (A. transmontanus) and provide recommendations to improve the management value of life stage monitoring. Developing the SAIL framework for SRWRC and sturgeon followed parallel approaches that included three steps. First, existing conceptual models (CMs) were reviewed and modified to characterize specific environmental and management factors that drive SRWRC responses within discrete geographic domains and life stages. Second, the existing monitoring network was compared to fish demographic responses in the CMs to identify deficiencies. The deficiencies were interpreted as gaps in the existing network that prevent annual, quantitative, population-level metrics from being developed that are needed to support water management actions, assess population viability, and prioritize population recovery actions among geographic domains across the freshwater landscape. Lastly, identified absences were used to develop recommendations on ways to improve the scientific and management value of the current monitoring network.

National Marine Fisheries Service. (2019). *Movement and Survival Rates of Butte Creek Spring-Run Chinook Salmon Smolts from the Sutter Bypass to the Golden Gate Bridge in 2015, 2016, and 2017*. Santa Cruz, CA https://doi.org/10.25923/cwry-bx03

California's Central Valley (CCV) Chinook salmon stocks have declined substantially since the mid-1800s with most of them listed as threatened or endangered, or heavily supplemented by hatcheries. Butte Creek supports the largest population of CCV wild spring-run Chinook, and represents an important component of this ESU. However, little information exists on Butte Creek juvenile mortality during out-migration to the ocean, which is considered a critical phase to the overall population dynamics. We used the high resolution Juvenile Salmon Acoustic Telemetry System (JSATS), and a mark-recapture modeling framework to track the movement and estimate survival of migrating wild Chinook salmon smolts from lower Butte Creek to the Golden Gate Bridge in three distinctly different hydrologic periods (spring of 2015, 2016, and 2017). The fish tagged were a mix of genetically identified spring- run and fall-run Chinook juveniles, which were not visually distinguishable. Our results show that outmigrant smolt survival and receiver detection strongly varies by location and year. The highest survival of these outmigrant juveniles to the Golden Gate Bridge was observed in 2017 which was the wettest year of our study, and survival was extremely low in 2015 and 2016 (0.7% in 2015, 2.0% in 2016, and 10.0% in 2017). We observed that survival and migration varied significantly among years and regions; fish migrated faster and experienced higher survival in 2017 than in 2015 and 2016; fish migrated faster and experienced higher survival in the lower Sacramento River than in the Sutter Bypass, Delta and Bay. We also showed that release date and Delta flow are significantly correlated with survival rates of these outmigrating smolts. These results are largely driven by 2017 data. Indeed, 2017 tagged fish were released a month later than those in 2015 and 2016, and Delta flow and smolt survival were significantly higher than in the previous two years. More tagging years including measurements of more potentially important environmental factors (such as turbidity) are required to robustly identify the influence of various factors on Butte Creek spring-run Chinook outmigrant smolt survival.

Notch, J. J., McHuron, A. S., Michel, C. J., Cordoleani, F., Johnson, M., Henderson, M. J., & Ammann, A. J. (2020). Outmigration Survival of Wild Chinook Salmon Smolts through the Sacramento River During Historic Drought and High Water Conditions. *Environmental Biology of Fishes, 103*(5), https://doi.org/10.1007/s10641-020-00952-1

Populations of wild spring-run Chinook salmon in California's Central Valley, once numbering in the millions, have dramatically declined to record low numbers. Dam construction, habitat degradation, and altered flow regimes have all contributed to depress populations, which currently persist in only a few tributaries to the Sacramento River. Mill Creek (Tehama County) continues to support these threatened fish, and contains some ofthe most pristine spawning and rearing habitat available in the Central Valley. Despite this pristine habitat, the number ofChinook salmon returning to spawn has declined to record low numbers, likely due to poor outmigration survival rates. From 2013 to 2017, 334 smolts were captured and acoustic tagged while outmigrating from Mill Creek, allowing for movement and survival rates to be tracked over 250 km through the Sacramento River. During this study California experienced both a historic drought and record rainfall, resulting in dramatic fluctuations in year-to-year river flow and water temperature. Cumulative survival of tagged smolts from Mill Creek through the Sacramento River was 9.5% (±1.6) during the study, with relatively low survival during historic drought conditions in 2015 (4.9%± 1.6) followed by increased survival during high flows in 2017 (42.3% ± 9.1). Survival in Mill Creek and the Sacramento River was modeled over a range offlow values, which indicated that higher flows in each region result in increased survival rates. Survival estimates gathered in this study can help focus management and restoration actions over a relatively long migration corridor to specific regions of low survival, and provide guidance for management actions in the Sacramento River aimed at restoring populations ofthreatened Central Valley spring-run Chinook salmon.

O'Farrell, M. R., & Satterthwaite, W. H. (2015). Inferred Historical Fishing Mortality Rates for an Endangered Population of Chinook Salmon (Oncorhynchus tshawytscha). *Fishery Bulletin, 113*(3), https://doi.org/10.7755/fb.113.3.9

The time series of estimated fishery exploitation rates for endangered Sacramento River winter Chinook salmon (Oncorhynchus tshawytscha) is confined to a relatively recent period for which coded-wire tag data have been available. However, the nature of ocean salmon fisheries before this period was substantially different, and it is likely that recent exploitation rates do not represent the level of fishing mortality experienced by these Chinook salmon in earlier years. To infer historical exploitation rates, a model was developed to hindcast the impact rate for age-3 winter Chinook salmon (an approximation of the exploitation rate) by using 35 years of fishing effort estimates coupled with contemporary estimates of fishery encounter rates. The impact-rate hindcasts were highest during a period from the mid-1980s through the mid-1990s. Over time, the proportion of the impact rate attributed to com-mercial and recreational fisheries diverged from approximately equal shares early in the time series to an impact rate mostly composed of recreational fishery-induced mortality in more recent years. The inferred exploitation rates provide context for the fishing-induced mortality experienced by winter Chinook salmon both before and after the time of the initial inclusion of this species on the Endangered Species Act (ESA) list in 1989 and through a dynamic period for ocean salmon fisheries in California.

O'Farrell, M. R., Satterthwaite, W. H., Hendrix, A. N., & Mohr, M. S. (2018). Alternative Juvenile Production Estimate (Jpe) Forecast Approaches for Sacramento River Winter-Run Chinook Salmon. *San Francisco Estuary and Watershed Science, 16*(4), https://doi.org/10.15447/sfews.2018v16iss4art4

Sacramento River winter-run Chinook salmon are listed under the Endangered Species Act as Endangered and there are substantial efforts to estimate, predict, and limit mortalities at various stages of their life cycle. One such effort is the annual forecast of the number of juvenile winter-run entering the Sacramento-San Joaquin Delta. The natural-origin Juvenile Production Estimate (JPE) is defined as the number of winter-run juveniles produced from natural spawning areas that enter the Delta, and its forecast is used to determine the allowable level of winter-run incidental take at the state and federal pumping facilities located in the south Delta. Current monitoring programs in the Sacramento Basin do not allow for direct estimation of the JPE and thus various methods have been used to forecast this value annually. Here we describe three alternative methods for forecasting the natural-origin JPE. The methods range from the status quo approach (Method 1), which expresses the JPE forecast only as a point estimate, to two other methods that account for forecast uncertainty to various degrees. A comparison of JPE forecasts for 2018 across the three methods indicates that relative to Method 1, Methods 2 and 3 result in lower JPE forecasts, by 24 and 18 percent, respectively, primarily owing to lower forecasts of the fry-to-smolt transition and the smolt survival rate occurring downstream of Red Bluff Diversion Dam. Because post-hoc estimates of juvenile winter-run abundance at the entrance to the Delta do not currently exist, we are unable to evaluate forecast skill among the three methods.

Pearse, D. E., & Campbell, M. A. (2018). Ancestry and Adaptation of Rainbow Trout in Yosemite National Park. *Fisheries*, https://doi.org/10.1002/fsh.10136

California's Central Valley contains an abundance of rivers with historical and potential productivity for anadromous salmonids, which are currently limited by impacts such as dams, water diversions, and high temperatures. We surveyed genetic variation in Rainbow Trout Oncorhynchus mykiss within the upper Tuolumne and Merced rivers in and around Yosemite National Park to evaluate both population origins (ancestry) and the evolutionary response to natural and artificial barriers to migration (adaptation). This analysis revealed that despite extensive stocking with hatchery Rainbow Trout strains throughout the study area, most populations retained largely indigenous ancestry. Adaptive genomic variation associated with anadromy was distributed throughout the study area, with higher frequencies observed in populations connected to reservoirs that are known to support adfluvial life history variants. Fish in southern Central Valley rivers experience temperatures near the upper thermal limit for salmonids and represent an important reservoir of genomic diversity for adaptation to climate change. These results highlight the importance of local adaptation as well as the potential for resident Rainbow Trout populations above barrier dams to contribute to the recovery of steelhead (anadromous Rainbow Trout) once migratory connectivity is restored between upstream spawning and rearing habitats and the ocean

Pearse, D. E., & Garza, J. C. (2015). You Can't Unscramble an Egg: Population Genetic Structure of Oncorhynchus mykiss in the California Central Valley Inferred from Combined Microsatellite and Single Nucleotide Polymorphism Data. *San Francisco Estuary and Watershed Science, 13*(4), https://doi.org/10.15447/sfews.2015v13iss4art3

Steelhead/rainbow trout (Oncorhynchus mykiss) are found in all of the major tributaries of the Sacramento and San Joaquin rivers, which flow through California's Central Valley and enter the ocean through San Francisco Bay and the Golden Gate. This river system is heavily affected by water development, agriculture, and invasive species, and salmon and trout hatchery propagation has been occurring for over 100 years. We collected genotype data for 18 highly variable microsatellite loci and 95 single nucleotide polymorphisms (SNPs) from more than 1,900 fish from Central Valley drainages to analyze genetic diversity, population structure, differentiation between populations above and below dams, and the relationship of Central Valley O. mykiss populations to coastal California steelhead. In addition, we evaluate introgression by both hatchery rainbow trout strains, which have primarily native Central Valley ancestry, and imported coastal steelhead stocks. In contrast to patterns typical of coastal steelhead, Central Valley O. mykiss above and below dams within the same tributary were not found to be each others' closest relatives, and we found no relationship between genetic and geographic distance among below-barrier populations. While introgression by hatchery rainbow trout strains does not appear to be widespread among above-barrier populations, steelhead in the American River and some neighboring tributaries have been introgressed by coastal steelhead. Together, these results demonstrate that the ancestral population genetic structure that existed among Central Valley tributaries has been significantly altered in contemporary populations. Future conservation, restoration, and mitigation efforts should take this into account when working to meet recovery planning goals.

Peterson, J. T., & Duarte, A. (2020). Decision Analysis for Greater Insights into the Development and Evaluation of Chinook Salmon Restoration Strategies in California's Central Valley. *Restoration Ecology*, https://doi.org/10.1111/rec.13244

Considerable amounts of resources have been invested in ecological restoration projects across the globe to restore ecosystem integrity. Restoration strategies are often diverse and have been met with mixed success. In this paper, we describe the Chinook salmon (Oncorhynchus tshawytscha) decision-support models developed by the Central Valley Project Improvement Act Science Integration Team as part of a larger structured decision making effort aimed at maximizing natural adult production of Chinook salmon in California's Central Valley, USA. We then describe the decision analytic tools the stakeholder group used to solve the models and explore model results, including stochastic dynamic programming, forward simulation, proportional scoring, relative loss, expected value of perfect information, response profile analyses, and indifference curves. Using these tools, the stakeholder group was able to develop and evaluate restoration strategies for multiple Chinook salmon runs simultaneously, a first for the restoration program. We found that actions targeted at one run were detrimental to others, which was unexpected. Furthermore, information uncovered during this process was used to direct efforts towards targeted research/monitoring to reduce critical uncertainties in salmon demographic rates and make better restoration decisions moving forward. The decision sciences have established a wide range of analytical tools and approaches to simplify complex problems into key components, and we believe the concepts described in this paper are of great interest and can be applied by many restoration practitioners that undoubtedly face similar difficulties when implementing restoration strategies for complex systems.

Phillis, C. C., Sturrock, A. M., Johnson, R. C., & Weber, P. K. (2018). Endangered Winter-Run Chinook Salmon Rely on Diverse Rearing Habitats in a Highly Altered Landscape. *Biological Conservation, 217*, https://doi.org/10.1016/j.biocon.2017.10.023

Protecting habitats for imperiled species is central to conservation efforts. However, for migratory species, identifying juvenile habitats that confer success requires tracking individuals to reproduction. Here, we used otolith strontium isotope ratios (87Sr/86Sr) to reconstruct juvenile habitat use by endangered Sacramento River winter-run Chinook salmon that survived to adulthood. The isotope data revealed that 44–65% of surviving adults reared in non-natal habitats, most of which is not designated as critical habitat under the Endangered Species Act. Juveniles entered these non-natal habitats at small sizes, yet left freshwater at a similar size to those that reared in the mainstem Sacramento River, suggesting these alternate rearing habitats provide suitable growth conditions. These findings indicate Sacramento River winter-run Chinook salmon rely on rearing habitats across a broader geographic region than previously known, potentially opening up greater restoration and conservation opportunities for species recovery.

Plumb, J., Hansen, A., Adams, N., Evans, S., & Hannon, J. (2019). Movement and Apparent Survival of Acoustically Tagged Juvenile Late-Fall Run Chinook Salmon Released Upstream of Shasta Reservoir, California. *San Francisco Estuary and Watershed Science, 17*(3), https://doi.org/10.15447/sfews.2019v17iss3art4

Stakeholder interests have spurred the reintroduction of the critically endangered populations of Chinook Salmon to tributaries upstream of Shasta Dam, in northern California. We released two groups of acoustically tagged, juvenile hatchery, late-fall Chinook Salmon to determine how juvenile salmon would distribute and survive. We measured travel times to Shasta Dam, and the number of fish that moved between locations within Shasta Reservoir. We used mark-recapture methods to determine detection and apparent survival probabilities of the tagged fish as they traveled through five reaches of the Sacramento River from the McCloud River to San Francisco Bay (~590 km) over the two 3-month observation periods. After our first (February) release of 262 tagged fish, 182 fish (70%) were detected at least once at the dam, 41 (16%) were detected at least once downstream of Shasta Dam, and 3 (1%) traveled as far as San Francisco Bay. After the second (November) release of 355 tagged fish, only 4 (1%) were detected at Shasta Dam. No fish were detected below Shasta Dam, so we could not estimate survival for this second release group. The first release of fish was fortuitously exposed to exceptionally high river flows and dam discharges, which may have contributed to the more distant downstream migration and detection of these fish - though other factors such as season, diploid versus triploid, and fish maturation and size may have also contributed to release differences. The reported fish travel times as well as detection and survival rates are the first estimates of juvenile salmon emigration from locations above Shasta Dam in more than 70 years. This information should help inform resource managers about how best to assess juvenile winter-run Chinook Salmon and assist in their reintroduction to watersheds upstream of Shasta Dam.

San Joaquin River Restoration Program. (2019). *2018 Spring-Run Chinook Salmon Spawning Assessment within the San Joaquin River, California*. Retrieved from http://www.restoresjr.net/

After the construction of Friant Dam in the 1940's and subsequent increase in water diversions for agricultural use, fall-run and spring-run Chinook salmon (Oncorhynchus tshawytscha) were extirpated from the San Joaquin River upstream of the confluence with the Merced River to Friant Dam (Restoration Area). Currently, the San Joaquin River Restoration Program (SJRRP) is working towards restoring the river and maintaining naturally-reproducing and self-sustaining populations of Chinook salmon. Although there is consensus among managers that river connectivity (i.e., flow) and fish passage are restoration priorities, there are additional criteria that need to be addressed for the successful reestablishment of Chinook salmon populations within the San Joaquin River. The current quantity and quality of suitable Chinook salmon spawning habitat in Reach 1 of the Restoration Area remains unclear. To address this concern, we report on spawning activity, habitat preferences, and egg-to-fry survival of adult spring-run Chinook salmon broodstock released into Reach 1 in 2018. Between June and August 2018, the SJRRP released 120 male and 59 female adult broodstock into Reach 1 of the Restoration Area to assess spawning activity. Redd and carcass surveys and emergence trap monitoring were conducted from August 27, 2018 through February 7, 2019 to evaluate spawning success of spring-run Chinook salmon. We identified a total of 42 redds from 59 adult females released in 2018, yielding a redd creation rate of 71%. Redd size and physical characteristics were consistent with natural spring-run Chinook Salmon redds reported in other studies, as were redd substrate composition assessments. We observed low temperatures (<17 °C) in Reach 1 during 2018 and accordingly saw redds more spatially distributed across the reach than during previousChinook Salmon survey years. Spawning activity was detected from September 19 through November 20. carcasses were recovered (12 female, 10 male, 1 unknown) during 2018 and 92% of female carcasses were fully spawned. This year represented the first year that emergence trap installation and monitoring were performed on springrun Chinook Salmon redds in the San Joaquin River. We observed a total of 165 fry emerge from 10 traps installed within Reach 1, with most emergence coming from one trap. Due to low emergence numbers, we could not discern any clear patterns of emergence timing based off our data. Overall, we observed high levels spring-run Chinook salmon spawning activity in Reach 1 during 2018 but low observed emergence. As a result, we recommend that the SJRRP continue spring-run redd and carcass surveys and expand emergence studies to evaluate the restoration requirements needed for successful longterm establishment of spring-run Chinook salmon in the San Joaquin River. These surveys provide valuable information for future habitat improvement projects, reintroduction activities (i.e. SJRRP salmon population targets), and aid in the development of future management practices.

San Joaquin River Restoration Program. (2019). *Distribution and Abundance of California Central Valley Steelhead/Rainbow Trout and Late-Fall Chinook Salmon Redds in Clear Creek, Winter 2015 to Spring 2016*. Retrieved from https://www.fws.gov

Since 1995, the Central Valley Project Improvement Act, Clear Creek Restoration Program, and later the California Ecosystem Restoration Program have taken restoration actions to improve anadromous salmonid habitat in Clear Creek. The Red Bluff Fish and Wildlife Office, as part of the Clear Creek Restoration Program, has conducted Central Valley steelhead/Rainbow Trout Onchorynchus mykiss and late-fall run Chinook Salmon O. tshawytscha spawning ground surveys in Clear Creek since 2003. The purpose of these surveys is to evaluate population trends of these species on an annual basis through redd counts and carcass recoveries. Surveyors observed 149 California Central Valley steelhead/Rainbow Trout and 22 late-fall Chinook Salmon redds over 8 creek-length surveys from December 2015 to April 2016. Eighty-one percent of California Central Valley steelhead/Rainbow Trout and 100% of late-fall Chinook Salmon redds were located in the unconfined alluvial reach spanning from the Gorge Cascade to the confluence of the Sacramento River and seven of 27 Chinook Salmon carcasses inspected had a hatchery mark (26%).

San Joaquin River Restoration Program. (2019). *Genetic Analysis for Spring-Run San Joaquin River Chinook Salmon*. Retrieved from http://www.restoresjr.net/

Through Interagency Agreement R14PG00097, the NOAA Southwest Fisheries Science Center (SWFSC) collected genotypic data from Chinook salmon and performed genetic analyses to inform the actions of the Salmon Conservation and Research Facility (SCARF) and other relevant components of the San Joaquin River Restoration Program (SJRRP). The following were specified as deliverables of the genetic monitoring and management program, intended to minimize genetic impacts on donor stock populations and augment the long-term sustainability of the San Joaquin River salmon populations: Annual sex identification for the Salmon Conservation and Research Facility (SCARF) broodstock; Broodstock family reconstruction and creation of spawner candidate list based on relatedness for the SCARF; Establishment of Parentage Based Tagging (PBT) program for the San Joaquin River Chinook salmon population;Parentage inference for San Joaquin River young of year juvenile and returning adult salmon; Population genetics analysis for the San Joaquin River population; Annual and summary reporting; Raw genotype data acquired through the agreement.

Sandstrom, P. T., Ammann, A. J., Michel, C., Singer, G., Chapman, E. D., MacFarlane, R. B., . . . Klimley, A. P. (2020). Low River Survival of Juvenile Steelhead in the Sacramento River Watershed. *Environmental Biology of Fishes, 103*(5), https://doi.org/10.1007/s10641-020-00954-z

Steelhead (Oncorhynchus mykiss) areaspecies ofconservation concern in California'sSacramento River, and their poor status is hypothesized to be due in significant part to poor survival in freshwater. We used acoustic telemetry to examine the migratory survival of hatchery reared steelhead smolts through five contiguous regions of the Sacramento River and its estuary (upper river, lower river, delta, north bays, central San Francisco Bay) from 2006 to 2011. We consistently observed the highest losses in the upper river with only 20.5%, 33.7%, 43.3%, 21.3%, and 29.0% ofthe tagged population successfully passing through the 210-km region in years one through five respectively. Average migratory success was similar among the other regions with reduced rates of loss in the lower river (139.5-km, 8.4% ± 4.2), delta (99-km, 7.9% ± 3.4), and Estuary (69.5-km, 6.8% ± 2.9). The average survival through the Sacramento River to the Pacific Ocean across all five years was 5.6% ±3.6 SE. In the first study year we observed tagged steelhead responding to an increase in river discharge. Sixty-seven percent ofall steelhead that successfully migrated to the entrance to the Pacific Ocean began their migration during an increased discharge event. A similar pattern was observed in years two, four and five (77.8%, 77.8%, and 84%). Steelhead survival rates to the Pacific Ocean were highest in year five of the study (9.3% in January and 8.0% in December) when the largest discharges in the Sacramento River were observed (2200 m3 s−1).

Sapin, J. R., Saito, L., Dai, A., Rajagopalan, B., Hanna, R. B., & Kauneckis, D. (2017). Demonstration of Integrated Reservoir Operations and Extreme Hydroclimate Modeling of Water Temperatures for Fish Sustainability Below Shasta Lake. *Journal of Water Resources Planning and Management, 143*(10), https://doi.org/10.1061/(asce)wr.1943-5452.0000834

Construction of Shasta Dam on the Sacramento River in 1945 prevented anadromous fish from accessing their natural cold-water spawning habitat above the dam and is one of the factors that caused population declines in Chinook salmon and other species. To address listing of winter-run Chinook salmon under the Endangered Species Act, the U.S. Bureau of Reclamation began operating a temperature-control device (TCD) on Shasta Dam in 1997 that enabled selective withdrawal of reservoir outflows for control of downstream water temperatures while maximizing power generation. However, effectiveness of TCD operations for addressing fisheries concerns under hydroclimate variability is unknown. Stochastic methods to generate synthetic extreme hydroclimate conditions were combined with hydrodynamic modeling of reservoir operations and interactions with reservoir managers to examine the TCD's ability to meet downstream temperature objectives. Model simulations suggest that TCD withdrawal schedules could reduce outflow temperature target exceedances when compared with more traditional dam operations such as solely hypolimnetic or epilimnetic releases. However, constraints imposed by multipurpose operational considerations, especially under extreme climate conditions, and the Sacramento-San Joaquin system's complex regulatory environment limit use of reservoir management to provide optimal thermal conditions best for Chinook salmon spawning and recruitment.

Satterthwaite, W. H., Carlson, S. M., & Criss, A. (2017). Ocean Size and Corresponding Life History Diversity among the Four Run Timings of California Central Valley Chinook Salmon. *Transactions of the American Fisheries Society, 146*(4), https://doi.org/10.1080/00028487.2017.1293562

We used coded wire tag data to compare spawner age structure and seasonal patterns ofage-specificsize at dateamong fish harvested in the ocean from the four seasonal run timings (fall, late-fall, winter, and spring) of Chinook Salmon Oncorhynchus tshawytscha from the Central Valley, California, and we examined differences between the fall-run fish (the most abundant run) from the Sacramento and San Joaquin River basins. The runs varied in their ocean size at a common age and date, and within each run, monthly mean ocean sizes appeared to stop increasing when spawners began to return to freshwater. Despite support for multiple hypotheses, no single factor explained all of the variation among and within runs. Ocean size at a common date was well explained by a “juvenile head-start” hypothesis, predicting larger sizes for the spring and fall runs due to earlier ocean entry. Month of spawner return was well explained by a “premature adult migration” hypothesis, predicting earlier returns (within years, regardless ofage) by winter- and spring-run fish spawning further upstream. However, neither release timing nor spawning elevation could fully explain observed patterns in spawner age structure, such as an unusually high occurrence of age-2 San Joaquin River fall-run spawners and the near absence of age-4 or older spawners in the winter run. Larger smolt size might explain earlier maturation by the San Joaquin versus SacramentoRiver fall run, but smolt size could not explain patterns in age structure across runs.Metabolic costs of holding upstream with large size might explain the lack of older spawners among the winter run but are inconsistent with the late-fall run having the highest frequency of age-4 and older spawners. Our results demonstrate multiple pathways by which differences both within and among the runs may contribute to differences in their fishery vulnerability and demographic decoupling, which could contribute to a stabilizing portfolio effect.

Satterthwaite, W. H., Ciancio, J., Crandall, E., Palmer-Zwahlen, M. L., Grover, A. M., O'Farrell, M. R., . . . Garza, J. C. (2015). Stock Composition and Ocean Spatial Distribution Inference from California Recreational Chinook Salmon Fisheries Using Genetic Stock Identification. *Fisheries Research, 170*, https://doi.org/10.1016/j.fishres.2015.06.001

We apply genetic stock identification (GSI) data and models of the catch and sampling process to describe spatial and temporal patterns in the stock composition and stock-specific catch-per-unit-effort (CPUE) of both tagged and untagged stocks encountered in California recreational ocean Chinook salmon fisheries during the period 1998-2002. Spatial and temporal distributions inferred from GSI sampling of stocks with tagged hatchery components were broadly consistent with those previously inferred from studies of tag recoveries alone, while GSI provided additional insight into untagged stocks of conservation concern. The catch in all times and areas was dominated (typically >= 90%) by the "Central Valley Fall" genetic reporting group, which is comprised primarily of Sacramento River fall run Chinook. Other contributing stocks were more spread out in space and time with the exception of Central Valley winter run Chinook, which were rarely encountered by boats fishing in port areas north of Point Reyes. Localized stock-specific CPUE appeared to increase near a stock's respective natal river while decreasing in other port areas at the time of adult return to freshwater for spawning. We describe methods for quantifying uncertainty in stock proportions, stock-specific catch, and determining the statistical support for proposed management boundaries hypothesized to represent "break points" in the spatial distributions for stocks of concern, and find at most equivocal support for a proposed delineation line at Point Reyes in north-central California. Published by Elsevier B.V.

Satterthwaite, W. H., Cordoleani, F., O'Farrell, M. R., Kormos, B., & Mohr, M. S. (2018). Central Valley Spring-Run Chinook Salmon and Ocean Fisheries: Data Availability and Management Possibilities. *San Francisco Estuary and Watershed Science, 16*(1), https://doi.org/10.15447/sfews.2018v16iss1/art4

Central Valley spring-run Chinook Salmon (CVSC) are designated threatened by state and federal authorities. Although CVSC are caught in ocean fisheries, their harvest is not actively managed, because it is assumed that measures currently in place to protect endangered Sacramento River winter-run Chinook Salmon (SWRC) will also sufficiently protect CVSC. Recoveries of tags and genetically-identified CVSC suggest these fish have a more northerly distribution than SRWC. Further, escapement data and cohort reconstructions suggest that CVSC mature later than SRWC. Thus, regulations (time/area restrictions and minimum size limits) crafted to protect SRWC alone may not adequately protect CVSC; on the other hand, regulations to constrain impacts on Klamath River and California coastal Chinook

Salmon populations may also reduce impacts on CVSC. Trends in CVSC escapement were deemed acceptable in recent status updates, but concerns remain because of the negative effects caused by recent drought and ocean conditions. Should more active management of CVSC be desired, current options are limited. The most promising approach is based on estimating agespecific ocean fishing mortality rates by using cohort reconstructions applied to tagged Chinook Salmon that originate from the Feather River Hatchery. At a minimum, ocean fishing mortality rates could be monitored and compared to proxy thresholds. If reference harvest rates were established, harvest models could be developed to predict how CVSC would be affected by fishing regulations, similar to the way fall-run Chinook Salmon fisheries are evaluated. Abundance forecasts would require improved juvenile production data (e.g., from genetic sampling of juvenile emigrants), since sibling-based forecasts commonly used for fall-run Chinook Salmon would not be available in time for pre-season planning. It is unclear if ocean fishing mortality rate estimates derived from hatchery proxies for naturalorigin fish are truly representative, but existing data do not demonstrate obvious differences in ocean distribution or size-at-age fish. Substantial new investments in tagging or sampling would be needed to directly estimate ocean fishing mortality rates for natural-origin CVSC. Establishing specific harvest targets or limits for CVSC requires an improved understanding of production throughout their life cycle through juvenile production estimates and long-term information on spawner age structure.

Stewart, I. T., Rogers, J., & Graham, A. (2020). Water Security under Severe Drought and Climate Change: Disparate Impacts of the Recent Severe Drought on Environmental Flows and Water Supplies in Central California. *Journal of Hydrology X, 7*, https://doi.org/10.1016/j.hydroa.2020.100054

The record-breaking 2014–2016 California drought, emblematic of the more frequent and extreme climatic events projected under climate change, highlighted the complex challenges of supplying water for competing uses in water-limited regions during times of severe shortages. The Tuolumne watershed in Central California supplies water to urban users in the San Francisco Bay Area and agricultural regions in the Central Valley, while also constituting important habitat for Chinook salmon. This study examines the equity of drought impacts in the watershed between the agricultural, and different urban sectors, and environmental needs. Analyzing the relative magnitude of flow and storage in different parts of the watershed during ‘no drought’, ‘moderate drought’, and ‘severe drought conditions during the 2008–2018 study period, we found that ‘moderate’ and ‘severe’ drought events affected sections of Tuolumne watershed in profoundly different ways. Water storage and supplies in the upper watershed for urban users in economically well-off areas were not affected by drought, while supplies to agricultural and urban users in the Central Valley were curtailed by about 30%, and flow reductions in the lower portion of the watershed important to salmon migration amounted to 85–90% during ‘severe’ drought conditions. Concurrent with the water scarcity, stream temperatures in the lower watershed were significantly warmer, and salmon populations lower during ‘moderate’ and ‘severe drought’. We outline integrative drought-preparation strategies for California and other water-limited regions that prioritize water security through an equitable and sustainable distribution of the available water resources while minimizing the impact on human water supplies and ecosystems.

Sutphin, Z., Durkacz, S., Grill, M., Smith, L., & Ferguson, P. (2019). *Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul and Rescue Actions in the San Joaquin River Restoration Area*. Retrieved from http://www.restoresjr.net/

The objective of this effort was to identify returning adult spring-run Chinook Salmon through passive (i.e., Vaki Camera Monitoring) or active (i.e., fyke trapping or netting) monitoring in the lower reaches of the RA. Once detected, the objective was to quantify the number of adult Salmon in the RA, trap and haul the adults around in-river migration impediments and release them into upper reaches of the RA to support additional monitoring efforts (e.g., adult holding and spawning, fry emergence, and juvenile monitoring studies).

Von Bargen, J., Smith, C. T., & Rueth, J. (2015). Development of a Chinook Salmon Sex Identification Snp Assay Based on the Growth Hormone Pseudogene. *Journal of Fish and Wildlife Management, 6*(1), https://doi.org/10.3996/012014-JFWM-004

Genotypic sex identification assays can provide valuable information about fish populations when phenotypic sex determination is difficult. Here we describe the development of a TaqMan(R) assay (Ots_SexID) designed to identify the genotypic sex by targeting a region previously examined in the growth hormone pseudogene for winter-run Chinook salmon (Oncorhynchus tshawytscha) collected from the Sacramento River and spawned at the Livingston Stone National Fish Hatchery. Accuracy of the marker was assessed by comparing genotypic sex assignments for Chinook salmon spawned at Livingston Stone National Fish hatchery in 2012 (n = 84) with phenotypic sex recorded during spawning. Genotypic sex was observed to be concordant with phenotypic sex identified using Ots_SexID in 83/84 individuals, suggesting that the assay could be used to predict phenotypic sex with ~99% accuracy. To evaluate the utility of the TaqMan assay in other parts of the species' range, we examined collections from 29 other populations ranging from Alaska to California. Genotypic sex assignments based on the assay were generally concordant with observed phenotypes, but there were some strong exceptions. These results suggest that the new assay will be very useful for Sacramento River winter-run Chinook salmon, but also highlight the importance of thoroughly testing any genotypic sex identification assay before application in a population of interest.

Welch, D. W., Porter, A. D., & Rechisky, E. L. (2018). The Coast-Wide Collapse in Marine Survival of West Coast Chinook and Steelhead: Slowmoving Catastrophe or Deeper Failure? In *bioRxiv preprint*. Retrieved from https://www.biorxiv.org/content/10.1101/476408v1

Accelerating decreases in survival are evident for northern Hemisphere salmon populations. We collated smolt survival and smolt-to-adult (marine) survival data for all regions of the Pacific coast of North America excluding California to examine the forces shaping salmon returns. A total of 3,055 years of annual survival estimates were available for Chinook (Oncorhynchus tshawytscha) and steelhead (O. mykiss). This dataset provides a fundamentally different perspective on west coast salmon conservation problems from the previously accepted view. We found that marine survival collapsed over the past half century by a factor of at least 4-5 fold to similar low levels (~1%) for most regions of the west coast. The size of the decline is too large to be compensated by freshwater habitat remediation or cessation of harvest, and too large-scale to be attributable to specific anthropogenic impacts such as dams in the Columbia River or salmon farming in British Columbia. Within the Columbia River, both smolt survivals during downstream migration in freshwater and adult return rates (SARs) of Snake River populations, often singled out as exemplars of poor survival, appear unexceptional and are in fact higher than estimates reported from other regions of the west coast lacking dams. Formal Columbia River rebuilding targets of 2-6% SARs may therefore be unachievable if regions with nearly pristine freshwater conditions also fail to achieve these targets. Finally, we present case studies demonstrating that the historical response to evidence that the salmon problems are primarily ocean-related was to re-emphasize freshwater actions and to stop work on ocean issues. With ocean temperatures forecast to increase far further, the failure of management to identify the drivers of salmon collapse and respond appropriately suggest that the future of most west coast salmon populations is bleak.

Willmes, M., Jacinto, E. E., Lewis, L. S., Fichman, R. A., Bess, Z., Singer, G., . . . Chapman, E. D. (2020). Geochemical Tools Identify the Origins of Chinook Salmon Returning to a Restored Creek. *Fisheries*, https://doi.org/10.1002/fsh.10516

Chinook Salmon (Oncorhynchus tshawytscha) populations in California are in decline due to the

combined effects of habitat degradation, water diversions, and climate change. Reduced life-history diversity within these populations inhibits their ability to respond to these stressors. Putah Creek, a small creek in California's Central Valley that once supported Chinook Salmon, is undergoing restoration to provide spawning habitats for this imperiled species. Beginning in 2014, increasing numbers of Chinook Salmon spawned throughout the creek and emigrating juveniles were observed in the following months. Here we used otolith annual growth bands and microchemistry to investigate the age structure and natal origins of the adult spawners. Most individuals were 2 or 3 years old and originated from at least seven different natal sources, overwhelmingly from Central Valley hatcheries (~88%). These findings highlight that straying fall-run Central Valley Chinook Salmon can rapidly utilize restored habitats, potentially establishing new populations. However, to facilitate local adaptations, straying rates and gene flow will have to be managed over time. Reconnecting migratory pathways and restoring many small and diverse streams like Putah Creek thus provides an opportunity to increase life-history diversity, strengthening the recovery and resilience of Chinook Salmon.

Zarri, L. J., Danner, E. M., Daniels, M. E., Palkovacs, E. P., & Arlinghaus, R. (2019). Managing Hydropower Dam Releases for Water Users and Imperiled Fishes with Contrasting Thermal Habitat Requirements. *Journal of Applied Ecology, 56*(11), https://doi.org/10.1111/1365-2664.13478

The construction of dams on large rivers has negative impacts on native species. Environmental flows have been proposed as a tool to mitigate these impacts, but in order for these strategies to be effective they must account for disparate temperature and flow needs of different species. We applied a multi-objective approach to identify trade-offs in dam release discharge and temperature for imperiled fishes with contrasting habitat requirements, while simultaneously meeting the needs of human water users. Using the Sacramento River (California, USA) as a case study, our model suggests that current management aimed at providing high discharge for downstream water users and cold water for endangered winter-run Chinook salmon (Oncorhynchus tshawytscha) has detrimental impacts on threatened green sturgeon (Acipenser medirostris), which require warm water for juvenile growth. We developed an optimal dam release scenario that can be used to meet the needs of salmon, sturgeon and human water users. Our results show that dam releases can be managed to successfully achieve these multiple objectives in all but the most severe drought years. Synthesis and applications. This study shows that managing dam releases to meet the needs of a single species can have detrimental effects on other native species with different flow and temperature requirements. We applied a multi-objective approach to balance environmental requirements of multiple species with the needs of human water users. Our findings can be used to guide management of Shasta Dam and our approach can be applied to achieve multi-object management goals in other impounded rivers.

Zeug, S. C., Sellheim, K., Melgo, J., & Merz, J. E. (2020). Spatial Variation of Juvenile Chinook Salmon (Oncorhynchus tshawytscha) Survival in a Modified California River. *Environmental Biology of Fishes, 103*(5), https://doi.org/10.1007/s10641-019-00919-x

Spatial variation in habitat structure is a wellrecognized characteristic oflotic ecosystems. The resulting patchwork mosaic provides opportunities for growth and survival as well as mortality risks for fish migrating through these systems. Dam construction within a watershed has numerous downstream tail water effects that alter creation and evolution ofhabitat features used by anadromous fishes that spawn and rear in these reaches. California Central Valley Pacific salmon (Oncorhynchus spp) are largely restricted to areas below impassable dams and these populations are undergoing widespread declines. High mortality of juvenile salmon in these reaches is thought to be a limitation to recovery. We conducted a radio telemetry study to evaluate spatial variation in juvenile Chinook Salmon (O. tschawytscha) survival and survival-environment relationships in three reaches of a Central Valley tail water. Additionally, we used mobile surveys to identify the location of last known detections to elucidate areas ofdisproportionate mortality. Our results indicated variation in flow and salmon size had greater explanatory power than year effects. However, relationships between flow, salmon size and survival were reachspecific indicating drivers of survival are spatially heterogeneous. Significant clumping oflast known detections in the two lower reaches of the river suggests that mortality may be more frequent in these locations. Our results suggest that there is substantial spatial variation in migration mortality and both environmental conditions (flow) and salmon characteristics (size) have a strong influence on observed mortality. This information should be used to target actions that can support Chinook Salmon recovery.

Section II: South-Central & Southern California Coast

Abadía-Cardoso, A., Pearse, D., Jacobson, S., Marshall, J., Dalrymple, D., Kawasaki, F., . . . Garza, J. (2016). Population Genetic Structure and Ancestry of Steelhead/Rainbow Trout (Oncorhynchus mykiss) at the Extreme Southern Edge of Their Range in North America. *Conservation Genetics, 17*(3), https://doi.org/10.1007/s10592-016-0814-9

Steelhead (Oncorhynchus mykiss) populations have declined dramatically in many parts of their range in North America, most critically in Southern California, where these anadromous trout are now classified as 'Endangered' under the United States Endangered Species Act. The widespread introduction of hatchery rainbow trout, the domesticated freshwater resident form of the species O. mykiss, is one factor threatening the long-term persistence of native steelhead and other trout populations. To identify where native fish of coastal steelhead lineage remained, we performed a population genetic analysis of microsatellite and SNP genotypes from O. mykiss populations at the extreme southern end of their range in Southern California, USA and Baja California, Mexico. In the northern part of this region, nearly all populations appeared to be primarily descendants of native coastal steelhead. However, in the southern, more urbanized part of this region, the majority of the sampled populations were derived primarily from hatchery trout, indicating either complete replacement of native fish or a strong signal of introgression overlaying native ancestry. Nevertheless, these genetically introgressed populations represent potentially critical genetic resources for the continued persistence of viable networks of O. mykiss populations, given the limited native ancestry uncovered in this region and the importance of genetic variation in adaptation. This study elucidates the geographic distribution of native trout populations in this region, and serves as a baseline for evaluating the impacts of hatchery trout on native O. mykiss populations and the success of steelhead conservation and recovery efforts.

Arriaza, J. L., Boughton, D. A., Urquhart, K., & Mangel, M. (2017). Size-Conditional Smolting and the Response of Carmel River Steelhead to Two Decades of Conservation Efforts. *Plos One, 12*(11), https://doi.org/10.1371/journal.pone.0188971

Threshold effects are common in ecosystems and can generate counterintuitive outcomes in management interventions. A threshold effect proposed for steelhead trout (Oncorhynchus mykiss) is size-conditional smolting and marine survival. Steelhead are anadromous, maturing in the ocean but migrating to freshwater to spawn, where their offspring reside for one or more years before smolting D physiologically transforming to a saltwater form D and migrating to the ocean. In conditional smolting, juveniles transform only if growth exceeds a threshold body size prior to migration season, and subsequent marine survival correlates with size at ocean entry. Conditional smolting suggests that efforts to improve freshwater survival of juveniles may reduce smolt success if they increase competition and reduce growth. Using model-selection techniques, we asked if this effect explained declining numbers of adult Carmel River steelhead. This threatened population has been the focus of two decades of habitat restoration, as well as active translocation and captive-rearing of juveniles stranded in seasonally dewatered channels. In the top-ranked model selected by information-theoretic criteria, adult decline was linked to reduced juvenile growth rates in the lower river, consistent with the conditional smolting hypothesis. According to model inference, since 2005 most returning adult steelhead were captively-reared. However, a lower-ranked model without conditional smolting also had modest support, and suggested a negative effect of captive rearing. Translocations of juvenile fish to perennial reaches may have reduced the steelhead run slightly by raising competition, but this effect is confounded in the data with effects of river flow on growth. Efforts to recover Carmel River steelhead will probably be more successful if they focus on conditions promoting rapid growth in the river. Our analysis clearly favored a role for size-conditional smolting and marine survival in the decline of the population, but did not definitively rule out alternative explanations.

Booth, D. B., Cui, Y. T., Diggory, Z., Pedersen, D., Kear, J., & Bowen, M. (2014). Determining Appropriate Instream Flows for Anadromous Fish Passage on an Intermittent Mainstem River, Coastal Southern California, USA. *Ecohydrology, 7*(2), https://doi.org/10.1002/eco.1396

Setting instream flows to protect aquatic resources is required by California state law, but this task is not straightforward for an intermittent river that is naturally dry six or more months of every year. The Santa Maria River, 200km northwest of the Los Angeles metropolitan area, lies within the northern range of the federally endangered southern California steelhead (Oncorhynchus mykiss) and is a logical candidate for instream flow protection: the watershed historically supported the anadromous life history of this species, but fish must navigate the lowermost 39km of the commonly dry mainstem river to move between the ocean and freshwater habitats in the upper watershed. Mainstem flows are partly controlled by Twitchell Dam, constructed across one of the Santa Maria River's two main tributaries in 1962. The dam is operated to maximize groundwater recharge through the bed of the mainstem Santa Maria River, thus minimizing discharge to the Pacific Ocean and so reducing already limited steelhead passage opportunities. Conventional criteria for determining suitable instream flows for steelhead passage are ill-suited to intermittent, Mediterranean-type rivers because they ignore the dynamic channel morphology and critical importance of headwater flows in providing cues that once presaged passage-adequate mainstem discharges but no longer do so. Hydrologic analysis of pre-dam flows, coupled with established criteria for successful O.mykiss migration, provides an objective basis for evaluating alternative dam-management scenarios for enhancing steelhead passage, although their implementation would redirect some water that for the past half-century has exclusively supported irrigated agriculture and municipal water supplies. Copyright (c) 2013 John Wiley & Sons, Ltd.

Booth, M. T. (2020). Patterns and Potential Drivers of Steelhead Smolt Migration in Southern California. *North American Journal of Fisheries Management, 40*(4), https://doi.org/10.1002/nafm.10475

Downstream migration of smolts is a critical aspect of the life history pathway for anadromous salmonids. Timing of downstream migration can vary along latitudinal and climatic gradients. Steelhead Oncorhynchus mykiss occur over a broad range of climate and hydrologic conditions, but relatively little is known about migration timing of smolts in the southern extent of the species’ range. Using a 19-year data set (1994–2014) of smolt arrivals collected in a downstream migrant trap at the Vern Freeman Diversion facility on the Santa Clara River, one of the largest coastal watersheds in southern California, I report patterns of migration and potential environmental drivers determining migration timing. Large sections of the Santa Clara River and the confluences of its perennial tributaries are intermittent except during winter and spring stormflows, limiting migration opportunities. If tributaries were connected, smolts were regularly encountered in the downstream migrant trap between March and May, with rare observations of downstream migrants in January (0.1%) or February (0.3%). Although these migration data are limited by low smolt abundance and sampling efficiency during high-flow events, potential environmental drivers were identified as cues for smolt migration timing in this region. Day length was a consistent predictor of smolt migration, while hydrology was both a constraint and a cue, with migrants only arriving after tributaries had reconnected to the main stem and with many arrivals occurring weeks or months after storm events had passed. Smolt migration was not consistently synchronized with periods when intermittent sections of the main stem were wetted and passable to the ocean. Between 0% and 70% of smolts arrived at the Vern Freeman Diversion after natural flows were likely insufficient for passage to the ocean. Smolt migration is a critical piece of the management puzzle for southern California steelhead, and these data will serve to inform effective management strategies and research needs for the successful recovery of the species.

Boughton, D. A., East, A., Hampson, L., Kiernan, J. D., Leiker, S., Mantua, N. J., . . . Harrison, L. R. (2016). *Removing a Dam and Re-Routing a River : Will Expected Benefits for Steelhead Be Realized in Carmel River, California*. https://doi.org/10.7289/V5/TM-SWFSC-553

The question of where to upgrade and where to decommission aging dams is currently a matter of national debate. Ecological benefits of dam removal are diverse, but a key expected benefit is improved wild fish populations and fisheries, particularly for migratory fish such as anadromous salmonids. However, in general one cannot expect with certainty how strongly or how soon such benefits will materialize after dam removal, due to inadequate data on ecological impacts, unpredictable ecosystem dynamics, or poor understanding of the processes themselves. Each dam removal is thus an experiment, and each expected benefit is an hypothesis to be tested and learned from. The scientific literature suggests that river restoration in the USA has been impeded because individual projects were not viewed as learning opportunities to help inform and refine future projects elsewhere, but in the past decade this situation has started to improve. Here we outline how to transform a large dam removal project in California into an opportunity to learn about ecological benefits for a threatened population of steelhead trout (anadromous Oncorhyn---chus mykiss) inhabiting one of the distinctive “episodic” type river systems of the state. The Carmel River Reroute and Dam Removal project (CRRDR), now underway near Monterey California, is the largest dam removal project ever in California, and one of the largest in the USA. The principal goals of the project emphasize ecological benefits for steelhead, by improving ecological connectivity to habitat upstream of the dam, habitat--forming processes downstream of the dam, and restoration of habitats within the former damsite itself. Here we describe a research framework to discern which of these expected benefits are realized, on what timescale, and with what magnitude and effects on steelhead population viability. A long--established scientific concept is that viable salmonid populations need rivers with abundant habitat and natural (minimally altered) flow dynamics. However, CRRDR is expected to have modest effects on the amount of accessible habitat and on flow dynamics: The amount of accessible habitat upstream of the dam will not increase much because an existing fish ladder already provides passage for migrating adults; and flow dynamics will not change much due to the modest storage capacity of the reservoir. A broader conceptual framework for steelhead viability emphasizes not just habitat abun---dance and flow dynamics, but also ecological connectivity and unimpaired habitat--forming processes, and it is improvement of these two latter characteristics that is the focus of the CRRDR. The research program that we outline has applicability to dam removals whose goals are framed within this broader concept of viable salmonid populations.

Boughton, D. A., Harrison, L. R., Pike, A. S., Arriaza, J. L., & Mangel, M. (2015). Thermal Potential for Steelhead Life History Expression in a Southern California Alluvial River. *Transactions of the American Fisheries Society, 144*(2), https://doi.org/10.1080/00028487.2014.986338

Steelhead Oncorhynchus mykiss (anadromous Rainbow Trout) near the southern limit of the species' range commonly use shallow alluvial rivers for migration, spawning, and rearing. These rivers have been widely modified for water management, and an enduring question is whether their rehabilitation would create summer nursery habitat for steelhead. We used process-based models to evaluate the thermal potential for steelhead nursery habitat in the Santa Ynez River, California, a regulated alluvial river that currently supports few steelhead. We assessed (1) how well a calibrated model of river heat fluxes predicted summer temperature patterns for a warm year and an average year; (2) whether those patterns created thermal potential for the rapid growth that is characteristic of steelhead nursery habitat; and (3) whether manipulation of flows from an upstream dam significantly altered thermal potential. In the heat flux model, the root mean square error for 15-min temperatures was 1.51°C, about three times greater than that of the larger, deeper Sacramento River in northern California. Generally, the Santa Ynez River was thermally suitable but stressful for juvenile steelhead. Flow augmentation reduced the number of thermally stressful days only near the dam, but it reduced the intensity of thermal stress throughout the river. Daytime movement of steelhead into natural, thermally stratified pools would reduce stress intensity by similar levels. In this region, O. mykiss commonly pursue an anadromous (steelhead) life history by entering nursery habitat early in their first or second summer and rapidly growing to attain a threshold size for anadromy by fall. In the average year, the river was thermally suitable for the first-summer pathway under high food availability and for the second-summer pathway under medium food availability. The warm year also supported the second-summer pathway under high food availability. Currently, the Santa Ynez River's capacity to support these pathways does not appear to be limited by summer temperature, thus indicating a need to identify other limiting factors. Received July 21, 2014; accepted November 5, 2014

California Department of Fish and Wildlife. (2016). *Instream Flow Regime Recommendations Big Sur River, Monterey County*. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=145698

The Big Sur River is a significant watercourse for which instream flow regime levels need to be established in order to assure the continued viability of stream-related fish and wildlife resources. The free-flowing, unregulated, Big Sur River was selected for development of flow recommendations because it is a significant watercourse with high resource value, and because it is an important source stream for the South-Central Coast Distinct Population Segment (DPS) of south-central coast steelhead (Oncorhynchus mykiss) per NOAA's South-Central California Steelhead Recovery Plan (NMFS, 2013). The Big Sur River steelhead population represents a Core 1 population that is intended to serve as a foundation stock source for the recovery of steelhead in the South-Central California Coast Steelhead Evolutionary Significant Unit (ESU); therefore, it is imperative that this steelhead population be restored to viable selfsustaining population levels that maintain persistence through time and which is capable of becoming a substantial donor stock source to enable recovery of steelhead populations in adjacent streams within the South Central Coast Steelhead ESU. California's south-central coast steelhead populations have declined significantly and as a result are listed as threatened (NMFS, 2011). Insufficient instream flow has been identified as a key factor preventing recovery of steelhead population viability in the Big Sur River. Increasing instream flows is expected to provide substantive progress towards recovery of steelhead in the Big Sur River.

Dagit, R., Bell, E., Adamek, K., Mongolo, J., Montgomery, E., Trusso, N., & Baker, P. (2017). The Effects of a Prolonged Drought on Southern Steelhead Trout (Oncorhynchus mykiss) in a Coastal Creek, Los Angeles, California. *Bulletin, Southern California Academy of Sciences, 116*(3) Retrieved from https://doi.org/10.3160/soca-116-03-162-173.1

Long-term lifecycle monitoring of federally endangered southern steelhead trout (Oncorhynchus mykiss) in Topanga Creek provides a unique opportunity to examine the health and abundance of a steelhead population before (2008--2011) and during (2012--2016) a prolonged drought. We found that the five-year drought resulted in a substantial and significant decline in available wetted habitat suitable for rearing and upstream migratory access for anadromous adults. The response of the steelhead population has been a significant reduction in anadromous spawning, distribution of rearing, and abundance of all life stages of anadromous and resident steelhead. After five years of drought a population that exceeded 325 individuals in 2008, now numbers fewer than 50 fish, and appears to be at extremely high risk of extirpation. Acknowledging the possibility of increased drought regionally and globally, the need to bolster southern steelhead resiliency to additional disturbance is paramount.

Dagit, R., & Krug, J. (2016). Rates and Effects of Branding Due to Electroshock Observed in Southern California Steelhead in Topanga Creek, California. *North American Journal of Fisheries Management, 36*(4), https://doi.org/10.1080/02755947.2016.1173136

As part of a 7-year lifecycle monitoring study, electroshocking was used to capture and characterize a small population of federally listed endangered southern California steelhead Oncorhynchus mykiss in Topanga Creek, Los Angeles, California. Electroshocking is a tool widely used to study fish populations, despite its potential behavioral and physical effects on individuals. We examined rates of external hemorrhaging (i.e., branding) and its effect on growth rates and survival of recaptured individuals. Rates of branding were low (0–3%) during most November events from 2008 to 2014, but higher during all March events (8–23%) and during the November 2011 event (13%). Overall, 5% of the total captured individuals exhibited branding. Growth rates (mm/d) of individuals recaptured after branding were not significantly different, but on average were 9% lower than average daily growth rates for individuals in the same size-class captured and recaptured in the same time periods. In general, larger fish were more likely to be branded than were smaller fish ($P < 0.0001$). Although 69% of brandings occurred in pool habitats, which tend to be larger and deeper than other habitats, branding was not significantly more likely to occur in any habitat type ($P = 0.13$) or in any substrate type ($P = 0.16$), and mean or maximum depth of habitat was not related to the rate of branding. The population-level effects associated with branding remain unclear. Although important information has been obtained through the use of electroshocking, the cumulative effects of electroshocking-induced injuries to this endangered species need to be considered.

Holmes, R. W., Rankin, D. E., Ballard, E., & Gard, M. (2016). Evaluation of Steelhead Passage Flows Using Hydraulic Modeling on an Unregulated Coastal California River. *River Research and Applications, 32*(4), https://doi.org/10.1002/rra.2884

Passage and habitat connectivity flows for steelhead Oncorhynchus mykiss through depth sensitive natural, low gradient, critical riffle sites were investigated in the unregulated Big Sur River, California. The River2D two-dimensional hydraulic habitat model, along with quantitative passage metrics and species-specific and lifestage-specific depth criteria, were used to evaluate and compare predicted fish passage flows with flows derived by a traditional empirical critical riffle fish passage method. Passage flows were also compared with historical unimpaired natural hydrology patterns to assess the frequency and duration of suitable passage flows under the naturally variable flow regimes characteristic of Central California coastal rivers. A strong relationship (r2 = 0.93) was observed between flows predicted by hydraulic modeling and flows identified by the empirical critical riffle method. River2D provided validation that the flows derived using the traditional critical riffle methodology provided for contiguous passable pathways of suitable hydraulic (depth and velocity) conditions through complex cobble-dominated riffle sites. Furthermore, steelhead passage flows were spatially and temporally consistent between lagoon and upstream riffles for adults, and were generally indicative of a river system in equilibrium with a naturally variable flow regime and associated intact ecological processes. An analysis of 25 years of continuous flow data indicated sufficient flows for upstream passage by young-of-year and juvenile steelhead were produced between 37% and 100% and between 1% and 95% of the time, respectively. September and October are the most challenging months for natural flows to meet young-of-year and juvenile passage and habitat connectivity flows. Careful consideration of seasonal and interannual flow variability dynamics, therefore, are critical components of an effective flow management strategy for the maintenance and protection of passage and habitat connectivity flows between lagoon and upriver habitats. Published 2015. This article is a U.S. Government work and is in the public domain in the USA.

Homes, R., Rankin, D., Gard, M., & Ballard, E. (2014). *Instream Flow Evaluation Steelhead Passage and Connectivity of Riverine and Lagoon Habitats Big Sur River, Monterey County*. (STREAM EVALUATION REPORT 14-3). Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=99799&inline

Instream flows for protecting steelhead (Oncorhynchus mykiss) passage through depth sensitive natural, low gradient, alluvial critical riffle sites were evaluated in the Big Sur River, California from 2009 - 2012. Flows were evaluated using the California Department of Fish and Wildlife critical riffle analysis protocol and the River 2D twodimensional hydraulic and habitat model along with quantitative passage metrics and species- and lifestage-specific depth criteria. Flows identified for protecting passage and habitat connectivity at critical riffle sites between lagoon and lower river habitats were 18 cfs, 32 cfs, and 75 cfs for young-of-year, juvenile, and adult steelhead, respectively. A strong relationship (r2 = 0.93) was observed between flow requirements identified by each method. Flow requirements were spatially and temporally consistent at critical riffles between the upper river and lagoon for adult steelhead, and generally indicative of a river system in equilibrium with a naturally variable flow regime, and associated intact ecological processes. An analysis of over twenty-five years of continuous flow data records indicated sufficient flows at critical riffle locations for young-of-year and juvenile steelhead were produced between 37% and 100% and between 1% and 95% of the time, respectively. The months of September and October were the most challenging months to obtain natural flows to meet young-of-year and juvenile passage and habitat connectivity flows. Flows identified for adult steelhead passage were produced naturally between 52% and 74% of the time during the core adult migratory period of January through April. Naturally produced flows for adult steelhead migration were less reliable at the beginning and end of the migration season with flow criteria being met 3% and 30% for November and May, respectively. Careful consideration of seasonal and interannual flow variability dynamics, therefore, are critical components of an effective flow management strategy for the maintenance and protection of passage and habitat connectivity flows between lagoon and upriver habitats, and are essential for the survival and longevity of steelhead in the Big Sur River and other coastal California streams.

Huber, E. R., & Carlson, S. M. (2020). Environmental Correlates of Fine-Scale Juvenile Steelhead Trout (Oncorhynchus mykiss) Habitat Use and Movement Patterns in an Intermittent Estuary During Drought. *Environmental Biology of Fishes, 103*(5), https://doi.org/10.1007/s10641-020-00971-y

We used acoustic telemetry and environmental monitoring to elucidate preferred microhabitats ofjuvenile steelhead trout (Oncorhynchus mykiss)inaCentralCalifornia intermittent estuary (IE) during historic drought. We collected over halfa million fish locations in the Pescadero IE (San Mateo County, CA) across 15 weeks during an extended sandbar-closed period which permitted quantification of fine scale habitat use and movement patterns. Tagged juvenile steelhead expressed strong site fidelity, especially at night when core habitat area - defined as the 50% probability ofbeing present in an area - contracted by over one order ofmagnitude. The rate of movement was slow overall (~0.4 to 0.6 lengths·s−1) and remained at baseline levels at night (~40 mm·s−1). Thedaytimerate of movement generally tracked solar radiation levels and appeared to be moderated bywater temperatures. Spikes in the rate ofmovement occurred during crepuscular periods and the maximum hourly rate ofmovement (138 mm·s−1) was observed during the early study period from 10:00 to 11:00 when water temperatures were physiologically optimal (17–18 °C). Water quality worsened upstream when water temperatures exceeded 18 °C and dissolved oxygen concentrations declined below 7.0 mg·L−1. Fish tag detections at stationary receivers in the upper estuary declined linearly with deteriorating water quality conditions. Qualitative analysis of juvenile steelhead habitat utilization indicated a strong preference for two microhabitat features in the estuary during the study; both were shallow (~1.5 m), wind-protected, and possessed cover and sandy substrates that occurred within the fresh or near fresh epilimnion where lagoon water quality was best and benthic prey was likely most abundant. Upstream movement occurred in late fall for over half of the tagged cohort, which likely enhances population resiliency by allowing these fish to escape lethal water quality conditions coincident with the transition from closed to open estuary in late fall. Climate projections for California’s Central Coast predict an increase in extreme dry events and the information presented here can help natural resource managers prepare for the future, such as the critical need to promote development of a sufficiently oxygenated epilimnion during extended sandbar-closed ecosystem states.

Jarrett, K. W., Bell, E., Wilson, E. A., Dudley, T., & Geraghty, C. M. (2019). Using Edna to Validate Predation on Native Oncorhynchus mykiss by Invasive Sacramento Pikeminnow (Ptychocheilus grandis). *California Fish and Game, 105*(3) Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=172792&inline

In this study, we assessed evidence for predation by non-native Sacramento pikeminnow (Ptychocheilus grandis) (hereafter referred to as "pikeminnow") on California redlegged frog (CRLF) (Rana draytonii) and steelhead/rainbow trout (Oncorhynchus mykiss) in Chorro Creek using traditional assessments and genetic analysis of samples collected from pikeminnow stomachs.

Swift, C. C., Holland, D., Booker, M., Woodfield, R., Gutierrez, A., Howard, S., . . . Bailey, E. (2018). Long-Term Qualitative Changes in Fish Populations and Aquatic Habitat in San Mateo Creek Lagoon, Northern San Diego County, California. *Bulletin, Southern California Academy of Sciences, 117*(1), https://doi.org/10.3160/soca-117-01-1-28.1

Patterns of abundance were documented for 17 species of fish in the lagoon at the mouth of San Mateo Creek, northern San Diego County, California from occasional observations (1974-1997) and multiple samples per year (1998-2008). Fish populations varied with Mediterranean climate patterns of rainfall, stream flow and consequent breaching of the lagoon to the ocean through the barrier sand berm. Two near-record rainfall seasons occurred during this period; the 1997-1998 El Niño due to southern storms and the 2004-2005 winter wet season of more usual storms from the north and northwest. The lagoon stabilized as fresh to brackish in the dry season and for multiple years during successive drier winters. Closed conditions benefitted the native, federally endangered southern tidewater goby, Eucyclogobius kristinae,but were less suitable for other native estuarine species more common in wetter years. Wet year flows also reduced non-native freshwater species; some thrived and increased predation pressure on the southern tidewater goby. Historically these exotics were absent and two additional native species were present, partially armored threespine stickleback, Gasterosteus aculeatus, and the federally endangered southern steelhead, Oncorhynchus mykiss. Restoring and maintaining a full suite of native species will require a combination of 1) habitat maintenance and restoration, 2) control or management of non-native species, and 3) reintroduction of some native fishes and amphibians.

Swift, C. C., Mulder, J., Dellith, C., & Kittleson, K. (2018). Mortality of Native and Non-Native Fishes During Artificial Breaching of Coastal Lagoons in Southern and Central California. *Bulletin, Southern California Academy of Sciences, 117*(3), https://doi.org/10.3160/1767.1

Fishes of California coastal streams and associated coastal lagoons have adapted to the Mediterranean-style rainfall cycle. Winter rains open the lagoons to the ocean; subsequent lack of rain and seasonal changes in beach dynamics typically closes them for much of the year. Dry and wet season artificial breaching or opening of barrier sand berms has been suspected to disrupt fish populations and lead to mortality of many aquatic organisms including federally endangered species. Such breaches have been rarely observed and then only after at least a few days or more have passed. Artificial breachings of three lagoons have been observed during or within a few hours after breaching and provide documentation of extensive disruption and mortality of aquatic organisms. These observations, Aliso Creek, Orange County (1975), Santa Clara River, Ventura County (2010), and Corcoran Lagoon, Santa Cruz County (2014-2015), confirmed many changes and effects of these events, including mortality of the federally endangered northern and southern tidewater gobies and southern steelhead. Despite the many ostensibly beneficial and non-faunal related reasons for breaching, our observations confirm such actions can cause considerable mortality of threatened and endangered species and are probably more severe than natural wet season breachings. Many city, county, as well as state and federal laws provide regulation of lagoon breaching to protect habitat and minimize or mitigate for impact to sensitive species and these need to be maintained and strengthened.

Taylor, J. B., Stein, E. D., Beck, M., Flint, K., & Kinoshita, A. (2019). *Vulnerability of Stream Biological Communities in Los Angeles and Ventura Counties to Climate Change Induced Alterations of Flow and Temperature.* Retrieved from http://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1084_ClimateChangeVulnerability.pdf

Climate change induced shifts in precipitation and temperature patterns have the potential to alter habitat suitability and distribution of aquatic species throughout the Los Angeles and Ventura regions (Figure ES-1). In this study, we predict alterations to the distribution of six aquatic species that represent a range of habitat preferences and use these predictions to infer where aquatic life beneficial uses may be supported in the future.

US Department of the Interior Bureau of Reclamation. (2015). *Salinas and Carmel River Basins Study*. Retrieved from https://digitalcommons.csumb.edu/cgi/viewcontent.cgi?article=1010&context=hornbeck_cgb_1

Within the Salinas and Carmel River basins an imbalance in the water supply and demand is being exacerbated by the extended drought, competing demands, and climate change. The goal of the study is to understand, anticipate, and adapt to these effects and to identify adaptive management strategies that will yield sustainable surface water and groundwater supplies capable of meeting the needs of agriculture, municipal users, the environment, an expanding population, and recreation.

Section III: North-Central California Coast

Apgar, T. M., Pearse, D. E., & Palkovacs, E. P. (2017). Evolutionary Restoration Potential Evaluated through the Use of a Trait-Linked Genetic Marker. *Evolutionary Applications, 10*(5), https://doi.org/10.1111/eva.12471

Human-driven evolution can impact the ecological role and conservation value of impacted populations. Most evolutionary restoration approaches focus on manipulating gene flow, but an alternative approach is to manipulate the selection regime to restore historical or desired trait values. Here we examined the potential utility of this approach to restore anadromous migratory behavior in coastal California steelhead trout (Oncorhynchus mykiss) populations. We evaluated the effects of natural and anthropogenic environmental variables on the observed frequency of alleles at a genomic marker tightly associated with migratory behavior across 39 steelhead populations from across California, USA. We then modeled the potential for evolutionary restoration at sites that have been impacted by anthropogenic barriers. We found that complete barriers such as dams are associated with major reductions in the frequency of anadromy-associated alleles. The removal of dams is therefore expected to restore anadromy significantly. Interestingly, accumulations of large numbers of partial barriers (passable under at least some flow conditions) were also associated with significant reductions in migratory allele frequencies. Restoration involving the removal of partial barriers could be evaluated alongside dam removal and fishway construction as a cost-effective tool to restore anadromous fish migrations. Results encourage broader consideration of in situ evolution during the development of habitat restoration projects.

California Department of Fish and Wildlife. (2016). *California Department of Fish and Wildlife Plan for Assessment and Management of California Coastal Chinook Salmon*. (CDFW Fisheries Administrative Report 2016-02). Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=133266&inline

This report describes the California Department of Fish and Wildlife's (CDFW) plan to assess status and trend of CC Chinook Salmon populations and explores a path forward for improving fishery management while protecting the species. In the short term, we will improve status and trend monitoring by increasing the priority of CC Chinook Salmon monitoring and implementing the California Coastal Salmonid Monitoring Plan (CMP) in key watersheds for CC Chinook Salmon. In the longer term, CDFW will move toward full implementation of the CMP for CC Chi nook Salmon and other anadromous salmonids across California's coastal watersheds. CDFW will also work with NOAA Fisheries' Southwest Fisheries Science Center (SWFSC) to explore and evaluate alternatives to the existing Klamath four year-old surrogate for CC Chinook ocean fishery management.

California Trout. (2017). *State of the Salmonids: Status of California's Emblematic Fishes 2017.* Center for Watershed Sciences, University of California, Davis and California Trout San Francisco, CA. Retrieved from https://www.arroyoseco.org/documents/SoCalSteelhead2017.pdf

California has, or had, 32 distinct kinds of salmonid fishes. They are either endemic to California or at the southern end of their ranges. Most are in serious decline: 45% and 74% of all salmonids will likely become extirpated from California in the next 50 and 100 years, respectively, if present trends continue. Our results suggest that California will lose more than half (52%) of its native anadromous salmonids and nearly a third (30%) of its inland taxa in just 50 years under current conditions. Climate change is a major overarching threat driving population declines throughout California and strongly affects the status of 84% of all salmonids reviewed. In addition, dams, agricultural operations, estuary alteration, non-native species, production hatcheries, and myriad other human-induced threats have contributed to declines. 81% of salmonids in California are now worse off than they were in 2007, when the previous version of this report was prepared. The changes in species status are the result of the 2012-2016 historic drought, improved data collection and review, and an improved understanding of climate change impacts. Returning these iconic species to sustainable levels requires access to productive and diverse habitats which promote the full range of life history diversity necessary to weather change. We recommend (i) protecting and investing in fully functioning watersheds such as the Smith River and Blue Creek, (ii) protecting and restoring source waters such as Sierra meadow systems, groundwater, and springs so that the impacts of climate change are reduced, (iii) restoring function and access to once productive and diverse habitats such as Central Valley floodplains, coastal lagoons, and estuaries, (iv) adopting reconciliation ecology as a basis for management in human dominated landscapes, (v) improving habitat connectivity and passage to historical spawning and rearing habitat, and (vi) improving salmonid genetic management throughout California.

Carah, J. K., Blencowe, C. C., Wright, D. W., & Bolton, L. A. (2014). Low-Cost Restoration Techniques for Rapidly Increasing Wood Cover in Coastal Coho Salmon Streams. *North American Journal of Fisheries Management, 34*(5), https://doi.org/10.1080/02755947.2014.943861

Like many rivers and streams in forests of the Pacific Northwest, California north coast rivers and streams have been depleted of downed wood through timber harvest and direct wood removal. Due to the important role of wood in creating and maintaining salmonid habitat, wood augmentation has become a common element of stream restoration. Restoration efforts in North America often focus on building anchored, engineered wood structures at the site scale; however, these projects can fail to meet restoration goals at the watershed scale, do not closely mimic natural wood loading processes or dynamics, and can be expensive to implement. For critically imperiled populations of Coho Salmon Oncorhynchus kisutch in California, there is a strong impetus to achieve as much habitat restoration as possible in priority watersheds in the shortest time and with limited resources, so cost-efficient techniques are necessary. In this multi-site project, we investigated unanchored techniques for wood loading to evaluate cost and contribution to salmonid habitat in Mendocino County, California. Over a period of 6 years, 72.4 km of stream were treated with 1,973 pieces of strategically placed wood. We found that unanchored wood loading techniques were much less costly than commonly used anchored techniques, reliably improved habitat, and retained wood at high rates (mean = 92%) in small- to moderate-sized streams, at least over the short term (<6 years). The average cost of design and construction for the unanchored projects was US$259 per log, equivalent to 22% of the cost associated with the anchored wood augmentation methods examined here. Our results suggest that this unanchored wood loading approach has the potential to increase the pace and scale at which wood augmentation projects are implemented in the Pacific Northwest and beyond.

Chapman, E. D., Hearn, A. R., Singer, G. P., Brostoff, W. N., Lacivita, P. E., & Klimley, A. P. (2015). Movements of Steelhead (Oncorhynchus mykiss) Smolts Migrating through the San Francisco Bay Estuary. *Environmental Biology of Fishes, 98*(4), https://doi.org/10.1007/s10641-014-0341-9

We used acoustic telemetry to monitor the out-migration of 1,000 steelhead smolts (Oncorhynchus mykiss) through the San Francisco Bay Estuary during spring of 2009 and 2010. The smolts transited the estuary rapidly (2-4 days) and utilized flows in the main channel during their migration. Fewer smolts were detected in marinas, tributaries and other shallow areas surrounding the estuary. Many of the smolts made repeated upriver and downriver movements that were related to the tidal flow, moving upstream during flood tides and downstream during ebb tides. These results show that steelhead smolts migrating from the Sacramento River transit rapidly through the lower reaches and do not use the estuary for feeding, rearing, or smoltification purposes.

Cochran, S. M., Ricker, S., Anderson, C., Gallagher, S. P., & Ward, D. M. (2019). Comparing Abundance-Based and Tag-Based Estimates of Coho Salmon Marine Survival. *Fisheries Management and Ecology, 26*(2), https://doi.org/10.1111/fme.12339

Obtaining reliable estimates of marine survival is essential for understanding anadromous salmon population dynamics. Two common approaches to estimating marine survival are (a) dividing abundance of returning adult salmon abundance by abundance of smolts from the same cohort, or (b) tagging a portion of the migrating smolts and estimating the return rate of tagged adults. This study compared these two approaches to estimating marine survival for coho salmon, Oncorhynchus kisutch (Walbaum), across multiple years in three California streams. Abundance-based survival estimates were higher than tag-based estimates; average estimates for the two techniques differed from 1.5-fold to 7.4-fold across streams. One likely cause for these divergent estimates is migration of juveniles from natal habitat before smolt trapping begins, resulting in an underestimate of smolt abundance and an overestimate of marine survival rate for the abundance-based method. Estimates of marine survival obtained from abundance estimates and tag returns are not directly comparable.

Cooper, E. J., O'Dowd, A. P., Graham, J. J., Mierau, D. W., Trush, W. J., & Taylor, R. (2020). Salmonid Habitat and Population Capacity Estimates for Steelhead Trout and Chinook Salmon Upstream of Scott Dam in the Eel River, California. *Northwest Science, 94*(1), https://doi.org/10.3955/046.094.0106

Estimating salmonid habitat capacity upstream of a barrier can inform priorities for fisheries conservation. Scott Dam in California's Eel River is an impassable barrier for anadromous salmonids. With Federal dam relicensing underway, we demonstrated recolonization potential for upper Eel River salmonid populations by estimating the potential distribution (stream-km) and habitat capacity (numbers of parr and adults) for winter steelhead trout (Oncorhynchus mykiss) and fall Chinook salmon (O. tshawytscha) upstream of Scott Dam. Removal of Scott Dam would support salmonid recovery by increasing salmonid habitat stream-kms from 2 to 465 stream-km for steelhead trout and 920 to 1,071 stream-km for Chinook salmon in the upper mainstem Eel River population boundaries, whose downstream extents begin near Scott Dam and the confluence of South Fork Eel River, respectively. Upstream of Scott Dam, estimated steelhead trout habitat included up to 463 stream-kms for spawning and 291 stream-kms for summer rearing; estimated Chinook salmon habitat included up to 151 stream-kms for both spawning and rearing. The number of returning adult estimates based on historical count data (1938 to 1975) from the South Fork Eel River produced wide ranges for steelhead trout (3,241 to 26,391) and Chinook salmon (1,057 to 10,117). An approach that first estimated juvenile habitat capacity and then used subsequent life stage survival rates yielded 1,281 (CV 56%) steelhead trout and 4,593 (CV 34%) Chinook salmon returning adults. Variability in estimated fish numbers reflects application of densities and survival rates from other populations, assumptions about salmonid productivity in response to potential spawning habitat capacity, residency and outmigration of early life-stages, summertime water quality conditions, and inter-annual hydrograph, marine, and population variability.

Crozier, L. G., McClure, M. M., Beechie, T., Bograd, S. J., Boughton, D. A., Carr, M., . . . Willis-Norton, E. (2019). Climate Vulnerability Assessment for Pacific Salmon and Steelhead in the California Current Large Marine Ecosystem. *Plos One, 14*(7), https://doi.org/10.1371/journal.pone.0217711

Major ecological realignments are already occurring in response to climate change. To be successful, conservation strategies now need to account for geographical patterns in traits sensitive to climate change, as well as climate threats to species-level diversity. As part of an effort to provide such information, we conducted a climate vulnerability assessment that included all anadromous Pacific salmon and steelhead (Oncorhynchus spp.) population units listed under the U.S. Endangered Species Act. Using an expert-based scoring system, we ranked 20 attributes for the 28 listed units and 5 additional units. Attributes captured biological sensitivity, or the strength of linkages between each listing unit and the present climate; climate exposure, or the magnitude of projected change in local environmental conditions; and adaptive capacity, or the ability to modify phenotypes to cope with new climatic conditions. Each listing unit was then assigned one of four vulnerability categories. Units ranked most vulnerable overall were Chinook (O. tshawytscha) in the California Central Valley, coho (O. kisutch) in California and southern Oregon, sockeye (O. nerka) in the Snake River Basin, and spring-run Chinook in the interior Columbia and Willamette River Basins. We identified units with similar vulnerability profiles using a hierarchical cluster analysis. Life history characteristics, especially freshwater and estuary residence times, interplayed with gradations in exposure from south to north and from coastal to interior regions to generate landscape-level patterns within each species. Nearly all listing units faced high exposures to projected increases in stream temperature, sea surface temperature, and ocean acidification, but other aspects of exposure peaked in particular regions. Anthropogenic factors, especially migration barriers, habitat degradation, and hatchery influence, have reduced the adaptive capacity of most steelhead and salmon populations. Enhancing adaptive capacity is essential to mitigate for the increasing threat of climate change. Collectively, these results provide a framework to support recovery planning that considers climate impacts on the majority of West Coast anadromous salmonids.

David, A. T., Simenstad, C. A., Cordell, J. R., Toft, J. D., Ellings, C. S., Gray, A., & Berge, H. B. (2016). Wetland Loss, Juvenile Salmon Foraging Performance, and Density Dependence in Pacific Northwest Estuaries. *Estuaries and Coasts, 39*(3), https://doi.org/http://dx.doi.org/10.1007/s12237-015-0041-5

During the transition of juveniles from fresh water to estuarine and coastal environments, the survival of Pacific salmon (Oncorhynchus spp.) can be strongly size selective and cohort abundance is partly determined at this stage. Because quantity and quality of food influence juvenile salmon growth, high rates of prey and energy acquisition during estuarine residence are important for survival. Human activities may have affected the foraging performance of juvenile salmon in estuaries by reducing the area of wetlands and by altering the abundance of salmon. To improve our understanding of the effects of wetland loss and salmon density on juvenile salmon foraging performance and diet composition in estuaries, we assembled Chinook salmon (Oncorhynchus tshawytscha) diet and density data from nine US Pacific Northwest estuaries across a gradient of wetland loss. We evaluated the influence of wetland loss and density on juvenile Chinook salmon instantaneous ration and energy ration, two measures of foraging performance, and whether the effect of density varied among estuaries with different levels of wetland loss. We also assessed the influence of wetland loss and other explanatory variables on salmon diet composition. There was no evidence of a direct effect of wetland loss on juvenile salmon foraging performance, but wetland loss appeared to mediate the effect of density on salmon foraging performance and alter salmon diet composition. Specifically, density had no effect on foraging performance in the estuaries with less than 50 % wetland loss but had a negative effect on foraging performance in the estuaries with greater than 50 % wetland loss. These results suggest that habitat loss may interact with density to constrain the foraging performance of juvenile Chinook salmon, and ultimately their growth, during a life history stage when survival can be positively correlated with growth and size.

Deitch, M. J., & Dolman, B. (2017). Restoring Summer Base Flow under a Decentralized Water Management Regime: Constraints, Opportunities, and Outcomes in Mediterranean-Climate California. *Water, 9*(1), https://doi.org/10.3390/w9010029

Seasonal rainfall dynamics in Mediterranean-climate coastal California place pressures on humans and aquatic ecosystems. Without rainfall during summer, residents and land managers commonly turn to streams and adjacent shallow aquifers to meet domestic, irrigation, and recreational water needs, often depleting the water necessary to support stream biota. The potential for adverse ecological impacts within this coupled natural-human system has led to interest in restoring summer base flow (especially for federally protected steelhead and coho salmon, which depend on flow through the summer dry season for juvenile survival) through methods such as reducing dry-season water abstractions. Characterizing constraints and opportunities has proven useful for planning streamflow restoration in Mediterranean-climate coastal California. Biophysical parameters such as ample rainfall and very low summer discharge are critical considerations, but institutional parameters are equally important: regional management practices and state laws can inhibit streamflow restoration, and implementation is dependent on interrelationships among residents, agency staff, and other stakeholders (which we term the egosystem) within each watershed. Additionally, while watershed-scale spatial analysis and field-based evaluations provided a solid foundation for exploring streamflow restoration needs, adaptation based on information from local stakeholders was often essential for prioritizing projects and understanding whether projects will have their intended benefits.

Deitch, M. J., Van Docto, M., Obedzinski, M., Nossaman, S. P., & Bartshire, A. (2018). Impact of Multi-Annual Drought on Streamflow and Habitat in Coastal California Salmonid Streams. *Hydrological Sciences Journal, 63*(8), https://doi.org/10.1080/02626667.2018.1492722

The 2012–2015 drought in north-central coastal California ranks among the three most prolonged periods of below-median annual rainfall in the past 65 years. In three critical coho salmon streams, summer baseflow was less each additional dry year; streams with summer flow early in the drought had no flow for more than two months in latter years. By the third dry year, summer discharge was 1–5% of recent wet-type years, and 10–20% of the first dry year. Multiannual drought also caused increased dry channel conditions: the percentage of flowing channel reduced from 28 to 55% from the first to the third dry years among three study streams. In the first year following drought, dry-season streamflow resembled early to-mid-drought conditions, while in the second, it approached pre-drought discharge. This multiannual drought foreshadows how multi-annual drought predicted under future climate scenarios may affect critical salmonid streams later this century.

Dusterhoff, S. R., Sloat, M. R., & Ligon, F. K. (2017). The Influence of Coarse Particle Mobility on Scour Depth in Salmonid Spawning Habitat. *River Research and Applications, 33*(8), https://doi.org/10.1002/rra.3178

This study examined the influence of flow hydraulics and coarse particle mobility on bed scour adjacent to coho salmon (Oncorhynchus kisutch) redds in a coastal California watershed for a bankfull flood. It was theorized that coarse particle mobility (i.e., mobility of particles larger than the median bed particle size, D-50) exerts a strong control on bed scour depth. Maximum scour depth at the study sites was found to be negatively correlated with flow shear stress, which is dissimilar to findings from previous scour studies in spawning reaches. This resulted from a relatively similar coarse particle size (D-84) for all study sites and a negative relationship between shear stress and coarse particle exposure to flow (or the D-84/D-50 ratio), which together caused sites with low shear stress to have a high degree of localized coarse particle mobility and an associated high maximum scour depth. This study provides new insights into the vulnerability of spawning reaches with low flow energy to redd scour and highlights the need to consider the mobility of coarse particle sizes explicitly when examining the dominant controls on redd scour.

Eel River Forum Members. (2016). *The Eel River Action Plan a Compilation of Information and Recommended Actions.* Retrieved from https://caltrout.org/wp-content/uploads/2016/06/2016.03.FINAL_.EelRiverActionPlan.ERF_.pdf

The Eel River is the third largest river entirely in California. The Eel River ecosystem, its salmon and steelhead populations, and other native fish and wildlife populations have been in decline for the past century and a half. It has been transformed from one of the most productive river ecosystems along the Pacific Coast to a degraded river with heavily impaired salmonid populations. The mission of the Eel River Forum is to "coordinate and integrate conservation and recovery efforts in the Eel River watershed to conserve its ecological resilience, restore its native fish populations, and protect other watershed beneficial uses." The Forum was convened in July 2012 and adopted its charter in June 2013. The purpose of this document is to provide a summary description of issues the ERF has agreed are primary factors impairing salmonid recovery and ecological health of the Eel River.

FishBio. (2014). *A Decision Matrix for Coho Salmon and Steelhead Life-Cycle Monitoring Stations in California Coastal Streams: Scott Creek Case Study.* FISHBIO R. C. D. o. S. Cruz. Retrieved from https://fishbio.com/field-notes/population-dynamics/inside-the-matrix-for-salmonid-life-cycle-monitoring

The objective of this study was to develop a decision tool to assist resource managers, researchers, and other fisheries professionals in designing a sampling program for CCC coho salmon and steelhead populations to collect reliable data in a cost effective and scientifically sound manner. This tool should give those resource managers a stepping-stone to produce a sampling strategy that will satisfy the CMP objectives. This report will first describe development of the tool and then provide a case study to demonstrate how it can be used to determine the most suitable monitoring techniques.

Frechette, D., Osterback, A. M. K., Hayes, S. A., Moore, J. W., Shaffer, S. A., Pavelka, M., . . . Harvey, J. T. (2015). Assessing the Relationship between Gulls Larus Spp. And Pacific Salmon in Central California Using Radiotelemetry. *North American Journal of Fisheries Management, 35*(4), https://doi.org/10.1080/02755947.2015.1032450

Predation by marine birds has resulted in substantial losses to runs of Pacific salmon Oncorhynchus spp., in some cases necessitating management action. Recovery of PIT tags on a seabird breeding colony (Ano Nuevo Island) indicated that western gulls Larus occidentalis prey upon federally listed Coho Salmon Oncorhynchus kisutch and steelhead O. mykiss in central California. Whereas salmonid populations in central California have decreased in recent decades, the western gull population on Ano Nuevo Island has increased. We observed gulls Larus spp. within estuaries to document predation and used radiotelemetry to examine gull movement in relation to the availability of salmonids. During 2008 and 2009, observed predation events of out- migrating salmonids by gulls were rare; 21 events occurred during 338 h of observations at two estuaries. During the prehatch and chick-rearing phases of breeding, which coincided with migration of salmonids from fresh to salt water, 74% of the detections of radio-tagged western gulls occurred within 25 km of Ano Nuevo Island, suggesting that the relative susceptibility of predation by western gulls using Ano Nuevo Island decreased with distance from the island. Western gull presence at creek mouths was greatest during daylight hours (91% of detections), while juvenile salmonids were present predominantly at night (65% of detections). The greatest overlap between western gulls and salmonids occurred at dusk, and predation of out-migrating salmonids was likely opportunistic. Deterring gulls from creek mouths when overlap between predator and prey might otherwise occur may buffer out-migrating salmonids from predation. Our results will inform management strategies to most effectively reduce the impacts of gull predation on central California salmonids.

Gallagher, S. P., Ferreira, J., Lang, E., Holloway, W., & Wright, D. W. (2014). Investigation of the Relationship between Physical Habitat and Salmonid Abundance in Two Coastal Northern California Streams. *California Fish and Game, 100*(4) Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=99282

Understanding the relationship between fish abundance and stream habitat variables is critical to designing and implementing effective freshwater habitat restoration projects for coho salmon (Oncorhynchus kisutch) and other anadromous salmonids. In this study, we investigated the relationship between summer coho salmon and steelhead trout (O. mykiss) parr abundance and physical stream habitat variables in Caspar and Pudding creeks in Mendocino County, California. Relationships between summer habitat and juvenile abundance were investigated using a stratified random experimental design. Our hypothesis was that one or more of the habitat unit types and variables examined would be associated with salmonid abundance. Habitat differences were examined between the two streams, and we tested our hypotheses regarding habitat variables and salmon id abundance using a variety of statistical tools that included two-way ANOVA, factor analysis, and negative binomial regression modeling. The results indicated that juvenile coho salmon abundance was positively (proportionally) associated with slow water, water volume, and dry large-wood abundance, and negatively associated with fast-water habitat variables. Young-of-the-year steelhead trout were positively associated with water volume and dry large-wood and negatively (or inversely) associated with overhead vegetation and fast water habitats. Older age steelhead abundance was positively associated with slow water, water volume; cover habitat formed by wet and dry wood, and undercut banks. We discuss our findings relative to the use of large wood in anadromous salmonid habitat recovery programs in California coastal watersheds.

Gilbert-Horvath, E. A., Pipal, K. A., Spence, B. C., Williams, T. H., & Garza, J. C. (2016). Hierarchical Phylogeographic Structure of Coho Salmon in California. *Transactions of the American Fisheries Society, 145*(5), https://doi.org/10.1080/00028487.2016.1201003

Evaluation of population genetic structure and variation is an important part of planning for the recovery and management of protected species. Data from 18 polymorphic microsatellite DNA markers were used to analyze the phylogeographic structure of protected Coho Salmon Oncorhynchus kisutch from populations throughout California. Fish from 30 locations in two evolutionarily significant units (ESUs) representing most of the extant populations in the state were studied. Multiple analyses indicated a hierarchical pattern of population structure: the greatest divergence was found at the broadest geographic scale (ESU), followed by the divergences between basins and populations within basins. The populations of the large Klamath River basin were consistently identified as a distinct phylogenetic group, nearly as divergent from all other populations as the two ESUs were from each other. All populations in different basins were differentiated from each other and a pattern of isolation by distance was found at a California-wide scale, but not at smaller spatial scales. Similarly, most individuals were accurately assigned to their population of origin, and almost all misassignments were to an adjacent or geographically proximal basin, indicating that there is substantial gene flow within each region but much less between regions. The number of parents contributing to each population was highly variable and reflected larger patterns of genetic variation, which was found to be generally higher in the southerly, low-elevation coastal populations than in the northern, interior, higher-elevation populations. The results strongly support the current boundary between the two ESU regions, and the detailed understanding of phylogeographic structure provided here will help to guide the management and recovery of Coho Salmon at the southern end of their geographic range.

Hassrick, J. L., Henderson, M. J., Huff, D. D., Sydeman, W. J., Sabal, M. C., Harding, J. A., . . . Hayes, S. A. (2016). Early Ocean Distribution of Juvenile Chinook Salmon in an Upwelling Ecosystem. *Fisheries Oceanography, 25*(2), https://doi.org/10.1111/fog.12141

Extreme variability in abundance of California salmon populations is often ascribed to ocean conditions, yet relatively little is known about their marine life history. To investigate which ocean conditions influence their distribution and abundance, we surveyed juvenile Chinook salmon (Oncorhynchus tshawytscha) within the California Current (central California [37 degrees 30N) to Newport, Oregon (44 degrees 00N]) for a 2-week period over three summers (2010-2012). At each station, we measured chlorophyll-a as an indicator of primary productivity, acoustic-based metrics of zooplankton density as an indicator of potential prey availability and physical characteristics such as bottom depth, temperature and salinity. We also measured fork lengths and collected genetic samples from each salmon that was caught. Genetic stock identification revealed that the majority of juvenile salmon were from the Central Valley and the Klamath Basin (91-98%). We constructed generalized logistic-linear negative binomial hurdle models and chose the best model(s) using Akaike's Information Criterion (AIC) to determine which covariates influenced the salmon presence and, at locations where salmon were present, determined the variables that influenced their abundance. The probability of salmon presence was highest in shallower waters with a high chlorophyll-a concentration and close to an individual's natal river. Catch abundance was primarily influenced by year, mean fork length and proximity to natal rivers. At the scale of sampling stations, presence and abundance were not related to acoustic indices of zooplankton density. In the weeks to months after ocean entry, California's juvenile Chinook salmon population appears to be primarily constrained to coastal waters near natal river outlets.

Henderson, M., Fiechter, J., Huff, D. D., & Wells, B. K. (2019). Spatial Variability in Ocean-Mediated Growth Potential Is Linked to Chinook Salmon Survival. *Fisheries Oceanography, 28*(3), https://doi.org/10.1111/fog.12415

Early ocean survival of Chinook salmon, Oncorhynchus tshawytscha, varies greatly inter-annually and may be the period during which later spawning abundance and fishery recruitment are set. Therefore, identifying environmental drivers related to early survival may inform better models for management and sustainability of salmon in a variable environment. With this in mind, our main objectives were to (a) identify regions of high temporal variability in growth potential over a 23-year time series, (b) determine whether the spatial distribution of growth potential was correlated with observed oceanographic conditions, and (c) determine whether these spatial patterns in growth potential could be used to estimate juvenile salmon survival. We applied this method to the fall run of the Central Valley Chinook salmon population, focusing on the spring and summer period after emigration into central California coastal waters. For the period from 1988 to 2010, juvenile salmon growth potential on the central California continental shelf was described by three spatial patterns. These three patterns were most correlated with upwelling, detrended sea level anomalies, and the strength of onshore/offshore currents, respectively. Using the annual strength of these three patterns, as well as the overall growth potential throughout central California coastal waters, in a generalized linear model we explained 82% of the variation in juvenile salmon survival estimates. We attributed the relationship between growth potential and survival to variability in environmental conditions experienced by juvenile salmon during their first year at sea, as well as potential shifts in predation pressure following out-migration into coastal waters.

Hines, D., Liermann, M., Seder, T., Cluer, B., Pess, G., & Schoenebeck, C. (2017). Diel Shifts in Microhabitat Selection of Steelhead and Coho Salmon Fry. *North American Journal of Fisheries Management, 37*(5), https://doi.org/10.1080/02755947.2017.1339648

Diel shifts in habitat selection of newly emerged steelhead Oncorhynchus mykiss and Coho Salmon O. kisutch fry were investigated in three northern California coastal watersheds. Steelhead and Coho Salmon fry occupied shallow water near stream margins during both day and night; however, the proportion of fry within 0.5 m of the stream margin increased from 6% during the day to 44% at night. Similarly, the proportion of fry in 10 cm of water or less increased from 26% during the day to 76% at night. Reductions in depth and distance to stream margins were significant at all sites, suggesting that these behaviors are common attributes for steelhead and Coho Salmon fry in this region. These results also suggest that newly emerged fry are potentially vulnerable to becoming stranded due to reductions in stream stage and water surface area, particularly at night. Although our observations were undertaken to better understand the risks to salmonids from vineyard water use for frost protection, the results have implications for any anthropogenic streamflow changes during the spring season.

Kelson, S. J., & Carlson, S. M. (2019). Do Precipitation Extremes Drive Growth and Migration Timing of a Pacific Salmonid Fish in Mediterranean-Climate Streams? *Ecosphere, 10*(3), https://doi.org/10.1002/ecs2.2618

Climate change is expected to increase weather extremes and variability, including more frequent weather whiplashes or extreme swings between severe drought and extraordinarily wet years. Shifts in precipitation patterns will alter stream flow regimes, affecting critical life history stages of sensitive aquatic organisms. Understanding how threatened fish species, such as steelhead/rainbow trout (Oncorhynchus mykiss), are affected by stream flows in years with contrasting environmental conditions is important for their conservation. Here, we report how extreme wet and dry years, from 2015 to 2018, affected stream flow patterns in two tributaries to the South Fork Eel River, California, USA, and aspects of O. mykiss ecology, including over-summer fish growth and body condition as well as spring out-migration timing. We found that stream flow patterns differed across years in the timing and magnitude of large winter-spring flow events and in summer low-flow levels. We were surprised to find that differences in stream flows did not impact growth, body condition, or timing of out-migration of O. mykiss. Fish growth was limited in the late summer in these streams (average of 0.02 +/- 0.05 mm/d), but was similar across dry and wet years, and so was end-of-summer body condition and pool-specific biomass loss from the beginning to the end of the summer. Similarly, O. mykiss migrated out of tributaries during the last week of March/first week of April regardless of the timing of spring flow events. We suggest that the muted response to inter-annual hydrologic variability is due to the high quality of habitat provided by these unimpaired, groundwater-fed tributaries. Similar streams that are likely to maintain cool temperatures and sufficient base flows, even in the driest years, should be a high priority for conservation and restoration efforts.

Kelson, S. J., Miller, M. R., Thompson, T. Q., O'Rourke, S. M., & Carlson, S. M. (2019). Do Genomics and Sex Predict Migration in a Partially Migratory Salmonid Fish, Oncorhynchus mykiss? *Canadian Journal of Fisheries and Aquatic Sciences, 76*(11), https://doi.org/10.1139/cjfas-2018-0394

Partial migration is a common phenomenon wherein populations include migratory and resident individuals. Whether an individual migrates or not has important ecological and management implications, particularly within protected populations. Within partially migratory populations of Oncorhynchus mykiss, migration is highly correlated with a specific genomic region, but it is unclear how well this region predicts migration at the individual level. Here, we relate sex and life history genotype, determined using >400 single nucleotide polymorphisms (SNPs) on the migratory-linked genomic region, to life history expression of marked juvenile O. mykiss from two tributaries to the South Fork Eel River, northern California. Most resident fish were resident genotypes (57% resident, 37% heterozygous, 6% migratory genotype) and male (78%). Most migratory fish were female (62%), but were a mixture of genotypes (30% resident, 45% heterozygous, 25% migratory genotype). Sex was more strongly correlated with life history expression than genotype, but the best-supported model included both. Resident genotypes regularly migrated, highlighting the importance of conserving the full suite of life history and genetic diversity in partially migratory populations.

Larsen, L. G., & Woelfle-Erskine, C. (2018). Groundwater Is Key to Salmonid Persistence and Recruitment in Intermittent Mediterranean-Climate Streams. *Water Resources Research, 54*(11), https://doi.org/10.1029/2018wr023324

Juvenile coho salmon thrive in intermittent streams of the Pacific Northwest yet are in danger of increased mortality from drought and rising temperatures. With warmer temperatures and more frequent climate extremes projected, the need to understand how intermittent stream hydrology and biogeochemistry impact juvenile salmonid habitat and behavior is imperative. Previous investigations indicated that dissolved oxygen limits the persistence of coho salmon in intermittent streams, leading to the hypothesis that groundwater inflow would ultimately control patterns of salmon recruitment and persistence. Here we tested that hypothesis in paired tributaries of Salmon Creek, Sonoma County, CA during California's extreme drought of 2011-2017. We used the fluorescent fingerprint of dissolved organic carbon, together with a parallel factor analysis, to estimate groundwater influence in individual stream pools, corroborating those estimates with stable isotope and radon analyses. Repeat snorkel surveys provided fish counts in those pools at the beginning and end of the period of surface-water disconnection. Results suggested that coho salmon fry preferentially selected pools with a groundwater inflow signal and persisted in pools maintaining that signal through the dry season. This groundwater inflow signal was distinct from hyporheic influence, which exhibited little correlation with fish distribution. Groundwater within pools was young, and spot measurements suggested that it was relatively oxygenated. Proportional groundwater contributions to pools increased as drought deepened. Results suggest that maintaining relatively high groundwater levels in coastal aquifers may be imperative to the persistence of vulnerable salmonid populations in a changing climate. Plain Language Summary In northern California and much of the Pacific Northwest, coho salmon thrive in intermittent streams that lack contiguous surface-water flow for part of the year. The young fish grow for 1year in these streams and may be particularly vulnerable to climate warming and extreme drought conditions. However, little is understood about the factors that promote young salmonid survival or demise during dry conditions. We evaluated the role of groundwater on fish persistence through a combination of fish snorkel surveys, dissolved oxygen measurements, and water sample collection and analysis. We found that all of the pools to which fish moved at the start of the summer dry period had groundwater inflow and that the oxygen content of that groundwater was moderately high. Fish persisted only in those pools that maintained groundwater inflow through the summer dry period. Groundwater inflow promotes circulation of water and may deliver oxygen to pools, both of which may enhance the chances of fish survival. Maintaining high groundwater levels during dry periods may thus be necessary for the long-term persistence of salmon in intermittent streams.

Lee, J., Hong, S., Sun, J. H., Moon, J. K., Boo, K. H., Lee, S. M., & Lee, J. W. (2019). Toxicity of Dietary Selenomethionine in Juvenile Steelhead Trout, Oncorhynchus mykiss: Tissue Burden, Growth Performance, Body Composition, Hematological Parameters, and Liver Histopathology. *Chemosphere, 226*, https://doi.org/10.1016/j.chemosphere.2019.03.184

The steelhead trout (Oncorhynchus mykiss) is the species most at risk from selenium (Se) exposure in the San Francisco Bay Delta (SFBD). However, although steelhead trout are usually exposed to environmental Se in the juvenile stage, data to test their sensitivity to excess Se, especially its organic form, in the juvenile stage are scarce. Therefore, the objective of the current study was to assess the sensitivity of juvenile steelhead trout to ecologically relevant forms of Se using integrated sensitive endpoints. Fish (mean weight: 22.3 g) were fed one of five diets containing 1.1 (control), 8.8, 15.4, 30.8, and 61.6 sg Se/g diet dw (Sell, Se8.8, Se15.4, Se30.8, and Se61.6, respectively) in the form of selenomethionine for 4 weeks. After 4 weeks, Se significantly accumulated in a dose-dependent manner in all tissues at different rates. The growth rate and plasma cholesterol were significantly depressed in fish fed diets containing Se30.8 and above. Hematological parameters and mortality were significantly elevated in fish fed the Se61.6 diet. Marked histopathological alterations were observed in fish fed the Se8.8 diet (the lowest observed effect concentration, LOEC) and above. The current results suggest that the steelhead trout is more sensitive to excess Se than nonanadromous rainbow trout used in previous studies because of its lower LOEC despite the use of selenomethionine and the shorter experimental duration. Additionally, it should be noted that the current Se levels found in the SFBD are already a threat to the threatened population of steelhead trout on the central California coast.

Leitwein, M., Garza, J. C., & Pearse, D. E. (2017). Ancestry and Adaptive Evolution of Anadromous, Resident, and Adfluvial Rainbow Trout (Oncorhynchus mykiss) in the San Francisco Bay Area: Application of Adaptive Genomic Variation to Conservation in a Highly Impacted Landscape. *Evolutionary Applications, 10*(1), https://doi.org/10.1111/eva.12416

The streams draining of into San Francisco Bay, California, have been impacted by habitat alteration for over 150 years, and roads, dams, water diversions, and other impediments now block the paths of many aquatic migratory species. These changes can affect the genetic structure of fish populations, as well as driving adaptive evolution to novel environmental conditions. Here, we determine the evolutionary relationships of San Francisco Bay Area steelhead/rainbow trout (Oncorhynchus mykiss) populations and show that (i) they are more closely related to native coastal steelhead than to the California Central Valley lineage, with no evidence of introgression by domesticated hatchery rainbow trout, (ii) populations above and below barriers within watersheds are each other's closest relatives, and (iii) adaptive genomic variation associated with migratory life- history traits in O. mykiss shows substantial evolutionary differences between fish above and below dams. These findings support continued habitat restoration and protection of San Francisco Bay Area O. mykiss populations and demonstrate that ecological conditions in novel habitats above barriers to anadromy influence life- history evolution. We highlight the importance of considering the adaptive landscape in conservation and restoration programs for species living in highly modified habitats, particularly with respect to key life- history traits.

Litz, M. N. C., Miller, J. A., Brodeur, R. D., Daly, E. A., Weitkamp, L. A., Hansen, A. G., & Claiborne, A. M. (2019). Energy Dynamics of Subyearling Chinook Salmon Reveal the Importance of Piscivory to Short-Term Growth During Early Marine Residence. *Fisheries Oceanography, 28*(3), https://doi.org/10.1111/fog.12407

Variation in prey quantity and quality can influence growth and survival of marine predators, including anadromous fish that migrate from freshwater systems. The objective of this study was to examine the energy dynamics of subyearling Chinook salmon (Oncorhynchus tshawytscha) following freshwater emigration. To address this objective, a population of Chinook salmon and their marine prey were repeatedly sampled from June to September over 2 years in coastal waters off Oregon and Washington. Subyearlings from the same population were also reared under laboratory conditions. Using a bioenergetics model evaluated in the laboratory, we found that growth rate variability in the field was associated more with differences in northern anchovy (Engraulis mordax) consumption and less with variation in diet energy density or ocean temperature. Highest growth rates (2.43-3.22% body weight/day) occurred in months when anchovy biomass peaked, and the timing of peak anchovy biomass varied by year. Our results support a general pattern among subyearling Chinook salmon occurring from Alaska to California that feeding rates contribute most to growth rate variability during early marine residence, although dominant prey types can differ seasonally, annually, or by ecosystem. In the northern California Current, faster growth appears to be associated with the availability of age-0 anchovy. Identifying factors that influence the seasonal development of the prey field and regulate prey quantity and quality will improve understanding of salmon growth and survival during early marine residence.

Lohse, K. A., Brooks, C. N., & Kelly, M. (2005). Influence of Land Use on Fine Sediment in Salmonid Spawning Gravels within the Russian River Basin, California. *Canadian Journal of Fisheries and Aquatic Sciences, 62*(12), https://doi.org/10.1139/F05-187

Relationships between land use or land cover and embeddedness, a measure of fine sediment in spawning gravels, were examined at multiple scales across 54 streams in the Russian River Basin, California. The results suggest that coarse-scale measures of watershed land use can explain a large proportion of the variability in embeddedness and that the explanatory power of this relationship increases with watershed size. Agricultural and urban land uses and road density were positively associated with embeddedness, while the opposite was true for forest cover. The ability of land use and land cover to predict embeddedness varied among five zones of influence, with the greatest explanatory power occurring at the entire-watershed scale. Land use within a more restricted riparian corridor generally did not relate to embeddedness, suggesting that reach-scale riparian protection or restoration will have little influence on levels of fine sediment. The explanatory power of these models was greater when conducted among a subset of the largest watersheds (maximum r(2) = 0.73) than among the smallest watersheds (maximum r(2) = 0.46).

Losee, J. P., Fisher, J., Teel, D. J., Baldwin, R. E., Marcogliese, D. J., & Jacobson, K. C. (2014). Growth and Condition of Juvenile Coho Salmon Oncorhynchus kisutch Relate Positively to Species Richness

Of trophically Transmitted Parasites. *Journal of Fish Biology, 85*(5), https://doi.org/10.1111/jfb.12525

The aims of this study were first, to test the hypothesis that metrics of fish growth and condition relate positively to parasite species richness (SR) in a salmonid host; second, to identify whether SR differs as a function of host origin; third, to identify whether acquisition of parasites through marine v. freshwater trophic interactions was related to growth and condition of juvenile salmonids. To evaluate these questions, species diversity of trophically transmitted parasites in juvenile coho salmon Oncorhynchus kisutch collected off the coast of the Oregon and Washington states, U.S.A. in June 2002 and 2004 were analysed. Fish infected with three or more parasite species scored highest in metrics of growth and condition. Fish originating from the Columbia River basin had lower SR than those from the Oregon coast, Washington coast and Puget Sound, WA. Parasites obtained through freshwater or marine trophic interactions were equally important in the relationship between SR and ocean growth and condition of juvenile O. kisutch salmon.

Marin Municipal Water District. (2015). *Adult Salmonid Monitoring in the Lagunitas Creek Watershed – 2014-15.* Retrieved from https://www.marinwater.org/DocumentCenter/View/3429/Lagunitas-Creek-Adult-Salmonid-Monitoring-Report-2014-15

Adult salmonid surveys were conducted by staff and volunteers of the Marin Municipal Water District (MMWD), National Park Service (NPS), Salmon Protection and Watershed Network (SPAWN), and the Watershed Stewards Project (WSP). Surveys were conducted on the main stem of Lagunitas Creek and four tributaries: San Geronimo Creek, Devil's Gulch, Cheda Creek, and Olema Creek. Surveys began on November 10, 2014 and ended on May 7, 2015 These annual surveys are intended to document the spawning run of coho salmon (Oncorhynchus kisutch), while also collecting data on steelhead trout (O. mykiss), Chinook or "king" salmon (O. tshawytscha) and chum salmon (O. keta). This year, 146 coho redds and 300 live coho were observed in the Lagunitas Creek Watershed. The coho escapement estimate was 292, based on the assumption of two spawners per redd. This year's redd count was very similar to the count in 2011-12, when the parent generation for this year's coho spawned. In fact, the redd counts were similar in each of the surveyed streams. The apparent marine survival rate for the approximately 7,500 coho smolts that emigrated to the ocean in 2013 was 3.8%, which was below average. Just over half of the coho spawned in Lagunitas Creek this year, where 80 redds were observed. In addition, 37 redds were seen in San Geronimo Creek and its tributaries, 20 were in Devil's Gulch, five were in Olema Creek, and four were in Cheda Creek The steelhead run was average in size, with 167 steelhead redds and only 74 live steelhead. The steelhead escapement estimate was 334, based on the assumption of two spawners per redd. The redd counts were close to average in every stream surveyed, except for in Olema Creek, where a record 45 steelhead redds were observed. An unusually large number of Chinook salmon were observed in 2014-15. In Lagunitas Creek, 94 live Chinook and 19 redds were seen. An additional six Chinook and one redd were seen in San Geronimo Creek. This was the second largest number of Chinook salmon seen in the watershed since 1995. The Chinook escapement estimate was 40, and the discrepancy with the live Chinook count may have been due to counting the same fish over multiple weeks. For only the fifth time in 20 years more than one Chum salmon were seen in the watershed. At least three live chum salmon and a chum redd were seen between late November and early December in Lagunitas Creek.

Matsubu, W., Simenstad, C. A., & Horton, G. E. (2017). Juvenile Steelhead Locate Coldwater Refugia in an Intermittently Closed Estuary. *Transactions of the American Fisheries Society, 146*(4), https://doi.org/10.1080/00028487.2017.1301993

Many coastal estuaries in Mediterranean climates are susceptible to inlet closures resulting from barrier beach formation. These closures are ecologically important because they eliminate tidal exchange and connectivity of nekton movement to the coastal ocean and, depending on closure duration, can convert a dynamic estuary into a quiescent lagoon. Although closures can create lethal or stressful conditions for nekton and benthic communities, especially obligate diadromous species, under some conditions they can enhance survival of juvenile steelhead Oncorhynchus mykiss. However, the mechanisms explaining how closed conditions enhance the growth of juvenile steelhead and how inhabitants avoid physiologically stressful conditions remain unknown. In the present study, recent technological advances in sensor-encoded acoustic telemetry provided the ability to simultaneously locate and determine the temperature of juvenile steelhead as small as 93 mm FL by using mobile and stationary tracking. In the Russian River estuary, an intermittently closed estuary in northern California, we used acoustic telemetry to infer water quality exposure by linking the temperature of individually tagged fish with water quality profiles collected in close proximity. Under open-inlet conditions, juvenile steelhead experienced primarily brackish and saline water in the lower and middle reaches and warm freshwater in the upper reach, whereas under closed-inlet conditions they experienced warm freshwater in the middle and upper reaches. During closed conditions, juvenile steelhead displayed behavior that suggested the ability to mediate stressful environmental conditions; specifically, they responded to closed conditions by moving greater distances and aggregating near thermal refugia. Our findings show the importance of recognizing these strategies when contemplating changes to estuary management and highlight the significance of tributary hydrogeomorphic processes and groundwater linkages in subwatersheds that are sources of cool water for thermal refugia in intermittently closed estuaries.

McCormick, J. L., & Falcy, M. R. (2015). Evaluation of Non-Traditional Modelling Techniques for Forecasting Salmon Returns. *Fisheries Management and Ecology, 22*(4), https://doi.org/10.1111/fme.12122

Forecasting adult salmon abundance is problematic when the number of observations is small relative to the number of potential explanatory variables. Machine learning and other non-traditional techniques employ algorithms designed to prevent model overfitting. Data from 18 coho salmon, Oncorhynchus kisutch (Walbaum), and seven Chinook salmon, Oncorhynchus tschawytscha (Walbaum), populations on the Oregon coast were used to evaluate the forecast performance of artificial neural networks, elastic net, least absolute shrinkage and selection operator, principal component regression (PCR) and ridge regression (RR) compared to several more traditional techniques. In general, the non-traditional modelling techniques evaluated in this study performed similarly to the traditional techniques with the exception of sibling regression. This suggests that they have merit for improving actual predictions. Among the non-traditional techniques, PCR resulted in the lowest prediction error for the coho salmon populations, and RR predicted Chinook salmon returns most accurately. The techniques explored are not an easy solution to a difficult problem. Spurious conclusions about the processes that generate salmon returns still may result as evidenced by the inclusion of an unrelated variable in many of the non-traditional models.

Mierau, D. W., Trush, W. J., Rossi, G. J., Carah, J. K., Clifford, M. O., & Howard, J. K. (2018). Managing Diversions in Unregulated Streams Using a Modified Percent-of-Flow Approach. *Freshwater Biology, 63*(8), https://doi.org/10.1111/fwb.12985

In Mediterranean-type river systems, naturally low seasonal stream flows are often overexploited, which has implications for managing flows for environmental as well as human needs. Traditional approaches to instream flow management are not well suited to unregulated systems with strong seasonal patterns of water availability and many water diverters, and are challenging to implement in such systems. They often do not protect the full range of variability in the annual hydrograph, require extensive site-specific data, expensive modelling or both. In contrast, holistic flow management strategies, such as percent-of-flow (POF) strategies are designed to protect multiple ecological processes and preserve inter-annual flow variability. However, POF approaches typically require real-time streamflow gauging, and often lack a robust metric relating a diversion rate to ecological processes in the stream. To address these challenges, we present a modified percent-of-flow (MPOF) diversion approach where diversions are allocated from a streamflow baseline which is derived from a regional relationship between a conservative streamflow-exceedance and date. The streamflow baseline remains the same from year to year, and is independent of water-year type. This approach protects inter-annual flow variability and provides a predictable daily allowable volume of diversion at any diversion pointsupporting efficient water management planning. The allowable diversion rate in the MPOF approach is based not on a fixed percentage of the ambient streamflow, but rather on a maximum allowable percentage change in riffle crest thalweg depth, an ecologically meaningful, common hydraulic measurement. In this paper, we demonstrate that the MPOF approach is a holistic approach well suited to manage diversions in unregulated streams typical of California's Mediterranean-type coastal drainages.

National Marine Fisheries Service. (2015). *California Coastal Chinook Salmon Fishery Management : Future Prospects*. Retrieved from https://repository.library.noaa.gov/view/noaa/4924

A joint National Marine Fisheries Service and California Department of Fish and Wildlife workshop with the title "California coastal Chinook salmon (CC-Chinook) fishery management: future prospects" convened in Santa Rosa, California, September 3-4, 2014. The goals of the workshop were to identify the level of information necessary to allow for development of an abundance-based fishery management (ABM) approach and evaluate the feasibility of collecting that level of information for the CC-Chinook salmon Evolutionarily Significant Unit (ESU). Workshop participants noted that the collection of sufficient data to enable ABM will be difficult to achieve in the CC-Chinook salmon ESU. The level of data needed for ABM is greater than the level of data currently collected, and is greater than the level of data that would be generated with full implementation of the California Coastal Monitoring Plan (CMP). There are substantial technical difficulties associated with spawner surveys in the ESU and new programs would need to be developed to obtain ocean harvest data. Looking toward the future, important steps include (1) addressing the technical challenges associated with implementation of the CMP and moving toward full implementation, (2) giving consideration to a pilot study aimed at assessing the feasibility of marking and tagging programs that would provide sufficient information for estimation of ocean harvest and enable cohort reconstruction assessments, and (3) identification of stable funding for this monitoring work.

National Marine Fisheries Service. (2016). *Coastal Multispecies Plan: California Coastal Chinook Salmon*. Santa Rosa, California Retrieved from https://www.fisheries.noaa.gov/resource/document/final-coastal-multispecies-recovery-plan-california-coastal-chinook-salmon

The California Coastal (CC) Chinook salmon Evolutionarily Significant Unit (ESU) includes all naturally spawned populations of Chinook salmon from rivers and streams south of the Klamath River (Humboldt County, CA.) to the Russian River (Sonoma County, CA) (70 FR 37160). The ESU was historically comprised of 38 populations which included 32 fall-run populations and 6 spring-run populations across four Diversity Strata (Spence et al. 2008). All six of the spring-run populations were classified as functionally independent, but are considered extinct (Williams et al. 2011). The delineation of the CC Chinook salmon ESU Diversity Strata was based on environmental and ecological similarities and life history differences between fall-run and springrun Chinook. Four strata were identified by Bjorkstedt et al. (2005): North Coastal, North Mountain Interior, North-Central Coastal and Central Coastal. Of the 32 fall-run populations, 15 populations were considered either functionally independent or potentially independent, while the remaining populations were classified as dependent populations (Spence et al. 2008). We have selected 17 of the 32 fall-run populations across the four Diversity Strata to represent the recovery scenario for the CC Chinook salmon ESU.

National Marine Fisheries Service. (2016). *Coastal Multispecies Plan: Central California Coast Steelhead*. Retrieved from https://www.fisheries.noaa.gov/resource/document/final-coastal-multispecies-recovery-plan-california-coastal-chinook-salmon

The Central California Coast (CCC) steelhead Distinct Population Segment (DPS) historically consisted of five Diversity Strata with 38 independent populations of winter-run steelhead (12 functionally independent and 26 potentially independent) and 22 dependent populations (Spence et al. 2008; Spence et al. 2012). The delineation of the CCC steelhead DPS Diversity Strata was based on environmental and ecological similarities and life history. Five strata were identified by Bjorkstedt et al. (2005): North Coastal, Interior, Santa Cruz Mountains, Coastal San Francisco Bay, and Interior San Francisco Bay. From the historical structure, we have selected a total of 56 populations across the five Diversity Strata to represent the recovery scenario for the CCC steelhead DPS (Figure 1). To meet the minimum biological viability criteria set forth in Spence et al. (2012), passage above several man-made dams is recommended for the CCC steelhead recovery scenario.

National Marine Fisheries Service. (2016). Coastal Multispecies Plan: Northern California Steelhead. *3* Retrieved from https://www.fisheries.noaa.gov/resource/document/final-coastal-multispecies-recovery-plan-california-coastal-chinook-salmon

The Northern California (NC) steelhead Distinct Population Segment (DPS) historically consisted of five Diversity Strata with 41 independent populations of winter-run steelhead (19 functionally independent and 22 potentially independent) and 10 populations of summer steelhead (all functionally independent) (Spence et al. 2008; Spence et al. 2012). The delineation of the NC steelhead DPS Diversity Strata was based on environmental and ecological similarities and life history differences between winter run and summer run steelhead. Five strata were identified by Bjorkstedt et al. (2005): Northern Coastal, Lower Interior, North Mountain Interior, North Central Coastal, and Central Coastal. We have selected 51 winter-run populations across the five Diversity Strata and 10 summer-run populations across two Diversity strata to represent the recovery scenario for the NC steelhead DPS

National Marine Fisheries Service. (2016). *Steelhead Abundance in Seasonally Closed Estuaries Estimated Using Mark Recapture Methods*. https://doi.org/10.7289/V5/TM-SWFSC-555

Seasonally-closed estuaries in central California are important rearing habitat for populations of steelhead (Oncorhynchus mykiss). During periods of estuary closure, juvenile steelhead recruit to the resulting freshwater lagoons, where they may benefit from enhanced growth conditions afforded by inputs of marine nutrients and subsequent increased marine survival, but also face high predation pressure. Accurate estimation of the number of steelhead rearing in lagoon habitat is, therefore, essential for effective management. We implemented a monthly mark-recapture sampling protocol to estimate abundance of steelhead in the Scott Creek lagoon (Santa Cruz County, California) during three years that experienced different patterns of sandbar closure. Specifically, we conducted paired sampling events in which a marking event and a recapture event were conducted each month during the period of sandbar closure. We used recaptures of steelhead individually marked with passive integrated transponders (PIT tags) to assess performance of three methods of abundance estimation; two methods assuming an open population and one assuming a closed population. Monthly estimates of abundance generated using the open population methods were similar to the closed-population method when recapture rates were e10% and the assumption of closure was met. By incorporating each encounter with an individually marked steelhead to inform the estimates of lagoon abundance, the open population methods increased the number of recaptured steelhead in the sampled population, thereby increasing the precision of our abundance estimates relative to the closed-population method. Thus, the open population methods allowed us to more precisely estimate the lagoon population during months when recaptures were very low (0-4%) or the closure assumption was not met. Further, our paired, two-day mark-recapture sampling program provided a consistent sampling routine that could be applied across years with different lagoon closure and population closure dynamics, while minimizing sampling effort and disturbance to the lagoon. Our methods may be broadly applied to bar-built estuary systems throughout central California and will offer valuable insights into ecology and population biology of Central Coast steelhead, which can be applied directly to management of this threatened Distinct Population Segment.

National Marine Fisheries Service. (2017). *Spatial Structure of Water-Quality Impacts and Foraging Opportunities for Steelhead in the Russian River Estuary : An Energetics Perspective*. https://doi.org/10.7289/V5/TM-SWFSC-569

Estuaries along the California coast are recognized as critical rearing habitat for juvenile salmonids, particularly because they provide abundant feeding opportunities that support rapid growth. However, these estuaries exhibit a high degree of spatial and temporal variability in both food availability and elements of risk such as predation risk and mediocre water quality, varying greatly in response to natural seasonal changes as well as anthropogenic effects and management. Physical models such as a quantified conceptual model (QCM) developed by UC Davis for the Russian River Estuary can be used to predict the spatially explicit response of Estuary water quality and quantity to seasonal change and management interventions. These predictions take the form of depth-profiles of temperature, dissolved oxygen and salinity throughout the Estuary, calibrated to sonde measurements collected as part of regular monitoring. To aid in the interpretation of the outputs of such models, here we synthesize a categorical rating scheme for how water quality and spatial location in the Estuary affects rearing steelhead in terms of foraging opportunity, predation risk, and physiological impacts of water quality. We adopt a bioenergetics perspective as a conceptual framework because energy provides a unifying framework for thinking about how behavioral and physiological responses to predation risk, water quality, and foraging opportunity translate to somatic growth of rearing salmonids. However, our review and synthesis indicates that the tradeoffs posed to rearing salmonids by an estuary among foraging opportunities and the different dimensions of water quality impacts, for example is multidimensional and complex. Rather than propose explicit quantitative models of behavior and physiology that capture all this complexity which is outside our scope and in any case requires further work for simplicity we develop a categorical (or qualitative) scheme to make sense of this complexity. It is our hope that this scheme will aid fisheries managers in interpreting the complex output of physical estuary models, and point the way toward more focused development of coupled behavioral-bioenergetics models of salmonids rearing in estuaries. Such models will need to address the spatial and temporal structure of the tradeoffs, as well as the important role of induced physiological tolerance for salinity and possibly hypoxic conditions, and its relationship to strategies for feeding, growth efficiency, and predator avoidance. For convenience the qualitative rating scheme is summarized in a short appendix at the end of the text.

Native Fish Society. (2017). *Native Fish Society Upper Eel River Temperature Monitoring Report Data from Years: 2015 & 2016.* Native Fish Society Retrieved from https://nativefishsociety.org/campaigns/eel-river-monitoring

For the last two years, Native Fish Society staff, River Stewards and volunteers have placed fourteen digital temperature monitors in the upper mainstem of California's Eel River and its tributaries above Scott Dam/Lake Pillsbury. Our goal is to contribute a greater scientific understanding about the area's potential to serve the temperature-driven life history requirements of native fish in the upper Eel watershed including salmon, steelhead and trout.

Obedzinski, M., Nossaman Pierce, S., Horton, G. E., & Deitch, M. J. (2018). Effects of Flow-Related Variables on Oversummer Survival of Juvenile Coho Salmon in Intermittent Streams. *Transactions of the American Fisheries Society, 147*(3), https://doi.org/10.1002/tafs.10057

While many studies have established the importance of streamflow as a driver of fish population dynamics, few have examined relationships between survival of juvenile salmonids and flow-related variables in intermittent streams. With predictions for a higher frequency of drought conditions due to climate change and the associated increasing human demand for water during the dry season, understanding fish–flow relationships is becoming increasingly important for the protection of sensitive aquatic species. To examine the effects of low streamflow on juvenile salmonids rearing in small intermittent streams, we estimated survival and collected environmental data in four coastal California watersheds from 2011 to 2013. We used an individual-based mark–recapture modeling approach to evaluate the influence of flow-related variables on oversummer survival of PIT-tagged juvenile Coho Salmon Oncorhynchus kisutch stocked into eight stream reaches. Survival was positively associated with streamflow magnitude, wetted volume, and dissolved oxygen and negatively associated with days of disconnected surface flow (days of disconnection) and temperature. Days of disconnection best explained survival, though the relationship varied by geomorphic reach type. Survival was lower in alluvial reaches than in bedrock and clay reaches and showed a faster rate of decline with increasing days of disconnection and drought condition. In all reaches, the onset of pool disconnection represented a turning point at which water quality, water quantity, and survival declined. For this reason, we suggest that days of disconnection (or the flow magnitude at which pools become disconnected) is a useful metric for identifying flow-impaired reaches, informing streamflow protection strategies, and prioritizing streamflow enhancement efforts designed to benefit sensitive salmonid populations in intermittent streams.

Ohlberger, J., Ward, E. J., Schindler, D. E., & Lewis, B. (2018). Demographic Changes in Chinook Salmon across the Northeast Pacific Ocean. *Fish and Fisheries, 19*(3), https://doi.org/10.1111/faf.12272

The demographic structure of populations is affected by life history strategies and how these interact with natural and anthropogenic factors such as exploitation, climate change, and biotic interactions. Previous work suggests that the mean size and age of some North American populations of Chinook salmon (Oncorhynchus tshawytscha, Salmonidae) are declining. These trends are of concern because Chinook salmon are highly valued commercially for their exceptional size and because the loss of the largest and oldest individuals may lead to reduced population productivity. Using long-term data from wild and hatchery populations, we quantified changes in the demographic structure of Chinook salmon populations over the past four decades across the Northeast Pacific Ocean, from California through western Alaska. Our results show that wild and hatchery fish are becoming smaller and younger throughout most of the Pacific coast. Proportions of older age classes have decreased over time in most regions. Simultaneously, the length-at-age of older fish has declined while the length-at-age of younger fish has typically increased. However, negative size trends of older ages were weak or non-existent at the southern end of the range. While it remains to be explored whether these trends are caused by changes in climate, fishing practices or species interactions such as predation, our qualitative review of the potential causes of demographic change suggests that selective removal of large fish has likely contributed to the apparent widespread declines in average body sizes.

Oregon Department of Fish and Wildlife. (2015). *Salmonid Life Cycle Monitoring in Western Oregon Streams, 2012–2014*. Monitoring Program Report Number OPSW-ODFW-2015-2, Oregon Department of Fish … Retrieved from https://nrimp.dfw.state.or.us/crl/Reports/AnnPro/LCMRpt2014.pdf

This report summarizes data collected at eight LCM basins for adult salmonids (1997-2013 return years) and out-migrating juveniles (1997-2014 sample years). In addition to previously unpublished data for the 2012-2014 sample years the out-migrant estimates have been recalculated with a new estimator (Bonner and Schwarz 2011). The report is organized into chapters for each LCM site from north to south along the Oregon Coast (Figure 1). LCM sites are located on North Scappoose Creek (Columbia River), North Fork Nehalem River, East Fork Trask River (Tillamook River basin), Mill Creek (Siletz River basin), Mill Creek (Yaquina River basin), Cascade Creek (Alsea River basin), West Fork Smith River (Umpqua River basin) and Winchester Creek (Coos River basin).

Osterback, A.-M. K., Frechette, D. M., Hayes, S. A., Bond, M. H., Shaffer, S. A., & Moore, J. W. (2014). Linking Individual Size and Wild and Hatchery Ancestry to Survival and Predation Risk of Threatened Steelhead (Oncorhynchus mykiss). *Canadian Journal of Fisheries and Aquatic Sciences, 71*(12), https://doi.org/10.1139/cjfas-2014-0097

We examined the role of individual size and origin (wild versus hatchery) to predation risk and marine survival for threatened juvenile steelhead (Oncorhynchus mykiss) in a coastal California watershed. In this study, we found that individual size and origin were strongly associated with increased predation risk ofsteelhead by a generalist avian predator (western gull, Larus occidentalis) and associated with survival to reproduction by tracking the fate ofjuvenile steelhead tagged with passive integrated transponder (PIT) tags. Across six cohorts (2005–2010), larger steelhead (>170 mm fork length (FL)) experienced marine survival rates at least 60 times higher than the smallest individuals. Predation risk by western gulls was highest for intermediate-sized fish (145–190 mm FL), which was at least ten times higher than the predation risk of the smallest individuals and four times higher than the predation risk of the largest individuals. Wild steelhead experienced both higher predation risk and higher survival rates than hatchery fish of the same size. Although gulls disproportionately remove intermediate-sized wild steelhead from the population, they also remove large wild individuals that may otherwise experience the highest adult return rates. Instead offocusing on population size alone, conservation measures could also be guided towards the recovery oflarger and wild individuals, whose survival is paramount for population recovery.

Osterback, A.-M. K., Frechette, D. M., Hayes, S. A., Shaffer, S. A., & Moore, J. W. (2015). Long-Term Shifts in Anthropogenic Subsidies to Gulls and Implications for an Imperiled Fish. *Biological Conservation, 191*, https://doi.org/10.1016/j.biocon.2015.07.038

Over the last century, human activities have altered coastal ecosystems by fishing through the marine food web and increasing anthropogenic resources (e.g. landfills), both of which may alter native predator–prey interactions. We conducted a 100-year retrospective stable isotope analysis to investigate temporal shifts in relative resource use and individual variation of a generalist seabird (Western Gull, Larus occidentalis) and the implications of gulls' shifting resource use on one of their native prey—threatened steelhead populations (Oncorhynchus mykiss). We applied a Bayesian mixing model (MixSIAR) to historical (early 1900s) and modern (early 2000s) populations of generalist gulls and compared changes in resource use to a piscivorous seabird population (Brandt's Cormorant, Phalacrocorax penicillatus) in Monterey Bay (California, USA). δ15N significantly declined for both seabird species, suggesting shifts to lower trophic-level marine prey in the last 100years. The shift in δ15N was significantly larger for Western Gulls, suggesting a shift in gull resource use to prey not in the marine environment. Mixing models suggest anthropogenic resources (e.g., landfills) comprise the majority of modern gull diet (0.31; 0.18–0.44 95% CI), whereas it contributed relatively little to gull diet in the early 1900s (0.10; 0.01–0.26 CI). Furthermore, we found although steelhead contribute relatively less to overall modern gull diet, increasing gull populations and simultaneous steelhead population decline likely results in increased per capita predation risk to modern steelhead populations—our best estimate is that modern predation risk is ~2.4 times higher than historically, but this estimate depends on parameter values and overlaps with zero. This study highlights the impact of human activities on coastal predators and the potential consequences for native imperiled prey.

Osterback, A. M. K., Kern, C. H., Kanawi, E. A., Perez, J. M., & Kiernan, J. D. (2018). The Effects of Early Sandbar Formation on the Abundance and Ecology of Coho Salmon (Oncorhynchus kisutch) and Steelhead Trout (Oncorhynchus mykiss) in a Central California Coastal Lagoon. *Canadian Journal of Fisheries and Aquatic Sciences, 75*(12), https://doi.org/10.1139/cjfas-2017-0455

We investigated how extreme drought conditions influenced the abundance, growth, movement, and seawater readiness of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Oncorhynchus mykiss) in a small central California coastal lagoon. In 2015, the seasonal sandbar at the mouth of Scott Creek formed over 2 months earlier than average, effectively trapping fish in the lagoon for 7 additional months (mid-May through December) before outmigration opportunities eventually resumed. Monthly mark-recapture sampling demonstrated that juvenile coho salmon and steelhead were able to persist in the lagoon during extended periods of high water temperature and low dissolved oxygen concentration. Both salmonid species exhibited similar temporal trends in abundance, growth, and Na+-K+-ATPase activity levels during lagoon residence; however, abundance and growth rates were consistently higher for steelhead. Stationary passive integrated transponder tag antenna detections revealed recurrent movement of individuals between the warm lagoon and cooler lower mainstem creek, suggesting individuals regulated key physiological processes by moving between the adjacent habitats. Our study provides new insight concerning the consequences of drought for imperiled salmonid populations and underscores the importance of life-history diversity during extreme climatic events.

Pfeiffer, A. M., & Finnegan, N. J. (2017). Basin-Scale Methods for Predicting Salmonid Spawning Habitat Via Grain Size and Riffle Spacing, Tested in a California Coastal Drainage. *Earth Surface Processes and Landforms, 42*(6), https://doi.org/10.1002/esp.4053

Basin-scale predictive geomorphic models for river characteristics, particularly grain size, can aid in salmonid habitat identification. However, these basin-scale methods are largely untested with actual habitat usage data. Here, we develop and test an approach for predicting grain size distributions from high resolution LiDAR (Light Detection and Ranging)-derived topographic data for a 77 km2 watershed along the central California Coast. This approach improves on previous efforts in that it predicts the full grain size distribution and incorporates an empirically calibrated shear stress partitioning factor. The predicted grain size distributions are used to calculate the fraction of the bed area movable by spawning fish. We then compare the 'movable fraction' with 7 years of observed spawning data. We find that predicted movable fraction explains the paucity of spawning in the upper reaches of the study drainage, but does not explain variation along the mainstem. In search of another morphologic characteristic that may help explain the variation within the mainstem, we measure riffle density, a proxy for physical habitat complexity. We find that field surveys of riffle density explain 64% of the variation in spawning in these mainstem reaches, suggesting that within reaches of appropriate sized gravel, spawning density is related to riffle density. Because riffle density varies systematically with channel width, predicting riffle spacing is straightforward with LiDAR data. Taken together, these findings demonstrate the efficacy of basin-scale spawning habitat predictions made using high-resolution digital elevation models.

Potter Valley Project. (2018). *Coastal Multispecies Recovery Plan Vol. Ii, California Coastal Chinook Salmon, Upper Eel River.* Retrieved from http://pottervalleyproject.org/wp-content/uploads/2018/04/upper-eel-river-Chinook-profile-with-PVP-passage-language-highlighted.pdf

This is a profile of the California Coastal chinook written by Congressman Jared Huffman's Ad Hoc Committee, charged with collaboratively developing recommendations for the future of the Potter Valley Project to inform the Federal Energy Regulatory Commission relicensing process.

Power, M. E., Bouma-Gregson, K., Higgins, P., & Carlson, S. M. (2015). The Thirsty Eel: Summer and Winter Flow Thresholds That Tilt the Eel River of Northwestern California from Salmon-Supporting to Cyanobacterially Degraded States. *Copeia, 103*(1), https://doi.org/10.1643/Ce-14-086

Although it flows through regions of northwestern California that are thought to be relatively well watered, the Eel River is increasingly stressed by drought and water withdrawals. We discuss how critical threshold changes in summer discharge can potentially tilt the Eel from a recovering salmon-supporting ecosystem toward a cyanobacterially degraded one. To maintain food webs and habitats that support salmonids and suppress harmful cyanobacteria, summer discharge must be sufficient to connect mainstem pools hydrologically with gently moving, cool base flow. Rearing salmon and steelhead can survive even in pools that become isolated during summer low flows if hyporheic exchange is sufficient. But if the ground water discharge that sustains river flow during summer drought drops below critical levels, warm stagnant conditions will kill salmonids, and cyanobacteria will thrive. Challenges and opportunities for restoring the Eel and increasing its resilience to climate extremes, water diversions, and excessive loading of fine sediments point toward exploring how land use and terrestrial vegetation affect delivery from uplands of water, heat, sediments, solutes, organic matter, and organisms—in ways that either heal or damage rivers.

Quiñones, R. M., Grantham, T. E., Harvey, B. N., Kiernan, J. D., Klasson, M., Wintzer, A. P., & Moyle, P. B. (2015). Dam Removal and Anadromous Salmonid (Oncorhynchus Spp.) Conservation in California. *Reviews in Fish Biology and Fisheries, 25*(1), https://doi.org/10.1007/s11160-014-9359-5

Dam removal is often proposed for restoration of anadromous salmonid populations, which are in serious decline in California. However, the benefits of dam removal vary due to differences in affected populations and potential for environmental impacts. Here, we develop an assessment method to examine the relationship between dam removal and salmonid conservation, focusing on dams that act as complete migration barriers. Specifically, we (1) review the effects of dams on anadromous salmonids, (2) describe factors specific to dam removal in California, (3) propose a method to evaluate dam removal effects on salmonids, (4) apply this method to evaluate 24 dams, and (5) discuss potential effects of removing four dams on the Klamath River. Our flexible rating system can rapidly assess the likely effects of dam removal, as a first step in the prioritization of multiple dam removals. We rated eight dams proposed for removal and compared them with another 16 dams, which are not candidates for removal. Twelve of the 24 dams evaluated had scores that indicated at least a moderate benefit to salmonids following removal. In particular, scores indicated that removal of the four dams on the

Klamath River is warranted for salmonid conservation. Ultimately, all dams will be abandoned, removed, or rebuilt even if the timespan is hundreds of years. Thus, periodic evaluation of the environmental benefits of dam removal is needed using criteria such as those presented in this paper.

Ruzicka, J. J., Daly, E. A., & Brodeur, R. D. (2016). Evidence That Summer Jellyfish Blooms Impact Pacific Northwest Salmon Production. *Ecosphere, 7*(4), https://doi.org/10.1002/ecs2.1324

Interannual variability in salmon (Oncorhynchus spp.) production in the northeast Pacific is understood to be driven by oceanographic variability and bottom-up processes affecting prey availability to juvenile salmon. Scyphozoan jellyfish have an important role in shaping the pathways of energy flow through pelagic food webs. While jellyfish obtain high production rates and biomasses as major consumers of zooplankton production, they have few predators and may divert plankton production away from higher trophic levels. Although jellyfish are planktivorous and juvenile coho (O. kisutch) and Chinook (O. tshawytscha) salmon are mainly piscivorous, they may be indirect competitors for plankton production. Ecosystem model simulations suggested that among all trophic interactions within the Pacific Northwest coastal food web, juvenile salmon are particularly sensitive to jellyfish blooms, and that salmon production will be suppressed in years of high summer jellyfish biomass. Pelagic surveys off Oregon and Washington (1999–2012) were used to examine the interannual relationship between salmon production and the dominant jellyfish species, the sea nettle Chrysaora fuscescens, off the Pacific Northwest coast. There was a significant, negative correlation between sea nettle biomass and the strength of adult coho and Chinook salmon returns to the Columbia River. Examination of spatial distributions across years showed a positive association between sea nettles and salmon. Within individual years, significant differences between the distribution of sea nettles and yearling coho and Chinook salmon generally occurred during cooler ocean summers, perhaps due to the greater expanse of optimal salmon habitat resulting from more upwelling. Whether the association is behavioral or a product of oceanographic processes, association enhances the opportunity for indirect competition. Examination of feeding incidence in September showed that salmon stomachs were less full at locations with higher sea nettle biomass.

Satterthwaite, W. H., Andrews, K. S., Burke, B. J., Gosselin, J. L., Greene, C. M., Harvey, C. J., . . . Sobocinski, K. L. (2020). Ecological Thresholds in Forecast Performance for Key United States West Coast Chinook Salmon Stocks. *Ices Journal of Marine Science, 77*(4), https://doi.org/10.1093/icesjms/fsz189

Preseason abundance forecasts drive management of US West Coast salmon fisheries, yet little is known about how environmental variability influences forecast performance. We compared forecasts of Chinook salmon (Oncorhynchus tshawytscha) against returns for (i) key CaliforniaOregon ocean fishery stocks and (ii) high priority prey stocks for endangered Southern Resident Killer Whales (Orcinus orca) in Puget Sound, Washington. We explored how well environmental indices (at multiple locations and time lags) explained performance of forecasts based on different methods (i.e. sibling-based, production-based, environment-based, or recent averages), testing for nonlinear threshold dynamics. For the California stocks, no index tested explained >50% of the variation in forecast performance, but spring Pacific Decadal Oscillation and winter North Pacific Index during the year of return explained >40% of the variation for the sibling-based Sacramento Fall Chinook forecast, with nonlinearity and apparent thresholds. This suggests that oceanic conditions experienced by adults (after younger siblings returned) have the most impact on sibling-based forecasts. For Puget Sound stocks, we detected nonlinear/threshold relationships explaining >50% of the variation with multiple indices and lags. Environmental influences on preseason forecasts may create biases that render salmon fisheries management more or less conservative, and therefore could motivate the development of ecosystem-based risk assessments.

Satterthwaite, W. H., & O'Farrell, M. R. (2018). Inferred Ocean Distributions of Genetically Similar Chinook Salmon Stocks Compared across Run Timing and River/Hatchery of Origin. *Fisheries Research, 199*, https://doi.org/10.1016/j.fishres.2017.11.006

Klamath River Fall Chinook (KRFC) salmon from the Klamath-Trinity Basin are central to management of the ocean salmon fishery off the coasts of northern California and southern Oregon, with tagged KRFC serving as proxies for other stocks including spring run (KRSC). There has been no formal comparison of fall versus spring run ocean distributions, and published studies using genetic stock identification do not distinguish the runs. We modeled the spatial distribution of hatchery-origin fall versus spring run, inferred from coded-wire tag recoveries in the ocean commercial (troll) fishery while explicitly accounting for fishing effort, sampling rate, and release of sublegal-sized fish before sampling. Distributions for all stocks were confined to a similar core range, but varied seasonally, and with higher relative density of KRSC in the north. Only equivocal evidence was found for differences by age or within-basin source hatchery. The potential for such differences should be considered for analyses of coarser groupings in these and other stocks. Sensitivity analyses revealed differences in distributions inferred from recreational versus commercial fishery data, emphasizing the importance of recognizing the limitations of fishery-dependent data in representing the underlying spatial distribution of fish populations rather than spatial patterns in their interactions with specific fisheries.

Schaaf, C. J., Kelson, S. J., Nussle, S. C., & Carlson, S. M. (2017). Black Spot Infection in Juvenile Steelhead Trout Increases with Stream Temperature in Northern California. *Environmental Biology of Fishes, 100*(6), https://doi.org/10.1007/s10641-017-0599-9

Climate change will increase water temperature in rivers and streams that provide critical habitat for imperiled species. Warmer water temperatures will influence the intensity and nature of biotic interactions, including parasitism. To better understand the factors influencing a neascus-type parasitic infection known as black spot disease, we examined the relationship between infection rate in juvenile steelhead trout (Oncorhynchus mykiss), abundance of another intermediate host (ramshorn snail, Planorbella trivolvis), and water temperature. We quantified infection patterns of trout at seven sites within the South Fork Eel River in northern California, visiting each site on three different occasions across the summer, and recording water temperature at each site. We also quantified infection patterns in trout captured from two tributaries to the South Fork Eel River. Overall, trout infection rates were highest in sites with the warmest temperatures. The abundance of ramshorn snails was positively related to both water temperature and black spot infection rates in juvenile trout. Both snail abundance and infection rates increased rapidly above a 23 A degrees C daily maximum, suggesting a threshold effect at this temperature. We suggest that warmer temperatures are associated with environmental and biotic conditions that increase black spot disease prevalence in threatened steelhead trout. A comparison of our results with similar data collected from a more northern latitude suggests that salmonids in California may be warm-adapted in terms of their parasite susceptibility.

Shelton, A. O., Satterthwaite, W. H., Ward, E. J., Feist, B. E., & Burke, B. (2019). Using Hierarchical Models to Estimate Stock-Specific and Seasonal Variation in Ocean Distribution, Survivorship, and Aggregate Abundance of Fall Run Chinook Salmon. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(1), https://doi.org/10.1139/cjfas-2017-0204

Ocean fisheries often target and catch aggregations comprising multiple populations or groups of a given species. Chinook salmon (Oncorhynchus tshawytscha) originating from rivers throughout the west coast of North America support mixed-stock ocean fisheries and other ecosystem components, notably as prey for marine mammals. We construct the first coastwide state-space model for fall Chinook salmon tagged fish released from California to British Columbia between 1977 and 1990 to estimate seasonal ocean distribution along the west coast of North America. We incorporate recoveries from multiple ocean fisheries and allow for regional variation in fisheries vulnerability and maturation. We show that Chinook salmon ocean distribution depends strongly on region of origin and varies seasonally, while survival showed regionally varying temporal patterns. Simulations incorporating juvenile production data provide proportional stock composition in different ocean regions and the first coastwide projections of Chinook salmon aggregate abundance. Our model provides an extendable framework that can be applied to understand drivers of Chinook salmon biology (e.g., climate effects on ocean distribution) and management effects (e.g., consequences of juvenile production changes).

Sonoma County Water Agency. (2016). *Russian River Biological Opinion Status and Data Report 2014-2015*. Retrieved from https://evogov.s3.amazonaws.com/185/media/165011.pdf

On September 24, 2008, the National Marine Fisheries Service (NMFS) issued a 15-year Biological Opinion for water supply, flood control operations, and channel maintenance conducted by the U.S. Army Corps of Engineers (USACE), Sonoma County Water Agency (Water Agency), and Mendocino County Russian River Flood Control and Water Conservation Improvement District in the Russian River watershed (NMFS 2008). The Biological Opinion authorizes incidental take of threatened and endangered Chinook salmon, coho salmon, and steelhead pending implementation of a Reasonable and Prudent Alternative (RPA) to status quo management of reservoir releases, river flow, habitat condition, and facilities in portions of the mainstem Russian River, Dry Creek, and Russian River Estuary. Mandated projects to ameliorate impacts to listed salmonids in the RPA are partitioned among USACE and the Water Agency. Each organization has its own reporting requirements to NMFS. Because coho salmon are also listed as endangered by the California Endangered Species Act (CESA), the Water Agency is party to a Consistency Determination issued by the California Department of Fish and Wildlife (CDFW) in November 2009. The Consistency Determination mandates that the Water Agency implement a subset of Biological Opinion projects that pertain to coho and the Water Agency is required to report progress on these efforts to CDFW.

Sonoma County Water Agency. (2019). *Implementation of California Coastal Salmonid Monitoring in the Russian River Watershed (2015-2019)*. Retrieved from https://www.sonomawater.org/media/PDF/Environment/Fisheries/reports/cmp-report-2019_ADA.pdf

Between June 2015 and February 2019, the Sonoma County Water Agency (Sonoma Water) and California Sea Grant continued implementation of the Coastal Monitoring Plan (CMP, Adams et al. 2011) in the Russian River Watershed. During this contract period, we further refined the Russian River sample frame and completed four seasons of data collection, adding to a long-term dataset which began in 2013 when CMP implementation first began in the Russian River watershed.

Swift, C. C., Mulder, J., Dellith, C., & Kittleson, K. (2018). Mortality of Native and Non-Native Fishes During Artificial Breaching of Coastal Lagoons in Southern and Central California. *Bulletin, Southern California Academy of Sciences, 117*(3) Retrieved from https://doi.org/10.3160/1767.1

Fishes of California coastal streams and associated coastal lagoons have adapted to the Mediterranean-style rainfall cycle. Winter rains open the lagoons to the ocean; subsequent lack of rain and seasonal changes in beach dynamics typically closes them for much of the year. Dry and wet season artificial breaching or opening of barrier sand berms has been suspected to disrupt fish populations and lead to mortality of many aquatic organisms including federally endangered species. Such breaches have been rarely observed and then only after at least a few days or more have passed. Artificial breachings of three lagoons have been observed during or within a few hours after breaching and provide documentation of extensive disruption and mortality of aquatic organisms. These observations, Aliso Creek, Orange County (1975), Santa Clara River, Ventura County (2010), and Corcoran Lagoon, Santa Cruz County (2014-2015), confirmed many changes and effects of these events, including mortality of the federally endangered northern and southern tidewater gobies and southern steelhead. Despite the many ostensibly beneficial and non-faunal related reasons for breaching, our observations confirm such actions can cause considerable mortality of threatened and endangered species and are probably more severe than natural wet season breachings. Many city, county, as well as state and federal laws provide regulation of lagoon breaching to protect habitat and minimize or mitigate for impact to sensitive species and these need to be maintained and strengthened.

Torregrosa, A., Flint, L. E., & Flint, A. L. (2019). Hydrologic Resilience from Summertime Fog and Recharge: A Case Study for Coho Salmon Recovery Planning. *JAWRA Journal of the American Water Resources Association, 56*(1), https://doi.org/10.1111/1752-1688.12811

Fog and low cloud cover (FLCC) and late summer recharge increase stream baseflow and decrease stream temperature during arid Mediterranean climate summers, which benefits salmon especially under climate warming conditions. The potential to discharge cool water to streams during the late summer (hydrologic capacity; HC) furnished by FLCC and recharge were mapped for the 299 subwatersheds ranked Core, Phase 1, or Phase 2 under the National Marine Fisheries Service Recovery Plan that prioritized restoration and threat abatement action for endangered Central California Coast Coho Salmon evolutionarily significant unit. Two spatially continuous gridded datasets were merged to compare HC: average hrs/day FLCC, a new dataset derived from a decade of hourly National Weather Satellite data, and annual average mm recharge from the USGS Basin Characterization Model. Two use-case scenarios provide examples of incorporating FLCC-driven HC indices into long-term recovery planning. The first, a thermal analysis under future climate, projected 65% of the watershed area for 8-19 coho population units as thermally inhospitable under two global climate models and identified several units with high resilience (high HC under the range of projected warming conditions). The second use case investigated HC by subwatershed rank and coho population, and identified three population units with high HC in areas ranked Phase 1 and 2 and low HC in Core. Recovery planning for cold-water fish species would benefit by including FLCC in vulnerability analyses.

Tsui, M. T. K., Blum, J. D., Finlay, J. C., Balogh, S. J., Nollet, Y. H., Palen, W. J., & Power, M. E. (2014). Variation in Terrestrial and Aquatic Sources of Methylmercury in Stream Predators as Revealed by Stable Mercury Isotopes. *Environmental Science & Technology, 48*(17), https://doi.org/10.1021/es500517s

Mercury (Hg) is widely distributed in the environment, and its organic form, methylmercury (MeHg), can extensively bioaccumulate and biomagnify in aquatic and terrestrial food webs. Concentrations of MeHg in organisms are highly variable, and the sources in natural food webs are often not well understood. This study examined stable isotope ratios of MeHg (mass-dependent fractionation, as delta Hg-202(MeHg); and mass-independent fractionation, as Delta Hg-199(MeHg)) in benthic invertebrates, juvenile steelhead trout (Oncorhynchus mykiss), and water striders (Gerris remigis) along a stream productivity gradient, as well as carnivorous terrestrial invertebrates, in a forested watershed at the headwater of South Fork Eel River in northern California. Throughout the sampling sites, delta Hg-202(MeHg) (after correction due to the effect of MeHg photodegradation) was significantly different between benthic (median = -1.40 parts per thousand; range, -2.34 to -0.78 parts per thousand; total number of samples = 29) and terrestrial invertebrates (median = +0.51 parts per thousand; range, -0.37 to +1.40 parts per thousand; total number of samples = 9), but no major difference between these two groups was found for Delta Hg-199(MeHg). Steelhead trout (52 individual fishes) have MeHg of predominantly aquatic origins, with a few exceptions at the upstream locations (e.g., 1 fish collected in a tributary had a purely terrestrial MeHg source and 4 fishes had mixed aquatic and terrestrial MeHg sources). Water striders (seven pooled samples) derive MeHg largely from terrestrial sources throughout headwater sections. These data suggest that direct terrestrial subsidy (e.g., terrestrial invertebrates falling into water) can be important for some stream predators in headwater streams and could represent an important means of transfer of terrestrially derived MeHg (e.g., in situ methylation within forests, atmospheric sources) to aquatic ecosystems. Moreover, these findings show that terrestrial subsidies can enhance MeHg bioaccumulation of consumers in headwater streams where aqueous MeHg levels are very low.

U.S. Army Corp of Engineers. (2018). *Corte Madera Creek Flood Risk Management Project Section 404 (B)(1) Evaluation*. Retrieved from https://www.marinwatersheds.org/sites/default/files/2018-10/Appendix_O_404(b)(1).pdf

The U.S. Army Corps of Engineers (USACE) and Marin County Flood Control District (District) propose to reduce the risk of flooding to commercial, residential, and public infrastructure along Corte Madera Creek consistent with protecting the nation's environment, pursuant to national environmental statutes, applicable executive orders, and other federal planning requirements. This document presents the USACE 404(b)(1) evaluation for the study.

Woelfle-Erskine, C., Larsen, L. G., & Carlson, S. M. (2017). Abiotic Habitat Thresholds for Salmonid over-Summer Survival in Intermittent Streams. *Ecosphere, 8*(2), https://doi.org/10.1002/ecs2.1645

Intermittent streams lose surface flow during part of the year but can provide important habitat for imperiled fishes in residual pools. However, extended intermittency can drive high mortality as pool contraction decreases pool quality, and some pools dry completely. We evaluated the influence of a suite of abiotic habitat characteristics on the over-summer survival of two imperiled salmonid fishes (coho salmon Oncorhynchus kisutch; steelhead trout Oncorhynchus mykiss) at four study sites on two tributaries of Salmon Creek (Sonoma County, California, USA) from 2012 to 2014, during deepening drought conditions. Study sites spanned an intermittency gradient from continuous flow to near-dry conditions, and included alluvial and bedrock stream reaches. We estimated over-summer survival at the pool scale from fish presence-absence data based on paired early-late summer snorkel surveys. We measured pool dimensions and water quality parameters monthly (more frequently during summer dry down) and, in 2013 and 2014, recorded water quality with continuous loggers in selected pools. We performed: (1) logistic regression in a generalized linear modeling framework to identify factors limiting over-summer survival and (2) classification trees using the random forests ensemble learning method to identify abiotic thresholds for sustaining sal-monids. Results suggested that different factors governed mortality of the two species. Coho salmon, which tended to survive in large, deep pools, were limited by minimum dissolved oxygen (DO) concentrations. In contrast, steelhead trout, which tended to survive in pools with large surface area, were sensitive to pool geometry and temperature. Both species persisted for weeks in large pools with low DO levels, including in pools where at least part of the water column reached sublethal or lethal levels. Our results suggest that shallow, lateral hyporheic flow may be important for maintaining DO and temperatures suitable for sustaining salmonids in isolated pools, whereas groundwater discharge originating from deeper flow paths may generate low-DO conditions that inhibit salmonid persistence. Geomorphically complex watersheds with a variety of pool geometries and high rates of lateral hyporheic exchange are those most likely to serve as "sanctuary reaches" for imperiled Pacific salmonid populations in semi-arid regions in the context of a changing climate.

Zipper, S. C., Carah, J. K., Dillis, C., Gleeson, T., Kerr, B., Rohde, M. M., . . . Zimmerman, J. K. H. (2019). Cannabis and Residential Groundwater Pumping Impacts on Streamflow and Ecosystems in Northern California. *Environmental Research Communications, 1*(12), https://doi.org/10.1088/2515-7620/ab534d

Cannabis is an emerging agricultural frontier, but due to its quasi-legal status its environmental impacts are poorly understood. Where cannabis is irrigated by groundwater, pumping can lead to streamflow depletion in surrounding streams which may impair other water users or aquatic ecosystems. Here, we investigate the impacts of groundwater pumping for cannabis irrigation at the scale of the watershed, the individual well, and the stream segment, and contextualize by comparing with residential groundwater use. Combining mapped cannabis cultivation and residential structure locations with grower reports of irrigation water sources, we develop distributed estimates of groundwater pumping and associated streamflow depletion caused by cannabis and residential users within the Navarro River

Watershed in Northern California (USA). An estimated 73% of cannabis cultivation sites and 92% of residential structures in the watershed rely on groundwater, and groundwater abstraction leads to streamflow depletion during late summer when groundwater is a critical source of baseflow to ecologically important streams. However, streamflow depletion caused by cannabis cultivation is dwarfed by the impacts of residential use, which causes >5 times as much streamflow depletion and is concentrated close to ecologically important stream segments. Focusing on cannabis, a small number of wells (50%), and significant predictors for impacts of a well are the annual pumping rate, the distance to the closest stream, and the transmissivity between the well and the stream. Streamflow depletion increases nonlinearly when pumping occurs within 1.2 km of streams, and most cannabis and residential groundwater use is within this critical distance. Given the rapid increase in cannabis cultivation, these results indicate that potential streamflow depletion from groundwater irrigation of cannabis is a current and future concern, and will be superimposed on top of significant depletion already occurring due to residential use in the region studied.

Section IV: Southern Oregon & Northern California Coast

Brewitt, K. S., Danner, E. M., & Moore, J. W. (2017). Hot Eats and Cool Creeks: Juvenile Pacific Salmonids Use Mainstem Prey While in Thermal Refuges. *Canadian Journal of Fisheries and Aquatic Sciences, 74*(10), https://doi.org/10.1139/cjfas-2016-0395

Thermal refuges form important habitat for cold-water fishes in the face of rising temperatures. As fish become concentrated in refuges, food resources may become depleted. In this study, we used invertebrate drift sampling and fish density surveys to quantify potential in-refuge food limitation, temperature-sensitive radio-tagging studies to quantify thermal habitat use, and isotopic analyses to determine diet sources for juvenile Pacific salmonids using thermal refuges in California's Klamath River. Juvenile salmonids using refuges formed by tributary junctions with the mainstem river obtained the majority (range = 47%-97%) of their diet from mainstem prey sources. Mean steelhead (Oncorhynchus mykiss) body temperatures were significantly cooler (similar to 3.5 degrees C) than diet-inferred foraging temperatures. Thus, while fish seek cooler habitat for physiological benefits, they rely primarily on mainstem prey. Moreover, consistently high densities of fish in refuges (mean = 3.5 fish.m(-2)) could lead to density-dependent food limitation. Thus, mobile consumers like fish can exploit existing heterogeneity associated with cold-water refuges by gaining thermal benefits from a food-limited cold-water habitat while deriving the majority of their prey from the warm mainstem river.

California Department of Fish and Wildlife. (2016). *Annual Report Trinity River Basin Salmon and Steelhead Monitoring Project: Chinook and Coho Salmon and Fall-Run Steelhead Run-Size Estimates Using Mark-Recapture Methods 2015-16 Season*. Retrieved from https://www.trrp.net/library/document/?id=2299

California Department of Fish and Wildlife's Trinity River Project conducted tagging and recapture operations from June 2015 through March 2016 to produce run-size, angler harvest, and spawner escapement estimates of spring- and fall-run Chinook salmon (Oncorhynchus tshawytscha)], coho salmon (O. kisutch), and fall steelhead (O. mykiss) in the Trinity River basin. Monitoring results informs the Trinity River Restoration Program's (TRRP) adaptive management decision making process and helps evaluate progress toward achieving fundamental objectives outlined in the Integrated Assessment Plan (TRRP, 2009) Using a Petersen mark-recapture methodology, we estimated a run-size of 4,408 (95% CI 3,752 – 5,119) spring-run (spring) Chinook migrated into Trinity River basin upstream of Junction City weir (JCW). The run was comprised of an estimated 1,146 naturallyproduced adults and 177 naturally-produced jacks and 2,772 hatchery-produced adults and 313 hatchery-produced jacks. Using tags returned by anglers we estimate 190 spring Chinook were harvested, yielding an escapement of 4,218 fish. Escapement of 1,090 naturally-produced adult spring Chinook was 18.2% of the TRRP goal of 6,000 spring Chinook. An estimated run-size of 10,365 (95% CI 9,230 – 11,569) fall-run (fall) Chinook migrated past Willow Creek weir (WCW). The run was comprised of an estimated 3,609 naturallyproduced adults and 2,226 naturally-produced jack salmon and 4,006 hatcheryproduced adults and 524 hatchery-produced jacks. We estimate 56 fall Chinook were harvested by anglers, yielding a total escapement of 10,309 fish. Escapement of 3,592 naturally-produced adult fall Chinook was 5.8% of the 62,000 fish TRRP goal. Both coho run-size and escapement in the Trinity above Willow Creek were estimated at 4,619 (95% CI 4,169 – 5,094), because no coho were reported as harvested. Coho escapement was comprised of an estimated 748 naturally-produced adult and 65 naturally-produced jack coho and 2,936 hatchery-produced adult and 870 hatcheryproduced jacks. Escapement of 748 naturally-produced coho adults was 53.4% of the TRRP goal of 1,400 fish. An estimated run-size of 11,167 (95% CI 9,962 – 12,445) adult fall steelhead returned to the Trinity River basin upstream of WCW. Anglers harvested an estimated 436 adult fall steelhead above WCW, leaving 10,732 (2,454 naturally-produced and 8,278 hatchery-produced) fish as potential spawners. Escapement of 2,454 naturallyproduced adult steelhead was 6.1% of the 40,000 fish TRRP goal.

California Department of Fish and Wildlife. (2016). *Distribution and Relative Abundance of Juvenile Coho Salmon in the Redwood Creek Basin, Humboldt County, California*. Retrieved from https://cuca.humboldt.edu/sites/default/files/cuca/reports/redwoodcreek2016P1210320.pdf

Coho Salmon (Oncorhynchus kisutch) in the Redwood Creek basin are listed threatened under the Federal Endangered Species Act (ESA), and the California Endangered Species Act (CESA). Both the ESA and CESA require that recovery plans be developed for all listed species. To comply with the ESA, recovery plans must contain objective, measurable delisting criteria, and a description of site-specific actions necessary to return the species to a self-sustaining, viable condition that would justify delisting. The National Marine Fisheries Service (NMFS) defines a viable salmonid population (VSP) as "An independent population that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, or changes in genetic diversity over a 100-year time frame (McElhany 2000)." To predict the long-term persistence of salmonid populations, stock assessment scientists require scientifically defensible data pertaining to four key population parameters (VSP parameters): abundance, productivity (growth rate), diversity (genetic and phenotypic), and spatial structure (geographic distribution). These parameters must be monitored to evaluate progress towards specific recovery goals. In the Redwood Creek basin, monitoring requirements for three of the four VSP parameters (abundance, productivity and diversity) are largely addressed by existing projects. The objective of this project is evaluate the fourth parameter (spatial distribution) through occupancy modeling based on snorkel surveys conducted underwater census of a spatially balanced random selection of reaches during the summers of 2013 and 2014.

California Department of Fish and Wildlife. (2017). *Annual Report Trinity River Basin Salmon and Steelhead Monitoring Project: Chinook and Coho Salmon and Fall-Run Steelhead Run-Size Estimates Using Mark-Recapture Methods 2016-17 Season*. Retrieved from https://www.trrp.net/library/document/?id=2397

California Department of Fish and Wildlife's Trinity River Project conducted tagging and recapture operations from July 2016 through March 2017 to produce run-size, angler harvest, and spawner escapement estimates of spring- and fall-run Chinook Salmon (Oncorhynchus tshawytscha), Coho Salmon (O. kisutch), and fall-run steelhead (O. mykiss) in the Trinity River basin. Monitoring results informs the Trinity River Restoration Program's (TRRP) adaptive management decision making process and help evaluate progress toward achieving fundamental objectives outlined in the Integrated Assessment Plan (TRRP 2009). Additionally, run-size estimates are used in annual fishery management decisions, feeding into the Pacific Fishery Management Council's Klamath River basin fishery regulation and quota determination process. Using a Petersen mark-recapture methodology, we estimated 3,904 (95% CI 3,013 – 5,158) spring-run Chinook Salmon migrated into Trinity River basin upstream of Junction City weir. The run was comprised of an estimated 1,337 natural-origin adults, 178 natural-origin jacks, 2,022 hatchery-produced adults and 367 hatchery-produced jacks. Using tags returned by anglers we estimate 216 spring Chinook were harvested, yielding an escapement of 3,688 fish. Escapement of 1,258 natural-origin adult spring Chinook is 21.0% of the TRRP goal of 6,000. An estimated 6,196 (95% CI 5,007 – 7,823) fall-run Chinook Salmon migrated upstream of Willow Creek weir (WCW). The run was comprised of an estimated 2,987 naturalorigin adults, 1,022 natural-origin jacks, 1,548 hatchery-origin adults and 639 hatcheryorigin jacks. We estimated that 40 fall Chinook were harvested by anglers, yielding a total escapement of 6,156 fish. Escapement of 3,592 natural-origin adult fall Chinook is 5.8% of the 62,000 fish TRRP goal. Coho Salmon run-size, estimated by linear regression of returns to the Trinity River Hatchery, was 1,325 (95% CI 1,183 – 1,484). Because no Coho were reported as harvested, estimated escapement was also 1,325. Using a Peterson mark-recapture methodology we estimated 4,540 (95% CI 3,903 – 5,229) adult fall-run steelhead returned to the Trinity River basin upstream of WCW. Anglers harvested an estimated 96 adult fall-run steelhead upstream of the weir, leaving 4,444 (1,972 natural-origin and 2,568 hatchery-origin) fish as potential spawners. Escapement of 1,944 natural-origin adult steelhead is 4.9% of the 40,000 fish TRRP goal.

California Department of Fish and Wildlife. (2018). *Annual Report Trinity River Basin Salmon and Steelhead Monitoring Project: Chinook and Coho Salmon and Fall-Run Steelhead Run-Size Estimates Using Mark-Recapture Methods 2017-18 Season*. Retrieved from https://www.trrp.net/library/document/?id=2409

California Department of Fish and Wildlife's Trinity River Project conducted tagging and recapture operations from July 2017 through March 2018 to produce run-size, angler harvest, and spawner escapement estimates of spring- and fall-run Chinook Salmon (Oncorhynchus tshawytscha), Coho Salmon (O. kisutch), and fall-run steelhead (O. mykiss) in the Trinity River basin. Monitoring results inform the Trinity River Restoration Program's (TRRP) adaptive management decision making process and help evaluate progress toward achieving fundamental objectives outlined in the Integrated Assessment Plan (TRRP 2009). Additionally, run-size estimates are used in annual fishery management decisions, feeding into the Pacific Fishery Management Council's Klamath River basin fishery regulation and harvest allocation process. Using a Petersen mark-recapture methodology, we estimated 4,425

(95% CI 3,387 – 5,959) spring-run Chinook Salmon migrated into Trinity River basin upstream of Junction City weir. The run was comprised of an estimated 1,454 natural-origin adults, 280 natural-origin jacks, 2,139 hatchery-origin adults and 447 hatchery-origin jacks. Using tags returned by anglers we estimate 104 spring Chinook were harvested, yielding an escapement of 4,320 fish. Escapement of 1,454 natural-origin adult spring Chinook is 24.2% of the TRRP goal of 6,000. An estimated 15,450 fall-run Chinook Salmon migrated upstream of Willow Creek weir (WCW) in 2017. The stratified run-size of 5,837 jacks (95% CI 5,212 – 6,502) and 9,613 adult fall Chinook Salmon adults (95% CI 8,701 – 10,573) was comprised of an estimated 4,961 natural-origin adults, 3,096 natural-origin jacks, 4,652 hatchery-origin adults and 2,741 hatchery-origin jacks. There was no harvest reported (there was no legal harvest of fall Chinook Salmon permitted in 2017) so the total escapement is the same as the estimated run-size. Escapement of 4,475 natural-origin adult fall Chinook Salmon is 8.0% of the 62,000 fish TRRP goal. Both Coho Salmon run-size and escapement in the Trinity above WCW were estimated at 655 (95% CI 475 - 921), because no Coho Salmon were reported as harvested. Coho Salmon escapement was comprised of an estimated 57 natural-origin adult and 9 natural-origin jacks and 354 hatchery-origin adult and 236 hatchery-origin jacks. Escapement of 57 natural-origin Coho adults was 4.1% of the TRRP goal of 1,400 fish. Using a Peterson mark-recapture methodology we estimated 6,846 (95% CI 5,873 – 7,897) adult fall steelhead returned to the Trinity River basin upstream of WCW. Anglers harvested an estimated 253 adult fall steelhead upstream of the weir, leaving 6,593 (2,348 natural-origin and 4,245 hatchery-origin) fish as potential spawners. Escapement of 2,348 natural-origin adult steelhead is 5.9% of the 40,000 fish TRRP goal.

California Department of Fish and Wildlife. (2019). *Annual Report Trinity River Basin Salmon and Steelhead Monitoring Project: Chinook and Coho Salmon and Fall-Run Steelhead Run-Size Estimates Using Mark-Recapture Methods 2018-19 Season*. Retrieved from https://www.trrp.net/library/document/?id=2450

California Department of Fish and Wildlife's Trinity River Project conducted tagging and recapture operations from June 2018 through March 2019 to produce run-size, angler harvest, and spawner escapement estimates of spring- and fall-run Chinook Salmon (Oncorhynchus tshawytscha), Coho Salmon (O. kisutch), and fall-run steelhead (O. mykiss) in the Trinity River basin. Monitoring results inform the Trinity River Restoration Program's (TRRP) adaptive management decision making process and help evaluate progress toward achieving fundamental objectives outlined in the Integrated Assessment Plan (TRRP 2009). Additionally, run-size estimates are used in annual fishery management decisions, feeding into the Pacific Fishery Management Council's Klamath River basin fishery regulation and harvest allocation process. Using a Petersen mark-recapture methodology, we estimated 8,032 (95% CI 7,250 – 8,858) spring-run Chinook Salmon migrated into Trinity River basin upstream of Junction City weir. The run was comprised of an estimated 927 jacks [346 natural origin (NOR) and 581 hatchery origin (HOR)] and 7,105 adults (2,032 NOR and 5,073 HOR). Using tags returned by anglers we estimate zero jack and 265 adult spring Chinook were harvested, yielding a total escapement of 7,767 fish, including 2,908 spring Chinook that entered Trinity River Hatchery and 4,859 estimated natural area spawners. Escapement of 1,938 NOR adult spring Chinook Salmon is 32.3% of the TRRP goal of 6,000. An estimated 26,848 (95% CI 24,413 – 29,634) fall-run Chinook Salmon migrated upstream of Willow Creek weir (WCW) in 2018. The run consisted of an estimated 22,402 (8,650 NOR and 13,752 HOR) adult and 4,446 (4,087 NOR and 359 HOR) jack fall Chinook Salmon. Using tags returned by anglers we estimate 961 fall Chinook Salmon were harvested, yielding an escapement of 25,887. Escapement of 8,357 NOR adult fall Chinook Salmon is 13.5% of the 62,000 fish TRRP goal. Both Coho Salmon run-size and escapement in the Trinity River upstream of WCW were estimated at 1,486 (95% CI 1,084 – 2,100), because no Coho Salmon were reported as harvested. Coho Salmon escapement was comprised of an estimated 42 NOR adults, 18 NOR jacks, 1,017 HOR adults, and 409 HOR jacks. Escapement of 42 NOR Coho Salmon adults was 3.0% of the TRRP goal of 1,400 fish. Using a Petersen mark-recapture methodology we estimated 5,885 (95% CI 5,007 – 6,835) adult fall steelhead returned to the Trinity River basin upstream of WCW. Anglers harvested an estimated 157 adult fall steelhead upstream of the weir, leaving 5,728 (2,326 NOR and 3,402 hatchery-origin) fish as potential spawners. Escapement of 2,326 NOR adult steelhead is 5.8% of the 40,000 fish TRRP goal.

Carah, J. K., Blencowe, C. C., Wright, D. W., & Bolton, L. A. (2014). Low-Cost Restoration Techniques for Rapidly Increasing Wood Cover in Coastal Coho Salmon Streams. *North American Journal of Fisheries Management, 34*(5), https://doi.org/10.1080/02755947.2014.943861

Like many rivers and streams in forests of the Pacific Northwest, California north coast rivers and streams have been depleted of downed wood through timber harvest and direct wood removal. Due to the important role of wood in creating and maintaining salmonid habitat, wood augmentation has become a common element of stream restoration. Restoration efforts in North America often focus on building anchored, engineered wood structures at the site scale; however, these projects can fail to meet restoration goals at the watershed scale, do not closely mimic natural wood loading processes or dynamics, and can be expensive to implement. For critically imperiled populations of Coho Salmon Oncorhynchus kisutch in California, there is a strong impetus to achieve as much habitat restoration as possible in priority watersheds in the shortest time and with limited resources, so cost-efficient techniques are necessary. In this multi-site project, we investigated unanchored techniques for wood loading to evaluate cost and contribution to salmonid habitat in Mendocino County, California. Over a period of 6 years, 72.4 km of stream were treated with 1,973 pieces of strategically placed wood. We found that unanchored wood loading techniques were much less costly than commonly used anchored techniques, reliably improved habitat, and retained wood at high rates (mean = 92%) in small-to moderate-sized streams, at least over the short term (<6 years). The average cost of design and construction for the unanchored projects was US$259 per log, equivalent to 22% of the cost associated with the anchored wood augmentation methods examined here. Our results suggest that this unanchored wood loading approach has the potential to increase the pace and scale at which wood augmentation projects are implemented in the Pacific Northwest and beyond.

Chiaramonte, L. V., Ray, R. A., Corum, R. A., Soto, T., Hallett, S. L., & Bartholomew, J. L. (2016). Klamath River Thermal Refuge Provides Juvenile Salmon Reduced Exposure to the Parasite Ceratonova Shasta. *Transactions of the American Fisheries Society, 145*(4), https://doi.org/10.1080/00028487.2016.1159612

Salmon in the Klamath River of northern California contend with water temperatures that reach stressful and sometimes lethal levels during summer, forcing them to seek thermal refuge at coolwater tributary junctions. During migration, these fish also encounter a range of pathogens that affect their survival. A significant myxozoan parasite,Ceratonova shasta, causes enteronecrosis in salmon, and this disease increases in severity as temperature and parasite dose increase. In complementary laboratory and field studies, we examined how the use of a thermal refuge (an area at least 2°C colder than the main stem) affects progression of enteronecrosis in juvenile Chinook Salmon Oncorhynchus tshawytscha and Coho SalmonO. kisutch. We compared fish use, water temperature, and C. shasta concentration in a refuge at the Beaver Creek–Klamath River confluence during the summer in 2008 and 2010. Salmonid numbers ranged from 190 to 2,125, and temperatures were 2–8°C cooler than in the main stem. In June and July of 2008, parasite levels in the refuge were lower than in the main stem, where they exceeded 100 spores/L. In 2010, main-stem parasite levels did not exceed 10 spores/L, and levels in the refuge were lower in June. In the laboratory, we compared the effect of fluctuating and constant temperature treatments on mortality rates of Chinook Salmon and Coho Salmon exposed to C. shasta. Under most experimental conditions, fluctuating temperature, within the range experienced by fish using thermal refuges (15.5–21°C), had no significant effect on disease progression compared with a constant midrange temperature (18.5°C) with equivalent degree-day accumulation. We propose that in the Klamath River thermal refuges can function as disease refuges from enteronecrosis by (1) providing areas of decreased C. shastaexposure and/or (2) alleviating disease effects as a result of relatively lower water temperatures. The trend of increasing water temperatures suggests that juvenile salmon will rely even more on these critical habitats in the future.

Faukner, J., Sillowaway, S., Sparkman, M., & Drobny, P. (2017). A Previously Undocumented Life History Behavior in Juvenile Coho Salmon (Oncorhynchus Kisutch) from the Klamath River, California. *California Fish and Game, 103*(2) Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=149057&inline

During the fall of 2012 juvenile coho salmon (Oncorhynchus kisutch) were sampled by Yurok Tribe employees in two tributaries of the Lower Klamath River: McGarvey Creek (41°29’03.09”N, 124°00’48.09”W) and Hunter Creek (41°35’44.28”N, 124°02’12.02”W). Fish were captured by either seining or electrofishing and if the FL was greater than 65 mm then a full duplex Passive Integrated Transponder (PIT) tag was inserted into the body cavity. A hand-held device was used to scan each PIT tag before it was implanted. The code was manually recorded and later proofed against the electronic download from the scanner. All fish were released in the immediate vicinity of each sampling site. A total of 32 coho was implanted with PIT tags in McGarvey Creek on 5 September 2012 and 70 in Hunter Creek on 15 October 2012.

Gallagher, S. P., Ferreira, J., Lang, E., Holloway, W., & Wright, D. W. (2014). Investigation of the Relationship between Physical Habitat and Salmonid Abundance in Two Coastal Northern California Streams. *California Fish and Game, 100*(4) Retrieved from https://www.wildlife.ca.gov/Publications/Journal/Contents#2014

Understanding the relationship between fish abundance and stream habitat variables is critical to designing and implementing effective freshwater habitat restoration projects for coho salmon (Oncorhynchus kisutch) and other anadromous salmonids. In this study, we investigated the relationship between summer coho salmon and steelhead trout (O. mykiss) parr abundance and physical stream habitat variables in Caspar and Pudding creeks in Mendocino County, California. Relationships between summer habitat and juvenile abundance were investigated using a stratified random experimental design. Our hypothesis was that one or more of the habitat unit types and variables examined would be associated with salmonid abundance. Habitat differences were examined between the two streams, and we tested our hypotheses regarding habitat variables and salmonid abundance using a variety of statistical tools that included twoway ANOVA, factor analysis, and negative binomial regression modeling. The results indicated that juvenile coho salmon abundance was positively (proportionally) associated with slow water, water volume, and dry large-wood abundance, and negatively associated with fast-water habitat variables. Young-of-the-year steelhead trout were positively associated with water volume and dry large-wood and negatively (or inversely) associated with overhead vegetation and fast water habitats. Older age steelhead abundance was positively associated with slow water, water volume; cover habitat formed by wet and dry wood, and undercut banks. We discuss our findings relative to the use of large wood in anadromous salmonid habitat recovery programs in California coastal watersheds.

Goodman, D. H., Som, N. A., Alvarez, J., & Martin, A. (2015). A Mapping Technique to Evaluate Age-0 Salmon Habitat Response from Restoration. *Restoration Ecology, 23*(2), https://doi.org/10.1111/rec.12148

To combat decades of anthropogenic degradation, restoration programs seek to improve ecological conditions through habitat enhancement. Rapid assessments of condition are needed to support adaptive management programs and improve the understanding of restoration effects at a range of spatial and temporal scales. Previous attempts to evaluate restoration practices on large river systems have been hampered by assessment tools that are irreproducible or metrics without clear connections to population responses. We modified a demonstration flow assessment approach to assess the realized changes in habitat quantity and quality attributable to restoration effects. We evaluated the technique's ability to predict anadromous salmonid habitat and survey reproducibility on the Trinity River in northern California. Fish preference clearly aligned with a priori designations of habitat quality: the odds of observing rearing Chinook or coho salmon within high-quality habitats ranged between 10 and 16 times greater than low qualities, and in all cases the highest counts were associated with highest quality habitat. In addition, the technique proved to be reproducible with "substantial" to "almost perfect" agreement of results from independent crews, a considerable improvement over a previous demonstration flow assessment. These results support the use of the technique for assessing changes in habitat from restoration efforts and for informing adaptive management decisions.

Larsen, L. G., & Cleo, W. E. (2018). Groundwater Is Key to Salmonid Persistence and Recruitment in Intermittent Mediterranean-Climate Streams. *Water Resources Research, 54*(11), https://doi.org/10.1029/2018WR023324

Juvenile coho salmon thrive in intermittent streams of the Pacific Northwest yet are in danger of increased mortality from drought and rising temperatures. With warmer temperatures and more frequent climate extremes projected, the need to understand how intermittent stream hydrology and biogeochemistry impact juvenile salmonid habitat and behavior is imperative. Previous investigations indicated that dissolved oxygen limits the persistence of coho salmon in intermittent streams, leading to the hypothesis that groundwater inflow would ultimately control patterns of salmon recruitment and persistence. Here we tested that hypothesis in paired tributaries of Salmon Creek, Sonoma County, CA during California's extreme drought of 2011–2017. We used the fluorescent fingerprint of dissolved organic carbon, together with a parallel factor analysis, to estimate groundwater influence in individual stream pools, corroborating those estimates with stable isotope and radon analyses. Repeat snorkel surveys provided fish counts in those pools at the beginning and end of the period of surface-water disconnection. Results suggested that coho salmon fry preferentially selected pools with a groundwater inflow signal and persisted in pools maintaining that signal through the dry season. This groundwater inflow signal was distinct from hyporheic influence, which exhibited little correlation with fish distribution. Groundwater within pools was young, and spot measurements suggested that it was relatively oxygenated. Proportional groundwater contributions to pools increased as drought deepened. Results suggest that maintaining relatively high groundwater levels in coastal aquifers may be imperative to the persistence of vulnerable salmonid populations in a changing climate.

Martin, D. J., Shelly, A. A., Danehy, R. J., Lang, E. D., & Hvozda, J. (2019). Coho Salmon Growth in Relation to Natural Turbidity Regimes in a Coastal Stream of Northern California. *Transactions of the American Fisheries Society, 148*(4), https://doi.org/10.1002/tafs.10174

We examined how the growth rate and food consumption of juvenile Coho Salmon Oncorhynchus kisutch varied in relation to natural turbidity regimes in a coastal stream of northern California. Instream sensors were used to continuously monitor the location, turbidity, and temperature exposure of juvenile Coho Salmon fitted with passive integrated transponder tags. We observed that overwinter growth rate and food consumption varied in relation to the duration and magnitude of turbidity and temperature exposure. Growth rate and food consumption were positively associated with low-to-moderate turbidity exposures that ranged from >3 NTU to >20 NTU and negatively associated with elevated turbidity exposures that ranged from > 55 NTU to >150 NTU. This shift to negative associations for fish that experienced long exposures at turbidity levels > 55 NTU suggests a threshold for assessing potential risk of impairment. However, our analyses show that the influence of turbidity on consumption and growth rate is complicated by a fish's temperature exposure history, which varies among fish depending on individual movement patterns and duration of residency within different stream reaches. Consequently, Coho Salmon growth reflects the net effect of turbidity, temperature, and other environmental factors that are associated with specific life history patterns. These findings advance our understanding of how natural turbidity regimes may influence Coho Salmon growth and offer insight for assessing biological impairment in streams. Moreover, our findings indicate how knowledge of environmental context is crucial for understanding the applicability of laboratory-derived turbidity thresholds for fish populations in streams. Such findings corroborate other field-based studies and add to evidence that laboratory-derived turbidity thresholds alone may be inadequate predictors of biological impairment to stream fish populations.

National Marine Fisheries Service. (2014). *Final Recovery Plan for the Southern Oregon/ Northern California Coast Evolutionarily Significant Unit of Coho Salmon (Oncorhynchus Kisutch)*. Retrieved from https://archive.fisheries.noaa.gov/wcr/publications/recovery_planning/salmon_steelhead/domains/southern_oregon_northern_california/sonccfinal_ch1to6_mainchapters__1_.pdf

This plan provides a comprehensive roadmap for the recovery of SONCC coho salmon to be followed by conservation partners. Recovery will require implementation of actions that conserve and restore the key biological, ecological, and landscape processes that support the ecosystems upon which coho salmon populations depend. The Plan identifies specific recovery actions that protect or restore coho salmon or their habitat and outlines a monitoring and evaluation program to guide its adaptive management elements so that the most effective means of achieving recovery will be utilized. Biological recovery goals, objectives and measurable criteria, and web-based management tools, will provide for a mechanism to track recovery progress. Salmon recovery is best viewed as an opportunity to diversify and strengthen the economy while enhancing the quality of life for present and future generations.

National Marine Fisheries Service. (2016). *2016 5-Year Review : Summary & Evaluation of Southern Oregon/Northern California Coast Coho Salmon*. Retrieved from https://repository.library.noaa.gov/view/noaa/17026

Many West Coast salmon and steelhead (Oncorhynchus spp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led the National Marine Fisheries Service to list 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. Such reviews for the Southern Oregon/Northern California Coast (SONCC) coho salmon Evolutionarily Significant Unit (ESU) occurred in 2005 (Good et al. 2005) and 2011 (NMFS 2011). This document describes the results of the 2015 review of ESAlisted SONCC coho salmon.

Quinones, R. M., Grantham, T. E., Harvey, B. N., Kiernan, J. D., Klasson, M., Wintzer, A. P., & Moyle, P. B. (2015). Dam Removal and Anadromous Salmonid (Oncorhynchus Spp.) Conservation in California. *Reviews in Fish Biology and Fisheries, 25*(1), https://doi.org/10.1007/s11160-014-9359-5

Dam removal is often proposed for restoration of anadromous salmonid populations, which are in serious decline in California. However, the benefits of dam removal vary due to differences in affected populations and potential for environmental impacts. Here, we develop an assessment method to examine the relationship between dam removal and salmonid conservation, focusing on dams that act as complete migration barriers. Specifically, we (1) review the effects of dams on anadromous salmonids, (2) describe factors specific to dam removal in California, (3) propose a method to evaluate dam removal effects on salmonids, (4) apply this method to evaluate 24 dams, and (5) discuss potential effects of removing four dams on the Klamath River. Our flexible rating system can rapidly assess the likely effects of dam removal, as a first step in the prioritization of multiple dam removals. We rated eight dams proposed for removal and compared them with another 16 dams, which are not candidates for removal. Twelve of the 24 dams evaluated had scores that indicated at least a moderate benefit to salmonids following removal. In particular, scores indicated that removal of the four dams on the Klamath River is warranted for salmonid conservation. Ultimately, all dams will be abandoned, removed, or rebuilt even if the timespan is hundreds of years. Thus, periodic evaluation of the environmental benefits of dam removal is needed using criteria such as those presented in this paper.

Rebenack, J. J., Ricker, S., Anderson, C., Wallace, M., & Ward, D. M. (2015). Early Emigration of Juvenile Coho Salmon: Implications for Population Monitoring. *Transactions of the American Fisheries Society, 144*(1), https://doi.org/10.1080/00028487.2014.982258

Salmon monitoring programs often measure juvenile production by operating migrant traps downstream of spawning and rearing areas during smolt migration. However, this approach does not account for individuals that move downstream of trapping locations prior to smolt sampling. We used a mark–recapture study with passive integrated transponder tagging to estimate the proportion of Coho Salmon Oncorhynchus kisutch juveniles, tagged in the fall in a Northern California stream, that migrated to rearing habitat downstream of a seasonally operated trap before spring smolt sampling. Emigrants were detected by using the migrant trap, located near the upstream limit of tidal influence, and continuously operated antennas located in tidal wetlands downstream of the trap. For all three cohorts sampled (2010, 2011, 2012), we identified two distinct emigration periods (not including fry emigrants that emigrated in spring at a size too small to tag): a fall–winter period, when early emigrant parr moved into a restored tidal wetland (early emigrants); and a spring period, when smolts emigrated (smolt emigrants). There was little movement in the intervening period. Emigration timing varied depending on the location in the basin where fish were tagged; locations in the lower main stem generally produced more early emigrants, while locations in the upper basin produced more smolt emigrants. Across locations, early emigrants accounted for 2–25% of the fall-marked juveniles from 2010, 8–29% from 2011, and 7–13% in 2012. Smolt emigrants accounted for 15–49% of the fall-marked juveniles from 2010, 13–14% from 2011, and 3–35% from 2012. The consistent occurrence of early emigration in this and other recent studies brings into question estimates of smolt abundance and demographic rates (e.g., overwinter and marine survival) that do not account for this life history variant.

Stinson, M. E. T., Atkinson, S. D., & Bartholomew, J. L. (2018). Widespread Distribution of Ceratonova Shasta (Cnidaria: Myxosporea) Genotypes Indicates Evolutionary Adaptation to Its Salmonid Fish Hosts. *Journal of Parasitology, 104*(6), https://doi.org/10.1645/18-79

The distribution of the freshwater myxozoan parasite Ceratonova shasta in the Pacific Northwest of North America is limited to overlap in the ranges of its 2 hosts: the polychaete Manyunkia sp., and Pacific salmonids. Studies in the Klamath River (Oregon/California) and Deschutes River (Oregon), showed that the parasite population is comprised of multiple sympatric genotypes, some of which correlate with particular salmonid host species and with differences in clinical disease in those hosts. The 3 primary genotypes O, I, and II are defined by the number of a specific tri-nucleotide repeat in the internal transcribed spacer-1 region. To understand the spatial extent of host-parasite genotype patterns, we sequenced the parasite from 448 salmonid fishes from river basins in California, Oregon, Washington, Idaho, and British Columbia, Canada. We sampled intestinal tissues from 6 species of salmon and trout, both those that exist naturally with the parasite (sympatric) and those that do not naturally co-occur with the parasite and were exposed artificially in cages (allopatric). In most river basins we detected the same primary C. shasta genotypes that were described from the Klamath and Deschutes rivers, and we did not detect any novel primary genotypes. Host- parasite genotype patterns were consistent with previous data: genotype O was found in sympatric trout only; genotype I predominantly in Chinook salmon, and genotype II in all 6 fish species but dominant in coho salmon. Our findings of widespread, consistent host-parasite genotype patterns support the hypothesis that C. shasta has a long evolutionary history with salmonid fishes in the Pacific Northwest, and impels additional studies to determine if these parasite genotypes should be considered different species.

U.S. Department of Agriculture. (2018). *Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California*. Retrieved from https://www.fs.fed.us/pnw/pubs/pnw_rp613.pdf

This case study was developed as part of a larger, interdisciplinary research project to assess the social, hydrological, and ecological effects of beaver-related watershed restoration approaches in rangeland streams of the Western United States. It is one of five case studies being undertaken to investigate the social context of beaver-related restoration in western rangelands. The Scott River basin in northern California is the first place in the state where watershed restoration using beaver dam analogues (BDAs, instream post and vegetation-weave structures that mimic natural beaver dams) has been tried. The project takes place on private lands and in streams where federal Endangered Species Act-listed southern Oregon/northern California coast coho salmon (Oncorhynchus kisutch) spawn and rear in fresh water before migrating out to the ocean. It started in 2014 as an initiative of a local community group, the Scott River Watershed Council, with technical support from a National Oceanic and Atmospheric Administration scientist. Project goals include improving instream habitat for coho salmon to promote population recovery, improving surface water flows, raising groundwater levels, reducing stream channel incision, and demonstrating the value of BDAs as a restoration tool in California. To date, 10 BDA structures have been built at five sites on streams running through private property in the Scott River basin, and more are planned. Beavers have been active, or have taken over maintenance of BDAs, at all sites. Because this is the first project in California to use this restoration approach, and because the BDAs are being built in critical fish habitat, the project has been undertaken on an experimental basis. It has entailed a large learning curve on the part of the Scott River Watershed Council and federal and state regulatory agencies, but over time the regulatory process for permitting BDAs has gotten easier, and stakeholders are working together to collectively find solutions to ongoing BDA-related challenges. Most of the private landowners involved are ranchers who also grow hay, and who have largely positive views of beavers and beaver dams, so long as they do not interfere with irrigation infrastructure. Monitoring data and interviews with stakeholders indicate that the BDAs are starting to achieve their goals, and are benefitting both landowners and fish, although impacts are localized because the project remains small in scale owing to its experimental status. The Scott Valley case offers important lessons learned for undertaking beaver-related restoration in a private lands context. Keywords: Scott River, beaver dam analogue, BDA, private land, ranchers,

Wallace, M., Ricker, S., Garwood, J., Frimodig, A., & Allen, S. (2015). Importance of the Stream-Estuary Ecotone to Juvenile Coho Salmon (Oncorhynchus Kisutch) in Humboldt Bay, California. *California Fish and Game, 101*(4) Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=113245&inline

Recent studies have shown the broad role estuaries plays in juvenile coho salmon (Oncorhynchus kisutch) life history; however, most of these studies were limited to the Pacific Northwest and did not include information from the southern end of its range in California. We sampled the stream-estuary ecotone (SEE) of numerous Humboldt Bay tributaries from 2003 to 2011 to document use by juvenile coho salmon. We sampled fish using seine nets and baited minnow traps and found that young-ofthe-year (YOY) and yearling plus (1+) coho salmon reared primarily in freshwater or tidal freshwater habitat in the SEE. We detected three basic life history strategies employed by juvenile coho salmon regarding their use of the SEE. The first group were YOY fish that arrived in the spring and resided mostly in mainstem channel habitat in the summer and early fall; the second group of nearly 1+ fish arrived after the first large stream flow event in the fall and resided extensively in smaller tributary and off-channel habitat during the winter and spring; and finally a third group of stream-reared 1+ coho salmon emigrated through the SEE quickly during the following spring. Juvenile coho salmon resided in the SEE an average of one to two months but some individuals reared there for over a year. We found that about 40% of the coho salmon smolt production from Freshwater Creek, Humboldt Bay's largest tributary, originated from the SEE. Juvenile coho salmon rearing in the SEE were larger than their cohorts rearing in stream habitat upstream of the SEE. Our results demonstrate that juvenile coho salmon utilize portions of the Humboldt Bay SEE in ways similar to those reported in Pacific Northwest estuaries, and suggest that the SEE of Humboldt Bay provides quality rearing habitat—especially over winter rearing habitat—for those juveniles. By incorporating this knowledge into habitat restoration plans we can design effective habitat restoration projects to improve habitat conditions and non-natal rearing for juvenile coho salmon.

Weybright, A. D., & Giannico, G. R. (2018). Juvenile Coho Salmon Movement, Growth and Survival in a Coastal Basin of Southern Oregon. *Ecology of Freshwater Fish, 27*(1), https://doi.org/10.1111/eff.12334

Juvenile salmonids display highly variable spatial and temporal patterns of early dispersal that are influenced by density- dependent and density- independent factors. Although juvenile coho salmon (Oncorhynchus kisutch) movement patterns in streams and their relationship with body mass and growth have been examined in previous studies, most observations were limited to one season or one stream section. In this study, we monitored the movement of juvenile coho salmon throughout their period of residence in a coastal basin to identify prevalent dispersal strategies and their relationships with body mass, growth rates and survival. Our results revealed seasonally and spatially variable movement patterns. Juvenile coho salmon that dispersed to tidally affected reaches soon after emergence remained more mobile and expressed lower site fidelity than those individuals that remained in upper riverine reaches. We did not detect significantly different growth rates between sedentary and mobile individuals. Although a greater proportion of sedentary than mobile fish survived winter to emigrate from the creek in the spring, reach of residence at the onset of winter influenced these survival estimates. Hence, apparent summer- to- smolt survival for mobile individuals was greater than for sedentary fish in tidally influenced reaches, whereas in riverine reaches the sedentary strategy seemed to be favoured. Our research identified complex movement patterns that reflect phenotypic and life history variation, and underscores the importance of maintaining diverse freshwater and estuarine habitats that support juvenile coho salmon before marine migration.

Wright, E. C., & Souder, J. A. (2018). Using Applied Science for Effective Watershed Restoration and Coho Salmon Recovery in Coastal Oregon Streams. *Case Studies in the Environment, 2*(1), https://doi.org/10.1525/cse.2017.000489

Coos Bay, located on the southern Oregon Coast, is the largest estuary between the Columbia River and San Francisco Bay. Palouse and Larson Creeks in the northern section of Coos Bay are the two most productive streams for coho salmon. Such productivity occurs despite the pressure salmon habitats have experienced through a long history of anthropogenic alterations, and continue to face from the region's robust industrial economy, including recreational and commercial fisheries, agricultural production, and forestry. Restoration efforts since the 1980s have helped mitigate environmental impacts, but the turn of the century brought a new era of coordinated research, monitoring, and restoration. Forming a multi-stakeholder partnership with the goal of restoring salmon runs, the local nonprofitnon-profit Coos Watershed Association and its partners worked together to learn about the strategies that coho use to survive in these altered landscapes and apply research findings to restore habitats. Specifically, they examined the most appropriate habitat restoration strategies for various life histories of coho salmon, while working within social and political constraints. As a result, these efforts over the past 35 years have led to a better understanding of salmon populations in Palouse and Larson Creeks and an effective restoration program that continues till today.

Section V: Oregon Coast

Anlauf-Dunn, K. J., Ward, E. J., Strickland, M., & Jones, K. (2014). Habitat Connectivity, Complexity, and Quality: Predicting Adult Coho Salmon Occupancy and Abundance. *Canadian Journal of Fisheries and Aquatic Sciences, 71*(12), https://doi.org/10.1139/cjfas-2014-0162

The distribution, quality, and connectivity ofinstream habitat can influence adult salmon occupancy and abundance patterns and alter population dynamics. In this study, we evaluated the relationships between adult coho salmon (Oncorhynchus kisutch) occupancy and abundance with instream habitat conditions, including measures ofspawning gravel, habitat complexity, and juvenile rearing habitat. We used corresponding adult salmon spawning and instream habitat data collected within coastal Oregon watersheds as part of a long-term monitoring program. We modeled two processes as a function of habitat characteristics: the number of coho salmon when they were present and the occupancy probabilities of coho salmon. The results from both submodels were then combined into an estimate of total abundance at each site. Adult coho salmon occupancy was best predicted by the capacity ofthe habitat to support parr during the winter, complex pools, percent bedrock, and site distance to the ocean. Although lacking the predictive capacity of the occupancy model, increases in adult coho counts at sites were also influenced by the site distance to the ocean, and there is evidence that both percent gravel and complex pools may also be valuable predictors. By taking advantage of long-term datasets with broad spatial range, using an integrative approach across coho salmon life stages, and utilizing innovative Bayesian modeling techniques, this study is a unique approach to understanding a complicated ecological narrative. Combined, our results indicate the spatial distribution and proximity of spawning and rearing habitats may maximize productivity for coho salmon in coastal Oregon watersheds.

Bair, R. T., Segura, C., & Lorion, C. M. (2019). Quantifying the Restoration Success of Wood Introductions to Increase Coho Salmon Winter Habitat. *Earth Surface Dynamics, 7*(3), https://doi.org/10.5194/esurf-7-841-2019

Large wood (LW) addition is often part of fish habitat restoration projects. However, there is limited information about the spatial-temporal variability in hydraulic changes after LW additions. We investigated reach-scale hydraulic changes triggered after the addition of LW that are relevant to juvenile coho salmon survival. We used Nays2DH, an unsteady two-dimensional flow model, to quantify the patterns and magnitudes of changes of stream velocity and shear stress in three alluvial gravel reaches. The study sites are located in low-gradient reaches draining 5 to 16 km(2) in the Oregon Coast Range. Survivable habitat was characterized in terms of critical swim speed for juvenile coho and bed stability considering the critical shear stress required to mobilize the median bed particle size. Model predictions indicated that survivable habitat during bankfull conditions, measured as the area with velocity below the critical swim speed for juvenile coho, increased by 95 %-113 % after the LW restoration. Bed stability also increased between 86 % and 128 % considering the shear stress required to mobilize the median bed particle size. Model predictions indicated more habitat created in the larger site; however, considering that wood would move more frequently in this site there appears to be a trade-off between the timing and the resilience of restoration benefits. Overall, this study quantifies how the addition of LW potentially changes stream hydraulics to provide a net benefit to juvenile salmonid habitat. Our findings are applicable to stream restoration efforts throughout the Pacific Northwest.

Bateman, D. S., Gresswell, R. E., Warren, D., Hockman-Wert, D. P., Leer, D. W., Light, J. T., & Stednick, J. D. (2018). Fish Response to Contemporary Timber Harvest Practices in a Second-Growth Forest from the Central Coast Range of Oregon. *Forest ecology and management, 411*, https://doi.org/10.1016/j.foreco.2018.01.030

We used a paired-watershed approach to investigate the effects of contemporary logging practices on headwater populations of coastal cutthroat trout (Oncorhynchus clarkii clarkii) and juvenile coho salmon (Oncorhynchus kisutch) in a second-growth Douglas-fir forested catchment in Oregon. Stream habitat and fish population characteristics, including biomass, abundance, growth, size, and movement, were assessed over a 9-year period (4 years pre- and 5 years postlogging). The logged catchment was located on private industrial forestland and had been previously logged in 1966. The reference catchment was covered by an unharvested, fire-regenerated forest approximately 150–160 years old, which was unroaded and managed as a Research Natural Area by the USDA Forest Service. A single clearcut harvest unit of the upper 40% of the treatment catchment was implemented following current forest practice regulations, including the retention of riparian buffer of standing trees adjacent to fish bearing channels. No statistically significant negative effects on coastal cutthroat trout or coho salmon occurred following logging, and in fact, both late-summer density and total biomass of age-1+ coastal cutthroat trout increased in the logged catchment following logging. Increases in age-1+ coastal cutthroat were greatest closest to the harvest area and declined downstream as distance from the logged area increased. In contrast to the previous timber harvest in the catchment when few logging regulations existed, current forest practice regulations and logging techniques appear to have reduced acute negative effects on coastal cutthroat trout.

Beeson, H. W., Flitcroft, R. L., Fonstad, M. A., & Roering, J. J. (2018). Deep-Seated Landslides Drive Variability in Valley Width and Increase Connectivity of Salmon Habitat in the Oregon Coast Range. *Journal of the American Water Resources Association, 54*(6), https://doi.org/10.1111/1752-1688.12693

Declines in populations of Pacific salmon have prompted extensive and costly restoration efforts, yet many populations are still in peril. An improved understanding of landscape-scale controls on salmon habitat should help focus restoration resources on areas with the greatest potential to host productive habitat. We investigate the contribution of deep-seated landslides (DSLs) to Coho Salmon habitat by comparing the quantity and connectivity of potential seasonal habitat observed in five streams with extensive DSLs to five lacking significant landsliding. Further, we measure valley width in these streams and relate it to connectivity. We show that median fractions of stream length identified as spawning, summer-rearing, winter-refuge habitat, and as having high connectivity among seasonal habitat types are greater in streams with DSLs and that distances between units of each seasonal habitat type are significantly lower in DSL terrain. The median R-2 value for the relationship between drainage area and valley width is lower in landslide terrain and we observed that high connectivity among seasonal habitat types tends to occur where valley width is variable. Our results suggest that DSLs promote connectivity among seasonal habitat types for Coho Salmon and that prioritizing restoration projects in streams in DSL terrain could improve the effectiveness of salmonid recovery programs.

Bladon, K. D., Cook, N. A., Light, J. T., & Segura, C. (2016). A Catchment-Scale Assessment of Stream Temperature Response to Contemporary Forest Harvesting in the Oregon Coast Range. *Forest ecology and management, 379*, https://doi.org/10.1016/j.foreco.2016.08.021

Historical forest harvesting practices, where the riparian canopy was removed, generally increased energy loading to the stream and produced higher stream temperatures. As such, contemporary forest management practices require maintenance of streamside vegetation as riparian management areas, with an important function of providing shade and minimizing solar radiation loading to streams to mitigate stream water temperature changes. The Alsea Watershed Study Revisited in the Oregon Coast Range provided a unique opportunity to investigate and compare the stream temperature responses to contemporary forest harvesting practices (i.e., maintenance of riparian vegetation) with the impacts from historical (1960s) harvesting practices (i.e., no riparian vegetation). Here we present an analysis of 6 years (3 years pre-harvest and 3 years post-harvest) of summer stream temperature data from a reference (Flynn Creek) and a harvested catchment (Needle Branch). There was no evidence that the (a) 7-day moving mean of daily maximum (T7DAYMAX) stream temperature, (b) mean daily stream temperature, or (c) diel stream temperature changed in the study stream reaches following contemporary forest harvesting practices. The only parameter of interest that changed after forest harvesting was the T7DAYMAX when analyses were constrained to the Oregon regulatory period of July 15 to August 15 and all sites in each catchment were grouped together—in this case stream temperature increased 0.6 ± 0.2 °C($p = 0.002$). However, over the entire post-harvest study period, the warmest maximum daily stream temperature observed in Needle Branch was 14.7 °C—in the original Alsea Watershed Study, maximum daily stream temperatures rose to 21.7 °C (1966) and 29.4 °C (1967) in the first two post-harvest years, providing evidence that current harvesting practices have improved protection for stream water temperatures.

Boisjolie, B. A., Flitcroft, R. L., & Santelmann, M. V. (2019). Patterns of Riparian Policy Standards in Riverscapes of the Oregon Coast Range. *Ecology & Society, 24*(1), https://doi.org/10.5751/ES-10676-240122

A riverscape perspective considers the ecological and social landscape of the river and its valley. In this context, we examined the spatial arrangement of protective policies for river networks. Riparian land-management standards are policy efforts that explicitly restrict certain management actions, e.g., timber harvest or land clearing, in stream-adjacent lands in order to protect water quality and aquatic habitat. In western Oregon, USA, management standards for riparian lands vary across federal, state, and private landownerships and land uses, projecting a patchwork of protective efforts across the landscape. The resulting variability in protection can complicate coordinated recovery efforts for threatened and endangered aquatic organisms, including migratory coho salmon (Oncorhynchus kisutch), that rely on stream habitats throughout the river network. Using a geographic information system, we quantified the spatial distribution of riparian management standards at multiple spatial extents: across the entire Oregon Coast Range, within the region's 84 HUC-10 watersheds, and in stream segments with high intrinsic potential to support coho salmon habitat. We found that the proportion of streams falling under protective efforts varied across watersheds in the region. In particular, watersheds containing streams of high intrinsic potential to support coho salmon habitat were associated with gaps in protective standards. By comparing the policy landscape to the biophysical landscape, our approach provides a novel framework for examining the spatial overlay of social and ecological concerns, and has direct relevance to assessments of population-scale restoration and recovery efforts.

Boisjolie, B. A., Santelmann, M. V., Flitcroft, R. L., & Duncan, S. L. (2017). Legal Ecotones: A Comparative Analysis of Riparian Policy Protection in the Oregon Coast Range, USA. *Journal of Environmental Management, 197*, https://doi.org/10.1016/j.jenvman.2017.03.075

Waterways of the USA are protected under the public trust doctrine, placing responsibility on the state to safeguard public resources for the benefit of current and future generations. This responsibility has led to the development of management standards for lands adjacent to streams. In the state of Oregon, policy protection for riparian areas varies by ownership (e.g., federal, state, or private), land use (e.g., forest, agriculture, rural residential, or urban) and stream attributes, creating varying standards for riparian land-management practices along the stream corridor. Here, we compare state and federal riparian landmanagement standards in four major policies that apply to private and public lands in the Oregon Coast Range. We use a standard template to categorize elements of policy protection: (1) the regulatory approach, (2) policy goals, (3) stream attributes, and (4) management standards. All four policies have similar goals for achieving water-quality standards, but differ in their regulatory approach. Plans for agricultural lands rely on outcome-based standards to treat pollution, in contrast with the prescriptive policy approaches for federal, state, and private forest lands, which set specific standards with the intent of preventing pollution. Policies also differ regarding the stream attributes considered when specifying management standards. Across all policies, 25 categories of unique standards are identified. Buffer widths vary from 0 to ~152 m, with no buffer requirements for streams in agricultural areas or small, non-fish-bearing, seasonal streams on private forest land; narrow buffer requirements for small, nonfish-bearing perennial streams on private forest land (3 m); and the widest buffer requirements for fish-bearing streams on federal land (two site-potential tree-heights, up to an estimated 152 m). Results provide insight into how ecosystem concerns are addressed by variable policy approaches in multiownership landscapes, an important consideration to recovery-planning efforts for threatened species.

Campbell, E. Y., Dunham, J. B., Reeves, G. H., & Wondzell, S. M. (2018). Phenology of Hatching, Emergence, and End-of-Season Body Size in Young-of-Year Coho Salmon in Thermally Contrasting Streams Draining the Copper River Delta, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(2), https://doi.org/10.1139/cjfas-2018-0003

Phenology can be linked to individual fitness, particularly in strongly seasonal environments 45 where the timing of events have important consequences for growth, condition, and survival. We studied the phenology of Coho Salmon hatching and emergence in streams with contrasting thermal variability, but in close geographic proximity. Following emergence, we tracked body sizes of cohorts of young-of-year fish until the end of the growing season. Hatch and emergence timing occurred at the same time among streams with marked variability in thermal regimes. We demonstrate that this can be explained in part by the thermal units accumulated during embryo development. At the end of the first growing season there were some differences in body size, however overall fish size among streams were similar despite strong differences in thermal regimes. Collectively these results provide novel insights into the interactions between environmental variability and the early life-history stages of Coho Salmon furthering our understanding of the consequences of phenology on growth and survival for individuals within the critical first summer of life.

Coast Coho Partnership. (2019). *Strategic Action Plan for Coho Salmon Recovery: The Siuslaw River.* Retrieved from https://www.wildsalmoncenter.org/wp-content/uploads/2019/03/Siuslaw-SAP-Coho-Salmon-Recovery.pdf

In 2015, the Siuslaw Coho Partnership (SCP) convened to develop a Strategic Action Plan (SAP) for the recovery of the Siuslaw's wild coho population. Developed in partnership with a broader coast-wide effort known as the "Coast Coho Salmon Business Plan," the SCP's goal in developing the SAP was to guide habitat restoration work in the Siuslaw watershed through a process that merges the best available science with local knowledge of the watershed. In addition, the SCP sought to coordinate work in the watershed and leverage funding to accelerate the implementation and effectiveness of on-the-ground habitat restoration projects. The SCP approached this effort guided by an inclusive vision to integrate science-driven watershed restoration priorities with social and economic goals that could promote healthy local communities and respect the rights and interests of private landowners.

Coos Watershed Association. (2014). *Palouse and Larson Creeks: 35 Years of Watershed Restoration and Research.* Retrieved from http://www.cooswatershed.org/wp-content/uploads/2017/01/Palouse-Larson-Case-Study-Newpdf.pdf

Coho salmon in coastal lowland streams have complex and diverse life histories, including movement patterns that may be governed by their genetic makeup. With the technological advancements of the past ten to fifteen years, it has become possible to pry apart coho life histories in these areas and understand how they contribute to the resiliency of these populations in the face of natural and human-caused disturbances to the system. Survival, growth, and recruitment differ among coho salmon life histories. These differences may be determined by availability and access to desired habitats. It is necessary to understand how coho—especially juveniles—are using lowland systems in order to design and implement effective restoration programs that can support the quality of habitat these fish require. Restoration efforts in Palouse and Larson Creeks thus far have already yielded substantial cumulative benefits for fish and people alike. There are additional opportunities to improve these streams, but care needs to be taken to attend to habitat needs as well as the needs of landowners. Continuing an exchange-based relationship and maintaining landowner support is critical to future research, monitoring, and restoration efforts.

Cramer, S. P., & Caldwell, L. (2020). Bias and Consequences in Attempts to Estimate Historical Salmon Abundance. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(1), https://doi.org/10.1139/cjfas-2018-0467

Status of salmon populations thought to be at risk is frequently evaluated by comparing estimated abundances in recent decades with approximations of peak abundance in the era when fisheries began. However, spawner escapements of Pacific salmon were generally not surveyed until 1950 or later, so most estimates of salmon abundance before 1950 have been derived from harvest data alone. We investigated historical data on Oregon Coast coho (Oncorhynchus kisutch) to test the reliability ofsuch estimates. In the "Recovery Plan for Oregon Coast Coho" (prepared by National Marine Fisheries Service (NMFS) in 2016), coho abundance was estimated back to 1892 by assuming that in-river landings before 1950 represented a constant 40% of the population. The first mark–recapture studies enabling estimation of harvest rates were completed in the early 1950s, shortly after regulatory action in 1947 sharply curtailed harvesting ofcoho. We used annual data on fishing licenses sold and length of fishing seasons before 1950 as indices of harvesting effort to reconstruct harvest rates before 1947 and determined in-river landings were near 80%, twice the level postulated by the Recovery Plan. Thus, spawner escapements before 1947 were roughly 20% rather than the 60% of adult recruitment assumed in the Recovery Plan. Actual spawner counts during the first decade of surveys (1945–1955) indicated that coho abundance was much lower and the population trend was opposite ofthat estimated in the Recovery Plan. However, when spawner abundance was estimated by assuming in-river harvest rates were 80% before 1947, predicted trends in spawner abundance and ocean harvest rates aligned with those from the earliest decade ofstudies, enabling direct estimates ofspawner abundance and ocean harvest rates. Further, the revised simulations indicate that Oregon Coast coho abundance during 1892–1956 probably varied within a range similar to recent decades. We find that use oflandings data to speculate about historical salmon abundance is unreliable and can lead to recovery goals that are unattainable, errant interpretation of population limiting factors, and high investment in well-intentioned but misaligned recovery actions. Correct diagnosis ofpopulation trends and their causes is best attained with contemporary data for which both precision and accuracy can be validated.

Falcy, M. R., & Suring, E. (2018). Detecting the Effects of Management Regime Shifts in Dynamic Environments Using Multi-Population State-Space Models. *Biological Conservation, 221*, https://doi.org/10.1016/j.biocon.2018.02.026

Detecting the effectiveness of management actions intended to increase the abundance of threatened or exploited species can help resolve uncertainties about cost-effective management tactics. However, the complexity of ecological systems can make it difficult to identify important factors causing change in population abundance. This difficulty extends from detecting naturally-caused ecosystem regime shifts to management induced regime shifts and the attendant change in population dynamics parameters. The adult abundance of naturally-produced coho salmon (Oncorhynchus kisutch) on the Oregon Coast generally declined until these fish were listed as threatened under the Endangered Species Act in 1998. The subsequent rebuilding of Oregon coastal coho adult abundance is coincident with increased habitat restoration, reduced hatchery production, and reduced harvest. Importantly, ocean survival also improved, thereby complicating the assessment of management effectiveness at the adult life stage. Our objective was to assess change in the freshwater production of juveniles (smolts) through time in order to determine if recent increases in adult abundance could be related to management affecting the freshwater juvenile production. We combined 46 years of data associated with 18 populations of Oregon coastal coho. Spawner-to-smolt relationships were modeled with Bayesian hierarchical state-space implementations of the logistic hockey stick recruitment function. We also develop a method of estimating the relative reproductive success of hatchery spawners. We found more evidence for decline than increase in productivity in the spawner-to-smolt life stage, suggesting that changes in physical oceanographic conditions are responsible for recent increases in adult abundance. The reproductive success of hatchery-origin fish relative to natural-origin fish was 0.51 with a 95% credible interval from 0.19 to 0.89. While some management effects may unfold on longer time-scales than we observed, we nonetheless contend that carefully tailored models of non-stationary population dynamics are needed to understand and the effectiveness of management actions intended to recover populations.

Flitcroft, R., Burnett, K., Snyder, J., Reeves, G., & Ganio, L. (2014). Riverscape Patterns among Years of Juvenile Coho Salmon in Midcoastal Oregon: Implications for Conservation. *Transactions of the American Fisheries Society, 143*(1), https://doi.org/10.1080/00028487.2013.824923

Patterns of salmon distribution throughout a riverscape may be expected to change over time in response to environmental conditions and population sizes. Changing patterns of use, including identification of consistently occupied locations, are informative for conservation and recovery planning. We explored interannual patterns of distribution by juvenile Coho Salmon Oncorhynchus kisutch in 11 subbasins on the midcoast of Oregon. We found that juvenile Coho Salmon distribution expanded and contracted around stream sections that were continuously occupied (core areas). Timing of expansion or contraction was synchronous among subbasins and appeared to be related to the size of the parental spawning run. Juvenile distribution expanded from core areas when adults were abundant and contracted into core areas at lower adult abundances. The “intrinsic potential” of stream sections to support high quality habitat for Coho Salmon also appeared to inform distribution patterns. In most subbasins, when populations expanded, they moved into areas of high intrinsic potential. We identified areas that were consistently used by juvenile Coho Salmon which may be important target locations for conservation and restoration. Our study contributes to the body ofwork that seeks to explain the processes behind spatial and temporal patterns of freshwater habitat use by salmonids in the Pacific Northwest, thereby enhancing understanding of the complexity of biological and environmental interactions over broad scales.

Flitcroft, R., Lewis, S., Arismendi, I., Davis, C., Giannico, G., Penaluna, B., . . . Snyder, J. (2019). Using Expressed Behaviour of Coho Salmon (Oncorhynchus Kisutch) to Evaluate the Vulnerability of Upriver Migrants under Future Hydrological Regimes: Management Implications and Conservation Planning. *Aquatic Conservation: Marine and Freshwater Ecosystems, 29*(7), https://doi.org/10.1002/aqc.3014

Globally, river systems have been extensively modified through alterations in riverscapes and flow regimes, reducing their capacity to absorb geophysical and environmental changes. In western North America and elsewhere, alterations in natural flow regimes and swimways through dams, levees, and floodplain development, work in concert with fire regime, forest management practices, as well as agriculture and urban development, to change recovery trajectories of river systems. Hydroregime scenarios for coho salmon, Oncorhynchus kisutch (Walbaum, 1792), were investigated in Washington and Oregon, USA, where long-term records of discharge, water temperature, and upstream fish passage are available. This novel approach combines hydrological and ecological data in a single visualization, providing empirical foundations for understanding upstream behavioural movement and tolerances of native fishes. The timing of coho salmon movement with respect to temperature and discharge were compared with scenarios representing possible future hydrological conditions associated with a changing climate. This approach provides a framework for the study of future hydrological alterations in other locations, and can inform local and regional conservation planning, particularly in view of water management policy. Management implications and recommendations for action that may expand the capacity of riverscapes to absorb perturbations are discussed.

Gavin, D. G., Kusler, J. E., & Finney, B. P. (2018). Millennial-Scale Decline in Coho Salmon Abundance since the Middle Holocene in a Coastal Oregon Watershed, USA. *Quaternary Research, 89*(2), https://doi.org/10.1017/qua.2017.106

The population size of anadromous salmon in the Pacific Northwest is strongly influenced by decadal variation in watershed and oceanographic conditions and therefore should also be influenced by larger magnitude millennial-scale variations in these conditions. We studied δ15N of bulk organic matter in lake sediment from Woahink Lake, Oregon, as a proxy of marine-derived nutrients (MDN) from spawning coho salmon. We compared this site to a control lake with a natural barrier to salmon migration. From 7.5 to 5.4 ka, a dune was emplaced, breached, and emplaced again, forming Woahink Lake in a former estuary. δ15N decreased steadily since 5.4 ka at Woahink but not at the control lake. δ15N reached a minimum just prior to anthropogenic nutrient loading, which caused an increase in δ15N, thus precluding a comparison with the historical decline in salmon abundance. A mixing model of lake-water nitrate, developed to explore alternate scenarios for the observed range of δ15N, could not explain these results without invoking MDN input from at least several hundred salmon annually. Our results show a previously unreported pattern of a millennial-scale decline in salmon that has plausible linkages to parallel changes in ocean circulation and productivity.

Hance, D. J., Ganio, L. M., Burnett, K. M., & Ebersole, J. L. (2016). Basin-Scale Variation in the Spatial Pattern of Fall Movement of Juvenile Coho Salmon in the West Fork Smith River, Oregon. *Transactions of the American Fisheries Society, 145*(5), https://doi.org/10.1080/00028487.2016.1194892

Abstract For several species of salmonids, Oncorhynchus and Salvelinus spp., inhabiting Pacific coastal temperate streams, juvenile fish have been recorded moving between main-stem and tributary habitats during the transition from the summer dry season to the winter wet season. Movement connecting summer and winter habitats may be particularly important for Coho Salmon O. kisutch because availability of overwintering habitat can limit freshwater survival for this species. Here, we describe basin-scale variability in movement between main-stem and tributary habitat for juvenile Coho Salmon tagged in the summer with PIT tags and detected in the fall at four stationary detection sites at tributary–main-stem confluences of the West Fork Smith River, Oregon. We used odds ratios to evaluate spatial patterns in tributary–main-stem movement across tributary junctions at upper-river, midriver, and lower-river locations. Three types of movement were assessed: (1) emigration out of tributaries into the main stem, (2) immigration into a tributary from the main stem downstream from the tributary junction, and (3) immigration from the main stem upstream from the tributary junction. The likelihood of emigration had a distinct spatial pattern. Only at the two upper-river detection sites were juvenile Coho Salmon more likely to emigrate than immigrate. Fish immigrating into a midriver tributary were more likely to originate from the main stem downstream from the confluence, whereas fish immigrating into two lower-river tributaries were more likely to originate from the main stem upstream from the confluence. This basin-scale variation in patterns of immigration and emigration demonstrates complexity in the connectivity of juvenile Coho Salmon seasonal habitats within a stream network. We conclude that effective restoration planning and watershed management should account for the spatial pattern of connectivity of summer-rearing and overwintering habitat throughout a stream network and consider the full diversity of movement patterns that may be required for fish to access seasonal habitats.

Homel, K. M., Lorion, C. M., & Clemens, B. J. (2019). Challenges and Opportunities to Apply Process-Based Restoration at Scales Appropriate to Anadromous Fishes. In *Multispecies and Watershed Approaches to Freshwater Fish Conservation.* D. C. Dauwalter, T. W. Birdsong, & G. P. Garrett (Eds.), (Vol. 91, pp. 479-514) Retrieved from https://fisheries.org/bookstore/all-titles/afs-symposia/54091c/

Habitat restoration in streams is critical to recovery of imperiled fishes. In the Pacific Northwest of North America, stream habitat restoration has focused primarily on anadromous salmonids Oncorhynchus spp. listed under the Endangered Species Act. Substantial restoration efforts have focused on the Oregon Coast evolutionary significant unit of Coho Salmon O. kisutch. However, many of these efforts have been local in scale (i.e., particular reaches within relatively small streams, high up in watersheds) and do not address habitat-forming processes at the watershed scale. Other anadromous species such as Chum Salmon O. keta and Pacific Lamprey Entosphenus tridentatus that co-occur in these watersheds are rarely targeted in habitat restoration yet are thought to benefit from restoration efforts for Coho Salmon. However, Chum Salmon and Pacific Lamprey tend to occur lower in watersheds than Coho Salmon, inhabit freshwater for different periods of time, and are therefore challenged by different limiting factors. As a result, benefits from restoration efforts for Coho Salmon may not be fully realized by Chum Salmon and Pacific Lamprey. Mounting evidence suggests that process-based restoration may yield substantial biological dividends for anadromous fishes. Although process-based restoration is still an area of active research, it does possess a stronger and more holistic conceptual foundation than restoration strategies aimed at creating particular channel forms. Process-based restoration addresses the geological, physical, chemical, climatic, and ecological processes that interact to form habitat mosaics to which anadromous fishes have adapted. Understanding and working within these processes

throughout entire watersheds and downstream into the estuary has the potential to benefit multiple anadromous fishes and substantially improve the ecological functions of watersheds. We explore the range of habitat relationships expressed among three imperiled anadromous fishes-Coho Salmon, Chum Salmon, and Pacific Lamprey-and present case studies to illustrate the importance of implementing process-based restoration to address limiting factors in their freshwater habitats.

Ioannidou, C., & O'Hanley, J. R. (2019). The Importance of Spatiotemporal Fish Population Dynamics in Barrier Mitigation Planning. *Biological Conservation, 231*, https://doi.org/10.1016/j.biocon.2019.01.001

In this study, we propose a novel framework combining spatially explicit population viability analysis and optimization for prioritizing fish passage barrier mitigation decisions. Our model aims to maximize the equilibrium population size, or alternatively minimize the extinction risk, of a target fish species subject to a budget on the total cost of barrier mitigation. A case study involving a wild coho salmon (Oncorhynchus kisutch) population from the Tillamook basin, Oregon, USA is used to illustrate the benefits of our approach. We consider two different spawning adult dispersal patterns, river and reach level homing, as well as straying. Under density dependent population growth, we find that homing behavior type has a significant effect on barrier mitigation decisions. In particular, with reach homing, our model produces virtually the same population sizes as a more traditional barrier prioritization procedure designed to maximize accessible habitat. With river homing, however, we find that it is not necessary to remove all barriers in order to maximize equilibrium population size. Indeed, a stochastic version of our model reveals that removing all barriers actually results in a marginal increase in quasi-extinction risk. We hypothesize that this is due to a population thinning effect of barriers, resulting in a surplus of recruits in areas of low spawner density. Our findings highlights the importance of considering spatiotemporal fish population dynamics in river connectivity restoration planning. By adding greater biological realism, models such as ours can help conservation managers to more strategically allocate limited resources, resulting in both cost savings and improved population status for a focal species.

Jones, K. K., Cornwell, T. J., Bottom, D. L., Stein, S., & Anlauf-Dunn, K. J. (2018). Population Viability Improves Following Termination of Coho Salmon Hatchery Releases. *North American Journal of Fisheries Management, 38*(1), https://doi.org/10.1002/nafm.10029

Recent genetic studies, meta-analyses, and retrospective analyses have documented reduced productivity of wild salmon and steelhead Oncorhynchus mykiss that interbreed with hatchery-reared fish, raising concerns about the long-term viability and recovery of at-risk stocks. In 2007, the Oregon Department of Fish and Wildlife discontinued a Coho Salmon Oncorhynchus kisutch hatchery program at the Salmon River to support recovery of a wild Coho Salmon population in the Oregon Coast Evolutionarily Significant Unit. This decision constituted a unique management experiment, allowing for direct measurement of the wild population's response after the discontinuation of a decades-old hatchery program. We used a before-after, control-impact design to examine whether selected viability metrics of the naturally produced population in the Salmon River changed after the hatchery program ended. We compared metrics for the 2006-2013 broods, representing periods after the hatchery program ended, to those for the 1995-2005 broods, when the hatchery program was still releasing 200,000 smolts annually. We also examined neighboring populations during similar time periods to account for changes or variation due to other factors. Although hatchery-origin spawners previously had accounted for most of the adults returning to the Salmon River, the naturally produced population did not collapse, and two viability metrics improved significantly after the Coho Salmon hatchery program ended: (1) adult abundance increased and (2) spawn timing expanded and moved closer to the historical timing. Recruits-to-spawner ratios in the Salmon River, although initially low, are now approximately equal to those of neighboring populations. The results indicate that hatchery closure can be an effective strategy to promote wild population recovery. However, considerable variability in population trends and environmental conditions will require continued monitoring to verify the long-term resilience and viability of the wild population.

Keefer, M. L., Blubaugh, T. J., Clabough, T. S., Jepson, M. A., Naughton, G. P., & Caudill, C. C. (2018). Coho Salmon Colonization of Oregon's Upper Willamette River Basin. *Transactions of the American Fisheries Society, 147*(6), https://doi.org/10.1002/tafs.10112

Coho Salmon Oncorhynchus kisutch were historically absent from a major Columbia River subbasin, the upper Willamette River (UWR), until a fishway was installed at Willamette Falls and a sustained stocking program was implemented in the 1950s. Despite decades of stocking from three diverse source populations (early run, late run, and coastal Coho Salmon) during the second half of the twentieth century, adult abundance above the falls was less than 1,000 annually during the 1990s. A recent surge (>25,000 adults in 2009) has raised concerns about potential interactions with two native anadromous salmonids listed under the U.S. Endangered Species Act: UWR winter-run steelhead O. mykiss and UWR spring-run Chinook Salmon O. tshawytscha. We analyzed Coho Salmon stocking records and estimates of abundance from 1954–2017 to summarize population history, demographics, and adult phenology. We also characterized current Coho Salmon distribution using radiotelemetry (n = 219 adults in 2014) and evaluated potential mechanisms associated with changes in adult abundance. We identified a shift in adult migration timing over the time series that was consistent with an increase in late-run traits and environmental changes affecting migration cues. The distribution of radio-tagged adults among UWR subbasins was only weakly correlated with past stocking efforts, suggesting that habitat conditions, stocked phenotype, adaptation and range expansion by descendants of the relict stocked populations, or colonization from regional source populations strongly influenced current subpopulation abundance. Annual counts of returning UWR Coho Salmon were positively correlated with counts of Columbia River Coho salmon, suggesting a shared response to freshwater habitat or ocean conditions. Regardless of the underlying mechanisms affecting UWR Coho Salmon distribution and population size, the results illustrate the complex dynamics between changing landscapes and migration corridors, the introduction of nonnative species for harvest management goals, and the potential for nonnative fish to affect the conservation of native populations.

Lewis, D. J., Dundas, S. J., Kling, D. M., Lew, D. K., & Hacker, S. D. (2019). The Non-Market Benefits of Early and Partial Gains in Managing Threatened Salmon. *Plos One, 14*(8), https://doi.org/10.1371/journal.pone.0220260

Threatened species are increasingly dependent on conservation investments for persistence and recovery. Information that resource managers could use to evaluate investments such as the public benefits arising from alternative conservation designs is typically scarce because conservation benefits arise outside of conventional markets. Moreover, existing studies that measure the public benefits of conserving threatened species often do not measure the benefits from partial gains in species abundance that fall short of official recovery, or the benefits from achieving gains in species abundance that happen earlier in time. We report on a stated preference choice experiment designed to quantify the non-market benefits for conservation investments aimed at threatened Pacific Coho salmon (Oncorhynchus kisutch) along the Oregon Coast (OC). Our results show that a program aimed at increasing numbers of returning salmon can generate sizable benefits of up to $518 million/y for an extra 100,000 returning fish, even if the species is not officially declared recovered. Moreover, while conservation investment strategies expected to achieve relatively rapid results are likely to have higher up-front costs, our results show that the public attaches substantial additional value of up to $277 million/y for achieving conservation goals quickly. Our results and approach can be used to price natural capital investments that lead to gains in returning salmon, and as inputs to evaluations of the benefits and costs from alternative conservation strategies.

Losee, J. P., Fisher, J., Teel, D. J., Baldwin, R. E., Marcogliese, D. J., & Jacobson, K. C. (2014). Growth and Condition of Juvenile coho salmon Oncorhynchus kisutch Relate Positively to Species Richness of Trophically Transmitted Parasites. *Journal of Fish Biology, 85*(5), https://doi.org/10.1111/jfb.12525

The aims of this study were first, to test the hypothesis that metrics of fish growth and condition relate positively to parasite species richness (SR) in a salmonid host; second, to identify whether SR differs as a function of host origin; third, to identify whether acquisition of parasites through marine v. freshwater trophic interactions was related to growth and condition of juvenile salmonids. To evaluate these questions, species diversity of trophically transmitted parasites in juvenile coho salmon Oncorhynchus kisutch collected off the coast of the Oregon and Washington states, U.S.A. in June 2002 and 2004 were analysed. Fish infected with three or more parasite species scored highest in metrics of growth and condition. Fish originating from the Columbia River basin had lower SR than those from the Oregon coast, Washington coast and Puget Sound, WA. Parasites obtained through freshwater or marine trophic interactions were equally important in the relationship between SR and ocean growth and condition of juvenile O. kisutch salmon.

Malick, M. J., Cox, S. P., Peterman, R. M., Wainwright, T. C., & Peterson, W. T. (2015). Accounting for Multiple Pathways in the Connections among Climate Variability, Ocean Processes, and coho salmon Recruitment in the Northern California Current. *Canadian Journal of Fisheries and Aquatic Sciences, 72*(10), https://doi.org/10.1139/cjfas-2014-0509

Pathways linking climate to population dynamics of higher-trophic-level fish species such as Pacific salmon often involve a hierarchy in which regional-scale physical and biological processes mediate the effects oflarge-scale climate variability. We used probabilistic networks to investigate 17 potential ecological pathways linking climate to Oregon coho salmon (Oncorhynchus kisutch) recruitment. We found that pathways originating with the Pacific Decadal Oscillation were the most influential on recruitment, with the net effect being two to four times greater than for pathways originating with the North Pacific Gyre Oscillation or the Oceanic Niño Index. Among all environmental variables, sea surface temperature and an index of juvenile salmon prey biomass had the greatest effects on recruitment, with a 76% chance ofrecruitment being equal to or below average given that ocean temperatures were above average and a 34% chance ofrecruitment being below average given that prey biomass was above average. Our results provide evidence that shifts in climate patterns could strongly influence recruitment simultaneously through multiple ecological pathways and highlight the importance of quantifying cumulative effects of these pathways on higher-trophic-level species.

Morgan, C. A., Beckman, B. R., Weitkamp, L. A., & Fresh, K. L. (2019). Recent Ecosystem Disturbance in the Northern California Current. *Fisheries, 44*(10), https://doi.org/10.1002/fsh.10273

An extended marine heat wave occurred across the North Pacific during 2014-2016, including the formation of the warm "Blob" followed by a strong El Nino in 2016. Coincident with this marine heat wave, we documented unprecedented biological changes in plankton and nekton in the Northern California Current (NCC) within pelagic surveys conducted over 20 years (1998-2017). The recent warm period was dominated by warmwater gelatinous invertebrates and fishes, some of which were previously either extremely rare or absent. Mixing of organisms originating from more southern or western regions with those previously present in the NCC may have resulted in novel and unpredictable trophic interactions that produced some of the observed changes in relative abundance. Continued long-term monitoring is needed to determine whether this is a temporary ecosystem disturbance or a fundamental change in the very productive NCC upwelling region.

National Marine Fisheries Service. (2016). *Final ESA Recovery Plan for Oregon Coast coho salmon (Oncorhynchus ksutch)*. Retrieved from https://repository.library.noaa.gov/view/noaa/15986

Oregon Coast coho salmon (Oncorhynchus kisutch) are protected under the Endangered Species Act (ESA). The fish spawn and rear in rivers, streams, and lakes along Oregon's coastline, from the Necanicum River near Seaside on the north to the Sixes River near Port Orford on the south (Figure S-1). NOAA's National Marine Fisheries Service (NMFS) first listed Oregon Coast coho salmon as a threatened species under the ESA in 1998. NMFS relisted the species in 2008 and reaffirmed the listing in 2011. This recovery plan (Plan) provides guidance to improve the viability of the species to the point that it meets the delisting criteria and no longer requires ESA protection. Under ESA direction, we need to resolve threats to the species and ensure the long-term persistence of naturally selfsustaining populations in the wild. Recovery direction for Oregon Coast coho salmon has one central overriding theme: to protect and restore the freshwater and estuarine rearing habitats that support juvenile survival and overall productivity. The Plan builds on past and current efforts to restore the coho salmon. In particular, this plan calls for continued actions to repair the ecosystem processes that influence the health and stability of the rearing habitats for juvenile coho salmon. The actions will also benefit many other fish and wildlife species, and could provide aid to land owners and local communities"

Oregon Department of Fish and Wildlife. (2014). *Oregon Coast Coho Conservation Plan Annual Report*. Retrieved from https://www.dfw.state.or.us/fish/CRP/docs/coastal_coho/economic_reports/OCCCP_Annual_Report-2014.pdf

In 2014, the OC coho salmon ESU had approximately 359,624 naturally-produced spawners, which was 44% of the abundance goal identified in the OCCCP. Abundance significantly increased from 2013 (124,411), and all five strata were substantially above the 24-year average abundance. Wild spawner abundance in 2014 was the highest for the OC coho salmon ESU since random surveys were implemented in 1990. All data reviewed suggested that the strategies in the OCCCP should continue to be implemented without revision. Habitat restoration planning and implementation actions to address key limiting factors occurred across the ESU to support OC coho salmon conservation and recovery. Terminal (estuary/freshwater) wild coho salmon fisheries were implemented in thirteen river basins under the Coastal Rivers Fishery Management and Evaluation Plan (FMEP) approved by NOAA Fisheries in 2009. Estimated spawning escapement for the ESU, following ocean and inbasin harvest impacts, was significantly higher (359,624) than the Pacific Fishery Management Council's (PFMC's) forecast (230,600). Based on observations of conservative harvest in fisheries conducted since 2009, many fisheries in 2014 were implemented with fixed seasons without quotas or creel sampling. Fisheries with quotas and creel sampling occurred in the Umpqua, Beaver Creek in Lincoln County, and Floras/New River system in Curry County. Creel-monitored terminal fishery harvest rates were consistent with the conservation measures identified in the FMEP. The Western Oregon Rearing Project (WORP) monitoring of parr abundance in pools and the Oregon Adult Salmonid Inventory & Sampling (OASIS) monitoring of abundance of female spawners that produced them, suggests there are limitations to parr production in freshwater habitats.

Oregon Department of Fish and Wildlife. (2015). *Oregon Coast Coho Conservation Plan Annual Report*. Retrieved from https://www.dfw.state.or.us/fish/CRP/docs/coastal_coho/economic_reports/OCCCP%20Annual%20Report-2015.pdf

In 2015, the forecast was for 206,600 fish, however, the OC coho ESU had approximately 57,106 naturally-produced spawners following ocean and in-basin harvest impacts, which was approximately 15% of the abundance goal identified in the OCCCP. Abnormally warm ocean conditions persisting since 2014 contributed to a significant decrease in OC coho ESU abundance, resulting in the lowest level recorded since 1999. All five strata were substantially below the prior 25 year average abundance. Wild OC coho spawner abundance decreased between 2014 and 2015, from the highest to the eighth lowest observed during 26 years of monitoring. During the 2010-2014 fisheries, the allowable rate was consistent across all strata in the ESU. Due to a wider variation in parental returns to the individual basins in 2015, different allowable rates were assigned to each stratum and (consistent with Amendment-13), exploitation rates were based on the most constrained OC coho stratum, which was the North strata. Therefore, a wild OC coho salmon fishery was not implemented in the Nehalem River basin. Terminal (estuary/freshwater) wild coho salmon fisheries were implemented in twelve systems under the Coastal Rivers Fishery Management and Evaluation Plan approved by NOAA Fisheries in 2009. Western Oregon Rearing Project (WORP) monitoring of parr abundance in pools and the Oregon Adult Salmonid Inventory & Sampling (OASIS) monitoring of abundance of female spawners that produced them suggests productivity is limited when spawner abundance exceeds 80,000 females. This implies there are limitations to parr production in freshwater habitats. All data reviewed suggested that the strategies in the OCCCP should continue to be implemented without revision. However, budget constraints have led to a significant reduction in ODFW staff to support priority habitat restoration planning and implementation actions to address key limiting factors. Therefore, high priority habitat restoration projects that create high quality OC coho salmon rearing habitat continue to be developed and implemented at a highly reduced scale across the ESU.

Oregon Department of Fish and Wildlife. (2015). *Status of Oregon Stocks of Coho Salmon, 2014*. (OPSW-ODFW-2016-3). Retrieved from https://digital.osl.state.or.us/islandora/object/osl%3A44879

This report summarizes the results of status and trend monitoring for Oregon's naturally spawning coho salmon, Oncorhynchus kisutch, through the 2015 run year (October 2015 through February 2016). Monitoring results include: Abundance of naturally spawning coho salmon; Density (fish/mile) of naturally spawning coho salmon; Coho salmon spawn timing and distribution; Proportion of hatchery (marked) coho salmon in naturally spawning populations Results in this report are based on data from randomly selected spawning surveys and other methods used in areas without adequate random surveys. Results for coho salmon standard spawning surveys and spawning surveys for other species are covered in data summaries and reports posted on an Oregon Department of Fish and Wildlife (ODFW) web page.

Oregon Department of Fish and Wildlife. (2016). *Oregon Coast Coho Conservation Plan Annual Report*. Retrieved from https://www.dfw.state.or.us/fish/CRP/docs/coastal_coho/economic_reports/OCCCP%20Annual%20Report-2016.pdf

Following abnormally warm ocean temperatures that started in 2014 and encompassed a large portion of the Pacific West Coast, referred to as 'the Blob", and a strong El Niño pattern in 2015, poor marine survival for OC Coho Salmon resulted in 2016 having the third lowest wild spawner abundance estimate recorded for OC Coho Salmon since the peak in 2002. This increase in ocean temperature created adverse effects on the OC Coho Salmon prey sources, survival, and fisheries; fishing harvest was less than half of the allowable harvest approved by the Pacific Fishery Management Council under Amendment 13. Overall, overwinter rearing habitat likely continues to limit freshwater productivity. However, focused efforts for watershed scale OC Coho Salmon habitat restoration are being supported by state and federal agencies, Tribes, and other non-governmental organizations. These entities are working to develop and implement Coho Salmon-specific strategic actions plans to address limiting factors. Given that freshwater production continues to be limiting, implementation of the OCCCP should continue.

Oregon Department of Fish and Wildlife. (2017). *Oregon Coast Coho Conservation Plan Annual Report*. Retrieved from https://www.dfw.state.or.us/fish/CRP/docs/coastal_coho/economic_reports/OCCCP%202017%20Annual%20Report%20draft.pdf

Still recovering from poor ocean conditions that created adverse effects on the OC Coho Salmon prey sources, survival, and fisheries, OC Coho spawner abundance estimates for the ESU decreased from 2016 estimates, resulting in the second lowest wild OC Coho Salmon spawner abundance estimate recorded since 1999. Fishing harvest was less than half of the allowable harvest approved by the Pacific Fishery Management Council (PFMC) under Amendment 13 (A13). Overall, overwinter rearing habitat likely continues to limit freshwater productivity. However, focused efforts for watershed scale OC Coho Salmon habitat restoration are being supported by state and federal agencies, tribes, and other non-governmental organizations. These entities are working to develop and implement Coho Salmon-specific strategic actions plans to address limiting factors. Given that freshwater production continues to be limiting, implementation of the OCCCP should continue.

Oregon Department of Fish and Wildlife. (2018). *Oregon Coast Coho Conservation Plan 2018 Annual Report*. Retrieved from https://www.dfw.state.or.us/fish/crp/docs/coastal_coho/economic_reports/OCCCP%20Annual%20Report%202018.pdf

The Oregon Coast Coho Conservation Plan (OCCCP) was adopted by the Oregon Fish and Wildlife Commission in March 2007. The plan serves as the State of Oregon's management plan for the Oregon Coast (OC) Coho Salmon Evolutionarily Significant Unit (ESU). The OC Coho Salmon ESU is comprised of 5 strata (North Coast, Mid-Coast, Mid-South Coast, Lakes, and Umpqua) and 21 independent OC Coho Salmon populations within these 5 strata.

Oregon Department of Fish and Wildlife. (2018). *Winter Habitat Condition of Oregon Coast coho salmon Populations, 2007-2014*. Oregon Department of Fish and Wildlife Retrieved from https://digital.osl.state.or.us/islandora/object/osl%3A139012

In this report we summarize results of eight years (2007-2014) of habitat surveys for 18 independent Oregon coast coho salmon populations across four monitoring strata (North Coast, Mid Coast, MidSouth Coast, and Umpqua) in the Oregon Coast Coho Salmon Evolutionary Significant Unit (ESU). We also sampled dependent population blocks across three monitoring strata (North Coast, Mid Coast, and Mid-South Coast). Using a spatially balanced site selection process (Generalized Random Tessellation Stratification; GRTS) we surveyed 451 unique sites within the range of coho salmon spawning or rearing. With the exception of the 2014 survey year, habitat data were collected during winter conditions (February – March). Habitat sampled in 2014 occurred within the summer field season (June – September). We used a Habitat Limiting Factors Model (HLFM) to estimate habitat capacity for winter coho parr and the HabRate model to assess habitat quality for each surveyed stream reach. HLFM estimates were expanded based on the total coho distribution in each population. Based on the habitat data the HLFM predicted the Floras population could support the highest density of juvenile coho (1568 parr/km), while the streams in the Siltcoos watershed could support the least (290 parr/km). At the ESU-level, there was no detectable change of high quality rearing habitat (≥ 1850 parr/km) when compared to previous studies, but changes were observed among populations over the course of these survey years. We compared individual habitat metrics across populations, land use, geology, and between independent and dependent populations. While no significant differences were observed between independent and dependent populations, differences in habitat metrics were detected among individual populations, land use types, and geologies. In addition, we detected a difference in reproductive habitat quality (spawning and emergence) between both populations and land use types.

Petro, V. M., Taylor, J. D., & Sanchez, D. M. (2015). Evaluating Landowner-Based Beaver Relocation as a Tool to Restore Salmon Habitat. *Global Ecology and Conservation, 3*, https://doi.org/10.1016/j.gecco.2015.01.001

Relocating American beavers (Castor canadensis) from unwanted sites to desirable sites (i.e., where damage exceeds stakeholder capacity) has been posited as a method to enhance in-stream habitat for salmonids in the Pacific Northwest region of the US; however, no studies have evaluated this method. From September–December 2011, we trapped and relocated 38 nuisance beavers using guidelines available to Oregon landowners. Release sites were selected from models that identified high values of beaver dam habitat suitability and where dams would increase intrinsic potential of coho salmon (Oncorhynchus kisutch). Mean distance moved from release sites within 16 weeks post-release was 3.3 ±0.2 (SE) stream km (max 29.2 km). Mean survival rate for relocated beavers was 0.47 ±0.12 (95% CI: 0.26–0.69) for 16 weeks post-release, while the probabilities of an individual dying to predation or disease/illness during the same period were 0.26 (95% CI: 0.09–0.43) and 0.16 (95% CI: 0.01–0.30), respectively. Dam construction was limited and ephemeral due to winter high flows, providing no in-stream habitat for coho. We conclude beaver relocation options available to landowners in Oregon may not be an effective option for stream restoration in coastal forestlands due to infrequent dam occurrence and short dam longevity.

Silver, B. P., Hudson, J. M., Lohr, S. C., & Whitesel, T. A. (2017). Short-Term Response of a Coastal Wetland Fish Assemblage to Tidal Regime Restoration in Oregon. *Journal of Fish and Wildlife Management, 8*(1), https://doi.org/10.3996/112016-jfwm-083

Bandon Marsh National Wildlife Refuge, Oregon, completed construction of a large-scale tidal marsh restoration project on the Ni-les'tun Unit within the Coquille River estuary in 2011. To understand the initial effects of restoration construction and establish a baseline for long-term monitoring, we documented the assemblage of fish species 3 y before and 2 y after restoration construction. The overall fish assemblage in the Ni-les'tun Unit was substantially different after restoration construction, with an increased abundance, frequency, and richness of estuarine and diadromous fish species. Threespine Stickleback Gasterosteus aculeatus and species of Sculpin (family Cottidae) dominated the Ni-les'tun Unit and control area in both relative abundance and capture frequency throughout this study. Among salmonids, Coastal Cutthroat Trout Oncorhynchus clarkii and Coho Salmon Oncorhynchus kisutch had the highest frequency of occurrence and relative abundance both before and after restoration construction. Fish occupied newly constructed channels within 2 y. Species found in new channels included freshwater species (e.g., juvenile salmonids), introduced species (e.g., Mosquitofish Gambusia affinis), and estuarine species (e.g., Sculpin, Threespine Stickleback, and Shiner Perch Cymatogaster aggregata). Changes were likely due to improved access and changing habitat created by the reintroduced tidal regime. We recommend long-term monitoring to assess the trajectory of the biological response to the restoration over time.

Steel, E. A., Muldoon, A., Flitcroft, R. L., Firman, J. C., Anlauf-Dunn, K. J., Burnett, K. M., & Danehy, R. J. (2017). Current Landscapes and Legacies of Land-Use Past: Understanding the Distribution of Juvenile Coho salmon (Oncorhynchus kisutch) and Their Habitats Along the Oregon Coast, USA.

Canadian Journal of Fisheries & Aquatic Sciences, 74(4), https://doi.org/10.1139/cjfas-2015-0589

The Oregon Coast landscape displays strong spatial patterns in air temperature, precipitation, and geology, which can confound our ability to detect relationships among land management, instream conditions, and fish at broad spatial scales. Despite this structure, we found that a suite of immutable or intrinsic attributes (e.g., reach gradient, drainage area, elevation, and percent weak rock geology of the catchments draining to each of our 423 study reaches) could explain much of the variation in pool surface area across the landscape and could contribute to an estimate of how many juvenile coho salmon (Oncorhynchus kisutch) one might expect to find in those pools. Further, we found evidence of differences in pool surface area across land ownership categories that reflect differing management histories. Our results also suggest that historical land and river management activities, in particular splash dams that occurred at least 50 years ago, continue to influence the distribution of juvenile coho salmon and their habitats today.

Thompson, N. F., Leblanc, C. A., Romer, J. D., Schreck, C. B., Blouin, M. S., & Noakes, D. L. G. (2016). Sex-Biased Survivorship and Differences in Migration of Wild Steelhead (Oncorhynchus mykiss) Smolts from Two Coastal Oregon Rivers. *Ecology of Freshwater Fish, 25*(4), https://doi.org/10.1111/eff.12242

In salmonids with partial migration, females are more likely than males to undergo smoltification and migrate to the ocean (vs. maturing in freshwater). However, it is not known whether sex affects survivorship during smolt migration (from fresh water to entry into the ocean). We captured wild steelhead (Oncorhynchus mykiss) smolts in two coastal Oregon rivers (USA) and collected fin tissue samples for genetic sex determination (2009; N = 70 in the Alsea and N = 69 in the Nehalem, 2010; N = 25 in the Alsea). We implanted acoustic tags and monitored downstream migration and survival until entry in to the Pacific Ocean. Survival was defined as detection at an estuary/ocean transition array. We found no effect of sex on smolt survivorship in the Nehalem River in 2009, or in the Alsea River in 2010. However, males exhibited significantly lower survival than females in the Alsea River during 2009. Residency did not influence this result as an equal proportion of males and females did not reach the estuary entrance (11% of males, 9% of females). The sexes did not differ in timing or duration of migration, so those variables seem unlikely to explain sex-biased survivorship. Larger males had higher odds of survival than smaller males in 2009, but the body size of females did not affect survivorship. The difference in survivorship between years in the Alsea River could be due to flow conditions, which were higher in 2010 than in 2009. Our findings suggest that sex may affect steelhead smolt survival during migration, but that the difference in survivorship may be weak and not a strong factor influencing adult sex ratios.

Tullos, D., & Walter, C. (2015). Fish Use of Turbulence around Wood in Winter: Physical Experiments on Hydraulic Variability and Habitat Selection by Juvenile Coho Salmon, Oncorhynchus kisutch. *Environmental Biology of Fishes, 98*(5), https://doi.org/10.1007/s10641-014-0362-4

Re-introduction of large wood for expanding hydraulic variability is an increasingly common practice, yet it is not yet known what elements of hydraulic variability are most beneficial to fish. In an experiment designed to emphasize the minimization of energy expenditure through controlled predation and drift, we investigated whether juvenile coho, under winter conditions, discriminated between microhabitats based primarily on flow strength, depth, distance to wood, or based on temporal or spatial variability of the flow field, with the hypothesis that turbulence would be a strong factor in habitat selection. We conducted physical experiments in a 1:1 scale model of a large wood jam at the Oregon Hatchery Research Center in Alsea, Oregon. We conducted high resolution (0.1 m) mapping of the flow field using an acoustic Doppler velocimeter array and underwater videogrammetry of fish locations. Results indicated that discrimination of microhabitats by juvenile coho salmon in cold, low flows emphasized depth and distance to wood over any hydraulic measures of the flow field. Correlations between hydraulic parameters and distance to wood limited our ability to distinguish the importance of turbulence measures relative to velocities, but highlighted the positive relationships between velocity and turbulence measures and the negative relationships between hydraulics and distance from the roughness elements. Findings suggest areas of further study including potential thresholds of temperature and flow intensity on the importance of turbulence in habitat selection.

Weybright, A. D., & Giannico, G. R. (2018). Juvenile Coho Salmon Movement, Growth and Survival in a Coastal Basin of Southern Oregon. *Ecology of Freshwater Fish, 27*(1), https://doi.org/10.1111/eff.12334

Juvenile salmonids display highly variable spatial and temporal patterns of early dispersal that are influenced by density-dependent and density-independent factors. Although juvenile coho salmon (Oncorhynchus kisutch) movement patterns in streams and their relationship with body mass and growth have been examined in previous studies, most observations were limited to one season or one stream section. In this study, we monitored the movement of juvenile coho salmon throughout their period of residence in a coastal basin to identify prevalent dispersal strategies and their relationships with body mass, growth rates and survival. Our results revealed seasonally and spatially variable movement patterns. Juvenile coho salmon that dispersed to tidally affected reaches soon after emergence remained more mobile and expressed lower site fidelity than those individuals that remained in upper riverine reaches. We did not detect significantly different growth rates between sedentary and mobile individuals. Although a greater proportion of sedentary than mobile fish survived winter to emigrate from the creek in the spring, reach of residence at the onset of winter influenced these survival estimates. Hence, apparent summer-to-smolt survival for mobile individuals was greater than for sedentary fish in tidally influenced reaches, whereas in riverine reaches the sedentary strategy seemed to be favoured. Our research identified complex movement patterns that reflect phenotypic and life history variation, and underscores the importance of maintaining diverse freshwater and estuarine habitats that support juvenile coho salmon before marine migration.

Section VI: Upper Willamette River

Benda, S. E., Naughton, G. P., Caudill, C. C., Kent, M. L., & Schreck, C. B. (2015). Cool, Pathogen-Free Refuge Lowers Pathogen-Associated Prespawn Mortality of Willamette River Chinook Salmon. *Transactions of the American Fisheries Society, 144*(6), https://doi.org/10.1080/00028487.2015.1073621

Spring Chinook Salmon Oncorhynchus tshawytscha are transported above dams in the Willamette River to provide access to blocked spawning habitat. However, 30-95% of these transplants may die before spawning in some years. To varying degrees, salmon in other tributaries-both blocked and unblocked-have similar prespawn mortality (PSM) rates. Our study determined whether holding fish in constant temperature, pathogen-free conditions prior to spawning increased survival through spawning in 2010 through 2012. In addition, we evaluated pathogens as a potential cause of PSM. To monitor survival we captured adult Chinook Salmon early and late in the season from the lower Willamette River and upper tributaries and held them until spawning in 13 degrees C, pathogen-free water. Samples were collected at the time of transport, from moribund or dead fish throughout the summer, and after spawning in the autumn. Prespawn mortalities and postspawned fish from river surveys on holding and spawning reaches above traps were also sampled. Necropsies were performed on all fish, and representative organs were processed for histopathological analysis. Using multiple logistic regression odds ratio analysis, fish that were held were up to 12.6 times less likely to experience PSM than fish that were outplanted to the river. However, Aeromonas salmonicida and Renibacterium salmoninarum were more prevalent in held fish that had PSM than in outplanted fish with PSM, suggesting that fish that were held were more susceptible to these bacteria. Spawned held fish were more likely to have Myxobolus sp. brain infections and less likely to be infected with the kidney myxozoan, Parvicapusla minibicornis, than were spawned outplanted fish. The equal likelihood of other pathogens for held fish and outplanted spawned fish suggests interactive effects determine survival and that holding Chinook Salmon at 13 degrees C prevented expression of lethal pathogenesis. Overall, holding could be a viable method to reduce PSM, but issues of transport stress, proliferative disease, and antibiotics remain.

Billman, E. J., Whitman, L. D., Schroeder, R. K., Sharpe, C. S., Noakes, D. L. G., & Schreck, C. B. (2014). Body Morphology Differs in Wild Juvenile Chinook Salmon Oncorhynchus tshawytscha That Express Different Migratory Phenotypes in the Willamette River, Oregon, U.S.A. *Journal of Fish Biology, 85*(4), https://doi.org/10.1111/jfb.12482

Body morphology of juvenile Chinook salmon Oncorhynchus tshawytscha in the upper Willamette River, Oregon, U. S. A., was analysed to determine if variation in body shape is correlated with migratory life-history tactics followed by juveniles. Body shape was compared between migrating juveniles that expressed different life-history tactics, i. e. autumn migrants and yearling smolts, and among parr sampled at three sites along a longitudinal river gradient. In the upper Willamette River, the expression of life-history tactics is associated with where juveniles rear in the basin with fish rearing in downstream locations generally completing ocean ward migrations earlier in life than fish rearing in upstream locations. The morphological differences that were apparent between autumn migrants and yearling smolts were similar to differences between parr rearing in downstream and upstream reaches, indicating that body morphology is correlated with life-history tactics. Autumn migrants and parr from downstream sampling sites had deeper bodies, shorter heads and deeper caudal peduncles compared with yearling smolts and parr from the upstream sampling site. This study did not distinguish between genetic and environmental effects on morphology; however, the results suggest that downstream movement of juveniles soon after emergence is associated with differentiation in morphology and with the expression of life-history variation.

Bourret, S. L., Kennedy, B. P., Caudill, C. C., & Chittaro, P. M. (2014). Using Otolith Chemical and Structural Analysis to Investigate Reservoir Habitat Use by Juvenile Chinook Salmon Oncorhynchus tshawytscha. *Journal of Fish Biology, 85*(5), https://doi.org/10.1111/jfb.12505

Isotopic composition of Sr and natural elemental tracers (Sr, Ba, Mg, Mn and Ca) were quantified from otoliths in juvenile and adult Chinook salmon Oncorhynchus tshawytscha to assess the ability of otolith microchemistry and microstructure to reconstruct juvenile O. tshawytscha rearing habitat and growth. Daily increments were measured to assess relative growth between natal rearing habitats. Otolith microchemistry was able to resolve juvenile habitat use between reservoir and natal tributary rearing habitats (within headwater basins), but not among catchments. Results suggest that 90% (n=18) of sampled non-hatchery adults returning to the Middle Fork Willamette River were reared in a reservoir and 10% (n= 2) in natal tributary habitat upstream from the reservoir. Juveniles collected in reservoirs had higher growth rates than juveniles reared in natal streams. The results demonstrate the utility of otolith microchemistry and microstructure to distinguish among rearing habitats, including habitats in highly altered systems.

Bowerman, T., Keefer, M. L., & Caudill, C. C. (2016). Pacific Salmon Prespawn Mortality: Patterns, Methods, and Study Design Considerations. *Fisheries, 41*(12), https://doi.org/10.1080/03632415.2016.1245993

Adult Pacific salmon Oncorhynchus spp. may reach spawning grounds but perish before reproducing, a phenomenon known as “prespawn mortality” (PSM). This review synthesizes information on PSM rates and estimation methods to evaluate patterns and facilitate study design development. Questionnaire responses from 60 fisheries professionals indicated that female PSM was routinely monitored in numerous Pacific salmon populations, but variations in data collection and reporting could lead to systematic biases in estimates. Reported PSM rates varied among years and locations, ranging from 0% to over 90%. An evaluation of methodological variations within a single data set illustrated that PSM estimates were sensitive to estimation method, the timing and spatial extent of sampling, and inclusion of male data. To improve accuracy of PSM estimates based on carcass data, we recommend frequent surveys during holding and spawning periods, use of spatially and temporally balanced study designs with adequate sample sizes, and separate reporting for males and females.

Bowerman, T., Roumasset, A., Keefer, M. L., Sharpe, C. S., & Caudill, C. C. (2018). Prespawn Mortality of Female Chinook Salmon Increases with Water Temperature and Percent Hatchery Origin. *Transactions of the American Fisheries Society, 147*(1), https://doi.org/10.1002/tafs.10022

High rates of prespawn mortality, when adult salmon die after completing migration but prior to spawning, can lead to population declines and can impede recovery of threatened stocks. In this study, annual prespawn mortality of female Chinook Salmon Oncorhynchus tshawytscha ranged from 1% to 100% over 14years in seven study reaches located throughout the upper Willamette River basin, Oregon. Prespawn mortality rates were positively correlated with the annual maximum 7-d average maximum stream temperature and the percentage of spawning fish of hatchery origin. Observed prespawn mortality rates varied considerably, but annual female prespawn rates were consistently >80% where maximum temperatures exceeded 20 degrees C and the composition of spawning fish was >80% hatchery origin. In several spawning tributaries, prespawn mortality rates generally decreased at higher elevations. The proximate cause of prespawn death was not evaluated here, and observed patterns likely reflected additional factors that influence mortality either directly or indirectly, such as handling, dam passage, fishing pressure, instream habitat, energetic budget, fish density, and pathogen loads.

Chittaro, P., Johnson, L., Teel, D., Moran, P., Sol, S., Macneale, K., & Zabel, R. (2018). Variability in the Performance of Juvenile Chinook Salmon Is Explained Primarily by When and Where They Resided in Estuarine Habitats. *Ecology of Freshwater Fish, 27*(3), https://doi.org/10.1111/eff.12398

Estuarine habitats provide rearing opportunities for the juvenile life stage of anadromous fishes. Because survival is positively correlated with juvenile performance, these estuarine habitats play an important role in population abundance and productivity. To provide information for the recovery of several depressed stocks of Chinook salmon in the Columbia River Basin, we sought to identify the factors that explain variability in performance. Using otolith-derived estimates of juvenile somatic growth rate as an index of recent performance, we observed a negative nonlinear relationship between growth rate and day of year, and a decreasing and increasing trend of growth rate over the 8 years of this study and distance from the river mouth respectively. Using a generalised linear modelling approach, we found that variability in juvenile somatic growth rate was best explained by where and when individuals were collected, their body size, contaminant loads, stock of origin, and whether a fish was hatchery produced or unmarked. Lastly, we argue that a considerable improvement to the growth rate of juveniles in estuarine habitats is physiologically possible. The results of this 8-year study provide a baseline of the performance of juvenile Chinook salmon to evaluate habitat restoration programs and to compare against future anthropogenic conditions.

Clemens, B. J. (2015). A Survey of Steelhead Age and Iteroparity Rates from a Volunteer Angler Program in the Willamette River Basin, Oregon. *North American Journal of Fisheries Management, 35*(5), https://doi.org/10.1080/02755947.2015.1079572

The iteroparous life history of steelhead Oncorhynchus mykiss can provide genetic variability and increase recruitment, thereby sustaining populations. Steelhead are difficult to survey given that (1) they spawn during high river flows, which can flush carcasses away; (2) they spend a short time on the spawning grounds; (3) nonspawning fish are elusive; and (4) adults that do not die after spawning can evade surveyors. An angler volunteer program was implemented in Oregon to monitor steelhead populations. Recreational anglers collected scales from 2,216 steelhead in the Willamette River basin during 1981–1994; the scales were used to estimate ages and iteroparity rates. A freshwater age of 2 and a saltwater age of 2 were the most common, followed by saltwater ages 3 and 4. The incidence of iteroparity was greater among female steelhead than among males and was greater for winter-run steelhead than for summer-run fish. Wild fish had a higher incidence of repeat spawning than hatchery fish, which may be partly attributable to hatchery practices (e.g., recycling the fish through the fishery or using them for spawning). These results agree with previously published information for steelhead. The overall iteroparity rate of 3.4% for Willamette River basin steelhead appears to be moderate in comparison with other populations; for instance, iteroparity in Willamette River steelhead was much lower than rates for Oregon coastal stocks, was similar to rates for lower Columbia River stocks, and was higher than rates for interior Columbia River stocks. I offer the following hypotheses to explain these geographical trends in iteroparity: (1) Willamette River basin steelhead have a greater distance to migrate than coastal stocks and iteroparity may be selected against by barriers to adult and juvenile passage, (2) similar iteroparity rates for Willamette River basin and lower Columbia River steelhead stocks suggest similarity in migratory conditions, and (3) by contrast, the interior Columbia River stocks have a longer migration distance and also experience challenges associated with the hydropower system.

Cogliati, K. M., Unrein, J. R., Stewart, H. A., Schreck, C. B., & Noakes, D. L. G. (2018). Egg Size and Emergence Timing Affect Morphology and Behavior in Juvenile Chinook Salmon, Oncorhynchus tshawytscha. *Ecology and Evolution, 8*(1), https://doi.org/10.1002/ece3.3670

Variation in early life history traits often leads to differentially expressed morphological and behavioral phenotypes. We investigated whether variation in egg size and emergence timing influence subsequent morphology associated with migration timing in juvenile spring Chinook Salmon, Oncorhynchus tshawytscha. Based on evidence for a positive relationship between growth rate and migration timing, we predicted that fish from small eggs and fish that emerged earlier would have similar morphology to fall migrants, while fish from large eggs and individuals that emerged later would be more similar to older spring yearling migrants. We sorted eyed embryos within females into two size categories: small and large. We collected early and late-emerging juveniles from each egg size category. We used landmark-based geometric morphometrics and found that egg size appears to drive morphological differences. Egg size shows evidence for an absolute rather than relative effect on body morphology. Fish from small eggs were morphologically more similar to fall migrants, while fish from large eggs were morphologically more similar to older spring yearling migrants. Previous research has shown that the body morphology of fish that prefer the surface or bottom location in a tank soon after emergence also correlates with the morphological variations between wild fall and spring migrants, respectively. We found that late-emerging fish spent more time near the surface. Our study shows that subtle differences in early life history characteristics may correlate with a diversity of future phenotypes.

Colvin, M. E., Peterson, J. T., Sharpe, C., Kent, M. L., & Schreck, C. B. (2018). Identifying Optimal Hauling Densities for Adult Chinook Salmon Trap and Haul Operations. *River Research and Applications, 34*(9), https://doi.org/10.1002/rra.3348

Trap and haul programmes are used to conserve fish populations by circumventing high mortality locations or events and enhancing population abundance by reintroducing fish to historical habitats and mitigating for fish passage limitations. Spring-run Chinook salmon are transported in trucks upstream of barrier dams in Willamette River Tributaries as part of fish conservation efforts. Fish mortalities occurring during hauling minimize the utility of the effort because natural origin fish are targeted for theses outplanting efforts. The objectives of this study were to develop models predicting hauling mortality and identify optimal hauling densities that minimize mortality risk and effort. We used an information-theoretic approach to evaluate multiple models predicting hauling mortality. Predictors identified varied between the two dams evaluated but were related to operations and annual or in-river conditions. The amount of time loading fish and the density of fish in tank trucks were positively associated with hauling mortality. Instream flows and thermal exposure were also identified as factors predicting with hauling mortality. We used the results of model selection to predict mortality risk and calculate daily hauling effort. Risk and effort were combined into a utility to identify optimal hauling densities for varying numbers of fish to haul and transport truck volume. Optimal hauling densities varied between dams reflecting whether loading time or hauling density was associated with hauling mortality. This analysis provides managers a way to integrate research, monitoring, and management to improve understanding of factors associated with hauling mortality and adjust optimal hauling densities using adaptive management.

Courter, I. I., Wyatt, G. J., Perry, R. W., Plumb, J. M., Carpenter, F. M., Ackerman, N. K., . . . Galbreath, P. F. (2019). A Natural-Origin Steelhead Population's Response to Exclusion of Hatchery Fish. *Transactions of the American Fisheries Society, 148*(2), https://doi.org/10.1002/tafs.10140

It is asserted that reduction or elimination of hatchery stocking will increase natural-origin salmon Oncorhynchus spp. and steelhead O. mykiss production. We conducted an analysis of steelhead population census data (1958–2017) to determine whether elimination of summer steelhead stocking in the upper Clackamas River in 1998 increased the productivity of natural-origin winter steelhead. A Bayesian state–space stock–recruitment model was fitted to the adult steelhead data set, and productivity was estimated as a function of hatchery-origin spawner abundance as well as other environmental factors. When used as a predictive variable in our model, the abundance of hatchery summer steelhead spawners (1972–2001) did not have a negative effect on winter steelhead recruitment. However, spill at North Fork Dam (the gateway to the upper Clackamas River basin) and the Pacific Decadal Oscillation (an index of ocean conditions) were both negatively associated with winter steelhead recruitment. Moreover, winter steelhead abundance in the upper Clackamas River basin failed to rebound to abundances observed in years prior to the hatchery program, and fluctuations in winter steelhead abundance were correlated with those of other regional winter steelhead stocks. Our assessment underscores the need for studies that (1) directly quantify the effects of hatchery fish on the production of natural-origin salmon and steelhead, (2) empirically test published theories about mechanisms of hatchery fish impacts on natural-origin populations, and (3) document population responses to major changes in hatchery programs.

Crozier, L. G., McClure, M. M., Beechie, T., Bograd, S. J., Boughton, D. A., Carr, M., . . . Willis-Norton, E. (2019). Climate Vulnerability Assessment for Pacific Salmon and Steelhead in the California Current Large Marine Ecosystem. *Plos One, 14*(7), https://doi.org/10.1371/journal.pone.0217711

Major ecological realignments are already occurring in response to climate change. To be successful, conservation strategies now need to account for geographical patterns in traits sensitive to climate change, as well as climate threats to species-level diversity. As part of an effort to provide such information, we conducted a climate vulnerability assessment that included all anadromous Pacific salmon and steelhead (Oncorhynchus spp.) population units listed under the U.S. Endangered Species Act. Using an expert-based scoring system, we ranked 20 attributes for the 28 listed units and 5 additional units. Attributes captured biological sensitivity, or the strength of linkages between each listing unit and the present climate; climate exposure, or the magnitude of projected change in local environmental conditions; and adaptive capacity, or the ability to modify phenotypes to cope with new climatic conditions. Each listing unit was then assigned one of four vulnerability categories. Units ranked most vulnerable overall were Chinook (O. tshawytscha) in the California Central Valley, coho (O. kisutch) in California and southern Oregon, sockeye (O. nerka) in the Snake River Basin, and spring-run Chinook in the interior Columbia and Willamette River Basins. We identified units with similar vulnerability profiles using a hierarchical cluster analysis. Life history characteristics, especially freshwater and estuary residence times, interplayed with gradations in exposure from south to north and from coastal to interior regions to generate landscape-level patterns within each species. Nearly all listing units faced high exposures to projected increases in stream temperature, sea surface temperature, and ocean acidification, but other aspects of exposure peaked in particular regions. Anthropogenic factors, especially migration barriers, habitat degradation, and hatchery influence, have reduced the adaptive capacity of most steelhead and salmon populations. Enhancing adaptive capacity is essential to mitigate for the increasing threat of climate change. Collectively, these results provide a framework to support recovery planning that considers climate impacts on the majority of West Coast anadromous salmonids.

Dolan, B. P., Fisher, K. M., Colvin, M. E., Benda, S. E., Peterson, J. T., Kent, M. L., & Schreck, C. B. (2016). Innate and Adaptive Immune Responses in Migrating Spring-Run Adult Chinook Salmon, Oncorhynchus tshawytscha. *Fish & Shellfish Immunology, 48*, https://doi.org/10.1016/j.fsi.2015.11.015

Adult Chinook salmon (Oncorhynchus tshawytscha) migrate from salt water to freshwater streams to spawn. Immune responses in migrating adult salmon are thought to diminish in the run up to spawning, though the exact mechanisms for diminished immune responses remain unknown. Here we examine both adaptive and innate immune responses as well as pathogen burdens in migrating adult Chinook salmon in the Upper Willamette River basin. Messenger RNA transcripts encoding antibody heavy chain molecules slightly diminish as a function of time, but are still present even after fish have successfully spawned. In contrast, the innate anti-bacterial effector proteins present in fish plasma rapidly decrease as spawning approaches. Fish also were examined for the presence and severity of eight different pathogens in different organs. While pathogen burden tended to increase during the migration, no specific pathogen signature was associated with diminished immune responses. Transcript levels of the immunosuppressive cytokines 1L-10 and TGF beta were measured and did not change during the migration. These results suggest that loss of immune functions in adult migrating salmon are not due to pathogen infection or cytokine-mediated immune suppression, but is rather part of the life history of Chinook salmon likely induced by diminished energy reserves or hormonal changes which accompany spawning.

Erdman, C. S., Caudill, C. C., Naughton, G. P., & Jepson, M. A. (2018). Release of Hatchery Adult Steelhead for Angler Opportunity Increases Potential for Interactions with Endemic Steelhead. *Ecosphere, 9*(10), https://doi.org/10.1002/ecs2.2448

Translocation is often used to increase local abundance of fish and wildlife populations for conservation or harvest purposes, and effects of releases on recipient populations are context dependent. Release of non-local animals intended for harvest can have negative demographic, genetic, and ecological risks to endemic populations when not harvested. In 2012–2014, we used radiotelemetry to monitor the fate and potential for interactions between non-local hatchery-origin adult summer-run steelhead Oncorhynchus mykiss (n = 423) and Endangered Species Act (ESA)-listed native winter-run steelhead (WRS) in two tributaries of the Willamette River, Oregon, USA. Summer steelhead were recycled—collected, translocated downstream, and released—to provide additional angler opportunity as a part of a regional mitigation program. Overall, reported harvest rate of recycled steelhead was low (15%) and a majority of individuals (62%) were last recorded in the release tributary. Furthermore, 14% of radio-tagged recycled steelhead were last detected outside the release tributary (i.e., strayed after release). Expanded estimates indicate the number of recycled summer-run steelhead remaining in the South Santiam River exceeded the WRS spawning population size. Low reported harvest and straying and demographic estimates indicate the recycling program may have negative effects on endemic WRS. Translocation and hatchery supplementation are likely to remain important conservation and mitigation tools in the future, though these results highlight the importance of post-release monitoring and considering both the risks and benefits of translocations to endemic populations and communities.

Evans, M. L., Hard, J. J., Black, A. N., Sard, N. M., & O'Malley, K. G. (2019). A Quantitative Genetic Analysis of Life-History Traits and Lifetime Reproductive Success in Reintroduced Chinook Salmon. *Conservation Genetics, 20*(4), https://doi.org/10.1007/s10592-019-01174-4

Reintroductions are widely implemented as a means of reestablishing wild populations and genetic parentage methods can be used in concert with theseeffortsto monitorand evaluate efficacy. In addition to understanding demographic outcomes, reconstructed pedigrees,when combined with phenotypic data, can provide insight into the adaptive potential of reintroduced individuals. Here, we examined the heritability and evolvability of life-history traits and lifetime reproductive success in two threatened Chinook salmon populations undergoing reintroduction to historical habitats above dams in Oregon, USA, using previously-developed multigenerational genetic pedigrees. All of the examined life-history traits: length-at-maturity, age-at-maturity, and arrival timing to the spawning grounds, and lifetime reproductive success exhibited significant narrow-sense heritabilities and evolvabilities. There was also a detectable influence of parental effects (i.e., paternal or maternal effects) on life-history traitvariation, suggesting that in addition to genetic effects, nongenetic inheritance mechanisms are influencing life-history diversity in the populations. Additionally, our analyses revealed evidence ofnatural selection on the date of reintroduction, although the form and intensity of selection differed between the two populations; the forms of selection alsopoint to the potential for phenotype-environment mismatch under some conditions. Overall, our results suggest that these threatened Chinook salmon populations exhibit significant adaptive potential, a factor that should be important to the longer-term success of recovery efforts.

Harnish, R. A., Green, E. D., Vernon, C. R., & Mcmichael, G. A. (2014). *Ecological Interactions between Hatchery Summer Steelhead and Wild Oncorhynchus mykiss in the Willamette River Basin, 2014.* Pacific Northwest National Lab.(PNNL), Richland, WA (United States) Retrieved from https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23891.pdf

The ecological interactions study described herein was conducted by researchers from the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE) during the spring and summer of 2014 as a follow-on to a study conducted in 2013. The purpose of this study was to determine the extent to which hatchery summer and wild winter steelhead juveniles overlapped in space and time and to investigate the potential for negative behavioral interactions. Because it is not possible to visually discern juvenile winter steelhead from resident rainbow trout Oncorhynchus mykiss, we treated all unclipped juvenile O. mykiss as one group that represented juvenile wild winter steelhead.

Herron, C. L., Kent, M. L., & Schreck, C. B. (2018). Swimming Endurance in Juvenile Chinook Salmon Infected with Salmincola Californiensis. *Journal of Aquatic Animal Health, 30*(1), https://doi.org/10.1002/aah.10010

Juvenile Chinook Salmon Oncorhynchus tshawytscha moving downstream through tributaries of the upper Willamette River basin can spend months in reservoirs created by dams. While residing in the reservoirs, they often obtain heavy infections of the freshwater parasitic copepod Salmincola californiensis. The physiologic effect these parasites have on salmonids is poorly understood. We developed a method to infect juvenile Chinook Salmon in a laboratory with the copepodid stage of S. californiensis. Infected and uninfected fish were subjected to a swimming challenge to ascertain swimming endurance. Severity of gill damage was assessed using a dissecting microscope. Juvenile Chinook Salmon naturally infected with S. californiensis in Cougar Reservoir, Oregon, were also challenged and compared with their lab-infected counterparts. Copepod infection greatly impaired the swimming ability of laboratory fish, and the naturally infected fish were entirely incapable of swimming at low velocity. Chinook Salmon collected in the wild were more heavily infected than the laboratory fish and had trouble surviving collection and transport to our laboratory. The intensity of infection and severity of gill damage were positively correlated with diminished swimming ability, suggesting that heavy infection with copepods impairs gas exchange and osmotic regulation, which likely results in diminished fitness and decreased survival of infected fish.

Jager, H. I., King, A. W., Gangrade, S., Haines, A., DeRolph, C., Naz, B. S., & Ashfaq, M. (2018). Will Future Climate Change Increase the Risk of Violating Minimum Flow and Maximum Temperature Thresholds Below Dams in the Pacific Northwest? *Climate Risk Management, 21*, https://doi.org/10.1016/j.crm.2018.07.001

Detecting and avoiding environmental thresholds that lead to catastrophic change in ecological communities is an important goal, and one that is especially challenging to address over broad geographic extents. Here, we conducted a regional-scale climate vulnerability assessment (RCVA) to quantify the risk of violating thermal and minimum-flow thresholds below reservoirs. Our analysis used hybrid (process-based and empirical) models of tailwater temperature and flow driven by 4-km downscaled CMIP5 climate projections. Downscaling employed a combination of process-based models, quantile mapping, and a non-linear ‘reservoir’ transform function. RCVA can be applied at regional scales without proprietary and data-intensive physical models of reservoir systems or ecological models of species that comprise tailwater communities. Using RCVA, we produced ensemble projections of risk and duration of extreme high-temperature or low-flow events below federal reservoirs in the Pacific Northwest (PNW), USA. Bayesian modeling of simulated results allowed us to evaluate differences between risk under a future and baseline scenario relative to model uncertainties and to quantify uncertainty in modeled risks. Based on assumptions that historical patterns of reservoir dynamics and operation will continue, and that regulatory thresholds will not change, the risk of thermal exceedance was projected to increase by an average of 0.27 and extend into late-spring and fall (average change in duration of 10.3 d). For flow, RCVA projected an increase of 0.07 in the average risk below-thresholds flows, with an average increase in duration of 4.6 d. Both results raise concerns that cold-water salmonids of the PNW will be at increased risk under a future climate scenario.

Johnson, M. A., & Friesen, T. A. (2014). Genetic Diversity and Population Structure of Spring Chinook Salmon from the Upper Willamette River, Oregon. *North American Journal of Fisheries Management, 34*(4), https://doi.org/10.1080/02755947.2014.920739

Effective management of Pacific salmon requires an accurate understanding of both population genetic diversity and structure. Spring Chinook Salmon Oncorhynchus tshawytscha from the upper Willamette River (UWR), Oregon, are listed as threatened under the U. S. Endangered Species Act, and although this evolutionarily significant unit is recognized to be distinct from other Columbia River stocks, genetic relationships among its constituent hatchery and wild populations remain obscure. We used genotypic data from 13 microsatellite loci to test whether hatchery populations of UWR spring Chinook Salmon are most similar to wild populations within the same subbasin, or whether hatchery populations from different subbasins are more similar to each other than to local wild populations. We also tested for differences between the genetic diversities of hatchery and wild populations, as measured through heterozygosity and allelic richness. Our results suggest that populations are weakly structured among subbasins and, in all cases, hatchery populations are genetically most similar to local wild populations. We also found heterozygosity to be higher ($P = 0.009$) in hatchery populations (median, 81.5%) than in wild populations (median, 75.2%), but observed no significant difference with respect to allelic richness ($P = 0.406$). We conclude that hatchery-origin UWR spring Chinook Salmon represent genetically appropriate founder populations for ongoing reintroduction programs and recommend that the conservation and recovery of this stock proceed through management actions developed specifically for each subbasin. We further recommend that current restrictions on hatchery stock transfers among UWR subbasins be continued to preserve extant population genetic structure.

Johnson, M. A., Noakes, D. L. G., Friesen, T. A., Dittman, A. H., Couture, R. B., Schreck, C. B., . . . Quinn, T. P. (2019). Growth, Survivorship, and Juvenile Physiology of Triploid Steelhead (Oncorhynchus mykiss). *Fisheries Research, 220*, https://doi.org/10.1016/j.fishres.2019.105350

Induced triploidy typically causes sterility in teleost fishes, and has therefore been proposed as a tool to manage genetic risks that farmed and hatchery-produced salmon pose to wild populations. Application of this technology for aquaculture has been challenged by inferior growth, survivorship and, in the case of free-ranging anadromous salmonids, relatively low numbers of adult returns. There is little information on whether or not triploidy affects the physiological development of juvenile salmonids in ways that impair their ability to grow, imprint on natal waters, survive, and return from the ocean as adults. In this study we pressure treated fertilized eggs to produce two cohorts of triploid hatchery steelhead trout (i.e., anadromous Oncorhynchus mykiss). We calculated survivorship through early life stages, and measured gill ATPase and plasma thyroxine (T4) for yearling triploids and their full-sibling diploid controls. We found no clear pattern of difference between diploid and triploid steelhead for the biomarkers of smoltification T4 or ATPase. After a year of freshwater rearing, we transferred 448 tagged treatment and control fish to a saltwater tank, and tracked their growth and survivorship for over 15 months. Diploids outperformed triploids in growth and, by the end of our study, survivorship of diploids (72%) was more than twice that of triploids (35%). Our findings suggest that inferior growth and survivorship of triploids in saltwater seriously challenge the application of this technology for free-ranging steelhead and, by extension, Pacific salmon. Additional research is needed to identify and offset the causal mechanisms underpinning triploid attrition during saltwater rearing.

Johnston, R. J., Jarvis, D., Wallmo, K., & Lew, D. K. (2015). Multiscale Spatial Pattern in Nonuse Willingness to Pay: Applications to Threatened and Endangered Marine Species. *Land Economics, 91*(4), https://doi.org/10.3368/le.91.4.739

This paper demonstrates methods that may be combined to characterize otherwise undetectable spatial heterogeneity in stated preference willingness to pay (WTP) estimates that may occur at multiple geospatial scales. These include methods applicable to large-scale analysis with diffuse policy impacts and uncertainty regarding the appropriate scales over which spatial patterns should be evaluated. Illustrated methods include spatial interpolation and multiscale analysis of hot/cold spots using local indicators of spatial association. An application to threatened and endangered marine species illustrates the empirical findings that emerge. Findings include large-scale clustering of nonuse WTP estimates at multiple scales of analysis.

Keefer, M. L., Blubaugh, T. J., Clabough, T. S., Jepson, M. A., Naughton, G. P., & Caudill, C. C. (2018). Coho Salmon Colonization of Oregon's Upper Willamette River Basin. *Transactions of the American Fisheries Society, 147*(6), https://doi.org/10.1002/tafs.10112

Coho Salmon Oncorhynchus kisutch were historically absent from a major Columbia River subbasin, the upper Willamette River (UWR), until a fishway was installed at Willamette Falls and a sustained stocking program was implemented in the 1950s. Despite decades of stocking from three diverse source populations (early run, late run, and coastal Coho Salmon) during the second half of the twentieth century, adult abundance above the falls was less than 1,000 annually during the 1990s. A recent surge (>25,000 adults in 2009) has raised concerns about potential interactions with two native anadromous salmonids listed under the U.S. Endangered Species Act: UWR winter-run steelhead O. mykiss and UWR spring-run Chinook Salmon O. tshawytscha. We analyzed Coho Salmon stocking records and estimates of abundance from 1954-2017 to summarize population history, demographics, and adult phenology. We also characterized current Coho Salmon distribution using radiotelemetry (n = 219 adults in 2014) and evaluated potential mechanisms associated with changes in adult abundance. We identified a shift in adult migration timing over the time series that was consistent with an increase in late-run traits and environmental changes affecting migration cues. The distribution of radio-tagged adults among UWR subbasins was only weakly correlated with past stocking efforts, suggesting that habitat conditions, stocked phenotype, adaptation and range expansion by descendants of the relict stocked populations, or colonization from regional source populations strongly influenced current subpopulation abundance. Annual counts of returning UWR Coho Salmon were positively correlated with counts of Columbia River Coho salmon, suggesting a shared response to freshwater habitat or ocean conditions. Regardless of the underlying mechanisms affecting UWR Coho Salmon distribution and population size, the results illustrate the complex dynamics between changing landscapes and migration corridors, the introduction of nonnative species for harvest management goals, and the potential for nonnative fish to affect the conservation of native populations.

Keefer, M. L., Clabough, T. S., Jepson, M. A., Naughton, G. P., Blubaugh, T. J., Joosten, D. C., & Caudill, C. C. (2015). Thermal Exposure of Adult Chinook Salmon in the Willamette River Basin. *Journal of Thermal Biology, 48*, https://doi.org/10.1016/j.jtherbio.2014.12.002

Radiotelemetry and archival temperature loggers were used to reconstruct the thermal experience of adult spring Chinook salmon (Oncorhynchus tshawytscha) in the highly regulated Willamette River system in Oregon. The study population is threatened and recovery efforts have been hampered by episodically high prespawn mortality that is likely temperature mediated. Over three years, 310 salmon were released with thermal loggers and 68 were recovered in spawning tributaries, primarily at hatchery trapping facilities downstream from high-head dams. More than 190,000 internal body temperature records were collected (mean similar to 2800 per fish) and associated with 14 main stem and tributary reaches. Most salmon experienced a wide temperature range (minima similar to 8-10 degrees C; maxima similar to 13-22 degrees C) and 65% encountered potentially stressful conditions (>= 18 degrees C). The warmest salmon temperatures were in lower Willamette River reaches, where some fish exhibited short-duration behavioral thermoregulation. Cumulative temperature exposure, measured by degree days (DD) above 0 degrees C, varied more than seven-fold among individuals (range=208-1498 DDs) and more than two-fold among sub-basin populations, on average. Overall, similar to 72% of DDs accrued in tributaries and similar to 28% were in the Willamette River main stem. DD differences among individuals and populations were related to migration distance, migration duration, and salmon trapping protocols (i.e., extended pre-collection holding in tributaries versus hatchery collection shortly after tributary entry). The combined data provide spatially- and temporally-referenced information on both short-duration stressful temperature exposure and the biologically important total exposure. Thermal exposure in this population complex proximately influences adult salmon physiology, maturation, and disease processes and ultimately affects prespawn mortality and fitness. The results should help managers develop more effective salmon recovery plans in basins with marginal thermal conditions.

Keefer, M. L., Jepson, M. A., Naughton, G. P., Blubaugh, T. J., Clabough, T. S., & Caudill, C. C. (2017). Condition-Dependent En Route Migration Mortality of Adult Chinook Salmon in the Willamette River Main Stem. *North American Journal of Fisheries Management, 37*(2), https://doi.org/10.1080/02755947.2016.1269032

Episodically high adult mortality during migration and near spawning sites has hindered the recovery of threatened spring-run Chinook Salmon Oncorhynchus tshawytscha in Oregon's Willamette River basin. In 2011-2014, we assessed migration mortality for 762 radio-tagged adults along a similar to 260-km reach of the main stem of the Willamette River. Annual survival of salmon to spawning tributaries ranged from 0.791 (95% CI = 0.741-0.833) to 0.896 (0.856-0.926), confirming concerns about mortality in the migration corridor. In a series of general linear models, descaling, marine mammal injuries, and head injuries to adult Chinook Salmon were linked to reduced survival during migration to tributaries. Many injuries were minor (i. e., epidermal abrasions), which we hypothesize were unlikely to have caused direct mortality but may have increased salmon vulnerability to pathogens or other disease processes. Mortality in the main stem was not significantly associated with salmon body size, energetic status, sex, origin (hatchery, wild), river discharge, or water temperature metrics. The similar to 10-21% estimates of en route mortality in this study provide an important benchmark for the main stem of the Willamette River. The estimates complement ongoing efforts to quantify mortality of adult Chinook Salmon in Willamette River tributaries and after collection and transport to spawning sites above high-head hydroelectric dams.

Kent, M. L., Soderlund, K., Thomann, E., Schreck, C. B., & Sharpton, T. J. (2014). Post-Mortem Sporulation of Ceratomyxa Shasta (Myxozoa) after Death in Adult Chinook Salmon. *Journal of Parasitology, 100*(5), https://doi.org/10.1645/13-490.1

Ceratomyxa shasta (Myxozoa) is a common gastrointestinal pathogen of salmonid fishes in the Pacific Northwest of the United States. We have been investigating this parasite in adult Chinook salmon (Oncorhynchus tshawytscha) in the Willamette River, Oregon. In prior work, we observed differences in the pattern of development of C. shasta in adult salmon compared to juvenile salmon. Adult salmon consistently had large numbers of prespore stages in many of the fish that survived to spawn in the fall. However, myxospores were rarely observed, even though they were exposed and presumably infected for months before spawning. We evaluated the ability of C. shasta to sporulate following fish death because it is reported that myxosores are common in carcasses of Chinook salmon. We collected the intestine from 30 adult salmon immediately after artificial spawning and death (T-0). A total of 23 fish were infected with C. shasta based on histology, but only a few myxospores were observed in 1 fish by histology. Intestines of these fish were examined at T-0 and T-7 (latter held at 17 C for 7 days) using quantified wet mount preparations. An increase in myxospore concentrations was seen in 39% of these fish, ranging between a 1.5- to a 14.5-fold increase. The most heavily infected fish exhibited a 4.6-fold increase from 27,841 to 129,352 myxospores/cm. This indicates, supported by various statistical analyses, that under certain conditions presporogonic forms are viable and continue to sporulate after death in adult salmon. Considering the life cycle of C. shasta and anadromous salmon, the parasite may have evolved 2, non-mutually exclusive developmental strategies. In young fish (parr and smolts), the parasite sporulates shortly after infection and is released into freshwater from either live or dead fish before their migration to seawater, where the alternate host is absent. The second strategy occurs in adult salmon, particularly spring Chinook salmon, which become infected upon their return to freshwater in the spring or early summer. For several months throughout the summer, only prespore stages are observed in most fish, even at the time of spawning. But once the fish dies, environmental conditions experienced by C. shasta change and viable presporogonic stages are induced to sporulate. As the post-spawned fish occur in the upper reaches of rivers, the myxospores would be released in a freshwater environment that would provide a reasonable opportunity for them to encounter their freshwater polychaete hosts, which reside downstream.

Kock, T. J., Perry, R. W., Pope, A. C., Serl, J. D., Kohn, M., & Liedtke, T. L. (2018). Responses of Hatchery- and Natural-Origin Adult Spring Chinook Salmon to a Trap-and-Haul Reintroduction Program. *North American Journal of Fisheries Management, 38*(5), https://doi.org/10.1002/nafm.10199

The construction of impassable dams severely affected many Pacific salmon Oncorhynchus spp. populations, resulting in reintroduction efforts that are now focused on returning anadromous fish to areas located upstream of these dams. A primary strategy for moving adult salmon and steelhead O. mykiss around a dam or multiple dams involves trapping fish downstream and transporting them to upstream areas ("trap and haul") for spawning. We conducted a 4-year radiotelemetry study to evaluate behavior and movement patterns of hatchery- and natural-origin adult spring Chinook Salmon O. tshawytscha after a trap-and-haul program was implemented around three dams on the Cowlitz River, Washington. A multistate model was used to describe how factors such as origin, sex, release site location, and discharge affected transition rates to riverine areas where spawning habitat was located. Natural-origin Chinook Salmon moved upstream from a reservoir release site and entered one of two rivers more quickly and in greater proportions than hatchery-origin fish. Results from the multistate model indicated that transition rates from the reservoir to the Cowlitz River were 2.2 times higher for natural-origin Chinook Salmon than for hatchery-origin fish. About one-half (49.6%) of the reservoir-released hatchery-origin Chinook Salmon moved upstream into the Cowlitz River or the Cispus River during the spawning period. The release of hatchery-origin Chinook Salmon directly into these rivers increased the percentage of fish with river fates during the spawning period to 72.3–75.4%. Results from the multistate model showed that factors such as release site location, origin, day of year, and discharge were important predictors of transition intensities between specific locations in the study area. These findings illustrate the need to evaluate how salmon and steelhead respond to trap-and-haul methods, allowing for better management of reintroduction efforts in the future.

Lundin, J. I., Spromberg, J. A., Jorgensen, J. C., Myers, J. M., Chittaro, P. M., Zabel, R. W., . . . Scholz, N. L. (2019). Legacy Habitat Contamination as a Limiting Factor for Chinook Salmon Recovery in the Willamette Basin, Oregon, USA. *Plos One, 14*(3), https://doi.org/10.1371/journal.pone.0214399

In the western United States, the long-term recovery of many Pacific salmon populations is inextricably linked to freshwater habitat quality. Industrial activities from the past century have left a legacy of pollutants that persist, particularly near working waterfronts. The adverse impacts of these contaminants on salmon health have been studied for decades, but the population-scale consequences of chemical exposure for salmonids are still poorly understood. We estimated acute and delayed mortality rates for seaward migrating juvenile Chinook salmon that feed and grow in a Superfund-designated area in the Lower Willamette River in Portland, Oregon. We combined previous, field-collected exposure data for juvenile Chinook salmon together with reduced growth and disease resistance data from earlier field and laboratory studies. Estimates of mortality were then incorporated into a life cycle model to explore chemical habitat-related fish loss. We found that 54% improved juvenile survival—potentially as a result of future remediation activities—could increase adult Chinook salmon population abundance by more than 20%. This study provides a framework for evaluating pollution remediation as a positive driver for species recovery.

Matala, A. P., Ackerman, M. W., Campbell, M. R., & Narum, S. R. (2014). Relative Contributions of Neutral and Non-Neutral Genetic Differentiation to Inform Conservation of Steelhead Trout across Highly Variable Landscapes. *Evolutionary Applications, 7*(6), https://doi.org/10.1111/eva.12174

Mounting evidence of climatic effects on riverine environments and adaptive responses of fishes have elicited growing conservation concerns. Measures to rectify population declines include assessment of local extinction risk, population ecology, viability, and genetic differentiation. While conservation planning has been largely informed by neutral genetic structure, there has been a dearth of critical information regarding the role of non-neutral or functional genetic variation. We evaluated genetic variation among steelhead trout of the Columbia River Basin, which supports diverse populations distributed among dynamic landscapes. We categorized 188 SNP loci as either putatively neutral or candidates for divergent selection (non-neutral) using a multitest association approach. Neutral variation distinguished lineages and defined broad-scale population structure consistent with previous studies, but fine-scale resolution was also detected at levels not previously observed. Within distinct coastal and inland lineages, we identified nine and 22 candidate loci commonly associated with precipitation or temperature variables and putatively under divergent selection. Observed patterns of non-neutral variation suggest overall climate is likely to shape local adaptation (e.g., potential rapid evolution) of steelhead trout in the Columbia River region. Broad geographic patterns of neutral and non-neutral variation demonstrated here can be used to accommodate priorities for regional management and inform long-term conservation of this species.

Monzyk, F. R., Friesen, T. A., & Romer, J. D. (2015). Infection of Juvenile Salmonids by Salmincola Californiensis (Copepoda: Lernaeopodidae) in Reservoirs and Streams of the Willamette River Basin, Oregon. *Transactions of the American Fisheries Society, 144*(5), https://doi.org/10.1080/00028487.2015.1052558

We assessed infection prevalence and intensity by the ectoparasitic copepod Salmincola californiensis among salmonid species rearing in reservoirs and streams upstream of reservoirs in the Willamette River basin, Oregon, during 2012 and 2013. Infection levels of juvenile Chinook Salmon Oncorhynchus tshawytscha, Rainbow Trout O. mykiss, and Cutthroat Trout O. clarkii were greater in reservoirs than in streams and increased with the age and size of fish. Copepods were more likely to be attached within the brachial cavity of reservoir fish (79%), whereas fins were the most common attachment site on stream fish (71%). Chinook Salmon in reservoirs were more vulnerable to infection than other species. Age-0 Chinook Salmon in reservoirs showed increasing infection prevalence throughout the year, reaching 84% by fall (compared with 11% in streams). Infection intensity was greater for age-0 Chinook Salmon in reservoirs than for those in streams. Infection prevalence for reservoir-rearing Rainbow Trout was < 1% at age 0, 22% at age 1, 36% at age 2, and 38% at age 3. Intensity was low for age-1 Rainbow Trout and increased for age-2 and age-3 fish. Infection prevalence for reservoir-rearing Cutthroat Trout collected in spring (39%) was greater than for those rearing in streams (4.5%). Juvenile kokanee O. nerka were only present in reservoirs and were rarely infected with copepods. The lack of water current in reservoirs may increase the likelihood of infection in the brachial cavity. Greater infection levels observed for juvenile Chinook Salmon compared with the other species in reservoirs may be a function of behavioral, physiological, and habitat differences. We concluded that copepod infection in reservoirs reached levels that could decrease the fitness and survival of Chinook Salmon smolts, potentially hampering conservation and recovery efforts.

Murphy, C. A., Taylor, G., Pierce, T., Arismendi, I., & Johnson, S. L. (2019). Short-Term Reservoir Draining to Streambed for Juvenile Salmon Passage and Non-Native Fish Removal. *Ecohydrology, 12*(6), https://doi.org/10.1002/eco.2096

Fish passage out of reservoirs is a critical issue for downstream movement of juvenile salmonids and other migratory species. Reservoirs can delay downstream migrations by juvenile salmon for months or years. Here, we examine whether a novel management activity implementing annual short-term draining of a reservoir to streambed improves timely downstream migration of juvenile salmonids. We analyse 12 years of fish capture data from a screw trap located downstream of Fall Creek Reservoir (Oregon, USA) to examine changes in timing of passage out of the reservoir and to compare fish species composition pre- and post-draining. We observed a contraction in the timing of downstream migration for juvenile Chinook Salmon and reduction of yearlings in years following draining. We suggest that briefly draining the reservoir to streambed leads to reduced abundance of warm-water invasive fishes in the reservoir after it refills. These changes could decrease predation and shift competition between invasive and resident riverine-adapted native fishes in the reservoir. Collectively, our findings suggest that this low-cost reservoir management option may improve passage and connectivity for juvenile Chinook Salmon while also decreasing the abundance of invasive fish species in the reservoir. This case study underscores the crucial need for further evaluations of reservoir draining in other systems and contexts.

National Marine Fisheries Service. (2016). *2016 5-Year Review : Summary & Evaluation of Upper Willamette River Steelhead Upper Willamette River Chinook*. https://doi.org/10.1254/jjp.27.9

Many West Coast salmon and steelhead (Oncorhynchus sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the 2016 five-year reviews of the ESA-listed Upper Willamette River (UWR) steelhead and Chinook salmon.

Oregon Department of Fish and Wildlife. (2018). *Genetic Influence from Hatchery Stocks on Upper Willamette River Steelhead Oncorhynchus mykiss*. Oregon Department of Fish and Wildlife Retrieved from https://odfw.forestry.oregonstate.edu/willamettesalmonidrme/sites/default/files/info_report_2018-03_uwr_steelhead.pdf

In this study we used microsatellite markers to genetically characterize 1,012 unmarked (presumed to be naturally produced), juvenile Oncorhynchus mykiss, collected at Willamette Falls in 2009, 2010 and 2011, and from multiple locations throughout the upper Willamette River basin in 2014. From the genetic data, we estimated the proportion of each year's sample that could be assigned as native resident rainbow trout, native winter steelhead, hatchery summer steelhead, the likely descendants of a discontinued hatchery winter steelhead program, or hybrids of these groups. We also attempted to assign individuals to pure or hybrid classes (e.g. F1, F2, backcrosses) and evaluated the predicted accuracy of these class assignments. Although the majority of fish analyzed in each year were assigned as native winter steelhead, we found evidence of natural production by introduced stocks of steelhead. Genetic influence from a discontinued winter steelhead hatchery program was most evident in the Tualatin, Yamhill, Molalla, and below-dam reaches of the North and South Santiam rivers. Pure and hybrid signals from introduced summer steelhead were almost entirely restricted to below-dam reaches of major eastern tributaries and the Molalla River. Evidence of non-native steelhead was nearly absent from above-dam reaches of major tributaries and the Calapooia River. Despite continued hatchery releases of summer steelhead in the Willamette River, we found no compelling evidence for the presence of first-generation hybrid offspring (F1s) that might result from hatchery summer and native winter steelhead matings. However, simulation analyses revealed low statistical power to confidently identify such individuals from our data. We recommend that areas containing native steelhead populations with high genetic integrity receive protection through directed conservation efforts, and continued genetic monitoring should be conducted to inform these efforts and future status reviews

Romer, J. D., & Monzyk, F. R. (2014). Adfluvial Life History in Spring Chinook Salmon from Quartzville Creek, Oregon. *North American Journal of Fisheries Management, 34*(5), https://doi.org/10.1080/02755947.2014.923073

Through spawning ground and snorkel surveys, we confirmed the presence of adfluvial spring Chinook SalmonOncorhynchus tshawytschaina a tributary upstream from a high-head dam in the upper Willamette River in northwest Oregon. Spring Chinook Salmon previously had been extirpated above the dam but juvenile hatchery fish were released in the reservoir in subsequent years. In 2012, we recovered six carcasses of adfluvial Chinook Salmon adults, identified nine live adults, and recorded nine redds. Analyses of scales from carcasses revealed those fish were ages 5–6. Otolith microchemistry from an unmarked adult female Chinook Salmon did not indicate ocean residence, and no hatchery thermal marks were observed, suggesting this fish was the progeny of adfluvial adults. In 2013, we observed one live, unclipped adult and three juvenile Chinook Salmon. We conclude that adfluvial spring Chinook Salmon exist in Green Peter Reservoir and successfully reproduce. This is the first documentation of adfluvial Chinook Salmon in Oregon, and this unusual life history should be considered in the context of research, monitoring, and recovery actions pertaining to ongoing reintroduction programs for threatened Willamette River spring Chinook Salmon above dams.

Schroeder, R. K., Whitman, L. D., Cannon, B., & Olmsted, P. (2016). Juvenile Life-History Diversity and Population Stability of Spring Chinook Salmon in the Willamette River Basin, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences, 73*(6), https://doi.org/10.1139/cjfas-2015-0314

Migratory and rearing pathways of juvenile spring Chinook salmon (Oncorhynchus tshawytscha) were documented in the Willamette River basin to identify life histories and estimate their contribution to smolt production and population stability. We identified six primary life histories that included two phenotypes for early migratory tactics: fry that migrated up to 140-200 km shortly after emergence (movers) and fish that reared for 8-16 months in natal areas (stayers). Peak emigration of juvenile salmon from the Willamette River was in June-July (subyearling smolts), March-May (yearling smolts), and November-December (considered as "autumn smolts"). Alternative migratory behaviors of juvenile salmon were associated with extensive use of diverse habitats that eventually encompassed up to 400 rkm of the basin, including tributaries in natal areas and large rivers. Juvenile salmon that reared in natal reaches and migrated as yearlings were the most prevalent life history and had the lowest temporal variability. However, the total productivity of the basin was increased by the contribution of fish with dispersive life histories, which represented over 50% of the total smolt production. Life-history diversity reduced the variability in the total smolt population by 35% over the weighted mean of individual life histories, providing evidence of a considerable portfolio effect through the asynchronous contributions of life histories. Protecting and restoring a diverse suite of connected habitats in the Willamette River basin will promote the development and expression of juvenile life histories, thereby providing stability and resilience to native salmon populations.

Sorel, M. H., Hansen, A. G., Connelly, K. A., & Beauchamp, D. A. (2016). Trophic Feasibility of Reintroducing Anadromous Salmonids in Three Reservoirs on the North Fork Lewis River, Washington: Prey Supply and Consumption Demand of Resident Fishes. *Transactions of the American Fisheries Society, 145*(6), https://doi.org/10.1080/00028487.2016.1219678

The reintroduction of anadromous salmonids in reservoirs is being proposed with increasing frequency, requiring baseline studies to evaluate feasibility and estimate the capacity of reservoir food webs to support reintroduced populations. Using three reservoirs on the north fork Lewis River as a case study, we demonstrate a method to determine juvenile salmonid smolt rearing capacities for lakes and reservoirs. To determine if the Lewis River reservoirs can support reintroduced populations of juvenile stream-type Chinook Salmon Oncorhynchus tshawytscha, we evaluated the monthly production of daphnia Daphnia spp. (the primary zooplankton consumed by resident salmonids in the system) and used bioenergetics to model the consumption demand of resident fishes in each reservoir. To estimate the surplus of Daphnia prey available for reintroduced salmonids, we assumed a maximum sustainable exploitation rate and accounted for the consumption demand of resident fishes. The number of smolts that could have been supported was estimated by dividing any surplus Daphnia production by the simulated consumption demand of an individual Chinook Salmon fry rearing in the reservoir to successful smolt size. In all three reservoirs, densities of Daphnia were highest in the epilimnion, but warm epilimnetic temperatures and the vertical distribution of planktivores suggested that access to abundant epilimnetic prey was limited. By comparing accessible prey supply and demand on a monthly basis, we were able to identify potential prey supply bottlenecks that could limit smolt production and growth. These results demonstrate that a bioenergetics approach can be a valuable method of examining constraints on lake and reservoir rearing capacity, such as thermal structure and temporal food supply. This method enables numerical estimation of rearing capacity, which is a useful metric for managers evaluating the feasibility of reintroducing Pacific salmon Oncorhynchus spp. in lentic systems.
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Teel, D. J., Burke, B. J., Kuligowski, D. R., Morgan, C. A., & Van Doornik, D. M. (2015). Genetic Identification of Chinook Salmon: Stock-Specific Distributions of Juveniles Along the Washington and Oregon Coasts. *Marine and Coastal Fisheries, 7*(1), https://doi.org/10.1080/19425120.2015.1045961

We used microsatellite DNA data and genetic stock identification methods to delineate the temporal and spatial distributions of juvenile Chinook Salmon Oncorhynchus tshawytscha occupying coastal habitats extending from central Oregon to northern Washington. Juveniles were collected in trawl surveys conducted during spring, summer, and autumn over 15 years. Distributions (mean latitude and distance from shore) differed between yearling and subyearling life history types and between stocks; many of these differences were consistent across years. Yearlings were nearly all (98%) from Columbia River sources, and only 6% were naturally produced. In late May, yearlings from the lower Columbia and Willamette rivers were farther north than other yearlings, likely due to the early spring timing of their releases from hatcheries and subsequent out-migration from the Columbia River. However, yearling distributions in late June reflected known migration behaviors. Yearlings from interior Columbia and Snake River sources were farthest north by June, whereas yearlings from other stocks were more spread out in latitude. Subyearlings sampled in early summer were also largely from the Columbia River (98%), but greater percentages of subyearlings from coastal rivers were present during the fall (24%). In contrast to yearlings, natural production accounted for nearly one-third of subyearlings. Subyearlings of most stocks tended to remain relatively near their point of sea entry throughout the summer. Subyearlings from the Snake River fall-run stock and upper Columbia River summer–fall-run stock exhibited diverse distributions that included both southward and northward dispersal. Overall, distributions of Chinook Salmon stocks and life history types reflected differences in migration behavior but also reflected the influence of environmental factors and hatchery practices.

U.S. Geological Survey. (2016). *Water Temperature Effects from Simulated Dam Operations and Structures in the Middle Fork Willamette River, Western Oregon*. (Open-File Report 2016-1159). https://doi.org/10.3133/ofr20161159

Streamflow and water temperature in the Middle Fork Willamette River (MFWR), western Oregon, have been regulated and altered since the construction of Lookout Point, Dexter, and Hills Creek Dams in 1954 and 1961, respectively. Each year, summer releases from the dams typically are cooler than pre-dam conditions, with the reverse (warmer than pre-dam conditions) occurring in autumn. This pattern has been detrimental to habitat of endangered Upper Willamette River (UWR) Chinook salmon (Oncorhynchus tshawytscha) and UWR winter steelhead (O. mykiss) throughout multiple life stages. In this study, scenarios testing different dam-operation strategies and hypothetical dam-outlet structures were simulated using CE-QUAL-W2 hydrodynamic/temperature models of the MFWR system from Hills Creek Lake (HCR) to Lookout Point (LOP) and Dexter (DEX) Lakes to explore and understand the efficacy of potential flow and temperature mitigation options. Model scenarios were run in constructed wet, normal, and dry hydrologic calendar years, and designed to minimize the effects of Hills Creek and Lookout Point Dams on river temperature by prioritizing warmer lake surface releases in May–August and cooler, deep releases in September– December. Operational scenarios consisted of a range of modified release rate rules, relaxation of power-generation constraints, variations in the timing of refill and drawdown, and maintenance of different summer maximum lake levels at HCR and LOP. Structural scenarios included various combinations of hypothetical floating outlets near the lake surface and hypothetical new outlets at depth. Scenario results were compared to scenarios using existing operational rules that give temperature management some priority (Base), scenarios using pre-2012 operational rules that prioritized power generation over temperature management (NoBlend), and estimated temperatures from a without-dams condition (WoDams).

Unrein, J. R., Billman, E. J., Cogliati, K. M., Chitwood, R., Noakes, D. L. G., & Schreck, C. B. (2018). Vertical Self-Sorting Behavior in Juvenile Chinook Salmon (Oncorhynchus tshawytscha): Evidence for Family Differences and Variation in Growth and Morphology. *Environmental Biology of Fishes, 101*(2), https://doi.org/10.1007/s10641-017-0702-2

Life history variation is fundamental to the evolution of Pacific salmon and their persistence under variable conditions. We discovered that Chinook salmon sort themselves into surface- and bottom-oriented groups in tanks within days after exogenous feeding. We hypothesised that this behaviour is correlated with subsequent differences in body morphology and growth (as measured by final length and mass) observed later in life. We found consistent morphological differences between surface and bottom phenotypes. Furthermore, we found that surface and bottom orientation within each group is maintained for at least one year after the phenotypes were separated. These surface and bottom phenotypes are expressed across genetic stocks, brood years, and laboratories and we show that the proportion of surface- and bottom-oriented offspring also differed among families. Importantly, feed delivery location did not affect morphology or growth, and the surface fish were longer than bottom fish at the end of the rearing experiment. The body shape of the former correlates with wild individuals that rear in mainstem habitats and migrate in the fall as subyearlings and the latter resemble those that remain in the upper tributaries and migrate as yearling spring migrants. Our findings suggest that early self-sorting behaviour may have a genetic basis and be correlated with other phenotypic traits that are important indicators for juvenile migration timing.

Van Doornik, D. M., Hess, M. A., Johnson, M. A., Teel, D. J., Friesen, T. A., & Myers, J. M. (2015). Genetic Population Structure of Willamette River Steelhead and the Influence of Introduced Stocks. *Transactions of the American Fisheries Society, 144*(1), https://doi.org/10.1080/00028487.2014.982178

Conservation genetics studies are frequently conducted on Pacific salmon Oncorhynchus spp. to delineate their population structure and to quantify their genetic diversity, especially for populations that have experienced declines in abundance and are subject to anthropogenic activities. One such group of salmonids is steelhead O. mykiss (anadromous Rainbow Trout) from the Willamette River, a tributary of the Columbia River. Within the Willamette River there are multiple steelhead life history and run-timing types, some of which originated from nonnative populations. Late winter-run steelhead and Rainbow Trout are native to the Willamette River, whereas early winter-run and summer-run steelhead have been introduced into the system via releases from artificial propagation efforts. We conducted genetic analyses of Willamette River steelhead to determine the effect that nonnative steelhead released into the Willamette River basin have had on the genetic population structure of native steelhead. We found genetic differentiation among the samples that separated steelhead into four population groups that corresponded to run type. Possibly due to local adaptation, the native run type has retained its genetic distinctiveness from the introduced types, despite there being opportunities for gene flow among all types. Introduced early winter-run steelhead appear to be the origin of steelhead inhabiting certain Willamette River tributaries where native steelhead did not historically spawn.

Wade, A. A., Hand, B. K., Kovach, R. P., Luikart, G., Whited, D. C., & Muhlfeld, C. C. (2017). Accounting for Adaptive Capacity and Uncertainty in Assessments of Species' Climate-Change Vulnerability. *Conservation Biology, 31*(1), https://doi.org/10.1111/cobi.12764

Climate-change vulnerability assessments (CCVAs) are valuable tools for assessing species' vulnerability to climatic changes, yet failure to include measures of adaptive capacity and to account for sources of uncertainty may limit their effectiveness. We took a more comprehensive approach that incorporates exposure, sensitivity, and capacity to adapt to climate change. We applied our approach to anadromous steelhead trout (Oncorhynchus mykiss) and nonanadromous bull trout (Salvelinus confluentus), threatened salmonids within the Columbia River Basin (U.S.A.). We quantified exposure on the basis of scenarios of future stream temperature and flow, and we represented sensitivity and capacity to adapt to climate change with metrics of habitat quality, demographic condition, and genetic diversity. Both species were found to be highly vulnerable to climate change at low elevations and in their southernmost habitats. However, vulnerability rankings varied widely depending on the factors (climate, habitat, demographic, and genetic) included in the CCVA and often differed for the 2 species at locations where they were sympatric. Our findings illustrate that CCVA results are highly sensitive to data inputs and that spatial differences can complicate multispecies conservation. Based on our results, we suggest that CCVAs be considered within a broader conceptual and computational framework and be used to refine hypotheses, guide research, and compare plausible scenarios of species' vulnerability to climate change.

Weber, M. A. (2015). Navigating Benefit Transfer for Salmon Improvements in the Western Us. *Frontiers in Marine Science, 2*(74), https://doi.org/10.3389/fmars.2015.00074

A perennial problem in environmental resource management is targeting an efficient level of resource provision that maximizes societal well-being. Such management requires knowledge of both costs and benefits associated with varying management options. This paper illustrates the challenge of estimating the benefits of an improvement in a marine resource when secondary data must be used, and when total economic benefits include non-use values. An example of non-use values is existence value, which is not contingent on resource extraction nor recreational activities. State of the art techniques for adapting secondary data, or "benefit transfer", are reviewed in the context of increasing anadromous salmon for an example Western US policy scenario. An extensive summary of applicable primary studies is provided, compiling observations from several studies surveying several thousand Western US households. The studies consistently indicate a high willingness to pay for increased salmon abundance. Analytical techniques for transferring data are described, with calculation examples using published tools, focusing on meta-regression and structural benefit transfer. While these advanced benefit transfer tools offer perspective on benefits beyond what can be learned by relying on a single study, they also represent a variety of challenges limiting their usefulness. While transparently navigating these issues, a monetized estimate of increased salmon for the policy case is provided, along with discussion on interpreting benefit transfer techniques and their results more generally. From this synthesis, several suggestions are also made for future primary salmon valuation studies.

Weigel, D. E., Adams, J. R., Jepson, M. A., Waits, L. P., & Caudill, C. C. (2019). Introgressive Hybridization between Native and Non-Local Steelhead (Oncorhynchus mykiss) of Hatchery Origin. *Aquatic Conservation: Marine and Freshwater Ecosystems, 29*(2), https://doi.org/10.1002/aqc.3028

The artificial propagation and release of individuals from non-local populations is a widespread practice that can threaten the genetic integrity of native, locally adapted populations, because of domestication effects from the artificial rearing environments and inter-breeding with the local populations. Introgressive hybridization was examined in a threatened population of anadromous Oncorhynchus mykiss (Walbaum, 1792) (winter-run steelhead) in the Willamette Basin, Oregon. Non-local, hatchery-reared, summer-run steelhead are released annually into the basin as mitigation for the impact of numerous dams. Sixteen microsatellite loci were used to detect introgression in adult steelhead of natural origin migrating into the basin before spawning during 2013 and 2014. Bayesian clustering analysis (structure) was used to identify the level of admixture in the population and to assign individuals to clusters. The Bayesian clustering analysis indicated that there are most likely two populations (or clusters) in the study area: a native, coastal, winter-run steelhead population and a non-local, summer-run steelhead population that was derived from artificial crosses between summer-run coastal and interior redband populations. Introgressive hybridization was detected in 26.4% of the natural-origin adult steelhead. First-generation (F1) hybrids were estimated as 4.9–10.1% of the natural-origin adult steelhead. Hybrids backcrossed to the native, coastal, winter-run steelhead were nine times more numerous than backcrosses to the hatchery, summer-run steelhead. The timing of upstream migration was significantly different between the native, winter steelhead and the F1 hybrids. Low numbers of summer steelhead and back-cross summer-run hybrids were identified in the natural-origin population, consistent with the reduced fitness of hatchery-reared summer steelhead in natural environments. Conservation actions that protect native populations from hatchery fish include altering stocking practices (such as integrated management or sterility), and protecting the remaining intact populations by designating genetic preserves and preventing the release of hatchery-origin or hybrid steelhead into these areas.

Weitkamp, L. A., Teel, D. J., Liermann, M., Hinton, S. A., Doornik, D. M. V., & Bentley, P. J. (2015). Stock-Specific Size and Timing at Ocean Entry of Columbia River Juvenile Chinook Salmon and Steelhead: Implications for Early Ocean Growth. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 7*(7), https://doi.org/10.1080/19425120.2015.1047476

Juvenile salmon transitioning from freshwater to marine environments experience high variation in growth and survival, yet the specific causes of this variation are poorly understood. Size at and timing of ocean entry may contribute to this variation because they influence both the availability of prey and vulnerability to predators. To explore this issue, we used stock assignments based on genetic stock identification and internal tags to document the stock-specific size and timing of juvenile hatchery and presumed wild Columbia River Chinook Salmon Oncorhynchus tshawytscha and steelhead O. mykiss at ocean entry during 2007–2011. We found that juvenile salmon and steelhead had consistent stock-specific capture dates, with lower-river stocks typically having earlier timing than those originating farther upstream. Mean size also varied among stocks and was related to hatchery practices. Hatchery yearling Chinook Salmon and steelhead were consistently larger than wild fish from the same stocks, although timing in the estuary was similar. In contrast, hatchery subyearling Chinook Salmon were of similar size to wild fish but entered the ocean up to a month earlier. We evaluated the potential importance of these traits on early marine growth by estimating stock-specific growth rates for Chinook Salmon caught in estuarine and ocean habitats. Growth rates were related to relative ocean entry timing, with lower growth rates for stocks that had only recently arrived in marine waters. Our results demonstrate that stocks within a single basin can differ in their size and timing of ocean entry, life history traits that contribute to early marine growth and potentially to the survival of juvenile salmon. Our results also highlight the necessity of considering stock-specific variation in life history traits to understand salmon ecology and survival across the entire life cycle.

Section VII: Puget Sound

Adams, J., Kaplan, I. C., Chasco, B., Marshall, K. N., Acevedo-Gutiérrez, A., & Ward, E. J. (2016). A Century of Chinook Salmon Consumption by Marine Mammal Predators in the Northeast Pacific Ocean. *Ecological Informatics, 34*, https://doi.org/10.1016/j.ecoinf.2016.04.010

As many marine mammal populations have increased following bans on their harvest, there has been a growing need to understand potential impacts of these population changes on coastal marine ecosystems. Quantifying consumption of prey species, such as fish, is particularly important when those same prey are also targeted by commercial fisheries. Estimating the impact of marine mammal predators on prey fish depends upon knowledge of marine mammal diet composition; scientific advances over the last century have improved understanding of diets but have also led to inconsistent methods that challenge attempts at synthesis and comparison. Meta-analysis techniques offer the opportunity to overcome such challenges, yet have not been widely applied to synthesize marine mammal diets over space and time. As a case study, we focus on synthesizing diet studies of Chinook (king) salmon (Oncorhynchus tshawytscha) by four species of marine mammal predators in the Northeast Pacific Ocean: Steller sea lions (Eumetopias jubatus), California sea lions (Zalophus californianus), harbor seals (Phoca vitulina), and killer whales (Orcinus orca). We also highlight several simple meta-analyses for which these types of diet databases may be employed. Our assembled database consists of >330 records, spanning more than 100years. Results indicate that the frequency of occurrence of Chinook salmon in killer whale studies is high (63%) relative to pinniped studies (<10%). They also suggest a strong increasing ability to discriminate Chinook salmon from other salmonids, which we attribute to switches in diet studies from lethal or observational sampling toward molecular methods (DNA, fatty acids). Our database and analysis code are published as supplementary material, which we hope will be useful for other researchers and will inspire more of these syntheses.

Adams, J. N., Brodeur, R. D., Daly, E. A., & Miller, T. W. (2017). Prey Availability and Feeding Ecology of Juvenile Chinook (Oncorhynchus tshawytscha) and Coho (O. kisutch) Salmon in the Northern California Current Ecosystem, Based on Stomach Content and Stable Isotope Analyses. *Marine Biology, 164*(5), https://doi.org/10.1007/s00227-017-3095-z

To understand the factors that regulate early marine survival of juvenile Chinook (Oncorhynchus tshawytscha) and coho (Oncorhynchus kisutch) salmon, it is necessary to characterize their prey availability, selectivity, and dietary niche widths. Currently, no sampling protocol exists that directly measures the salmonid prey field and quantifies dietary niche width via stable isotope analysis (SIA). The main goals of this study were to quantify the dietary niche widths of juvenile salmon and to compare environmental prey community compositions to juvenile salmon diets. Juvenile Chinook and coho salmon and their prey were collected in the northern California Current ecosystem via herring and Nordic trawls during 9-15 June 2010. The catch per unit effort of the salmonid prey field was compared to juvenile salmon stomach contents, and a Manly-Chesson index was used to quantify prey selectivity. Salmon and their prey were measured for δ13C and δ15N values and salmon were analyzed via Stable Isotope Bayesian Ellipses in R. Results indicated that there was no significant difference between juvenile Chinook and coho salmon diets and that they principally consumed rockfish juveniles (Sebastes spp.) and Cancer megalopae. Juvenile salmon consumed somewhat different prey items compared to both herring and Nordic nets and these nets sampled different assemblages of similar prey communities. Though juvenile salmon were in isotopic disequilibrium with their marine prey, both species occupied similar isotopic niche widths. These results demonstrate that SIA provides complementary information to stomach content analysis.

Anderson, J. H., & Topping, P. C. (2018). Juvenile Life History Diversity and Freshwater Productivity of Chinook Salmon in the Green River, Washington. *North American Journal of Fisheries Management, 38*(1), https://doi.org/10.1002/nafm.10013

Life history diversity and productivity are key metrics used to evaluate the status of salmon populations. In this paper, we use long-term monitoring data from spawning escapement and a rotary screw trap to describe juvenile migration strategies and identify factors affecting freshwater productivity of Chinook Salmon Oncorhynchus tshawytscha inhabiting the Green River, Washington. Similar to other populations in Puget Sound, Green River Chinook Salmon exhibit two distinct pulses of downstream, subyearling, juvenile migration. Small-bodied fry move downstream in late winter shortly after emergence (peaking in March), whereas larger-bodied parr migrate downstream after spending some time rearing and growing in freshwater (peaking in late May or early June). A series of stock–recruit models demonstrated that the production of parr was density dependent, as the Green River reaches rearing capacity at most observed spawner abundances and river conditions. By contrast, the production of fry was density independent. Furthermore, several river discharge metrics were significantly related to Chinook Salmon productivity. Total juvenile production was lower in years when incubating embryos experienced high-magnitude peak flows, most likely due to redd scour. Parr productivity was greater in years with higher discharge during the spring (April–June), which we hypothesize is related to increased accessibility of side channels for rearing and/or increased survival during migration. Combined, these results suggest that restoration of juvenile rearing habitats offers substantial potential benefits to parr productivity. Setting escapement goals for fishery planning that consider freshwater habitat capacity and life history diversity will largely depend on the relative marine survival of the fry and parr migration strategies. Our analysis also provides insight to managing water at an upstream dam to benefit Chinook Salmon productivity, though any such strategy faces trade-offs with other fish conservation goals and will be constrained by the dam’s primary purpose of reducing flood risk.

Arostegui, M. C., Essington, T. E., & Quinn, T. P. (2017). Interpreting Vertical Movement Behavior with Holistic Examination of Depth Distribution: A Novel Method Reveals Cryptic Diel Activity Patterns of

Chinook Salmon in the Salish Sea. *Animal Biotelemetry, 5*(2), https://doi.org/10.1186/s40317-016-0116-5

Aquatic organisms exhibit a variety of diel changes in vertical movement that are investigable through the use of biotelemetry. While certain species do not change their movements between day and night, others exhibit diel vertical migration (DVM) or a diverse range of diel activity patterns (DAPs). Consequently, day–night differences in depth distribution may be stark and easily detectable, or more subtle and difficult to identify. To augment the discovery and classification of cryptic diel vertical movement behavior, we developed and utilized a novel method that analyzed entire depth distributions while comparing diel period, season, and season/diel period models. This analysis revealed a seasonally variable DAP previously unreported in Chinook salmon (Oncorhynchus tshawytscha). In summer and fall, Chinook salmon in the Salish Sea juxtaposed shallow and confined daytime movements with nighttime bounce diving. This DAP was reversed in winter, when they occupied deeper sections of the water column during the day, resulting in a substantially overlapping, but more even depth distribution than at night. These results demonstrate the analytical utility of accompanying other metrics with holistic examination and visualization of the entire distribution of depth data. Additionally, we highlight the need to use a framework that answers all of the following questions: (1) does the target species exhibit seasonal variation in depth, (2) does it undergo DVM, (3) if it does not undergo DVM, does it follow a DAP, and (4) if it follows a DAP, what is the difference in vertical movement behavior between diel periods?

Arostegui, M. C., Smith, J. M., Kagley, A. N., Spilsbury-Pucci, D., Fresh, K. L., & Quinn, T. P. (2017). Spatially Clustered Movement Patterns and Segregation of Subadult Chinook Salmon within the Salish Sea. *Marine and Coastal Fisheries, 9*(1), https://doi.org/10.1080/19425120.2016.1249580

While Pacific salmon are known for their extensive marine migrations, some species display much more limited alternative patterns, including residence within interior marine waters. To more clearly define the scale of movement of these residents, we used acoustic telemetry to track subadult Chinook Salmon Oncorhynchus tshawytscha caught in and released from discrete areas of the Salish Sea. Their movements were determined from detections at fixed receivers in central Puget Sound, Admiralty Inlet, the San Juan Islands, and the Strait of Juan de Fuca. Cluster analysis of the detections indicated four groups, with much less commonality of movement than might be inferred from the proximity of the tagging locations, which were only tens of kilometers apart. For example, none of the salmon tagged in central Puget Sound were detected in the San Juan Islands and vice versa. Thus, Chinook Salmon occupying central Puget Sound and the San Juan Islands may exhibit different distributions, extents of movement, and degrees of basin fidelity. These results provide information relevant to the management and conservation of this species, which is listed as threatened under the U.S. Endangered Species Act, and whose movements cross the U.S.–Canadian boundary. These findings may also help explain the variation in organic contaminant levels among Puget Sound-origin Chinook Salmon.

Bartz, K. K., Ford, M. J., Beechie, T. J., Fresh, K. L., Pess, G. R., Kennedy, R. E., . . . Sheer, M. (2015). Trends in Developed Land Cover Adjacent to Habitat for Threatened Salmon in Puget Sound, Washington, USA. *Plos One, 10*(4), https://doi.org/10.1371/journal.pone.0124415

For widely distributed species at risk, such as Pacific salmon (Oncorhynchus spp.), habitat monitoring is both essential and challenging. Only recently have widespread monitoring programs been implemented for salmon habitat in the Pacific Northwest. Remote sensing data, such as Landsat images, are therefore a useful way to evaluate trends prior to the advent of species-specific habitat monitoring programs. We used annual (1986-2008) land cover maps created from Landsat images via automated algorithms (LandTrendr) to evaluate trends in developed (50-100% impervious) land cover in areas adjacent to five types of habitat utilized by Chinook salmon (O. tshawytscha) in the Puget Sound region of Washington State, U.S.A. For the region as a whole, we found significant increases in developed land cover adjacent to each of the habitat types evaluated (nearshore, estuary, mainstem channel, tributary channel, and floodplain), but the increases were small (<1% total increase from 1986 to 2008). For each habitat type, the increasing trend changed during the time series. In nearshore, mainstem, and floodplain areas, the rate of increase in developed land cover slowed in the latter portion of the time series, while the opposite occurred in estuary and tributary areas. Watersheds that were already highly developed in 1986 tended to have higher rates of development than initially less developed watersheds. Overall, our results suggest that developed land cover in areas adjacent to Puget Sound salmon habitat has increased only slightly since 1986 and that the rate of change has slowed near some key habitat types, although this has occurred within the context of a degraded baseline condition.

Basova, I. N., Basova, N. E., & Yagodina, O. V. (2015). Catalytic Properties of Liver Monoamine Oxidase in the Chum Salmon Oncorhynchus Keta. *Journal of Evolutionary Biochemistry and Physiology, 51*(5), https://doi.org/10.1134/s0022093015050026

The substrate and inhibitory specificity of mitochondrial monoamine oxidase (MAO) was studied in the summer-run male chum salmon Oncorhynchus keta liver. By the spectrum of deaminated substrates, chum salmon liver MAO is similar to that in most terrestrial mammals, with similarities in substrate characteristics found for eight classical MAO substrates. An assay of anti-monoamine oxidase efficacy of the two 2-propinilamine derivatives, five acridine derivatives and pyronine G revealed significant qualitative and quantitative differences as compared with tuna and whitefish liver MAO. The compounds tested were found to be irreversible inhibitors of chum salmon liver MAO exhibiting various efficacy, but lacking selectivity dependening on a deaminated substrate. The data of substrate–inhibitory analysis provide indirect evidence for the presence of a single molecular MAO form in the chum salmon liver.

Berejikian, B. A., Moore, M. E., & Jeffries, S. J. (2016). Predator-Prey Interactions between Harbor Seals and Migrating Steelhead Trout Smolts Revealed by Acoustic Telemetry. *Marine Ecology Progress Series, 543*, https://doi.org/10.3354/meps11579

Changes in the Puget Sound ecosystem over the past 3 decades include increases in harbor seal (Phoca vitulina) abundance and declines in many of their preferred prey species. Harbor seals were outfitted with acoustic telemetry receivers and GPS tags to investigate spatial and temporal interactions with steelhead trout Oncorhynchus mykiss smolts implanted with acoustic transmitters. A total of 6846 tag detections from 44 different steelhead trout smolts (from an initial group of 246 smolts released into 2 rivers) were recorded by the 11 recovered sealmounted receivers. Central Puget Sound seal receivers detected a greater proportion of smolts surviving to the vicinity of the haul-out locations (29 of 51; 58%)

than Admiralty Inlet seal receivers (7 of 50; 14%; $p < 0.001$). Detection data suggest that none of the tagged smolts were consumed by the 11 monitored seals. Nine smolts were likely consumed by non-tagged harbor seals based partly on detections of stationary tags at the seal capture haul-outs, although tag deposition by other predators cannot be ruled out. Smolts implanted with continuously pinging tags and smolts implanted with tags that were silent for the first 10 d after release were detected in similar proportions leaving Puget Sound (95% CI for the difference between proportions: -0.105 to 0.077) and stationary at harbor seal haul-outs (95% CI: -0.073 to 0.080). This study suggests that harbor seals contribute to mortality of migrating steelhead smolts, and we hypothesize that documented changes in the Puget Sound ecosystem may currently put steelhead smolts at greater risk of predation by harbor seals and possibly other predators.

Berejikian, B. A., & Van Doornik, D. M. (2018). Increased Natural Reproduction and Genetic Diversity One Generation after Cessation of a Steelhead Trout (Oncorhynchus mykiss) Conservation Hatchery Program. *Plos One, 13*(1), https://doi.org/10.1371/journal.pone.0190799

Spatial and temporal fluctuations in productivity and abundance confound assessments of captive propagation programs aimed at recovery of Threatened and Endangered populations. We conducted a 17 year before-after-control-impact experiment to determine the effects of a captive rearing program for anadromous steelhead trout (Oncorhynchus mykiss) on a key indicator of natural spawner abundance (naturally produced nests or 'redds'). The supplemented population exhibited a significant (2.6-fold) increase in redd abundance in the generation following supplementation. Four non-supplemented (control) populations monitored over the same 17 year period exhibited stable or decreasing trends in redd abundance. Expected heterozygosity in the supplemented population increased significantly. Allelic richness increased, but to a lesser (non-significant) degree. Estimates of the effective number of breeders increased from a harmonic mean of 24.4 in the generation before supplementation to 38.9 after supplementation. Several non-conventional aspects of the captive rearing program may have contributed to the positive response in the natural population.

Bourret, S. L., Caudill, C. C., & Keefer, M. L. (2016). Diversity of Juvenile Chinook Salmon Life History Pathways. *Reviews in Fish Biology and Fisheries, 26*(3), https://doi.org/10.1007/s11160-016-9432-3

Life history variability includes phenotypic variation in morphology, age, and size at key stage transitions and arises from genotypic, environmental, and genotype-by-environment effects. Life history variation contributes to population abundance, productivity, and resilience, and management units often reflect life history classes. Recent evidence suggests that past Chinook salmon (Oncorhynchus tshawytscha) classifications (e.g., 'stream' and 'ocean' types) are not distinct evolutionary lineages, do not capture the phenotypic variation present within or among populations, and are poorly aligned with underlying ecological and developmental processes. Here we review recently reported variation in juvenile Chinook salmon life history traits and provide a refined conceptual framework for understanding the causes and consequences of the observed variability. The review reveals a broad continuum of individual juvenile life history pathways, defined primarily by transitions among developmental stages and habitat types used during freshwater rearing and emigration. Life history types emerge from discontinuities in expressed pathways when viewed at the population scale. We synthesize recent research that examines how genetic, conditional, and environmental mechanisms likely influence Chinook salmon life history pathways. We suggest that threshold models hold promise for understanding how genetic and environmental factors influence juvenile salmon life history transitions. Operational life history classifications will likely differ regionally, but should benefit from an expanded lexicon that captures the temporally variable, multi-stage life history pathways that occur in many Chinook salmon populations. An increased mechanistic awareness of life history diversity, and how it affects population fitness and resilience, should improve management, conservation, and restoration of this iconic species.

Brenkman, S. J., Sutton, K. T., & Marshall, A. R. (2017). Life History Observations of Adfluvial Chinook Salmon Prior to Reintroduction of Anadromous Salmonids. *North American Journal of Fisheries Management, 37*(6), https://doi.org/10.1080/02755947.2017.1353562

Pacific salmon Oncorhynchus spp. vary in life history and degree of anadromy, but information on populations inhabiting only freshwater throughout their life cycle is limited. We confirmed the presence of a self-sustaining population of adfluvial Chinook Salmon O. tshawytscha upstream of century-old hydroelectric dams in the Skokomish River system, Washington. Snorkel, redd, and juvenile-trapping surveys revealed their life history attributes prior to planned reintroductions of anadromous salmonids above the dams. Adult Chinook Salmon in Lake Cushman (a reservoir) were large-bodied fish (mean length = 610 mm; mean weight = 5.4 kg), up to 4 years of age, and migrated into the inlet river to spawn in October and November. Annual peak counts of adult spawners were chronically low (35 or less) based on interannual snorkel surveys since 1994. Chinook Salmon parr (n = 780; mean length = 105 mm) of a single cohort were captured (June–August) at the upper dam and had faded parr marks and bright, silvery coloration typical of smolts. Our study confirmed that Chinook Salmon reared and reproduced exclusively in freshwater and suggested a life history pattern most closely resembling anadromous fallrun Chinook Salmon. We reviewed annual hatchery release records from 1926 to 2016 and found no evidence of Chinook Salmon being planted above the dams, in contrast to landlocked Chinook Salmon occurring in Oregon and California reservoirs. These adfluvial Chinook Salmon may be descendants of the native Skokomish River anadromous population, including fish from below the dam, and represent adaptations to the reservoir after dam construction. Lake Cushman Chinook Salmon are federally threatened, the only reported landlocked population in Puget Sound and coastal Washington, and may represent a unique evolutionary legacy worthy of protection.

Brieuc, M. S. O., Ono, K., Drinan, D. P., & Naish, K. A. (2015). Integration of Random Forest with Population-Based Outlier Analyses Provides Insight on the Genomic Basis and Evolution of Run Timing in Chinook Salmon (Oncorhynchus tshawytscha). *Molecular Ecology, 24*(11), https://doi.org/10.1111/mec.13211

Anadromous Chinook salmon populations vary in the period of river entry at the initiation of adult freshwater migration, facilitating optimal arrival at natal spawning. Run timing is a polygenic trait that shows evidence of rapid parallel evolution in some lineages, signifying a key role for this phenotype in the ecological divergence between populations. Studying the genetic basis of local adaptation in quantitative traits is often impractical in wild populations. Therefore, we used a novel approach, Random Forest, to detect markers linked to run timing across 14 populations from contrasting environments in the Columbia River and Puget Sound, USA. The approach permits detection of loci of small effect on the phenotype. Divergence between populations at these loci was then examined using both principle component analysis and FST outlier analyses, to determine whether shared genetic changes resulted in similar phenotypes across different lineages. Sequencing of 9107 RAD markers in 414 individuals identified 33 predictor loci explaining 79.2% of trait variance. Discriminant analysis of principal components of the predictors revealed both shared and unique evolutionary pathways in the trait across different lineages, characterized by minor allele frequency changes. However, genome mapping of predictor loci also identified positional overlap with two genomic outlier regions, consistent with selection on loci of large effect. Therefore, the results suggest selective sweeps on few loci and minor changes in loci that were detected by this study. Use of a polygenic framework has provided initial insight into how divergence in a trait has occurred in the wild.

Brown, S. K., Seamons, T. R., Crewson, M., Whitney, J., & Verhey, P. (2017). *Genetic-Based Abundance Estimates for Snohomish River Chinook Salmon.* Retrieved from https://www.psc.org/fund-project/genetic-based-abundance-estimates-for-snohomish-river-chinook-salmon/

The Snohomish River basin is comprised of two Chinook salmon populations: the Skykomish River summer Chinook population (which includes Skykomish, mainstem Snohomish, and Pilchuck River) and the Snoqualmie River fall Chinook population. The combined Skykomish and Snoqualmie populations comprise the Snohomish River Chinook (Summer/Fall) management unit or "stock", which is one of five in Puget Sound used by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC) as an escapement indicator for Puget Sound Natural Summer/Fall Fingerlings. Escapement indicator stocks monitor the effectiveness of the management regimes and, if necessary, their status may trigger additional management actions in AABM and ISBM fisheries.

Burke, B. J., Anderson, J. J., Miller, J. A., Tomaro, L., Teel, D. J., Banas, N. S., & Baptista, A. M. (2016). Estimating Behavior in a Black Box: How Coastal Oceanographic Dynamics Influence Yearling Chinook Salmon Marine Growth and Migration Behaviors. *Environmental Biology of Fishes, 99*(8-9), https://doi.org/10.1007/s10641-016-0508-7

Ocean currents or temperature may substantially influence migration behavior in many marine species. However, high-resolution data on animal movement in the marine environment are scarce; therefore, analysts and managers must typically rely on unvalidated assumptions regarding movement, behavior, and habitat use. We used a spatially explicit, individual-based model of early marine migration with two stocks of yearling Chinook salmon to quantify the influence of external forces on estimates of swim speed, consumption, and growth. Model results suggest that salmon behaviorally compensate for changes in the strength and direction of ocean currents. These compensations can result in salmon swimming several times farther than their net movement (straight-line distance) would indicate. However, the magnitude of discrepancy between compensated and straight-line distances varied between oceanographic models. Nevertheless, estimates of relative swim speed among fish groups were less sensitive to the choice of model than estimates of absolute individual swim speed. By comparing groups of fish, this tool can be applied to management questions, such as how experiences and behavior may differ between groups of hatchery fish released early vs. later in the season. By taking into account the experiences and behavior of individual fish, as well as the influence of physical ocean processes, our approach helps illuminate the "black box" of juvenile salmon behavior in the early marine phase of the life cycle.

Campbell, L. A., Claiborne, A. M., & Anderson, J. H. (2017). *Salish Sea Marine Survival Project (4): 2017 Annual Report.* Washington Department of Fish and Wildlife S. D. Fish Program. Retrieved from https://marinesurvivalproject.com/wp-content/uploads/Campbell-et-al.-2017-Chinook-life-history-and-growth-Tech-Rept.pdf

This report provides results for two research topics funded under the Salish Sea Marine Survival Project to examine early marine survival in Chinook salmon as it relates to life history expression and growth. The first, an otolith microchemistry project examining juvenile life history strategies of surviving adults and the second investigating the relationship between early marine growth (inferred from fish scales), marine survival, and ocean conditions.

Chamberlin, J. W., Beckman, B. R., Greene, C. M., Rice, C. A., & Hall, J. E. (2017). How Relative Size and Abundance Structures the Relationship between Size and Individual Growth in an Ontogenetically Piscivorous Fish. *Ecology and Evolution, 7*(17), https://doi.org/10.1002/ece3.3218

While individual growth ultimately reflects the quality and quantity of food resources, intra and interspecific interactions for these resources, as well as individual size, may have dramatic impacts on growth opportunity. Out- migrating anadromous salmonids make rapid transitions between habitat types resulting in large pulses of individuals into a given location over a short period, which may have significant impact on demand for local resources. We evaluated the spatial and temporal variation in IGF- 1 concentrations (a proxy for growth rate) and the relationship between size and concentration for juvenile Chinook salmon in Puget Sound, WA, USA, as a function of the relative size and abundance of both Chinook salmon and Pacific herring, a species which commonly co- occurs with salmonids in nearshore marine habitats. The abundance of Chinook salmon and Pacific herring varied substantially among the sub- basins as function of outmigration timing and spawn timing, respectively, while size varied systematically and consistently for both species. Mean IGF- 1 concentrations were different among sub- basins, although patterns were not consistent through time. In general, size was positively correlated with IGF- 1 concentration, although the slope of the relationship was considerably higher where Pacific herring were more abundant than Chinook salmon; specifically where smaller individual herring, relative to Chinook salmon, were more abundant. Where Pacific herring were less abundant than Chinook salmon, IGF- 1 concentrations among small and large Chinook salmon were more variable and showed no consistent increase for larger individuals. The noticeable positive effect of relative Pacific herring abundance on the relationship between size and individual growth rates likely represents a shift to predation based on increased IGF- 1 concentrations for individual Chinook salmon that are large enough to incorporate fish into their diet and co- occur with the highest abundances of Pacific herring.

Chasco, B., Kaplan, I. C., Thomas, A., Acevedo-Gutiérrez, A., Noren, D., Ford, M. J., . . . Ward, E. J. (2017). Estimates of Chinook Salmon Consumption in Washington State Inland Waters by Four Marine Mammal Predators from 1970 to 2015. *Canadian Journal of Fisheries and Aquatic Sciences, 74*(8), https://doi.org/10.1139/cjfas-2016-0203

Conflicts can arise when the recovery ofone protected species limits the recovery ofanother through competition or predation. The recovery of many marine mammal populations on the west coast of the United States has been viewed as a success; however, within Puget Sound in Washington State, the increased abundance ofthree protected pinniped species maybe adversely affecting the recovery ofthreatened Chinook salmon (Oncorhynchus tshawytscha) and endangered killer whales (Orcinus orca) within the region. Between 1970 and 2015, we estimate that the annual biomass ofChinook salmon consumed by pinnipeds has increased from 68 to 625 metric tons. Converting juvenile Chinook salmon into adult equivalents, we found that by 2015, pinnipeds consumed double that ofresident killer whales and six times greater than the combined commercial and recreational catches. We demonstrate the importance of interspecific interactions when evaluating species recovery. As more protected species respond positively to recovery efforts, managers should attempt to evaluate tradeoffs between these recovery efforts and the unintended ecosystem consequences of predation and competition on other protected species.

Chen, M. F., O'Neill, S. M., Carey, A. J., Conrad, R. H., Stewart, B. A., Snekvik, K. R., . . . Hershberger, P. K. (2018). Infection by Nanophyetus Salmincola and Toxic Contaminant Exposure in out-Migrating Steelhead from Puget Sound, Washington: Implications for Early Marine Survival. *Journal of Aquatic Animal Health, 30*(2), https://doi.org/10.1002/aah.10017

Out-migrating steelhead Oncorhynchus mykiss from four Puget Sound rivers and associated marine basins of Puget Sound in Washington State were examined for the parasite, Nanophyetus salmincola in 2014 to determine whether recent trends in reduced marine survival are associated with the presence of this pathogen. A subset of steelhead from three of these river–marine basin combinations was analyzed for the presence of persistent organic pollutants (POPs) to assess whether exposure to these contaminants is a contributing factor to their reduced marine survival. The prevalence and parasite load of N. salmincola were significantly higher in fish from central and southern Puget Sound than in fish from river systems in northern Puget Sound. The proportion of steelhead samples with concentrations of POPs higher than adverse effects thresholds (AETs) or concentrations known to cause adverse effects was also greater in fish from the central and southern regions of Puget Sound than in those from the northern region. Polybrominated diphenyl ether concentrations associated with increased disease susceptibility were observed in 10% and 40% of the steelhead sampled from central and southern Puget Sound regions, respectively, but in none of the fish sampled from the northern region. The AET for polychlorinated biphenyls was exceeded in steelhead collected from marine habitats: 25% of the samples from the marine basins in the central and southern regions of Puget Sound and 17% of samples from northern Puget Sound region. Both N. salmincola and POP levels suggest there are adverse health effects on out-migrating steelhead from one southern and one central Puget Sound river that have lower early marine survival than those from a river system in northern Puget Sound.

Chen, M. F., O'Neill, S. M., Carey, A. J., Conrad, R. H., Stewart, B. A., Snekvik, K. R., . . . Hershberger, P. K. (2018). Infection by Nanophyetus Salmincola and Toxic Contaminant Exposure in out-Migrating Steelhead from Puget Sound, Washington: Implications for Early Marine Survival. *Journal of Aquatic Animal Health, 30*(2), https://doi.org/10.1002/aah.10017

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Chittenden, C. M., Sweeting, R., Neville, C. M., Young, K., Galbraith, M., Carmack, E., . . . Beamish, R. J. (2018). Estuarine and Marine Diets of out-Migrating Chinook Salmon Smolts in Relation to Local Zooplankton Populations, Including Harmful Blooms. *Estuarine, Coastal and Shelf Science, 200*, https://doi.org/10.1016/j.ecss.2017.11.021

Changes in food availability during the early marine phase of wild Chinook Salmon (O. tshawytscha) are being investigated as a cause of their recent declines in the Salish Sea. The marine survival of hatchery smolts, in particular, has been poor. This part of the Salish Sea Marine Survival Project examined the diet of young out-migrating Chinook Salmon for four consecutive years in the Cowichan River estuary and in Cowichan Bay, British Columbia, Canada. Local zooplankton communities were monitored during the final year of the study in the Cowichan River estuary, Cowichan Bay, and eastward to the Salish Sea to better understand the bottom-up processes that may be affecting Chinook Salmon survival. Rearing environment affected body size, diet, and distribution in the study area. Clipped smolts (hatchery-reared) were larger than the unclipped smolts (primarily naturally-reared), ate larger prey, spent very little time in the estuary, and disappeared from the bay earlier, likely due to emigration or mortality. Their larger body size may be a disadvantage for hatchery smolts if it necessitates their leaving the estuary prematurely to meet energy needs; the onset of piscivory began at a forklength of approximately 74 mm, which was less than the average forklength of the clipped fish in this study. The primary zooplankton bloom occurred during the last week of April/first week of May 2013, whereas the main release of hatchery-reared Chinook Salmon smolts occurs each year in mid-May—this timing mismatch may reduce their survival. Gut fullness was correlated with zooplankton biomass; however, both the clipped and unclipped smolts were not observed in the bay until the bloom of harmful Noctiluca was finished—20 days after the maximum recorded zooplankton abundance. Jellyfish medusa flourished in nearshore areas, becoming less prevalent towards the deeper waters of the Salish Sea. The sizable presence of Noctiluca and jellyfish in the zooplankton blooms may be repelling young salmon from a critical early marine food source and reducing their survival.

Christie, P., Fluharty, D., Kennard, H., Pollnac, R., Warren, B., & Williams, T. (2018). Policy Pivot in Puget Sound: Lessons Learned from Marine Protected Areas and Tribally-Led Estuarine Restoration. *Ocean & Coastal Management, 163*, https://doi.org/10.1016/j.ocecoaman.2018.05.020

Environmental change amplifies the challenge of protecting and restoring Puget Sound. As rising pressures from population growth, development, unsustainable resource use, climate impacts and other factors alter this urbanizing basin, efforts to recover salmon and ecosystem health and to enhance climate resilience face unprecedented social complexities and intensifying competition for space. A multi-method study of citizen and practitioner perspectives on protection and restoration suggests that capacity to manage under these conditions can be improved through strengthening an approach that has already become central in restoration practice: multiple-benefit planning. In this research, we examine and compare planning approaches used to develop marine protected areas (MPA) and estuary restoration (ER) projects in Puget Sound. Surveying non-tribal public attitudes toward these projects, we found limited knowledge concerning existing MPAs but support for wider use of such protections. We find that initiatives pursuing conservation, protection, restoration and resilience can gain advantage from (a) broadly inclusive and collaborative planning; (b) recognition of tribal treaty rights, management authorities, and leadership; (c) careful consideration and mitigation of project impacts on affected people (e.g. especially tribal and non-tribal fisheries for MPAs; farm interests and landowners for restoration projects). We note that "no-take" MPA designation has stalled, while ER efforts are overcoming sharp objections and controversies by crafting projects to deliver multiple social-ecological benefits: improved flood control and drainage, salmon recovery, recreational enjoyment, and resilience to climate change. Comparable strategies have not yet evolved in designation of "no-take" MPAs in Puget Sound. We offer conclusions and recommendations for accelerating conservation and resilience initiatives to keep pace with a changing environment. A key human dimensions research-based recommendation is that increasing environmental pressures intensify the need to strengthen collaborative and sustained planning and implementation processes.

Connelly, K. A., Gardner, J. R., Gamble, M. M., Chamberlin, J. W., Winans, A., Keister, J., & Beauchamp, D. A. (2018). *Marine Survival of Puget Sound Chinook: Size-Selective Mortality Growth Limitation and Bioenergetics of Sub-Yearling Chinook Salmon in Puget Sound, Washington.* Retrieved from https://marinesurvivalproject.com/wp-content/uploads/LLTK-SSMSP-9-Final-Report-Chinook-Size-Selective-Mort-Crit-GrowthEnergetics-June-2018.pdf

The primary objective of this report was to evaluate the major factors affecting growth and survival of sub-yearling Chinook salmon during their first marine growing season as they migrated into and reared in Puget Sound. Identifying, quantifying, and understanding these factors can guide future restoration and management practices within the region to improve survival of Chinook salmon from Puget Sound and the Salish Sea more broadly. This work is part of the Salish Sea Marine Survival Project, an international research collaboration designed to determine the primary factors affecting the survival of juvenile salmon and steelhead in the Salish Sea. We address the primary hypotheses: 1) That strong size-selective mortality operates on one or more early marine life stages of subyearling Chinook salmon associated with estuarine delta, marine nearshore or offshore habitats; 2) That growth performance associated with these life stages strongly influences survival during subsequent life stages and overall marine survival; and 3) That growth during critical life stages is affected by food supply (as indicated by feeding rate, energetic quality of prey, or thermal regime). As part of this project, an extensive sampling scheme was undertaken in 2014 and 2015 to sample sub-yearling Chinook salmon in Puget Sound across regions, habitats and throughout the duration of the outmigration. Biological samples from subyearling Chinook salmon, zooplankton and temperature data were collected concurrently at a variety of temporal and spatial scales in order to investigate the dynamics of growth and the ecological factors that affect growth during a critical growth period identified during previous research wherein the size achieved in offshore habitats by mid-July was strongly and positively correlated overall marine survival (Duffy and Beauchamp 2011). Our specific research objectives were: Size-selective mortality analysis - Use scale based growth histories to determine if sizeselective mortality occurred during life stages leading to or during the critical growth period in Puget Sound, if so at what temporal and spatial scales; Ecological factors affecting stage-specific growth – Use bioenergetics models to mechanistically link Chinook size and growth with ecological factors including diet, water temperature and prey availability.

Cram, J., Kendall, N., Marshall, A., Buehrens, T., Seamons, T., Leland, B., . . . Neatherlin, E. (2018). Steelhead at Risk Report: Assessment of Washington's Steelhead Populations. Retrieved from https://wdfw.wa.gov/publications/02070

Purpose and Scope: In 2008, in response to declining abundance, the Washington Department of Fish and Wildlife (WDFW) Fish Program completed a Statewide Steelhead Management Plan (SSMP) that outlined policies, strategies, and actions for managing steelhead (Washington Department of Fish and Wildlife (WDFW) 2008). The SSMP is intended to direct WDFW activities towards maintaining and restoring abundance, productivity, distribution, and diversity of wild steelhead and their habitats to assure long-term health of populations. A key action stipulated in the SSMP was the production at 5-year intervals of a report on the current status of wild steelhead populations at risk of extinction. This current report fulfills that obligation and in it we 1) analyze available biological data for steelhead populations to assess status, 2) identify focal populations at high risk, 3) identify threats to viability at statewide, DPS, and focal population scales, and 4) recommend actions that can be taken to improve status and reduce extinction risks at each scale.

Davis, M. J., Chamberlin, J. W., Gardner, J. R., Connelly, K. A., Gamble, M. M., Beckman, B. R., & Beauchamp, D. A. (2020). Variable Prey Consumption Leads to Distinct Regional Differences in Chinook Salmon Growth During the Early Marine Critical Period. *Marine Ecology Progress Series, 640*, https://doi.org/10.3354/meps13279

Growth during the early marine critical period is positively associated with survival and recruitment for Pacific salmon Oncorhynchus spp., so it is important to understand how certain foraging strategies may bolster growth in estuarine and marine environments. To elucidate how spatiotemporal and demographic differences in diet contribute to growth rate variability, we analyzed stomach contents in tandem with morphometric and hormonal indices of growth for subyearling Chinook salmon O. tshawytscha captured in Puget Sound, Washington, USA. Regional dietary patterns indicated that fish caught in northern Puget Sound ate insects in the estuarine and nearshore habitats, followed by decapod larvae, euphausiids, or forage fish in the offshore zone. In southern Puget Sound, fish ate insects in the estuary but were more likely to eat mysids and other crustaceans in the nearshore zone. In the marine habitats adjacent to the San Juan Islands, subyearlings ate forage fish, and their stomachs were as much as 1.4 to 3 times fuller than salmon captured in other regions. Scale-derived growth rates and insulin-like growth factor-1 levels showed distinct growth advantages for San Juan Islands fish which were strongly associated with the early adoption of piscivory. However, consumption of larger crustaceans such as mysids and euphausiids was also associated with greater relative growth regardless of where individuals were captured. These findings highlight how spatiotemporal differences in prey quantity, prey profitability, and individual foraging strategies result in variable growth rates among salmon populations. Specifically, they emphasize the role of piscivory in promoting early marine growth for out-migrating Chinook salmon.

Davis, M. J., Ellings, C. S., Woo, I., Hodgson, S., Larsen, K., & Nakai, G. (2018). Gauging Resource Exploitation by Juvenile Chinook Salmon (Oncorhynchus tshawytscha) in Restoring Estuarine Habitat. *Restoration Ecology, 26*(5), https://doi.org/10.1111/rec.12643

In the context of delta restoration and its impact on salmonid rearing, success is best evaluated based onwhether out-migrating juvenile salmon can access and benefit from suitable estuarine habitat. Here, we integrated 3 years of post-restoration monitoring data including habitat availability, invertebrate prey biomass, and juvenile Chinook salmon (Oncorhynchus tshawytscha) physiological condition to determine whether individuals profited from the addition of 364 ha of delta habitat in South Puget Sound,Washington, United States. Productivity in the restored mudflat was comparable to reference sites 3 years after dike removal, surpassing a mean total of 6 million kJ energy from invertebrate prey. This resulted from the development of a complex network of tidal channels and a resurgence in dipteran biomass that was unique to the restoration area. Consequently, a notable shift in invertebrate consumption occurred between 2010 and 2011, whereby individuals switched from eating primarily amphipods to dipteran flies; however, dietary similarity to the surrounding habitat did not change from year to year, suggesting that this shift was a result of a change in the surrounding prey communities. Growth rates did not differ between restored and reference sites, but catch weight was positively correlated with prey biomass, where greater prey productivity appeared to offset potential density-dependent effects. These results demonstrate how the realized function of restoring estuarine habitat is functionally dependent. High prey productivity in areas with greater connectivity may support healthy juvenile salmon that are more likely to reach the critical size class for offshore survival.

Davis, M. J., Woo, I., Ellings, C. S., Hodgson, S., Beauchamp, D. A., Nakai, G., & De La Cruz, S. E. W. (2018). Integrated Diet Analyses Reveal Contrasting Trophic Niches for Wild and Hatchery Juvenile Chinook Salmon in a Large River Delta. *Transactions of the American Fisheries Society, 147*(5), https://doi.org/10.1002/tafs.10088

Hatchery programs have been used as a conservation tool to bolster declining populations of Chinook Salmon Oncorhynchus tshawytscha along much of the North American Pacific coast. In many watersheds, hatchery stocks are released concurrently with the wild population, thus raising the potential for density-dependent effects. Competition for prey resources during the critical period for early marine growth and survival may diminish the foraging capacity and growth potential of wild Chinook Salmon, highlighting the importance of a diverse and productive delta habitat mosaic. We used an integrated diet approach with stomach content and stable isotope analyses to evaluate contrasting patterns of habitat use and prey consumption in a fall-run population of juvenile Chinook Salmon from the Nisqually River delta in Puget Sound, Washington. We examined size-class and origin-level differences throughout a gradient of delta habitat types. Wild (unmarked) and hatchery juveniles exhibited distinct habitat use patterns whereby unmarked fish were captured more frequently in tidally influenced freshwater and mesohaline emergent marsh areas, while hatchery fish were caught more often in the nearshore intertidal zone. Consequently, hatchery fish were less likely to consume the energy-dense terrestrial insects that were more common in freshwater and brackish marshes. Stable isotope signatures from muscle and liver tissues corroborated this finding, showing that unmarked juveniles had derived 24–31% of their diets from terrestrially sourced prey, while terrestrial insects only made up 2–8% of hatchery fish diets. This may explain why unmarked fish were in better condition than hatchery fish and had stomach contents that were 15% more energy-rich than those of hatchery fish. We did not observe strong evidence for trophic overlap in juvenile Chinook Salmon of different rearing origins, but our results suggest that hatchery juveniles could be more sensitive to diet-mediated effects on growth and survival.

Dietrich, J. P., Strickland, S. A., Hutchinson, G. P., Van Gaest, A. L., Krupkin, A. B., Ylitalo, G. M., & Arkoosh, M. R. (2015). Assimilation Efficiency of Pbde Congeners in Chinook Salmon. *Environmental Science & Technology, 49*(6), https://doi.org/10.1021/es5057038

Polybrominated diphenyl ether (PEPE) flame retardants are environmental contaminants that can accumulate in biota. PBDE accumulation in an organism depends on exposure, assimilation efficiency, and elimination/Metabolism. Net assimilation efficiency represents the fraction of the contaminant that is retained in the organism after exposure. In the present study, congener-specific estimates of net PBDE assimilation efficiencies were calculated from dietary exposures of juvenile Chinook salmon. The fish were exposed to one to eight PBDE congeners up to 1500 ng total PBDEs/g food. Mean assimilation efficiencies varied from 0.32 to 0.50 for BDE congeners 28, 47, 99, 100; 153, and 154. The assimilation efficiency of BDE49 was significantly greater than 100%, suggesting biotransformation from higher brominated congeners. Whole body concentrations of BDE49 significantly increased with both exposure to increasing concentrations of BDE99 and decreasing fish lipid levels, implying lipid-influenced debromination of BDE99 to BDE49. Excluding BDE49, PBDE assimilation efficiency was not significantly related to the numbers of congeners in the diets, or congener hydrophobicity, but was greater hi foods with higher lipid levels. Estimates of PBDP, assimilation efficiency can be used in bioaccumulation models to assess threats from PBDE exposure to Chinook salmon health and recovery efforts, as well as to their predators.

Doctor, K., Berejikian, B., Hard, J. J., & VanDoornik, D. (2014). Growth-Mediated Life History Traits of Steelhead Reveal Phenotypic Divergence and Plastic Response to Temperature. *Transactions of the American Fisheries Society, 143*(2), https://doi.org/10.1080/00028487.2013.849617

Growth-mediated early life history traits affect an individual's fitness and reflect both evolutionary adaptations and phenotypic responses to environmental conditions. We tested for phenotypic plasticity of growth-mediated life history traits between and within two depressed populations of steelhead Oncorhynchus mykiss from Hood Canal, Washington. We conducted a reciprocal transplant "common garden" experiment at two temperature regimes and measured individual growth rate, condition factor, proportion of age-1 smolts and proportion of age-1 mature males. We found phenotypic plasticity in growth rate, condition factor, and proportion of age-1 smolts in both populations, demonstrating that genotype-temperature interaction plays an important role in determining phenotypic expression of growth and development. Growth rates were highest in the warm temperature treatment for both populations. More Dewatto River individuals smolted in their first year than Duckabush River individuals, which is consistent with data from the natural populations and provides evidence for phenotypic divergence in this life history trait. However, direct tests of neutrality provided no evidence that this divergence had resulted from diversifying selection, suggesting instead that the divergence may be largely plastic. All age-1 mature males were observed in the warm temperature treatments for both populations, indicating that temperature plays a large role in determining age-1 male maturation under these conditions. Broad-sense heritability estimates for growth rate, condition factor, and smolts at age-1 were generally high, revealing the potential opportunity for selection to act on these traits in both populations. Understanding the effect of temperature on life history differences between populations is important for management decisions and conservation, including anticipating responses to changing environmental conditions.

Doctor, K. K., Berejikian, B. A., Winans, G. A., & Van Doornik, D. M. (2015). Evidence of between-Population Variation in Morphology and Thermal Plasticity of Agonistic Behavior in Two Genetically Distinct Populations of Steelhead (Oncorhynchus mykiss). *Environmental Biology of Fishes, 98*(7), https://doi.org/10.1007/s10641-015-0399-z

Morphological and behavioral traits affect an individual's fitness and can reflect both evolutionary adaptations and phenotypic responses to environmental conditions. We conducted a reciprocal transplant 'common garden' experiment at two temperature regimes to test for phenotypic plasticity in morphological and behavioral traits between and within two populations of steelhead Oncorhynchus mykiss from Hood Canal, WA, USA. The Dewatto River and Duckabush River populations exhibited asymmetric changes in body morphology in response to the two temperature regimes, suggesting both between- and within-population variation in morphological plasticity. In most cases, within population variation in body shapes was less than between temperature regimes. Most notably the populations differed in dorso-ventral and caudal regions, body depth, and head shape, with some differences on the anterior-posterior placement of the dorsal and ventral fins. The warm temperature regime caused more exploratory behavior, more charging behavior, and higher fin erosion, and population effects included slight differences in feeding aggression frequency. Morphology appeared to vary more between populations than between temperature regimes, and behavioral traits varied more between temperature regimes than between populations. Morphological variation may reflect adaptations to variation in freshwater habitat conditions, and both populations show behavioral plasticity in response to temperature. This study sheds new light on the role of genetic and environmental influence on morphology and behavior in juvenile steelhead.

Dumbauld, B. R., Hosack, G. R., & Bosley, K. M. (2015). Association of Juvenile Salmon and Estuarine Fish with Intertidal Seagrass and Oyster Aquaculture Habitats in a Northeast Pacific Estuary. *Transactions of the American Fisheries Society, 144*(6), https://doi.org/10.1080/00028487.2015.1054518

Structured estuarine habitats, such as salt marshes, seagrass beds, and oyster reefs, are recognized as critical nurseries for juvenile fish and crustaceans. Estuarine habitat usage by fish, including juvenile

Pacific salmon Oncorhynchus spp., was characterized by sampling with a modified tow net in Willapa Bay, Washington, where 20% of the intertidal area is utilized for shellfish aquaculture and thus is difficult to sample with conventional gear. Our goal was to compare fish use of relatively undisturbed habitats (open mudflat, seagrass, and channel habitats) with the use of nearby oyster culture habitat. Although many species showed significant temporal and spatial trends within the estuary, only Shiner Perch Cymatogaster aggregata exhibited a significant association with habitat. Juveniles of three salmonid species exhibited few associations with the low intertidal habitats over which they were captured or in the prey types they consumed there. Chinook Salmon O. tshawytscha, likely hatchery-released oceantype fish, were the most common salmonid captured, and they utilized low intertidal areas throughout the summer as their mean size increased from 85 to 100 mm FL. Diets consumed by these larger juvenile Chinook Salmon were not associated with benthic habitat but instead consisted primarily of (1) insects from nearby marsh or terrestrial habitats and (2) planktonic prey, like decapod larvae and tunicate larvaceans. Juvenile Coho Salmon O. kisutch and Chum Salmon O. keta were captured earlier (April and May) and fed on a slightly different suite of prey taxa, which were also primarily pelagic rather than associated with the intertidal benthos. Our findings suggest that in this relatively shallow coastal estuary, the role of benthic habitat is not closely linked to its value as a source of food for large juvenile salmon out-migrants utilizing the low intertidal areas where aquaculture occurs.

Ford, M., Pearsons, T. N., & Murdoch, A. (2015). The Spawning Success of Early Maturing Resident Hatchery Chinook Salmon in a Natural River System. *Transactions of the American Fisheries Society, 144*(3), https://doi.org/10.1080/00028487.2015.1009561

Hatchery propagation of spring Chinook Salmon Oncorhynchus tshawytscha has been shown to increase the proportion of males maturing as minijacks (age 2) or microjacks (age 1) relative to those proportions in wild populations. However, little is known about the success of early maturing males when they spawn in the wild. A captive broodstock program for spring Chinook Salmon in the White River (a tributary of the Wenatchee River, Washington) has a high rate of early male maturity. We used genetic parentage analysis to evaluate the spawning success of anadromous males in comparison with inferred early maturing resident, hatchery-origin males that spawned naturally. Based on samples of juvenile offspring (n D 1,007–1,368 fish/year) and a nearly complete sample of the potential anadromous parents, we found that during 2006–2009, 26–45% of the progeny did not have a male parent in the anadromous sample. In contrast, 0–23% of the progeny did not have a female parent represented in the sample. Using grandparentage analysis, we eliminated wild resident fish as a likely source of the unsampled male parents; thus, we concluded that those male parents were most likely early maturing resident fish that had been released from the captive broodstock program. The inferred spawning success of the unsampled resident males was significantly lower than that of the anadromous males. The typical mating pattern was for an anadromous female to produce about two-thirds of her offspring with one or two anadromous males and the remaining one-third with as many as 12 or more apparently resident males. To our knowledge, this is the first study to present evidence of successful reproduction by early maturing resident, hatchery-origin Chinook Salmon in the wild. The conservation implications of this finding are complex and will depend upon the genetic basis of early maturity and its causes in hatchery settings.

Gamble, M. M., Connelly, K. A., Gardner, J. R., Chamberlin, J. W., Warheit, K. I., & Beauchamp, D. A. (2018). Size, Growth, and Size-Selective Mortality of Subyearling Chinook Salmon During Early Marine Residence in Puget Sound. *Transactions of the American Fisheries Society, 147*(2), https://doi.org/10.1002/tafs.10032

In marine ecosystems, survival can be heavily influenced by size-selective mortality during juvenile life stages. Understanding how and when size-selective mortality operates on a population can reveal underlying growth dynamics and size-selective ecological processes affecting the population and thus can be used to guide conservation efforts. For subyearling Chinook Salmon Oncorhynchus tshawytscha in Puget Sound, previous research reported a strong positive relationship between marine survival and body mass during midsummer in epipelagic habitats within Puget Sound, suggesting that early marine growth drives survival. However, a fine-scale analysis of size-selective mortality is needed to identify specific critical growth periods and habitats. The objectives of this study were to (1) describe occupancy patterns across estuarine delta, nearshore marine, and offshore epipelagic habitats in Puget Sound; (2) describe changes in FL and weight observed across habitats and time; (3) evaluate evidence for size-selective mortality; and (4) illustrate how marine survival of the stocks studied may be affected by variation in July weight. In 2014 and 2015, we sampled FLs, weights, and scales from seven hatchery-origin and two natural-origin stocks of subyearling Chinook Salmon captured every 2 weeks during out-migration and rearing in estuary, nearshore, and offshore habitats within Puget Sound. Natural-origin stocks had more protracted habitat occupancy patterns than hatchery-origin stocks and were smaller than hatchery-origin stocks in both years. Regardless of origin, subyearlings were longer and heavier and grew faster in offshore habitats compared to estuary and nearshore habitats. For all stocks, we found little evidence of size-selective mortality among habitats in Puget Sound. These patterns were consistent in both years. Finally, the weights of subyearlings sampled during July in the offshore habitat predicted Puget Sound-wide marine survival rates of 0.4% for 2014 and 2.0% for 2015, with stock-specific predictions ranging from 0.18% to 11.70%.

Gayeski, N., Pess, G., & Beechie, T. (2016). A Life-Table Model Estimation of the Parr Capacity of a Late 19th Century Puget Sound Steelhead Population. *FACETS, 1*(1), https://doi.org/10.1139/facets-2015-0010

An age-structured life-cycle model of steelhead (Oncorhynchus mykiss) for the Stillaguamish River in Puget Sound, Washington, USA, was employed to estimate the number of age-1 steelhead parr that could have produced the estimated adult return of69 000 in 1895. We then divided the estimated parr numbers by the estimated area of steelhead rearing habitat in the Stillaguamish River basin in 1895 and under current conditions to estimate density of rearing steelhead then and now. Scaled to estimates of total wetted area of tributary and mainstem shallow shoreline habitat, our historic estimates averaged 0.39–0.49 parr·m−2, and ranged from 0.24 to 0.7 parr·m−2. These values are significantly greater than current densities in the Stillaguamish (mainstem average: 0.15 parr·m−2, tributaries: 0.07 parr·m−2), but well within the range of recent estimates of steelhead parr rearing densities in high-quality habitats. Our results indicate that modest improvement in the capacity of mainstem and tributary rearing habitat in Puget Sound rivers will yield large recovery benefits if realized in a large proportion of the area of river basins currently accessible to steelhead.

Goetz, F. A., Jeanes, E., Moore, M. E., & Quinn, T. P. (2015). Comparative Migratory Behavior and Survival of Wild and Hatchery Steelhead (Oncorhynchus mykiss) Smolts in Riverine, Estuarine, and Marine Habitats of Puget Sound, Washington. *Environmental Biology of Fishes, 98*(1), https://doi.org/10.1007/s10641-014-0266-3

Declines in the survival of steelhead (Oncorhynchus mykiss) populations in protected waters of Washington and British Columbia have drawn attention to the need for more information on migratory patterns and losses in river, estuary, and nearshore habitats. Accordingly, acoustic telemetry was used to quantify movements by wild and hatchery steelhead smolts released from 2006 to 2009 in the Green River, and tracked through Puget Sound, Washington. Survival varied by release group and migration segment but overall survival rates from release to the Strait of Juan de Fuca were 9.7 % for wild and 3.6 % for hatchery fish. These rates are low relative to similar studies on steelhead. Survival was higher for wild fish along all migration segments than hatchery-origin fish; the greatest loss for both groups coincided with the slowest travel rates as fish first entered the estuary and as they exited Puget Sound. Wild fish travelled faster than hatchery fish in the river (15.1 vs. 4.4 km/d) with the fastest travel in the lower river (41 vs. 20.2 km/d) and slowest immediately after release (3.7 vs. 2.4 km/d). The travel rates of wild and hatchery fish became progressively more similar over time: 15.4 vs. 10.6 km/d in the estuary, and 10.3 vs. 9.3 km/d in nearshore areas. Movement was primarily nocturnal in the river, nearly equal between day and night in the upper estuary, and predominately diurnal in the lower estuary and nearshore waters, with no difference between wild and hatchery fish. The migration in marine water showed an early offshore movement and a strong northward and westward orientation, and all fish exited the Strait of Juan de Fuca rather than the Strait of Georgia. The findings support research suggesting that declines in wild and hatchery steelhead populations may be caused primarily by factors in the early marine period.

Greene, C., Beamer, E., & Anderson, J. (2016). *Skagit River Estuary Intensively Monitored Watershed Annual Report.* S. R. I. M. W. I. Project. Retrieved from http://skagitcoop.org/wp-content/uploads/EB2918_Greene-et-al_2016.pdf

Our study plan and summary of results highlights the hypotheses, restoration projects, methodologies, and results of the Skagit system-wide monitoring. In doing so, we address how our methodologies are answering two general questions relevant to monitoring the population response of Chinook salmon to estuary restoration: 1) do salmon exhibit limitations during estuarine life stages related to capacity and connectivity, and 2) has estuary restoration resulted in population- or system-level responses?

Hall, J. E., Greene, C. M., Stefankiv, O., Anderson, J. H., Timpane-Padgham, B., Beechie, T. J., & Pess, G. R. (2018). Large River Habitat Complexity and Productivity of Puget Sound Chinook Salmon. *Plos One, 13*(11), https://doi.org/10.1371/journal.pone.0205127

While numerous studies have shown that floodplain habitat complexity can be important to fish ecology, few quantify how watershed-scale complexity influences productivity. This scale mismatch complicates population conservation and recovery strategies that evaluate recovery at regional or multi-basin scales. We used outputs from a habitat status and trends monitoring program for ten of Puget Sound's large river systems to examine whether juvenile Chinook salmon productivity relates to watershed-scale habitat complexity. We derived habitat complexity metrics that quantified wood jam densities, side and braid to main channel ratios, and node densities from a remote sensing census of Puget Sound's large river systems. Principal component analysis revealed that 91% of variance in these metrics could be explained by two principal components. These metrics revealed gradients in habitat complexity across Puget Sound which were sensitive to changes in complexity as a result of restoration actions in one watershed. Mixed effects models revealed that the second principle component term (PC2) describing habitat complexity was positively related to log transformed subyearling Chinook per spawner productivity rates from 6–18 cohorts per watershed. Total subyearling productivity (subyearlings per spawner) and fry productivity (subyearling fry per spawner) rates were best described by models that included a positive effect of habitat complexity (PC2) and negative relationships with log transformed peak flow recurrence interval, suggestive of reduced survival due to egg destruction during floods. Total subyearling productivity (subyearlings per spawner) and parr productivity (subyearling parr per spawner) rates were best described by models that included a positive effect of habitat complexity (PC2) and negative relationships with log transformed spawner density, suggestive of density dependent limits on juvenile rearing habitat. We also found that coefficient of variation for log transformed subyearling productivity and subyearling fry productivity rates declined with increasing habitat complexity, supporting the idea that habitat complexity buffers populations from annual variation in environmental conditions. Therefore, we conclude that our watershed-scale census-based approach provided habitat complexity metrics that explained some of the variability in productivity of subyearling juveniles among Chinook salmon populations. Furthermore, this approach may provide a useful means to track and evaluate aggregate effects of habitat changes on the productivity of Endangered Species Act (ESA) listed Chinook salmon populations over time.

Hall, J. E., Khangaonkar, T. P., Rice, C. A., Chamberlin, J., Zackey, T., Leonetti, F., . . . Rowse, M. (2018). Characterization of Salinity and Temperature Patterns in a Large River Delta to Support Tidal Wetland Habitat Restoration. *Northwest Science, 92*(1), https://doi.org/10.3955/046.092.0105

Although the Snohomish River estuary remains the second largest tidal wetland complex in Puget Sound, approximately 90% of pre-settlement habitat has been disconnected from tidal exchange. This estuary is currently the focus of the largest restoration effort in Puget Sound, with opportunity to restore tidal exchange to over 50% of pre-settlement levels. The Snohomish River also currently supports populations of all anadromous Pacific salmon species, including Endangered Species Act listed Chinook (Oncorhynchus tshawytscha), steelhead (O. mykiss), and bull trout (Salvelinus confluentus). The combination of extant anadromous Pacific salmon populations, large existing tidal wetland complexes, and large restoration potential make the Snohomish River estuary a great opportunity to benefit salmon population recovery and conservation efforts. To support restoration planning and effectiveness monitoring, we developed baseline characterizations of key physical attributes (salinity and temperature). Our results indicated that brackish (0.5–30 ppt) conditions extended farther upriver than previously described, with distributary channels downstream of the middle mainstem and lower Ebey Slough remaining brackish throughout most of the year. During extreme low flows (< 0.65 m3 s-1), salt water (> 0.5 ppt) can at times intrude throughout the distributaries and up to river kilometer 15.9 above the first bifurcation. We also observed temperatures exceeding stress thresholds for juvenile salmonids throughout the estuary from July through September, a period that overlaps with juvenile rearing. This research is timely with several large restoration projects scheduled for construction by 2020, and these baseline characterizations can be used to evaluate restoration responses, as well as to inform project prioritization and monitoring.

Hayes, M. C., Hodgson, S., Ellings, C. S., Duval, W. D., & Rubin, S. P. (2019). Seasonal Use of a Nonnatal Marine Basin by Juvenile Hatchery Chinook Salmon. *Marine and Coastal Fisheries, 11*(6), https://doi.org/10.1002/mcf2.10098

Information on the movement patterns of fishes is essential for managers that are making critical resource decisions. We examined the frequency of a keystone species, Chinook Salmon Oncorhynchus tshawytscha that migrated from different marine basins to the Nisqually River estuary, which lies within the southernmost marine basin (hereafter, "South basin") in Puget Sound (Washington, USA). Hatchery-reared juvenile fish were sampled by using beach seine, lampara seine, and fyke nets to determine seasonal trends in frequency, habitat use, and the influence of different capture methods. The captured fish originated from three marine basins, nine Puget Sound rivers, and fourteen hatcheries. The data revealed a consistent pattern showing that most of the tagged fish (72%) were from the nearby Nisqually River (in the South basin), but fish from more northerly marine basins (hereafter, "Outbasin") were also common. Although the majority of the tagged fish (99%) that were captured during April and May were originally released into rivers adjacent to the South basin, 90% of the fish that were captured in August and September had originated from rivers adjacent to Outbasin locations (up to 130 km distant). A comparison of sampling methods showed that the beach seine produced 27% Outbasin fish compared with 53% that were obtained with the lampara seine. The analysis of habitat use suggested that during June and July, more Outbasin fish (>40%) were captured in delta flats and nearshore habitats than in estuarine emergent marsh habitat (26%). Release location (river basin), but not distance, appeared to be an important factor that influenced the percentage of Outbasin fish that were captured in the South basin. However, it appeared that the fish that were released at light weights and early dates were more likely to be captured. Information on the movement of juvenile salmon to a nonnatal marine basin may help to increase our understanding of features of life history and survival, and it has application elsewhere, as many marine species are artificially propagated, released in large numbers, and have the potential to use nonnatal habitats.

Hearsey, J. W., & Kinziger, A. P. (2015). Diversity in Sympatric Chinook Salmon Runs: Timing, Relative Fat Content and Maturation. *Environmental Biology of Fishes, 98*(1), https://doi.org/10.1007/s10641-014-0272-5

Since salmon species commonly undertake long spawning migrations and often have multiple runs in the same river system, this study explored the run timing and physiology of sympatric Chinook salmon Oncorhynchus tshawytscha stocks in the Klamath River Basin, CA. Genetic methods revealed that the Trinity-Salmon Spring run entered first, followed by the Klamath Fall run, and the Lower Basin Fall run. The Trinity-Salmon Fall run entered continuously. There was however, considerable overlap in run timing which was thought may be due a morphological threshold being met. Due to longer off-feeding freshwater residency, the earlier-returning fish have higher metabolic demands during their spawning migration and enter freshwater with greater relative fat reserves, estimated by non-water fraction of liver tissue (NWF) and Relative Weight (Wr). They also arrive less mature (as estimated by gonadosomatic index (GSI), which also places a greater demand on their energy reserves for gonadal development. There was a decrease in relative fat reserves and an increase in maturity by freshwater entry date. At spawning however, the Trinity River Hatchery spring- and fall-run fish, after travelling the same distance, had the same relative fat content and size-specific gonad mass and fecundity. The higher energetic cost associated with the early entry of the spring-run fish, and reduced at-sea feeding period, may be the cause for their smaller average body mass. This study suggests that imminent freshwater residency duration is important in determining the relative fat content, maturity leveland size of returning Chinook salmon.

Heerhartz, S. M., & Toft, J. D. (2015). Movement Patterns and Feeding Behavior of Juvenile Salmon (Oncorhynchus Spp.) Along Armored and Unarmored Estuarine Shorelines. *Environmental Biology of Fishes, 98*(6), https://doi.org/10.1007/s10641-015-0377-5

Estuarine nearshore environments are important habitats for many organisms, including juveniles of several Pacific salmon species (Oncorhynchus spp.). These habitats provide shallow water and high prey productivity, but are increasingly modified by anthropogenic activity including shoreline armoring, which disrupts connectivity between aquatic and terrestrial realms and artificially steepens the shore. Such effects may have adverse consequences for juvenile salmon, particularly Chinook (O. tshawytscha) and chum (O. nerka), which are known to rely on shallow, productive nearshore habitats for foraging and refuge from predators during their outmigration from natal streams to the sea. We developed snorkel methods to quantify feeding rates, movement rates, and path complexity of juvenile salmon along armored and unarmored shorelines in Puget Sound, WA, USA. We found that juvenile salmon had relatively high feeding rates along all shoreline types, but that path straightness and movement rates showed some variation between armored and unarmored sites. Feeding fish swam in more complex paths and were observed in larger schools than non-feeding fish, and path straightness and movement rate were negatively correlated with proportion of time feeding. Feeding behavior, school size, and movement rates also showed variation by species. Shoreline type (armored or unarmored) influenced juvenile salmon distribution, and unarmored shorelines appear to accommodate a greater diversity of movement patterns than armored shorelines. Our results show that juvenile salmon feed at high rates along armored and unarmored estuarine shorelines, thus decreased prey availability or altered prey resources are likely the most detrimental foraging effects of armoring in estuarine nearshore ecosystems.

Howe, E., & Simenstad, C. A. (2015). Using Isotopic Measures of Connectivity and Ecosystem Capacity to Compare Restoring and Natural Marshes in the Skokomish River Estuary, Wa, USA. *Estuaries and Coasts, 38*(2), https://doi.org/10.1007/s12237-014-9831-4

Estuarine detritus-based food webs typically rely on diverse sources and timing of organic matter (OM) delivery. Access to detritus requires adequate hydraulic connectivity for consumer migration into productive locations and the transfer of allochthonous detritus into consumer habitats. These processes are particularly important to the patterns and rates of community development in restoring estuarine marshes where OM sources and connectivity might vary as a function of landscape setting. This study quantifies trophic dynamics in restoring and natural marsh ecosystems in the Skokomish estuary, Washington, USA, using Pacific blue mussels (Mytilus trossulus), stable isotopes, and a Bayesian multiple source mixing model to estimate available suspended food resources. The restoring marshes represent different ages since restoration implementation--14 and 3 years--as well as different restoration approaches--a levee breach and a full levee removal. Sestonic OM was less available and of lower quality in the two restoring marshes than in the natural marsh site. Mussel diets tracked seasonal trends in OM availability: Phytoplankton consumption was highest in spring, marsh detritus consumption was highest in winter (but consistently comprised at least 30 % of OM assimilated by mussels), and macroalgae consumption was highest in September. Trophic equivalency with mussels inhabiting the natural marsh appears to be restoring more rapidly in the younger restoration site, perhaps because increased hydrologic connectivity achieved through full levee removal promotes greater OM exchange compared to the single levee breach restoration approach. We conclude that increasing ecosystem capacity for detritus production by restoring emergent marsh ecosystems can bolster support for detritus-based food webs and suggest that restoration actions enhancing connectivity may achieve functional equivalency more rapidly than restoration projects exhibiting limited connectivity to the surrounding landscape.

Kagley, A. N., Smith, J. M., Fresh, K. L., Frick, K. E., & Quinn, T. P. (2017). Residency, Partial Migration, and Late Egress of Subadult Chinook Salmon (Oncorhynchus tshawytscha) and Coho Salmon (O. kisutch) in Puget Sound, Washington. *Fishery Bulletin, 115*(4), https://doi.org/10.7755/fb.115.4.10

Migratory behavior affects growth, survival, and fitness of individual fish, the dynamics and resilience of populations, and the ecosystems that fish occupy. Many salmonids are anadromous but individuals vary in the duration and spatial extent of marine migrations. We used telemetry to investigate movements of Chinook salmon (Oncorhynchus tshawytscha) that remained in Puget Sound (residents) rather than migrated to the Pacific Ocean. Most tagged Chinook salmon (26 of 37=70%) remained in Puget Sound for a substantial period, staying in the region where captured. However, 30% of tagged individuals, termed “transients,” subsequently left Puget Sound. Residents and transients did not differ in tagging date, body size, or origin (hatchery or wild). Compared with sympatric coho salmon (O. kisutch) where 80% remained as residents according to similar data, Chinook salmon tended to be detected closer to shore, in shallower water, and on fewer different receivers. For both species, residents showed limited movement within Puget Sound. We conclude that Chinook and coho salmon display resident and transient movement patterns across a behavioral continuum rather than within discrete migrational categories. These movement patterns are important because they affect the role of salmon in the ecosystem, their vulnerability to fisheries, and their accumulation of chemical contaminants.

Kendall, N. W., Marston, G. W., & Klungle, M. M. (2017). Declining Patterns of Pacific Northwest Steelhead Trout (Oncorhynchus mykiss) Adult Abundance and Smolt Survival in the Ocean. *Canadian Journal of Fisheries and Aquatic Sciences, 74*(8), https://doi.org/10.1139/cjfas-2016-0486

Examination of population abundance and survival trends over space and time can guide management and conservation actions with information about the spatial and temporal scale of factors affecting them. Here, we analyzed steelhead trout (anadromous Oncorhynchus mykiss) adult abundance time series from 35 coastal British Columbia and Washington populations along with smolt-to-adult return (smolt survival) time series from 48 populations from Washington, Oregon, and the Keogh River in British Columbia. Over 80% of the populations have declined in abundance since 1980. A multivariate autoregressive statespace model revealed smolt survival four groupings: Washington and Oregon coast, lower Columbia River, Strait of Juan de Fuca, and Puget Sound - Keogh River populations. Declines in smolt survival rates were seen for three of the four groupings. Puget Sound and Keogh River populations have experienced low rates since the early 1990s. Correlations between population pairs' time series and distance apart illustrated that smolt survival rates were more positively correlated for proximate populations, suggesting that important processes, including those related to ocean survival, occur early in the marine life of steelhead.

Kendall, N. W., Nelson, B. W., & Losee, J. P. (2020). Density-Dependent Marine Survival of Hatchery-Origin Chinook Salmon May Be Associated with Pink Salmon. *Ecosphere, 11*(4), https://doi.org/10.1002/ecs2.3061

Understanding how protected species influence the population dynamics of each other is an essential part of ecosystem-based management. Chinook salmon (Oncorhynchus tshawytscha) are critical prey for endangered southern resident killer whales (SRKWs; Orcinus orca), and increasing releases of hatchery Chinook salmon has been proposed to aid SRKW recovery. We analyzed 30 yr of data and found that density-dependent survival of hatchery Chinook salmon released into the central and southern parts of the Salish Sea (Washington, USA; and British Columbia, Canada) may be associated with the presence of naturally produced pink salmon (O. gorbuscha), which are highly abundant as juveniles only in evennumbered years. We first modeled hatchery Chinook salmon marine survival as a function of the numbers of juvenile Chinook released and the presence of emigrating juvenile pink salmon between 1983 and 2012. Then, we related reconstructed numbers of hatchery Chinook salmon returning to Puget Sound to the abundance of juvenile Chinook released in even (pink emigration) and odd (non-pink emigration) years from 1980 to 2010. We found that in some regions of the Salish Sea, both hatchery Chinook salmon marine survival and adult Chinook returns varied depending on the number of hatchery Chinook released and the presence of juvenile pink salmon. Specifically, in some regions survival of hatchery Chinook salmon decreased when greater numbers of juveniles were released into the Salish Sea in even years, when large numbers of pink salmon were present, but increased or remained stable when pink salmon were not present in large numbers (in odd years). This suggests lower, density-dependent survival of juvenile Salish Sea Chinook salmon during even outmigration years. Our analyses suggest that scientists and managers should further investigate potential mechanisms for density-dependent survival of hatchery Chinook salmon from Salish Sea hatcheries when designing strategies to maximize adult returns.

Khangaonkar, T., Nugraha, A., Hinton, S., Michalsen, D., & Brown, S. (2017). Sediment Transport into the Swinomish Navigation Channel, Puget Sound-Habitat Restoration Versus Navigation Maintenance Needs. *Journal of Marine Science and Engineering, 5*(2), https://doi.org/10.3390/jmse5020019

The 11 mile (1.6 km) Swinomish Federal Navigation Channel provides a safe and short passage to fishing and recreational craft in and out of Northern Puget Sound by connecting Skagit and Padilla Bays, US State abbrev., USA. A network of dikes and jetties were constructed through the Swinomish corridor between 1893 and 1936 to improve navigation functionality. Over the years, these river training dikes and jetties designed to minimize sedimentation in the channel have deteriorated, resulting in reduced protection of the channel. The need to repair or modify dikes/jetties for channel maintenance, however, may conflict with salmon habitat restoration goals aimed at improving access, connectivity and brackish water habitat. Several restoration projects have been proposed in the Skagit delta involving breaching, lowering, or removal of dikes. To assess relative merits of the available alternatives, a hydrodynamic model of the Skagit River estuary was developed using the Finite Volume Community Ocean Model

(FVCOM). In this paper, we present the refinement and calibration of the model using oceanographic data collected from the years 2006 and 2009 with a focus on the sediment and brackish water transport from the river and Skagit Bay tide flats to the Swinomish Channel. The model was applied to assess the feasibility of achieving the desired dual outcome of (a) reducing sedimentation and shoaling in the Swinomish Channel and (b) providing a direct migration pathway and improved conveyance of freshwater into the Swinomish Channel. The potential reduction in shoaling through site-specific structure repairs is evaluated. Similarly, the potential to significantly improve of brackish water habitat through dike breach restoration actions using the McGlinn Causeway project example, along with its impacts on sediment deposition in the Swinomish Navigation Channel, is examined.

Landis, W. G., Chu, V. R., Graham, S. E., Harris, M. J., Markiewicz, A. J., Mitchell, C. J., . . . Stark, J. D. (2019). The Integration of Chlorpyrifos Acetylcholinesterase Inhibition, Water Temperature and Dissolved Oxygen Concentration into a Regional Scale Multiple Stressor Risk Assessment Estimating Risk to Chinook Salmon in Four Rivers in Washington State, USA. *Integrated Environmental Assessment and Management, 16*(1), https://doi.org/10.1002/ieam.4199

We estimated the risk to populations of Chinook salmon (Oncorhynchus tshawytscha) due to chlorpyrifos (CH), water temperature (WT), and dissolved oxygen concentration (DO) in 4 watersheds in Washington State, USA. The watersheds included the Nooksack and Skagit Rivers in the Northern Puget Sound, the Cedar River in the Seattle–Tacoma corridor, and the Yakima River, a tributary of the Columbia River. The Bayesian network relative risk model (BN-RRM) was used to conduct this ecological risk assessment and was modified to contain an acetylcholinesterase (AChE) inhibition pathway parameterized using data from CH toxicity data sets. The completed BN-RRM estimated risk at a population scale to Chinook salmon employing classical matrix modeling runs up to 50-y timeframes. There were 3 primary conclusions drawn from the modelbuilding process and the risk calculations. First, the incorporation of an AChE inhibition pathway and the output from a population model can be combined with environmental factors in a quantitative fashion. Second, the probability of not meeting the management goal of no loss to the population ranges from 65% to 85%. Environmental conditions contributed to a larger proportion of the risk compared to CH. Third, the sensitivity analysis describing the influence of the variables on the predicted risk varied depending on seasonal conditions. In the summer, WT and DO were more influential than CH. In the winter, when the seasonal conditions are more benign, CH was the driver. Fourth, in order to reach the management goal, we calculated the conditions that would increase juvenile survival, adult survival, and a reduction in toxicological effects. The same process in this example should be applicable to the inclusion of multiple pesticides and to more descriptive population models such as those describing metapopulations

Landis, W. G., Chu, V. R., Graham, S. E., Harris, M. J., Markiewicz, A. J., Mitchell, C. J., . . . Stark, J. D. (2020). Integration of Chlorpyrifos Acetylcholinesterase Inhibition, Water Temperature, and Dissolved Oxygen Concentration into a Regional Scale Multiple Stressor Risk Assessment Estimating Risk to Chinook Salmon. *Integrated Environmental Assessment and Management, 16*(1), https://doi.org/10.1002/ieam.4199

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Larson, W. A., Palti, Y., Gao, G., Warheit, K. I., & Seeb, J. E. (2017). Rapid Discovery of Snps That Differentiate Hatchery Steelhead Trout from ESA-Listed Natural-Origin Steelhead Trout Using a 57k Snp Array. *Canadian Journal of Fisheries and Aquatic Sciences, 75*(7), https://doi.org/10.1139/cjfas-2017-0116

Natural-origin steelhead trout in the Pacific Northwest USA are threatened by a number of factors including habitat destruction, disease, decline in marine survival and a potential erosion of genetic viability due to introgression from hatchery strains. Our major goal was to use a recently developed SNP array containing ~57,000 SNPs to identify a subset of SNPs that differentiate hatchery- and natural-origin populations. We analyzed 35,765 polymorphic SNPs in nine populations of steelhead trout sampled from Puget Sound, Washington State, USA. We then conducted two outlier tests and found 360 loci that were candidates for divergent selection between hatchery and natural-origin populations (average FCT = 0.29, max = 0.65) and 595 SNPs that were candidates for selection among natural-origin populations (average FST = 0.25, max = 0.51). Comparisons with a linkage map revealed that two chromosomes (Omy05, Omy25) contained significantly more outliers than other chromosomes, suggesting that regions on Omy05 and Omy25 may be of adaptive significance. Our results highlight several advantages of the 57K SNP array as a tool for population and conservation genomics studies.

Lestelle, L., Brocksmith, R., Johnson, T., & Sands, N. (2014). *Guidance for Updating Recovery Goals for the Hood Canal and Strait of Juan De Fuca Summer Chum Salmon Populations*. Hood Canal Coordinating Council, Retrieved from http://hccc.wa.gov/sites/default/files/resources/downloads/Guidance%20for%20Updating%20SumChum%20Goals_FINAL_1.pdf

This report reviews the status of the existing recovery goals of the Hood Canal Summer Chum evolutionarily significant unit (ESU) and provides new analyses for updating the goals and assessing the gaps between current population performance and those goals. Seven recommendations are offered with respect to updating the goals, prioritizing future habitat restoration and protection actions, addressing harvest goals, continuing reintroduction efforts, and maintaining monitoring and evaluation efforts.

Lestelle, L., Sands, N., Johnson, T., & Downen, M. (2018). *Recovery Goal Review and Updated Guidance for the Hood Canal Summer Chum Salmon Esu.* Retrieved from http://hccc.wa.gov/SummerChum

This report reviews the existing recovery goals for the Hood Canal Summer Chum evolutionarily significant unit (ESU) and provides guidance for updating the goals from those contained in the recovery plan for the ESU. Various analyses presented herein are based on data collected through 2016, though some additional insights are given based on preliminary data from 2017.

Losee, J. P., Kendall, N. W., & Dufault, A. (2019). Changing Salmon: An Analysis of Body Mass, Abundance, Survival, and Productivity Trends across 45 Years in Puget Sound. *Fish and Fisheries, 20*(5), https://doi.org/10.1111/faf.12385

Pacific salmon and trout (Oncorhynchus spp., Salmonidae) of the Puget Sound region of Washington State, USA, have experienced recent and longer-term (multidecadal) variability in abundance while supporting robust fisheries. As part of the post-season salmon management process, population-specific estimates of total adult abundance to Puget Sound (Strait of Juan de Fuca) for pink (O. gorbuscha), chum (O. keta), coho (O. kisutch), sockeye (O. nerka), and Chinook (O. tshawytscha) salmon and steelhead trout (O. mykiss) are calculated annually. We compiled annual estimates of body mass, abundance and survival of hatchery- and naturally produced salmon from 1970 to 2015 to compare spatial and temporal patterns across species. Average weights of adult salmon and steelhead returning to Puget Sound, with the exception of coho salmon, have decreased since the 1970s. Temporal trends in abundance, survival and productivity varied by species and origin (hatchery vs. naturally produced). Generally, abundance and survival rates of natural-origin species decreased whereas those of hatchery-produced species did not, which is in contrast with other studies' general conclusions of decreasing survival among Puget Sound salmonids. Species diversity has decreased in recent years, with salmonids that rely on a short freshwater rearing phase in the natural environment (hatchery-produced fish and naturally produced pink and chum) representing >90% of total returns in most years. This new information reveals patterns of body size, abundance, survival and productivity across species, life history and rearing type over the past 45 years and, in doing so, demonstrates the strength in multidecadal, multifactor time series to critically evaluate salmonid species.

Lowery, E. D., & Beauchamp, D. A. (2015). Trophic Ontogeny of Fluvial Bull Trout and Seasonal Predation on Pacific Salmon in a Riverine Food Web. *Transactions of the American Fisheries Society, 144*(4), https://doi.org/10.1080/00028487.2015.1035452

Bull Trout Salvelinus confluentus are typically top predators in their host ecosystems. The Skagit River in northwestern Washington State contains Bull Trout and Chinook Salmon Oncorhynchus tshawytscha populations that are among the largest in the Puget Sound region and also contains a regionally large population of steelhead O. mykiss (anadromous Rainbow Trout). All three species are listed as threatened under the Endangered Species Act (ESA). Our objective was to determine the trophic ecology of Bull Trout, especially their role as predators and consumers in the riverine food web. We seasonally sampled distribution, diets, and growth of Bull Trout in mainstem and tributary habitats during 2007 and winter–spring 2008. Consumption rates were estimated with a bioenergetics model to (1) determine the annual and seasonal contributions of different prey types to Bull Trout energy budgets and (2) estimate the potential impacts of Bull Trout predation on juvenile Pacific salmon populations. Salmon carcasses and eggs contributed approximately 50% of the annual energy budget for large Bull Trout in main-stem habitats, whereas those prey types were largely inaccessible to smaller Bull Trout in tributary habitats. The remaining 50% of the energy budget was acquired by eating juvenile salmon, resident fishes, and immature aquatic insects. Predation on listed Chinook Salmon and steelhead/Rainbow Trout was highest during winter and spring (January–June). Predation on juvenile salmon differed between the two study years, likely due to the dominant odd-year spawning cycle for Pink Salmon O. gorbuscha. The population impact on ocean- and streamtype Chinook Salmon was negligible, whereas the impact on steelhead/Rainbow Trout was potentially very high. Due to the ESA-listed status of Bull Trout, steelhead, and Chinook Salmon, the complex trophic interactions in this drainage provide both challenges and opportunities for creative adaptive management strategies.

Meador, J. P., Yeh, A., & Gallagher, E. P. (2018). Adverse Metabolic Effects in Fish Exposed to Contaminants of Emerging Concern in the Field and Laboratory. *Environmental Pollution, 236*, https://doi.org/10.1016/j.envpol.2018.02.007

Several metabolic parameters were assessed in juvenile Chinook salmon (Oncorhynchus tshawytscha) and staghorn sculpin (Leptocottus armatus) residing in two estuaries receiving wastewater treatment effluent and one reference estuary. We also conducted a laboratory study with fish dosed for 32 days with 16 of the most common contaminants of emerging concern (CECs) detected in feral fish. Several blood chemistry parameters and other indicators of health were measured in fish from the field and laboratory study that were used to assess potential metabolic disruption. The blood chemistry values observed in feral juvenile Chinook salmon were relatively consistent among fish collected from effluent-impacted sites and substantially different compared to reference site fish. These responses were more pronounced in Chinook salmon, which is supported by the disparity in accumulated CECs. The blood chemistry results for juvenile Chinook salmon collected at effluent-impacted sites exhibited a pattern generally consistent with starvation because of similarities to observations from studies of food-deprived fish; however, this response is not consistent with physical starvation but may be contaminant induced. The altered blood chemistry parameters are useful as an early indicator of metabolic stress, even though organismal characteristics (lipid content and condition factor) were not different among sites indicating an early response. Evidence of metabolic disruption was also observed in juvenile Chinook salmon that were exposed in the laboratory to a limited mixture of CECs; however, the plasma parameters were qualitatively different possibly due to exposure route, season, or the suite of CECs. Growth was impaired in the high-dose fish during the dosing phase and the low- and medium-dose fish assayed after 2 weeks of depuration. Overall, these results are consistent with metabolic disruption for fish exposed to CECs, which may result in early mortality or an impaired ability to compete for limited resources.

Moore, M. E., & Berejikian, B. A. (2017). Population, Habitat, and Marine Location Effects on Early Marine Survival and Behavior of Puget Sound Steelhead Smolts. *Ecosphere, 8*(5), https://doi.org/10.1002/ecs2.1834

Steelhead trout (Onchorhynchus mykiss) smolts suffer high mortality rates during their rapid migration through the Salish Sea. Among-population variability in mortality rates may reflect (1) genetic fitness variation among populations, (2) freshwater environmental effects on fish condition, or (3) differences in local marine conditions upon seawater entry. A reciprocal transplant experiment was conducted to separate the influence of freshwater effects (combined effects of population and freshwater environment) from effects of local marine conditions on survival of two Puget Sound steelhead populations. Steelhead smolts from the Green River in Central Puget Sound (urbanized and hatchery-influenced) and the Nisqually River in South Puget Sound (less urbanized; no hatchery influence) were tagged with acoustic telemetry transmitters and released back into their natal river or transported and released into the other river. Population of origin had little influence on probability of surviving the migration through Puget Sound. However, smolts released into the Green River had higher survival through Puget Sound (17%) than smolts released into the Nisqually River (6%); the extra 64-km migration segment for the Nisqually-released fish accounted for most of the difference between the two release locations. Neither fork length nor translocation influenced survival, though release date did affect survival of Nisqually population smolts regardless of their release location. Residence time and behavior in the two estuaries were similar, and no effects of population of origin or release date were evident. Marine travel rates also did not differ between populations, release dates, or release locations. This study indicates that mortality occurring in the Salish Sea is likely driven by processes in inland marine environments, more so than intrinsic effects of population or freshwater-rearing environments.

Moore, M. E., Berejikian, B. A., Goetz, F. A., Berger, A. G., Hodgson, S. S., Connor, E. J., & Quinn, T. P. (2015). Multi-Population Analysis of Puget Sound Steelhead Survival and Migration Behavior. *Marine Ecology Progress Series, 537*, https://doi.org/10.3354/meps11460

Until recently, research on mortality of anadromous fishes in the marine environment was largely limited to estimates of total mortality and association with group characteristics or the environment. Advances in sonic transmitter technology now allow estimates of survival in discrete marine habitats, yielding important information on species of conservation concern. Previous telemetry studies of steelhead Oncorhynchus mykiss smolts in Puget Sound, Washington, USA indicated that approx. 80% of fish entering marine waters did not survive to the Pacific Ocean. The present study re-examined data from previous research and incorporated data from additional Puget Sound populations (n = 7 wild and 6 hatchery populations) tagged during the same period (2006-2009) for a comprehensive analysis of steelhead early marine survival. We used mark-recapture models to examine the effects of several factors on smolt survival and to identify areas of Puget Sound where mortality rates were highest. Wild smolts had higher survival probabilities in general than hatchery smolts, with exceptions, and wild smolts released in early April and late May had a higher probability of survival than those released in early and mid-May. Steelhead smolts suffered greater instantaneous mortality rates in the central region of Puget Sound and from the north end of Hood Canal through Admiralty Inlet than in other monitored migration segments. Early marine survival rates were low (16.0 and 11.4% for wild and hatchery populations, respectively) and consistent among wild populations, indicating a common rather than watershed-specific mortality source. With segment-specific survival information we can begin to identify locations associated with high rates of mortality, and identify the mechanisms responsible.

National Marine Fisheries Service. (2015). *Data and Estimating Missing Data for the Puget Sound Chinook Salmon Esu 5-Year Status Review*. National Marine Fisheries Service https://doi.org/10.7289/V5/NWFSC-PR-2015-01

This report documents the data used for the National Marine Fisheries Service's 2010 5-year status review of the Puget Sound Chinook Salmon Evolutionarily Significant Unit (ESU) populations (Ford 2011, NMFS 2011). It also documents the methods used to estimate values for missing years of data in order to develop the complete time series needed for cohort run reconstruction. The length of the time series for each population was determined by the availability of spawning abundance estimates. Data were supplied by state and tribal comanagers, either in reports or directly as the result of the public request for data as part of the 5-year status review of the Puget Sound Chinook Salmon ESU (NMFS 2010). The status review focused primarily on abundance and productivity of the 22 populations identified by the Puget Sound Technical Recovery Team (PS TRT) and used in the recovery plan (Ruckelshaus et al. 2006, SSDC 2007). In Table 1 through Table 22 of this report, data supplied by comanagers or obtained from reports are in normal font and estimates for missing data used in this analysis are in boldface. Methods for estimating missing data are provided in detail in the descriptions of each watershed population (22 populations in the 12 subsections of the Population-specific Data and Methods section).

National Marine Fisheries Service. (2015). *Fishes of the Salish Sea; a Compilation and Distributional Analysis*. (Professional paper NMFS 18). https://doi.org/10.7755/PP.18

As part of a current effort to restore the Salish Sea, a 16,925-km2 inland waterway shared by Washington State and British Columbia, a definitive, up-to-date list of the fishes that inhabit this marine ecosystem has been badly needed. The last such effort was published more than three decades ago. In response to this deficiency, we compiled information from various sources and identified 253 fish species observed in marine or brackish waters of the Salish Sea ecosystem, an increase of nearly 14% since the last published checklist. These 253 species, encompassing 1 myxinid, 2 petromyzontids, 18 chondrichthyans, 2 chondrosteans, and 230 teleosts, are contained within 78 families and 31 orders. This comprehseive list of the Salish Sea ichthyofauna will serve as a foundation for determining the occurrence of new species and perhaps the disappearance of others, enabling the selection of species as indicators of ecosystem health, and will provide a basis for identifying the mechanisms responsible for marine animal declines.

National Marine Fisheries Service. (2015). *Identifying Historical Populations of Steelhead within the Puget Sound Distinct Population Segment*. National Oceanic and Atmospheric Administration https://doi.org/10.7289/V5/TM-NWFSC-128

The Puget Sound Steelhead Technical Recovery Team (PSS TRT) convened in March 2008 to review information relevant to the identification of historical demographically independent populations (DIPs) of steelhead (Oncorhynchus mykiss) in the Puget Sound steelhead distinct population segment (DPS). The PSS TRT identified three major population groups (MPGs) containing a total of 32 steelhead DIPs in Puget Sound. Steelhead in the Puget Sound DPS exhibit two distinct life history strategies: summer-run and winter-run migrations. Winter-run steelhead, also known as ocean-maturing steelhead, return to freshwater during the winter and early spring months and spawn relatively soon after entering freshwater. Alternatively, summer-run (stream-maturing) steelhead return to freshwater during late spring and early summer in a relatively immature state and hold there until spawning in the following winter/spring. Generally, but not necessarily, summer-run steelhead return-timing is coordinated with river flow patterns that allow access past barriers to headwater spawning areas. Presently and historically, winter-run steelhead numerically represent the predominant life history type in Puget Sound

National Marine Fisheries Service. (2015). *Puget Sound Chinook Salmon Recovery : A Framework for the Development of Monitoring and Adaptive Management Plans*. U.S. Dept. Commerce https://doi.org/10.7289/V5/TM-NWFSC-130

This technical memorandum was developed by the Puget Sound Recovery Implementation Technical Team (PS RITT) to provide a formal monitoring and adaptive management framework (hereinafter called the framework) for assessing Puget Sound Chinook salmon recovery. Monitoring and adaptive management have occurred at the watershed and regional scales as implementation of the Recovery Plan has proceeded. However, the lack of a formal framework has meant that there is no standardized vocabulary or shared common approach to articulate the key assumptions of the chapters in Volume II, test assumptions across chapters, or connect the local, watershed-scale information in Volume II with the regional-scale information in Volume I. This gap limits the collective ability of resource managers to assess the effectiveness of salmon recovery efforts across the region, identify uncertainties, and update priorities and actions in the Recovery Plan. Furthermore, the framework is intended to help salmon recovery managers formalize their local-scale monitoring and adaptive management plans using a common approach

National Marine Fisheries Service. (2015). *Viability Criteria for Steelhead within the Puget Sound Distinct Population Segment*. National Oceanic and Atmospheric Administration https://doi.org/10.7289/V5/TM-NWFSC-129

Under the U.S. Endangered Species Act (ESA), the National Oceanographic and Atmospheric Administration's National Marine Fisheries Service (NMFS) is required to identify measurable and objective delisting criteria as part of recovery planning. These delisting criteria must describe the conditions under which a listed species or distinct population segment (DPS) is no longer in danger of extinction (endangered) or likely to become so in the foreseeable future (threatened). We define a viable DPS as one that is unlikely to be at risk of extinction in the foreseeable future; for this purpose, we adopted the viable salmonid population (VSP) criterion of a 100-year timeline (McElhany et al. 2000, Viable Salmon Populations and the Recovery of Evolutionarily Significant Units, NOAA Tech. Memo. NMFS-NWFSC-42) to evaluate risk of extinction. Ultimately, the identification of delisting criteria requires the consideration of technical analyses relating to viability, which are contained in this report, and policy decisions such as acceptable levels of risk, which are not. It presents the biological viability

criteria recommended by the Puget Sound Steelhead Technical Recovery Team (PSS TRT). The framework and the analyses it supports do not set targets for delisting, nor do they explicitly identify specific populations or groups of populations for recovery priority. Rather, the framework and associated analyses are meant to provide a technical foundation for those charged with recovery of listed steelhead (Oncorhynchus mykiss) in Puget Sound, from which they can develop effective recovery plans at the watershed scale (and higher) that are based on biologically meaningful criteria.

National Marine Fisheries Service. (2017). *2016 5-Year Review : Summary & Evaluation of Puget Sound Chinook Salmon Hood Canal Summer-Run Chum Salmon Puget Sound Steelhead*. Portland, OR: National Oceanic and Atmospheric Administration Retrieved from https://repository.library.noaa.gov/view/noaa/17015

Many West Coast salmon and steelhead (Oncorhynchus sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the review of the ESA-listed salmon and steelhead species in Puget Sound including: Puget Sound (PS) Chinook salmon, Hood Canal summer-run (HCS) chum salmon, and PS steelhead.

National Marine Fisheries Service. (2017). *Monitoring Salmon Habitat Status and Trends in Puget Sound : Development of Sample Designs, Monitoring Metrics, and Sampling Protocols for Large River, Floodplain, Delta, and Nearshore Environments*. https://doi.org/10.7289/V5/TM-NWFSC-137

Our goal in this project was to develop a habitat monitoring program for the four distinct salmon and steelhead spawning and rearing environments of Puget Sound: large rivers, floodplains, deltas, and the nearshore. This program will provide data to assess habitat changes across each ESU and help determine whether habitat conditions are improving, static, or declining at future status reviews for each of the listed species. We have five objectives for the first year of this monitoring effort: 1) to develop a hierarchical sampling design to monitor habitat status and trends, 2) to identify habitat metrics that are cost-effective and related to Viable Salmonid Population (VSP) parameters (abundance, population growth rate, population structure, and diversity), 3) to develop protocols to measure these metrics, 4) to test satellite, aerial photography, and field observation methods for repeatability and reliability, and 5) to evaluate habitat status to assess the ability of each metric to detect habitat differences among the chosen land-cover strata.

National Marine Fisheries Service. (2019). *ESA Recovery Plan for the Puget Sound Steelhead Distinct Population Segment*. Retrieved from https://www.fisheries.noaa.gov/webdam/download/100387986

This recovery plan (Plan or recovery plan) provides guidance for the protection and recovery of Puget Sound steelhead, a listed threatened species under the federal Endangered Species Act (ESA). NOAA's National Marine Fisheries Service (NMFS) recognizes Puget Sound steelhead as a distinct population segment (DPS)1 of steelhead (Oncorhynchus mykiss). The Puget Sound steelhead DPS (shown in Figure ES-1) includes all naturally spawned steelhead originating below natural and manmade impassable barriers in rivers flowing into Puget Sound from the Elwha River (inclusive) eastward, including rivers in Hood Canal, South Sound, North Sound, and the Strait of Georgia. The DPS includes steelhead from six artificial propagation programs.

Nelson, B. W., Walters, C. J., Trites, A. W., & McAllister, M. K. (2019). Wild Chinook Salmon Productivity Is Negatively Related to Seal Density and Not Related to Hatchery Releases in the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(3), https://doi.org/10.1139/cjfas-2017-0481

Predation risk and competition among conspecifics significantly affect survival of juvenile salmon, but are rarely incorporated into models that predict recruitment in salmon populations. Using densities of harbour seals (Phoca vitulina) and numbers of hatchery-released Chinook salmon (Oncorhynchus tshawytscha) smolts as covariates in spatially structured Bayesian hierarchical stock-recruitment models, we found significant negative correlations between seal densities and productivity of Chinook salmon for 14 of 20 wild Chinook populations in the Pacific Northwest. Changes in numbers of seals since the 1970s were associated with a 74% decrease (95% CI: -85%, -64%) in maximum sustainable yield in Chinook stocks. In contrast, hatchery releases were significantly correlated with Chinook productivity in only one of 20 populations. Our findings are consistent with recent research on predator diets and bioenergetics modeling that suggest there is a relationship between harbour seal predation on juvenile Chinook and reduced marine survival in parts of the eastern Pacific. Forecasting, assessment, and recovery efforts for salmon populations of high conservation concern should thus consider including biotic factors, particularly predatorprey interactions.

Neville, C. M., Beamish, R. J., & Chittenden, C. M. (2015). Poor Survival of Acoustically-Tagged Juvenile Chinook Salmon in the Strait of Georgia, British Columbia, Canada. *Transactions of the American Fisheries Society, 144*(1), https://doi.org/10.1080/00028487.2014.954053

The collapse of the commercial fishery and the major decline in catches in the recreational fishery for Chinook Salmon Oncorhynchus tshawytscha in the Strait of Georgia since the mid-1990s represents a major economic loss to British Columbia. Early marine residence is critical for survival of Chinook Salmon, but measuring the amount of mortality has been difficult. Acoustic tags can be used to measure marine mortality and study migratory behavior. We surgically implanted 278 juvenile Chinook Salmon with acoustic tags to monitor when and how many tagged fish moved out of the Strait of Georgia. Only eight tagged fish were detected leaving the Strait of Georgia, indicating that there could have been substantial mortality of the tagged juvenile Chinook Salmon within the strait. Tagging mortality was minimal, and the detection of tags was shown not to be a major source of error in this study. A major change in population structure between the spring and fall tagging periods meant that it was unlikely that most of the fish tagged in June and July remained within the Strait of Georgia. The decline in abundance of juvenile Chinook Salmon in November 2008 also indicates that the lack of detections of all tagged fish is unlikely a consequence of fish remaining in the Strait of Georgia. This information and the low catches in winter surveys indicated that most juvenile Chinook salmon were no longer in the strait in the late fall and winter. If the tagged fish were representative of the untagged fish, the current brood-year strength probably is largely determined within the Strait of Georgia.

Northwest Indian Fisheries Commission. (2016). *2016 State of Our Watersheds: A Report by the Treaty Tribes in Western Washington.* Retrieved from https://geo.nwifc.org/SOW/SOW2016_Report/SOW2016.pdf

Estuaries in western Washington are losing functional habitat because of population increases in the lower watersheds. For example, since the publication of the 2012 State of Our Watersheds Report, the Stillaguamish Salmon Recovery Plan's 10-year target for estuary habitat restoration has expanded from 315 acres to 548 acres. As of 2013, only 150 acres had been restored toward that target. The restoration of estuarine habitat is a goal in many of the salmon recovery plans, with identified restoration benchmarks during the first 10-year period. The overall trend for estuary restoration is the continued loss of functional habitat due to the increase in residential and commercial development in the lower watersheds, and the lack of completion of restoration projects. However, some restoration work has made a positive change. For example, about 12% of the 2005 Skagit Chinook Recovery Plan's habitat restoration goal has been met. Since the 2012 State of Our Watersheds Report, Turner Bay and Dugualla Heights have changed from active restoration projects to completed restoration projects.

O'Neill, S. M., Carey, A. J., Harding, L. B., West, J. E., Ylitalo, G. M., & Chamberlin, J. W. (2019). Chemical Tracers Guide Identification of the Location and Source of Persistent Organic Pollutants in Juvenile Chinook Salmon (Oncorhynchus tshawytscha), Migrating Seaward through an Estuary with Multiple Contaminant Inputs. *Science of the Total Environment, 712*, https://doi.org/10.1016/j.scitotenv.2019.135516

Understanding the spatial extent, magnitude, and source of contaminant exposure in biota is necessary to formulate appropriate conservation measures to reduce or remediate contaminant exposure. However, obtaining such information for migratory animals is challenging. Juvenile Chinook salmon (Oncorhynchus tshawytscha), a threatened species throughout the US Pacific Northwest, are exposed to persistent organic pollutants (POPs), including polybrominated diphenyl ether (PBDE) flame retardants and polychlorinated biphenyls (PCBs), in many developed rivers and estuaries. This study used three types of complementary chemical tracer data (contaminant concentrations, POP fingerprints, and stable isotopes), to determine the location and source of contaminant exposure for natural- and hatchery-origin Chinook salmon migrating seaward through a developed watershed with multiple contaminant sources. Concentration data revealed that salmon were exposed to and accumulated predominantly PBDEs and PCBs in the lower mainstem region of the river, with higher PBDEs in natural- than hatchery-origin fish but similar PCBs in both groups, associated with differences in contaminant inputs and/or habitat use. The POP fingerprints of the natural-origin-fish captured from this region were also distinct from other region and origin sample groups, with much higher proportions of PBDEs in the total POP concentration, indicating a different contaminant source or habitat use than the hatchery-origin fish.

Stable isotopes, independent tracers of food sources and habitat use, revealed that natural-origin fish from this region also had depleted delta(15)N signatures compared to other sample groups, associated with exposure to nutrient-rich wastewater. The PBDE-enhanced POP fingerprints in these salmon were correlated with the degree of depletion in nitrogen stable isotopes of the fish, suggesting a common wastewater source for both the PBDEs and the nitrogen. Identification of the location and source of contaminant exposure allows environmental managers to establish conservation measures to control contaminant inputs, necessary steps to improve the health of Chinook salmon and enhance their marine survival.

Pacific Commission Sentinel Stocks Committee. (2018). *Pacific Salmon Commission Sentinel Stocks Committee Final Report 2009- 2014.* Pacific Salmon Commission Vancouver. Retrieved from http://www.psc.org/publications/technical-reports/technical-report-series/

The Sentinel Stocks Program (SSP) was an ad hoc effort negotiated by the Pacific Salmon Commission (the Commission or the PSC) in 2008 to improve information on escapements for a set of Chinook salmon Oncorhynchus tshawytscha stocks in the United States and Canada. Improvements were envisioned to be: more accurate and more precise estimates from existing agency assessment programs; funding of new agency programs to estimate escapements; and funding development of new, more cost-effective methods of estimating escapements. These improvements were to be realized through funding projects proposed by those agencies with management authority over fisheries exploiting stocks spawning in the following areas: Northern British Columbia (NBC); Fraser River Watershed; West Coast of Vancouver Island (WCVI); Puget Sound; and North Oregon Coast (NOC). Chinook salmon stocks in these areas were chosen for the SSP because insufficient information on these stocks had complicated the renewal of the Pacific Salmon Treaty in 2008. A committee of scientists representing management agencies from both countries (the Sentinel Stocks Committee or SSC) was empaneled to annually solicit, assess, coordinate, and recommend proposals to the Commission for funding, and to review and report results of those projects. The SSC was also charged with improving projects by sharing expertise among themselves and with project proponents, by fostering the development of new methods to cost-effectively estimate escapement, and by leveraging experience gained through the SSP to improve escapement estimation after the SSP had ended. The SSP funded 67 projects at a cost of 10 million US$ from 2009 through 2014 (Table ES.1). Funds were to be drawn equally from the annual earnings of the Northern and Southern Endowment Funds. This allocation was to support projects at 2 million US$ per year from 2009−2013. However, some of the allotted 10 million US$ was unspent at the end of 2013 funds that were used to extend the SSP into 2014. Fortyone projects were Canadian and 26 U.S. although the funds spent in each nation 5,648.3 k Can$ in Canada and 4,823.9 k US$ in the U.S.were similar, especially when currency exchange rates are considered. Preparation, evaluation, and recommendation of proposals to the Commission followed protocols and a schedule (Figure ES.1) established by the SSC during the first year of the program.

Piper, S., McHenry, M., Hagerty, S., Butler, D., & Metzger, B. (2016). *Dungeness River Watershed Action Plan.* Hood Canal Ranger District Olympic National Forest Retrieved from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd525831.pdf

The Dungeness watershed has been the focus for numerous committees, studies, and government projects to recover depleted wild stocks of salmon, restore salmon habitat, improve water quality and the overall condition of the watershed. The Olympic National Forest (ONF) has participated with other government agencies, citizens, and stakeholders to develop long-term management of the river and its resources, outline watershed restoration priorities, and implement the actions.

Puget Sound Indian Tribes, & Washington Department of Fish and Wildlife. (2017). *Comprehensive Management Plan for Puget Sound Chinook: Harvest Management Component.* Retrieved from https://wdfw.wa.gov/sites/default/files/publications/01947/wdfw01947.pdf

This Harvest Management Plan will guide the Washington co-managers in planning annual harvest regimes, as they affect listed Puget Sound Chinook salmon, for management years 2019-2020 through 2028-2029. Harvest regimes will be developed to achieve stated objectives (i.e., total or Southern U.S. exploitation rate ceilings, and / or abundance thresholds) for each of fifteen management units. This Plan describes how these guidelines are applied to annual harvest planning.

Reum, J. C., Hovel, R. A., & Greene, C. M. (2015). Estimating Continuous Body Size-Based Shifts in Δ15n–Δ13c Space Using Multivariate Hierarchical Models. *Marine Biology, 162*(2), https://doi.org/10.1007/s00227-014-2574-8

Stable isotopes (δ15N and δ13C) offer one representation of an individual's trophic niche and are important tools for elucidating ecological patterns and testing a diversity of hypotheses. Because δ15N and δ13C values are often obtained from the same sample, they compose a bivariate response that researchers commonly analyze using multivariate statistical methods. However, stable isotope data sets often exhibit hierarchical structure whereby samples may be clustered or grouped at multiple levels either as an artifact of sampling design or due to structure inherent in the sampled population (e.g., samples from individuals grouped according to life history stages, social groups, ages, or sizes classes). Ignoring such structure can result in overly optimistic confidence intervals and heighten the risk of observing significant differences where none exist. To address these issues, we suggest researchers utilize multivariate hierarchical models, which are a simple extension of univariate hierarchical methods. The models account for potential dependencies between δ15N and δ13C values, permit valid predictions of shifts in δ15N–δ13C space related to predictor variables, provide more accurate estimates of parameter uncertainty, and improved inferences on coefficients that correspond to groups with small to moderate quantities of data. We demonstrate advantages of multivariate hierarchical models by examining size-dependent shifts in δ15N–δ13C space in outmigrating post-smolt Chinook salmon sampled from an estuarine habitat. Given the prevalence of complex structure in ecological stable isotope data sets, multivariate hierarchical models should hold considerable value to food web and stable isotope ecologists.

Rubin, S. P., Hayes, M. C., & Grossman, E. E. (2018). Juvenile Chinook Salmon and Forage Fish Use of Eelgrass Habitats in a Diked and Channelized Puget Sound River Delta. *Marine and Coastal Fisheries, 10*(4), https://doi.org/10.1002/mcf2.10035

Eelgrass Zostera marina can form extensive meadows on Puget Sound river deltas. The extent to which these meadows provide critical rearing habitat for local estuarine fishes, especially out-migrating juvenile salmon, is not well understood. Further, delta eelgrass has been impacted by diking and river channelization with unknown consequences for fish. We sampled fish in the Skagit River delta, Washington, during April–September with a lampara net, which is well suited to capturing fish in eelgrass. We compared abundance and body size of Chinook Salmon Oncorhynchus tshawytscha and three forage fish species between eelgrass and nearby unvegetated habitat. We also assessed combined effects of eelgrass characteristics (meadow size and morphology) and oceanographic conditions (temperature and salinity), which covaried according to proximity and orientation to channelized distributary outlets, diked shorelines, and a jetty. Chinook Salmon were more abundant in eelgrass than in unvegetated habitat in June–July and were relatively more abundant in eelgrass compared with unvegetated habitat in regions with intact eelgrass than offshore from a channelized distributary outlet. Abundances of Pacific Herring Clupea pallasii and Shiner Perch Cymatogaster aggregata were consistently severalfold higher in eelgrass than in unvegetated habitat. Surf Smelt Hypomesus pretiosus were more abundant in eelgrass than in unvegetated habitat at some locations, but never less abundant in eelgrass. Our results suggest that conservation and restoration of delta eelgrass would benefit these species and help to identify the settings in which these actions would be most beneficial.

Ruff, C. P., Anderson, J. H., Kemp, I. M., Kendall, N. W., Mchugh, P. A., Velez-Espino, A., . . . Rawson, K. (2017). Salish Sea Chinook Salmon Exhibit Weaker Coherence in Early Marine Survival Trends Than Coastal Populations. *Fisheries Oceanography, 26*(6), https://doi.org/10.1111/fog.12222

Identifying factors that influence anadromous Pacific salmon (Oncorhynchus spp.) population dynamics is complicated by their diverse life histories and large geographic range. Over the last several decades, Chinook salmon (O. tshawytscha) populations from coastal areas and the Salish Sea have exhibited substantial variability in abundance. In some cases, populations within the Salish Sea have experienced persistent declines that have not rebounded. We analyzed a time series of early marine survival from 36 hatchery Chinook salmon populations spanning ocean entry years 1980–2008 to quantify spatial and temporal coherence in survival. Overall, we observed higher inter-population variability in survival for Salish Sea populations than non-Salish Sea populations. Annual survival patterns of Salish Sea populations covaried over smaller spatial scales and exhibited less synchrony among proximate populations relative to non-Salish Sea populations. These results were supported by multivariate autoregressive state space (MARSS) models which predominantly identified region-scale differences in survival trends between northern coastal, southern coastal, Strait of Georgia, and Puget Sound population groupings. Furthermore, Dynamic Factor Analysis (DFA) of regional survival trends showed that survival of southern coastal populations was associated with the North Pacific Gyre Oscillation, a large-scale ocean circulation pattern, whereas survival of Salish Sea populations was not. In summary, this study demonstrates that survival patterns in Chinook salmon are likely determined by a complex hierarchy of processes operating across a broad range in spatial and temporal scales, presenting challenges to the management of mixed-stock fisheries.

Sandell, T. A., Teel, D. J., Fisher, J., Beckman, B., & Jacobson, K. C. (2015). Infections by Renibacterium Salmoninarum and Nanophyetus Salmincola Chapin Are Associated with Reduced Growth of Juvenile

Chinook Salmon, Oncorhynchus tshawytscha (Walbaum), in the Northeast Pacific Ocean. *Journal of Fish Diseases, 38*(4), https://doi.org/10.1111/jfd.12243

We examined 1454 juvenile Chinook salmon, Oncorhynchus tshawytscha (Walbaum), captured in nearshore waters off the coasts of Washington and Oregon (USA) from 1999 to 2004 for infection by Renibacterium salmoninarum, Nanophyetus salmincola Chapin and skin metacercariae. The prevalence and intensities for each of these infections were established for both yearling and subyearling Chinook salmon. Two metrics of salmon growth, weight residuals and plasma levels of insulin- like growth factor-1, were determined for salmon infected with these pathogens/parasites, both individually and in combination, with uninfected fish used for comparison. Yearling Chinook salmon infected with R. salmoninarum had significantly reduced weight residuals. Chinook salmon infected with skin metacercariae alone did not have significantly reduced growth metrics. Dual infections were not associated with significantly more severe effects on the growth metrics than single infections; the number of triple infections was very low and precluded statistical comparison. Overall, these data suggest that infections by these organisms can be associated with reduced juvenile Chinook salmon growth. Because growth in the first year at sea has been linked to survival for some stocks of Chinook salmon, the infections may therefore play a role in regulating these populations in the Northeast Pacific Ocean.

Satterthwaite, W. H., Andrews, K. S., Burke, B. J., Gosselin, J. L., Greene, C. M., Harvey, C. J., . . . Sobocinski, K. L. (2020). Ecological Thresholds in Forecast Performance for Key United States West Coast Chinook Salmon Stocks. *Ices Journal of Marine Science, 77*(4), https://doi.org/10.1093/icesjms/fsz189

Preseason abundance forecasts drive management of US West Coast salmon fisheries, yet little is known about how environmental variability influences forecast performance. We compared forecasts of Chinook salmon (Oncorhynchus tshawytscha) against returns for (i) key CaliforniaOregon ocean fishery stocks and (ii) high priority prey stocks for endangered Southern Resident Killer Whales (Orcinus orca) in Puget Sound, Washington. We explored how well environmental indices (at multiple locations and time lags) explained performance of forecasts based on different methods (i.e. sibling-based, production-based, environment-based, or recent averages), testing for nonlinear threshold dynamics. For the California stocks, no index tested explained >50% of the variation in forecast performance, but spring Pacific Decadal Oscillation and winter North Pacific Index during the year of return explained >40% of the variation for the sibling-based Sacramento Fall Chinook forecast, with nonlinearity and apparent thresholds. This suggests that oceanic conditions experienced by adults (after younger siblings returned) have the most impact on sibling-based forecasts. For Puget Sound stocks, we detected nonlinear/threshold relationships explaining >50% of the variation with multiple indices and lags. Environmental influences on preseason forecasts may create biases that render salmon fisheries management more or less conservative, and therefore could motivate the development of ecosystem-based risk assessments.

Sauk-Suiattle Indian Tribe, Swinomish Tribal Community, Upper Skagit Indian Tribe, Skagit River System Cooperative, & Wildlife, W. D. o. F. a. (2016). *Skagit River Steelhead Fishery Resource Management Plan*. Retrieved from https://archive.fisheries.noaa.gov/wcr/publications/fishery_management/salmon_steelhead/skagit_rmp/skagit_r_sh_rmp_pepd_final.pdf

The Skagit RMP, submitted by co-managers, covers fishery management activities for natural origin Skagit River steelhead in the Skagit River watershed for five years beginning in 2018. Historically, the Skagit Basin has maintained the largest steelhead natural origin population and has been one of the most productive steelhead basins in the Puget Sound Steelhead DPS (Busby et al. 1996; Hard et al. 2007). The demographically independent populations (DIPs) that comprise the proposed Skagit steelhead management unit (SMU) represent about 40% of all returning natural origin steelhead to the Puget Sound Steelhead DPS (Hard et al. 2015). Trends in abundance indicate modest increases from 2009 to 2014 for 13 of the 22 DIPs, including Skagit River winter-run steelhead, even though most populations fall below viability parameters1 (NWFSC 2015). Several of these upward trends are not statistically different from neutral trends, and most populations within the Puget Sound Steelhead DPS remain small in size (NWFSC 2015). However, the Skagit has been one of the largest and most productive steelhead basins in the Puget Sound Steelhead DPS and the estimated probability that Skagit Basin steelhead would reach the quasi-extinction threshold of 157 fish established by the NMFS Puget Sound Steelhead Technical Review Team (PSS TRT) is very low – less than 10% within 100 years (Hard et al. 2015). Skagit River steelhead counts have been highly variable over time. While the population estimates have generally declined since the early 1980s, there is no significant evidence to determine a population trend at this time (Hard et al. 2015). Steelhead spawners in the Skagit River reached the lowest estimate of roughly 2,000 spawners in 2009. Since 2009, Skagit River spawners have increased by 350% and have averaged 8,800 from 2013 to 2015

Shaffer, J. A., Juanes, F., Quinn, T. P., Parks, D., McBride, T., Michel, J., . . . Byrnes, C. (2017). Nearshore Fish Community Responses to Large Scale Dam Removal: Implications for Watershed Restoration and Fish Management. *Aquatic Sciences, 79*(3), https://doi.org/10.1007/s00027-017-0526-3

The nearshore is a critical zone for northeast Pacific Ocean fish communities, including ecologically and culturally important salmon species. The largest dam removal in the world was recently completed on the Elwha River, with the goal of restoring fisheries and ecosystems to the watershed. The nearshore Elwha fish community was monitored monthly from January 2008 to November 2015 before, during and after dam removal. As of September 2015, approximately 2.6 million m3 of sediment material had increased the area of the Elwha delta to over 150 ha. Newly formed nearshore habitats were quickly colonized by fish communities during the dam removal period but the communities were similar in total species richness and Shannon diversity before and after dam removal, and were similar to a nearby reference site (Salt Creek estuary). Select fish species, including ESA-listed Pacific salmon and trout Oncorhynchus spp., and eulachon Thaleichthys pacificus, and non-native, American shad (Alosa sapidissima), appeared quickly in these new habitats. Hatchery releases of Chinook, O. tshawytscha, coho, O. kisutch, and steelhead, O. mykiss (over 3 million total fish annually to the lower river), dominated the Elwha estuary catch from April through August of each year before, during, and after dam removal. Chum salmon catch rate, size, and duration of estuary occupancy declined during and after dam removal. Overall catches of chum salmon fry prior to, during, and after dam removal were significantly negatively correlated with Chinook salmon catches but significantly, and positively, correlated with coho salmon. When assessed at the Elwha estuary separately, chum abundance was significantly positively correlated with Chinook, coho, and steelhead abundance. These patterns indicate overlap, and likely interaction between these respective groups of hatchery and wild fish. Continued hatchery releases may therefore further challenge chum salmon recovery and should be considered when planning for watershed recovery.

Skagit River System Cooperative. (2018). *Skagit Habitat Status & Trends for Freshwater Rearing Targets.* Retrieved from http://skagitcoop.org/wp-content/uploads/2017-Freshwater-Indicator-Report_Final_.pdf

This collection of studies aims to assess the status of Skagit basin habitat throughout the anadromous fish zone. We used 2015 USDA-NAIP orthophotography to map Skagit basin freshwater habitats into categories consistent with previous mapping efforts that utilized 1998 and 2006 data sets for the purposes of the Skagit Chinook Recovery Plan (SRSC and WDFW 2005), the Skagit Yearling Study (Beamer et al 2010), and the SWC Strategy and Application (Beamer et al 1998). The study area focused on mainstem, floodplain and selected tributary habitats. Identified trends were assessed in the context of the 2005 Skagit Chinook Recovery Plan, NOAA status & trends monitoring program and Puget Sound Partnership common indicators. This study will support the implementation of the Skagit Monitoring and Adaptive Management Strategy and a forthcoming update in the 2005 Chinook Recovery Plan. It will also support the 2017 Skagit Steelhead Recovery Plan.

Small, M. P., Rogers Olive, S. D., Seeb, L. W., Seeb, J. E., Pascal, C. E., Warheit, K. I., & Templin, W. (2015). Chum Salmon Genetic Diversity in the Northeastern Pacific Ocean Assessed with Single Nucleotide Polymorphisms (Snps): Applications to Fishery Management. *North American Journal of Fisheries Management, 35*(5), https://doi.org/10.1080/02755947.2015.1055014

We examined genetic diversity patterns among 55 collections of Chum Salmon from the northeastern Pacific Ocean using 89 single nucleotide polymorphisms (SNPs). The distribution of Chum Salmon samples extended from the Nass River along the coast of British Columbia and along the coast of Washington as far south as the Columbia River. Chum Salmon represented three previously defined run-groups: fall (primarily), summer, and winter. Genetic variation at SNP loci, as measured by FST, ranged from 0.002 to 0.279 over all collections and averaged 0.062 over all loci. Similar to the genetic patterns detected with microsatellites and allozymes, genetic variation followed a regional structure along geographic distance, with genetic diversity being highest in the north and decreasing southward, then increasing in and near the Columbia River. Within Puget Sound, Washington, genetic variation was structured further according to run timing (fall, summer, and winter) and shared ancestry. Simulations indicated that this suite of SNPs is powerful for identifying regional components in a Chum Salmon mixed fishery. Because of the transferability of SNP data, the growing SNP baseline for Chum Salmon will be useful for multiple agencies managing Chum Salmon around the Pacific Rim.

Smith, J. M., Fresh, K. L., Kagley, A. N., & Quinn, T. P. (2015). Ultrasonic Telemetry Reveals Seasonal Variation in Depth Distribution and Diel Vertical Migrations of Sub-Adult Chinook and Coho Salmon in Puget Sound. *Marine Ecology Progress Series, 532*, https://doi.org/10.3354/meps11360

Many aquatic organisms display seasonal and diel vertical migration (DVM) patterns, which are influenced by complex combinations of biotic and abiotic factors. Here, we examined the vertical distributions of sub-adult coho Oncorhynchus kisutch and Chinook salmon O. tshawytscha in Puget Sound, Washington, USA, using acoustic telemetry to (1) compare the depths occupied by each species, (2) determine whether DVM occurred, (3) ascertain if depth distributions changed seasonally, and (4) consider hypotheses regarding abiotic and biotic factors that could affect these behavior patterns. We modeled the data on individual fish depths and detected significant interactions among species, diel period, and season. Coho salmon spent more time near the surface than Chinook salmon overall, and exhibited DVM during the spring, being farther below the surface at night and closer during the day. This reversal of the typical DVM pattern was not evident in other seasons. Chinook salmon showed no evidence of diel movement, only a seasonal shift from being closest to the surface in spring, deeper in summer, deeper yet in fall, and deepest in winter. The proximity of Chinook salmon to the surface coincided with peak productivity measured as chlorophyll a, which could affect the salmon through decreased water clarity or some ecological process. The DVM exhibited by coho salmon in spring may be related to water clarity and avoidance of predatory mammals but these hypotheses could not be tested with the available data. Our results emphasize the complexity of diel activity patterns among closely related species, and even among individuals.

Sobocinski, K. L., Greene, C. M., & Schmidt, M. W. (2018). Using a Qualitative Model to Explore the Impacts of Ecosystem and Anthropogenic Drivers Upon Declining Marine Survival in Pacific Salmon. *Environmental Conservation, 45*(3), https://doi.org/10.1017/s0376892917000509

Coho salmon (Oncorhynchus kisutch), Chinook salmon (Oncorhynchus tshawytscha) and steelhead (Oncorhynchus mykiss) in Puget Sound and the Strait of Georgia have exhibited declines in marine survival over the last 40 years. While the cause of these declines is unknown, multiple factors, acting cumulatively or synergistically, have likely contributed. To evaluate the potential contribution of a broad suite of drivers on salmon survival, we used qualitative network modelling (QNM). QNM is a conceptually based tool that uses networks with specified relationships between the variables. In a simulation framework, linkages are weighted and then the models are subjected to user-specified perturbations. Our network had 33 variables, including: environmental and oceanographic drivers (e.g., temperature and precipitation), primary production variables, food web components from zooplankton to predators and anthropogenic impacts (e.g., habitat loss and hatcheries). We included salmon traits (survival, abundance, residence time, fitness and size) as response variables. We invoked perturbations to each node and to suites of drivers and evaluated the responses of these variables. The model showed that anthropogenic impacts resulted in the strongest negative responses in salmon survival and abundance. Additionally, feedbacks through the food web were strong, beginning with primary production, suggesting that several food web variables may be important in mediating effects on salmon survival within the system. With this model, we were able to compare the relative influence of multiple drivers on salmon survival.

Sobocinski, K. L., Kendall, N. W., Greene, C. M., & Schmidt, M. W. (2020). Ecosystem Indicators of Marine Survival in Puget Sound Steelhead Trout. *Progress in Oceanography, 188*, https://doi.org/10.1016/j.pocean.2020.102419

Understanding ecosystem drivers of fish stock performance is essential to improving conservation and management. We used a hypothesis-driven approach to identify potential ecosystem indicators and developed a retrospective analysis using regression models of steelhead trout marine survival in Puget Sound, an urban estuary in Washington State, USA, over a 30-year time series. Indicators related to predator abundance, the presence of hatchery Chinook salmon in the system, salinity of marine waters, and timing of cumulative river discharge explained the most variance in smolt survival. Seal abundance was the strongest predictor, showing a strong negative relationship with steelhead marine survival, indicating that predation pressure may influence marine survival. Several other predictors were supported in our models, but with much less individual explanatory power. Our results support the conclusion that a combination of factors with differing mechanisms have likely contributed to declining survival of steelhead in inland marine waters. This study emphasizes the importance of collecting long-term survival and environmental data, taking a hypothesis-based approach to understanding ecosystem drivers related to marine survival, and evaluating the mechanisms associated with survival for species with complex life histories like anadromous steelhead trout.

Teel, D. J., Burke, B. J., Kuligowski, D. R., Morgan, C. A., & Van Doornik, D. M. (2015). Genetic Identification of Chinook Salmon: Stock-Specific Distributions of Juveniles Along the Washington and Oregon Coasts. *Marine and Coastal Fisheries, 7*(1), https://doi.org/10.1080/19425120.2015.1045961

We used microsatellite DNA data and genetic stock identification methods to delineate the temporal and spatial distributions of juvenile Chinook Salmon Oncorhynchus tshawytscha occupying coastal habitats extending from central Oregon to northern Washington. Juveniles were collected in trawl surveys conducted during spring, summer, and autumn over 15 years. Distributions (mean latitude and distance from shore) differed between yearling and subyearling life history types and between stocks; many of these differences were consistent across years. Yearlings were nearly all (98%) from Columbia River sources, and only 6% were naturally produced. In late May, yearlings from the lower Columbia and Willamette rivers were farther north than other yearlings, likely due to the early spring timing of their releases from hatcheries and subsequent out-migration from the Columbia River.

Thompson, J. N., & Beauchamp, D. A. (2014). Size-Selective Mortality of Steelhead During Freshwater and Marine Life Stages Related to Freshwater Growth in the Skagit River, Washington. *Transactions of the American Fisheries Society, 143*(4), https://doi.org/10.1080/00028487.2014.901253

We evaluated freshwater growth and survival from juvenile (ages 0-3) to smolt (ages 1-5) and adult stages in wild steelhead Oncorhynchus mykiss sampled in different precipitation zones of the Skagit River basin, Washington. Our objectives were to determine whether significant size-selective mortality (SSM) in steelhead could be detected between early and later freshwater stages and between each of these freshwater stages and returning adults and, if so, how SSM varied between these life stages and mixed and snow precipitation zones. Scale-based size-at-annulus comparisons indicated that steelhead in the snow zone were significantly larger at annulus 1 than those in the mixed rain-snow zone. Size at annuli 2 and 3 did not differ between precipitation zones, and we found no precipitation zone life stage interaction effect on size at annulus. Significant freshwater and marine SSM was evident between the juvenile and adult samples at annulus 1 and between each life stage at annuli 2 and 3. Rapid growth between the final freshwater annulus and the smolt migration did not improve survival to adulthood;

rather, it appears that survival in the marine environment may be driven by an overall higher growth rate set earlier in life, which results in a larger size at smolt migration. Efforts for recovery of threatened Puget Sound steelhead could benefit by considering that SSM between freshwater and marine life stages can be partially attributed to growth attained in freshwater habitats and by identifying those factors that limit growth during early life stages. Received December 3, 2013; accepted February 25, 2014

U.S. Environmental Protection Agency. (2020). Puget Sound Steelhead East Kitsap Dip Recovery Plan. Retrieved from http://westsoundwatersheds.org/default.aspx?ID=2

The purpose of a recovery plan is to communicate the current understanding of the species biology and the ecological requirements for the species to be viable within the geographic area of focus, as well as the strategies necessary to improve ecological function in order to increase viability in the time horizon of the plan. Viability of the East Kitsap steelhead (Oncorhynchus mykiss) population, which would support the delisting of Puget Sound steelhead is a desired outcome from successful implementation of this recovery plan. Delisting is the determination that the Puget Sound steelhead are no longer under threat of extinction and can be removed from the Endangered Species list. However, a fully recovered and harvestable population is the ultimate outcome for successfully implementing recovery. This plan describes the current understanding of steelhead in the East Kitsap geography, including the habitats that steelhead rely on as the current and predicted future causes of degradation to those habitats. The plan includes a set of strategies to protect and restore the most important habitats to expedite recovery within the next 50 years. While all ecosystem function is important, this plan recognizes that finite resources require a focus on the most important habitat types first. Many stakeholders are responsible for recovering steelhead throughout Puget Sound. This plan provides a road map for how various stakeholders in East Kitsap are expected to play a role in the local recovery of steelhead, including city and county jurisdictions, Tribes, non-profits, and private landowners. The plan was developed and written for stakeholders involved in recovery. Communication to the general public will likely require additional messaging and outreach so that they understand what actions they can take to assist with recovery. Many of the strategies and actions identified in the plan will benefit not only East Kitsap steelhead, but other important populations that support the Suquamish Tribe's treaty rights and ecosystem functions that support multiple salmonid species.

U.S. Geological Survey. (2017). *Suspended Sediment, Turbidity, and Stream Water Temperature in the Sauk River Basin, Western Washington, Water Years 2012-16*. (2017-5113). Reston, VA: U.S. Geological Survey https://doi.org/10.3133/sir20175113

The Sauk River is a federally designated Wild and Scenic River that drains a relatively undisturbed landscape along the western slope of the North Cascade Mountain Range, Washington, which includes the glaciated volcano, Glacier Peak. Naturally high sediment loads characteristic of basins draining volcanoes like Glacier Peak make the Sauk River a dominant contributor of sediment to the downstream main stem river, the Skagit River. Additionally, the Sauk River serves as important spawning and rearing habitat for several salmonid species in the greater Skagit River system. Because of the importance of sediment to morphology, flow-conveyance, and ecosystem condition, there is interest in understanding the magnitude and timing of suspended sediment and turbidity from the Sauk River system and its principal tributaries, the White Chuck and Suiattle Rivers, to the Skagit River.

Van Doornik, D. M., & Berejikian, B. A. (2015). Landscape Factors Affect the Genetic Population Structure of Oncorhynchus mykiss Populations in Hood Canal, Washington. *Environmental Biology of Fishes, 98*(2), https://doi.org/10.1007/s10641-014-0301-4

Among salmonids, local adaptation can reduce gene flow among populations, which can then lead to population sub-division. As such, it is important to understand what landscape variables affect local adaptation, especially for populations for which conservation concerns exist. By examining allele frequencies at 15 microsatellite DNA loci from anadromous (steelhead) and freshwater resident (rainbow trout) Oncorhynchus mykiss collected from 7 Hood Canal, Washington rivers, we surveyed the genetic population structure within and among populations, and examined the landscape factors that could be affecting their genetic population structure. We found that samples from within a river system were more genetically similar to each other regardless of life history type or sampling location than they were to similar types from other rivers. Rainbow trout samples had lower genetic diversity then steelhead samples. We identified two main population groups among the steelhead samples. Genetic distance among populations was most strongly influenced by the populations' locations on one of two peninsulas, and to a lesser extent, river flow rate and hydrological characteristics. These factors influence genetic population structure and local adaptation more than geographic distance, river gradient, or mean annual river temperature.

Waples, R. K., Seeb, J. E., & Seeb, L. W. (2017). Congruent Population Structure across Paralogous and Nonparalogous Loci in Salish Sea Chum Salmon (Oncorhynchus Keta). *Molecular Ecology, 26*(16), https://doi.org/10.1111/mec.14163

Whole-genome duplications are major evolutionary events with a lasting impact on genome structure. Duplication events complicate genetic analyses as paralogous sequences are difficult to distinguish; consequently, paralogs are often excluded from studies. The effects of an ancient whole-genome duplication (approximately 88 MYA) are still evident in salmonids through the persistence of numerous paralogous gene sequences and partial tetrasomic inheritance. We use restriction site-associated DNA sequencing on 10 collections of chum salmon from the Salish Sea in the USA and Canada to investigate genetic diversity and population structure in both tetrasomic and rediploidized regions of the genome. We use a pedigree and high-density linkage map to identify paralogous loci and to investigate genetic variation across the genome. By applying multivariate statistical methods, we show that it is possible to characterize paralogous loci and that they display similar patterns of population structure as the diploidized portion of the genome. We find genetic associations with the adaptively important trait of run-timing in both sets of loci. By including paralogous loci in genome scans, we can observe evolutionary signals in genomic regions that have routinely been excluded from population genetic studies in other polyploid-derived species.

Washington Department of Fish and Wildlife. (2015). *Toxic Contaminants in Juvenile Chinook Salmon (Oncorhynchus tshawytscha) Migrating through Estuary, Nearshore and Offshore Habitats of Puget Sound*. (FPT 16-02). Retrieved from https://wdfw.wa.gov/publications/01796

Juvenile Chinook salmon (Oncorhynchus tshawytscha) can encounter a wide range of water quality conditions, from relatively clean to highly contaminated, as they migrate from rivers into Puget Sound. During this life stage, as they transition into saltwater, they are particularly sensitive to stressors such as toxic contaminants. This study was designed to provide a synoptic assessment of contaminant exposure for major populations of juvenile Chinook salmon from Puget Sound as the fish migrate from their freshwater to marine habitats. Overall, the study estimated exposure of salmon to toxics chemicals in 1) the estuary habitats of major river systems entering Puget Sound, 2) the nearshore marine habitats associated with those rivers systems, and 3) the offshore marine habitats of the major basins of Puget Sound. The study addresses the general hypothesis that chemicals released into Puget Sound from human activities and development reduces the health and productivity of salmon and their food supply. Specifically, we hypothesized that juvenile Chinook salmon residing and feeding in the more urbanized and industrial estuary, nearshore marine, and offshore habitats of Puget Sound are exposed to higher concentrations of toxic contaminants than those in less developed habitats. In addition, we hypothesized that the elevated contaminant concentrations in the more urban areas are high enough to affect juvenile Chinook survival through reductions in growth, disease resistance, and altered hormone and protein levels.

Washington Department of Fish and Wildlife. (2016). *Duckabush Summer and Fall Chum Salmon 5 Year Review: Brood Year 2010-2014*. Fish Program, Science Division Retrieved from https://wdfw.wa.gov/sites/default/files/publications/01845/wdfw01845.pdf

This report summarizes the results from the juvenile monitoring study on the Duckabush River from 2011 to 2015. We evaluated freshwater productivity, juvenile outmigration timing, adult abundance and egg to migrant survival of summer and fall chum salmon. Abundance of adult summer chum was higher than fall chum four out of the 5 years of our study, and was composed almost entirely of natural-origin fish. Although we had no direct evidence, based on the exceedingly high survival rate needed to account for adult fall chum escapement from a single cohort monitored through the marine phase, we speculate that a significant number of fall chum spawners were stray hatchery origin fish from releases elsewhere within Hood Canal. Juvenile summer chum abundance ranged from three to twenty seven times larger than fall chum. Summer chum juveniles exhibited an earlier timed migration with peak outmigration occurring from late February to the middle of March. Egg to migrant survival for summer chum was higher than fall chum and was similar to values reported for other chum stocks on west coast. Fall chum egg to migrant survival was at the lower range of reported values for other fall chum stocks. Summer and fall chum freshwater survival appear to be negatively impacted by peak flow events and high spawning densities. Based on the results of this study, summer chum appear to be meeting the adult abundance and recruits per spawner recovery goals listed in the Summer Chum Salmon Conservation Initiative.

Washington Department of Fish and Wildlife. (2017). *Evaluation of Juvenile Salmon Production in 2015 from the Cedar River and Bear Creek*. (FPA 16-01). Olympia, WA: Washington Department of Fish and Wildlife Retrieved from https://wdfw.wa.gov/publications/01794

This report describes the emigration of five salmonid species from two tributaries in the Lake Washington watershed: Cedar River and Bear Creek. Cedar River flows into the southern end of Lake Washington; Bear Creek flows into the Sammamish River, which flows into the north end of Lake Washington (Figure 1). In each watershed, the abundance of juvenile migrants is the measure of freshwater production upstream from the trapping location. In 1992, the Washington Department of Fish and Wildlife (WDFW) initiated an evaluation of sockeye fry migrants in the Cedar River to investigate the causes of low adult sockeye returns. In 1999, the Cedar River juvenile monitoring study was expanded in scope in order to include juvenile migrant Chinook salmon. This new scope extended the trapping season to a six month period and, as a consequence, also allowed estimation of coho production, and assessment of steelhead and cutthroat trout movement. In 1997, WDFW initiated an evaluation of sockeye fry migrants in the Sammamish watershed. In 1997 and 1998, a juvenile trap was operated in the Sammamish River during the downstream sockeye migration. In 1999, this monitoring study was moved to Bear Creek in order to simultaneously evaluate Chinook and sockeye production. Since 1999, the Bear Creek juvenile monitoring study has also provided estimates of coho production and described ancillary data on movement patterns of steelhead and cutthroat trout. The primary study goal of this program in 2015 was to estimate the number of juvenile sockeye fry, and natural-origin Chinook and coho migrating from the Cedar River and Bear Creek into Lake Washington. This estimate was used to calculate survival of the 2014 brood from egg deposition to lake/river entry and to describe the migration timing of each species. Cutthroat and steelhead movements were assessed through catch totals but no abundance estimates were made. Biological data representing each population is also summarized.

Washington Department of Fish and Wildlife. (2017). *Final Assessment of Threatened and Endangered Marine and Anadromous Fish Presence Adjacent to the Manchester Fuel Department: 2015-16 Beach Seine Survey Results. Final Report to Navfac Nw.* Olympia, WA: Washington Department of Fish and Wildlife Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC%20Atlantic/NAVFAC%20Northwest/PDFs/About%20Us/Natural_Resources/nw_Manchester_seine_2017_FINAL.pdf

Puget Sound is home to a variety of marine and anadromous fish species that are afforded legal protection under the Endangered Species Act (ESA). The ESA-listed fish species within Puget Sound most relevant to this study include three species of rockfish (Yelloweye, Canary, and Bocaccio), four species of salmonid (Chinook, Hood Canal summer-run Chum, steelhead, and Bull Trout), and one species of forage fish (Eulachon). In an effort to determine whether occurrence of these ESA-listed species has the potential to affect operations in the waters adjacent to the Manchester Fuel Department (MFD), the Naval Facilities Engineering Command Northwest (NAVFAC NW) and the Washington Department of Fish and Wildlife (WDFW) entered into a cooperative agreement whereby the WDFW agreed to survey these waters to evaluate both the seasonal and resident presence of ESA-listed fish. The MFD, specifically the areas adjacent to the Manchester Fuel Department Naval Restricted Area (MFDNRA), was surveyed by the WDFW in 2015 and 2016. After reviewing the geographic scope, depth profile, water quality, and security restrictions associated with the survey area, it was determined that a combination of sampling methods including a beach seine and scuba divers would be used to survey the MFDNRA and immediate adjacent areas. Beach seine surveys targeted forage fish and juvenile salmonids in the nearshore, while scuba survey techniques were specific to rockfish and critical habitat evaluation. Surveys for rockfish were conducted once in October 2015, while beach seining surveys occurred monthly in 2015 and 2016 in order to detect any temporal changes in fish abundance or distribution. See Appendix A for a comprehensive list of fish species recorded for beach seining in 201516. For results on rockfish, their critical habitat, and a description of sampling methods other than beach seine see the 2014-15 final report. The only confirmed ESA-listed species recorded at the MFD was juvenile Chinook Salmon, with peak catch rates occurring in June 2015 and March 2016. Based on results from the 2015-16 surveys, we preliminarily conclude that the work window (August 1 to February 15) for the MFD facilities' in-water maintenance, military construction (MILCON), mitigation projects, future Fleet training and testing should not include March through July, as is consistent with the measures outlined in WAC 220-660-330.

Washington Department of Fish and Wildlife. (2017). *Final Assessment of Threatened and Endangered Marine and Anadromous Fish Presence Adjacent to the Nas Whidbey Island Crescent Harbor: 2015-16 Beach Seine Survey Results. Final Report to Navfac Nw.* Olympia, WA: Washington Department of Fish and Wildlife Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC%20Atlantic/NAVFAC%20Northwest/PDFs/About%20Us/Natural_Resources/nw_Whidbey_seine_2017_FINAL.pdf

Puget Sound is home to a variety of marine and anadromous fish species that are afforded legal protection under the Endangered Species Act (ESA). The ESA-listed fish species within Puget Sound most relevant to this study include three species of rockfish (Yelloweye, Canary, and Bocaccio), four species of salmonid (Chinook, Hood Canal summer-run Chum, steelhead, and Bull Trout), and one species of forage fish (Eulachon). In an effort to determine whether occurrence of these ESA-listed species has the potential to affect operations in the waters adjacent to the Naval Air Station (NAS) Whidbey Island Crescent Harbor, the Naval Facilities Engineering Command Northwest (NAVFAC NW) and the Washington Department of Fish and Wildlife (WDFW) entered into a cooperative agreement whereby the WDFW agreed to survey these waters to evaluate both the seasonal and resident presence of ESA-listed fish. The NAS Whidbey Island Crescent Harbor was surveyed by the WDFW in 2014, 2015, and 2016 using various techniques and technologies. After reviewing the geographic scope, depth profile, water quality, and security restrictions associated with the survey area, it was determined that a combination of sampling methods including a remotely operated vehicle (ROV), split-beam echosounder (hydroacoustics), scuba diving, lighted fish traps, and beach seining would be used to survey the entire Crescent Harbor area. Beach seine surveys targeted forage fish and juvenile salmonids in the nearshore, while all other sampling techniques were appropriate to surveying rockfish and critical habitat for all species. Surveys for rockfish were conducted at six month intervals in 2014 and 2015, while surveys for forage fish and juvenile salmonids occurred monthly 2015 and 2016 in order to detect temporal changes in fish abundance or distribution. See Appendix A for a comprehensive list of fish species recorded for beach seining in 201516. For results on rockfish, their critical habitat, and a description of sampling methods other than beach seine see the 2014-15 final report. There were three ESA-listed species captured with the beach seine at the NAS Whidbey Island Crescent Harbor; these included Chinook Salmon, Bull Trout, and steelhead. Based on results from the 2015-16 surveys, we preliminarily conclude that the work window (July 15 to February 15) for any of the NAS Whidbey Island Crescent Harbor facilities' in-water maintenance, military construction (MILCON), mitigation projects, and future Fleet training and testing should not include March through July, as is consistent with the measures outlined in WAC 220-660-330. We recommend that the aforementioned activities should also be avoided during the month of August and September due to potential late occurrence of Chinook Salmon in the nearshore, which is not consistent with the measures outlined in WAC 220-660-330.

Washington Department of Fish and Wildlife. (2017). *Final Assessment of Threatened and Endangered Marine and Anadromous Fish Presence Adjacent to the Nas Whidbey Island Lake Hancock: 2015-16 Beach Seine Survey Results.* Olympia, WA: Washington Department of Fish and Wildlife Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC%20Atlantic/NAVFAC%20Northwest/PDFs/About%20Us/Natural_Resources/nw_Lake%20Hancock_seine_2017_FINAL.pdf

Puget Sound is home to a variety of marine and anadromous fish species that are afforded legal protection under the Endangered Species Act (ESA). The ESA-listed fish species within Puget Sound most relevant to this study include three species of rockfish (Yelloweye, Canary, and Bocaccio), four species of salmonid (Chinook, Hood Canal summer-run Chum, steelhead, and Bull Trout), and one species of forage fish (Eulachon). In an effort to determine whether occurrence of these ESA-listed species has the potential to affect operations in the waters adjacent to the Naval Air Station (NAS) Whidbey Island Lake Hancock, the Naval Facilities Engineering Command Northwest (NAVFAC NW) and the Washington Department of Fish and Wildlife (WDFW) entered into a cooperative agreement whereby the WDFW agreed to survey these waters to evaluate both the seasonal and resident presence of ESA-listed fish. The NAS Whidbey Island Lake Hancock was surveyed by the WDFW in 2015 and 2016 with a beach seine, focusing on the shoreline areas adjacent to Admiralty Inlet. Beach seine surveys targeted forage fish and juvenile salmonids in the nearshore habitat, which occurred monthly from May to September 2015 and January to September 2016 in order to detect any temporal changes in fish abundance or distribution. See Appendix A for a comprehensive list of fish species recorded for beach seining in 2015-16. There were three confirmed ESA-listed species captured with the beach seine at the NAS Whidbey Island Lake Hancock. These included Hood Canal summer-run Chum, Chinook Salmon, and steelhead. Summer-run Chum Salmon cannot be visually distinguished from fall-run Chum Salmon juveniles; therefore, tissue samples collected in 2016 facilitated run assignment through genetic analysis in a separate report. Sampling in 2016 began in January with the intention to capture Hood Canal summer-run Chum Salmon that were detected in nearshore areas earlier (January-February) than fall-run Chum Salmon (March-April). The peak catch rate for Chinook Salmon juveniles occurred in June of both survey years. The single adult steelhead was captured in July 2015. Based on results from the 2015-16 surveys, we preliminarily conclude the work window (July 15 to February 15) for the NAS Whidbey Island Lake Hancock properties' in-water maintenance, military construction (MILCON), mitigation projects, future Fleet training and testing should not include February through July, as consistent with the measures outlined in WAC 220-660-330.

Washington Department of Fish and Wildlife. (2017). *Final Assessment of Threatened and Endangered Marine and Anadromous Fish Presence Adjacent to the Navbase Kitsap Bangor: 2015-16 Beach Seine Survey Results. Final Report to Navfac Nw.* Olympia, WA: Washington Department of Fish and Wildlife. Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC%20Atlantic/NAVFAC%20Northwest/PDFs/About%20Us/Natural_Resources/nw_Bangor_seine_2017_FINAL.pdf

Puget Sound is home to a variety of marine and anadromous fish species that are afforded legal protection under the Endangered Species Act (ESA). The ESA-listed fish species within Puget Sound most relevant to this study include three species of rockfish (Yelloweye, Canary, and Bocaccio), four species of salmonid (Chinook, Hood Canal summer-run Chum, steelhead, and Bull Trout), and one species of forage fish (Eulachon). In an effort to determine whether occurrence of these ESA-listed species has the potential to affect operations in the waters adjacent to the Naval Base Kitsap (NBK) at Bangor, the Naval Facilities Engineering Command Northwest (NAVFAC NW) and the Washington Department of Fish and Wildlife (WDFW) entered into a cooperative agreement whereby the WDFW agreed to survey these waters to evaluate both the seasonal and resident presence of ESA-listed fish. The NAVBASE Kitsap Bangor, specifically the Bangor Naval Restricted Area (BNRA), was surveyed by the WDFW in 2014, 2015, and 2016 using various techniques and technologies. After reviewing the geographic scope, depth profile, water quality, and security restrictions associated with the survey area, it was determined that a combination of sampling methods including a remotely operated vehicle (ROV), split-beam echosounder (hydroacoustics), scuba diving, lighted fish traps, and beach seining would be used to survey the BNRA. Beach seine surveys targeted forage fish and juvenile salmonids in the nearshore, while all other sampling techniques were appropriate to surveying rockfish and critical habitat for all species. Surveys for rockfish were conducted at six month intervals in 2014 and 2015, while surveys for forage fish and juvenile salmonids occurred monthly in 2015 and 2016, in order to detect temporal changes in fish abundance or distribution. This report is only intended to outline the 2016 beach seine results and follow up one full year of sampling that began in 2015. See Appendix A for a comprehensive list of fish species recorded for beach seining in 2015-16. For results on rockfish, their critical habitat, and a description of sampling methods other than beach seine see the 2014-15 final report. Surveys focused on juvenile rockfish and their rearing habitat (i.e., nearshore vegetation) are planned to begin in early 2017. There were two confirmed ESA-listed species captured with the beach seine at the NAVBASE Kitsap Bangor, Hood Canal summer-run Chum and Chinook Salmon. Summer-run Chum Salmon cannot be visually distinguished from fall-run Chum Salmon juveniles; therefore, tissue samples collected in 2016 facilitated run assignment through genetic analysis in a separate report. Sampling in 2016 began in January with the intention to capture Hood Canal summer-run Chum Salmon that were detected in nearshore areas earlier (January-February) than fall-run Chum Salmon (March-April). The peak catch rate for Chinook Salmon occurred in June for both survey years, primarily at the site south of the FSB. However, based on results from the 2015-16 surveys we preliminarily conclude that in order to reduce impact on juvenile salmon, the work window (July 15 to January 15) for the NAVBASE Kitsap Bangor facilities' in-water maintenance, military construction (MILCON), mitigation projects, future Fleet training and testing should not include February through July, as is consistent with the measures outlined in WAC 220-660-330.

Washington Department of Fish and Wildlife. (2017). *Final Assessment of Threatened and Endangered Marine and Anadromous Fish Presence Adjacent to Zelatched Point: 2016 Beach Seine Survey Results.* Olympia, WA: Washington Department of Fish and Wildlife Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC%20Atlantic/NAVFAC%20Northwest/PDFs/About%20Us/Natural_Resources/nw_Lake%20Hancock_seine_2017_FINAL.pdf

Puget Sound is home to a variety of marine and anadromous fish species that are afforded legal protection under the Endangered Species Act (ESA). The ESA-listed fish species within Puget Sound most relevant to this study include three species of rockfish (Yelloweye, Canary, and Bocaccio), four species of salmonid (Chinook, Hood Canal summer-run Chum, steelhead, and Bull Trout), and one species of forage fish (Eulachon). In an effort to determine whether occurrence of these ESA-listed species has the potential to affect operations in the waters adjacent to Zelatched Point, the Naval Facilities Engineering Command Northwest (NAVFAC NW) and the Washington Department of Fish and Wildlife (WDFW) entered into a cooperative agreement whereby the WDFW agreed to survey these waters to evaluate both the seasonal and resident presence of ESA-listed fish. Zelatched Point, at the control center for the Dabob Bay Range Complex in Hood Canal, was surveyed by the WDFW in 2015 and 2016 using various techniques and technologies. After reviewing the geographic scope, depth profile, water quality, and security restrictions associated with the survey area, it was determined that a combination of sampling methods including scuba diving, split-beam echosounder (hydroacoustics), and beach seining would be used to survey the pier and the immediate offshore area. Beach seine surveys targeted forage fish and juvenile salmonids in the nearshore, while all other sampling techniques were appropriate to surveying rockfish and critical habitat for all species. Surveys for rockfish were conducted once in February 2015, while surveys for forage fish and juvenile salmonids occurred monthly in 2016 in order to detect temporal changes in fish abundance or distribution. See Appendix A for a comprehensive list of fish species recorded for beach seining in 2016. For results on rockfish, their critical habitat, and a description of sampling methods other than beach seine see the 2015 final report. There were two confirmed ESA-listed species captured with the beach seine at Zelatched Point, Hood Canal summer-run Chum and Chinook Salmon. Summer-run Chum Salmon cannot be visually distinguished from fall-run Chum Salmon juveniles; therefore, tissue samples collected in 2016 facilitated run assignment through genetic analysis in a separate report. Sampling at Zelatched Point in 2016 began in February, and at NAVBASE Kitsap Bangor in January, with the intention to capture Hood Canal summer-run Chum Salmon that were detected in nearshore areas earlier (January-February) than fall-run Chum Salmon (March-April). Chinook Salmon were captured at low catch rates from May through September 2016. However, based on results from 2016 we preliminarily conclude that in order to reduce impact on juvenile salmon, the work window (July 15 to January 15) for the Zelatched Point facilities' inwater maintenance, military construction (MILCON), mitigation projects, future Fleet training and testing should not include February through July, as is consistent with the measures outlined in WAC 220-660330. We recommend that the aforementioned activities should also be avoided during August and September due to potential late occurrence of Chinook Salmon in the nearshore, which is not consistent with the measures outlined in WAC 220-660-330.

Weinheimer, J., Anderson, J., Cooper, R., Williams, S., McHenry, M., Crain, P., . . . Hugunin, H. (2017). *Age Structure and Hatchery Fraction of Elwha River Chinook Salmon: 2016 Carcass Survey Report*. Retrieved from https://wdfw.wa.gov/publications/01922

Monitoring the recolonization of Pacific salmon and steelhead following the removal of two dams is a critical component of the Elwha Restoration Project. During the fall of 2016, we collected adult Chinook salmon (Oncorhynchus tshawytscha) carcasses from the Elwha River in order to evaluate the proportion of hatchery fish, the age distribution of returning adults, and the ratio of fish that exhibited stream vs ocean type life history strategies. Surveys were conducted from the confluence of Idaho Creek at Geyser Valley (river km 31.5) downstream to where the river enters into the Strait of Juan de Fuca, including three tributaries. Of the carcasses sampled from the river and its tributaries (N = 264), the majority (88 %) were located upstream of the former Elwha Dam site. We also sampled fish (N = 290) throughout the season at the WDFW hatchery in the lower Elwha River. Carcasses were sampled for physical measurements, hatchery marks, scales and genetics. We sampled 422 non-jack carcasses during the sampling season, representing 20.1 % of the estimated escapement above the Elwha SONAR site. Over

95% of the fish sampled were marked hatchery fish. Age-4 was the dominant age class (61.6%), and age-2 fish (jacks) accounted for less 6% of our total sample. We sampled two age-3 natural origin fish and ten age-4 natural origin fish whose parents had access to habitat upstream of the former Elwha dam site following its removal in 2012. However, we have not observed a reduction in hatchery mark rate for the age classes that might have been produced by spawners upstream of the Elwha Dam site, and thus have no evidence that recolonization of newly accessible habitat has boosted natural production of Chinook salmon. Natural origin fish returning to the river as age-3 or age-4 adults to date were exposed to extreme environmental conditions associated with dam removal. All of the Chinook that migrated to the ocean as yearlings were hatchery origin, and so we did not observe any streamtype life histories among unmarked fish. We estimated that Chinook that spawned naturally in the Elwha could have deposited over 5.9 million eggs in 2016. Finally, an analysis of spawner to spawner productivity indicated that naturally spawning fish from the four most recent complete cohorts (brood years 2007 – 2011) did not replace themselves (average productivity = 0.33), whereas the combined productivity of natural plus hatchery spawners did exceed replacement (average productivity = 2.5).

Weinheimer, J., Anderson, J. H., Downen, M., Zimmerman, M., & Johnson, T. (2017). Monitoring Climate Impacts: Survival and Migration Timing of Summer Chum Salmon in Salmon Creek, Washington. *Transactions of the American Fisheries Society, 146*(5), https://doi.org/10.1080/00028487.2017.1321580

In rivers of the Pacific Northwest, climate change is predicted to increase flow variability and water temperature, which may ultimately affect salmonid survival and the seasonal timing of key life history transitions. Summer Chum Salmon Oncorhynchus keta, native to tributaries flowing into Hood Canal and Strait of Juan de Fuca in Washington State, are particularly vulnerable to flow and temperature changes given their early spawn timing, yet relatively little is known regarding their juvenile life history. We investigated how flow and incubation temperatures influenced juvenile survival and timing of Chum Salmon in Salmon Creek between 2008 and 2016. Egg-tomigrant survival ranged from 0.9% to 46.3%, and was negatively related to the peak flow experienced during egg incubation from November 1 to January 31. Warm temperatures advanced emergence timing, as the number of days between the median spawning date and the median juvenile migration date was negatively related to average stream temperature during the same period. We used empirical data to estimate the range of accumulated temperature units (TUs) and survival that best explained the observed juvenile migration in the spring. The model indicated that incubating eggs experiencing warmer temperatures (2010, 2015, and 2016) accrued more TUs before emigration than did eggs incubating during colder years (2008, 2009, and 2014). Although the population exhibited some ability to compensate for warmer temperatures and stabilize emergence timing by increasing TU thresholds, our analysis, when combined with climate projections, suggests that warming temperature trends could significantly advance the timing of marine entry by weeks or more. Such a change could carry a corresponding impact on marine survival if emigration timing becomes desynchronized with spring zooplankton blooms in the marine environment, the primary source of nutrition for juvenile summer Chum Salmon.

Woo, I., Davis, M. J., Ellings, C. S., Hodgson, S., Takekawa, J. Y., Nakai, G., & De La Cruz, S. E. W. (2019). A Mosaic of Estuarine Habitat Types with Prey Resources from Multiple Environmental Strata Supports a Diversified Foraging Portfolio for Juvenile Chinook Salmon. *Estuaries and Coasts, 42*(7), https://doi.org/10.1007/s12237-019-00613-2

Estuaries provide a mosaic of vital nursery habitat types for threatened Chinook salmon (Oncorhynchus tshawytscha) by promoting an ecological portfolio effect, whereby multiple habitat types and networked environmental strata maximize foraging opportunities for out-migrating Chinook salmon by varying the abundance and composition of prey through space and time. To study this portfolio effect, the foraging capacity of five estuarine habitat types was evaluated within the Nisqually River Delta (Puget Sound, Washington, USA). Within each habitat type, invertebrate prey resources were sampled from the terrestrial, aquatic, benthic, and epifaunal environmental strata and compared with juvenile Chinook salmon diets from corresponding sampling events. The estuarine emergent salt marsh supplied twice as much aquatic prey biomass as any other habitat type (720-5523 mg/m(3)), followed by the mudflat (246-2543 mg/m(3)) and eelgrass (Zostera marina; 141-2694 mg/m(3)). Despite some evidence for selectivity, juvenile Chinook salmon diets exhibited substantial compositional overlap, especially when compared with among-habitat differences in available prey resources. Fish that were captured in the emergent salt marsh, mudflat, and eelgrass habitat types consumed aquatic crustaceans such as mysids, while fish captured upriver in freshwater tidal forest and transitional emergent marsh habitat types ate a higher proportion of adult and larval insects. The availability and consumption of greater quantities of energy-poor crustaceans in the salt marsh and lower quantities of energy-rich insects upriver highlights a quantity-for-quality trade-off among estuarine habitat types. Overall results indicate that the timing, productivity, and diversity of prey across multiple habitat types and environmental strata determine an estuary's capacity to support foraging for multiple life history strategies, size classes, and cohorts of juvenile Chinook salmon.

Woo, I., Davis, M. J., Ellings, C. S., Nakai, G., Takekawa, J. Y., & De La Cruz, S. (2018). Enhanced Invertebrate Prey Production Following Estuarine Restoration Supports Foraging for Multiple Species of Juvenile Salmonids (Oncorhynchus Spp.). *Restoration Ecology, 26*(5), https://doi.org/10.1111/rec.12658

Estuaries provide crucial foraging resources and nursery habitat for threatened populations of anadromous salmon. As such, there has been a global undertaking to restore habitat and tidal processes in modified estuaries. The foraging capacity of these ecosystems to support various species of out-migrating juvenile salmon can be quantified by monitoring benthic, terrestrial, and pelagic invertebrate prey communities. Here, we present notable trends in the availability of invertebrate prey at several sites within a restoring large river delta in Puget Sound, Washington, U.S.A. Three years after the system was returned to tidal influence, we observed substantial additions to amphipod, copepod, and cumacean abundances in newly accessible marsh channels (from 0 to roughly 5,000–75,000 individuals/m2). In the restoration area, terrestrial invertebrate colonization was dependent upon vegetative cover, with dipteran and hymenopteran biomass increasing 3-fold between 1 and 3 years post-restoration. While the overall biodiversity within the restoration area was lower than in the reference marsh, estimated biomasswas comparable to or greater than that found within the other study sites. This additional prey biomass likely provided foraging benefits for juvenile Chinook, chum, and coho salmon. Primary physical drivers differed for benthic, terrestrial, and pelagic invertebrates, and these invertebrate communities are expected to respond differentially depending on organic matter exchange and vegetative colonization. Restoring estuaries may take decades to meet certain success criteria, but our study demonstrates rapid enhancements in foraging resources understood to be used for estuary-dependent wildlife.

Yeh, A., Marcinek, D. J., Meador, J. P., & Gallagher, E. P. (2017). Effect of Contaminants of Emerging Concern on Liver Mitochondrial Function in Chinook Salmon. *Aquatic Toxicology, 190*, https://doi.org/10.1016/j.aquatox.2017.06.011

We previously reported the bioaccumulation of contaminants of emerging concern (CECs), including pharmaceuticals and personal care products (PPCPs) and perfluorinated compounds, in field-collected juvenile Chinook salmon from urban estuaries of Puget Sound, WA (Meador et al., 2016). Although the toxicological impacts of CECs on salmon are poorly understood, several of the detected contaminants disrupt mitochondrial function in other species. Here, we sought to determine whether environmental exposures to CECs are associated with hepatic mitochondrial dysfunction in juvenile Chinook. Fish were exposed in the laboratory to a dietary mixture of 16 analytes representative of the predominant CECs detected in our field study. Liver mitochondrial content was reduced in fish exposed to CECs, which occurred concomitantly with a 24–32% reduction in expression of peroxisome proliferator-activated receptor (PPAR) Y coactivator-1a (pgc-1α), a positive transcriptional regulator of mitochondrial biogenesis. The laboratory exposures also caused a 40–70% elevation of state 4 respiration per unit mitochondria, which drove a 29–38% reduction of efficiency of oxidative phosphorylation relative to controls. The mixture-induced elevation of respiration was associated with increased oxidative injury as evidenced by increased mitochondrial protein carbonyls, elevated expression of glutathione (GSH) peroxidase 4 (gpx4), a mitochondrial-associated GSH peroxidase that protects against lipid peroxidation, and reduction of mitochondrial GSH. Juvenile Chinook sampled in a WWTP effluent-impacted estuary with demonstrated releases of CECs showed similar trends toward reduced liver mitochondrial content and elevated respiratory activity per mitochondria (including state 3 and uncoupled respiration). However, respiratory control ratios were greater in fish from the contaminated site relative to fish from a minimally-polluted reference site, which may have been due to differences in the timing of exposure to CECs under laboratory and field conditions. Our results indicate that exposure to CECs can affect both mitochondrial quality and content, and support the analysis of mitochondrial function as an indicator of the sublethal effects of CECs in wild fish.

Zimmerman, M. S., Irvine, J. R., O'Neill, M., Anderson, J. H., Greene, C. M., Weinheimer, J., . . . Rawson, K. (2015). Spatial and Temporal Patterns in Smolt Survival of Wild and Hatchery Coho Salmon in the Salish Sea. *Marine and Coastal Fisheries, 7*(1), https://doi.org/10.1080/19425120.2015.1012246

Understanding the factors contributing to declining smolt-to-adult survival (hereafter "smolt survival") of Coho Salmon Oncorhynchus kisutch originating in the Salish Sea of southwestern British Columbia and Washington State is a high priority for fish management agencies. Uncertainty regarding the relative importance of mortality operating at different spatial scales hinders the prioritization of science and management activities. We therefore examined spatial and temporal coherence in smolt survivals for Coho Salmon based on a decision tree framework organized by spatial hierarchy. Smolt survival patterns of populations that entered marine waters within the Salish Sea were analyzed and compared with Pacific coast reference populations at similar latitudes. In all areas, wild Coho Salmon had higher survival than hatchery Coho Salmon. Coherence in Coho Salmon smolt survival occurred at multiple spatial scales during ocean entry years 1977–2010. The primary pattern within the Salish Sea was a declining smolt survival trend over this period. In comparison, smolt survival of Pacific coast reference populations was low in the 1990s but subsequently increased. Within the Salish Sea, smolt survival in the Strait of Georgia declined faster than it did in Puget Sound. Spatial synchrony was stronger among neighboring Salish Sea populations and occurred at a broader spatial scale immediately following the 1989 ecosystem regime shift in the North Pacific Ocean than before or after. Smolt survival of Coho Salmon was synchronized at a more local scale than reported by other researchers for Chinook Salmon O. tshawytscha, Pink Salmon O. gorbuscha, Chum Salmon O. keta, and Sockeye Salmon O. nerka, suggesting that early marine conditions are especially important for Coho Salmon in the Salish Sea. Further exploration of ecosystem variables at multiple spatial scales is needed to effectively address linkages between the marine ecosystem and Coho Salmon smolt survival within the Salish Sea. Since the relative importance of particular variables may have changed during our period of record, researchers will need to carefully match spatial and temporal scales to their questions of interest.

Zimmerman, M. S., Kinsel, C., Beamer, E., Connor, E. J., & Pflug, D. E. (2015). Abundance, Survival, and Life History Strategies of Juvenile Chinook Salmon in the Skagit River, Washington. *Transactions of the American Fisheries Society, 144*(3), https://doi.org/10.1080/00028487.2015.1017658

To identify potential actions for conserving Chinook Salmon Oncorhynchus tshawytscha in the Skagit River, Washington, we used a 16-year time series of streamflow data, adult escapement, and out-migrant abundance to understand how out-migrant abundance and life history diversity were related to spawner abundance and incubation flows. Three freshwater rearing strategies were distinguished based on body size at out-migration: fry (45 mm FL), subyearling parr (46–100 mm FL), and yearling smolts (>100 mm FL). Density-independent and density-dependent processes were hypothesized to influence survival in sequence, with density-independent mechanisms operating during incubation and density-dependent mechanisms operating between emergence and out-migration. A model selection process compared spawner–recruit models with and without different incubation flow metrics. Density-independent models that included measures of flow duration and magnitude were strongly supported (Akaike's information criterion [AIC] difference 3). Sustained flow events of moderate magnitude (1-year recurrence interval) were an equivalent if not better predictor of freshwater survival than short-duration flow events of high magnitude (peak flows). A second model selection process evaluated density dependence of each life history type. The composition of out-migrants (fry, subyearling parr, and yearling smolts) was a densitydependent function of spawner abundance. Fry out-migrant abundance was density independent, and subyearling parr out-migrant abundance was density dependent. Neither model was supported for yearling smolts. At least one out-migrant life history, subyearling parr, should benefit from continued restoration of freshwater habitats in the Skagit River system. Factors contributing to the yearling smolt life history will benefit from additional study.

Section VIII: Washington Coast

Beacham, T. D., Beamish, R. J., Candy, J. R., Wallace, C., Tucker, S., Moss, J. H., & Trudel, M. (2014). Stock-Specific Migration Pathways of Juvenile Sockeye Salmon in British Columbia Waters and in the Gulf of Alaska. *Transactions of the American Fisheries Society, 143*(6), https://doi.org/10.1080/00028487.2014.935476

We outlined the route and relative timing of juvenile Sockeye Salmon Oncorhynchus nerka migration by analyzing stock composition and relative CPUE in marine sampling conducted in coastal British Columbia and the Gulf of Alaska. Variation at 14 microsatellites was analyzed for 10,500 juvenile Sockeye Salmon obtained from surveys conducted during 1996–2011. Using a 404-population baseline, we identified the sampled individuals to 47 populations or stocks of origin. Stock compositions of the mixtures increased in diversity in more northerly sampling locations, indicating a general northward movement of juveniles. The primary migration route of Columbia River and Washington stocks was northward along the west coast of Vancouver Island, with a majority of the juveniles subsequently migrating through Queen Charlotte Sound and Dixon Entrance. Fraser River stocks migrated principally through the Strait of Georgia and Johnstone Strait. Some Fraser River populations, such as the Cultus Lake population, appeared to spend little time rearing in the Strait of Georgia, as individuals from this population were primarily observed in July samples from Hecate Strait, Dixon Entrance, and Southeast Alaska. Other Fraser River populations, such as the Chilko Lake and Quesnel Lake populations, were widely distributed during July surveys, as they were observed from the Gulf of Alaska to the Strait of Georgia. For the British Columbia central coast and Owikeno Lake stocks, not all individuals migrated northward in the summer: some individuals were still present in local areas during the fall and winter after spring entry into the marine environment. Juvenile Fraser River Sockeye Salmon dominated the catch of juveniles at the Yakutat, Prince William Sound, Kodiak Island, and Alaska Peninsula sampling locations. There was a wide divergence among stocks in dispersion among sampling locations.

Beacham, T. D., Beamish, R. J., Candy, J. R., Wallace, C., Tucker, S., Moss, J. H., & Trudel, M. (2014). Stock-Specific Size of Juvenile Sockeye Salmon in British Columbia Waters and the Gulf of Alaska. *Transactions of the American Fisheries Society, 143*(4), https://doi.org/10.1080/00028487.2014.889751

The variation at 14 microsatellites was analyzed for 10,500 juvenile Sockeye Salmon Oncorhynchus nerka obtained from coastal British Columbia and Gulf of Alaska surveys during 1996–2011. A 404-population baseline was used to determine the individual identifications of the fish sampled, with individuals being identified to 47 populations or stocks of origin. Columbia River and Washington juveniles were consistently larger than those from British Columbia and Alaska. During July, larger individuals from the same Fraser River stock were observed in more northerly locations compared with those in the Strait of Georgia. There was a relationship between the timing of northward migration from the Strait of Georgia and juvenile body size, with individuals from larger populations or stocks migrating earlier than individuals from smaller stocks which remain resident for longer. There was a wide divergence among stocks in juvenile size and dispersion among sampling locations.

Boyd, C., DeMaster, D. P., Waples, R. S., Ward, E. J., & Taylor, B. L. (2017). Consistent Extinction Risk Assessment under the U.S. Endangered Species Act. *Conservation Letters, 10*(3), https://doi.org/10.1111/conl.12269

Identifying species at risk of extinction is essential for effective conservation priority-setting in the face of accelerating biodiversity loss. However, the levels of risk that lead to endangered or threatened listing decisions under the United States Endangered Species Act (ESA) are not well defined. We used a Bayesian population modeling approach to estimate levels of risk consistently for 14 marine species previously assessed under the ESA. For each species, we assessed the risks of declining below various abundance thresholds over various time horizons. We found that high risks of declining below 250 mature individuals within five generations matched well with ESA endangered status, while number of populations was useful for distinguishing between threatened and "not warranted" species. The risk assessment framework developed here could enable more consistent, predictable, and transparent ESA status assessments in the future.

National Marine Fisheries Service. (2016). *2016 5-Year Review: Summary and Evaluation of Ozette Lake Sockeye*. NOAA Retrieved from https://repository.library.noaa.gov/view/noaa/17020

Many West Coast salmon and steelhead (Oncorhynchus spp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contributed to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the review for ESAlisted Ozette Lake sockeye salmon.

North Pacific Coast Lead Entity. (2018). *Public Review Draft: 2018 North Pacific Coast (Wria 20) Salmon Restoration Strategy.* University of Washington Forks, WA. Retrieved from https://www.jeffersoncountypublichealth.org/DocumentCenter/View/1292/Public-Review-Draft-North-Pacific-Coast-WRIA-20-Salmon-Restoration-Strategy-2018-Edition-PDF

This strategy document has two primary sections: The first section describes the goals and objectives of the plan, the methodology of how projects are identified and annually prioritized, and the application procedure for individuals and organizations who wish to apply as project sponsors. The second section is broken down into geographic regions by watersheds, and contains a final section that covers a nearshore project area along the entire coastline of WRIA 20. Chapters within Section 2 first provide the context of restoration in the specific basin and then provide a current list of prioritized projects for each basin or habitat region.

North Pacific Coast Lead Entity. (2020). *North Pacific Coast (Wria 20) Salmon Restoration Strategy.* Retrieved from https://www.coastsalmonpartnership.org/wp-content/uploads/2020/05/FINAL-NPCLE-2020-Strategy-2.pdf

For on-the-ground restoration projects, a guideline publication consulted in most of the salmon habitat prioritization processes applied to WRIA 20 basins in recent years is "A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds" (Roni, Beechie, Bilby, Leonetti, Pollock and Pess, 2002). This publication presents the results of an analysis by Northwest Fisheries Science Center scientists of several types of restoration approaches and their effects on multiple salmonid species over time. The primary recommendations promoted in this publication have been adopted by the North Pacific Coast Lead Entity in its project prioritization process (NPCLE, 2007), and they serve as the default prioritization guidance for projects that have not yet been identified and ranked in this document.

Quinn, T. P., McGinnity, P., & Reed, T. E. (2015). The Paradox of "Premature Migration" by Adult Anadromous Salmonid Fishes: Patterns and Hypotheses. *Canadian Journal of Fisheries and Aquatic Sciences, 73*(7), https://doi.org/10.1139/cjfas-2015-0345

In several groups of anadromous fishes, but especially the salmonids, some populations migrate from the ocean to fresh water many months prior to spawning. This "premature migration" reduces growth opportunities at sea, compels them to occupy much less productive freshwater habitats, and exposes them to extremes of flow and temperature, disease, and predation. We first review migration in salmonids and find great variation in timing patterns among and within species, relative to the timing of reproduction. Premature migration is widely distributed among species but not in all populations, and we propose two hypotheses to explain it. First, the fish may be making "the best of a bad situation" by entering early because access to suitable breeding sites is constrained seasonally by flow or temperature regimes, so they sacrifice growing opportunities at sea. Alternatively or additionally, some populations may be "balancing risks and benefits" as they trade off the benefits of growth at sea against the risk of mortality there. In this model, the reduced risk of mortality at sea must be balanced against the risk of mortality in freshwater habitats from thermal stress, disease, and predators. Premature migration may be favored where temperatures and flows are moderate or where lakes provide safety from predators and reduce energetic expenditure. Consistent with this hypothesis, early return is characteristic of larger, older salmonids (that would benefit less from additional time at sea to grow than would smaller fish). Finally, we consider the vulnerability of premature migrants to climate change and selective fisheries. Migration timing is an important part of the portfolio of phenotypic diversity that conveys resilience to species, population complexes, and the fisheries that depend on them. The premature migrants are often especially valued in fisheries and also often of particular conservation concern, and the phenomenon merits further research.

Scordino, J. J., et al. (2016). River Otter (Lontra Canadensis) Food Habits in a Washington Coast Watershed: Implications for a Threatened Species. *Northwestern Naturalist: A Journal of Vertebrate Biology, 97*(1), https://doi.org/10.1898/1051-1733-97.1.36

North American River Otter (Lontra canadensis) predation on salmon is of concern in the Lake Ozette watershed due to potential impacts on ESA listed Lake Ozette Sockeye Salmon (Oncorhynchus nerka). To better understand the impact of River Otters on Lake Ozette Sockeye Salmon, we examined prey remains recovered from 291 scat samples collected around Lake Ozette and near a fish counting weir in the Ozette River between 1998 and 2003. We found evidence that prey taxon differs by habitat type with significantly greater occurrence of fish and amphibians recovered from scat collected in the lake habitat, while a significantly higher occurrence of invertebrates was identified in scat from the river habitat. We also found a significantly greater frequency of adult salmon prey remains in scat collected in the river habitat than in the lake habitat. It is likely the fish counting weir increased adult salmon vulnerability to River Otter predation in Ozette River. Genetic analysis revealed that 79.4% of the adult salmon consumed by River Otters were Lake Ozette Sockeye Salmon. The frequency of occurrence of adult Sockeye Salmon in scat samples peaked in July with 25% of scat collected having adult Sockeye Salmon remains, well after the late May to the middle of June peak in upriver migration. Predation of Sockeye Salmon at all life stages has been listed as a key factor in limiting the ability of Sockeye Salmon to recover in the Lake Ozette watershed. Efforts are currently underway to address many of the factors limiting recovery of Lake Ozette Sockeye Salmon. The high occurrence of adult salmon remains near the fish counting weir, and results of past studies, suggests that predator mitigation at the weir through acoustic harassment devices or other methods could benefit the recovery of Lake Ozette Sockeye Salmon

U.S. Geological Survey. (2019). *Life-History Model for Sockeye Salmon (Oncorhynchus Nerka) at Lake Ozette, Northwestern Washington—Users' Guide*. (2019-1031). Reston, VA https://doi.org/10.3133/ofr20191031

Salmon populations spawning in the Lake Ozette watershed of northwestern Washington were once sufficiently abundant to support traditional Tribal fisheries, and were later harvested by settlers (Swindell, 1941; Gustafson and others, 1997). However, in 1974 and 1975, the sockeye salmon (Oncorhynchus nerka) harvest decreased to 0 from a high of more than 17,500 in 1949 (Washington Department of Fisheries, 1955), thus stimulating research into the causes of decrease, which resulted in eventual listing of the population as threatened under the Endangered Species Act in 1999 (National Oceanic and Atmospheric Administration, 1999). The listing status was upheld in 2005 (National Oceanic and Atmospheric Administration, 2005) and 2014 (National Oceanic and Atmospheric Administration, 2014) following 5-year reviews. Meanwhile, research results were compiled in a limiting factors analysis (LFA; Haggerty and others, 2009) and a recovery plan was developed (National Marine Fisheries Service, 2009). Although there has been some improvement in sockeye abundance since listing, the numbers remain too low to allow harvest and it is not yet clear which of the many potential limiting factors are most consequential. As part of the LFA process, a population model was developed to determine values of lifehistory parameters that would enable the population to survive for 100 years. The model was based on the best available data, but data are limited for the Lake Ozette system. Results informed the qualitative assessment of the importance of limiting factors used to develop the recovery plan for Lake Ozette sockeye (National Marine Fisheries Service, 2009). The model was built in Microsoft Excel® and is difficult to use. The purpose of the model described herein is to synthesize the results of the LFA in a form that can be manipulated by resource managers and the public to create scenarios, test hypotheses, and observe sensitivities of results to changes in parameters. The goal is to provide a tool that enables research, monitoring and management to be focused on the most impactful elements and processes, including identifying the information gaps that are most critical to fill.

Section IX: Lower Columbia River

Bond, M. H., Nodine, T. G., Beechie, T. J., & Zabel, R. W. (2019). Estimating the Benefits of Widespread Floodplain Reconnection for Columbia River Chinook Salmon. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(7), https://doi.org/10.1139/cjfas-2018-0108

In the Pacific Northwest, widespread stream channel simplification has led to a loss of habitat area and diversity for rearing salmon. Subsequent efforts throughout the Columbia River basin (CRB) have attempted to restore habitats altered through land development to recover imperiled salmon populations. However, there is scant evidence for demographic change in salmon populations following restoration. We used a process-based approach to estimate the potential benefit of floodplain reconnection throughout the CRB to Chinook salmon (Oncorhynchus tshawytscha) parr. Using satellite imagery, we measured stream habitats at 2093 CRB stream reaches to construct random forest models of habitat based on geomorphic and regional characteristics. Connected floodplain width was the most important factor for determining side channel presence. Weestimated a current CRB-wide decrease in side channel habitat area of 26% from historical conditions. Reconnection of historical floodplains currently used for agriculture could increase side channel habitat by 25% and spring Chinook salmon parr total rearing capacity by 9% over current estimates. Individual watersheds vary greatly in habitat factors that limit salmon recovery, and large-scale estimates of restoration potential like these are needed to make decisions about long-term restoration goals among imperiled populations.

Breyta, R., McKenney, D., Tesfaye, T., Ono, K., & Kurath, G. (2016). Increasing Virulence, but Not Infectivity, Associated with Serially Emergent Virus Strains of a Fish Rhabdovirus. *Virus Evolution, 2*(1), https://doi.org/10.1093/ve/vev018

Surveillance and genetic typing of field isolates of a fish rhabdovirus, infectious hematopoietic necrosis virus (IHNV), has identified four dominant viral genotypes that were involved in serial viral emergence and displacement events in steelhead trout (Oncorhynchus mykiss) in western North America. To investigate drivers of these landscape-scale events, IHNV isolates designated 007, 111, 110, and 139, representing the four relevant genotypes, were compared for virulence and infectivity in controlled laboratory challenge studies in five relevant steelhead trout populations. Viral virulence was assessed as mortality using lethal dose estimates (LD50), survival kinetics, and proportional hazards analysis. A pattern of increasing virulence for isolates 007, 111, and 110 was consistent in all five host populations tested, and correlated with serial emergence and displacements in the virus-endemic lower Columbia River source region during 1980–2013. The fourth isolate, 139, did not have higher virulence than the previous isolate 110. However, the mG139M genotype displayed a conditional displacement phenotype in that it displaced type mG110M in coastal Washington, but not in the lower Columbia River region, indicating that factors other than evolution of higher viral virulence were involved in some displacement events. Viral infectivity, measured as infectious dose (ID50), did not correlate consistently with virulence or with viral emergence, and showed a narrow range of variation relative to the variation observed in virulence. Comparison among the five steelhead trout populations confirmed variation in resistance to IHNV, but correlations with previous history of virus exposure or with sites of viral emergence varied between IHNV source and sink regions. Overall, this study indicated increasing viral virulence over time as a potential driver for emergence and displacement events in the endemic Lower Columbia River source region where these IHNV genotypes originated, but not in adjacent sink regions.

Brosnan, I. G., Welch, D. W., & Scott, M. J. (2016). Survival Rates of out-Migrating Yearling Chinook Salmon in the Lower Columbia River and Plume after Exposure to Gas-Supersaturated Water. *Journal of Aquatic Animal Health, 28*(4), https://doi.org/10.1080/08997659.2016.1227398

In 2011, unusually high flows caused total dissolved gas (TDG) levels in the Columbia River, USA, to escalate well above the 120% regulatory limit that was imposed to prevent harmful impacts to aquatic organisms. After observing gas bubble trauma (GBT) in dead yearling Chinook Salmon Oncorhynchus tshawytscha (smolts) held in tanks, we compared estimated survival rates of acoustic-tagged in-river-migrating (IR) and transported (TR) smolts that were released below Bonneville Dam prior to and during the period of elevated TDG (>120%). The log odds of estimated daily survival in the lower river and plume was significantly lower for IR smolts that were released during elevated TDG (maximum possible exposure = 134%) than for IR smolts released when TDG was less than 120%. The TR smolts that were released 10–13 km below Bonneville Dam during elevated TDG had lower maximum possible exposure levels (126% TDG), and the log odds of estimated daily survival in the lower river and plume did not differ from that of TR smolts released when TDG was less than 120%. Direct mortality due to GBT is probably reduced in natural settings relative to laboratory experiments because smolts can move to deeper water, where pressure keeps gasses in solution, and can migrate downstream of the spillway, where TDG levels decrease as the river returns to equilibrium with the atmosphere. However, initially nonlethal GBT may reduce survival rates by increasing smolt susceptibility to predation and infection. Although our findings are limited by the observational nature of the study, our analysis is the first direct assessment of gas supersaturation’s potential influence on survival of free-ranging smolts in the river and coastal ocean below a large dam. Experiments using simultaneous releases of control and gas-exposed groups are warranted and should consider the possibility that the chronic effects of TDG exposure on survival are important and persist into the early marine period.

Campbell, N. R., Kamphaus, C., Murdoch, K., & Narum, S. R. (2017). Patterns of Genomic Variation in Coho Salmon Following Reintroduction to the Interior Columbia River. *Ecology and Evolution, 7*(23), https://doi.org/10.1002/ece3.3492

Coho salmon were extirpated in the mid-20th century from the interior reaches of the Columbia River but were reintroduced with relatively abundant source stocks from the lower Columbia River near the Pacific coast. Reintroduction of Coho salmon to the interior Columbia River (Wenatchee River) using lower river stocks placed selective pressures on the new colonizers due to substantial differences with their original habitat such as migration distance and navigation of six additional hydropower dams. We used restriction site-associated DNA sequencing (RAD-seq) to genotype 5,392 SNPs in reintroduced Coho salmon in the Wenatchee River over four generations to test for signals of temporal structure and adaptive variation. Temporal genetic structure among the three broodlines of reintroduced fish was evident among the initial return years (2000, 2001, and 2002) and their descendants, which indicated levels of reproductive isolation among broodlines. Signals of adaptive variation were detected from multiple outlier tests and identified candidate genes for further study. This study illustrated that genetic variation and structure of reintroduced populations are likely to reflect source stocks for multiple generations but may shift over time once established in nature.

Carlson, T. J., Johnson, G. E., Skalski, J. R., & Woodley, C. M. (2019). Estimating the Take of Migrating Adult Chum Salmon (Oncorhynchus Keta) Caused by Confined Underwater Rock Blasting. *Environmental Impact Assessment Review, 77*, https://doi.org/10.1016/j.eiar.2019.04.001

This paper describes a methodology for estimating the take of upstream migrating adult chum salmon (Oncorhynchus keta) caused by confined underwater rock blasting. Because these fish are listed under the Endangered Species Act, it is unlawful to take (i.e., harm, capture, collect, injure, kill, etc.) them without a federal permit. In the permit for an underwater blasting project to deepen a 2 km section of the Columbia River navigation channel linking Portland, Oregon, to the Pacific Ocean, regulators defined take as the mortality of adult chum salmon due to underwater blasting. They required monitoring to estimate take to track compliance with the permit. Conventional predictive models of fish mortality from underwater blasting depend on data about the explosive charges; however, such data for this project were not available for proprietary reasons. Therefore, an innovative approach had to be conceived. The dose-exposure-response methodology we developed provided an unobtrusive, science-based methodology for monitoring and near real-time reporting of adult chum salmon take. We applied the methodology for 99 blasting events from November 1, 2009, through February 5, 2010, in the lower Columbia River (rkm 139–141). The mean absolute peak pressure in underwater sound generated by blast events was 151,685 Pa (22 psi) at a range of 42.7 m. The estimated cumulative take for the project was 0.126 adult chum salmon, far below the 10-fish mortality limit regulators set for the project. We propose that this dose-exposure-response methodology be considered wherever underwater blasting has the potential to have an adverse effect on important fish species.

Ciancio, J. E., Rossi, C. R., Pascual, M., Anderson, E., & Garza, J. C. (2015). The Invasion of an Atlantic Ocean River Basin in Patagonia by Chinook Salmon: New Insights from Snps. *Biological Invasions, 17*(10), https://doi.org/10.1007/s10530-015-0928-x

Chinook salmon spawning was first reported in the 1980s in the Caterina River tributary of the Santa Cruz River basin of Patagonia, which drains into the Atlantic Ocean. A naturalized population now persists and its source has been debated. Chinook salmon from California populations was directly released into the Santa Cruz River in the early twentieth century, but ocean ranching experiments on the Pacific coast of Patagonia (Chile) also released Chinook salmon of lower Columbia River origin (University of Washington hatchery stock) in the late twentieth century. We used genetic stock identification with single nucleotide polymorphisms to explore the origin of this Chinook salmon population. The genotypes ofsalmon that invaded the Santa Cruz River were compared with those derived from 69 known populations from the Northern Hemisphere. Chinook Salmon of the Santa Cruz River were found to be most similar to those from the lower Columbia River. This supports the hypothesis that the Santa Cruz River population was founded from the ocean ranching in southern Chile and the river was invaded by fish straying from Pacific coast basins. Moreover, we find that the life history of these naturalized fish, as inferred from scale analysis, was similar to that of the progenitor stock. We suggest that the successful invasion of the Caterina River in Patagonia by Chinook salmon was aided by pre-adaptations of some of the stocks used in the ocean ranching experiments to conditions in the new environment, rather than a post-colonization adaptation.

Claxton, A., Weitkamp, L., & Jacobson, K. (2018). Prevalence of the Nematode Hysterothylacium Aduncum in the Amphipod Americorophium Salmonis Consumed by Juvenile Chinook Salmon (Oncorhynchus tshawytscha) in the Columbia River Estuary. *Northwest Science, 92*(1), https://doi.org/10.3955/046.092.0108

Parasites transmitted through the consumption of infected prey items are commonly used to examine patterns of host feeding. However, an estimate of the prevalence of larval parasites in consumed prey items is often lacking restricting the ability to translate the number of parasites observed into the number of prey consumed. This study examined the prevalence of the nematode parasite Hysterothylacium aduncum in the benthic amphipod Americorophium salmonis recovered from the stomachs of juvenile Chinook salmon (Oncorhynchus tshawytscha) collected near the mouth of the Columbia River estuary (USA) in May, June, and July of 2011. This study represents the first estimate of the prevalence of H. aduncum in A. salmonis from this locality. The stomachs of 118 subyearling Chinook salmon were examined for prey items. We recovered 472 undigested A. salmonis from stomachs that were then examined for juvenile H. aduncum. Six of the 472 A. salmonis were infected with H. aduncum (1.3%). However, prevalence and mean intensity of H. aduncum was 74.6% and 12.9 ± 15.0 S.D. respectively in the gastrointestinal tracts of those salmon. The low prevalence of the parasite in the ingested A. salmonis and the high recovery of adult parasites in subyearling salmon suggest salmon fed on perhaps hundreds of this prey item to acquire the observed numbers of H. aduncum as opposed to the 4.0 ± 6.2 S.D. A. salmonis found on average during stomach content examination. This reemphasizes the importance of A. salmonis as a prey item for subyearling Chinook salmon within the estuary.

Clemens, B. J. (2015). A Survey of Steelhead Age and Iteroparity Rates from a Volunteer Angler Program in the Willamette River Basin, Oregon. *North American Journal of Fisheries Management, 35*(5), https://doi.org/10.1080/02755947.2015.1079572

The iteroparous life history of steelhead Oncorhynchus mykiss can provide genetic variability and increase recruitment, thereby sustaining populations. Steelhead are difficult to survey given that (1) they spawn during high river flows, which can flush carcasses away; (2) they spend a short time on the spawning grounds; (3) nonspawning fish are elusive; and (4) adults that do not die after spawning can evade surveyors. An angler volunteer program was implemented in Oregon to monitor steelhead populations. Recreational anglers collected scales from 2,216 steelhead in the Willamette River basin during 1981-1994; the scales were used to estimate ages and iteroparity rates. A freshwater age of 2 and a saltwater age of 2 were the most common, followed by saltwater ages 3 and 4. The incidence of iteroparity was greater among female steelhead than among males and was greater for winter-run steelhead than for summer-run fish. Wild fish had a higher incidence of repeat spawning than hatchery fish, which may be partly attributable to hatchery practices (e.g., recycling the fish through the fishery or using them for spawning). These results agree with previously published information for steelhead. The overall iteroparity rate of 3.4% for Willamette River basin steelhead appears to be moderate in comparison with other populations; for instance, iteroparity in Willamette River steelhead was much lower than rates for Oregon coastal stocks, was similar to rates for lower Columbia River stocks, and was higher than rates for interior Columbia River stocks. I offer the following hypotheses to explain these geographical trends in iteroparity: (1) Willamette River basin steelhead have a greater distance to migrate than coastal stocks and iteroparity may be selected against by barriers to adult and juvenile passage, (2) similar iteroparity rates for Willamette River basin and lower Columbia River steelhead stocks suggest similarity in migratory conditions, and (3) by contrast, the interior Columbia River stocks have a longer migration distance and also experience challenges associated with the hydropower system.

Correa, C., & Moran, P. (2017). Polyphyletic Ancestry of Expanding Patagonian Chinook Salmon Populations. *Scientific Reports, 7*(1), https://doi.org/10.1038/s41598-017-14465-y

Chinook salmon native to North America are spreading through South America's Patagonia and have become the most widespread anadromous salmon invasion ever documented. To better understand the colonization history and role that genetic diversity might have played in the founding and radiation of these new populations, we characterized ancestry and genetic diversity across latitude (39–48°S). Samples from four distant basins in Chile were genotyped for 13 microsatellite loci, and allocated, through probabilistic mixture models, to 148 potential donor populations in North America representing 46 distinct genetic lineages. Patagonian Chinook salmon clearly had a diverse and heterogeneous ancestry. Lineages from the Lower Columbia River were introduced for salmon openocean ranching in the late 1970s and 1980s, and were prevalent south of 43°S. In the north, however, a diverse assembly of lineages was found, associated with net-pen aquaculture during the 1990s. Finally, we showed that possible lineage admixture in the introduced range can confound allocations inferred from mixture models, a caveat previously overlooked in studies of this kind. While we documented high genetic and lineage diversity in expanding Patagonian populations, the degree to which diversity drives adaptive potential remains unclear. Our new understanding of diversity across latitude will guide future research.

Daehnke, J. D. (2017). *Chinook Resilience: Heritage and Cultural Revitalization on the Lower Columbia River*: University of Washington Press. Retrieved from https://uwapress.uw.edu/book/9780295742267/chinook-resilience/

The Chinook Indian Nation—whose ancestors lived along both shores of the lower Columbia River, as well as north and south along the Pacific coast at the river's mouth—continue to reside near traditional lands. Because of its nonrecognized status, the Chinook Indian Nation often faces challenges in its efforts to claim and control cultural heritage and its own history and to assert a right to place on the Columbia River. Chinook Resilience is a collaborative ethnography of how the Chinook Indian Nation, whose land and heritage are under assault, continues to move forward and remain culturally strong and resilient. Jon Daehnke focuses on Chinook participation in archaeological projects and sites of public history as well as the tribe's role in the revitalization of canoe culture in the Pacific Northwest. This lived and embodied enactment of heritage, one steeped in reciprocity and protocol rather than documentation and preservation of material objects, offers a tribally relevant, forward-looking, and decolonized approach for the cultural resilience and survival of the Chinook Indian Nation, even in the face of federal nonrecognition.

Di Prinzio, C. Y., Rossi, C. R., Ciancio, J., Garza, J. C., & Casaux, R. (2015). Disentangling the Contributions of Ocean Ranching and Net-Pen Aquaculture in the Successful Establishment of Chinook Salmon in a Patagonian Basin. *Environmental Biology of Fishes, 98*(9), https://doi.org/10.1007/s10641-015-0418-0

The presence of Chinook salmon in Patagonia is an example of a successful invasion by a Pacific salmon species. The combination of historical records and genetic data can help to determine the origin of invasive / introduced species and allow the identification ofthe sources and dispersal process.We analyzed the genetic structure ofChinook salmon in the Futaleufú River (Pacific slope basin of Patagonia) using single nucleotide polymorphism genotypes and a recently described baseline dataset of native North American Chinook salmon populations. Our results revealed that Chinook salmon established in the Futaleufú River have high levels of within-population genetic diversity compared with populations from across the native range. Based on genetic similarity and historical reports, our results indicate that the Futaleufú population was first established by colonizing fish derived from the Lower Columbia River Basin, imported into Chile for ocean ranching purposes during the 1970s and 1980s, and afterward it was strongly supplemented by escaped fish from net pen aquaculture that used broodstock imported during the 1990s from various sources, including the California Central Valley (via NewZealand), the Middle Oregon Coast, and Vancouver Island. The higher incidence offish derived from the most recent introductions in our sample suggest that the contribution of escaped salmon from these posterior stockings on establishment success must have been particularly strong because included different sources. Subsequent admixture and hybridization among these multiple independent source stocks is likely responsible for the high level ofstanding genetic variation, which may be facilitating local adaptation and augmenting the opportunity for successful invasion and further colonization.

Dietrich, J., Eder, K., Thompson, D., Buchanan, R., Skalski, J., McMichael, G., . . . Loge, F. (2016). Survival and Transit of in-River and Transported Yearling Chinook Salmon in the Lower Columbia River and Estuary. *Fisheries Research, 183*, https://doi.org/10.1016/j.fishres.2016.07.005

The lower Columbia River and estuary (LRE) is a critically important environment for outmigrating salmonids, yet uncertainties remain about the survival and behavior of barged and in-river migrating fish. Although studies have used telemetry to monitor Chinook salmon movement and survival through the LRE, comparisons between outmigration years are confounded by differences in tag technologies, array locations, and experimental designs. In the present study, multiple releases of barged and in-river Snake River spring/summer Chinook salmon were implanted with acoustic tags and monitored at multiple locations between Lower Granite Dam on the Snake River (695 km from the mouth of the Columbia River) to within 3 km of the Pacific Ocean. LRE survival estimates and transit rates of barged fish significantly varied throughout the outmigration season. The transit rates of in-river fish also varied, but without a corresponding seasonal difference in LRE survival estimates. Early release groups of barged salmon were slower and had lower survival in the LRE than in-river salmon. Estuary arrival timing and the magnitude of transit rates may contribute to significant differences in LRE mortality between in-river and barged juvenile salmon. Survival in the Lower River reaches was stable and exceeded 0.90 for both barged and in-river fish, while survival decreased markedly in the Estuary. Differential distributions of arrival to the LRE, transit rates, and survival suggest that the outmigration experience is not homogenous for barged and in-river yearling Snake River Chinook salmon, and that previous outmigration experience of threatened and endangered salmon should be considered in future management decisions and recovery plans.

Elder, T., Woodley, C. M., Weiland, M. A., & Strecker, A. L. (2016). Factors Influencing the Survival of Outmigrating Juvenile Salmonids through Multiple Dam Passages: An Individual-Based Approach. *Ecology and Evolution, 6*(16), https://doi.org/10.1002/ece3.2326

Substantial declines of Pacific salmon populations have occurred over the past several decades related to large-scale anthropogenic and climatic changes in freshwater and marine environments. In the Columbia River Basin, migrating juvenile salmonids may pass as many as eight large-scale hydropower projects before reaching the ocean; however, the cumulative effects of multiple dam passages are largely unknown. Using acoustic transmitters and an extensive system of hydrophone arrays in the Lower Columbia River, we calculated the survival of yearling Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) passing one, two, or three dams. We applied a unique index of biological characteristics and environmental exposures, experienced by each fish individually as it migrated downstream, in order to examine which factors most influence salmonid survival. High outflow volumes led to involuntary spill in 2011 and created an environment of supersaturated dissolved gas concentrations. In this environment, migrating smolt survival was strongly influenced by barometric pressure, fish velocity, and water temperature. The effect of these variables on survival was compounded by multiple dam passages compared to fish passing a single dam. Despite spatial isolation between dams in the Lower Columbia River hydrosystem, migrating smolt appear to experience cumulative effects akin to a press disturbance. In general, Chinook salmon and steelhead respond similarly in terms of survival rates and responses to altered environmental conditions. Management actions that limit dissolved gas concentrations in years of high flow will benefit migrating salmonids at this life stage.

Ferguson, P. F. B., Breyta, R., Brito, I., Kurath, G., & LaDeau, S. L. (2018). An Epidemiological Model of Virus Transmission in Salmonid Fishes of the Columbia River Basin. *Ecological Modelling, 377*, https://doi.org/10.1016/j.ecolmodel.2018.03.002

We have developed a dynamic epidemiological model informed by records of viral presence and genotypes to evaluate potential transmission routes maintaining a viral pathogen in economically and culturally important anadromous fish populations. In the Columbia River Basin, infectious hematopoietic necrosis virus (IHNV) causes severe disease, predominantly in juvenile steelhead trout (Oncorhynchus mykiss) and less frequently in Chinook salmon (O. tshawytscha). Mortality events following IHNV infection can be devastating for individual hatchery programs. Despite reports of high local mortality and extensive surveillance efforts, there are questions about how viral transmission is maintained. Modeling this system offers important insights into disease transmission in natural aquatic systems, as well as about the data requirements for generating accurate estimates about transmission routes and infection probabilities. We simulated six scenarios in which testing rates and the relative importance of different transmission routes varied. The simulations demonstrated that the model accurately identified routes of transmission and inferred infection probabilities accurately when there was testing of all cohort-sites. When testing records were incomplete, the model accurately inferred which transmission routes exposed particular cohort-sites but generated biased infection probabilities given exposure. After validating the model and generating guidelines for result interpretation, we applied the model to data from 14 annual cohorts (2000–2013) at 24 focal sites in a sub-region of the Columbia River Basin, the lower Columbia River (LCR), to quantify the relative importance of potential transmission routes in this focal sub-region. We demonstrate that exposure to IHNV via the return migration of adult fish is an important route for maintaining IHNV in the LCR sub-region, and the probability of infection following this exposure was relatively high at 0.16. Although only 1% of cohort-sites experienced self-exposure by infected juvenile fish, this transmission route had the greatest probability of infection (0.22). Increased testing and/or determining whether transmission can occur from cohort-sites without testing records (e.g., determining there was no testing record because there were no fish at the cohort-site) are expected to improve inference about infection probabilities. Increased use of secure water supplies and continued use of biosecurity protocols may reduce IHNV transmission from adult fish and juvenile fish within the site, respectively, to juvenile salmonids at hatcheries. Models and conclusions from this study are potentially relevant to understanding the relative importance of transmission routes for other important aquatic pathogens in salmonids, including the agents of bacterial kidney disease and coldwater disease, and the basic approach may be useful for other pathogens and hosts in other geographic regions.

Hand, B. K., Muhlfeld, C. C., Wade, A. A., Kovach, R. P., Whited, D. C., Narum, S. R., . . . Luikart, G. (2016). Climate Variables Explain Neutral and Adaptive Variation within Salmonid Metapopulations: The Importance of Replication in Landscape Genetics. *Molecular Ecology, 25*(3), https://doi.org/10.1111/mec.13517

Understanding how environmental variation influences population genetic structure is important for conservation management because it can reveal how human stressors influence population connectivity, genetic diversity and persistence. We used riverscape genetics modelling to assess whether climatic and habitat variables were related to neutral and adaptive patterns of genetic differentiation (population-specific and pairwise FST) within five metapopulations (79 populations, 4583 individuals) of steelhead trout (Oncorhynchus mykiss) in the Columbia River Basin, USA. Using 151 putatively neutral and 29 candidate adaptive SNP loci, we found that climate-related variables (winter precipitation, summer maximum temperature, winter highest 5% flow events and summer mean flow) best explained neutral and adaptive patterns of genetic differentiation within metapopulations, suggesting that climatic variation likely influences both demography (neutral variation) and local adaptation (adaptive variation). However, we did not observe consistent relationships between climate variables and FST across all metapopulations, underscoring the need for replication when extrapolating results from one scale to another (e.g. basin-wide to the metapopulation scale). Sensitivity analysis (leave-one-population-out) revealed consistent relationships between climate variables and FST within three metapopulations; however, these patterns were not consistent in two metapopulations likely due to small sample sizes (N = 10). These results provide correlative evidence that climatic variation has shaped the genetic structure of steelhead populations and highlight the need for replication and sensitivity analyses in land and riverscape genetics.

Haskell, C. A., Beauchamp, D. A., & Bollens, S. M. (2017). Linking Functional Response and Bioenergetics to Estimate Juvenile Salmon Growth in a Reservoir Food Web. *Plos One, 12*(10), https://doi.org/10.1371/journal.pone.0185933

Juvenile salmon (Oncorhynchus spp.) use of reservoir food webs is understudied. We examined the feeding behavior of subyearling Chinook salmon (O. tshawytscha) and its relation to growth by estimating the functional response of juvenile salmon to changes in the density of Daphnia, an important component of reservoir food webs. We then estimated salmon growth across a broad range of water temperatures and daily rations of two primary prey, Daphnia and juvenile American shad (Alosa sapidissima) using a bioenergetics model. Laboratory feeding experiments yielded a Type-II functional response curve: C = 29.858 P *(4.271 + P)-1 indicating that salmon consumption (C) of Daphnia was not affected until Daphnia densities (P) were < 30 . L-1. Past field studies documented Daphnia densities in lower Columbia River reservoirs of < 3 . L-1 in July but as high as 40 . L-1 in August. Bioenergetics modeling indicated that subyearlings could not achieve positive growth above 22 degrees C regardless of prey type or consumption rate. When feeding on Daphnia, subyearlings could not achieve positive growth above 20 degrees C (water temperatures they commonly encounter in the lower Columbia River during summer). At 16-18 degrees C, subyearlings had to consume about 27,000 Daphnia . day-1 to achieve positive growth. However, when feeding on juvenile American shad, subyearlings had to consume 20 shad . day-1 at 16-18 degrees C, or at least 25 shad . day-1 at 20 degrees C to achieve positive growth. Using empirical consumption rates and water temperatures from summer 2013, subyearlings exhibited negative growth during July (-0.23 to -0.29 g . d-1) and August (-0.05 to -0.07 g . d-1). By switching prey from Daphnia to juvenile shad which have a higher energy density, subyearlings can partially compensate for the effects of higher water temperatures they experience in the lower Columbia River during summer. However, achieving positive growth as piscivores requires subyearlings to feed at higher consumption rates than they exhibited empirically. While our results indicate compromised growth in reservoir habitats, the long-term repercussions to salmon populations in the Columbia River Basin are unknown.

Haskell, C. A., Beauchamp, D. A., & Bollens, S. M. (2017). Trophic Interactions and Consumption Rates of Subyearling Chinook Salmon and Nonnative Juvenile American Shad in Columbia River Reservoirs. *Transactions of the American Fisheries Society, 146*(2), https://doi.org/10.1080/00028487.2016.1264997

We used a large lampara seine coupled with nonlethal gastric lavage to examine the diets and estimate consumption rates of subyearling Chinook Salmon Oncorhynchus tshawytscha during July and August 2013. During August we also examined the diet and consumption rates of juvenile American Shad Alosa sapidissima,a potential competitor of subyearling Chinook Salmon. Subyearling Chinook Salmon consumed Daphnia in July but switched to feeding on smaller juvenile American Shad in August. We captured no juvenile American Shad in July, but in August juvenile American Shad consumed cyclopoid and calanoid copepods. Stomach evacuation rates for subyearling Chinook Salmon were high during both sample periods (0.58 h−1 in July, 0.51 h−1 in August), and daily ration estimates were slightly higher than values reported in the literature for other subyearlings. By switching from planktivory to piscivory, subyearling Chinook Salmon gained greater growth opportunity. While past studies have shown that juvenile American Shad reduce zooplankton availability for Chinook Salmon subyearlings, our work indicates that they also become important prey after Daphnia abundance declines. The diet and consumption data here can be used in future bioenergetics modeling to estimate the growth of subyearling Chinook Salmon in lower Columbia River reservoirs.

Hess, J. E., Ackerman, M. W., Fryer, J. K., Hasselman, D. J., Steele, C. A., Stephenson, J. J., . . . Narum, S. R. (2016). Differential Adult Migration-Timing and Stock-Specific Abundance of Steelhead in Mixed Stock Assemblages. *Ices Journal of Marine Science, 73*(10), https://doi.org/10.1093/icesjms/fsw138

Stock-specific migration-timing and relative abundance of exploited fish species are critical parameters to estimate for management of mixed stock fisheries. Here, we used parentage-based tagging (PBT) together with mixed stock analyses (MSA) to estimate stock-specific abundance and migration-timing in anadromous adult steelhead (Oncorhynchus mykiss) sampled at Bonneville Dam in the lower Columbia River. Results indicate that natural-origin steelhead was represented by 11 of 13 possible stocks found throughout the Columbia-Snake river basins, while hatchery-origin steelhead was primarily composed of five stocks from the Snake River drainage. Further, migration-timing differentiated stocks and allowed categorization of early, intermediate, and late migrating stocks. Analyses of age and length data for these stocks also showed that late-arriving fish were larger due to older age and originated primarily from the Clearwater River, South Fork Salmon River, and Dworshak Hatchery, all from the Snake River drainage. Sex ratios tended to be skewed towards females and ranged from 51.5 to 68.9% for hatchery stocks and 60.5–71.8% for natural-origin stocks. This suggests that anadromous migration is favored by females while males are more likely to residualize in freshwater. Overall, this study demonstrates how the use of PBT in MSA can reveal important stock-specific differences in migration-timing and relative abundance and provides critical information for management of mixed stock fisheries.

Hess, M. A., Hess, J. E., Matala, A. P., French, R. A., Steele, C. A., Lovtang, J. C., & Narum, S. R. (2016). Migrating Adult Steelhead Utilize a Thermal Refuge During Summer Periods with High Water Temperatures. *Ices Journal of Marine Science, 73*(10), https://doi.org/10.1093/icesjms/fsw120

Anadromous fishes often use various survival tactics while migrating through main stem rivers to successfully reach spawning grounds and reproduce. Mixed-stock assemblages of anadromous adult summer steelhead Oncorhynchus mykiss re-enter the Columbia River from late spring through fall including the period of peak summer water temperatures, and previous studies suggest that stocks alter migratory behaviour in response to warm temperatures by seeking cool water refuges. We combined parentage-based tagging with mixed stock analyses to test whether steelhead use a non-natal tributary (Deschutes River, OR, USA) as a thermal refuge and if this migratory behaviour is associated with stock-specific run-timing. Results collected over two migration years indicated that out-of-basin fish in the Deschutes River were disproportionately from specific stocks in the Snake River (Salmon and Grande Ronde) that had migrated through the main stem Columbia River when water temperatures exceeded 21 degrees C. Stocks migrating through the main stem river during cooler temperature periods were either less frequent (Clearwater River), or not encountered (lower Snake River) in the Deschutes River. This study facilitates an improved understanding of stock-specific migratory characteristics associated with environmental conditions in this system. Results potentially affect fisheries management, hatchery protocols, cool-water refuge maintenance, and conservation of wild Deschutes River populations.

Keefer, M. L., Clabough, T. S., Jepson, M. A., Johnson, E. L., Peery, C. A., & Caudill, C. C. (2018). Thermal Exposure of Adult Chinook Salmon and Steelhead: Diverse Behavioral Strategies in a Large and Warming River System. *Plos One, 13*(9), https://doi.org/10.1371/journal.pone.0204274

Rising river temperatures in western North America have increased the energetic costs of migration and the risk of premature mortality in many Pacific salmon (Oncorhynchus spp.) populations. Predicting and managing risks for these populations requires data on acute and cumulative thermal exposure, the spatio-temporal distribution of adverse conditions, and the potentially mitigating effects of cool-water refuges. In this study, we paired radiotelemetry with archival temperature loggers to construct continuous, spatially-explicit thermal histories for 212 adult Chinook salmon (O. tshawytscha) and 200 adult steelhead (O. mykiss). The fish amassed ~500,000 temperature records (30-min intervals) while migrating through 470 kilometers of the Columbia and Snake rivers en route to spawning sites in Idaho, Oregon, and Washington. Spring- and most summer-run Chinook salmon migrated before river temperatures reached annual highs; their body temperatures closely matched ambient temperatures and most had thermal maxima in the lower Snake River. In contrast, many individual fall-run Chinook salmon and most steelhead had maxima near thermal tolerance limits (20–22 ˚C) in the lower Columbia River. High temperatures elicited extensive use of thermal refuges near tributary confluences, where body temperatures were ~2–10 ˚C cooler than the adjacent migration corridor. Many steelhead used refuges for weeks or more whereas salmon use was typically hours to days, reflecting differences in spawn timing. Almost no refuge use was detected in a ~260-km reach where a thermal migration barrier may more frequently develop in future warmer years. Within population, cumulative thermal exposure was strongly positively correlated (0.88 less than or equal to r less than or equal to 0.98) with migration duration and inconsistently associated (-0.28 less than or equal r less than or equal 0.09) with migration date. All four populations have likely experienced historically high mean and maximum temperatures in recent years. Expected responses include population-specific shifts in migration phenology, increased reliance on patchily-distributed thermal refuges, and natural selection favoring temperaturetolerant phenotypes.

Kendall, N. W., & Kostow, K. E. (2016). Length-and Age-Selective Fishing on Chinook Salmon of the Columbia River Basin, 2002–2012. *Transactions of the American Fisheries Society, 145*(5), https://doi.org/10.1080/00028487.2016.1173589

Fisheries can influence the size and age of exploited stocks if they selectively remove fish. In this study, we quantified length and age selectivity of the commercial and recreational fisheries on upriver spawning stocks of Chinook Salmon Oncorhynchus tshawytscha in the lower Columbia River from 2002 to 2012. Length and age data were sampled from fish (hatchery and wild individuals together) that were caught by the fisheries and from fish that escaped and then entered a trap in a dam immediately upstream of the fisheries. We found that age- and lengthbased standardized selection differentials (SSDs) were generally small compared with other fisheries and varied over time. Across all years, fish that were caught were, on average, 0.006 years older and 0.19 cm longer than fish in the total return. These results were consistent with the low harvest rates over the 11 years (recreational fishery harvest rate = 4.9%, commercial fishery harvest rate = 3.7%). However, in some years the SSDs during certain fishing periods or overall were larger than in other years and harvested fish were significantly older and longer than the average fish in the total return. For most years and periods, these larger SSDs appeared to be driven by higher harvest rates by recreational fishing gear (hook and line). The SSDs were influenced by how many Chinook Salmon were available to be caught when and where fisheries were occurring, the size and age distribution of those fish, and the selectivity of the gear. We conclude that the SSDs for contemporary lower Columbia River Chinook Salmon fisheries have generally been small in magnitude and variable over time, though in some years and periods the fisheries caught larger- and older-than-average fish. Thus, the 2002–2012 lower Columbia River fisheries likely had a low influence on the fitness or potential changes in length and age at maturation of upriver Chinook Salmon.

Kendall, N. W., Marston, G. W., & Klungle, M. M. (2017). Declining Patterns of Pacific Northwest Steelhead Trout (Oncorhynchus mykiss) Adult Abundance and Smolt Survival in the Ocean. *Canadian Journal of Fisheries and Aquatic Sciences, 74*(8), https://doi.org/10.1139/cjfas-2016-0486

Examination of population abundance and survival trends over space and time can guide management and conservation actions with information about the spatial and temporal scale offactors affecting them. Here, we analyzed steelhead trout (anadromous Oncorhynchus mykiss) adult abundance time series from 35 coastal British Columbia and Washington populations along with smolt-to-adult return (smolt survival) time series from 48 populations from Washington, Oregon, and the Keogh River in British Columbia. Over 80% of the populations have declined in abundance since 1980. A multivariate autoregressive statespace model revealed smolt survival four groupings: Washington and Oregon coast, lower Columbia River, Strait ofJuan de Fuca, and Puget Sound – Keogh River populations. Declines in smolt survival rates were seen for three of the four groupings. Puget Sound and Keogh River populations have experienced low rates since the early 1990s. Correlations between population pairs' time series and distance apart illustrated that smolt survival rates were more positively correlated for proximate populations, suggesting that important processes, including those related to ocean survival, occur early in the marine life of steelhead.

Koch, I. J., & Narum, S. R. (2020). Validation and Association of Candidate Markers for Adult Migration Timing and Fitness in Chinook Salmon. *Evolutionary Applications, 00*, https://doi.org/10.1111/eva.13026

Recent studies have begun to elucidate the genetic basis for phenotypic traits in salmonid species, but many questions remain before these candidate genes can be directly incorporated into conservation management. In Chinook Salmon (Oncorhynchus tshawytscha), a region of major effect for migration timing has been discovered that harbors two adjacent candidate genes (greb1L, rock1), but there has been limited work to examine the association between these genes and migratory phenotypes at the individual, compared to the population, level. To provide a more thorough test of individual phenotypic association within lineages of Chinook Salmon, 33 candidate markers were developed across a 220 Kb region on chromosome 28 previously associated with migration timing. Candidate and neutral markers were genotyped in individuals from representative collections that exhibit phenotypic variation in timing of arrival to spawning grounds from each of three lineages of Chinook Salmon. Association tests confirmed the majority of markers on chromosome 28 were significantly associated with arrival timing and the strongest association was consistently observed for markers within the rock1 gene and the intergenic region between greb1L and rock1. Candidate markers alone explained a wide range of phenotypic variation for Lower Columbia and Interior ocean-type lineages (29% and 78%, respectively), but less for the Interior stream-type lineage (5%). Individuals that were heterozygous at markers within or upstream of rock1 had phenotypes that suggested a pattern of dominant inheritance for early arrival across populations. Finally, previously published fitness estimates from the Interior stream-type lineage enabled tests of association with arrival timing and two candidate markers, which revealed that fish with homozygous mature genotypes had slightly higher fitness than fish with premature genotypes, while heterozygous fish were intermediate. Overall, these results provide additional information for individual-level genetic variation associated with arrival timing that may assist with conservation management of this species.

Losee, J. P., Miller, J. A., Peterson, W. T., Teel, D. J., & Jacobson, K. C. (2014). Influence of Ocean Ecosystem Variation on Trophic Interactions and Survival of Juvenile Coho and Chinook Salmon. *Canadian Journal of Fisheries and Aquatic Sciences, 7*(11), https://doi.org/10.1139/cjfas-2014-0043

The community of trophically transmitted marine parasites of juvenile coho (Oncorhynchus kisutch) and Chinook (Oncorhynchus tshawytscha) salmon across 8 years (2002–2009) was related to indices of physical and biological ocean conditions and adult returns. When the biomass of lipid-poor, southern origin copepods in the coastal ocean was high during juvenile salmon outmigration from fresh water (April–June), yearling coho and Chinook salmon harbored a different trophically transmitted parasite fauna and exhibited lower survival compared with years when the southern copepod biomass was low. As copepods are key intermediate hosts in many marine parasite life cycles, these results support a trophic linkage between the copepod community and salmon prey. Interannual variation in the parasite community was correlated with survival ofcoho salmon (r = −0.67) measured 1 year later and adult returns ofUpper Columbia River summer and fall Chinook salmon (r = −0.94) 3 years from the time ofocean entry.

National Marine Fisheries Service. (2015). *Designation of Critical Habitat for Lower Columbia River Coho Salmon and Puget Sound Steelhead Final Biological Report*. Portland, OR Retrieved from https://repository.library.noaa.gov/view/noaa/18681

This report contains biological assessments supporting the National Marine Fisheries Service's (NMFS) final designation of critical habitat under section 4 of the Endangered Species Act (ESA) for two listed distinct population segments (DPS): lower Columbia River coho salmon and Puget Sound steelhead. NMFS convened two critical habitat analytical review teams (CHARTs) charged with analyzing the best available data for each DPS to make findings regarding the presence of essential habitat features in each watershed, potential management actions that may affect those features, and the conservation value of each watershed within each DPS's range. This report summarizes the agency's mapping efforts, methods and information used, and final CHART assessments for these two DPSs. This information will be used in conjunction with other agency analyses (e.g., a final economic analysis and ESA section 4(b)(2) analysis) to determine which areas to designate as critical habitat for lower Columbia River coho salmon and Puget Sound steelhead.

National Marine Fisheries Service. (2015). *Final Environmental Assessment Harvest Control Rule for Lower Columbia River Coho Evolutionarily Significant Unit in Fisheries Managed under the Pacific Coast Salmon Fishery Management Plan*. Retrieved from https://repository.library.noaa.gov/view/noaa/12819

Ocean salmon fisheries off the West Coast states of California, Oregon, and Washington are managed by the Pacific Fishery Management Council (Council) under the Pacific Coast Salmon Fishery Management Plan (FMP) (PFMC 2014a). Management of the salmon stocks in the FMP can be affected when the National Marine Fisheries Service (NMFS) lists evolutionarily significant units (ESUs) of Pacific salmon (Waples 1991) as either threatened or endangered under the U.S. Endangered Species Act (ESA). If a fishery is expected to interact with ESA-listed salmon (i.e., result in a "take" of an ESA-listed species), NMFS initiates a formal consultation under section 7 of the ESA to evaluate fishery impacts, and issues a biological opinion to report the findings. In 2005, the Lower Columbia River coho salmon ESU (LCR coho) was ESA-listed as threatened (70 FR 37160, June 28, 2005). Biological opinions issued by NMFS, beginning in 2006, have analyzed the use of a harvest control rule to determine the allowable level of take of LCR coho in Council-managed fisheries. In 2015, the Council recommended a new harvest control rule for consideration by NMFS (McIsaac 2015). This environmental assessment (EA) analyzes the environmental effects of implementing a new harvest control rule for LCR coho. The LCR coho ESU is synonymous with the Lower Columbia River natural coho stock (LCN coho) in the FMP. For consistency with NMFS documents, including biological opinions, this EA uses the ESU name, LCR coho, to refer to these salmon; LCN coho is used in relation to Council activities and documents.

National Marine Fisheries Service. (2016). *2016 5-Year Review : Summary & Evaluation of Lower Columbia River Chinook Salmon Columbia River Chum Salmon Lower Columbia River Coho Salmon Lower Columbia River Steelhead*. Portland, OR Retrieved from https://repository.library.noaa.gov/view/noaa/17021

Many West Coast salmon and steelhead (Oncorhynchus sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the agency's fiveyear status review for ESA-listed lower Columbia River salmon and steelhead species. These include: Lower Columbia River Chinook salmon, Columbia River chum salmon, Lower Columbia River coho salmon, and Lower Columbia River steelhead.

Oregon Department of Fish and Wildlife. (2019). *Monitoring Program Report Number Opsw-Odfw-2018-09*. (OPSW-ODFW-2018-09). Retrieved from https://odfw.forestry.oregonstate.edu/spawn/pdf%20files/reports/18STWAnnualReport.pdf

This report provides a summary of results from winter steelhead spawning ground surveys conducted in Lower Columbia (Oregon side only) and Oregon Coast basins in 2018. Also included is a brief summary of lamprey data collected from the same monitoring efforts. Total winter steelhead redd estimates in the

Southwest Washington (SWW) Evolutionary Significant Unit (ESU) were below the 5-year average, while estimates in the Lower Columbia River (LCR) ESU were above the 5-year average. Total winter steelhead redd estimates were approximately 98% of both the 5- and 10-year averages for the Oregon Coast (OC) Distinct Population Segment (DPS). Estimate precision goals were met for steelhead redd estimates in the LCR ESU, the OC DPS and the Nestucca River population. Precision goals were not met in the SWW ESU, nor in any of the four OC Monitoring Areas. Surveys were not conducted in the Klamath Mountains Province (KMP) DPS. Regional patterns are apparent for winter steelhead redd density, proportion of hatchery origin spawners and spawn timing. Indices for Pacific Lamprey were lower in 2018 in the Lower Columbia compared to recent years, but above average in the Oregon Coast.

Payton, Q., Hostetter, N. J., & Evans, A. F. (2019). Jointly Estimating Survival and Mortality: Integrating Recapture and Recovery Data from Complex Multiple Predator Systems. *Environmental and Ecological Statistics, 26*(2), https://doi.org/10.1007/s10651-019-00421-8

Identifying where, when, and how many animals live and die over time is principal to understanding factors that influence population dynamics. Capture-recapture-recovery (CRR) models are widely used to estimate animal survival and, in many cases, quantify specific causes of mortality (e.g., harvest, predation, starvation). However, the restrictive CRR framework can inhibit the consideration and inclusion of some types of recovery data. We developed an extension to the CRR framework to allow for the incorporation of recoveries from indeterminate temporal or spatial origin. This model jointly estimates cause-specific mortality and survival probabilities across multiple spatial and temporal scales, while accounting for differences in mortality-specific reporting and recovery rates. We fitted the model to data on a group of juvenile steelhead trout (Oncorhynchus mykiss) marked with passive integrated transponder tags in the Columbia River basin, USA. Following tagging and release, fish were detected alive at up to six downstream locations and/or recovered dead on one of nine bird colonies during seaward migration. We estimated that, in aggregate, avian predators consumed 31% of juvenile steelhead during outmigration to the ocean (95% CRI: [27, 36]). Colony-specific predation rates ranged from<1 to 14% among river reaches, with avian predation accounting for>95% of all steelhead mortality within some reaches. This integrated modelling approach provides a flexible framework to integrate multiple recapture and recovery data sources, providing a more holistic understanding of animal life history, including direct comparisons of cause-specific mortality factors and the cumulative impact of multiple mortality factors across time or space.

Portland General Electric Company. (2015). *Expert Habitat Mapping for 1+ Coho Habitat in the Lower Oak Grove Fork of the Clackamas River.* Retrieved from https://new.portlandgeneral.com/

On December 21, 2010, the Commission issued an Order Issuing New License, Portland General Electric Company, 133 FERC ¶ 62,281 (2010), order on reh'g 134 FERC ¶ 61,206 (2011). Appendix A, Condition 8(h)(4) and Appendix B, Article 18(a) of the license required Portland General Electric (PGE), within 12 months of license issuance, to file with the Commission a side channel habitat enhancement plan (Side Channel Plan) intended to provide, as a result of increased baseflows and specific side channel enhancement projects, a total of 40,000 ft2 of 1+ coho side channel habitat in the Oak Grove Fork below Lake Harriet Dam. The Side Channel Plan was filed with the Commission on November 29, 2011, and the Commission approved the plan on April 17, 2012. Appendix A, Condition 8(h)(4) and Appendix B, Article

18(a) also required that side channel enhancement projects be completed within five years of license issuance. PGE completed the enhancements in summer 2014.

Roegner, G., & Teel, D. J. (2014). Density and Condition of Subyearling Chinook Salmon in the Lower Columbia River and Estuary in Relation to Water Temperature and Genetic Stock of Origin. *Transactions of the American Fisheries Society, 143*(5), https://doi.org/10.1080/00028487.2014.918055

We examined the hypotheses that density and morphometric condition of subyearling juvenile Chinook Salmon Oncorhynchus tshawytscha would decline during periods of high water temperature in the lower Columbia River and estuary. The hypotheses were tested using salmon density measurements and a condition anomaly calculated from residuals of the length-weight linear regression based on 5,536 subyearlings collected from brackish estuarine and tidal freshwater (TFW) habitats. We captured Chinook Salmon at all temperatures encountered (4.2-23.5 degree C). In the TFW zone, densities were highest at optimal temperatures and lowest at suboptimal and supraoptimal temperatures; in the estuary, density did not differ among temperature regimes. Fish condition was lowest in winter, when temperatures were suboptimal, and highest in summer, when temperatures were supraoptimal. Pairwise comparisons of fish condition between periods of optimal temperature (spring) and supraoptimal or stressful temperature (summer) showed little change in the estuary but a large, positive increase with temperature in the TFW zone. Similarly, we examined seasonal differences in the condition of 50-60-mm fry and again found condition to be lowest in winter and highest in summer. Finally, using genetic information, we identified stock-specific differences in migration timing and concluded that most large yearlings and many subyearlings migrated in late winter or spring and therefore were never exposed to high temperatures. Other prevalent stocks persisted in the estuary during periods of elevated temperature; however, the condition of those fish also tended to be higher or neutral in summer than in spring. High temperatures appeared to influence migration timing, as evidenced by reduced density in TFW reaches during summer. However, we found little support for the hypothesis that condition of juvenile Chinook Salmon is reduced during periods of high water temperature in the lower Columbia River and estuary.

Roegner, G. C., Weitkamp, L. A., & Teel, D. J. (2016). Comparative Use of Shallow and Deepwater Habitats by Juvenile Pacific Salmon in the Columbia River Estuary Prior to Ocean Entry. *Marine and Coastal Fisheries, 8*(1), https://doi.org/10.1080/19425120.2016.1227889

The degree to which fine-scale habitat use by salmonid species and stocks varies within habitat types such as estuaries is not fully resolved. We sampled shallow shoreline and deeper main-stem channel habitats in the Columbia River estuary over 3 years to compare salmon species composition, migration timing, density, size, and production type (hatchery or natural). Results indicated a high degree of spatial heterogeneity in habitat occupancy by the five salmonid species that are native to the basin. Salmonid communities at two channel habitat sites were much more similar to each other than to the community at a shoreline site. Salmonids sampled at the shoreline site were primarily subyearling Chinook Salmon Oncorhynchus tshawytscha and Chum Salmon O. keta and yearling Coho Salmon O. kisutch, with few other salmonids present. In contrast, channel habitat contained a higher diversity ofsalmon species, with samples representing all species of anadromous salmonids, including Sockeye Salmon O. nerka and steelhead O. mykiss. Salmonids in deeper channel habitat were generally larger than salmonids found along the shore, and the proportion of hatchery-origin salmon was also higher in deep channel habitats. On a per-area basis, we also found much higher densities of salmon along the shoreline than in channel habitats. For Chinook Salmon, habitat use also differed by genetic stock of origin: upper-river stocks primarily used deeper channels, while lower-river populations used both channel and shoreline areas. We concluded that sampling at both habitat types is required to fully encompass the migration patterns of all salmon evolutionarily significant units in the Columbia River basin. These spatial and temporal variations in salmon timing and density have ramifications for feeding, growth, and competitive interactions. This study provides information that is relevant for conservation efforts targeting specific fish populations and efforts to evaluate the potential impacts of in-water activities in the Columbia River estuary.

Rub, A. M. W., Som, N. A., Henderson, M. J., Sandford, B. P., Van Doornik, D. M., Teel, D. J., . . . Huff, D. D. (2019). Changes in Adult Chinook Salmon (Oncorhynchus tshawytscha) Survival within the Lower Columbia River Amid Increasing Pinniped Abundance. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(10), https://doi.org/10.1139/cjfas-2018-0290

Considerable effort towards conservation has contributed to the recovery of historically depleted pinniped populations worldwide. However, in several locations where pinnipeds have increased, they have been blamed for preventing the recovery of commercially valuable fish species through predation. Prompted by increasing pinniped abundance within the Columbia River (CR), USA, over a 6-year period, we used passive integrated transponder tags to measure the survival of adult spring-run Chinook salmon (Oncorhynchus tshawytscha) through the estuary and lower CR to Bonneville Dam (river kilometre 234). We estimated 51 751 – 224 705 salmon died annually within this reach from sources other than harvest. Mixed-effects logistic regression modelling identified pinniped predation as the most likely source of this mortality. The odds of survival was estimated to decrease by 32% (95% CI: 6%–51%) for every additional 467 sea lions (Zalophus californianus and Eumetopias jubatus) present within the CR and to increase by 32% (95% CI: 8%–61%) for every increase of 1.5 in the log of American shad (Alosa sapidissima), a potential prey item for sea lions.

Small, M. P., Olive, S. D. R., Seeb, L. W., Seeb, J. E., Pascal, C. E., Warheit, K. I., & Templin, W. (2015). Chum Salmon Genetic Diversity in the Northeastern Pacific Ocean Assessed with Single Nucleotide Polymorphisms (Snps): Applications to Fishery Management. *North American Journal of Fisheries Management, 35*(5), https://doi.org/10.1080/02755947.2015.1055014

We examined genetic diversity patterns among 55 collections of Chum Salmon from the northeastern Pacific Ocean using 89 single nucleotide polymorphisms (SNPs). The distribution of Chum Salmon samples extended from the Nass River along the coast of British Columbia and along the coast of Washington as far south as the Columbia River. Chum Salmon represented three previously defined run-groups: fall (primarily), summer, and winter. Genetic variation at SNP loci, as measured by FST, ranged from 0.002 to 0.279 over all collections and averaged 0.062 over all loci. Similar to the genetic patterns detected with microsatellites and allozymes, genetic variation followed a regional structure along geographic distance, with genetic diversity being highest in the north and decreasing southward, then increasing in and near the Columbia River. Within Puget Sound, Washington, genetic variation was structured further according to run timing (fall, summer, and winter) and shared ancestry. Simulations indicated that this suite of SNPs is powerful for identifying regional components in a Chum Salmon mixed fishery. Because of the transferability of SNP data, the growing SNP baseline for Chum Salmon will be useful for multiple agencies managing Chum Salmon around the Pacific Rim.

Spromberg, J. A., Baldwin, D. H., Damm, S. E., McIntyre, J. K., Huff, M., Sloan, C. A., . . . Scholz, N. L. (2016). Coho Salmon Spawner Mortality in Western Us Urban Watersheds: Bioinfiltration Prevents Lethal Storm Water Impacts. *Journal of Applied Ecology, 53*(2), https://doi.org/10.1111/1365-2664.12534

Summary Adult coho salmon Oncorhynchus kisutch return each autumn to freshwater spawning habitats throughout western North America. The migration coincides with increasing seasonal rainfall, which in turn increases storm water run-off, particularly in urban watersheds with extensive impervious land cover. Previous field assessments in urban stream networks have shown that adult coho are dying prematurely at high rates (>50%). Despite significant management concerns for the long-term conservation of threatened wild coho populations, a causal role for toxic run-off in the mortality syndrome has not been demonstrated. We exposed otherwise healthy coho spawners to: (i) artificial storm water containing mixtures of metals and petroleum hydrocarbons, at or above concentrations previously measured in urban run-off; (ii) undiluted storm water collected from a high traffic volume urban arterial road (i.e. highway run-off); and (iii) highway run-off that was first pre-treated via bioinfiltration through experimental soil columns to remove pollutants. We find that mixtures of metals and petroleum hydrocarbons – conventional toxic constituents in urban storm water – are not sufficient to cause the spawner mortality syndrome. By contrast, untreated highway run-off collected during nine distinct storm events was universally lethal to adult coho relative to unexposed controls. Lastly, the mortality syndrome was prevented when highway run-off was pretreated by soil infiltration, a conventional green storm water infrastructure technology. Our results are the first direct evidence that: (i) toxic run-off is killing adult coho in urban watersheds, and (ii) inexpensive mitigation measures can improve water quality and promote salmon survival. Synthesis and applications. Coho salmon, an iconic species with exceptional economic and cultural significance, are an ecological sentinel for the harmful effects of untreated urban run-off. Wild coho populations cannot withstand the high rates of mortality that are now regularly occurring in urban spawning habitats. Green storm water infrastructure or similar pollution prevention methods should be incorporated to the maximal extent practicable, at the watershed scale, for all future development and redevelopment projects, particularly those involving transportation infrastructure.

Van Doornik, D. M., Beckman, B. R., Moss, J. H., Strasburger, W. W., & Teel, D. J. (2019). Stock Specific Relative Abundance of Columbia River Juvenile Chinook Salmon Off the Southeast Alaska Coast. *Deep Sea Research Part II: Topical Studies in Oceanography, 165*, https://doi.org/10.1016/j.dsr2.2019.05.008

Migration patterns of juvenile Columbia River Chinook salmon (Oncorhynchus tshawytscha) differ among stocks and life history types, creating diverse marine distributions of these fish. This results in different stocks being subject to different ocean conditions during their first summer of marine residence, a time that is critical for their survival. Understanding their early marine distributions, and the conditions that affect their survival, may enhance conservation efforts for these stocks, many of which are protected under the Endangered Species Act. We analyzed juvenile Chinook salmon samples collected in trawls made from 2011 to 2015 off the southeastern (SE) Alaskan panhandle, and off the coasts of Washington and Oregon. We used genetic stock identification techniques to estimate stock proportions of juvenile Chinook salmon in each of these areas. Results indicated that most juvenile Chinook salmon in our SE Alaska coast study area in July originate from Columbia River springrun stocks. We found a significant relationship in catch per unit effort (CPUE) over all stocks between the SE Alaska and the Washington and Oregon coast samples. In 2011, CPUE for Columbia River spring-run stocks for the SE Alaska coast was lower than for the Washington and Oregon coast, suggesting a differing level of marine mortality that year. We also found a significant relationship between juvenile CPUE of interior Columbia River spring-run stocks off the SE Alaska coast and adult counts at Bonneville Dam two years later. Our results provide marine life history, performance and survival information that supports management and recovery efforts for Columbia River Chinook salmon.

Westley, P. A. H., Dittman, A. H., Ward, E. J., & Quinn, T. P. (2015). Signals of Climate, Conspecific Density, and Watershed Features in Patterns of Homing and Dispersal by Pacific Salmon. *Ecology, 96*(10) Retrieved from www.jstor.org/stable/24702399

It is widely assumed that rates of dispersal in animal populations are plastic in response to intrinsic and extrinsic cues, yet the factors influencing this plasticity are rarely known. This knowledge gap is surprising given the important role of dispersal in facilitating range shifts that may allow populations to persist in a rapidly changing global climate. We used two decades of tagging and recapture data from 19 hatchery populations of Oncorhynchus tshawytscha (Chinook salmon) in the Columbia River, USA, to quantify the effects of regional and local climate conditions, density dependence, watershed features such as area and position on the landscape, and direct anthropogenic influence on dispersal rates by adult salmon during the breeding season. We found that the probability of dispersal, termed "straying" in salmon, is plastic in response to multiple factors and that populations showed varied responses that were largely idiosyncratic. A regional climate index (Pacific Decadal Oscillation), water temperatures in the mainstem Columbia River that was commonly experience by populations during migration, water temperatures in local subbasins unique to each population during the breeding season, migration distance, and density dependence had the strongest effects on dispersal. Patterns of dispersal plasticity in response to commonly experienced conditions were consistent with gene by environment interactions, though we are tentative about this interpretation given the domesticated history of these populations. Overall, our results warn against attempts to predict future range shifts of migratory species without considering population-specific dispersal plasticity, and also caution against the use of few populations to infer species-level patterns. Ultimately, our results provide evidence that analyses that examine the response of dispersal to single factors may be misleading.

Winans, G. A., Allen, M. B., Baker, J., Lesko, E., Shrier, F., Strobel, B., & Myers, J. (2018). Dam Trout: Genetic Variability in Oncorhynchus mykiss above and Below Barriers in Three Columbia River Systems Prior to Restoring Migrational Access. *Plos One, 13*(5), https://doi.org/10.1371/journal.pone.0197571

Restoration of access to lost habitat for threatened and endangered fishes above currently impassable dams represents a major undertaking. Biological monitoring is critical to understand the dynamics and success of anadromous recolonization as, in the case of Oncorhynchus mykiss, anadromous steelhead populations are reconnected with their conspecific resident rainbow trout counterparts. We evaluate three river systems in the Lower Columbia River basin: the White Salmon, Sandy, and Lewis rivers that are in the process of removing and/or providing passage around existing human-made barriers in O. mykiss riverine habitat. In these instances, now isolated resident rainbow trout populations will be exposed to competition and/or genetic introgression with steelhead and vice versa. Our genetic analyses of 2,158 fish using 13 DNA microsatellite (mSAT) loci indicated that within each basin anadromous O. mykiss were genetically distinct from and significantly more diverse than their resident above-dam trout counterparts. Above long-standing natural impassable barriers, each of these watersheds also harbors unique rainbow trout gene pools with reduced levels of genetic diversity. Despite frequent releases of non-native steelhead and rainbow trout in each river, hatchery releases do not appear to have had a significant genetic effect on the population structure of O. mykiss in any of these watersheds. Simulation results suggest there is a high likelihood of identifying anadromous x resident individuals in the Lewis and White Salmon rivers, and slightly less so in the Sandy River. These genetic data are a prerequisite for informed monitoring, managing, and conserving the different life history forms during upstream recolonization when sympatry of life history forms of O. mykiss is restored.

Section X: Middle Columbia River

Matala, A. P., Allen, B., Narum, S. R., & Harvey, E. (2017). Restricted Gene Flow between Resident Oncorhynchus mykiss and an Admixed Population of Anadromous Steelhead. *Ecology and Evolution, 7*(20), https://doi.org/10.1002/ece3.3338

The species Oncorhynchus mykiss is characterized by a complex life history that presents a significant challenge for population monitoring and conservation management. Many factors contribute to genetic variation in O. mykiss populations, including sympatry among migratory phenotypes, habitat heterogeneity, hatchery introgression, and immigration (stray) rates. The relative influences of these and other factors are contingent on characteristics of the local environment. The Rock Creek subbasin in the middle Columbia River has no history of hatchery supplementation and no dams or artificial barriers. Limited intervention and minimal management have led to a dearth of information regarding the genetic distinctiveness of the extant O. mykiss population in Rock Creek and its tributaries. We used 192 SNP markers and collections sampled over a 5- year period to evaluate the temporal and spatial genetic structures of O. mykiss between upper and lower watersheds of the Rock Creek subbasin. We investigated potential limits to gene flow within the lower watershed where the stream is fragmented by seasonally dry stretches of streambed, and between upper and lower watershed regions. We found minor genetic differentiation within the lower watershed occupied by anadromous steelhead (FST = 0.004), and evidence that immigrant influences were prevalent and ubiquitous. Populations in the upper watershed above partial natural barriers were highly distinct (FST = 0.093) and minimally impacted by apparent introgression. Genetic structure between watersheds paralleled differences in local demographics (e.g., variation in size), migratory restrictions, and habitat discontinuity. The evidence of restricted gene flow between putative remnant resident populations in the upper watershed and the admixed anadromous population in the lower watershed has implications for local steelhead productivity and regional conservation.

National Marine Fisheries Service. (2016). *2016 5-Year Review : Summary & Evaluation of Middle Columbia River Steelhead*. Retrieved from https://repository.library.noaa.gov/view/noaa/17022

Many West Coast salmon and steelhead (Oncorhynchus spp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the review of the ESA-listed Middle Columbia River (MCR) steelhead.

Oregon Department of Fish and Wildlife. (2019). *Conservation and Recovery Plan for Oregon Steelhead Populations in the Middle Columbia River Steelhead Distinct Population Segment: 2010 – 2016 Implementation Progress Report*. Retrieved from https://www.dfw.state.or.us

This report summarizes progress during the first seven years, 2010—2016, of implementing the Conservation and Recovery Plan for Oregon Steelhead Populations in the Middle Columbia River Steelhead Disntict Population Segment (Oregon Mid-C Plan; Mid-C Steelhead DPS).

Pierce, A. L., Blodgett, J. W., Cavileer, T. D., Medeiros, L. R., Boyce, J., Caldwell, L. K., . . . Nagler, J. J. (2017). Reproductive Development in Captive Reconditioned Female Steelhead Kelts: Evidence for Consecutive and Skip Spawning Life Histories. *Canadian Journal of Fisheries and Aquatic Sciences, 74*(7), https://doi.org/10.1139/cjfas-2016-0065

Reconditioning of post-spawned anadromous rainbow trout (steelhead kelts, Oncorhynchus mykiss) is being implemented as a recovery tool on the Yakima River in the mid-Columbia River Basin. We assessed reproductive development in female Yakima River kelts by measuring plasma estradiol-17β (E2) and vitellogenin (VG) levels during reconditioning in 2009– 2011. Plasma E2 and VG levels showed that fish separated into rematuring (consecutive spawning) and nonrematuring (presumed skip spawning) cohorts by October. Rematuration rates varied from 25% to 65%. Rematuring fish were consistently detected migrating toward spawning areas after release, whereas nonrematuring fish were occasionally detected on spawning migrations the following year. Rematuring fish grew more rapidly than nonrematuring fish over the reconditioning period and had higher muscle lipid levels and condition factor in October. Plasma E2 was elevated in rematuring fish by June–July, whereas plasma VG was elevated by June–August, suggesting that maturation decisions occur early in reconditioning. Rematuring and nonrematuring females could be separated by plasma E2 and VG levels by August–September, enabling separate management of consecutive and presumed skip spawners.

Richins, S. M., & Skalski, J. R. (2018). Steelhead Overshoot and Fallback Rates in the Columbia–Snake River Basin and the Influence of Hatchery and Hydrosystem Operations. *North American Journal of Fisheries Management, 38*(5), https://doi.org/10.1002/nafm.10219

Tributary overshoot occurs when adult salmonids homing to natal sites continue upstream past the mouth of their natal stream. Although overshooting is a common behavior by steelhead Oncorhynchus mykiss in the Columbia River basin, it has not been adequately quantified or explained. Using multistate release–recapture models, we examined the prevalence of overshooting and fallback to natal tributaries by 37,806 PIT-tagged steelhead from 14 tributaries of the Columbia River basin during 2005–2015. Eight populations had overshooting rates exceeding 50% in at least 1 year. Source of hatchery stock, rearing location, and release practices were found to have appreciable effects on overshoot rates. Overshooting was elevated in hatchery stocks reared upstream of release sites, but this effect may be lessened by utilizing endemic broodstocks and acclimating juveniles within the release basin. For one population of hatchery steelhead, acclimation within the release basin was found to decrease overshooting from 81% to 40%. Across both hatchery and wild populations, successful homing was found to decline 4 percentage points for every 5-percentagepoint increase in overshoot rate. Average annual fallback probabilities ranged from 0.18 for Walla Walla River hatchery steelhead to 0.75 for Umatilla River wild steelhead. Fish stocks with the greatest fallback probabilities also had the greatest interannual variability in fallback rates. For John Day River wild steelhead and Tucannon River hatchery steelhead, the interannual range in fallback probabilities exceeded 0.50. We found evidence that spill at dams during March may enhance the fallback of overshooting steelhead and contribute to increased homing to natal tributaries. Therefore, additional attention should be paid to facilitating downstream dam passage of adult salmon.

Simpson, W. G. (2018). The Entrainment and Screening of Returning and Post-Spawn Adult Salmonids at Irrigation Canals of the Umatilla River, Oregon. *Journal of Fish and Wildlife Management, 9*(1), https://doi.org/10.3996/072017-jfwm-058

Anadromous salmonids can be vulnerable to entrainment at diversion intake structures on streams, effectively trapping fish in irrigation canals and removing them from a population. Currently little is known about how the differences in timing and direction of movement among adult salmonids contribute to their risk of entrainment and how successful they are at escaping irrigation canals. Potential routes of escape include passing against water currents and through the headgate of an irrigation canal intake or by navigating through screen and bypass infrastructure primarily designed to return juvenile fish to a stream. In this study, passive integrated transponders (PIT tags) were used to track the movement of adult Chinook Salmon Oncorhynchus tshawytscha (n ¼ 573), Coho Salmon Oncorhynchus kisutch (n ¼ 39), and anadromous Rainbow Trout Oncorhynchus mykiss (steelhead, n ¼ 853) as they entered areas of the Umatilla River basin (Oregon) with irrigation canals and as they attempted to escape irrigation canals after entrainment. Although adult steelhead and spring Chinook Salmon often encountered diversions at similar times, the vast majority of entrained adults were steelhead (94%). Between 2% and 8% of adult steelhead observed entering the area were entrained. The entrainment of steelhead was strongly associated with downstream movements and Umatilla River discharge below 40 m3/s. Many downstream-moving steelhead were postspawning fish (kelts). As a result, vulnerability of anadromous adults to entrainment differed by species due to the direction of their movements and how these movements coincide with canal operations and river flows. It is unlikely that the screened irrigation canals acted as an ecological sink; the majority of adult salmonids approached the screen and bypass infrastructure (greater or equal to 88%) and later river detection confirmed that many had used that infrastructure to return to the river (greater or equal to 47%). However, half of steelhead appeared to experience bypass delays at fish screens. Adult steelhead that approached the canal headgate after becoming trapped in the canal did not successfully return to the Umatilla River using this route. Unscreened irrigation canals elsewhere may disproportionally trap downstream-moving steelhead, like postspawning kelts, due to their propensity for entrainment and their difficulties escaping through the water intakes of irrigation canals. In streams with anadromous salmonids, fish screen and bypass infrastructure primarily designed to eliminate the permanent entrainment of juvenile fish can also prevent the removal of adult fish that may reproductively contribute to the population.

Trammell, J. L. J., Fast, D. E., Hatch, D. R., Bosch, W. J., Branstetter, R., Pierce, A. L., . . . Frederiksen, C. R. (2016). Evaluating Steelhead Kelt Treatments to Increase Iteroparous Spawners in the Yakima River Basin. *North American Journal of Fisheries Management, 36*(4), https://doi.org/10.1080/02755947.2016.1165767

Steelhead Oncorhynchus mykiss are iteroparous, distinguishing them from Pacificsalmon Oncorhynchus spp. that are semelparous. In this study we evaluated enhancement techniques that exploit this life history strategy to facilitate species restoration and recovery. In the Columbia River basin, where the natural ecosystem has been substantially altered over several decades due to human influence, all steelhead populations are listed as threatened or endangeredunder the U.S. Endangered Species Act. One factor believed to be limiting survival of Columbia River kelt (postspawned) steelhead is poor migration success to the ocean past several dams. We evaluated three treatments for kelts captured in the Yakima River basin from 2002 to 2011: (1) transport and release below Bonneville Dam (to provide unimpeded access to the ocean); (2) short-term reconditioning (holding and feeding in an artificial environment to facilitate gonad maturation) with transport; and (3) long-term reconditioning. These treatments were compared with an in-river migration control group to identify differences in the rate at which kelts survived and returned to Prosser Dam for potential repeat spawning (hereafter repeat spawners). The long-term reconditioning treatment exhibited the highest return rate of repeat spawners (range, 11.5–17.6%). The short-term reconditioning treatment with transport downstream from Bonneville Dam had a 3.2% return rate. The transport only treatment exhibited the lowest return rate (0.9%); this was only onethird of the control group’s return rate (2.7%). Our results indicate that long-term steelhead kelt reconditioning is more successful than either transportation or in-river migration alternatives at increasing potential repeat spawner abundance and providing recovery benefits in river systems that have experienced substantial losses in natural productivity due to loss of habitat and habitat connectivity.

Section XI: Upper Columbia River

Bond, M. H., Nodine, T. G., Beechie, T. J., & Zabel, R. W. (2019). Estimating the Benefits of Widespread Floodplain Reconnection for Columbia River Chinook Salmon. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(7), https://doi.org/10.1139/cjfas-2018-0108

In the Pacific Northwest, widespread stream channel simplification has led to a loss of habitat area and diversity for rearing salmon. Subsequent efforts throughout the Columbia River basin (CRB) have attempted to restore habitats altered through land development to recover imperiled salmon populations. However, there is scant evidence for demographic change in salmon populations following restoration. We used a process-based approach to estimate the potential benefit of floodplain reconnection throughout the CRB to Chinook salmon (Oncorhynchus tshawytscha) parr. Using satellite imagery, we measured stream habitats at 2093 CRB stream reaches to construct random forest models of habitat based on geomorphic and regional characteristics. Connected floodplain width was the most important factor for determining side channel presence. Weestimated a current CRB-wide decrease in side channel habitat area of 26% from historical conditions. Reconnection of historical floodplains currently used for agriculture could increase side channel habitat by 25% and spring Chinook salmon parr total rearing capacity by 9% over current estimates. Individual watersheds vary greatly in habitat factors that limit salmon recovery, and large-scale estimates of restoration potential like these are needed to make decisions about long-term restoration goals among imperiled populations.

Child, A. W., & Moore, B. C. (2017). Stable Isotope (Δ13c, Δ15n, Δ34s) Analysis of Sediment Cores Suggests Sockeye Salmon (Oncorhynchus Nerka) Did Not Historically Spawn in Lake Roberta, Washington (USA). *Journal of Paleolimnology, 57*(1), https://doi.org/10.1007/s10933-016-9928-9

Historically, the Sanpoil River, Washington (USA) produced spawning runs of chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (O. mykiss). Lake Roberta is connected to the Sanpoil River and local oral history suggests it may have supported anadromous sockeye salmon (O. nerka) until the completion of Grand Coulee Dam in the 1940s. Post-spawning mortality of anadromous salmon provides large pulses of marine-derived nutrients to aquatic and terrestrial ecosystems in the vicinity of spawning sites. Unique isotopic ratios of these marine-derived nutrients are often transferred to freshwater algae and archived in lake sediments. However, marine-derived isotope signatures may be overpowered by large inputs of other nutrient sources such as agricultural fertilizers, reactive nitrogen deposition, nitrogen fixation, or poor trophic transfer to freshwater algae. We compared nitrogen and sulfur isotope compositions for pre-1940 and post-1940 sediments to those collected from a control lake with no history of anadromy to investigate the possible historic presence of anadromous salmon in Lake Roberta. We also analyzed carbon isotopes, carbon:nitrogen ratios, and sediment accumulation rates to determine if changes in the lake sediments resulted from eutrophication rather than salmon exclusion. If sockeye did spawn in Lake Roberta historically, and if excessive nitrogen inputs did not overpower the marine-derived signal, we would expect pre-1940 sediment organic matter isotope compositions indicative of the large pulses of marine nutrients from decomposing salmon carcasses. Isotope results and land use in the Lake Roberta watershed present no conclusive evidence to support anecdotal accounts of anadromy. There is some evidence to suggest that marine-derived nutrients transferred to riparian communities within the lake’s watershed may have moved downstream to the lake. However, most of the evidence suggests eutrophication and a switch to increased autochthonous productivity are the main causes of changes in the lake sediment isotope composition.

Columbia Basin Tribes and First Nations. (2015). *Fish Passage and Reintroduction into the U.S. & Canadian Upper Columbia Basin*. Retrieved from https://ucut.org/wp-content/uploads/2016/09/Fish_Passage_and_Reintroduction_into_the_US_And_Canadian_Upper_Columbia_River4-1.pdf

The Columbia Basin tribes and First Nations jointly developed this paper to inform the U.S. and Canadian Entities, federal governments, and other regional sovereigns and stakeholders on how anadromous salmon and resident fish can be reintroduced into the upper Columbia River Basin. Reintroduction and restoration of fish passage could be achieved through a variety of mechanisms, including the current effort to modernize the Columbia River Treaty (Treaty). Restoring fish passage and reintroducing anadromous fish should be investigated and implemented as a key element of integrating ecosystem-based function into the Treaty. Anadromous fish reintroduction is critical to restoring native peoples' cultural, harvest, and spiritual values, and First Foods taken through bilateral river development for power and flood risk management. Reintroduction is also an important facet of ecosystem adaptation to climate change as updated research indicates that only the Canadian portion of the basin may be snowmelt-dominated in the future, making it a critical refugium for fish as the Columbia River warms over time. This transboundary reintroduction proposal focuses on adult and juvenile fish passage at Chief Joseph and Grand Coulee dams in the U.S. and at Hugh Keenleyside, Brilliant, Waneta and Seven Mile dams in Canada. Reintroduction would occur incrementally, beginning with a series of preliminary planning, research, and experimental pilot studies designed to inform subsequent reintroduction and passage strategies. Long-term elements of salmon reintroduction would be adaptable and include permanent passage facilities, complemented by habitat improvement, artificial propagation, monitoring, and evaluation. Funding for planning, feasibility studies, construction and operations, and monitoring and evaluation can come from a variety of sources, with initial elements funded through the Northwest Power and Conservation Council's Columbia River Basin Fish and Wildlife Program. Some of the preliminary planning has already occurred at Canadian projects and power plant operators in Canada are legally obligated to consider fish passage at Hugh Keenleyside, Brilliant, and Waneta dams if anadromous fish are passed and restored above Chief Joseph and Grand Coulee dams in the U.S. The bilateral development and operation of the upper Columbia River was initiated with the construction of Grand Coulee Dam and is responsible for the loss of over 1,100 miles of salmon and steelhead habitat above Chief Joseph Dam and the loss of up to 4 million salmon harvested and consumed by native peoples throughout the basin annually. Fish passage technology has improved significantly in the past several years, particularly for juvenile fish. These newer technologies have recently been implemented at a number of other dams in the Pacific Northwest with the earlier installations demonstrating successful salmon passage and reintroduction programs. Additionally, the scientific tools and methods for investigating fish behavior and survival have markedly improved, providing the means to plan and design passage and reintroduction with greater certainty of success (see Future of Our Salmon Conference, www.critfc.org/future). These passage technologies allow existing project benefits to continue largely unencumbered by these passage, reintroduction, and monitoring programs and facilities. This paper is intended for informational purposes only for use in Treaty or other planning forums.

Elder, T., Woodley, C. M., Weiland, M. A., & Strecker, A. L. (2016). Factors Influencing the Survival of Outmigrating Juvenile Salmonids through Multiple Dam Passages: An Individual-Based Approach. *Ecology and Evolution, 6*(16), https://doi.org/10.1002/ece3.2326

Substantial declines of Pacific salmon populations have occurred over the past several decades related to large-scale anthropogenic and climatic changes in freshwater and marine environments. In the Columbia River Basin, migrating juvenile salmonids may pass as many as eight large-scale hydropower projects before reaching the ocean; however, the cumulative effects of multiple dam passages are largely unknown. Using acoustic transmitters and an extensive system of hydrophone arrays in the Lower Columbia River, we calculated the survival of yearling Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) passing one, two, or three dams. We applied a unique index of biological characteristics and environmental exposures, experienced by each fish individually as it migrated downstream, in order to examine which factors most influence salmonid survival. High outflow volumes led to involuntary spill in 2011 and created an environment of supersaturated dissolved gas concentrations. In this environment, migrating smolt survival was strongly influenced by barometric pressure, fish velocity, and water temperature. The effect of these variables on survival was compounded by multiple dam passages compared to fish passing a single dam. Despite spatial isolation between dams in the Lower Columbia River hydrosystem, migrating smolt appear to experience cumulative effects akin to a press disturbance. In general, Chinook salmon and steelhead respond similarly in terms of survival rates and responses to altered environmental conditions. Management actions that limit dissolved gas concentrations in years of high flow will benefit migrating salmonids at this life stage. Salmonid smolt experience an anthropogenically altered river environment during their seaward migration through the Lower Columbia River hydrosystem. High flow volumes and involuntary spillway discharge created an environment of supersaturated dissolved gas concentrations in which smolt survival was strongly influenced by barometric pressure, fish velocity, and water temperature and was compounded by multiple dam passages compared to fish passing a single dam. Despite spatial isolation between dams in the Lower Columbia River hydrosystem, migrating smolt appear to experience cumulative effects akin to a press disturbance.

Evans, A. F., Payton, Q., Turecek, A., Cramer, B., Collis, K., Roby, D. D., . . . Dotson, C. (2016). Avian Predation on Juvenile Salmonids: Spatial and Temporal Analysis Based on Acoustic and Passive Integrated Transponder Tags. *Transactions of the American Fisheries Society, 145*(4), https://doi.org/10.1080/00028487.2016.1150881

We evaluated the impact of predation on juvenile steelhead Oncorhynchus mykiss and yearling and subyearling Chinook Salmon O. tshawytscha by piscivorous waterbirds from 11 different breeding colonies in the Columbia River basin during 2012 and 2014. Fish were tagged with both acoustic tags and PIT tags and were tracked via a network of hydrophone arrays to estimate total smolt mortality (1 - survival) at various spatial and temporal scales during out-migration. Recoveries of PIT tags on bird colonies, coupled with the last known detections of live fish passing hydrophone arrays, were used to estimate the impact of avian predation relative to total smolt mortality. Results indicated that avian predation was a substantial source of steelhead mortality, with predation probability (proportion of available fish consumed by birds) ranging from 0.06 to 0.28 for fish traveling through the lower Snake River and the lower and middle Columbia River. Predation probability estimates ranged from 0.03 to 0.09 for available tagged yearling Chinook Salmon and from 0.01 to 0.05 for subyearlings. Smolt predation by gulls Larus spp. was concentrated near hydroelectric dams, while predation by Caspian terns Hydroprogne caspia was concentrated within reservoirs. No concentrated areas of predation were identified for double-crested cormorants Phalacrocorax auritus or American white pelicans Pelecanus erythrorhynchos. Comparisons of total smolt mortality relative to mortality from colonial waterbirds indicated that avian predation was one of the greatest sources of mortality for steelhead and yearling Chinook Salmon during out-migration. In contrast, avian predation on subyearling Chinook Salmon was generally low and constituted a minor component of total mortality. Our results demonstrate that acoustic and PIT tag technologies can be combined to quantify where and when smolt mortality occurs and the fraction of mortality that is due to colonial waterbird predation relative to non-avian mortality sources.

Ferguson, P. F. B., Breyta, R., Brito, I., Kurath, G., & LaDeau, S. L. (2018). An Epidemiological Model of Virus Transmission in Salmonid Fishes of the Columbia River Basin. *Ecological Modelling, 377*, https://doi.org/https://doi.org/10.1016/j.ecolmodel.2018.03.002

We have developed a dynamic epidemiological model informed by records of viral presence and genotypes to evaluate potential transmission routes maintaining a viral pathogen in economically and culturally important anadromous fish populations. In the Columbia River Basin, infectious hematopoietic necrosis virus (IHNV) causes severe disease, predominantly in juvenile steelhead trout (Oncorhynchus mykiss) and less frequently in Chinook salmon (O. tshawytscha). Mortality events following IHNV infection can be devastating for individual hatchery programs. Despite reports of high local mortality and extensive surveillance efforts, there are questions about how viral transmission is maintained. Modeling this system offers important insights into disease transmission in natural aquatic systems, as well as about the data requirements for generating accurate estimates about transmission routes and infection probabilities. We simulated six scenarios in which testing rates and the relative importance of different transmission routes varied. The simulations demonstrated that the model accurately identified routes of transmission and inferred infection probabilities accurately when there was testing of all cohort-sites. When testing records were incomplete, the model accurately inferred which transmission routes exposed particular cohort-sites but generated biased infection probabilities given exposure. After validating the model and generating guidelines for result interpretation, we applied the model to data from 14 annual cohorts (2000–2013) at 24 focal sites in a sub-region of the Columbia River Basin, the lower Columbia River (LCR), to quantify the relative importance of potential transmission routes in this focal sub-region. We demonstrate that exposure to IHNV via the return migration of adult fish is an important route for maintaining IHNV in the LCR sub-region, and the probability of infection following this exposure was relatively high at 0.16. Although only 1% of cohort-sites experienced self-exposure by infected juvenile fish, this transmission route had the greatest probability of infection (0.22). Increased testing and/or determining whether transmission can occur from cohort-sites without testing records (e.g., determining there was no testing record because there were no fish at the cohort-site) are expected to improve inference about infection probabilities. Increased use of secure water supplies and continued use of biosecurity protocols may reduce IHNV transmission from adult fish and juvenile fish within the site, respectively, to juvenile salmonids at hatcheries. Models and conclusions from this study are potentially relevant to understanding the relative importance of transmission routes for other important aquatic pathogens in salmonids, including the agents of bacterial kidney disease and coldwater disease, and the basic approach may be useful for other pathogens and hosts in other geographic regions.

Fisher, J. P., Weitkamp, L. A., Teel, D. J., Hinton, S. A., Orsi, J. A., Farley, E. V., Jr., . . . Trudel, M. (2014). Early Ocean Dispersal Patterns of Columbia River Chinook and Coho Salmon. *Transactions of the American Fisheries Society, 143*(1), https://doi.org/10.1080/00028487.2013.847862

Several evolutionarily significant units (ESUs) of Columbia River asin Chinook Salmon Oncorhynchus tshawytscha and Coho Salmon O. kisutch are listed as threatened or endangered under the U.S. Endangered Species Act. Yet little is known about the spatial and temporal distributions of these ESUs immediately following ocean entry, when year-class success may be determined. We documented differences in dispersal patterns during the early ocean period among groups defined by ESU, adult run timing, and smolt age. Between 1995 and 2006, 1,896 coded-wire-tagged juvenile fish from the Columbia River basin were recovered during 6,142 research trawl events along the West Coast of North America. Three distinct ocean dispersal patterns were observed: (1) age-1 (yearling) mid and upper Columbia River spring-run and Snake River spring-summer-run Chinook Salmon migrated rapidly northward and by late summer were not found south of Vancouver Island; (2) age-0 (subyearling) lower Columbia River fall, upper Columbia River summer, upper Columbia River fall, and Snake River fall Chinook Salmon dispersed slowly, remaining mainly south of Vancouver Island through autumn; and (3) age-1 lower Columbia River spring, upper Columbia River summer, and upper Willamette River spring Chinook Salmon and Coho Salmon were widespread along the coast from summer through fall, indicating a diversity of dispersal rates. Generally, the ocean dispersal of age-1 fish was faster and more extensive than that of age-0 fish, with some age-1 fish migrating as fast as 10-40 km/d (0.5-3.0 body lengths/s). Within groups, interannual variation in dispersal was moderate. Identification of the distinct temporal and spatial ocean distribution patterns of juvenile salmon from Columbia River basin ESUs is important in order to evaluate the potential influence of changing ocean conditions on the survival and long term sustainability of these fish populations. Received March 25, 2013; accepted September 6, 2013

Ford, M. J., Murdoch, A. R., Hughes, M. S., Seamons, T. R., & LaHood, E. S. (2016). Broodstock History Strongly Influences Natural Spawning Success in Hatchery Steelhead (Oncorhynchus mykiss). *Plos One, 11*(10), https://doi.org/10.1371/journal.pone.0164801

We used genetic parentage analysis of 6200 potential parents and 5497 juvenile offspring to evaluate the relative reproductive success of hatchery and natural steelhead (Onchorhynchus mykiss) when spawning in the wild between 2008 and 2011 in the Wenatchee River, Washington. Hatchery fish originating from two prior generation hatchery parents had <20% of the reproductive success of natural origin spawners. In contrast, hatchery females originating from a cross between two natural origin parents of the prior generation had equivalent or better reproductive success than natural origin females. Males originating from such a cross had reproductive success of 26–93% that of natural males. The reproductive success of hatchery females and males from crosses consisting of one natural origin fish and one hatchery origin fish was 24–54% that of natural fish. The strong influence of hatchery broodstock origin on reproductive success confirms similar results from a previous study of a different population of the same species and suggests a genetic basis for the low reproductive success of hatchery steelhead, although environmental factors cannot be entirely ruled out. In addition to broodstock origin, fish size, return time, age, and spawning location were significant predictors of reproductive success. Our results indicate that incorporating natural fish into hatchery broodstock is clearly beneficial for improving subsequent natural spawning success, even in a population that has a decades-long history of hatchery releases, as is the case in the Wenatchee River.

Goertler, P. A., Scheuerell, M. D., Simenstad, C. A., & Bottom, D. L. (2016). Estimating Common Growth Patterns in Juvenile Chinook Salmon (Oncorhynchus tshawytscha) from Diverse Genetic Stocks and a Large Spatial Extent. *Plos One, 11*(10), https://doi.org/10.1371/journal.pone.0162121

Life history variation in Pacific salmon (Oncorhynchus spp.) supports species resilience to natural disturbances and fishery exploitation. Within salmon species, life-history variation often manifests during freshwater and estuarine rearing, as variation in growth. To date, however, characterizing variability in growth patterns within and among individuals has been difficult via conventional sampling methods because of the inability to obtain repeated size measurements. In this study we related otolith microstructures to growth rates of individual juvenile Chinook salmon (O. tshawytscha) from the Columbia River estuary over a two-year period (2010-2012). We used dynamic factor analysis to determine whether there were common patterns in growth rates within juveniles based on their natal region, capture location habitat type, and whether they were wild or of hatchery origin. We identified up to five large-scale trends in juvenile growth rates depending on month and year of capture. We also found that hatchery fish had a narrower range of trend loadings for some capture groups, suggesting that hatchery fish do not express the same breadth of growth variability as wild fish. However, we were unable to resolve a relationship between specific growth patterns and habitat transitions. Our study exemplifies how a relatively new statistical analysis can be applied to dating or aging techniques to summarize individual variation, and characterize aspects of life history diversity.

Goertler, P. A., Simenstad, C. A., Bottom, D. L., Hinton, S., & Stamatiou, L. (2016). Estuarine Habitat and Demographic Factors Affect Juvenile Chinook (Oncorhynchus tshawytscha) Growth Variability in a Large Freshwater Tidal Estuary. *Estuaries and Coasts, 39*(2), https://doi.org/http://dx.doi.org/10.1007/s12237-015-0002-z

Estuarine rearing has been shown to enhance within watershed biocomplexity and support growth and survival for juvenile salmon (Oncorhynchus sp.). However, less is known about how growth varies across different types of wetland habitats and what explains this variability in growth. We focused on the estuarine habitat use of Columbia River Chinook salmon (Oncorhynchus tshawytscha), which are listed under the Endangered Species Act. We employed a generalized linear model (GLM) to test three hypotheses: (1) juvenile Chinook growth was best explained by temporal factors, (2) habitat, or (3) demographic characteristics, such as stock of origin. This study examined estuarine growth rate, incorporating otolith microstructure, individual assignment to stock of origin, GIS habitat mapping, and diet composition along ~130 km of the upper Columbia River estuary. Juvenile Chinook grew on average 0.23 mm/day in the freshwater tidal estuary. When compared to other studies in the basin our growth estimates from the freshwater tidal estuary were similar to estimates in the brackish estuary, but ~4 times slower than those in the plume and upstream reservoirs. However, previous survival studies elucidated a possible tradeoff between growth and survival in the Columbia River basin. Our GLM analysis found that variation in growth was best explained by habitat and an interaction between fork length and month of capture. Juvenile Chinook salmon captured in backwater channel habitats and later in the summer (mid-summer and late summer/fall subyearlings) grew faster than salmon from other habitats and time periods. These findings present a unique example of the complexity of understanding the influences of the many processes that generate variation in growth rate for juvenile anadromous fish inhabiting estuaries.

Johnson, B. M., Johnson, M. S., & Thorgaard, G. H. (2019). Salmon Genetics and Management in the Columbia River Basin. *Northwest Science, 92*(5), https://doi.org/10.3955/046.092.0505

Located in the Pacific Northwest, the Columbia River basin provides important spawning and rearing habitat for Pacific salmon and steelhead (Oncorhynchus spp.). These species were historically abundant throughout the basin but have experienced extensive declines linked to a complex suite of factors. These declines, in tandem with their cultural and economic significance, have led Pacific salmon and steelhead to become one of the most intensely managed groups of species in North America. Management actions have increasingly recognized the importance of genetic resources and have expanded the use of genetic tools to provide powerful data for the conservation and management of Pacific salmon. We provide a summary of historic management actions in the basin with a focus on those relevant to genetic applications. We describe the initial recognition of genetic differences and distinction of population units, how genetics applies to the hatchery controversy, as well as the progression of genetic investigations and applications used in management. Further, we outline some emerging and potential future genetic tools.

Johnson, B. M., Kemp, B. M., & Thorgaard, G. H. (2018). Increased Mitochondrial DNA Diversity in Ancient Columbia River Basin Chinook Salmon Oncorhynchus tshawytscha. *Plos One, 13*(1), https://doi.org/10.1371/journal.pone.0190059

The Columbia River and its tributaries provide essential spawning and rearing habitat for many salmonid species, including Chinook salmon (Oncorhynchus tshawytscha). Chinook salmon were historically abundant throughout the basin and Native Americans in the region relied heavily on these fish for thousands of years. Following the arrival of Europeans in the 1800s, salmon in the basin experienced broad declines linked to overfishing, water diversion projects, habitat destruction, connectivity reduction, introgression with hatchery-origin fish, and hydropower development. Despite historical abundance, many native salmonids are now at risk of extinction. Research and management related to Chinook salmon is usually explored under what are termed "the four H's": habitat, harvest, hatcheries, and hydropower; here we explore a fifth H, history. Patterns of prehistoric and contemporary mitochondrial DNA variation from Chinook salmon were analyzed to characterize and compare population genetic diversity prior to recent alterations and, thus, elucidate a deeper history for this species. A total of 346 ancient and 366 contemporary samples were processed during this study. Species was determined for 130 of the ancient samples and control region haplotypes of 84 of these were sequenced. Diversity estimates from these 84 ancient Chinook salmon were compared to 379 contemporary samples. Our analysis provides the first direct measure of reduced genetic diversity for Chinook salmon from the ancient to the contemporary period, as measured both in direct loss of mitochondrial haplotypes and reductions in haplotype and nucleotide diversity. However, these losses do not appear equal across the basin, with higher losses of diversity in the mid-Columbia than in the Snake subbasin. The results are unexpected, as the two groups were predicted to share a common history as parts of the larger Columbia River Basin, and instead indicate that Chinook salmon in these subbasins may have divergent demographic histories.

Johnson, G. E., Ploskey, G. R., Sather, N. K., & Teel, D. J. (2015). Residence Times of Juvenile Salmon and Steelhead in Off-Channel Tidal Freshwater Habitats, Columbia River, USA. *Canadian Journal of Fisheries and Aquatic Sciences, 72*(5), https://doi.org/10.1139/cjfas-2014-0085

We documented two life history strategies for juvenile salmonids as expressed in off-channel tidal freshwater habitats ofthe Columbia River: (i) active migrations by upper river Chinook salmon (Oncorhynchus tshawytscha) and steelhead (Oncorhynchus mykiss) during the primary spring and summer migration periods and (ii) overwinter rearing in tidal freshwater habitats by coho salmon (Oncorhynchus kisutch) and naturally produced Chinook salmon mostly from lower river sources. During spring–summer 2007–2008, acoustic-tagged fish originating above Bonneville Dam (rkm 234) had short residence times in off-channel areas (rkm 192–203): median 2.5 and 2.6 h for yearling (mean lengths 134 and 158 mm) and 3.0 and 3.4 h for subyearling (104 and 116 mm) Chinook salmon and 2.5 h for yearling steelhead (215 mm). The percentage offish in off-channel areas out of the total in the main- and off-channels areas was highest for yearling Chinook salmon (8.1% and 9.3% for 2007 and 2008, respectively) and lowest for steelhead (4.0% for 2008) and subyearling Chinook salmon (3.6% and 6.1% for 2007 and 2008, respectively). In late January and early February 2010, 2011, and 2012, we captured and tagged yearling Chinook and coho salmon occupying off-channel tidal freshwater habitats. Median residence times in off-channel areas were 11.6–25.5 days for juvenile Chinook (106, 115, and 118 mm, respectively by year) and 11.2 days for coho salmon (116 mm). This study is the first to estimate residence times for juvenile salmonids specifically in off-channel areas of tidal fresh water and, most importantly, residence times for Chinook salmon expressing a life history of overwintering in tidal fresh water. The findings support restoration of shallow off-channel habitats in tidal freshwater portions of the Columbia River.

Johnson, L. K., & Simenstad, C. A. (2015). Variation in the Flora and Fauna of Tidal Freshwater Forest Ecosystems Along the Columbia River Estuary Gradient: Controlling Factors in the Context of River Flow Regulation. *Estuaries and Coasts, 38*(2), https://doi.org/10.1007/s12237-014-9839-9

Tidal freshwater forested wetlands are dynamic, complex ecosystems that typically occur in large, floodplain river estuaries throughout the world. The estuarine portion of the Columbia River, in the Pacific Northwest region ofNorth America, is exceptionally large and extends from the Pacific Ocean to the head of tide at Bonneville Dam, located at river kilometer (RKm) 233. Our study focused on the freshwater portion ofthe estuarine gradient (RKm 40 to RKm 233) ofthe Columbia River estuary and the corresponding continuum of hydrologic regimes and biotic communities. Several diverse forested wetland community types occurred along this freshwater estuarine gradient with major shifts in community composition corresponding to the transition from predominantly tidal to predominantly fluvial hydrologic regimes. We quantitatively characterized the floristic structure, species composition, and species richness of these tidal wetlands. Additionally, we documented variation in the avifaunal and insect assemblages associated with the floral structure. We found that freshwater tidal forested wetlands in the lower reaches of the estuary were characterized by high vegetation species richness and complex forest and scrub-shrub ecosystems, while tidal wetlands in the upper reaches of the estuary displayed a greater diversity of wetland ecosystems (forested, scrub-shrub, emergent, and aquatic bed) but comparatively lower species richness. A transitional area in the mid-estuary contained forested wetlands that exhibited some similarities to estuarine forested wetlands in both the upper and lower reaches. Likewise, avifauna and insect assemblage composition transitioned along the tidal freshwater estuarine gradient. Differences in geomorphological and hydrological regimes along the estuarine gradient appear to be the factors controlling the variation in tidal freshwater forested wetland characteristics and species composition. A thorough understanding of this complex and understudied system is necessary for predicting the potential impacts of hydrologic regime alterations and climate change and for guiding ongoing restoration efforts in the region.

Krueger, K. L., Bottom, D. L., Hood, W. G., Johnson, G. E., Jones, K. K., & Thom, R. M. (2017). An Expert Panel Process to Evaluate Habitat Restoration Actions in the Columbia River Estuary. *Journal of Environmental Management, 188*, https://doi.org/10.1016/j.jenvman.2016.11.028

We describe a process for evaluating proposed ecosystem restoration projects intended to improve survival of juvenile salmon in the Columbia River estuary (CRE). Changes in the Columbia River basin (northwestern USA), including hydropower development, have contributed to the listing of 13 salmon stocks as endangered or threatened under the U.S. Endangered Species Act. Habitat restoration in the CRE, from Bonneville Dam to the ocean, is part of a basin-wide, legally mandated effort to mitigate federal hydropower impacts on salmon survival. An Expert Regional Technical Group (ERTG) was established in 2009 to improve and implement a process for assessing and assigning “survival benefit units” (SBUs) to restoration actions. The SBU concept assumes site-specific restoration projects will increase juvenile salmon survival during migration through the 234 km CRE. Assigned SBUs are used to inform selection of restoration projects and gauge mitigation progress. The ERTG standardized the SBU assessment process to improve its scientific integrity, repeatability, and transparency. In lieu of experimental data to quantify the survival benefits of individual restoration actions, the ERTG adopted a conceptual model composed of three assessment criteria—certainty of success, fish opportunity improvements, and habitat capacity improvements—to evaluate restoration projects. Based on these criteria, an algorithm assigned SBUs by integrating potential fish density as an indicator of salmon performance. Between 2009 and 2014, the ERTG assessed SBUs for 55 proposed projects involving a total of 181 restoration actions located across 8 of 9 reaches of the CRE, largely relying on information provided in a project template based on the conceptual model, presentations, discussions with project sponsors, and site visits. Most projects restored tidal inundation to emergent wetlands, improved riparian function, and removed invasive vegetation. The scientific relationship of geomorphic and salmonid responses to restoration actions remains the foremost concern. Although not designed to establish a broad strategy for estuary restoration, the scoring process has adaptively influenced the types, designs, and locations of restoration proposals. The ERTG process may be a useful model for others who have unique ecosystem restoration goals and share some of our common challenges.

Laramie, M. B., Pilliod, D. S., & Goldberg, C. S. (2015). Characterizing the Distribution of an Endangered Salmonid Using Environmental DNA Analysis. *Biological Conservation, 183*, https://doi.org/10.1016/j.biocon.2014.11.025

Determining species distributions accurately is crucial to developing conservation and management strategies for imperiled species, but a challenging task for small populations. We evaluated the efficacy of environmental DNA (eDNA) analysis for improving detection and thus potentially refining the known distribution of Chinook salmon (Oncorhynchus tshawytscha) in the Methow and Okanogan Subbasins of the Upper Columbia River, which span the border between Washington, USA and British Columbia, Canada. We developed an assay to target a 90 base pair sequence of Chinook DNA and used quantitative polymerase chain reaction (qPCR) to quantify the amount of Chinook eDNA in triplicate 1-L water samples collected at 48 stream locations in June and again in August 2012. The overall probability of detecting Chinook with our eDNA method in areas within the known distribution was 0.77 (±0.05 SE). Detection probability was lower in June (0.62, ±0.08 SE) during high flows and at the beginning of spring Chinook migration than during base flows in August (0.93, ±0.04 SE). In the Methow subbasin, mean eDNA concentration was higher in August compared to June, especially in smaller tributaries, probably resulting from the arrival of spring Chinook adults, reduced discharge, or both. Chinook eDNA concentrations did not appear to change in the Okanogan subbasin from June to August. Contrary to our expectations about downstream eDNA accumulation, Chinook eDNA did not decrease in concentration in upstream reaches (0–120 km). Further examination of factors influencing spatial distribution of eDNA in lotic systems may allow for greater inference of local population densities along stream networks or watersheds. These results demonstrate the potential effectiveness of eDNA detection methods for determining landscape-level distribution of anadromous salmonids in large river systems.

Losee, J. P., Fisher, J., Teel, D. J., Baldwin, R. E., Marcogliese, D. J., & Jacobson, K. C. (2014). Growth and Condition of Juvenile Coho Salmon Oncorhynchus kisutch Relate Positively to Species Richness Of trophically Transmitted Parasites. *Journal of Fish Biology, 85*(5), https://doi.org/10.1111/jfb.12525

The aims of this study were first, to test the hypothesis that metrics of fish growth and condition relate positively to parasite species richness (SR) in a salmonid host; second, to identify whether SR differs as a function of host origin; third, to identify whether acquisition of parasites through marine v. freshwater trophic interactions was related to growth and condition of juvenile salmonids. To evaluate these questions, species diversity of trophically transmitted parasites in juvenile coho salmon Oncorhynchus kisutch collected off the coast of the Oregon and Washington states, U.S.A. in June 2002 and 2004 were analysed. Fish infected with three or more parasite species scored highest in metrics of growth and condition. Fish originating from the Columbia River basin had lower SR than those from the Oregon coast, Washington coast and Puget Sound, WA. Parasites obtained through freshwater or marine trophic interactions were equally important in the relationship between SR and ocean growth and condition of juvenile O. kisutch salmon.

McKean, J. R., & Johnson, D. M. (2019). Difficulties for Cost-Benefit Analysis in the 2020 Environmental Impact Statement to Recover the Endangered Wild Salmon and Steelhead in the Columbia River Basin. *Journal of Environmental Management, 246*, https://doi.org/10.1016/j.jenvman.2019.05.099

Runs of the endangered wild salmon/steelhead in the Columbia River basin may be only two to seven percent of historic levels. These fish are a common-pool resource, where stakeholders over-consume, pollute rivers and oceans, block passage with dams and culverts, operate net pen fish farms, and plant huge numbers of hatchery fish that compete with and hybridize wild fish. Rivers provide free or subsidized services that stakeholders covet, however recovery of the endangered wild fish requires that peoples utilizing the rivers and the ocean must constrain their behavior, often reducing their profit. A new Environmental Impact Statement (EIS) and cost-benefit analysis are in progress for recovery of the endangered wild salmon/steelhead in the Columbia River basin. New regulations require surveys of U.S. households to measure the non-use benefits of salmon/steelhead recovery that can be important for endangered species. We review the 2002 EIS for juvenile salmon migration on the lower Snake River tributary to find mistakes to avoid in the new EIS and in other recovery studies.

Morton, C., Knowler, D., Brugere, C., Lymer, D., & Bartley, D. (2017). Valuation of Fish Production Services in River Basins: A Case Study of the Columbia River. *Ecosystem Services, 24*, https://doi.org/10.1016/j.ecoser.2017.02.007

This study uses a bio-economic model to assess the capacity of the Columbia River to provide a selection of four ecosystem services and estimates the actual use of those services in terms of net economic welfare. Our findings reinforce the observation that Columbia River habitat supports production of valuable fish species that provide: (i) food production from commercial fishing, (ii) recreational fishing, (iii) tribal subsistence fishing, and (iv) nutrient cycling services. Relative to the status quo, a 10% greater prioritization of salmon conservation via shifts in the flow regime would generate an increase of $4.8million/yr in the net economic benefit from these services. A return to pristine flow conditions would raise this value to $19.5million/yr. Re-prioritizing hydropower production to average 1976–1980 flow levels would result in a $3.5million/yr loss of net economic benefits. Recreational fishing is the most important ecosystem service we assessed. Under some scenarios, this sector generates twice the value of the next largest sector (commercial fishing). Although managers have placed greater emphasis on fish conservation in recent decades, opportunities for gains in economic welfare from fish production in the Columbia River may not be fully exploited, particularly considering that our conservation scenario only minimally alters the flow regime relative to the hydropower priority scenario.

Myrvold, K. M., & Kennedy, B. P. (2018). Shifts in Great Blue Heron Habitat Use Following Nest Site Usurpation: Implications for Salmonids. *The American Midland Naturalist, 179*(1), https://doi.org/10.1674/0003-0031-179.1.105

Interactions among predators can have important consequences for lower trophic levels. Here, we use individual tag data on juvenile salmonids to quantify how their geographic, taxonomic, and life-history representation in the diets of great blue herons (Ardea herodias) changed after a pair of bald eagles (Haliaeetus leucocephalus) usurped the colony's nesting site, forcing the colony to relocate. Heron diet composition changed significantly despite the short relocation distance (4.1 km). This was driven by a shift in space use, as herons to a greater extent began consuming fish from a river basin farther away from the bald eagle nest. As a consequence the species composition in heron diets changed significantly, with the largest increase in coho (Oncorhynchus kisutch) and largest decrease in Chinook salmon (O. tshawytscha). The representation of Chinook life-history types in the diets also shifted. Fall Chinook was the numerically dominant life-history type in the diets but decreased relative to spring and summer Chinook following relocation, accounting for differences in availability. Expressed by rearing type (natural or hatchery-produced), the prevalence of natural-origin Chinook in the diets increased whereas hatchery-origin Chinook decreased. For steelhead rearing type there were no significant changes. Finally, herons increased their use of a nearby tributary watershed following the relocation. Notwithstanding the potential confounding factors inherent to natural experiments, our results demonstrated marked shifts in space use among herons in response to the relocation and continued presence of bald eagles, which in turn shifted their predation pressure to other salmonid species.

National Marine Fisheries Service. (2016). *2016 5-Year Review: Summary & Evaluation of Upper Columbia River Steelhead Upper Columbia River Spring-Run Chinook Salmon*. Retrieved from https://repository.library.noaa.gov/view/noaa/17027

Many West Coast salmon and steelhead (Oncorhynchus sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the agency's 5-year status review for ESA-listed Upper Columbia River (UCR) salmon and steelhead species. These include: UCR spring-run Chinook salmon and UCR steelhead.

Oregon Department of Fish and Wildlife. (2017). *Oregon Lower Columbia River Recovery Plan Annual Report Card: 2017*. Retrieved from https://www.dfw.state.or.us/fish/CRP/lower_columbia_plan.asp

This annual report card is an abbreviated status report that reviews the most recent research, monitoring and evaluation data for Lower Columbia River Salmon and Steelhead. Viable salmonid population (VSP) metrics, where they exist, are used to compare against the populations status at the time the Plan was implemented to determine whether status has improved, remained the same or declined. The annual report card also documents formal adaptive management decisions, recommendations and actions in regards to achieving plan goals under the delisting scenarios in the plan. Detailed information regarding VSP metrics and yearly plan goals are found at http://www.odfwrecoverytracker.org/.

U.S. Department of Energy. (2015). *Threatened and Endangered Species Management Plan: Salmon, Steelhead, and Bull Trout*. Retrieved from https://www.hanford.gov/files.cfm/DOE-RL-2000-27_Rev_02.pdf

This Threatened and Endangered Species Management Plan for Salmon, Steelhead, and Bull Trout defines the U.S. Department of Energy-Richland Operations Office (RL) commitment to protecting the stocks of Upper Columbia River spring Chinook salmon (Oncorhynchus tschawytscha), Upper Columbia River steelhead (Oncorhynchus mykiss), and bull trout (Salvelinus confluentus) within the Hanford Reach of the Columbia River. The National Marine Fisheries Service (NMFS) is responsible for administering the Endangered Species Act (ESA) with regard to listed steelhead and Chinook salmon while the U.S. Fish and Wildlife Service (USFWS) is responsible for administering the ESA with regard to listed bull trout. In addition, federal agencies are required, under 305(b)(2) of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) and its implementing regulations, to consult with NMFS regarding actions that agency authorizes, funds, or undertakes that may adversely affect Essential Fish Habitat (EFH). This plan constitutes a partial consultation between the RL and both NMFS and USFWS as partial fulfillment of RL's responsibilities under the ESA and Magnuson-Stevens Act. In addition to this management plan, RL has agreed to request projectspecific consultation under Section 7 of ESA for remediation projects occurring below the wetted edge of the Columbia River.

U.S. Department of Energy. (2018). *Threatened and Endangered Species Management Plan: Salmon, Steelhead, and Bull Trout*. (DOE/RL-2000-27). Retrieved from https://www.hanford.gov/files.cfm/MSA-1803673_Attachment.pdf

This Threatened and Endangered Species Management Plan for Salmon, Steelhead, and Bull Trout defines the U.S. Department of Energy's (DOE) commitment to protecting the stocks of Upper Columbia River spring-run Chinook salmon (Oncorhynchus tschawytscha), Upper Columbia River steelhead (Oncorhynchus mykiss), and bull trout (Salvelinus confluentus) within the Hanford Reach of the Columbia River. The National Marine Fisheries Service (NMFS) is responsible for administering the Endangered Species Act (ESA) with regard to listed steelhead and Chinook salmon while the U.S. Fish and Wildlife Service (USFWS) is responsible for administering the ESA with regard to listed bull trout. In addition, federal agencies are required under the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) Section 305(b)(2) and its implementing regulations (50 CFR 600) to consult with NMFS regarding actions that are authorized, funded, or undertaken that may adversely affect Essential Fish Habitat (EFH). As partial fulfillment of DOE's responsibilities under the ESA and Magnuson-Stevens Act, this plan constitutes a partial consultation between the DOE, NMFS, and USFWS. In this plan, DOE has agreed to request project-specific consultation under ESA Section 7 for remediation projects occurring below the wetted edge of the Columbia River. The current revision (Revision 3) updates the plan to reflect the results of the NMFS's five-year review of the status of the Upper Columbia steelhead and Upper Columbia River spring-run Chinook salmon (NMFS 2016a), informal consultations that have occurred since the last revision, and recent changes on the Hanford Site.

Washington Department of Fish and Wildlife, & Lower Columbia Fish Recovery Board. (2017). *Lower Columbia Conservation and Sustainable Fisheries Plan*. Retrieved from https://www.lcfrb.gen.wa.us/hatcheryharvest

Operated to mitigate for the impacts hydroelectric dams and habitat losses, Lower Columbia salmon and steelhead hatcheries have helped to sustain commercial, sport and tribal fisheries in the Columbia River and its tributaries and in the Pacific Ocean from California to Alaska. However, past hatchery and harvest practices have also contributed to the decline of natural origin salmon and steelhead populations, many of which are now threatened with extinction. The Conservation and Sustainable Fisheries (CSF) Plan sets forth a comprehensive plan of action for Lower Columbia hatchery and harvest programs. The goal of this plan is to support efforts to return natural origin lower Columbia salmon and steelhead to healthy, harvestable levels while sustaining important fisheries. It sets forth strategies, actions, and management practices that Washington Department of Fish and Wildlife (WDFW) will use in maintaining and operating its Lower Columbia hatcheries and in managing related fisheries.

Section XII: Snake River

Alldredge, J. R., Bilby, R., Heller, D., Lutz, R. S., Maule, A., Naiman, R. J., . . . Wood, C. C. (2014). *Summary of Isrp Reviews of Steelhead and Spring and Fall Chinook Salmon Programs of the Lower Snake River Compensation Plan.* Independent Scientific Review Panel for the Northwest Power & Conservation Council Retrieved from https://www.fws.gov/lsnakecomplan/Meetings/ISRP%202014-6%20LSRCP_Summary%20Report_18June.pdf

The ISRP recently completed a review of the current status and progress of the LSRCP. This review was facilitated by three symposiums organized by the U.S. Fish and Wildlife Service for spring/summer Chinook (November 30 through December 2, 2010), steelhead (June 20-21, 2012) and fall Chinook (August 6-7, 2013). The ISRP produced species-specific reviews based on information presented at the symposiums, project summaries prepared for the ISRP reviews, and discussions at the symposiums among program managers, researchers, decision makers, and the ISRP (ISRP 2011-14, 2013-3, and 2014-4). The report presented here, a synthesis of ISRP findings, describes substantial progress made by the LSRCP in terms of increasing abundance and harvests of salmon while also identifying key challenges facing the program at present and in the near future.

Blumm, M. C., & DeRoy, D. (2019). The Fight over Columbia Basin Salmon Spills and the Future of the Lower Snake River Dams. *Washington Journal of Environmental Law & Policy, 9*(1) Retrieved from http://hdl.handle.net/1773.1/1865

One of the nation's most longstanding environmental-energy conflicts concerns the plight of numerous Columbia Basin salmon species which must navigate the Federal Columbia River Power System (FCRPS), a series of hydroelectric dams that make the basin one of the most highly developed in the world. Although the FCRPS dams produce a wealth of hydropower, the mortalities they cause due to the construction and operation of FCRPS dams led to Endangered Species Act listings for the basin's salmon. Since those listings a quarter-century ago, the federal government has repeatedly failed to produce biological opinions that can survive judicial scrutiny. The latest round of litigation resulted in renewed directives from the federal district court of Oregon to revise the current biological opinion and to spill more water at several dams in the interim to facilitate juvenile salmon migration. The directive to increase spill was upheld by the Ninth Circuit in 2018, but the U.S. House of Representatives quickly voted to overturn that decision, and the Senate now has the matter under consideration.

Bond, M. H., Westley, P. A. H., Dittman, A. H., Holecek, D., Marsh, T., & Quinn, T. P. (2017). Combined Effects of Barge Transportation, River Environment, and Rearing Location on Straying and Migration of Adult Snake River Fall-Run Chinook Salmon. *Transactions of the American Fisheries Society, 146*(1), https://doi.org/10.1080/00028487.2016.1235614

Homing and straying in salmon have been extensively studied, yet it has proven difficult to disentangle the biotic and abiotic factors that influence straying. In the Columbia River basin, some juvenile salmon are collected at dams and transported downstream to increase survival during seaward migration, and as returning adults they experience a range of environmental conditions as they ascend the river. We examined 8 years of PIT tag detection data for hatchery-reared, fall-run Chinook Salmon Oncorhynchus tshawytscha released in the Snake River to evaluate the combined effects of juvenile barging, rearing and release locations, and environmental conditions on adult migration speed and straying below and above the Columbia River–Snake River confluence. Straying to the upper Columbia River was 10–19 times more likely among adults that were barged as juveniles from Snake River dams than among adults that were in-river migrants or that were transported from McNary Dam (below the confluence) as juveniles. Similarly, barging from Snake River dams and warmer Columbia River temperatures increased the likelihood of straying into streams below the confluence. Furthermore, adult upstream migration was slower among juveniles that were reared at two mid-Columbia River hatcheries and juveniles that were barged, indicating possible navigational impairment. However, rearing location, release distance, and release age had relatively minimal effects on straying. Collectively, our results indicate that (1) adult migration and homing are affected by a complex combination of processes that take place during smolt out-migration and the adult return migration, and (2) enhancement efforts can inadvertently add to the challenge. The straying of barged fish demonstrates the potential for increasing adult returns to the Snake River by changing the barging process so that it more adequately supports the proper imprinting of juveniles.

Bowerman, T. E., Pinson-Dumm, A., Peery, C. A., & Caudill, C. C. (2017). Reproductive Energy Expenditure and Changes in Body Morphology for a Population of Chinook Salmon Oncorhynchus tshawytscha with a Long Distance Migration. *Journal of Fish Biology, 90*(5), https://doi.org/10.1111/jfb.13274

Energetic demands of a long freshwater migration, extended holding period, gamete development and spawning were evaluated for a population of stream-type Chinook salmon Oncorhynchus tshawytscha. Female and male somatic mass decreased by 24 and 21%, respectively, during migration and by an additional 18 and 12% during holding. Between freshwater entry and death after spawning, females allocated 14% of initial somatic energy towards gonad development and 78% for metabolism (46, 25 and 7% during migration, holding and spawning, respectively). Males used only 2% of initial somatic energy for gonad development and 80% on metabolic costs, as well as an increase in snout length (41, 28 and

11% during migration, holding and spawning, respectively). Individually marked O. tshawytscha took between 27 and 53 days to migrate 920 km. Those with slower travel times through the dammed section of the migration corridor arrived at spawning grounds with less muscle energy than faster migrants. Although energy depletion did not appear to be the proximate cause of death in most pre-spawn mortalities, average final post-spawning somatic energy densities were low at 3·6kJg−1 in females and 4·1kJg−1 in males, consistent with the concept of a minimum energy threshold required to sustain life in semelparous salmonids.

Chittaro, P. M., Hegg, J. C., Kennedy, B. P., Weitkamp, L. A., Johnson, L. L., Bucher, C., & Zabel, R. W. (2019). Juvenile River Residence and Performance of Snake River Fall Chinook Salmon. *Ecology of Freshwater Fish, 28*(3), https://doi.org/10.1111/eff.12462

An animal's performance during its early life stage can greatly influence its survival to adulthood. Therefore, understanding aspects of early life history can be informative, particularly when designing management plans to rebuild a population. For a threatened population of fall Chinook salmon (Oncorhynchus tshawytscha) in the Snake River of Idaho, we reconstructed the early life history for 124 returning wild and hatchery adults using information recorded in their otoliths. Of our sampled wild adults (n = 61), 43% and 49% reared within the Snake River and Clearwater/Salmon rivers. We also found that only 21% of our sampled wild adults exhibited the historically common subyearling out-migration strategy, in which juveniles exit freshwater shortly after hatching, while the remaining wild adults exhibited the yearling out-migration strategy (i.e., individuals delay their freshwater exit). As expected, yearlings had, on average, a significantly larger body size than subyearlings at ocean entry. However, 35% of wild yearlings overlapped in size with wild subyearlings suggesting that spending more time in freshwater might not necessarily result in a larger body size. Lastly, we observed that variability in fork length at Snake River egress and ocean entry were best explained by migration strategy and where it reared, followed by hatch year and sex. Results from this study highlight the utility of adult otoliths in providing details about early life history, an understanding of which is critical to the conservation of Snake River fall Chinook salmon.

Clarke, L. R., Flesher, M. W., Knox, W. J., & Carmichael, R. W. (2017). Increased Harvest of Anadromous Hatchery Steelhead, Oncorhynchus mykiss (Walbaum), through Return Timing Manipulation. *Fisheries Management and Ecology, 24*(4), https://doi.org/10.1111/fme.12221

Harvest hatchery programmes serve to augment fisheries but should also minimise impacts to wild populations. In an experiment to increase harvest in an anadromous hatchery steelhead, Oncorhynchus mykiss (Walbaum), terminal river fishery, a new hatchery strain, was created using selective breeding of early arriving adults to the river. First-generation progeny of the new early arriving strain were reared and released over 4 years concurrent with releases of the standard hatchery strain. This study compares adult return timing, terminal harvest and straying behaviour of progeny of the early arriving and standard hatchery strains. The new strain migrated towards the terminal river fishery earlier, they were harvested earlier in the eight-month fishing season and their overall harvest was 17% greater, but 7.7% of the new strain strayed to other rivers compared to 5.0% of the standard strain. Selective breeding to match adult return timing with fishing effort may help bolster harvest, but a paired release evaluation, such as was conducted in this study, would be prudent before switching all hatchery production to a selectively bred strain.

Collins, S. F., Baxter, C. V., Marcarelli, A. M., & Wipfli, M. S. (2016). Effects of Experimentally Added Salmon Subsidies on Resident Fishes Via Direct and Indirect Pathways. *Ecosphere, 7*(3), https://doi.org/10.1002/ecs2.1248

Artificial additions of nutrients of differing forms such as salmon carcasses and analog pellets (i.e. pasteurized fishmeal) have been proposed as a means of stimulating aquatic productivity and enhancing populations of anadromous and resident fishes. Nutrient mitigation to enhance fish production in stream ecosystems assumes that the central pathway by which effects occur is bottomup, through aquatic primary and secondary production, with little consideration of reciprocal aquaticterrestrial pathways. The net outcome (i.e. bottom- up vs. top- down) of adding salmon- derived materials to streams depend on whether or not these subsidies indirectly intensify predation on in situ prey via increases in a shared predator or alleviate such predation pressure. We conducted a 3- year experiment across nine tributaries of the N. Fork Boise River, Idaho, USA, consisting of 500- m stream reaches treated with salmon carcasses (n = 3), salmon carcass analog (n = 3), and untreated control reaches (n = 3). We observed 2–8 fold increases in streambed biofilms in the 2–6 weeks following additions of both salmon subsidy treatments in years 1 and 2 and a 1.5- fold increase in standing crop biomass of aquatic invertebrates to carcass additions in the second year of our experiment. The consumption of benthic invertebrates by stream fishes increased 110–140% and 44–66% in carcass and analog streams in the same time frame, which may have masked invertebrate standing crop responses in years 3 and 4. Resident trout directly consumed 10.0–24.0 g·m−2·yr−1 of salmon carcass and <1–11.0 g·m−2·yr−1 of analog material, which resulted in 1.2–2.9 g·m−2·yr−1 and 0.03–1.4 g·m−2·yr−1 of tissue produced. In addition, a feedback flux of terrestrial maggots to streams contributed 0.0–2.0 g·m−2·yr−1 to trout production. Overall, treatments increased annual trout production by 2–3 fold, though density and biomass were unaffected. Our results indicate the strength of bottom- up and top- down responses to subsidy additions was asymmetrical, with top- down forces masking bottom- up effects that required multiple years to manifest. The findings also highlight the need for nutrient mitigation programs to consider multiple pathways of energy and nutrient flow to account for the complex effects of salmon subsidies in stream-riparian ecosystems.

Connor, W. P., Tiffan, K. F., Chandler, J. A., Rondorf, D. W., Arnsberg, B. D., & Anderson, K. C. (2019). Upstream Migration and Spawning Success of Chinook Salmon in a Highly Developed, Seasonally Warm River System. *Reviews in Fisheries Science & Aquaculture, 27*(1), https://doi.org/10.1080/23308249.2018.1477736

This review summarizes what is known about the influence of water temperature and velocity on the migration and spawning success of an inland population of Chinook salmon Oncorhynchus tshawytscha. Models are then developed and used to illustrate how migration and spawning success might change if temperatures and velocities increase under a future climate. The illustration shows the potential for moderate increases in temperature and velocity to reduce homing and increase energy expenditure. Those two outcomes would reduce the abundance, productivity, and diversity of the population studied.

Under the future scenario illustrated, it would become difficult for fish management actions alone to recover conservation-reliant populations of inland Chinook salmon.

Copeland, T., Ackerman, M. W., Wright, K. K., & Byrne, A. (2017). Life History Diversity of Snake River Steelhead Populations between and within Management Categories. *North American Journal of Fisheries Management, 37*(2), https://doi.org/10.1080/02755947.2016.1264506

Grouping populations for management may overlook the fine-scale diversity underpinning the stability and resilience of meta-populations and fisheries. A bimodal timing distribution of summer-run steelhead Oncorhynchus mykiss (anadromous Rainbow Trout) historically was observed at Bonneville Dam (BON), the first barrier to upstream migration in the Columbia River basin. Early mode fish (A-run) tended to be younger and smaller (< 78 cm) than later fish (B-run). While A-run fish spawn throughout the Columbia River basin, B-run fish spawn primarily in the Snake River basin. Managers used indices of these modes to make fishery decisions, and later these criteria were adopted for conservation. It is still unclear how life history and body size differences among wild Snake River populations are related to the categories at BON. We examined population parameters characterizing the two categories (date of passage at BON, length) and parameters directly affecting population dynamics (age composition, sex ratio). The life history portfolio of Snake River steelhead is quite diverse. There was broad overlap among populations in several respects, forming a gradient in life history characteristics rather than a dichotomous break. All populations produced adults < 78 cm and adults returning after August 25. Median lengths of putative B-run populations were close to the criterion that was supposed to be a defining characteristic. In contrast, few A-run populations produced many adults >= 78 cm. Mean percentage of two-ocean fish was 52.1% for A-run populations and 82.0% for B-run populations. Mean age at spawn was greater in populations producing older smolts. Sex ratio was female biased, and older populations had greater percentages of females. Although the run-type dichotomy was useful for management of fisheries in the past, it is not useful for conservation. A combination of genetic stock identification at main-stem dams and population-specific monitoring in natal streams provides a unified framework for the assessment of fisheries management and conservation objectives.

Copeland, T., Bowersox, B. J., Ackerman, M. W., & Camacho, C. (2019). Patterns of Iteroparity in Wild Snake River Steelhead. *Transactions of the American Fisheries Society, 148*(5), https://doi.org/10.1002/tafs.10187

Some anadromous salmonids are iteroparous (repeat spawners); however, postspawn individuals are often not considered in management plans because of the lack of long-term studies of this life history. The balance of factors affecting survival between spawns and fecundity of repeat spawners should determine the percentage of iteroparous individuals in a population. Steelhead Oncorhynchus mykiss are capable of iteroparity, but Snake River populations in the interior Columbia River basin in the Pacific Northwest have the lowest iteroparity rates. Managers are interested in augmenting the incidence of iteroparity as a conservation measure. However, there is little information about repeat-spawning steelhead to guide and evaluate management. In this study, we elucidated patterns and characteristics of repeat-spawning steelhead in the Snake River basin. Repeat spawners were overwhelmingly female and were found in all 10 stocks. Most iteroparous fish first spawned after 1 year in the ocean (51.4%) and skipped a year between spawns (55.4%). Growth between spawns declined for longer, older steelhead. Survival from the first spawning migration to postspawn emigration increased during the study. However, survival in the Columbia River estuary and Pacific Ocean declined such that overall survival to second spawn varied little. Small females were most likely to survive to a second spawning migration. We hypothesized that iteroparity in Snake River steelhead was constrained by the energetic costs of the spawning migration (distance, elevation, timing, dam passage) combined with a lack of timely postspawn recovery. Hence, survival to second spawning migration is low for Snake River steelhead and most postspawn steelhead needed a full year to recover. Management programs intended to augment the incidence of iteroparity should account for (1) factors that increase stress and metabolic demand on spawning and postspawn fish and (2) factors that increase the time it takes for emigrating kelts to effectively refuel and recover.

Copeland, T., Bumgarner, J. D., Byrne, A., Cleary, P., Denny, L., Hebdon, J. L., . . . Yundt, S. P. (2015). *Reconstruction of the 2012/2013 Steelhead Spawning Run into the Snake River Basin*. Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Reconstruction%20of%20the%202012-2013%20steelhead%20spawning%20run%20into%20the%20Snake%20River%20basin.pdf

Steelhead trout in the Snake River basin are the focus of a variety of harvest and conservation programs. A run reconstruction model offers a systematic way to address information needs for management within the large and complex arena presented by Snake River steelhead. The purpose of this work is to summarize data describing the abundance of steelhead crossing Lower Granite Dam, the spatial distribution of spawning fish, and known fates/disposition. To achieve this, a group was convened of representatives from the anadromous fishery management agencies within the Snake River basin. The immediate objective was to estimate the disposition of the 2012-2013 return of steelhead within the Snake River basin. We estimated 91,106 adipose-clipped hatchery fish, 10,695 unmarked hatchery fish, and 26,095 wild steelhead entered the Snake River during the run (July 1, 2012 to June 30, 2013), which includes fish from hatchery stocks release outside the Snake River basin. Fishery-related mortality in the Snake River basin totaled 61,421 marked hatchery fish, 445 unmarked hatchery fish, and 950 wild steelhead. Further, 16,521 marked hatchery fish, 597 unmarked hatchery fish, and 10 wild fish were removed at weirs or as part of brood stock collections. Another 13 unclipped and 91 clipped hatchery fish were estimated to leave the Snake River to enter the Walla Walla River. Potential spawners remaining in the habitat totaled 13,682 marked hatchery fish, 9,068 unmarked hatchery fish, and 24,558 wild steelhead. Losses between BON and ICH were 24.8% across all wild Snake River stocks; presumably, most are due to anthropogenic sources; however, fishery-related losses within the Snake River basin were only 5.2%. Using the run reconstruction model, we attempted to quantify the fishery-related impacts on steelhead as they migrate to their natal or release area, and highlighted the benefits of hatchery programs. This work provides a useful framework for synthesizing data collected by fisheries managers that allows inferences regarding disposition and spatial distribution of spawning fish. The run reconstruction process is a good arena for critical review of the data that managers in the basin use. The model can be used to bridge gaps in the existing data using reasonable assumptions in a structured manner. The resulting output will help evaluate the performance of the Snake River steelhead evolutionarily significant unit (ESU) and hatchery programs towards management goals and ESA delisting criteria. Comparison with independent data suggested that the model provides realistic estimates for hatchery fish, but methodology for natural fish estimates needs refinement.

Copeland, T., Bumgarner, J. D., Byrne, A., Denny, L., Hebdon, J. L., Johnson, M., . . . Yundt, S. P. (2014). *Reconstruction of the 2011/2012 Steelhead Spawning Run into the Snake River Basin*. Report to Bonneville Power Administration, Portland, Oregon. Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Reconstruction%20of%20the%202011-2012%20steelhead%20spawning%20run%20into%20the%20Snake%20River%20basin.pdf

Steelhead trout in the Snake River basin are the focus of a variety of harvest and conservation programs. A run reconstruction model offers a systematic way to address information needs for management within the large and complex arena presented by Snake River steelhead. The purpose of this work is to summarize data describing the abundance of steelhead crossing Lower Granite Dam, the spatial distribution of spawning fish, and known fates/disposition. To achieve this, a group was convened of representatives from the anadromous fishery anagement agencies within the Snake River basin. The immediate objective was to estimate the disposition of the 2011-2012 return of steelhead within the Snake River basin. We estimated 146,264 adipose-clipped hatchery fish, 11,355 unmarked hatchery fish, and 44,750 wild steelhead entered the Snake River during the run (July 1, 2011 to June 30, 2012). Fishery-related mortality in the Snake River basin totaled 97,302 marked hatchery fish, 502 unmarked hatchery fish, and 1,511 wild steelhead. Further, 19,543 marked hatchery fish, 1,659 unmarked hatchery fish, and 72 wild fish were removed at weirs. Another 20 unclipped and 103 clipped hatchery fish were estimated to leave the Snake River to enter the Walla Walla River. Potential spawners remaining in the habitat totaled 30,494 marked hatchery fish, 8,495 unmarked hatchery fish, and 36,296 wild steelhead. Using the run reconstruction model, we attempted to quantify the fishery-related impacts on steelhead as they migrate to their natal or release area, and highlighted the benefits of hatchery programs. This useful framework also allows inferences regarding spatial distribution of spawners and disposition. Comparison with independent data suggested that the model provides realistic estimates for hatchery fish, but methodology for natural fish estimates needs refinement. We have developed a tool for comparative use by steelhead managers in the Snake River basin. This work provides a useful framework for synthesizing data collected by fisheries managers that allows inferences regarding disposition and spatial distribution of spawning fish. The run reconstruction process is a good arena for critical review of the data that managers in the basin use. The model can be used to bridge gaps in the existing data using reasonable assumptions in a structured manner. The resulting output will help evaluate the performance of the Snake River steelhead evolutionarily significant unit (ESU) and hatchery programs towards management goals and ESA delisting criteria. Future improvements will improve precision and accuracy.

Copeland, T., Hernandez, K., Davison, M. T., & Wright, K. (2018). Validation of Spawn Checks and Saltwater Age Assignments Based on Scales from Known Repeat-Spawning Steelhead. *North American Journal of Fisheries Management, 38*(5), https://doi.org/10.1002/nafm.10210

It is critical to resolve the effects of regeneration, false annuli, and resorption on interpretation of scale patterns. We used scales collected from known repeat-spawning steelhead Oncorhynchus mykiss from the Snake River to (1) determine the accuracy of spawn check identification and (2) investigate errors in assignment of saltwater ages before and after spawn checks. Scale readers (n=4) accurately identified over 96% of known repeat spawners (n=107) and did not identify spawn checks in known first-time spawners (n=197). Scale resorption associated with the spawn check caused an obscured or lost saltwater annulus in 66% of samples, most frequently in fish that spent 2years versus 1year in saltwater.

Presence or absence of an annulus after the spawn check was accurately assigned in 86% of samples (n=100). The potential for scale resorption to affect interpretation of the life history of iteroparous anadromous salmonids is significant. We supply two examples of how circulus counts can provide guidance to scale readers, but this analysis should be customized to the growth characteristics of each stock of interest.

Crozier, L. G., Bowerman, T. E., Burke, B. J., Keefer, M. L., & Caudill, C. C. (2017). High-Stakes Steeplechase: A Behavior-Based Model to Predict Individual Travel Times through Diverse Migration Segments. *Ecosphere, 8*(10), https://doi.org/10.1002/ecs2.1965

Many migratory species traverse highly heterogeneous landscapes, often including habitats that have been altered by human activities. Modeling migration dynamics is challenging because individual variability in behavior at multiple spatial and temporal scales can produce complex, multi-modal distributions in migration travel times. Moreover, behavioral responses to conditions encountered en route can affect habitat-specific migration rates which then influence bioenergetic costs and mortality risk over the entire migration. To quantify impacts of conditions within migration corridors, refined analyses of behavior are needed. In this study, we developed a behavior-based simulation model that predicts individual adult salmon migration duration over 24 distinct river reaches totaling 922 km, including eight hydropower dams. The study population, threatened Snake River spring/summer Chinook salmon (Oncorhynchus tshawytscha), had observed migration durations ranging from 23 to 108 d. In a novel application of N-dimensional mixture models, which can account for subpopulations that behave differently, we simulated "fast" vs. "slow" travel through migration reaches. The proportion of migrants in each category was determined by diel, seasonal, and proximate river conditions, which captured the temporally shifting bimodal patterns in the data. We fit reach-specific models with data from 2188 tagged salmon migrating in 2000-2013 and validated the cumulative model with additional data through 2015. By accounting for multiple behaviors in this way, the model successfully recreated the breadth and variability in total travel times to within 3% of observed durations throughout the 5th-95th quantiles. En route mortality appeared to account for the loss of the slowest fish that encountered record-breaking high temperatures in 2015. For Chinook salmon, this combined reach and cumulative travel-time model provides an opportunity to link high-resolution behavioral data to individual fitness and population-level impacts on viability. More generally, the N-dimensional modeling approach offers a framework for assessing the cumulative impacts of alternative behaviors at small spatial and temporal scales. Improved accounting of changes in migration rate in response to local conditions will aid recovery efforts for species of concern traversing complex migration corridors.

Dale, K. E., Daly, E. A., & Brodeur, R. D. (2017). Interannual Variability in the Feeding and Condition of Subyearling Chinook Salmon Off Oregon and Washington in Relation to Fluctuating Ocean Conditions. *Fisheries Oceanography, 26*(1), https://doi.org/10.1111/fog.12180

Chinook salmon (Oncorhynchus tshawytscha) is one of several economically-important species of salmon found in the Northeast Pacific Ocean. The first months at sea are believed to be the most critical for salmon survival, with the highest rate of mortality occurring during this period. In the present study, we examined interannual diet composition and body condition trends for late-summer subyearling Chinook salmon caught off Oregon and Washington from 1998 to 2012. Interannual variability was observed in juvenile salmon diet composition by weight of prey consumed. Juvenile subyearling Chinook salmon were mainly piscivorous, with northern anchovy (Engraulis mordax) being especially important, making up half the diet by weight in some years. Annual diets clustered into two groups, primarily defined by their proportion of invertebrate prey (14% versus 39% on average). Diet composition was found to influence adult returns, with salmon from high-invertebrate years returning in significantly larger numbers 2?3 yrs later. However, years that had high adult returns had overall lower stomach fullness and poorer body condition as juveniles, a counterintuitive result potentially driven by the enhanced survival of less fit individuals in better ocean conditions (top-down effect). Ocean conditions in years with a higher percentage of invertebrates in salmon diets were significantly cooler from May to August, and bottom-up processes may have led to a fall plankton community with a larger proportion of invertebrates. Our results suggest that the plankton community assemblage during this first fall may be critical in predicting adult returns of Chinook salmon in the Pacific Northwest.

Erhardt, J. M., & Tiffan, K. F. (2018). Post-Release Predation Mortality of Age-0 Hatchery-Reared Chinook Salmon from Non-Native Smallmouth Bass in the Snake River. *Fisheries Management and Ecology, 25*(6), https://doi.org/10.1111/fme.12322

Release of age-0 hatchery-reared fall Chinook salmon, Oncorhynchus tshawytscha (Walbaum), in the Snake River resulted in up to 30-fold increases in salmon consumption by non-native smallmouth bass, Micropterus dolomieu Lacep?de. In an upper river reach, smallmouth bass fed intensively during a release in May, but Chinook salmon consumption returned to pre-release levels within 1?2 days as hatchery-reared fish quickly emigrated downstream. The predation response during a June release located farther downstream was dissimilar. Chinook salmon consumption increased to a lesser extent (11-fold), lasted several days (~4) and no changes in feeding intensity were evident. Estimated numbers of age-0 hatchery-reared Chinook salmon lost to short-term predation varied by year and study reach and ranged from 12,007 (6.03% of those released) to 210,580 (14.6% of those released) fish. Short-term, intense feeding by smallmouth bass can contribute significantly to mortality of hatchery-reared fish and should be considered when supplementing populations with hatchery juveniles.

Erhardt, J. M., Tiffan, K. F., & Connor, W. P. (2018). Juvenile Chinook Salmon Mortality in a Snake River Reservoir: Smallmouth Bass Predation Revisited. *Transactions of the American Fisheries Society, 147*(2), https://doi.org/10.1002/tafs.10026

Predation by nonnative fishes has been identified as a contributing factor in the decline of juvenile salmonids in the Columbia River basin. We examined the diet composition of Smallmouth Bass Micropterus dolomieu and estimated the consumption and predation loss of juvenile Chinook Salmon Oncorhynchus tshawytscha in Lower Granite Reservoir on the Snake River. We examined 4,852 Smallmouth Bass stomachs collected from shoreline habitats during April–September 2013–2015. Chinook Salmon were the second most commonly consumed fish by all size-classes of Smallmouth Bass (≥150 mm TL) throughout the study. Over the 3 years studied, we estimated that a total of 300,373 Chinook Salmon were consumed by Smallmouth Bass in our 22-km study area, of which 97% (291,884) were subyearlings (age 0) based on length frequency data. A majority of the loss (61%) occurred during June, which coincided with the timing of hatchery releases of subyearling fall Chinook Salmon. Compared to an earlier study, mean annual predation loss increased more than 15-fold from 2,670

Chinook Salmon during 1996–1997 to 41,145 Chinook Salmon during 2013–2015 (in reaches that could be compared), despite lower contemporary Smallmouth Bass abundances. This increase can be explained in part by increases in Smallmouth Bass consumption rates, which paralleled increases in subyearling Chinook Salmon densities—an expected functional response by an opportunistic consumer. Smallmouth Bass are currently significant predators of subyearling Chinook Salmon in Lower Granite Reservoir and could potentially be a large source of unexplained mortality.

Evans, M. L., Kohler, A. E., Griswold, R. G., Tardy, K. A., Eaton, K. R., & Ebel, J. D. (2019). Salmon-Mediated Nutrient Flux in Snake River Sockeye Salmon Nursery Lakes: The Influence of Depressed Population Size and Hatchery Supplementation. *Lake and Reservoir Management, 36*(1), https://doi.org/10.1080/10402381.2019.1654571

Since the 1970s, Snake River sockeye salmon (Oncorhynchus nerka) have returned in low numbers to nursery lakes in central Idaho, consequently diminishing marine-derived nutrient subsidies to freshwater spawning and rearing environments. In healthy Pacific salmon populations, returning adults generally import more nutrients than juveniles export, resulting in net positive salmonmediated nutrient fluxes to freshwater ecosystems. To mitigate for declining sockeye salmon returns, Snake River nursery lakes have been stocked with embryos, with captive-reared juveniles and adults, and fertilized with inorganic nutrients. Here, we examine sockeye salmon-mediated nutrient flux in 3 nursery lakes, Alturas, Pettit, and Redfish, across 20 yr of study (1998–2017). In Redfish Lake, sockeye salmon-mediated nutrient flux was positive in all years when imports from the captive-rearing program were considered in our estimates. Without captive-rearing program inputs, Redfish Lake nutrient flux was positive in only 40% and 45% of years for phosphorus and nitrogen, respectively. In Alturas and Pettit lakes, nutrient export by juveniles exceeded nutrient import by adults in 67% and 56% of years for phosphorus and nitrogen, respectively. Overall, our findings suggest that a sufficient number of adult recruits relative to juvenile migrants, corresponding to a smolt-to-adult return rate>0.78%, is needed to achieve positive salmon-mediated nutrient flux within lakes and that this will depend on both adequate population productivity and enhanced marine and freshwater habitat connectivity.

Faulkner, J. R., Bellerud, B. L., Widener, D. L., & Zabel, R. W. (2019). Associations among Fish Length, Dam Passage History, and Survival to Adulthood in Two at-Risk Species of Pacific Salmon. *Transactions of the American Fisheries Society, 148*(6), https://doi.org/10.1002/tafs.10200

Threatened or endangered salmon and steelhead originating in the Snake River basin must pass through a series of eight major hydroelectric dams during their seaward migration. Understanding the effects of specific dam passage routes on lifetime survival for these stocks is essential for successful management. Juvenile fish may pass these dams via three primary routes: (1) spillways, (2) turbines, or (3) juvenile bypass systems, which divert fish away from turbines and route them downstream. Bypass systems may expose fish to trauma, increased stress, or disease. However, numerous studies have indicated that direct survival through bypass systems is comparable to and often higher than that through spillways. Some researchers have suggested that the route of dam passage affects mortality in the estuary or ocean, but this is complicated by studies finding that fish size affects the route of passage. We tested whether passage through bypass systems was associated with the probability of adult return after accounting for fish length and other covariates for two species of concern. We also investigated the association between fish length and the probability of bypass at dams and how this relationship could lead to spurious conclusions regarding effects of bypass systems on survival if length is ignored. We found that (1) larger fish had lower bypass probabilities at six of seven dams; (2) larger fish had a higher probability of surviving to adulthood; (3) bypass history had little association with adult return after accounting for fish length; and (4) simulations indicated that spurious effects of bypass on survival may arise when no true bypass effect exists, especially in models without length. Our results suggest that after fish leave the hydropower system, bypass passage history has little effect on mortality. Our findings underscore the importance of accounting for fish size in studies of dam passage or survival.

Feldhaus, J. W., Hoffnagle, T. L., & Carmichael, R. W. (2016). The Influence of Size at Release on Performance of Imnaha River Chinook Salmon Hatchery Smolts. *North American Journal of Fisheries Management, 36*(2), https://doi.org/10.1080/02755947.2015.1128999

Ten brood years (BYs 1988–1990 and 1992–1998) of spring–summer Chinook Salmon Oncorhynchus tshawytscha smolts that were reared at Lookingglass Fish Hatchery (Oregon) and released from the Imnaha River Weir and Acclimation Facility were evaluated to determine whether size at release affected juvenile migration survival, smoltto-adult survival (SAS) rate, smolt-to-adult return (SAR) rate, production efficiency, age composition, straying rate, or harvest rate. Smolts were marked with adipose fin clips and were tagged with coded wire tags (all BYs) and PIT tags (BYs 1992–1998). For BYs 1992–1998, the out-migration survival rate to Lower Granite Dam (LGD) on the Snake River was greater for large smolts (30–38 g) than for small smolts (18–23 g). This juvenile survival difference did not translate to an adult survival difference, as the total (ages 3–5) and adult (ages 4–5) SAR and SAS rates did not differ between large and small smolts. Straying rates were less than 0.02% and harvest rates were less than 0.05% for both treatments, and we found no significant differences between groups. Total production efficiency (number of mature salmon/10 kg of smolts released) was greater for small smolts than for large smolts but not significantly so. Small smolts produced significantly more (~10%) age-5 females than did large smolts. Treatments (smolt size at release) did not differ in sex ratio or the age composition of male returns. Because broodstock availability limited production in 5 of the 10 years, we also compared size at release within standard-density (14.8–22.2 kg/m3) and lowdensity (2.2–8.6 kg/m3) rearing years. At standard density but not at low density, juvenile survival to LGD was significantly greater for large smolts than for small smolts. Adult and total SAR and SAS rates, total production efficiency, and straying rates did not differ between standard-density and low-density rearing years. Harvest rate of the small smolts was significantly greater than that of the large smolts at low density but not at standard density. We found no performance benefit in rearing large Chinook Salmon smolts instead of small smolts.

Fullerton, A. H., Anzalone, S., Moran, P., Van Doornik, D. M., Copeland, T., & Zabel, R. W. (2016). Setting Spatial Conservation Priorities Despite Incomplete Data for Characterizing Metapopulations. *Ecological Applications, 26*(8), https://doi.org/10.1002/eap.1411

Management of spatially structured species poses unique challenges. Despite a strong theoretical foundation, practitioners rarely have sufficient empirical data to evaluate how populations interact. Rather, assumptions about connectivity and source-sink dynamics are often based on incomplete, extrapolated, or modeled data, if such interactions are even considered at all. Therefore, it has been difficult to evaluate whether spatially structured species are meeting conservation goals. We evaluated how estimated metapopulation structure responded to estimates of population sizes and dispersal probabilities and to the set of populations included. We then compared outcomes of alternative management strategies that target conservation of metapopulation processes. We illustrated these concepts for Chinook salmon (Oncorhynchus tshawytscha) in the Snake River, USA. Our description of spatial structure for this metapopulation was consistent with previous characterizations. We found substantial differences in estimated metapopulation structure when we had incomplete information about all populations and when we used different sources of data (three empirical, two modeled) to estimate dispersal, whereas responses to population size estimates were more consistent. Together, these findings suggest that monitoring efforts should target all populations occasionally and populations that play key roles frequently and that multiple types of data should be collected when feasible. When empirical data are incomplete or of uneven quality, analyses using estimates produced from an ensemble of available datasets can help conservation planners and managers weigh near-term options. Doing so, we found trade-offs in connectivity and source dominance in metapopulation-level responses to alternative management strategies that suggest which types of approaches may be inherently less risky.

Goertler, P. A. L., Simenstad, C. A., Bottom, D. L., Hinton, S., & Stamatiou, L. (2016). Estuarine Habitat and Demographic Factors Affect Juvenile Chinook (Oncorhynchus tshawytscha) Growth Variability in a Large Freshwater Tidal Estuary. *Estuaries and Coasts, 39*(2), https://doi.org/10.1007/s12237-015-0002-z

Estuarine rearing has been shown to enhance within watershed biocomplexity and support growth and survival for juvenile salmon (Oncorhynchus sp.). However, less is known about how growth varies across different types of wetland habitats and what explains this variability in growth. We focused on the estuarine habitat use of Columbia River Chinook salmon (Oncorhynchus tshawytscha), which are listed under the Endangered Species Act. We employed a generalized linear model (GLM) to test three hypotheses: (1) juvenile Chinook growth was best explained by temporal factors, (2) habitat, or (3) demographic characteristics, such as stock of origin. This study examined estuarine growth rate, incorporating otolith microstructure, individual assignment to stock of origin, GIS habitat mapping, and diet composition along ~130 km of the upper Columbia River estuary. Juvenile Chinook grew on average 0.23 mm/day in the freshwater tidal estuary. When compared to other studies in the basin our growth estimates from the freshwater tidal estuary were similar to estimates in the brackish estuary, but ~4 times slower than those in the plume and upstream reservoirs. However, previous survival studies elucidated a possible tradeoff between growth and survival in the Columbia River basin. Our GLM analysis found that variation in growth was best explained by habitat and an interaction between fork length and month of capture. Juvenile Chinook salmon captured in backwater channel habitats and later in the summer (mid-summer and late summer/fall subyearlings) grew faster than salmon from other habitats and time periods. These findings present a unique example of the complexity of understanding the influences of the many processes that generate variation in growth rate for juvenile anadromous fish inhabiting estuaries.

Gosselin, J. L., Holmes, C. V., Iltis, S., & Anderson, J. J. (2018). *Snake River Juvenile Salmon and Steelhead Transportation Synthesis Report.* Retrieved from http://www.cbr.washington.edu/papers

Purpose and Scope: Review and synthesize research related to the Juvenile Fish Transportation Program and smolt-to-adult return (SAR) survival patterns of Snake River salmon and steelhead migrating through the Federal Columbia River Power System (FCRPS or hydrosystem), Snake and Columbia rivers, Washington and Oregon, USA.

Haeseker, S. L., Scheer, G., & McCann, J. (2020). Avian Predation on Steelhead Is Consistent with Compensatory Mortality. *Journal of Wildlife Management, 84*(6), https://doi.org/10.1002/jwmg.21880

Numerous factors such as predation, disease, injury, and environmental conditions (e.g., river flows, hydropower operations) can influence survival rates of fish. Although mortality due to predation is commonly assumed to be additive and result in a directly proportional reduction on survival rates, compensatory processes may work to counteract or negate the effects of predation mortality on survival rates. We applied a random effects model to a long-term, mark-recapture-recovery data set on anadromous steelhead (Oncorhynchus mykiss) from the Snake River Basin in the northwestern United States to assess whether avian predation mortality constitutes an additive or compensatory source of mortality. Specifically, our assessment focused on predation mortality due to double-crested cormorants (Phalacrocorax auritus) and Caspian terns (Hydroprogne caspia) on colonies in the Columbia River estuary. In addition, we evaluated several candidate environmental indices to examine potential interactions between the effects of predation versus environmental conditions on steelhead survival rates. Average predation rates were 3.3% for the double-crested cormorant colony and 17.0% for the Caspian tern colony. For both colonies, the estimated correlation between the predation rate and survival rate of steelhead was near zero, indicating that mortality due to avian predation is compensatory. Models that included variables for river flow, juvenile migration timing, and an index of forage biomass in the ocean accounted for 56–59% of the variation in steelhead survival, whereas avian predation rates accounted for <1% of the variation. Management efforts to reduce the abundance of the bird colonies are unlikely to improve the survival or conservation status of steelhead; however, results indicate that steelhead survival could be improved by hydropower management decisions that increase river flows and reduce juvenile migration delays.

Hand, B. K., Flint, C. G., Frissell, C. A., Muhlfeld, C. C., Devlin, S. P., Kennedy, B. P., . . . Stanford, J. A. (2018). A Social–Ecological Perspective for Riverscape Management in the Columbia River Basin. *Frontiers in Ecology and the Environment, 16*(S1), https://doi.org/10.1002/fee.1752

Riverscapes are complex, landscape-scale mosaics of connected river and stream habitats embedded in diverse ecological and socioeconomic settings. Social–ecological interactions among stakeholders often complicate natural-resource conservation and management of riverscapes. The management challenges posed by the conservation and restoration of wild salmonid populations in the Columbia River Basin (CRB) of western North America are one such example. Because of their ecological, cultural, and socioeconomic importance, salmonids present a complex management landscape due to interacting environmental factors (eg climate change, invasive species) as well as socioeconomic and political factors (eg dams, hatcheries, land-use change, transboundary agreements). Many of the problems in the

CRB can be linked to social–ecological interactions occurring within integrated ecological, human–social, and regional–climatic spheres. Future management and conservation of salmonid populations therefore depends on how well the issues are understood and whether they can be resolved through effective communication and collaboration among ecologists, social scientists, stakeholders, and policy makers.

Harnish, R., Skalski, J., Townsend, R., & Ham, K. (2020). In Search of a Cost-Effective Approach for Estimating Dam Passage Survival. *North American Journal of Fisheries Management, 40*(4), https://doi.org/10.1002/nafm.10448

Passage of downstream-migrating fishes through hydropower dams poses a management issue in rivers throughout the world. As such, regulations have been enacted at many locales to understand and limit fish losses by requiring dam passage survival estimation. However, limiting estimates of survival to the dam and immediate tailrace presents a challenge to researchers. In this study, two alternative release–recapture methods were used to estimate dam passage survival of juvenile salmonids through Lower Granite Dam on the Snake River, Washington, in 2018. One approach, the virtual/paired-release (ViPRe) model, was extensively used in the Columbia–Snake River basin at federally operated hydroelectric dams during 2010–2014. This existing approach uses three releases of tagged smolts to isolate dam passage survival, defined as survival from the upstream dam face to the tailrace mixing zone 1–2 km downstream of the dam. An alternative approach, the virtual release/dead-fish correction (ViRDCt) model, uses one live-release group paired with a release of dead tagged fish at the dam to estimate the same survival parameter. The alternative estimation approaches were tested on two spring out-migrating stocks, yearling Chinook Salmon Oncorhynchus tshawytscha and steelhead Oncorhynchus mykiss, and on a summer out-migrating stock of subyearling Chinook Salmon. The alternative estimates for these stocks were all within 1 SE. However, the ViRDCt model produced survival estimates with SEs that were 59% smaller than those of the existing ViPRe model and did so using 42% fewer tagged fish and one less downstream acoustic detection array. Because of the reduced sample size, nearly US$540,000 less in tag costs and 4,000 fewer labor-hours were required to implement the ViRDCt model compared to the ViPRe model. As such, the ViRDCt model represents a cost-effective and precise approach to characterizing dam passage survival.

Hernandez, K., Copeland, T., & Wright, K. (2014). Quantitative Assessment of Scale Resorption in Migrating and Spawning Steelhead of the Snake River Basin. *Transactions of the American Fisheries Society, 143*(6), https://doi.org/10.1080/00028487.2014.954054

Scales have been used for decades as a tool to interpret life histories in steelhead Oncorhynchus mykiss. Resorption can affect the accuracy of life history interpretations based on scale patterns, depending on the amount of material resorbed. For example, resorption can affect the distinctiveness and characteristics of spawn checks. Spawn checks have been reported in iteroparous salmonids, but no published experimental studies have established the precise relationship between reproduction and scale features. Our objectives were (1) to quantify scale resorption, and (2) to identify contributing factors to the observed resorption in migrating and spawning Snake River steelhead. Prespawn and postspawn scale samples from 72 fish were paired for analysis. We found considerable individual variability in the amount of material resorbed between prespawn and postspawn samples (mean, 26%; SD, 13.7%). Most resorption occurred during the winter as gonads matured and secondary sex characteristics were formed. In over half of the postspawn samples, resorption was sufficient to obscure or eliminate an annulus. In a few cases, resorption was minor enough that the eventual spawn check may be indistinct or absent. We recommend that ancillary marks be investigated as a means to help identify weak spawn checks and an index of resorption developed to determine if resorption was sufficient to cause loss of an annulus.

Hess, J. E., Ackerman, M. W., Fryer, J. K., Hasselman, D. J., Steele, C. A., Stephenson, J. J., . . . Narum, S. R. (2016). Differential Adult Migration-Timing and Stock-Specific Abundance of Steelhead in Mixed Stock Assemblages. *Ices Journal of Marine Science, 73*(10), https://doi.org/10.1093/icesjms/fsw138

Stock-specific migration-timing and relative abundance of exploited fish species are critical parameters to estimate for management of mixed stock fisheries. Here, we used parentage-based tagging (PBT) together with mixed stock analyses (MSA) to estimate stock-specific abundance and migration-timing in anadromous adult steelhead (Oncorhynchus mykiss) sampled at Bonneville Dam in the lower Columbia River. Results indicate that natural-origin steelhead was represented by 11 of 13 possible stocks found throughout the Columbia-Snake river basins, while hatchery-origin steelhead was primarily composed of five stocks from the Snake River drainage. Further, migration-timing differentiated stocks and allowed categorization of early, intermediate, and late migrating stocks. Analyses of age and length data for these stocks also showed that late-arriving fish were larger due to older age and originated primarily from the Clearwater River, South Fork Salmon River, and Dworshak Hatchery, all from the Snake River drainage. Sex ratios tended to be skewed towards females and ranged from 51.5 to 68.9% for hatchery stocks and 60.5-71.8% for natural-origin stocks. This suggests that anadromous migration is favored by females while males are more likely to residualize in freshwater. Overall, this study demonstrates how the use of PBT in MSA can reveal important stock-specific differences in migration-timing and relative abundance and provides critical information for management of mixed stock fisheries.

Hess, M. A., Hess, J. E., Matala, A. P., French, R. A., Steele, C. A., Lovtang, J. C., & Narum, S. R. (2016). Migrating Adult Steelhead Utilize a Thermal Refuge During Summer Periods with High Water Temperatures. *Ices Journal of Marine Science, 73*(10), https://doi.org/10.1093/icesjms/fsw120

Anadromous fishes often use various survival tactics while migrating through main stem rivers to successfully reach spawning grounds and reproduce. Mixed-stock assemblages of anadromous adult summer steelhead Oncorhynchus mykiss re-enter the Columbia River from late spring through fall including the period of peak summer water temperatures, and previous studies suggest that stocks alter migratory behaviour in response to warm temperatures by seeking cool water refuges. We combined parentage-based tagging with mixed stock analyses to test whether steelhead use a non-natal tributary (Deschutes River, OR, USA) as a thermal refuge and if this migratory behaviour is associated with stock-specific run-timing. Results collected over two migration years indicated that out-of-basin fish in the Deschutes River were disproportionately from specific stocks in the Snake River (Salmon and Grande Ronde) that had migrated through the main stem Columbia River when water temperatures exceeded 21 °C. Stocks migrating through the main stem river during cooler temperature periods were either less frequent (Clearwater River), or not encountered (lower Snake River) in the Deschutes River. This study facilitates an improved understanding of stock-specific migratory characteristics associated with environmental conditions in this system. Results potentially affect fisheries management, hatchery protocols, cool-water refuge maintenance, and conservation of wild Deschutes River populations.

Hinrichsen, R. A., & Paulsen, C. M. (2020). Low Carrying Capacity a Risk for Threatened Chinook Salmon. *Ecological Modelling, 432*, https://doi.org/10.1016/j.ecolmodel.2020.109223

Since they were listed under the U. S. Endangered Species Act of 1973, Snake River spring-summer Chinook Salmon (Oncorhynchus tshawytscha) have been the subject of numerous population viability analyses (PVAs). In all of the previous PVAs that we are aware of, management actions to improve the species' status have focused on increasing survival rates of juveniles and adults. These PVAs did not explicitly treat carry capacity; instead, they assumed that survival rate improvements increased intrinsic productivity, and implicitly assumed that this would also increase carrying capacity. In a novel alternative approach, we instead examined how carrying capacity itself was related to extinction risk. We estimated three alternative multi-population PVAs using maximum likelihood estimation and chose the model with the best fit to the spawner-recruit data from 26 populations in the Snake River Spring/Summer Chinook Salmon evolutionarily significant unit. We then estimated carrying capacity and 24-year extinction probability for each of these populations using alternative quasiextinction thresholds. We found that carrying capacities estimates were low in several of the populations and that extinction probability increases sharply with decreasing carrying capacity. A sensitivity analysis with fixed carrying capacities and increasing intrinsic productivity illustrated that unless actions increase carrying capacity, little change in extinction risk can occur.

Hostetter, N. J., Evans, A. F., Cramer, B. M., Collis, K., Lyons, D. E., & Roby, D. D. (2015). Quantifying Avian Predation on Fish Populations: Integrating Predator-Specific Deposition Probabilities in Tag Recovery Studies. *Transactions of the American Fisheries Society, 144*(2), https://doi.org/10.1080/00028487.2014.988882

Accurate assessment of specific mortality factors is vital to prioritize recovery actions for threatened and endangered species. For decades, tag recovery methods have been used to estimate fish mortality due to avian predation. Predation probabilities derived from fish tag recoveries on piscivorous waterbird colonies typically reflect minimum estimates of predation due to an unknown and unaccounted-for fraction of tags that are consumed but not deposited on-colony (i.e., deposition probability). We applied an integrated tag recovery modeling approach in a Bayesian context to estimate predation probabilities that accounted for predator-specific tag detection and deposition probabilities in a multiple-predator system. Studies of PIT tag deposition were conducted across three bird species nesting at seven different colonies in the Columbia River basin, USA. Tag deposition probabilities differed significantly among predator species (Caspian terns Hydroprogne caspia: deposition probability = 0.71, 95% credible interval [CRI]=0.51-0.89; double-crested cormorants Phalacrocorax auritus: 0.51, 95% CRI = 0.34-0.70; California gulls Larus californicus: 0.15, 95% CRI = 0.11-0.21) but showed little variation across trials within a species or across years. Data from a 6-year study (2008-2013) of PIT-tagged juvenile Snake River steelhead Oncorhynchus mykiss (listed as threatened under the Endangered Species Act) indicated that colony-specific predation probabilities ranged from less than 0.01 to 0.17 and varied by predator species, colony location, and year. Integrating the predator-specific deposition probabilities increased the predation probabilities by a factor of approximately 1.4 for Caspian terns, 2.0 for double-crested cormorants, and 6.7 for California gulls compared with traditional minimum predation rate methods, which do not account for deposition probabilities. Results supported previous findings on the high predation impacts from strictly piscivorous waterbirds nesting in the Columbia River estuary (i.e., terns and cormorants), but our findings also revealed greater impacts of a generalist predator species (i.e., California gulls) than were previously documented. Approaches used in this study allow for direct comparisons among multiple fish mortality factors and considerably improve the reliability of tag recovery models for estimating predation probabilities in multiple-predator systems.

Idaho Department of Fish and Game. (2016). *Snake River Sockeye Salmon Captive Broodstock Program Research Element: 2013-2015 Annual Project Progress Report*. (IDFG Report Number 16-13). Boise, ID Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res16-13Johnson2015%20Sockeye%20Captive%20Broodstock%20Research.pdf

Sockeye Salmon returns to the basin have increased in recent years and the program has successfully prevented extinction and preserved the genetic lineage of the Redfish Lake stock. In 2013, 272 adults returned, 1,579 in 2014, and 91 in 2015 (35 were collected from Lower Granite Dam). Snake River Sockeye Salmon anadromous populations remain sporadic as a result of variable and oftentimes marginal in-river (e.g., 2015) and ocean environments, and the hatchery is needed to meet abundance and recovery criteria. While numbers have increased more recently, Snake River Sockeye Salmon are not considered recovered until the population is made up of natural-origin fish spawning in the wild in greater numbers, which will depend on increasing juvenile and adult survival.

Idaho Department of Fish and Game. (2018). *Natural-Origin Chinook Salmon and Steelhead Life History and Genetic Diversity at Pit Tag Detection Locations Throughout the Snake River Basin: Project Progress Report, 2017 Annual Report*. Boise, ID Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res18-14Powell2017Natural%20Origin%20Chinook%20Salmon%20and%20Steelhead%20Life%20History%20and%20Genetic%20Diversity.pdf

This report summarizes life history and genetic diversity information for wild adult steelhead and spring/summer Chinook Salmon sampled at Lower Granite Dam and later dtected in an Interior Columbia Technical Recovery Team population in the Snake River basin or the 01/2017 to 12/31/2017 reporting period. This reporting period covers analysis of idividuals crossing Lower Granite Dam in spawn years 2016 and 2017. A total of 7,320 steelhead and 3,771 Chinook Salmon were sampled at Lower Granite Dam, 2,781 and 2,089 of which were subsequently identified at a PIT tag detection location elsewhere in the Snake River basin. Fish were not classified based on hatchery or wild origin at Lower Granite Dam; panels of up to 298 SNPs were genotyped at both Idaho Department of Fish and Game's Eagle Fish Genetics Lab and its collaborating laboratory, the Columbia River Inter-Tribal Fish Commission's Hagerman Genetics Lab, to assign these fish to hatchery parents or wild genetic stocks. We describe the life history variation and genetic diversity of steelhead and Chinook Salmon detected in Interior Columbia Technical Recovery Team populations. The information presented in this report provides critical data for Viable Salmonid Population monitoring of the Snake River steelhead Distinct Population Segment and the Snake River spring/summer Chinook Salmon Evolutionary Significant Unit.

Idaho Department of Fish and Game. (2018). *Wild Adult Steelhead and Chinook Salmon Abundance and Composition at Lower Granite Dam, Spawn Year 2017*. (Idaho Department of Fish and Game Report 18-06). Boise, ID Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res18-06Camacho2017%20Wild%20Adult%20Steelhead%20and%20Chinook%20Salmon%20Abundance%20Composition%20LGD%20Spawn%20Year%202017.pdf

This report summarizes the abundance and composition of wild steelhead and springsummer Chinook Salmon returning to Lower Granite Dam in spawn year 2017. We used a combination of window counts and systematic biological samples from the fish trap to decompose each species by origin, body size, sex, age, and stock. These metrics were then used to calculate adult-to-adult productivity, expressed as recruits per spawner for each species, and smolt-to-adult return rate for spring-summer Chinook. The combined window count was 101,826 hatchery and wild steelhead. The estimated wild escapement was 15,576 fish and comprised 15% of the window count. Wild abundance decreased for all genetic stocks for the second consecutive year. The Grande Ronde River genetic stock was the most abundant followed by the Upper Clearwater River. Small steelhead (<78 cm, FL) dominated the total wild run; however, large fish (≥78 cm, FL) were as numerous as small fish in the Upper Clearwater River, South Fork Clearwater River, and South Fork Salmon River genetic stocks. Wild steelhead were female biased at 75%. Sex ratios for each genetic stock mirrored the aggregate wild run and ranged from 61% female for Lower Salmon River to 83% female for South Fork Salmon River. Sixteen different age classes were observed where age at spawn ranged from three to seven years, freshwater age ranged between one to four years, and saltwater age ranged from one to four years with additional fish returning as repeat spawners. Adult-to-adult productivity was completed for brood year 2009 at 0.96 returning recruits per spawner. The Upper Salmon River, South Fork Salmon River, Imnaha River, Grande Ronde River, and Lower Snake River genetic stocks were above replacement whereas the Middle Fork Salmon River, Lower Salmon River, and all Clearwater genetic stocks were below replacement. The combined window count was 48,192 hatchery and wild springsummer Chinook Salmon. The estimated wild escapement was 5,793 fish and comprised 12% of the window count. Wild abundance decreased for most genetic stocks for the third consecutive year. The Hells Canyon genetic stock was the most abundant followed by the South Fork Salmon River. Large Chinook Salmon (≥57 cm, FL) dominated the total wild run; however, small fish (<57 cm, FL) were as numerous as large fish in the Tucannon River genetic stock. Wild Chinook Salmon were male biased at 57%. However, some genetic stocks were either female biased or not biased to either sex. Thirteen different age classes were observed where age at spawn ranged from two to six years, freshwater age ranged between zero to two years, and saltwater age ranged from zero (mini-jacks) to four years. Adult-to-adult productivity for brood year 2011 was completed at 1.07 returning recruits per spawner. The Upper Salmon River, Middle Fork Salmon River, Hells Canyon, and Tucannon River genetic stocks were above replacement whereas the South Fork Salmon River and Chamberlain Creek were below replacement. The smolt-to-adult return rate forthe aggregate wild run was 2.82% for smolts crossing Lower Granite Dam in migration year 2013.

Idaho Department of Fish and Game. (2018). *Wild Juvenile Steelhead and Chinook Salmon Abundance and Composition at Lower Granite Dam, Migratory Years 2010-2017: Cumulative Progress Report*. (IDFG Report Number 18-05. Cumulative Report, BPA Projects 1990-055-00, 1991-073-00, 2010-026-00.). Boise, ID Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res18-

05Camacho%20Wild%20Juvenile%20Steelhead%20and%20Chinook%20Salmon%20Abundance%20Composition%20at%20LGD,%20Migratory%20Years%202010-2017.pdf

This report summarizes the abundance, composition, and productivity of wild juvenile steelhead and yearling and subyearling Chinook Salmon emigrating past Lower Granite Dam, migratory years 2010-2017. We used systematic biological samples from the Juvenile Fish Facility to decompose each species by origin, age, sex, and genetic stock. Steelhead juvenile emigration averaged 830,679 and ranged from 672,883 to 928,701 fish. Genetic stock abundance followed a general pattern with the Grande Ronde having the highest abundance (17-24%) in all years followed by the Upper Salmon (14-22%). The South Fork Salmon (2-7%) and Lower Salmon (2-5%) were the least abundant and the remaining genetic stocks (Middle Fork Salmon, Upper Clearwater, South Fork Clearwater, Lower Clearwater, Imnaha, and Lower Snake) fluctuated between years. Depending on the year, 4 to 5 freshwater age classes were observed with the vast majority of emigrants comprised of freshwater age-2 and age-3 fish. Genetic stock typically having large (≥78 cm) returning adults had higher proportions of freshwater age-3 juveniles than other genetic stocks. Sex ratios were female biased (54-67%) for the aggregate juvenile emigration. However, sex ratios by genetic stock were not biased towards either sex in most years, but were skewed towards female when biased. Juvenile per parent productivity was complete for the aggregate and individual genetic stocks for brood years 2009-2012 and ranged from 13-47 juveniles per parent. Brood year 2009 had the highest productivity and brood year 2011 had the lowest. Yearling Chinook Salmon juvenile emigration averaged 1,202,436 and ranged from 601,722 to 1,712,102 fish. Genetic stock abundance followed a general pattern of the Hells Canyon having the highest abundance (32-40%) in all years, while Fall (0-2%) and Tucannon (0-1%) were the least abundant. The remaining genetic stocks (Upper Salmon, Middle Fork Salmon, South Fork Salmon, and Chamberlain) fluctuated in proportion between years. Sex ratios were female biased (54-56%) for the aggregate juvenile emigration in all years except 2011 and 2015. However, sex ratios were not statistically biased in most years for each genetic stock. Juvenile per parent productivity was estimated for brood years 2010-2015 and updated the time series starting in brood year 1990. The aggregate juvenile productivity ranged from 28-403 juveniles per female. The most recent complete brood years were on the lower end of the observed range. A Beverton-Holt stock-recruit model computed intrinsic productivity to be 405 juveniles per female and asymptotic production was 1.40 million natural juveniles. Subyearling Chinook Salmon juvenile emigration was analyzed for migration years 2010-2014. Emigration estimates for all subyearling Chinook averaged 2,376,104 fish and ranged from 1,324,581 to 3,390,860 fish. The Fall genetic stock comprised 87-97% of the overall emigration abundance of subyearling Chinook. Sex ratios were not biased towards either sex. Sampling for subyearling Chinook Salmon was discontinued after migration year 2014 due to the lack of the target spring/summer Chinook in the sample and logistics. Productivity was not calculated for subyearling Chinook Salmon. This report is the second attempt at a stock assessment using genetic stock identification, but the first using a hierarchical compositional analysis (SCRAPI) for natural juvenile emigration from the Snake River steelhead DPS and spring/summer Chinook ESU. Estimates within this report supersede previous estimates covering the same migration years. The ultimate goal of this program is to develop productivity relationships at various population levels. Data provided here are essential to understanding productivity and diversity of the emigrating life stages.

Idaho Department of Fish and Game. (2019). *Chinook and Steelhead Genotyping for Genetic Stock Identification at Lower Granite Dam. Idaho Department of Fish and Game Report 19-08. Annual Report, Bpa Project 2010-026-00.* (IDFG Report Number 19-08). Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res19-

08Hargrove%202018%20Chinook%20Salmon%20and%20Steelhead%20Genotyping%20for%20GSI%20at%20LGR.pdf

This report summarizes progress in the development and implementation of genetic stock identifier (GSI) in the Snake River basin for natural-origin steelhead and spring/summer Chinook Salmon for the 01/01/2018 to 12/31/2018 reporting period. Four objectives for the GSI project are addressed in this report: 1) the maintenance and evaluation of single nucleotide polymorphism (SNP) panels for high-throughput genotyping of steelhead and Chinook Salmon in the Snake and Columbia river basins; 2) the updating, maintenance, and testing of SNP baselines to describe genetic variation and for use as a reference in conducting GSI for both species; 3) the implementation of GSI to estimate genetic stock composition and life history diversity of steelhead and spring/summer Chinook Salmon passing Lower Granite Dam (LGR); and 4) the summarization of life history and genetic diversity information for steelhead and spring/summer Chinook Salmon detected at PIT tag detection systems. For both species, panels of up to 379 SNPs have been in use for GSI and parentage-based tagging (PBT) at both Idaho Department of Fish and Game's Eagle Fish Genetics Lab, and its collaborating laboratory, the Columbia River Inter-Tribal Fish Commission's Hagerman Genetics Lab. Steelhead SNP baseline version v3.1 consists of 45 collections and 5,967 individuals. Chinook Salmon SNP baseline v3.1 consists of 30 collections and 4,356 individuals. SNP baselines are used to describe genetic diversity and structure of natural-origin populations throughout the Snake River. Based on population structure we have defined 10 genetic stocks for steelhead and 7 genetic stocks for Chinook Salmon for GSI analysis at LGR. We summarize GSI results for returning adults and emigrating juveniles during 2017-2018 at LGR using v3.1 baselines as reference. Finally, we describe the life history variation and genetic diversity of steelhead and Chinook Salmon detected at IPTDS. The information presented in this report provides critical data for viable salmonid population (VSP) monitoring of the Snake River steelhead DPS and the Snake River spring/summer Chinook Salmon ESU.

Johnson, E. L., Kozfkay, C. C., Powell, J. H., Peterson, M. P., Baker, D. J., Heindel, J. A., . . . Kline, P. A. (2020). Evaluating Artificial Propagation Release Strategies for Recovering Endangered Snake River Sockeye Salmon. *North American Journal of Aquaculture, 82*(3), https://doi.org/10.1002/naaq.10148

As a growing number of aquatic organisms become imperiled due to anthropogenic and environmental threats, there is an increasing need to implement captive propagation programs to conserve some species. These captive propagation programs can aid in the recovery of species, such as for Sockeye Salmon Oncorhynchus nerka, by providing individuals that can be used to supplement wild populations. The Snake River Sockeye Salmon Captive Broodstock Program implemented a comprehensive monitoring and evaluation plan to evaluate adult recruitment using three juvenile release strategies from excess eggs of captive females. Hatchery-produced eyed eggs, presmolts, and smolts were released into the upper Salmon River basin to increase the abundance of individuals expressing an anadromous life history as a way to support population augmentation. A mixed-effects logistic regression model used to evaluate eggto-adult returns between release strategies indicated that release strategies differed from one another. Full-term smolt production was observed to produce the highest recruitment among the release strategies and has become the focus of recovery efforts involving juvenile releases. The estimated odds of a fish (egg) returning as an adult were 9.7 times greater for smolts reared at the Oxbow Fish Hatchery and 3.6 times greater for smolts reared at the Sawtooth Fish Hatchery relative to eggs that were hatchery reared and released as presmolts or placed into in-lake incubator boxes. The variation observed in productivity and in expression of life history traits among release strategies indicates that juvenile releases are not one size fits all, and we recommend undertaking a similar assessment to match observed outcomes with desired objectives when initiating supplementation programs.

Kaylor, M. J., White, S. M., Sedell, E. R., & Warren, D. R. (2020). Carcass Additions Increase Juvenile Salmonid Growth, Condition, and Size in an Interior Columbia River Basin Tributary. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(4), https://doi.org/10.1139/cjfas-2019-0215

Numbers ofanadromous fish returning to freshwater ecosystems have declined precipitously across much ofwestern North America, reducing a potentially important resource subsidy for juvenile salmonids. We added carcasses to three sections of a Snake River tributary and assessed juvenile Chinook salmon (Oncorhynchus tshawytcha) and steelhead trout (Oncorhynchus mykiss) growth, body condition, size, and diet responses in summer and early fall. Juvenile salmonids consumed an abundance ofeggs and carcass tissue, which increased energy rations. Within 3 weeks ofcarcass additions, juvenile Chinook and steelhead growth rates were 1.1–5 and 6–23 times greater in treatment reaches relative to control reaches, respectively. We used long-term tagging and detection data from this system to assess the relationship between juvenile Chinook size and emigration survival for two different juvenile life histories. The increased growth rates and body size in response to carcass additions, coupled with a positive relationship between body size and survival, suggest that juvenile salmonid rearing productivity and emigration survival may be limited by depressed returns of anadromous fishes in this system and potentially other tributaries of the Columbia Basin.

Keefer, M. L., & Caudill, C. C. (2016). Estimating Thermal Exposure of Adult Summer Steelhead and Fall Chinook Salmon Migrating in a Warm Impounded River. *Ecology of Freshwater Fish, 25*(4), https://doi.org/10.1111/eff.12238

Rising river temperatures in western North America have increased the vulnerability of many Pacific salmon (Oncorhynchus spp.) populations to lethal and sublethal risks. There is a growing need to predict and manage such risks, especially for populations whose life history or geography increases the likelihood of warmwater exposure. We estimated thermal exposure of adult summer steelhead (O. mykiss) and fall-run Chinook salmon (O. tshawytscha) as they migrated through a warm (often > 20 °C), 157-km reach of the impounded Snake River, Washington. Archival temperature loggers and radiotelemetry were used to reconstruct thermal histories for 50 steelhead and 21 salmon. Encountered temperature maxima were mostly inside dam fishways and ranged from 15.8 to 24.0 °C (mean = 19.6 °C) for steelhead and from 18.0 to 21.6 °C (19.9 °C) for salmon. Behavioural thermoregulation was evident for ~50% of steelhead and ~30% of salmon in one of three reservoirs. Degree days (DDs) calculated from archival tags ranged from 74 to 973 DDs (median = 130) for steelhead and from 56 to 220 DDs (133) for salmon. Models using river temperature data and fish migration times accurately estimated total DDs for both species except some steelhead with extended thermoregulation. In a predictive application, we estimated exposure for 10,104 steelhead and 9071 Chinook salmon with passive integrated transponder-tag detections at dams and found considerable DD variability across individuals, species and years. This estimation method, combined with baseline thermal surveys and existing monitoring infrastructure, can help to address long-standing questions about how warm-water exposure affects

Snake River salmon and steelhead phenology, bioenergetics, physiology, survival and reproductive success.

Keefer, M. L., Clabough, T. S., Jepson, M. A., Bowerman, T., & Caudill, C. C. (2019). Temperature and Depth Profiles of Chinook Salmon and the Energetic Costs of Their Long-Distance Homing Migrations. *Journal of Thermal Biology, 79*, https://doi.org/10.1016/j.jtherbio.2018.12.011

River warming poses an existential threat to many Pacific salmon (Oncorhynchus spp) populations. However, temperature-mediated risks to salmon are often complex and addressing them requires species-and population specific data collected over large spatial and temporal scales. In this study, we combined radiotelemetry with archival depth and temperature sensors to collect continuous thermal exposure histories of 21 adult spring-and summer-run Chinook salmon (0. tshawytscha) as they migrated hundreds of kilometers upstream in the Columbia River basin. Salmon thermal histories in impounded reaches of the Columbia and Snake rivers were characterized by low daily temperature variation but frequent and extensive vertical movements. Dives were associated with slightly cooler salmon body temperatures (similar to 0.01 to 0.02 C/m), but there was no evidence for use of cool-water thermal refuges deep in reservoirs or at tributary confluences along the migration route. In tributaries, salmon were constrained to relatively shallow water, and they experienced similar to 2-5 degrees C diel temperature fluctuations. Differences in migration timing and among route-specific thermal regimes resulted in substantial among-individual variation in migration temperature exposure. Bioenergetics models using the collected thermal histories and swim speeds ranging from 1.0 to 1.5 body-lengths/s predicted median energetic costs of similar to 24-40% (spring-run) and 37-60% (summer-run) of initial reserves. Median declines in total mass were similar to 16-24% for spring-run salmon and similar to 19-29% for summer-run salmon. A simulated + 2 degrees C increase in water temperatures resulted in 4.0% (spring-run) and 6.3% (summer-run) more energy used per fish, on average. The biotelemetry data provided remarkable spatial and temporal resolution on thermal exposure. Nonetheless, substantial information gaps remain for the development of robust bioenergetics and climate effects models for adult Chinook salmon.

Keefer, M. L., Clabough, T. S., Jepson, M. A., Johnson, E. L., Peery, C. A., & Caudill, C. C. (2018). Thermal Exposure of Adult Chinook Salmon and Steelhead: Diverse Behavioral Strategies in a Large and Warming River System. *Plos One, 13*(9), https://doi.org/10.1371/journal.pone.0204274

Rising river temperatures in western North America have increased the energetic costs of migration and the risk of premature mortality in many Pacific salmon (Oncorhynchus spp.) populations. Predicting and managing risks for these populations requires data on acute and cumulative thermal exposure, the spatio-temporal distribution of adverse conditions, and the potentially mitigating effects of cool-water refuges. In this study, we paired radiotelemetry with archival temperature loggers to construct continuous, spatially-explicit thermal histories for 212 adult Chinook salmon (O. tshawytscha) and 200 adult steelhead (O. mykiss). The fish amassed ~500,000 temperature records (30-min intervals) while migrating through 470 kilometers of the Columbia and Snake rivers en route to spawning sites in Idaho, Oregon, and Washington. Spring- and most summer-run Chinook salmon migrated before river temperatures reached annual highs; their body temperatures closely matched ambient temperatures and most had thermal maxima in the lower Snake River. In contrast, many individual fall-run Chinook salmon and most steelhead had maxima near thermal tolerance limits (20–22 °C) in the lower Columbia River. High temperatures elicited extensive use of thermal refuges near tributary confluences, where body temperatures were ~2–10 °C cooler than the adjacent migration corridor. Many steelhead used refuges for weeks or more whereas salmon use was typically hours to days, reflecting differences in spawn timing. Almost no refuge use was detected in a ~260-km reach where a thermal migration barrier may more frequently develop in future warmer years. Within population, cumulative thermal exposure was strongly positively correlated ($0.88 \leq r \leq 0.98$) with migration duration and inconsistently associated ($-0.28 \leq r \leq 0.09$) with migration date. All four populations have likely experienced historically high mean and maximum temperatures in recent years. Expected responses include population-specific shifts in migration phenology, increased reliance on patchily-distributed thermal refuges, and natural selection favoring temperature-tolerant phenotypes.

Knut Marius, M., & Kennedy, B. P. (2017). Indexing Salmonid Abundance in Small Streams Using Reduced Effort Electrofishing. *91*(4), https://doi.org/10.3955/046.091.0404

A paradox in managing threatened and endangered species is the increased need for documenting population status, which in many instances requires capturing and handling individuals. Electrofishing is a widely used method for sampling fish in small streams, but the potential for detrimental effects call for its careful use. Methods that reduce exposure for individual fish, yet still provide useful abundance estimates, are therefore desirable. Using data from a juvenile steelhead (Oncorhynchus mykiss) monitoring program in Idaho, we quantified variation and bias in capture probability from three-pass depletion electrofishing, and evaluated a method for indexing abundance based on single-pass electrofishing. Capture probability varied primarily at the level of sampling visits, with little spatial variation (i.e. at the level of the study sites). Water temperature, channel depth and, to a lesser degree, discharge best described the variation in capture probability between sampling events. We found no effect of previous capture and handling on individual capture probability, and the capture probability did not differ between subyearling and overyearling fish. Finally, a simple mixed-effects model with study site as a random effect, which related first-pass catch to the associated multiple-pass removal estimate, explained 91% of the variation in our data. The main limitation of the approach is that it does not provide error propagation and confidence intervals to the abundance estimates. However, the approach can be useful where multiple depletion electrofishing data exist, and when a single point estimate is sufficient to monitor major population trends in small streams.

Kozfkay, C. C., Peterson, M., Sandford, B. P., Johnson, E. L., & Kline, P. (2019). The Productivity and Viability of Snake River Sockeye Salmon Hatchery Adults Released into Redfish Lake, Idaho. *Transactions of the American Fisheries Society, 148*(2), https://doi.org/10.1002/tafs.10136

In 1991, the Snake River Sockeye Salmon Captive Broodstock Program was initiated to prevent the extinction and preserve the genetic diversity of this evolutionarily significant unit protected by the Endangered Species Act. At the time of listing, the Redfish Lake Sockeye Salmon Oncorhynchus nerka population was considered functionally extinct. One of the recovery strategies entails the release of adults for volitional spawning in Redfish Lake, Idaho, for rebuilding of the natural population. In this paper, we describe the productivity metrics from this strategy. We evaluated eight spawn years to address three primary questions: (1) What metrics for eggs to smolts, smolts per female, and smolt-to-adult returns (SARs) result from recent adult releases? (2) How do these metrics compare with historical estimates for Redfish Lake and estimates for other Sockeye Salmon populations throughout the range? and (3) Does the current combination of smolts per female and SARs result in population replacement? Replacement was determined as two adult recruits per female assuming an even sex ratio. We found that the reintroduced adults, despite being derived from a multigenerational captive broodstock, were able to successfully spawn and produce offspring that migrated to the ocean and returned as adults. Smolt abundance, size, and age data suggest that the population is functioning below density dependence. However, increased smolt production did not translate into greater adult returns and this is likely due to out-of-basin factors. Productivity metrics were similar to those of the wild population in Redfish Lake during the 1950s and 1960s. However, both current and historic productivity estimates were near the low end of the range for other Sockeye Salmon populations and have not resulted in population replacement. Until freshwater and out-of-basin survival can be improved, our data suggest that adult releases will continue to be an important recovery strategy to prevent cohort collapse and to rebuild naturally spawning populations.

Li, X. Y., Deng, Z. Q. D., Brown, R. S., Fu, T., Martinez, J. J., McMichael, G. A., . . . Renholds, J. F. (2015). Migration Depth and Residence Time of Juvenile Salmonids in the Forebays of Hydropower Dams Prior to Passage through Turbines or Juvenile Bypass Systems: Implications for Turbine-Passage Survival. *Conservation Physiology, 3*(1), https://doi.org/10.1093/conphys/cou064

Little is known about the three-dimensional depth distributions in rivers of individually marked fish that are in close proximity to hydropower facilities. Knowledge of the depth distributions of fish approaching dams can be used to understand how vulnerable fish are to injuries such as barotrauma as they pass through dams. To predict the possibility of barotrauma injury caused by pressure changes during turbine passage, it is necessary to understand fish behaviour relative to acclimation depth in dam forebays as they approach turbines. A guiding study was conducted using high-resolution three-dimensional tracking results of salmonids implanted with Juvenile Salmon Acoustic Telemetry System transmitters to investigate the depth distributions of subyearling and yearling Chinook salmon (Oncorhynchus tshawytscha) and juvenile steelhead (Oncorhynchus mykiss) passing two dams on the Snake River in Washington State. Multiple approaches were evaluated to describe the depth at which fish were acclimated, and statistical analyses were performed on large data sets extracted from similar to 28 000 individually tagged fish during 2012 and 2013. Our study identified patterns of depth distributions of juvenile salmonids in forebays prior to passage through turbines or juvenile bypass systems. This research indicates that the median depth at which juvenile salmonids approached turbines ranged from 2.8 to 12.2 m, with the depths varying by species/life history, year, location (which dam) and diel period (between day and night). One of the most enlightening findings was the difference in dam passage associated with the diel period. The amount of time that turbine-passed fish spent in the immediate forebay prior to entering the powerhouse was much lower during the night than during the day. This research will allow scientists to understand turbine-passage survival better and enable them to assess more accurately the effects of dam passage on juvenile salmon survival.

Li, X. Y., Deng, Z. Q. D., Fu, T., Brown, R. S., Martinez, J. J., McMichael, G. A., . . . Townsend, R. L. (2018). Three-Dimensional Migration Behavior of Juvenile Salmonids in Reservoirs and near Dams. *Scientific Reports, 8*(1), https://doi.org/10.1038/s41598-018-19208-1

To acquire 3-D tracking data on juvenile salmonids, Juvenile Salmon Acoustic Telemetry System (JSATS) cabled hydrophone arrays were deployed in the forebays of two dams on the Snake River and at a mid-reach reservoir between the dams. The depth distributions of fish were estimated by statistical analyses performed on large 3-D tracking data sets from similar to 33,500 individual acoustic tagged yearling and subyearling Chinook salmon and juvenile steelhead at the two dams in 2012 and subyearling Chinook salmon at the two dams and the mid-reach reservoir in 2013. This research investigated the correlation between vertical migration behavior and passage routes. The depth distributions of fish within the forebays of the dams were significantly different from fish passing the mid-reach reservoir. Fish residing deeper in the forebay tended to pass the dam using deeper powerhouse routes. This difference in depth distributions indicated that the depth distribution of fish at the mid-reach reservoir was not related to behaviors of fish passing through certain routes of the adjacent dams. For fish that were detected deeper than 17.5 m in the forebays, the probability of powerhouse passage (i.e., turbine) increased significantly. Another important finding was the variation in depth distributions during dam passage associated with the diel period, especially the crepuscular periods.

Matala, A. P., Hatch, D. R., Everett, S., Ackerman, M. W., Bowersox, B., Campbell, M., & Narum, S. (2016). What Goes up Does Not Come Down: The Stock Composition and Demographic Characteristics of Upstream Migrating Steelhead Differ from Post-Spawn Emigrating Kelts. *Ices Journal of Marine Science, 73*(10), https://doi.org/10.1093/icesjms/fsw109

Iteroparity (repeat spawning) is a life history attribute with significant conservation value for at-risk populations of steelhead trout (Oncorhynchus mykiss). However, stock-specific rates of iteroparity and abundance of post-spawned steelhead “kelts” can be difficult to monitor in large river systems where multiple populations are commonly encountered as aggregated mixtures. We used genetic mixed-stock analysis (MSA) to determine steelhead origins and tested for stock-specific differences in the prevalence of an iterparous reproductive strategy. Steelhead from the Snake River, USA were sampled as “returns” migrating upstream to spawn and as emigrating post-spawned “kelts”. Fish were assigned between two regions that are characterized by predominant run-type. We observed a larger overall proportion of kelts from region-1 (putative-A run; 82%) compared to kelts from region-2 (putative B-run; 18%), but returns from region-2 (30%) were nearly twice as abundant as kelts. Female kelts were predominant throughout the basin, occurring in similar proportions between regions (72% region-1, 77% region-2). The inferred ocean age distribution of kelts was distinct between regions, and regional differences in body size and emigration timing were significant ($P < 0.0001$). Although the ocean age-classes for kelts and returns within the same region were similarly distributed, kelts were significantly smaller in average body size compared to returns, and the results were temporally consistent. The association between body size and post-spawn survival suggests that strategies to improve overall recovery of steelhead, such as artificial reconditioning, may achieve greater success by targeting smaller kelts. Moreover, monitoring of post-spawn survival, and repeat spawning potential will likely benefit from MSA to augment demographic information and improve the accuracy of differentiating among specific stocks or regions.

McCormick, J. L., Whitney, D., Schill, D. J., & Quist, M. C. (2015). Evaluation of Angler Reporting Accuracy in an Off-Site Survey to Estimate Statewide Steelhead Harvest. *Fisheries Management and Ecology, 22*(2), https://doi.org/10.1111/fme.12109

Accuracy of angler-reported data on steelhead, Oncorhynchus mykiss (Walbaum), harvest in Idaho, USA, was quantified by comparing data recorded on angler harvest permits to the numbers that the same group of anglers reported in an off-site survey. Anglers could respond to the off-site survey using mail or Internet; if they did not respond using these methods, they were called on the telephone. A majority of anglers responded through the mail, and the probability of responding by Internet decreased with increasing age of the respondent. The actual number of steelhead harvested did not appear to influence the response type. Anglers in the autumn 2012 survey overreported harvest by 24%, whereas anglers in the spring 2013 survey under-reported steelhead harvest by 16%. The direction of reporting bias may have been a function of actual harvest, where anglers harvested on average 2.6 times more fish during the spring fishery than the autumn. Reporting bias that is a function of actual harvest can have substantial management and conservation implications because the fishery will be perceived to be performing better at lower harvest rates and worse when harvest rates are higher. Thus, these findings warrant consideration when designing surveys and evaluating management actions.

Morrisett, C. N., Skalski, J. R., & Kiefer, R. B. (2019). Passage Route and Upstream Migration Success: A Case Study of Snake River Salmonids Ascending Lower Granite Dam. *North American Journal of Fisheries Management, 39*(1), https://doi.org/10.1002/nafm.10245

Lower Granite Dam is the last dam that federally protected Snake River salmonids Oncorhynchus spp. must ascend during their spawning migration. The dam has an adult fish ladder equipped with a trapping system to facilitate fisheries research and hatchery broodstock collection. There are three possible passage routes through the adult ladder: trapped, shunted, and free passage. During the adult trapping season, all fish must swim through 0.305-m shunt pipes outfitted with PIT tag arrays that allow the selection of fish for trapping. Selected fish use the "trapped" route and are kept in a holding area for up to 20 h before being sampled and returned to the ladder. Unselected fish use the "shunted" route and immediately resume upstream migration after swimming through the pipes. When the trap is not in operation, the shunted route is inaccessible, and all fish use the "free passage" route to ascend the ladder without additional impediment. In 2016, a temporary change in ladder operations permitted free passage for a portion of the trapping season. Our study used this rare opportunity to evaluate how different passage routes affect in-ladder transit time and upstream homing success for five salmonid stocks: Sockeye Salmon Oncorhynchus nerka; steelhead O. mykiss; and spring-, summer-, and fall-run Chinook Salmon O. tshawytscha. In 2016, only Sockeye Salmon and spring- and summer-run Chinook Salmon were given access to free passage, and we found evidence that free passage increased subsequent detection at natal sites upstream. An expanded analysis of shunted versus trapped fish during the years 2012-2016 found no difference in rates of detection to home tributaries by route of passage for any of the five fish stocks examined.

National Marine Fisheries Service. (2015). *ESA Recovery Plan for Snake River Sockeye Salmon (Oncorhynchus Nerka)*. Retrieved from https://repository.library.noaa.gov/view/noaa/16001

This recovery plan (Plan) serves as a blueprint for the protection and restoration of Snake River Sockeye Salmon (Oncorhynchus nerka). Snake River Sockeye Salmon were listed as an endangered species under the Endangered Species Act (ESA) in 1991. The listing was reaffirmed in 2005. The species remains at risk of extinction.

National Marine Fisheries Service. (2015). *Passage and Survival of Adult Snake River Sockeye Salmon within and Upstream from the Federal Columbia River Power System: 2014 Update*. Retrieved from https://www.nwfsc.noaa.gov/assets/26/9046_02102017_141813_Crozier%20et%20al%202015%20Sockeye_2008_2014.pdf

Sockeye salmon Oncorhynchus nerka originating in the Sawtooth Valley make up the only remaining population of this species in the upper Snake River Basin. These fish are listed as an evolutionary significant unit (ESU) under the U.S. Endangered Species Act. With adult returns as low as one in 1992 and three in 2006, this ESU is considered one of the most threatened among the listed stocks of Pacific salmon Oncorhynchus spp. In 1991, a captive broodstock rearing program was established for Snake River sockeye salmon. Production from this program has maintained genetic variation in the population. In recent years, larger numbers of hatchery smolt releases and relatively high ocean survival have led to an increased number of returning adults. The increased number of Snake River sockeye returns has made it possible to investigate factors influencing migration survival, an important step in reestablishing natural production of the anadromous population and determining strategies for recovery.

National Marine Fisheries Service. (2016). *2016 5-Year Review: Summary & Evaluation of Snake River Sockeye Snake River Spring-Summer Chinook Snake River Fall-Run Chinook Snake River Basin Steelhead*. Portland, OR Retrieved from https://repository.library.noaa.gov/view/noaa/17050

Many West Coast salmon and steelhead (Oncorhynchus spp.) stocks have declined substantially from their historical numbers and now are at a fraction of their historical abundance. Several factors contribute to these declines, including: overfishing, loss and degradation of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices. These factors collectively led to the National Marine Fisheries Service's (NMFS) listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA). The ESA, under section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent listing determinations for most salmon and steelhead occurred in 2005 and 2006. This document describes the results of the agency's 5-year review of the ESA-listed salmonid species in the Snake River basin. These include: Snake River Sockeye Salmon, Snake River spring/summer Chinook salmon, Snake River fall-run Chinook salmon, and Snake River steelhead.

National Marine Fisheries Service. (2017). *Characterizing Migration and Survival between the Upper Salmon River Basin and Lower Granite Dam for Juvenile Snake River Sockeye Salmon, 2011-2014*. Retrieved from https://www.nwfsc.noaa.gov/assets/26/9121_05192017_160028_Axel.et.al.2017-Sock-Surv-2011-2014.pdf

During spring 2011-2014, we tagged and released groups of juvenile hatchery Snake River sockeye salmon Oncorhynchus nerka to Redfish Lake Creek in the upper Salmon River Basin. These releases were part of a coordinated study to characterize migration and survival of juvenile sockeye to Lower Granite Dam. We estimated detection probability, survival, and travel time based on detections of fish tagged with either a passive integrated transponder (PIT) or radio transmitter and PIT tag. Passage metrics were then compared between cohorts of fish from Sawtooth vs. Oxbow Fish Hatcheries and between fish released during daytime vs. nighttime periods.

National Marine Fisheries Service. (2018). *Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2017*. Retrieved from https://www.nwfsc.noaa.gov/assets/26/9359_02262018_135356_Widener.et.al.2018-Spring-Survival-2017.pdf

In 2017, we completed the 25th year of a study to estimate survival and travel time of juvenile Pacific salmon Oncorhynchus spp. passing dams and reservoirs on the Snake and Columbia Rivers. All estimates were derived from detections of fish tagged with passive integrated transponder (PIT) tags. We tagged and released a total of 21,470 hatchery steelhead O. mykiss, 19,003 wild steelhead, and 14,247 wild yearling Chinook salmon O. tshawytscha at Lower Granite Dam on the Snake River. In addition to detections of these fish, we used detections of yearling Chinook and steelhead tagged by other researchers upstream from Lower Granite Dam and at other hatcheries and traps on the Snake and Columbia Rivers. Detection sites were the juvenile bypass systems at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dam, as well as the Bonneville corner collector and PIT-tag detector trawl operated in the Columbia River estuary. Survival estimates were calculated using a statistical model for tag-recapture data from single release groups (the single-release model). Primary research objectives in 2017 were: 1) Estimate reach survival and travel time in the Snake and Columbia Rivers throughout the migration period of yearling Chinook salmon and steelhead 2) Evaluate relationships between survival estimates and migration conditions 3) Evaluate the survival estimation models under prevailing conditions In 2017, we estimated reach survival and travel time for hatchery and wild yearling Chinook salmon, hatchery sockeye O. nerka, hatchery coho salmon O. kisutch, and hatchery and wild steelhead. During most of the migration season, detections of yearling Chinook salmon and steelhead were sufficient to estimate survival and detection probabilities for daily or weekly groups leaving Lower Granite and McNary Dam. Hatchery and wild fish were combined in some analyses. For PIT-tagged fish detected or released at Lower Granite Dam, overall percentages by origin were 61% hatchery and 39% wild for yearling Chinook and 72% hatchery and 28% wild for steelhead. Based on collection counts at Lower Granite Dam by the Fish Passage Center and on our estimates of daily detection probability, we estimated that 87.6% of the overall yearling Chinook salmon run in 2017 was of hatchery origin. We could not calculate this number for steelhead because separate collection counts of hatchery and wild fish were not available.

Nichols, K. M., Kozfkay, C. C., & Narum, S. R. (2016). Genomic Signatures among Oncorhynchus Nerka Ecotypes to Inform Conservation and Management of Endangered Sockeye Salmon. *Evolutionary Applications, 9*(10), https://doi.org/10.1111/eva.12412

Conservation of life history variation is an important consideration for many species with trade-offs in migratory characteristics. Many salmonid species exhibit both resident and migratory strategies that capitalize on benefits in freshwater and marine environments. In this study, we investigated genomic signatures for migratory life history in collections of resident and anadromous Oncorhynchus nerka (Kokanee and Sockeye Salmon, respectively) from two lake systems, using ~2,600 SNPs from restriction-site-associated DNA sequencing (RAD-seq). Differing demographic histories were evident in the two systems where one pair was significantly differentiated (Redfish Lake, FST = 0.091 [95% confidence interval: 0.087 to 0.095]) but the other pair was not (Alturas Lake, FST = ?0.007 [?0.008 to ?0.006]). Outlier and association analyses identified several candidate markers in each population pair, but there was limited evidence for parallel signatures of genomic variation associated with migration. Despite lack of evidence for consistent markers associated with migratory life history in this species, candidate markers were mapped to functional genes and provide evidence for adaptive genetic variation within each lake system. Life history variation has been maintained in these nearly extirpated populations of O. nerka, and conservation efforts to preserve this diversity are important for long-term resiliency of this species.

Oregon Department of Fish and Wildlife. (2014). *Lower Snake River Compensation Plan: Summer Steelhead Creel Surveys on the Grande Ronde, Wallowa, and Imnaha Rivers for the 2011-12 Run Year*. Retrieved from https://www.fws.gov/lsnakecomplan/reports/ODFW/Eval/2011-2012%20Annual%20Steelhead%20Creel%20Report.pdf

In the 2011-12 run year, estimated angler effort (20,724 hrs) was higher than the average (approx. 15,000 hrs) recorded since surveys began in 1985 on the lower Grande Ronde River; however, on the Imnaha River effort (3,647 hrs) was below average (4,205 hrs). Total catch estimates became available for run year 2010-11, and they were well above average on both the lower Grande Ronde River and the Imnaha rivers, as was catch and release of wild steelhead on the lower Grande Ronde. Fiftyfive percent of the catch on the lower Grande Ronde were wild fish that were subsequently released. On the Imnaha River the number of wild steelhead caught and released is unknown due to unmarked hatchery returns in recent years, although the number of unmarked hatchery and wild steelhead released was about average. On the lower Grande Ronde River we estimate that 1,427 hatchery steelhead were harvested, whereas 126 hatchery steelhead were harvested in the Imnaha River fishery. This report includes angler harvest card data for the Wallowa River and Rondowa survey areas for the 2010-11 run year, summarized in the appendices. Based on creel and harvest card data, harvest was 3,355 fish and total catch was 6,702 fish. Wild fish comprised 18% and 26% of the respective Wallowa and Rondowa catch, which was similar to previous years. In every Grande Ronde basin fishery surveyed, catch rates during the 2011-12 run year were nearly as good as the record setting 2009-10 run year (range: 3 – 6 hrs/fish), and were much better than the overall management goal of 10 hours per fish. On the Imnaha River, catch rates were 8 hrs/fish; the poorest rates since 1999-00.

Oregon Department of Fish and Wildlife. (2015). *A Compendium of Viable Salmonid Population Abundance and Productivity Indicators and Metrics for Natural Chinook Salmon and Steelhead Populations in Tributaries of the Middle Columbia and Snake Rivers of Northeast-Central Oregon from 1948 to 2014*. Retrieved from https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?p=202&XMLname=1100.xml

The North-East Central Oregon Fish Research and Monitoring Program (NECORM) is a fish research and monitoring program within the Oregon Department of Fish and Wildlife (ODFW). NECORM's main office is located on the campus of Eastern Oregon University in La Grande, OR, with field offices located throughout central and eastern Oregon. The mission of NECORM is to provide, through field investigations, laboratory experimentation and literature review, biological knowledge necessary for effective management of Oregon's fish and wildlife resources. The information provided is essential for accomplishing ODFW's mission to protect and enhance Oregon's fish and wildlife and their habitats for the use and enjoyment of present and future generations. Research projects are designed to produce new knowledge and techniques to solve problems that will ultimately result in recovery and enhancement of Oregon's fish resources and their habitats.

Oregon Department of Fish and Wildlife. (2015). *Lower Snake River Compensation Plan: Summer Steelhead Creel Surveys on the Grande Ronde, Wallowa, and Imnaha Rivers for the 2012-13 Run Year*. Retrieved from https://www.fws.gov/lsnakecomplan/reports/ODFW/Eval/2012-2013%20Annual%20Steelhead%20Creel%20Report_Final.pdf

Creel survey data for the 2012-13 run year were indicative of less successful summer steelhead fisheries in the Grande Ronde and Imnaha River basins than in recent years. Estimated angler effort on the lower Grande Ronde River (14,514 hrs) was below the 10-year average (approx. 19,808 hrs) and on the Imnaha River effort (3,857 hrs) was also below the 10-year average (5,706 hrs). Total catch on the lower Grande Ronde River was 1,986 fish and on the Imnaha River it was 336 fish; 57% and 19% of their respective 10-year averages. Total steelhead harvest was similarly low at 594 fish (lower Grande Ronde River) and 126 fish (Imnaha River). The total catch of wild steelhead in the lower Grande Ronde River for the current run year was 1,090 fish, which was the second lowest total since the 2000-01 run year. However, for the third year in a row catch of wild steelhead in the lower Grande Ronde River fishery comprised over 50% of the total steelhead catch. We speculate that the high percentage of wild steelhead in the catch may be due to a change in the ratio of hatchery to wild steelhead in the river, caused by a decline in the hatchery steelhead run. This report includes angler harvest card data (total catch, effort, and harvest) for the middle Grande Ronde River, the Wallowa River and Rondowa survey areas for the 2011-12 run year, summarized in the appendices. Based on creel and harvest card data, combined total catch in those areas was 5,225 fish, total harvest was 2,401 fish, and total effort was 23,543 hours. All three metrics were lower than the prior run year and they were below their respective 10-year averages. Wild fish comprised 23.8% and 15.5% of the respective Wallowa and Rondowa catch, which was similar to previous years. In every Grande Ronde basin fishery surveyed, catch rates during the 2012-13 run year were worse than they had been in at least the last three years. On the Wallowa River the catch rate (10 hrs/fish) was the poorest since the 2002-03 run year. Similarly, on the Imnaha River catch rates were 11 hrs/fish; the poorest rates since 1999-00.

Oregon Department of Fish and Wildlife. (2016). *Lower Snake River Compensation Plan: Summer Steelhead Creel Surveys on the Grande Ronde, Wallowa, and Imnaha Rivers for the 2013-14 Run Year*. Retrieved from https://www.fws.gov/lsnakecomplan/reports/ODFW/Eval/2013-2014%20Annual%20Steelhead%20Creel%20Report_Final.pdf

Creel survey data for the 2013-14 run year were indicative of less successful summer steelhead fisheries in the Grande Ronde and Imnaha River basins than in recent years. Estimated angler effort on the lower Grande Ronde River (12,296 hrs) was below the 10-year average (18,717 hrs) and on the Imnaha River effort (2,826 hrs) was also below the 10-year average (5,196 hrs). Total catch on the lower Grande Ronde River was 1,394 fish and on the Imnaha River it was 408 fish; 42% and 25% of their respective 10-year averages. Total steelhead harvest was similarly low at 454 fish (lower Grande Ronde River) and 106 fish (Imnaha River). The total catch of wild steelhead in the lower Grande Ronde River for the current run year was 786 fish, which was the second lowest total since the 2000-01 run year. However, for the fourth year in a row catch of wild steelhead in the lower Grande Ronde River fishery comprised over 50% of the total steelhead catch. We speculate that the high percentage of wild steelhead in the catch may be due to a change in the ratio of hatchery to wild steelhead in the river, caused by a decline in the hatchery steelhead run. Wild fish comprised 26.7% of the Wallowa River catch. Anglers reported having caught just three steelhead at Rondowa, only one of them being a wild fish. n every Grande Ronde basin fishery surveyed, catch rates during the 2013-14 run year were as bad, or worse, as in any of the last ten years. Most notable was the poor catch rate at Rondowa (65 hrs/fish) which was the lowest rate we have seen in the history of the program. In the Management Implications section of this report we provide some possible explanations for the unusually low catch rate at that location. However, on the Imnaha River catch rates were 7 hrs/fish; an improvement over the prior two years.

Oregon Department of Fish and Wildlife. (2017). *Lower Snake River Compensation Plan: Summer Steelhead Creel Surveys on the Grande Ronde, Wallowa, and Imnaha Rivers for the 2014-15 Run Year*. Retrieved from https://www.fws.gov/lsnakecomplan/reports/ODFW/Eval/2014-2015%20Annual%20Steelhead%20Creel%20Report_FINAL.pdf

Creel survey data for the 2014-15 run year were indicative of mixed success for summer steelhead fisheries in the Grande Ronde and Imnaha River basins. Metrics for angler effort on the lower Grande Ronde River (12,128 hrs) the Imnaha River (4,507 hrs), and total catch on both rivers (Grande Ronde = 1,654 fish, Imnaha = 802 fish) were all below their respective 10-year averages. However, anglers that participated experienced average fishing success as catch rates of 7.0 hrs/fish and 6.0 hrs/fish on the lower Grande Ronde River and Imnaha rivers.Total steelhead harvest was 401 fish on the lower Grande Ronde River and 243 fish on the Imnaha River. The total catch of wild steelhead in the lower Grande Ronde River for the current run year was 1,069 fish, below the 10-year average. However, for the fifth year in a row catch of wild steelhead in the lower Grande Ronde River fishery comprised over 50% of the total steelhead catch. We speculate that the high percentage of wild steelhead catch may be due to a decline in the returns of hatchery steelhead. Wild fish comprised 25.5% of the Wallowa River catch. This report includes angler harvest card data (total catch, effort, and harvest) for the middle Grande Ronde River, the Wallowa River and Rondowa survey areas for the 2013-14 run year, summarized in the appendices. Based on creel and harvest card data, combined total catch in those areas was 1,650 fish, total harvest was 904 fish, and total effort was 43,657 hours. For the second year in a row, catch and harvest were substantially lower than the prior run year and below their respective 10-year averages. Effort was substantially higher than the prior run year.

Oregon Department of Fish and Wildlife. (2018). *Lower Snake River Compensation Plan: Summer Steelhead Creel Surveys on the Grande Ronde, Wallowa, and Imnaha Rivers for the 2015-16 Run*

Year. Retrieved from https://www.fws.gov/lsnakecomplan/reports/ODFW/Eval/2015-2016%20Annual%20Steelhead%20Creel%20Report_FINAL.pdf

Creel survey data for the 2015-16 run year indicate average angler participation and success for summer steelhead fisheries in the Grande Ronde basin but poor participation and success in the Imnaha River basin. For example, angler effort on the lower Grande Ronde River (13,879 hrs) was higher than the prior two seasons and harvest in 2015-16 (903 fish) was near the 10-year average (974 fish). Conversely, Imnaha River effort (2,103 hrs) and harvest (73) were the lowest observed since the mid-1990s. Anglers that participated experienced better than average fishing success in the lower Grande Ronde River as catch rates were 5.0 hrs/fish, but poorer than average catch rates (9.0 hrs/fish) on the Imnaha River. The total catch of wild steelhead in the lower Grande Ronde River for the current run year was 1,410 fish, which was above the 10-year average of 1,303 fish. In 201516 wild fish comprised 50% of total catch, whereas in the prior 5 years wild steelhead were over 50% of the catch. This may be due to a decline in the hatchery steelhead run affecting the ratio of hatchery to wild steelhead in the river. Wild fish comprised 25.5% of the Wallowa River catch. This report includes angler harvest card data (total catch, effort, and harvest) for the middle Grande Ronde River, the Wallowa River and Rondowa survey areas for the 2014-15 run year, summarized in the appendices. Based on creel and harvest card data, combined total catch in those areas was 7,281 fish, total harvest was 3,248 fish, and total effort was 37,362 hours. Catch and harvest were at least three times higher than the 2013-14 season and near to or better than the 10-year averages.

Petrosky, C. E., Schaller, H. A., Tinus, E. S., Copeland, T., & Storch, A. J. (2020). Achieving Productivity to Recover and Restore Columbia River Stream-Type Chinook Salmon Relies on Increasing Smolt-to-Adult Survival. *North American Journal of Fisheries Management, 40*(3), https://doi.org/10.1002/nafm.10449

We analyzed and compared productivity and survival rates of populations of stream-type Chinook Salmon Oncorhynchus tshawytscha from the upper and middle ranges of their distribution in the Columbia River basin. These two groups of populations undergo vastly different exposures during migration through the Federal Columbia River Power System (FCRPS). Declines of the Snake River populations, listed as threatened under the U.S. Endangered Species Act, have been associated with the development and operation of the FCRPS. In contrast, John Day River streamtype Chinook Salmon populations, which were less affected by the FCRPS, have declined to a lesser extent and are not listed. Smolt-to-adult survival rates (SARs) accounted for a majority of the variation in life cycle survival rates of Snake River Chinook Salmon. Productivity declined to 13% and 44% of historical productivity levels for Snake River and John Day River populations, respectively. A synthesis of previous studies contrasting anthropogenic impacts between the two regions supports the conclusion that FCRPS impacts explain the large difference in population productivity. Our results suggest that SARs of 4% would result in an expected productivity of up to 70% of historical levels (a SAR level consistent with regional restoration objectives). The SARs have been shown to be highly influenced by conditions within the FCRPS (e.g., water velocity and passage through dam powerhouses). Marine conditions also influence SARs; however, meaningful management actions are only available to affect conditions within the FCRPS. Given the importance of SARs to overall life cycle productivity, recovery and restoration strategies need to prioritize actions that have potential to substantially increase SARs by addressing the significant impacts of main-stem dams. This study highlights the importance of considering river management options in the face of increasingly variable and warming ocean conditions.

Plumb, J. M. (2018). A Bioenergetics Evaluation of Temperature-Dependent Selection for the Spawning Phenology by Snake River Fall Chinook Salmon. *Ecology and Evolution, 8*(19), https://doi.org/10.1002/ece3.4353

High water temperatures can increase the energetic cost for salmon to migrate and spawn, which can be important for Snake River fall-run Chinook salmon because they migrate great distances (>500km) at a time when river temperatures (18-24 degrees C) can be above their optimum temperatures (16.5 degrees C). Average river temperatures and random combinations of migration and spawning dates were used to simulate fish travel times and determine the energetic consequences of different thermal experiences during migration. An energy threshold criterion (4kJ/g) was also imposed on survival and spawning success, which was used to determine how prevailing temperatures might select against certain migration dates and thermal experiences, and in turn, explain the selection for the current spawning phenology of the population. Scenarios of tributary use for thermal refugia under increasing water temperatures (1, 2, and 3 degrees C) were also run to determine which combinations of migration dates, travel rates, and resulting thermal experiences might be most affected by energy exhaustion. As expected, when compared to observations, the model under existing conditions and energy use could explain the onset, but not the end of the observed spawning migration. Simulations of early migrants had greater energy loss than late migrants regardless of the river temperature scenario, but higher temperatures disproportionately selected against a larger fraction of early-migrating fish, although using cold-water tributaries during migration provided a buffer against higher energy use at higher temperatures. The fraction of simulated fish that exceeded the threshold for migration success increased from 58% to 72% as average seasonal river temperatures over baseline temperatures increased. The model supports the conclusion that increases in average seasonal river temperatures as little as 1 degrees C could impose greater thermal constraints on the fish, select against early migrants, and in turn, truncate the onset of the current spawning migration.

Plumb, J. M., & Moffitt, C. M. (2015). Re-Estimating Temperature-Dependent Consumption Parameters in Bioenergetics Models for Juvenile Chinook Salmon. *Transactions of the American Fisheries Society, 144*(2), https://doi.org/10.1080/00028487.2014.986336

Researchers have cautioned against the borrowing of consumption and growth parameters from other species and life stages in bioenergetics growth models. In particular, the function that dictates temperature dependence in maximum consumption (Cmax) within the Wisconsin bioenergetics model for Chinook Salmon Oncorhynchus tshawytscha produces estimates that are lower than those measured in published laboratory feeding trials. We used published and unpublished data from laboratory feeding trials with subyearling Chinook Salmon from three stocks (Snake, Nechako, and Big Qualicum rivers) to estimate and adjust the model parameters for temperature dependence in Cmax. The data included growth measures in fish ranging from 1.5 to 7.2 g that were held at temperatures from 14°C to 26°C. Parameters for temperature dependence in Cmax were estimated based on relative differences in food consumption, and bootstrapping techniques were then used to estimate the error about the parameters. We found that at temperatures between 17°C and 25°C, the current parameter values did not match the observed data, indicating that Cmax should be shifted by about 4°C relative to the current implementation under the bioenergetics model. We conclude that the adjusted parameters for Cmax should produce more accurate predictions from the bioenergetics model for subyearling Chinook Salmon.

Powell, J. H., & Campbell, M. R. (2020). Contemporary Genetic Structure Affects Genetic Stock Identification of Steelhead Trout in the Snake River Basin. *Ecology and Evolution*, https://doi.org/10.1002/ece3.6708

Genetic stock identification is a widely applied tool for the mixed-stock management of salmonid species throughout the North Pacific Rim. The effectiveness of genetic stock identification is dependent on the level of differentiation among stocks which is often high due to the life history of these species that involves high homing fidelity to their natal streams. However, the utility of this tool can be reduced when natural genetic structuring has been altered by hatchery translocation and/or supplementation. We examined the genetic population structure of ESA-listed steelhead in the Snake River basin of the United States. We analyzed 9,613 natural-origin adult steelhead returning to Passive Integrated Transponder detection sites throughout the basin from 2010 through 2017. Individuals were genotyped at 180 single nucleotide polymorphic genetic markers and grouped into 20 populations based on their return location. While we expected to observe a common pattern of hierarchical genetic structuring due to isolation by distance, we observed low genetic differentiation between populations in the upper Salmon River basin compared to geographically distant populations in the lower Snake River basin. These results were consistent with lower genetic stock assignment probabilities observed for populations in this upper basin. We attribute these patterns of reduced genetic structure to the translocation of lower basin steelhead stocks and ongoing hatchery programs in the upper Salmon River basin. We discuss the implications of these findings on the utility of genetic stock identification in the basin and discuss opportunities for increasing assignment probabilities in the face of low genetic structure.

Rechisky, E. L., Welch, D. W., Porter, A. D., Hess, J. E., & Narum, S. R. (2014). Testing for Delayed Mortality Effects in the Early Marine Life History of Columbia River Basin Yearling Chinook Salmon. *Marine Ecology Progress Series, 496*, https://doi.org/http://dx.doi.org/10.3354/mepsl0692

Juvenile Snake River Chinook salmon Oncorhynchus tshawytscha pass through 8 major hydroelectric dams during their >700 km migration to the sea, or are transported downriver to avoid these dams. Both of these anthropogenic processes may decrease fitness and lead to delayed mortality in the estuary and coastal ocean, and thus reduce the rate at which adults return to spawn. Using a large-scale telemetry array, we tested whether there was support for (1) hydrosysteminduced delayed mortality (hydro-DM) of yearlings migrating from the Snake River relative to yearlings migrating from the mid-Columbia River, and (2) transportation-induced delayed mortality (transport-DM) for transported Snake River yearlings relative to yearlings which migrated in-river. We also tested for differential early marine survival between yearlings migrating from the Snake and upper Columbia Rivers. In 2010, seaward migrating yearling Chinook were captured at dam bypasses and origin was based on capture location; in 2011, dam-caught fish were identified using genetic stock identification. Survival of all groups during the initial 750 km, >1 mo long migration through the estuary and coastal ocean to northwestern Vancouver Island ranged between 14 and 19% in 2010 and was lower in 2011 (1.5-8 %). We found no supportfor hydro-DM, as survival of inriver migrating Snake and mid-Columbia River yearlings was indistinguishable. We found mixed results for our transportation study, with no support for transport-DM in 2010, and weak support in 2011. Our study provides further evidence that freshwater management strategies may not increase the rate of Chinook salmon returning to the Snake River if prior freshwater experience has no substantial influence on subsequent survival in the ocean.

Richins, S. M., & Skalski, J. R. (2018). Steelhead Overshoot and Fallback Rates in the Columbia-Snake River Basin and the Influence of Hatchery and Hydrosystem Operations. *North American Journal of Fisheries Management, 38*(5), https://doi.org/10.1002/nafm.10219

Tributary overshoot occurs when adult salmonids homing to natal sites continue upstream past the mouth of their natal stream. Although overshooting is a common behavior by steelhead Oncorhynchus mykiss in the Columbia River basin, it has not been adequately quantified or explained. Using multistate release-recapture models, we examined the prevalence of overshooting and fallback to natal tributaries by 37,806 PIT-tagged steelhead from 14 tributaries of the Columbia River basin during 2005-2015. Eight populations had overshooting rates exceeding 50% in at least 1year. Source of hatchery stock, rearing location, and release practices were found to have appreciable effects on overshoot rates. Overshooting was elevated in hatchery stocks reared upstream of release sites, but this effect may be lessened by utilizing endemic broodstocks and acclimating juveniles within the release basin. For one population of hatchery steelhead, acclimation within the release basin was found to decrease overshooting from 81% to 40%. Across both hatchery and wild populations, successful homing was found to decline 4 percentage points for every 5-percentage-point increase in overshoot rate. Average annual fallback probabilities ranged from 0.18 for Walla Walla River hatchery steelhead to 0.75 for Umatilla River wild steelhead. Fish stocks with the greatest fallback probabilities also had the greatest interannual variability in fallback rates. For John Day River wild steelhead and Tucannon River hatchery steelhead, the interannual range in fallback probabilities exceeded 0.50. We found evidence that spill at dams during March may enhance the fallback of overshooting steelhead and contribute to increased homing to natal tributaries. Therefore, additional attention should be paid to facilitating downstream dam passage of adult salmon.

Schaller, H. A., Petrosky, C. E., & Tinus, E. S. (2013). Evaluating River Management During Seaward Migration to Recover Columbia River Stream-Type Chinook Salmon Considering the Variation in Marine Conditions. *Canadian Journal of Fisheries and Aquatic Sciences, 71*(2), https://doi.org/10.1139/cjfas-2013-0226

Evidence suggests Snake River stream-type Chinook salmon (Oncorhynchus tshawytscha) experience substantial delayed mortality in the marine environment as a result of their outmigration experience through the Federal Columbia River Power System (FCRPS). We analyzed mortality patterns using methods that incorporated downriver reference populations passing fewer dams, and temporal approaches that were independent ofreference populations. Our results from the alternative spatial and temporal methods consistently corroborated with spawner–recruit residuals and smolt-to-adult survival rate data sets, indicating that Snake River salmon survived about one quarter as well as the reference populations. Temporal analysis indicated that a high percentage (76%) of Snake River juvenile salmon that survived the FCRPS subsequently died in the marine environment as a result of their outmigration experience. Through this and previous studies, it is evident that delayed hydrosystem mortality increases with the number of powerhouse passages and decreases with the speed of outmigration. Therefore, a promising conservation approach would be to explore management experiments that evaluate these relationships by increasing managed spill levels at the dams during the spring migration period.

Scheuerell, M. D., Buhle, E. R., Semmens, B. X., Ford, M. J., Cooney, T., & Carmichael, R. W. (2015). Analyzing Large-Scale Conservation Interventions with Bayesian Hierarchical Models: A Case Study of Supplementing Threatened Pacific Salmon. *Ecology and Evolution, 5*(10), https://doi.org/10.1002/ece3.1509

Myriad human activities increasingly threaten the existence of many species. A variety of conservation interventions such as habitat restoration, protected areas, and captive breeding have been used to prevent extinctions. Evaluating the effectiveness of these interventions requires appropriate statistical methods, given the quantity and quality of available data. Historically, analysis of variance has been used with some form of predetermined before-after control-impact design to estimate the effects of large-scale experiments or conservation interventions. However, ad hoc retrospective study designs or the presence of random effects at multiple scales may preclude the use of these tools. We evaluated the effects of a large-scale supplementation program on the density of adult Chinook salmon Oncorhynchus tshawytscha from the Snake River basin in the northwestern United States currently listed under the U.S. Endangered Species Act. We analyzed 43 years of data from 22 populations, accounting for random effects across time and space using a form of Bayesian hierarchical time-series model common in analyses of financial markets. We found that varying degrees of supplementation over a period of 25 years increased the density of natural-origin adults, on average, by 0–8% relative to nonsupplementation years. Thirty-nine of the 43 year effects were at least two times larger in magnitude than the mean supplementation effect, suggesting common environmental variables play a more important role in driving interannual variability in adult density. Additional residual variation in density varied considerably across the region, but there was no systematic difference between supplemented and reference populations. Our results demonstrate the power of hierarchical Bayesian models to detect the diffuse effects of management interventions and to quantitatively describe the variability of intervention success. Nevertheless, our study could not address whether ecological factors (e.g., competition) were more important than genetic considerations (e.g., inbreeding depression) in determining the response to supplementation.

Stark, E. J., Bretz, C., Byrne, A., Cleary, P., Copeland, T., Denny, L., . . . Warren, C. (2016). *Snake River Basin Steelhead 2013/2014 Run Reconstruction*. Retrieved from https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Snake%20River%20Basin%20Steelhead%202013-2014%20Run%20Reconstruction%20Report.pdf

Steelhead trout in the Snake River basin are the focus of a variety of harvest and conservation programs. A run reconstruction model offers a systematic way to address information needs for management within the large and complex arena presented by Snake River steelhead. The purpose of this work is to summarize data describing the abundance of steelhead crossing Lower Granite Dam, the spatial distribution of spawning fish, and known fates/disposition. To achieve this, a group was convened of representatives from the anadromous fishery management agencies within the Snake River basin. The immediate objective was to estimate the disposition of the 2013-2014 return of steelhead within the Snake River basin. We estimated 78,532 adipose-clipped hatchery fish, 6,887 unmarked hatchery fish, and 25,858 wild steelhead entered the Snake River during the run (July 1, 2013 to June 30, 2014). Fishery-related mortality in the Snake River basin totaled 56,229 marked hatchery fish, 1,523 unmarked hatchery fish, and 2,957 wild steelhead. Further, 17,348 marked hatchery fish, 227 unmarked hatchery fish, and 48 wild fish were collected for broodstock or donated to food banks (only hatchery fish). Another 237 clipped hatchery fish were estimated to leave the Snake River to enter the Walla Walla River. Potential spawners remaining in the habitat totaled 10,760 marked hatchery fish, 6,594 unmarked hatchery fish, and 24,018 wild steelhead. Losses between BON and ICH were 26.2% across all wild Snake River stocks, presumably most is due to anthropogenic sources; however, fishery-related losses within the Snake basin were 10.8%. Using the run reconstruction model, we attempted to quantify the fishery-related impacts on steelhead as they migrate to their natal or release area, and highlighted the benefits of hatchery programs. This work provides a useful framework for synthesizing data collected by fisheries managers that allows inferences regarding disposition and spatial distribution of spawning fish. The run reconstruction process is a good arena for critical review of the data that managers in the basin use. The model can be used to bridge gaps in the existing data using reasonable assumptions in a structured manner. The resulting output will help evaluate the performance of the Snake River steelhead evolutionarily significant unit (ESU) and hatchery programs towards management goals and ESA delisting criteria.

Steinhorst, K., Copeland, T., Ackerman, M. W., Schrader, W. C., & Anderson, E. C. (2017). Abundance Estimates and Confidence Intervals for the Run Composition of Returning Salmonids. *Fishery Bulletin, 115*(1), https://doi.org/10.7755/fb.115.1.1

In 2-stage fishery sampling, abundance is often estimated by using a primary sampling gear and total abundance is then partitioned into groups of interest by applying data on composition derived from a secondary sampling gear. However, the literature is sparse on statistical properties of estimates of run composition. We examined the accuracy and precision of estimators of composition of wild steelhead (Oncorhynchus mykiss) in the Snake River, in the Pacific Northwest. We simulated estimators, using pooled and time-stratified data. We compared confidence intervals (CIs) determined on the basis of asymptotical normality or a 2-stage bootstrap method. Stratified estimators were unbiased, except in a few cases. Joint CIs (all groups considered simultaneously) had coverages near nominal. Conversely, pooled estimators performed poorly; the proportion of biased estimates increased as the number of groups estimated increased. Using empirical data, we show that CIs met precision goals for most groups. Half-widths of CIs decreased and stabilized as the number sampled and group abundance increased. In complex scenarios, estimates of small groups will yield poor precision and some may be biased, but a stratified estimate with a conservative joint CI can be of practical use. The 2-step bootstrap approach is flexible and can incorporate other sources of variability or sampling constraints.

Tattam, I. A., & Ruzycki, J. R. (2020). Smolt Transportation Influences Straying of Wild and Hatchery Snake River Steelhead into the John Day River. *Transactions of the American Fisheries Society, 149*(3), https://doi.org/10.1002/tafs.10228

Barge transportation of steelhead Oncorhynchus mykiss smolts through the Snake and Columbia rivers can increase the probability of straying by returning adults at the individual scale. However, the effect of barge transportation on a major population group has not been evaluated. We estimated the proportion of hatchery-origin steelhead spawners present in the John Day River from 2004 to 2018 via observation of adults on spawning ground surveys and in traps. Despite no hatchery releases within the John Day River, up to 42% of the observed spawners in nature were of hatchery origin. The proportion of hatchery-origin spawners in the John Day River was best explained by the number of smolts that were barge transported from the Snake River 2–3 years prior to spawning and naturalorigin spawner abundance. At an individual scale, barged hatchery steelhead from the Snake River, when compared with hatchery and wild steelhead that were allowed to migrate in-river as smolts, were 73 times more likely to be detected in the John Day River during their adult return migration. Barged hatchery and barged wild steelhead exhibited no difference in the probability of adult detection in the John Day River. Our study demonstrates how a salmonid recovery effort in one portion of the Columbia River basin had an unintended and potentially adverse impact on nontarget populations. To minimize stray spawners (both hatchery and wild) in the John Day River, transportation of Snake River steelhead smolts should replicate spawning years 2013–2018 (i.e., the 2010–2016 smolt cohorts), with transportation not beginning until May 1 and with the total number of transported hatchery smolts maintained at a level no greater than 2.3 million annually.

Taylor, T. N., Knut Marius, M., & Kennedy, B. P. (2016). Food Habits of Sculpin Spp. In Small Idaho Streams: No Evidence of Predation on Newly Emerged Steelhead Alevins. *90*(4), https://doi.org/10.3955/046.090.0408

Recent declines of anadromous salmonids in the Pacific Northwest have prompted a need to understand the factors limiting populations across habitats and life stages. In the weeks following emergence from the spawning gravel, juvenile salmonids have limited swimming capacity and can be particularly vulnerable to predation by piscivores, such as sculpins (Cottus sp.) which are widespread in Pacific Northwest streams. The objective of this study was to investigate the extent to which sculpin prey on newly emerged steelhead (Oncorhynchus mykiss) in a threatened population in Idaho. Three species of sculpin were present in the watershed, including Paiute (C. beldingii), mottled (C. bairdii), and torrent (C. rhotheus) sculpin. Gut content analyses of 360 sculpin showed that invertebrates were the dominant food source (> 85% of all sculpin preyed mainly on invertebrates), and piscivory was rare (< 2%). None of the samples contained steelhead alevins. We conclude that there was no indication of predation during emergence in our study system, but note that future studies should incorporate stable isotope analyses or directly investigate the extent to which sculpin prey on salmonid eggs.

Tiffan, K. F., Erhardt, J. M., Hemingway, R. J., Bickford, B. K., & Rhodes, T. N. (2020). Impact of Smallmouth Bass Predation on Subyearling Fall Chinook Salmon over a Broad River Continuum. *Environmental Biology of Fishes, 103*(10), https://doi.org/10.1007/s10641-020-01016-0

Smallmouth bass (Micropterus dolomieu) predation on subyearling fall Chinook salmon (Oncorhynchus tshawytscha) was examined in the Snake River (USA) to identify seasonal and habitat-related changes in bass diets, and associated subyearling consumption and loss in various riverine and impounded reaches. Smallmouth bass diets reflected opportunistic foraging that at times showed predation on subyearlings is influenced by the consumption of other prey such as crayfish, sand roller (Percopsis transmontana), and smaller invertebrates. Estimated loss of subyearlings was influenced by bass abundance and consumption rates. The highest bass abundances (> 1,000 bass/river kilometer) were observed in the upper reach of Hells Canyon early in April and May, and in Lower Granite Reservoir. Peak consumption rates of subyearlings (>/= 0.12 subyearlings/bass/day) occurred in the upper reach of Hells Canyon during May and in most reservoir reaches in June. Predation losses accumulated evenly along the river continuum from riverine to reservoir habitats. We estimated that 869,371 subyearlings could be lost to smallmouth bass predation between riverine production areas and Lower Granite Dam in a given year. To provide a context for this estimated loss, we provide an illustration of its potential effect on the adult population. Assuming no juvenile mortality occurred downstream of the dam and depending on smolt-to-adult return rates, this represented up to 3.9-16.0% of the potential adult run that could have returned to Lower Granite Dam had no subyearling predation by smallmouth bass occurred upstream of the dam. Although this study was limited by a number of assumptions and constraints, it does provide an illustration of how predation affects juvenile and adult salmon loss over a broad, changing river landscape.

Tiffan, K. F., Hatten, J. R., & Trachtenbarg, D. A. (2016). Assessing Juvenile Salmon Rearing Habitat and Associated Predation Risk in a Lower Snake River Reservoir. *River Research and Applications, 32*(5), https://doi.org/10.1002/rra.2934

Subyearling fall Chinook salmon (Oncorhynchus?tshawytscha) in the Columbia River basin exhibit a transient rearing strategy and depend on connected shoreline habitats during freshwater rearing. Impoundment has greatly reduced the amount of shallow-water rearing habitat that is exacerbated by the steep topography of reservoirs. Periodic dredging creates opportunities to strategically place spoils to increase the amount of shallow-water habitat for subyearlings while at the same time reducing the amount of unsuitable area that is often preferred by predators. We assessed the amount and spatial arrangement of subyearling rearing habitat in Lower Granite Reservoir on the Snake River to guide future habitat improvement efforts. A spatially explicit habitat assessment was conducted using physical habitat data, two-dimensional hydrodynamic modelling and a statistical habitat model in a geographic information system framework. We used field collections of subyearlings and a common predator [smallmouth bass (Micropterus?dolomieu)] to draw inferences about predation risk within specific habitat types. Most of the high-probability rearing habitat was located in the upper half of the reservoir where gently sloping landforms created low lateral bed slopes and shallow-water habitats. Only 29% of shorelines were predicted to be suitable (probability >0.5) for subyearlings, and the occurrence of these shorelines decreased in a downstream direction. The remaining, less suitable areas were composed of low-probability habitats in unmodified (25%) and riprapped shorelines (46%). As expected, most subyearlings were found in high-probability habitat, while most smallmouth bass were found in low-probability locations. However, some subyearlings were found in low-probability habitats, such as riprap, where predation risk could be high. Given their transient rearing strategy and dependence on shoreline habitats, subyearlings could benefit from habitat creation efforts in the lower reservoir where high-probability habitat is generally lacking. Published 2015. This article is a U.S. Government work and is in the public domain in the USA.

Tiffan, K. F., Kock, T. J., Connor, W. P., Richmond, M. C., & Perkins, W. A. (2018). Migratory Behavior and Physiological Development as Potential Determinants of Life History Diversity in Fall Chinook Salmon in the Clearwater River. *Transactions of the American Fisheries Society, 147*(2), https://doi.org/10.1002/tafs.10035

We studied the influence of behavior, water velocity, and physiological development on the downstream movement of subyearling fall-run Chinook Salmon Oncorhynchus tshawytscha in both free-flowing and impounded reaches of the Clearwater and Snake rivers as potential mechanisms that might explain life history diversity in this stock. Movement rates and the percentage of radio-tagged fish that moved faster than the average current velocity were higher in the free-flowing Clearwater River than in impounded reaches. This supports the notion that water velocity is a primary determinant of downstream movement regardless of a fish's physiological development. In contrast, movement rates slowed and detections became fewer in impounded reaches, where water velocities were much lower. The percentage of fish that moved faster than the average current velocity continued to decline and reached zero in the lowermost reach of Lower Granite Reservoir, suggesting that the behavioral disposition to move downstream was low. These findings contrast with those of a similar, previous study of Snake River subyearlings despite similarity in hydrodynamic conditions between the two studies. Physiological differences between Snake and Clearwater River migrants shed light on this disparity. Subyearlings from the Clearwater River were parr-like in their development and never showed the increase in gill Na+/K+-ATPase activity displayed by smolts from the Snake River. Results from this study provide evidence that behavioral and life history differences between Snake and Clearwater River subyearlings may have a physiological basis that is modified by environmental conditions.

Tiffan, K. F., Perry, R. W., Connor, W. P., Mullins, F. L., Rabe, C. D., & Nelson, D. D. (2015). Survival, Growth, and Tag Retention in Age-0 Chinook Salmon Implanted with 8-, 9-, and 12-Mm Pit Tags. *North American Journal of Fisheries Management, 35*(4), https://doi.org/10.1080/02755947.2015.1052163

The ability to represent a population of migratory juvenile fish with PIT tags becomes difficult when the minimum tagging size is larger than the average size at which fish begin to move downstream. Tags that are smaller (e.g., 8 and 9 mm) than the commonly used 12-mm PIT tags are currently available, but their effects on survival, growth, and tag retention in small salmonid juveniles have received little study. We evaluated growth, survival, and tag retention in age-0 Chinook Salmon Oncorhynchus tshawytscha of three size-groups: 40–49-mm fish were implanted with 8- and 9-mm tags, and 50–59-mm and 60–69-mm fish were implanted with 8-, 9-, and 12-mm tags. Survival 28 d after tagging ranged from 97.8% to 100% across all trials, providing no strong evidence for a fish-size-related tagging effect or a tag size effect. No biologically significant effects of tagging on growth in FL (mm/d) or weight (g/d) were observed. Although FL growth in tagged fish was significantly reduced for the 40–49-mm and 50–59-mm groups over the first 7 d, growth rates were not different thereafter, and all fish were similar in size by the end of the trials (day 28). Tag retention across all tests ranged from 93% to 99%. We acknowledge that actual implantation of 8- or 9-mm tags into small fish in the field will pose additional challenges (e.g., capture and handling stress) beyond those observed in our laboratory. However, we conclude that experimental use of the smaller tags for small fish in the field is supported by our findings.

Trushenski, J. T., Larsen, D. A., Middleton, M. A., Jakaitis, M., Johnson, E. L., Kozfkay, C. C., & Kline, P. A. (2019). Search for the Smoking Gun: Identifying and Addressing the Causes of Postrelease Morbidity and Mortality of Hatchery-Reared Snake River Sockeye Salmon Smolts. *Transactions of the American Fisheries Society, 148*(5), https://doi.org/10.1002/tafs.10193

As part of the Snake River Sockeye Salmon Oncorhynchus nerka recovery effort, a dedicated smolt rearing facility was constructed in 2013 near Springfield, Idaho. In-hatchery performance and survival were typical for the species, but unexpectedly high mortality rates were observed in the first cohorts of Springfield-reared smolts upon release into Redfish Lake Creek (RFLC) and during out-migration. In response, a series of iterative experiments was conducted to identify the cause of the morbidity and mortality observed and to test a range of strategies to mitigate effects on postrelease survival. In the search for possible contributing factors, a difference in water chemistry was noted: whereas Springfield Hatchery's water source is "hard" and has high calcium concentrations, water at the RFLC release site is "soft" and has very low calcium concentrations. In both manipulative experiments and field evaluations, we demonstrated that juvenile Snake River Sockeye Salmon are profoundly affected by instantaneous transitions from high- to low-hardness water. Furthermore, we established a causal link between differences in water chemistry, the associated physiological stress, and morbidity/mortality observed during smolt releases and subsequent out-migration. A variety of mitigation strategies, including water mixing and water softening, was tested, but stepwise acclimation from high- to medium-hardness water and then from medium- to low-hardness water proved to be the most biologically and logistically effective means of addressing the identified water chemistry differences. Estimates of postrelease survival to Lower Granite Dam (similar to 430 river kilometers downstream) indicated significantly higher survival for acclimated groups (68.7-75.5%) compared to smolts directly released into RFLC (18.1%). Although Snake River Sockeye Salmon smolt survival rates will undoubtedly fluctuate annually with environmental conditions, it is clear that the elevated morbidity and mortality observed in previous years can be addressed through proper acclimation of smolts prior to release.

Tucker, S., Thiess, M. E., Morris, J. F. T., Mackas, D., Peterson, W. T., Candy, J. R., . . . Trudel, M. (2015). Coastal Distribution and Consequent Factors Influencing Production of Endangered Snake River Sockeye Salmon. *Transactions of the American Fisheries Society, 144*(1), https://doi.org/10.1080/00028487.2014.968292

Snake River Sockeye Salmon Oncorhynchus nerka were declared endangered in 1991 after several years of decreasing abundance. Several factors, including poor marine survival, likely contributed to the decline of Snake River Sockeye Salmon. Little is known about their migration and ocean distribution and the factors influencing their production. We sampled (1) coastal waters from southern British Columbia (BC) to southeast Alaska during June-July, October-November, and February-March 1998-2011; and (2) Oregon and Washington coastal waters during May-June and September 2007-2010. In total, 8,227 juvenile Sockeye Salmon were captured. Despite their extremely low abundance relative to other stocks, 15 coded-wire-tagged juveniles from Redfish Lake were recovered since 2007, primarily in spring and summer surveys off the BC coast. Genetic analyses revealed that an additional eight Redfish Lake juveniles were also present in this area during summer. Snake River smolts undertook a rapid northward migration that brought them well beyond the Columbia River estuary and plume, exposing them to ocean conditions prevailing off BC. Through a multimodel inference approach, we characterized associations between the number of returning adults and a suite of ocean and river variables. Seven ocean variables and five river variables were chosen for the model selection analysis (e.g., copepod biomass anomalies, coastal upwelling indices, date of the spring transition, river discharge, river temperature, and the proportion of smolts transported through the hydropower system). Although adult returns were highly correlated with smolt abundance, our analyses suggest that ocean conditions encountered during the first growing season (as indexed by copepod anomalies) contribute to the variability in total adult returns. There was also evidence for a negative effect of transporting smolts through the hydropower system, with the caveat that we used transportation data for steelhead O. mykiss as a proxy.

U.S. Army Corps of Engineers. (2014). *Passage Distribution and Federal Columbia River Power System Survival for Steelhead Kelts Tagged above and at Lower Granite Dam, Year 2*. (PNNL-23051 Rev.1). Retrieved from https://www.osti.gov/servlets/purl/1194330

Steelhead (Oncorhynchus mykiss) populations have declined throughout their range in the last century and many populations, including those of the Snake River Basin are listed under the Endangered Species Act of 1973. The reasons for their decline are many and complex, but include habitat loss and degradation, overharvesting, and dam construction. The 2008 Biological Opinion calls for an increase in the abundance of female steelhead through an increase in iteroparity (i.e., repeat spawning) and this can be realized through a combination of reconditioning and in-river survival of migrating kelts. The goal of this study is to provide the data necessary to inform fisheries managers and dam operators of Snake River kelt migration patterns, survival, and routes of dam passage. Steelhead kelts (n = 487) were captured and implanted with acoustic transmitters and passive integrated transponder (PIT)-tags at the Lower Granite Dam (LGR) Juvenile Fish Facility and at weirs located in tributaries of the Snake and Clearwater rivers upstream of LGR. Kelts were monitored as they moved downstream through the Federal Columbia River Power System (FCRPS) by 15 autonomous and 3 cabled acoustic receiver arrays. Cabled receiver arrays deployed on the dam faces allowed for three-dimensional tracking of fish as they approached the dam face and were used to determine the route of dam passage. Overall, 27.3% of the kelts tagged in this study successfully migrated to Martin Bluff (rkm 126, as measured from the mouth of the Columbia River), which is located downstream of all FCRPS dams. Within individual river reaches, survival per kilometer estimates ranged from 0.958 to 0.999; the lowest estimates were observed in the immediate forebay of FCRPS dams. Steelhead kelts tagged in this study passed over the spillway routes (spillway weirs, traditional spill bays) in greater proportions and survived at higher rates compared to the few fish passed through powerhouse routes (turbines and juvenile bypass systems). The results of this study provide information about the route of passage and subsequent survival of steelhead kelts that migrated through the Snake and Columbia rivers from LGR to Bonneville Dam in 2013. These data may be used by fisheries managers and dam operators to identify potential ways to increase the survival of kelts during their seaward migrations.

U.S. Department of Energy. (2015). *Factors Affecting Route Selection and Survival of Steelhead Kelts at Snake River Dams in 2012 and 2013*. (PNNL-24207). Retrieved from https://www.osti.gov/servlets/purl/1184297

In 2012 and 2013, Pacific Northwest National Laboratory (PNNL) conducted a study that summarized the passage route proportions and route-specific survival rates of steelhead kelts that passed through Federal Columbia River Power System (FCRPS) dams. To accomplish this, a total of 811 steelhead kelts were tagged with Juvenile Salmon Acoustic Telemetry System (JSATS) transmitters. Acoustic receivers, both autonomous and cabled, were deployed throughout the FCRPS to monitor the downstream movements of tagged kelts. Kelts were also tagged with passive integrated transponder tags to monitor passage through juvenile bypass systems (JBS) and detect returning fish. The current study evaluated data collected in 2012 and 2013 to identify environmental, temporal, operational, individual, and behavioral variables that were related to forebay residence time, route of passage, and survival of steelhead kelts at FCRPS dams on the Snake River. Multiple approaches, including 3-D tracking, bivariate and multivariable regression modeling, and decision tree analyses were used to identify the environmental, temporal, operational, individual, and behavioral variables that had the greatest effect on forebay residence time, route of passage, and route-specific and overall dam passage survival probabilities for tagged kelts at Lower Granite (LGR), Little Goose (LGS), and Lower Monumental (LMN) dams. In general, kelt behavior and discharge appeared to work independently to affect forebay residence times. Kelt behavior, primarily approach location, migration depth, and "searching" activities in the forebay, was found to have the greatest influence on their route of passage. The condition of kelts was the single most important factor affecting their survival. The information gathered in this study may be used by dam operators and fisheries managers to identify potential management actions to improve in-river survival of kelts or collection methods for kelt reconditioning programs to aid the recovery of Snake River steelhead populations.

Upper Snake River Tribes Foundation. (2018). *Hells Canyon Complex Fisheries Resource Management Plan.* Boise, ID. Retrieved from https://uppersnakerivertribes.org/app/uploads/2018/09/FRG-USRTsProposedFisheriesResourceManagementProgram_April-2018-2-1.pdf

Fishing opportunities above the Hells Canyon Complex (HCC) have been severely constrained by depressed runs of salmon caused in large part by the detrimental effects of hydroelectric development and early overfishing in the lower Columbia River. Anadromous fish runs above the HCC have been completely blocked. The HCC Fish Management Program (Program) seeks to restore fishing opportunities through anadromous and resident fish management programs in the Snake River and in significant tributaries; including the Bruneau/Jarbidge, Owyhee, Malheur, Boise, Payette, and Weiser Rivers. Restoration of these conservation and subsistence fisheries would be accomplished in a manner intended to complement the ongoing recovery efforts of anadromous and resident fish in the Upper Salmon River Basin.

Waples, R. S., Elz, A., Arnsberg, B. D., Faulkner, J. R., Hard, J. J., Timmins-Schiffman, E., & Park, L. K. (2017). Human-Mediated Evolution in a Threatened Species? Juvenile Life-History Changes in Snake River Salmon. *Evolutionary Applications, 10*(7), https://doi.org/10.1111/eva.12468

Evaluations of human impacts on Earth's ecosystems often ignore evolutionary changes in response to altered selective regimes. Freshwater habitats for Snake River fall Chinook salmon (SRFCS), a threatened species in the US, have been dramatically changed by hydropower development and other watershed modifications. Associated biological changes include a shift in juvenile life history: Historically essentially 100% of juveniles migrated to sea as subyearlings, but a substantial fraction have migrated as yearlings in recent years. In contemplating future management actions for this species should major Snake River dams ever be removed (as many have proposed), it will be important to understand whether evolution is at least partially responsible for this life-history change. We hypothesized that if this trait is genetically based, parents who migrated to sea as subyearlings should produce faster-growing offspring that would be more likely to reach a size threshold to migrate to sea in their first year. We tested this with phenotypic data for over 2,600 juvenile SRFCS that were genetically matched to parents of hatchery and natural origin. Three lines of evidence supported our hypothesis: (i) the animal model estimated substantial heritability for juvenile growth rate for three consecutive cohorts; (ii) linear modeling showed an association between juvenile life history of parents and offspring growth rate; and (iii) faster-growing juveniles migrated at greater speeds, as expected if they were more likely to be heading to sea. Surprisingly, we also found that parents reared a full year in a hatchery produced the fastest growing offspring of all-apparently an example of cross-generational plasticity associated with artificial propagation. We suggest that SRFCS is an example of a potentially large class of species that can be considered to be "anthro-evolutionary"-signifying those whose evolutionary trajectories have been profoundly shaped by altered selective regimes in human-dominated landscapes.

Washington Department of Fish and Wildlife. (2018). *Tucannon River Spring Chinook Salmon Hatchery Evaluation Program: 2018 Annual Report*. Retrieved from https://wdfw.wa.gov/sites/default/files/publications/02096/fpa_19-02_2018%20annual%20tuc%20sp%20ch%20report_0.pdf

Lyons Ferry Hatchery (LFH) and Tucannon Fish Hatchery (TFH) were built/modified under the Lower Snake River Fish and Wildlife Compensation Plan. One objective of the Plan is to compensate for the estimated annual loss of 1,152 Tucannon River spring Chinook caused by hydroelectric projects on the Snake River. This report summarizes activities of the Washington Department of Fish and Wildlife Lower Snake River Hatchery Evaluation Program for Tucannon River spring Chinook for the period May 2018 to April 2019. A total of 431 salmon were captured in the TFH trap in 2018 (62 natural adults, 11 natural jacks, 297 hatchery adults, and 61 hatchery jacks). Of these, 160 adults (37 natural, 123 hatchery) were collected and hauled to LFH for broodstock, 38 adipose clipped strays were killed outright, 18 were passed upstream (15 natural, 3 hatchery), and the remaining fish (215) were held at LFH for adult outplanting. During 2018, 20 (12.5%) salmon collected for broodstock died prior to spawning. Spawning of supplementation fish occurred once a week between 28 August and 18 September, with peak eggtake occurring on 11 September. A total of 212,973 eggs were collected from 9 natural and 67 hatchery-origin female Chinook. Egg mortality to eye-up was 3.1% (6,639 eggs) which left 206,334 live eggs. An additional 0.95% (1,970) loss of sac-fry left 204,364 BY 2018 fish for production. Weekly spawning ground surveys were conducted from 21 August and were completed by 1 October 2018. A total of 109 redds and 67 carcasses (9 natural, 58 hatchery) were found. Seventy-seven redds (76% of the total) were counted above the adult trap. Based on redd counts, carcasses recovered, and broodstock collection, the estimated return to the river for 2018 was 545 spring Chinook (80 natural adults, 0 natural jacks and 425 hatchery-origin adults, 40 hatchery jacks). Volitional release of the 2017 BY smolts began on 4 April and continued until 3 May, 2019 when the remaining fish were forced out. An estimated 144,219 BY17 smolts were released. Evaluation staff operated a downstream migrant trap to provide juvenile outmigration estimates. During the 2017/2018 emigration, we estimated that 8,058 (4,618-16,014 95% C.I.) natural spring Chinook (BY 2016) smolts emigrated from the Tucannon River. Smolt-to-adult return rates (SAR) for natural origin salmon are almost eight times higher on average (based on geometric means) than hatchery origin salmon. However, hatchery salmon survive almost three times greater than natural salmon from parent to adult progeny over the length of the project. A study was conducted for three brood years (BY11-13) to determine if rearing full term at TFH would return more adults back to the Tucannon River versus the current protocol of egg incubation and early life rearing at LFH. This study concluded with the final adult returns in 2018. Results from PIT tag detections did not show a significant benefit in either survival or homing back to the Tucannon River by rearing fish at TFH instead of LFH. Based on the findings, we will continue to use LFH for holding, spawning, and incubation and early life rearing of Tucannon River spring Chinook.

Williams, J. G., & Gessel, M. H. (2018). A History of Research to Develop Guidance Systems to Divert Juvenile Salmonids, Oncorhynchus Spp., from Turbines at Federal Hydroelectric Dams on the Mainstem Columbia and Snake Rivers, U.S.A. *Marine Fisheries Review, 80*(2), https://doi.org/http://dx.doi.org/10.7755/MFR.80.2.3

Eight large Federal hydropower dams were constructed between the 1930's and 1970's on the mainstem lower Columbia and Snake Rivers, U.S.A. The dams included fishways that enabled effective upstream passage of adult salmonids to Snake River basin spawning areas, but they lacked any facilities for protection of juvenile salmonids migrating downstream to the ocean. Prior to completion of the dam complex, early studies on mortality of juvenile salmon passing through turbines suggested that Snake River salmon stocks could not survive the cumulative mortalities to populations of fish that would have to pass downstream through turbines at all eight dams. This led to a more than 30-yr field effort conducted primarily by NOAA's National Marine Fisheries Service personnel to devise, test, and recommend for installation effective screening systems for turbine intakes at dams to decrease mortality of downstream migrating juvenile salmonids. This paper provides a history of the extensive research to accomplish this goal.

Young, W., Milks, D., Rosenberger, S., Powel, J., Campbell, M., Hasselman, D., & narum, S. (2017). *Snake River Hatchery and Natural Fall Chinook Salmon Escapement and Population Composition above Lower Granite Dam.* Retrieved from https://www.fws.gov

This report provides results of the abundance and genetic diversity performance metrics identified in the Addendum to Snake River fall Chinook salmon Hatchery Genetic Mangement Plan (HGMP) critical for understanding the effect of the Snake River fall Chinook hatchery program on Viable Salmonid Population (VSP) criteria. The addendum was developed in response to specific questions about abundance, productivity, spatial structure and diversity of the Snake River fall Chinook population, with detailed research, monitoring and evaluation studies identified to specifically address uncertainties identified at that time. Completion of this research directly addressed these uncertainties and provided information for adaptive management of Snake River fall Chinook salmon hatchery program. This information will also be critical for regional recovery planning, hatchery management, and harvest planning and management. Metrics presented here represent measures of abundance and diversity at the population level for hatchery and natural Snake River fall Chinook salmon including 1) hatchery and natural abundance to Lower Granite Dam (LGR); 2) hatchery and natural escapement above LGR; 3) proportion of hatchery-origin spawners (pHOS) at the population level; 4) proportion of naturalorigin spawners (pNOB) in the hatchery broodstock; 5) age composition at adult return and 6) genetic diversity.

Section XIII: Multi Recovery Domain/Multispecies Resources

Blumm, M. C., & DeRoy, D. (2019). The Fight over Columbia Basin Salmon Spills and the Future of the Lower Snake River Dams. *Washington Journal of Environmental Law & Policy, 9*(1/2) Retrieved from https://digitalcommons.law.uw.edu/cgi/viewcontent.cgi?article=1112&context=wjelp

One of the nation's most longstanding environmental-energy conflicts concerns the plight of numerous Columbia Basin salmon species which must navigate the Federal Columbia River Power System (FCRPS), a series of hydroelectric dams that make the basin one of the most highly developed in the world. Although the FCRPS dams produce a wealth of hydropower, the mortalities they cause due to the construction and operation of FCRPS dams led to Endangered Species Act listings for the basin's salmon. Since those listings a quarter-century ago, the federal government has repeatedly failed to produce biological opinions that can survive judicial scrutiny. The latest round of litigation resulted in renewed directives from the federal district court of Oregon to revise the current biological opinion and to spill more water at several dams in the interim to facilitate juvenile salmon migration. The directive to increase spill was upheld by the Ninth Circuit in 2018, but the U.S. House of Representatives quickly voted to overturn that decision, and the Senate now has the matter under consideration.

Boyd, C., DeMaster, D. P., Waples, R. S., Ward, E. J., & Taylor, B. L. (2017). Consistent Extinction Risk Assessment under the U.S. Endangered Species Act. *Conservation Letters, 10*(3), https://doi.org/10.1111/conl.12269

Identifying species at risk of extinction is essential for effective conservation priority-setting in the face of accelerating biodiversity loss. However, the levels of risk that lead to endangered or threatened listing decisions under the United States Endangered Species Act (ESA) are not well defined. We used a Bayesian population modeling approach to estimate levels of risk consistently for 14 marine species previously assessed under the ESA. For each species, we assessed the risks of declining below various abundance thresholds over various time horizons. We found that high risks of declining below 250 mature individuals within five generations matched well with ESA endangered status, while number of populations was useful for distinguishing between threatened and "not warranted" species. The risk assessment framework developed here could enable more consistent, predictable, and transparent ESA status assessments in the future.

Breyta, R., Black, A., Kaufman, J., & Kurath, G. (2016). Spatial and Temporal Heterogeneity of Infectious Hematopoietic Necrosis Virus in Pacific Northwest Salmonids. *Infection Genetics and Evolution, 45*, https://doi.org/10.1016/j.meegid.2016.09.022

The aquatic rhaboviral pathogen infectious hematopoietic necrosis virus (IHNV) causes acute disease in juvenile fish of a number of populations of Pacific salmonid species. Heavily managed in both marine and freshwater environments, these fish species are cultured during the juvenile stage in freshwater conservation hatcheries, where IHNV is one of the top three infectious diseases that cause serious morbidity and mortality. Therefore, a comprehensive study of viral genetic surveillance data representing 2590 field isolates collected between 1958 and 2014 was conducted to determine the spatial and temporal patterns of IHNV in the Pacific Northwest of the contiguous United States. Prevalence of infection varied over time, fluctuating over a rough 5-7yearcycle. The genetic analysis revealed numerous subgroups of IHNV, each of which exhibited spatial heterogeneity. Within all subgroups, dominant genetic types were apparent, though the temporal patterns of emergence of these types varied among subgroups. Finally, the affinity or fidelity of subgroups to specific host species also varied, where UC subgroup viruses exhibited a more generalist profile and all other subgroups exhibited a specialist profile. These complex patterns are likely synergistically driven by numerous ecological, pathobiological, and anthropogenic factors. Since only a few anthropogenic factors are candidates for managed intervention aimed at improving the health of threatened or endangered salmonid fish populations, determining the relative impact of these factors is a high priority for future studies.

Brignon, W. R. (2017). Spatial and Temporal Segregation of Wild and Hatchery Winter Steelhead Populations in Eagle Creek, Oregon. *North American Journal of Fisheries Management, 37*(3), https://doi.org/10.1080/02755947.2017.1308894

A segregated hatchery program promotes conservation by limiting the amount of overlap in return timing and spawning locations of hatchery- and natural-origin fish. The objective of the present study was to use radiotelemetry data collected from 2005 to 2007 to better understand the level of spatial and temporal segregation between hatchery and natural-origin steelhead Oncorhynchus mykiss in the Eagle Creek basin, Oregon. The analysis resulted in three key findings. First, hatchery-origin winter steelhead were unlikely to migrate into the North Fork Eagle Creek, a tributary that has historically lacked any hatchery releases or influence, suggesting a high level of segregation from the natural-origin population returning to that stream. Second, hatchery fish arrived at the lower fish ladder on Eagle Creek and at Eagle Creek National Fish Hatchery (NFH) earlier than natural-origin fish, suggesting that broodstock management practices to maintain an early returning hatchery stock (i.e., temporal segregation) have been somewhat successful. Finally, regardless of the differential arrival timing to Eagle Creek NFH, there is evidence of an increased probability of spatial and temporal overlap of the populations as the return progresses, and this may be explained by successful reproduction of hatchery-origin fish in main-stem Eagle Creek. Integrated and segregated hatchery programs should be monitored periodically to ensure that they are meeting their stated goals.

Burke, B. J., Anderson, J. J., Miller, J. A., Tomaro, L., Teel, D. J., Banas, N. S., & Baptista, A. M. (2016). Estimating Behavior in a Black Box: How Coastal Oceanographic Dynamics Influence Yearling Chinook Salmon Marine Growth and Migration Behaviors. *Environmental Biology of Fishes, 99*(8), https://doi.org/10.1007/s10641-016-0508-7

Ocean currents or temperature may substantially influence migration behavior in many marine species. However, high-resolution data on animal movement in the marine environment are scarce; therefore, analysts and managers must typically rely on unvalidated assumptions regarding movement, behavior, and habitat use. We used a spatially explicit, individual-based model of early marine migration with two stocks of yearling Chinook salmon to quantify the influence of external forces on estimates of swim speed, consumption, and growth. Model results suggest that salmon behaviorally compensate for changes in the strength and direction of ocean currents. These compensations can result in salmon swimming several times farther than their net movement (straight-line distance) would indicate. However, the magnitude of discrepancy between compensated and straight-line distances varied between oceanographic models. Nevertheless, estimates of relative swim speed among fish groups were less sensitive to the choice of model than estimates of absolute individual swim speed. By comparing groups of fish, this tool can be applied to management questions, such as how experiences and behavior may differ between groups of hatchery fish released early vs. later in the season. By taking into account the experiences and behavior of individual fish, as well as the influence of physical ocean processes, our approach helps illuminate the "black box" of juvenile salmon behavior in the early marine phase of the life cycle.

California Trout. (2017). *Sos Ii: Fish in Hot Water Status, Threats and Solutions for California Salmon, Steelhead, and Trout.* Retrieved from https://caltrout.org/wp-content/uploads/2017/05/SOS-II-Fish-in-Hot-Water-Report.pdf

This report includes an analysis of key threats to the survival of each species, starting with the overarching threat of climate change, which is likely to reduce the availability of cold water habitat that salmon, steelhead, and trout all depend on for survival. It also highlights various other human-induced threats, such as dams, agriculture, estuary alteration, urbanization, and transportation.

California Trout. (2017). *State of the Salmonids: Status of California's Emblematic Fishes.* Retrieved from https://watershed.ucdavis.edu/news/2017/08/24/state-salmonids-status-californias-emblematic-fishes-2017-scientific-report-released

California has, or had, 32 distinct kinds of salmonid fishes. They are either endemic to California or at the southern end of their ranges. Most are in serious decline: 45% and 74% of all salmonids will likely become extirpated from California in the next 50 and 100 years, respectively, if present trends continue. Our results suggest that California will lose more than half (52%) of its native anadromous salmonids and nearly a third (30%) of its inland taxa in just 50 years under current conditions. Climate change is a major overarching threat driving population declines throughout California and strongly affects the status of 84% of all salmonids reviewed. In addition, dams, agricultural operations, estuary alteration, non-native species, production hatcheries, and myriad other human-induced threats have contributed to declines. 81% of salmonids in California are now worse off than they were in 2007, when the previous version of this report was prepared. The changes in species status are the result of the 2012-2016 historic drought, improved data collection and review, and an improved understanding of climate change impacts. Returning these iconic species to sustainable levels requires access to productive and diverse habitats which promote the full range of life history diversity necessary to weather change. We recommend (i) protecting and investing in fully functioning watersheds such as the Smith River and Blue Creek, (ii) protecting and restoring source waters such as Sierra meadow systems, groundwater, and springs so that the impacts of climate change are reduced, (iii) restoring function and access to once productive and diverse habitats such as Central Valley floodplains, coastal lagoons, and estuaries, (iv) adopting reconciliation ecology as a basis for management in human dominated landscapes, (v) improving habitat connectivity and passage to historical spawning and rearing habitat, and (vi) improving salmonid genetic management throughout California.

Campbell, N. R., Kamphaus, C., Murdoch, K., & Narum, S. R. (2017). Patterns of Genomic Variation in Coho Salmon Following Reintroduction to the Interior Columbia River. *Ecology and Evolution, 7*(23), https://doi.org/10.1002/ece3.3492

Coho salmon were extirpated in the mid-20th century from the interior reaches of the Columbia River but were reintroduced with relatively abundant source stocks from the lower Columbia River near the Pacific coast. Reintroduction of Coho salmon to the interior Columbia River (Wenatchee River) using lower river stocks placed selective pressures on the new colonizers due to substantial differences with their original habitat such as migration distance and navigation of six additional hydropower dams. We used restriction site-associated DNA sequencing (RAD-seq) to genotype 5,392 SNPs in reintroduced Coho salmon in the Wenatchee River over four generations to test for signals of temporal structure and adaptive variation. Temporal genetic structure among the three broodlines of reintroduced fish was evident among the initial return years (2000, 2001, and 2002) and their descendants, which indicated levels of reproductive isolation among broodlines. Signals of adaptive variation were detected from multiple outlier tests and identified candidate genes for further study. This study illustrated that genetic variation and structure of reintroduced populations are likely to reflect source stocks for multiple generations but may shift over time once established in nature.

Carmichael, R. W., Chilcote, M. W., & Huntington, C. W. (2015). Comment: Natural Productivity in Steelhead Populations of Natural and Hatchery Origin—Assessing Hatchery Spawner Influence. *Transactions of the American Fisheries Society, 144*(6), https://doi.org/10.1080/00028487.2015.1052556

Interactions between hatchery-origin and wild anadromous salmonids, and their potential influence on the productivity of wild fish, are often a concern of those trying to maintain or recover natural populations. The concern stems from the large size and broad geographic scope of existing hatchery programs, increased emphasis on the use of hatcheries to enhance natural production for recovery, and recognition that the programs may be having consequential effects on wild salmonids. Answers to questions about the magnitude of such effects on individual programs or populations are often pursued but frequently unavailable. This makes it important in the instances in which answers are developed that they be reliable. The purpose of Lister (2014) was “to determine the influence of hatchery steelhead [Oncorhynchus mykiss] spawners on productivity of natural steelhead spawners in mixed populations that included adults of hatchery and natural origin.” In pursuit of this, the paper presents results that are dependent on confounded methods and unsupported assumptions as a basis for suggesting that hatchery-origin spawners (Sh) have not negatively influenced the natural productivity of multiple steelhead populations in the interior Columbia River basin. The paper has at least three critical flaws: the analytic approach, the use of a measure of productivity for natural fish that is inherently flawed, and the drawing of erroneous conclusions from irresolute data. The paper has additional technical shortcomings that we have chosen not to address here, particularly with regard to how specific data estimation errors and biases (other than those of the flawed productivity metric) have or have not been addressed.

Charnley, S., Gosnell, H., Wendel, K. L., Rowland, M. M., & Wisdom, M. J. (2018). Cattle Grazing and Fish Recovery on Us Federal Lands: Can Social–Ecological Systems Science Help? *Frontiers in Ecology and the Environment, 16*(S1), https://doi.org/10.1002/fee.1751

In the western US, grazing management on federal lands containing habitat for fish species listed under the US Endangered Species Act (ESA) has sparked social conflict and litigation for decades. To date, the problem has been addressed through a top- down environmental governance system, but rangeland managers and grazing permittees now believe there is a need for more innovative management strategies. This article explores how social–ecological systems (SES) science can address rangeland management challenges associated with the survival and recovery of ESA- listed fish species on federal lands where cattle grazing is a dominant type of land use. We focus on the Blue Mountains of eastern Oregon, where the Mountain Social Ecological Observatory Network's Blue Mountains Working Group is collaborating with diverse stakeholders to develop and test a novel grazing system designed to reduce the impact of cattle on riparian areas using an SES science approach. Although not a complete solution, SES science holds promise for improving rangeland management.

Clark, C., Roni, P., & Burgess, S. (2019). Response of Juvenile Salmonids to Large Wood Placement in Columbia River Tributaries. *Hydrobiologia, 842*(1), https://doi.org/10.1007/s10750-019-04034-x

Placement of large wood is a common stream restoration technique in western North America and increasingly in other parts of the world. Considerable information exists on response of anadromous salmonids in small (< 15 m bankfull width) coastal streams of western North America, but limited information exists on anadromous fish response to wood placement in larger streams or in the more arid interior Columbia River Basin. An extensive post-treatment design was used to sample 29 large wood placement projects to determine their physical and biological effectiveness. We sampled paired treatment and control reaches that were approximately 20 times longer than bankfull width and quantified fish abundance and habitat attributes during summer. Proportion of pool area, number of pools, large wood (LW), and pool forming large wood were significantly higher in paired treatment than control reaches. Juvenile Chinook salmon (Oncorhynchus tshawytscha), steelhead (O. mykiss) coho salmon (O. kisutch), and cutthroat trout (O. clarkii) abundances were significantly higher in treatment than control reaches, but no significant responses were detected for mountain whitefish (Prosopium williamsoni) or dace (Rhinichthys spp.). Chinook and coho responses were positively correlated with LW and pool area suggesting wood placement produced reach-scale increases of juvenile salmonid abundance.

Coast Coho Partnership. (2014). *Strategic Action Plan for Coho Salmon Recovery: The Elk River.* Retrieved from https://www.wildsalmoncenter.org/wp-content/uploads/2019/03/Elk-River-SAP-for-Coho-Salmon-Recovery.pdf

In 2015, the Wild Rivers Land Trust (WRLT) convened a planning process with several south coast partners to produce a Strategic Action Plan (SAP) for the recovery of the Elk River population of wild coho (Oncorhynchus kisutch). Working through a broader coast-wide recovery effort known as the "Coast Coho Business Plan," the Elk River Coho Partnership's (Elk Partnership) goal in developing the SAP was to prioritize habitat restoration work in the watershed through a transparent, science-driven process. In addition, the Elk Partnership sought to coordinate the work of local, state, and federal partners engaged in restoring the watershed in order to leverage more funding and accelerate the implementation of on-theground habitat restoration projects. The Elk Partnership approached this effort guided by a vision to assess habitat restoration needs and emerging threats in the context of local social and economic priorities. This approach recognized the inextricable link between watershed health and the economic and social well-being of local residents and landowners. Accordingly, this plan proposes to restore those habitats that can provide the greatest return on investment, while preventing further habitat loss. Two essential objectives of this prevention strategy are to: 1) incentivize landowner stewardship and 2) stop the conversion of working agriculture and timber lands to uses that are less compatible with coho recovery. Ultimately, this plan is intended to be a guide for the community to showcase how investments in resource conservation can serve the needs of communities and wild salmon.

Crozier, L. G., McClure, M. M., Beechie, T., Bograd, S. J., Boughton, D. A., Carr, M., . . . Willis-Norton, E. (2019). Climate Vulnerability Assessment for Pacific Salmon and Steelhead in the California Current Large Marine Ecosystem. *Plos One, 14*(7), https://doi.org/10.1371/journal.pone.0217711

Major ecological realignments are already occurring in response to climate change. To be successful, conservation strategies now need to account for geographical patterns in traits sensitive to climate change, as well as climate threats to species-level diversity. As part of an effort to provide such information, we conducted a climate vulnerability assessment that included all anadromous Pacific salmon and steelhead (Oncorhynchus spp.) population units listed under the U.S. Endangered Species Act. Using an expert-based scoring system, we ranked 20 attributes for the 28 listed units and 5 additional units. Attributes captured biological sensitivity, or the strength of linkages between each listing unit and the present climate; climate exposure, or the magnitude of projected change in local environmental conditions; and adaptive capacity, or the ability to modify phenotypes to cope with new climatic conditions. Each listing unit was then assigned one of four vulnerability categories. Units ranked most vulnerable overall were Chinook (O. tshawytscha) in the California Central Valley, coho (O. kisutch) in California and southern Oregon, sockeye (O. nerka) in the Snake River Basin, and spring-run Chinook in the interior Columbia and Willamette River Basins. We identified units with similar vulnerability profiles using a hierarchical cluster analysis. Life history characteristics, especially freshwater and estuary residence times, interplayed with gradations in exposure from south to north and from coastal to interior regions to generate landscape-level patterns within each species. Nearly all listing units faced high exposures to projected increases in stream temperature, sea surface temperature, and ocean acidification, but other aspects of exposure peaked in particular regions. Anthropogenic factors, especially migration barriers, habitat degradation, and hatchery influence, have reduced the adaptive capacity of most steelhead and salmon populations. Enhancing adaptive capacity is essential to mitigate for the increasing threat of climate change. Collectively, these results provide a framework to support recovery planning that considers climate impacts on the majority of West Coast anadromous salmonids.

Dietrich, J., Eder, K., Thompson, D., Buchanan, R., Skalski, J., McMichael, G., . . . Loge, F. (2016). Survival and Transit of in-River and Transported Yearling Chinook Salmon in the Lower Columbia River and Estuary. *Fisheries Research, 183*, https://doi.org/10.1016/j.fishres.2016.07.005

The lower Columbia River and estuary (LRE) is a critically important environment for outmigrating salmonids, yet uncertainties remain about the survival and behavior of barged and in-river migrating fish. Although studies have used telemetry to monitor Chinook salmon movement and survival through the LRE, comparisons between outmigration years are confounded by differences in tag technologies, array locations, and experimental designs. In the present study, multiple releases of barged and in-river Snake River spring/summer Chinook salmon were implanted with acoustic tags and monitored at multiple locations between Lower Granite Dam on the Snake River (695 km from the mouth of the Columbia River) to within 3 km of the Pacific Ocean. LRE survival estimates and transit rates of barged fish significantly varied throughout the outmigration season. The transit rates of in-river fish also varied, but without a corresponding seasonal difference in LRE survival estimates. Early release groups of barged salmon were slower and had lower survival in the LRE than in-river salmon. Estuary arrival timing and the magnitude of transit rates may contribute to significant differences in LRE mortality between in-river and barged juvenile salmon. Survival in the Lower River reaches was stable and exceeded 0.90 for both barged and in-river fish, while survival decreased markedly in the Estuary. Differential distributions of arrival to the LRE, transit rates, and survival suggest that the outmigration experience is not homogenous for barged and in-river yearling Snake River Chinook salmon, and that previous outmigration experience of threatened and endangered salmon should be considered in future management decisions and recovery plans.

Erhardt, J. M., Tiffan, K. F., & Connor, W. P. (2018). Juvenile Chinook Salmon Mortality in a Snake River Reservoir: Smallmouth Bass Predation Revisited. *Transactions of the American Fisheries Society, 147*(2), https://doi.org/10.1002/tafs.10026

Predation by nonnative fishes has been identified as a contributing factor in the decline of juvenile salmonids in the Columbia River basin. We examined the diet composition of Smallmouth Bass Micropterus dolomieu and estimated the consumption and predation loss of juvenile Chinook Salmon Oncorhynchus tshawytscha in Lower Granite Reservoir on the Snake River. We examined 4,852 Smallmouth Bass stomachs collected from shoreline habitats during April–September 2013–2015. Chinook Salmon were the second most commonly consumed fish by all size-classes of Smallmouth Bass (≥150 mm TL) throughout the study. Over the 3 years studied, we estimated that a total of 300,373 Chinook Salmon were consumed by Smallmouth Bass in our 22-km study area, of which 97% (291,884) were subyearlings (age 0) based on length frequency data. A majority of the loss (61%) occurred during June, which coincided with the timing of hatchery releases of subyearling fall Chinook Salmon. Compared to an earlier study, mean annual predation loss increased more than 15-fold from 2,670 Chinook Salmon during 1996–1997 to 41,145 Chinook Salmon during 2013–2015 (in reaches that could be compared), despite lower contemporary Smallmouth Bass abundances. This increase can be explained in part by increases in Smallmouth Bass consumption rates, which paralleled increases in subyearling Chinook Salmon densities—an expected functional response by an opportunistic consumer. Smallmouth Bass are currently significant predators of subyearling Chinook Salmon in Lower Granite Reservoir and could potentially be a large source of unexplained mortality.

Erickson, A. (2015). Efficient and Resilient Governance of Social-Ecological Systems. *Ambio, 44*(5), https://doi.org/10.1007/s13280-014-0607-7

New institutions are critically needed to improve the resilience of social–ecological systems globally. Watershed management offers an important model due to its ability to govern mixed-ownership landscapes through common property regimes, translating national goals into local action. Here, I assess the efficacy of state watershed management institutions in the Pacific Northwest, based on their ability to support local watershed groups. I use document analysis to describe and compare state institutions in Washington, Oregon, Idaho, and California. Results indicate that state institutional efficiency and resilience are the key factors determining watershed group activity and stability. The primary drivers of institutional efficiency and resilience were institutional unification, robust funding portfolios, low agency conflict, and strong support for economic multiplier effects, creative partnerships, and scholarly research. My findings elucidate the critical role of institutional efficiency and resilience in governing dynamic and complex social–ecological systems, enabling the flexibility to address emergent transformations.

Evans, A. F., Payton, Q., Cramer, B. M., Collis, K., Hostetter, N. J., Roby, D. D., & Dotson, C. (2019). Cumulative Effects of Avian Predation on Upper Columbia River Steelhead. *Transactions of the American Fisheries Society, 148*(5), https://doi.org/10.1002/tafs.10197

To investigate the cumulative effects of colonial waterbird predation on fish mortality and to determine what proportion of all sources of fish mortality (1 − survival) was due to bird predation, we conducted a mark–recapture– recovery study with upper Columbia River steelhead Oncorhynchus mykiss that were PIT-tagged and released (N= 78,409) at Rock Island Dam on the Columbia River, USA. We used a state–space Bayesian model that incorporated live detections and dead recoveries of tagged fish to jointly estimate predation and survival probabilities during smolt out-migration to the Pacific Ocean over an 11-year study period. Estimated cumulative (all colonies combined) avian predation probabilities ranged from 0.31 (95% credible interval [CRI] = 0.27–0.38) to 0.53 (95% CRI= 0.42– 0.64) annually, indicating that avian predation was a substantial source of mortality. Of the predator species evaluated, predation by Caspian terns Hydroprogne caspia was often the highest, with predation probabilities ranging from 0.11 (95% CRI = 0.09–0.14) to 0.38 (95% CRI= 0.29–0.47). Probabilities of predation by double-crested cormorants Phalacrocorax auritus and mixed colonies of California gulls Larus californicus and ring-billed gulls L. delawarensis were generally lower than the probabilities for terns but were also substantial, with upwards of 0.04 (95% CRI= 0.03–0.07; cormorants) and 0.31 (95% CRI= 0.25–0.39; gulls) of steelhead consumed. Comparisons of total smolt mortality with mortality due to avian predation indicated that avian predation accounted for 42% (95% CRI= 30–56%) to 70% (95% CRI= 53–87%) of total mortality, suggesting that more steelhead were consumed by avian predators than died from all other mortality sources combined. Results indicate that avian predation, although not the original cause of steelhead declines in the basin, is now a factor limiting the survival of upper Columbia River steelhead. Using the analytical framework developed in this study, future studies can consider the cumulative impact of multiple mortality sources across large spatial and temporal scales to more fully understand the extent to which they limit fish survival.

Evans, A. F., Payton, Q., Turecek, A., Cramer, B., Collis, K., Roby, D. D., . . . Dotson, C. (2016). Avian Predation on Juvenile Salmonids: Spatial and Temporal Analysis Based on Acoustic and Passive Integrated Transponder Tags. *Transactions of the American Fisheries Society, 145*(4), https://doi.org/10.1080/00028487.2016.1150881

We evaluated the impact of predation on juvenile steelhead Oncorhynchus mykiss and yearling and subyearling Chinook Salmon O. tshawytscha by piscivorous waterbirds from 11 different breeding colonies in the Columbia River basin during 2012 and 2014. Fish were tagged with both acoustic tags and PIT tags and were tracked via a network of hydrophone arrays to estimate total smolt mortality (1 - survival) at various spatial and temporal scales during outmigration. Recoveries of PIT tags on bird colonies, coupled with the last known detections of live fish passing hydrophone arrays, were used to estimate the impact of avian predation relative to total smolt mortality. Results indicated that avian predation was a substantial source of steelheadmortality, with predation probability (proportion of available fish consumed by birds) ranging from 0.06 to 0.28 for fish traveling through the lower Snake River and the lower and middle Columbia River. Predation probability estimates ranged from 0.03 to 0.09 for available tagged yearling Chinook Salmon and from 0.01 to 0.05 for subyearlings. Smolt predation by gulls Larus spp. was concentrated near hydroelectric dams, while predation by Caspian terns Hydroprogne caspia was concentrated within reservoirs. No concentrated areas of predation were identified for double-crested cormorants Phalacrocorax auritus or American white pelicans Pelecanus erythrorhynchos. Comparisons of total smolt mortality relative to mortality from colonial waterbirds indicated that avian predation was one of the greatest sources of mortality for steelhead and yearling Chinook Salmon during out-migration. In contrast, avian predation on subyearling Chinook Salmon was generally low and constituted a minor component of total mortality. Our results demonstrate that acoustic and PIT tag technologies can be combined to quantify where and when smolt mortality occurs and the fraction of mortality that is due to colonial waterbird predation relative to non-avian mortality sources.

Funk, W. C., Forester, B. R., Converse, S. J., Darst, C., & Morey, S. (2019). Improving Conservation Policy with Genomics: A Guide to Integrating Adaptive Potential into U.S. Endangered Species Act Decisions for Conservation Practitioners and Geneticists. *Conservation Genetics, 20*(1), https://doi.org/10.1007/s10592-018-1096-1

Rapid environmental change makes adaptive potential—the capacity of populations to evolve genetically based changes in response to selection—more important than ever for long-term persistence of at-risk species. At the same time, advances in genomics provide unprecedented power to test for and quantify adaptive potential, enabling consideration of adaptive potential in estimates of extinction risk and laws protecting endangered species. The U.S. Endangered Species Act (ESA) is one of the most powerful environmental laws in the world, but so far, the full potential of genomics in ESA listing and recovery decisions has not been realized by the federal agencies responsible for implementing the ESA or by conservation geneticists. The goal of our paper is to chart a path forward for integrating genomics into ESA decision making to facilitate full consideration of adaptive potential in evaluating long-term risk of extinction. For policy makers, managers, and other conservation practitioners, we outline why adaptive potential is important for population persistence and what genomic tools are available for quantifying it. For conservation geneticists, we discuss how federal agencies can integrate information on the effect of adaptive potential on extinction risk—and the related uncertainty—into decisions, and suggest next steps for advancing understanding of the effect of adaptive potential on extinction risk. The mechanisms and consequences of adaptation are incredibly complex, and we may never have a complete understanding of adaptive potential for any organism. Nevertheless, we argue that the best available evidence regarding adaptive potential can now be incorporated by federal agencies into modeling and decision making processes, while at the same time conserving genome-wide variation and striving for a deeper understanding of adaptive potential and its effects on population persistence to improve decision making into the future.

Gosselin, J. L., & Anderson, J. J. (2017). Combining Migration History, River Conditions, and Fish Condition to Examine Cross-Life-Stage Effects on Marine Survival in Chinook Salmon. *Transactions of the American Fisheries Society, 146*(3), https://doi.org/10.1080/00028487.2017.1281166

We examined delayed effects (or carryover effects) on marine survival from the freshwater experiences of migrating Chinook Salmon Oncorhynchus tshawytscha. Juvenile Chinook Salmon that differed in their freshwater experience in passing hydroelectric power dams of the Columbia and Snake rivers (Pacific Northwest) as run-of-the-river or barged fish were tested in challenge experiments at 23.5°C to determine the freshwater survival index m (i.e., the time to 80% mortality). Seasonal patterns of m were best predicted by (1) an index of migration timing (t) at the exit of the hydropower system and a barge index (B) or (2) a temperature exposure index (θ; i.e., 7-d average of river temperatures experienced prior to collection). Other predictors tested included river flow, wet mass, and Fulton's condition factor. Predicted m (mpred)based on t and B or based on θ was then related to seasonal patterns ofmarine survival. Significant relationships between mpred and marine survival provide support for the hypothesis that the seasonal patterns of freshwater experiences during hydropower system passage influence the biological condition of juvenile salmon at seawater entry and consequently their seasonal pattern ofmarine survival to the adult stage. Because temperature is a more direct and biologically relevant variable than migration timing with a barging index offset, further investigation of temperature-related factors affecting the biological condition of anadromous fishes as they exit freshwater—and subsequently their marine survival—is warranted.

Harper, B. L., & Walker, D. E. (2015). Comparison of Contemporary and Heritage Fish Consumption Rates in the Columbia River Basin. *Human Ecology, 43*(2), https://doi.org/10.1007/s10745-015-9734-4

Fish consumption rates (e.g., pounds or grams per day (gpd), or meals per week) are used in a variety of regulatory processes such as setting water quality standards. Many Native American tribes eat more fish than the general population, especially in areas such as the Columbia River Basin, which was renowned for abundant fish. However, contemporary fish consumption rates are lower (i.e., they have been suppressed) than baseline heritage rates due to contamination, habitat degradation, loss of access, and legal and physical assault on tribal fishing. Nevertheless, traditional lifestyles are recognized and protected by intergovernmental treaties and/or aboriginal rights. The understanding of heritage rates is gaining importance as tribal cultures are reinvigorated, watersheds are restored, and understanding and respect for tribal lifeways improves. We compare the different methods used to derive Columbia Basin contemporary and heritage fish consumption rates. We highlight the need for caution in selecting a fish consumption rate until the derivation and context of the rate have been considered.

Hess, J. E., Ackerman, M. W., Fryer, J. K., Hasselman, D. J., Steele, C. A., Stephenson, J. J., . . . Narum, S. R. (2016). Differential Adult Migration-Timing and Stock-Specific Abundance of Steelhead in Mixed

Stock Assemblages. *Ices Journal of Marine Science, 73*(10), https://doi.org/10.1093/icesjms/fsw138

Stock-specific migration-timing and relative abundance of exploited fish species are critical parameters to estimate for management of mixed stock fisheries. Here, we used parentage-based tagging (PBT) together with mixed stock analyses (MSA) to estimate stock-specific abundance and migration-timing in anadromous adult steelhead (Oncorhynchus mykiss) sampled at Bonneville Dam in the lower Columbia River. Results indicate that natural-origin steelhead was represented by 11 of 13 possible stocks found throughout the Columbia-Snake river basins, while hatchery-origin steelhead was primarily composed of five stocks from the Snake River drainage. Further, migration-timing differentiated stocks and allowed categorization of early, intermediate, and late migrating stocks. Analyses of age and length data for these stocks also showed that late-arriving fish were larger due to older age and originated primarily from the Clearwater River, South Fork Salmon River, and Dworshak Hatchery, all from the Snake River drainage. Sex ratios tended to be skewed towards females and ranged from 51.5 to 68.9% for hatchery stocks and 60.5–71.8% for natural-origin stocks. This suggests that anadromous migration is favored by females while males are more likely to residualize in freshwater. Overall, this study demonstrates how the use of PBT in MSA can reveal important stock-specific differences in migration-timing and relative abundance and provides critical information for management of mixed stock fisheries.

Hostetter, N. J., Evans, A. F., Cramer, B. M., Collis, K., Lyons, D. E., & Roby, D. D. (2015). Quantifying Avian Predation on Fish Populations: Integrating Predator-Specific Deposition Probabilities in Tag Recovery Studies. *Transactions of the American Fisheries Society, 144*(2), https://doi.org/10.1080/00028487.2014.988882

Accurate assessment of specific mortality factors is vital to prioritize recovery actions for threatened and endangered species. For decades, tag recovery methods have been used to estimate fish mortality due to avian predation. Predation probabilities derived from fish tag recoveries on piscivorous waterbird colonies typically reflect minimum estimates of predation due to an unknown and unaccounted-for fraction of tags that are consumed but not deposited on-colony (i.e., deposition probability). We applied an integrated tag recovery modeling approach in a Bayesian context to estimate predation probabilities that accounted for predator-specific tag detection and deposition probabilities in a multiple-predator system. Studies of PIT tag deposition were conducted across three bird species nesting at seven different colonies in the Columbia River basin, USA. Tag deposition probabilities differed significantly among predator species (Caspian terns Hydroprogne caspia: deposition probability D 0.71, 95% credible interval [CRI] D 0.51–0.89; double-crested cormorants Phalacrocorax auritus: 0.51, 95% CRI D 0.34–0.70; California gulls Larus californicus: 0.15, 95% CRI D 0.11–0.21) but showed little variation across trials within a species or across years. Data from a 6-year study (2008–2013) of PIT-tagged juvenile Snake River steelhead Oncorhynchus mykiss (listed as threatened under the Endangered Species Act) indicated that colony-specific predation probabilities ranged from less than 0.01 to 0.17 and varied by predator species, colony location, and year. Integrating the predator-specific deposition probabilities increased the predation probabilities by a factor of approximately 1.4 for Caspian terns, 2.0 for double-crested cormorants, and 6.7 for California gulls compared with traditional minimum predation rate methods, which do not account for deposition probabilities. Results supported previous findings on the high predation impacts from strictly piscivorous waterbirds nesting in the Columbia River estuary (i.e., terns and cormorants), but our findings also revealed greater impacts of a generalist predator species (i.e., California gulls) than were previously documented. Approaches used in this study allow for direct comparisons among multiple fish mortality factors and considerably improve the reliability of tag recovery models for estimating predation probabilities in multiple-predator systems.

Kagley, A. N., Smith, J. M., Fresh, K. L., Frick, K. E., & Quinn, T. P. (2017). Residency, Partial Migration, and Late Egress of Subadult Chinook Salmon (Oncorhynchus tshawytscha) and Coho Salmon (O-kisutch) in Puget Sound, Washington. *Fishery Bulletin, 115*(4), https://doi.org/10.7755/fb.115.4.10

Migratory behavior affects growth, survival, and fitness of individual fish, the dynamics and resilience of populations, and the ecosystems that fish occupy. Many salmonids are anadromous but individuals vary in the duration and spatial extent of marine migrations. We used telemetry to investigate movements of Chinook salmon (Oncorhynchus tshawytscha) that remained in Puget Sound (residents) rather than migrated to the Pacific Ocean. Most tagged Chinook salmon (26 of 37=70%) remained in Puget Sound for a substantial period, staying in the region where captured. However, 30% of tagged individuals, termed "transients," subsequently left Puget Sound. Residents and transients did not differ in tagging date, body size, or origin (hatchery or wild). Compared with sympatric coho salmon (O. kisutch) where 80% remained as residents according to similar data, Chinook salmon tended to be detected closer to shore, in shallower water, and on fewer different receivers. For both species, residents showed limited movement within Puget Sound. We conclude that Chinook and coho salmon display resident and transient movement patterns across a behavioral continuum rather than within discrete migrational categories. These movement patterns are important because they affect the role of salmon in the ecosystem, their vulnerability to fisheries, and their accumulation of chemical contaminants.

Keefer, M. L., & Caudill, C. C. (2014). Homing and Straying by Anadromous Salmonids: A Review of Mechanisms and Rates. *Reviews in Fish Biology and Fisheries, 24*(1), https://doi.org/10.1007/s11160-013-9334-6

There is a long research history addressing olfactory imprinting, natal homing, and non-natal straying by anadromous salmon and trout (Salmonidae). In undisturbed populations, adult straying is a fundamental component of metapopulation biology, facilitating genetic resilience, demographic stability, recolonization, and range expansion into unexploited habitats. Unfortunately, salmonid hatcheries and other human actions worldwide have affected straying in ways that can negatively affect wild populations through competitive interactions, reduced productivity and resiliency, hybridization and domestication effects, and outbreeding depression. Reduced adult straying is therefore an objective for many managed populations. Currently, there is considerable uncertainty about the range of ‘natural’ stray rates and about which mechanisms precipitate straying in either wild or human-influenced fish. Research in several disciplines indicates that adult straying is affected by endocrine physiology and neurological processes in juveniles, incomplete or interrupted imprinting during rearing and emigration, and by complex interactions among adult maturation processes, reproductive behaviors, olfactory memory, environmental conditions during migration, and senescence physiology. Reported salmonid stray rates indicate that the behavior varies among species, among life-history types, and among populations within species. Most strays enter sites near natal areas, but long-distance straying also occurs, especially in hatchery populations that were outplanted or transported as juveniles. A majority of past studies has estimated straying as demographic losses from donor populations, but some have estimated straying into recipient populations. Most recipient-based estimates have substantiated concerns that wild populations are vulnerable to swamping by abundant hatchery and farm-raised strays.

Keefer, M. L., Clabough, T. S., Jepson, M. A., Johnson, E. L., Peery, C. A., & Caudill, C. C. (2018). Thermal Exposure of Adult Chinook Salmon and Steelhead: Diverse Behavioral Strategies in a Large and Warming River System. *Plos One, 13*(9), https://doi.org/10.1371/journal.pone.0204274

Rising river temperatures in western North America have increased the energetic costs of migration and the risk of premature mortality in many Pacific salmon (Oncorhynchus spp.) populations. Predicting and managing risks for these populations requires data on acute and cumulative thermal exposure, the spatio-temporal distribution of adverse conditions, and the potentially mitigating effects of cool-water refuges. In this study, we paired radiotelemetry with archival temperature loggers to construct continuous, spatially-explicit thermal histories for 212 adult Chinook salmon (O. tshawytscha) and 200 adult steelhead (O. mykiss). The fish amassed -500,000 temperature records (30-min intervals) while migrating through 470 kilometers of the Columbia and Snake rivers en route to spawning sites in Idaho, Oregon, and Washington. Spring- and most summer-run Chinook salmon migrated before river temperatures reached annual highs; their body temperatures closely matched ambient temperatures and most had thermal maxima in the lower Snake River. In contrast, many individual fall-run Chinook salmon and most steelhead had maxima near thermal tolerance limits (20-22 degrees C) in the lower Columbia River. High temperatures elicited extensive use of thermal refuges near tributary confluences, where body temperatures were similar to 2-10 degrees C cooler than the adjacent migration corridor. Many steelhead used refuges for weeks or more whereas salmon use was typically hours to days, reflecting differences in spawn timing. Almost no refuge use was detected in a similar to 260-km reach where a thermal migration barrier may more frequently develop in future warmer years. Within population, cumulative thermal exposure was strongly positively correlated (0.88 <= r <= 0.98) with migration duration and inconsistently associated (-0.28 <= r <= 0.09) with migration date. All four populations have likely experienced historically high mean and maximum temperatures in recent years. Expected responses include population-specific shifts in migration phenology, increased reliance on patchily-distributed thermal refuges, and natural selection favoring temperature tolerant phenotypes.

Keefer, M. L., Jepson, M. A., Clabough, T. S., Johnson, E. L., Narum, S. R., Hess, J. E., & Caudill, C. C. (2018). Sea-to-Sea Survival of Late-Run Adult Steelhead (Oncorhynchus mykiss) from the Columbia and Snake Rivers. *Canadian Journal of Fisheries and Aquatic Sciences, 75*(3), https://doi.org/10.1139/cjfas-2016-0430

We used biotelemetry and genetic stock identification to assess sea-to-sea survival and run composition of 1212 late-migrating adult steelhead (anadromous Oncorhynchus mykiss) through the Columbia River and Snake River migratory corridors. The late run was predominated by steelhead from Idaho's Clearwater and Salmon rivers that must pass eight large hydroelectric dams during both prespawn and postspawn migrations. In 2 years (2013 and 2014), prespawn survival to Snake River tributaries (> 500 km) was 0.48-0.67 for the most abundant populations and was higher for females and 1-sea fish (i.e., fish that spend one winter at sea). Annual survival from Snake River tributary entry to postspawn kelt status was 0.14-0.17, with higher survival for females and those without hatchery fin clips. Kelt outmigration survival was 0.31-0.39 past four Snake River dams and 0.13-0.20 past all eight dams and was highest for smaller kelts. Full-cycle adult freshwater survival (sea-to-sea) including 16 dam passage events was 0.01-0.02. Younger steelhead and those without fin clips survived at the highest rates. This study uniquely partitioned mortality across prespawn, reproductive, and kelt life history stages and informs management strategies for this conservation-priority metapopulation.

Kilduff, D. P., Di Lorenzo, E., Botsford, L. W., & Teo, S. L. H. (2015). Changing Central Pacific El Ninos Reduce Stability of North American Salmon Survival Rates. *Proceedings of the National Academy of Sciences of the United States of America, 112*(35), https://doi.org/10.1073/pnas.1503190112

[Pacific salmon are a dominant component of the northeast Pacific ecosystem. Their status is of concern because salmon abundance is highly variable—including protected stocks, a recently closed fishery, and actively managed fisheries that provide substantial ecosystem services. Variable ocean conditions, such as the Pacific Decadal Oscillation (PDO), have influenced these fisheries, while diminished diversity of freshwater habitats have increased variability via the portfolio effect. We address the question of how recent changes in ocean conditions will affect populations of two salmon species. Since the 1980s, El Niño Southern Oscillation (ENSO) events have been more frequently associated with central tropical Pacific warming (CPW) rather than the canonical eastern Pacific warming ENSO (EPW). CPW is linked to the North Pacific Gyre Oscillation (NPGO), whereas EPW is linked to the PDO, different indicators of northeast Pacific Ocean ecosystem productivity. Here we show that both coho and Chinook salmon survival rates along western North America indicate that the NPGO, rather than the PDO, explains salmon survival since the 1980s. The observed increase in NPGO variance in recent decades was accompanied by an increase in coherence of local survival rates of these two species, increasing salmon variability via the portfolio effect. Such increases in coherence among salmon stocks are usually attributed to controllable freshwater influences such as hatcheries and habitat degradation, but the unknown mechanism underlying the ocean climate effect identified here is not directly subject to management actions.]

Kock, T. J., Verretto, N. E., Ackerman, N. K., Perry, R. W., Beeman, J. W., Garello, M. C., & Fielding, S. D. (2019). Assessment of Operational and Structural Factors Influencing Performance of Fish Collectors in Forebays of High-Head Dams. *Transactions of the American Fisheries Society, 148*(2), https://doi.org/10.1002/tafs.10146

Providing efficient downstream passage is critical for improving populations of migratory fishes in impounded river systems. High-head dams, such as those used for water storage or flood-risk management, pose unique passage challenges requiring unique solutions. Systems to collect fish in dam forebays ("forebay collectors") for transport to downstream release locations have been used at some high-head dams in the western United States since the 1950s. Collection efficiency of these facilities has ranged from nearly 0% to 100%, suggesting the need for a better understanding of factors affecting performance in these complex environments if they are to be designed and deployed at new sites. We compiled information on environmental, structural, and performance characteristics of seven existing forebay collectors to quantify factors affecting their performance based on a meta-analysis using a data set containing 52 separate collection estimates. Covariates included species type (steelhead Oncorhynchus mykiss, Chinook Salmon O. tshawytscha, Coho Salmon O. kisutch, and Sockeye Salmon O.

nerka), collector inflow, collector entrance area, relative size of the dam forebay, and whether or not nets were used to enhance collection. We found that inflow, the use of lead nets, the size of the collector entrance area, the relative size of the dam forebay, and the interaction between collector entrance and forebay areas were significant predictors of collection performance. There was also evidence for differences between species. Chinook Salmon exhibited the lowest collection rates among the projects we examined, while steelhead collection rates were highest. These results provide guidance to design more efficient forebay collectors and improve the success of existing systems.

Landis, W. G., Chu, V. R., Graham, S. E., Harris, M. J., Markiewicz, A. J., Mitchell, C. J., . . . Stark, J. D. (2019). The Integration of Chlorpyrifos Acetylcholinesterase Inhibition, Water Temperature and Dissolved Oxygen Concentration into a Regional Scale Multiple Stressor Risk Assessment Estimating Risk to Chinook Salmon in Four Rivers in Washington State, USA. *Integrated Environmental Assessment and Management, 16*(1), https://doi.org/10.1002/ieam.4199

We estimated the risk to populations of Chinook salmon (Oncorhynchus tshawytscha) due to chlorpyrifos (CH), water temperature (WT), and dissolved oxygen concentration (DO) in 4 watersheds in Washington State, USA. The watersheds included the Nooksack and Skagit Rivers in the Northern Puget Sound, the Cedar River in the Seattle-Tacoma corridor, and the Yakima River, a tributary of the Columbia River. The Bayesian network relative risk model (BN-RRM) was used to conduct this ecological risk assessment and was modified to contain an acetylcholinesterase (AChE) inhibition pathway parameterized using data from CH toxicity data sets. The completed BN-RRM estimated risk at a population scale to Chinook salmon employing classical matrix modeling runs up to 50-y timeframes. There were 3 primary conclusions drawn from the model-building process and the risk calculations. First, the incorporation of an AChE inhibition pathway and the output from a population model can be combined with environmental factors in a quantitative fashion. Second, the probability of not meeting the management goal of no loss to the population ranges from 65% to 85%. Environmental conditions contributed to a larger proportion of the risk compared to CH. Third, the sensitivity analysis describing the influence of the variables on the predicted risk varied depending on seasonal conditions. In the summer, WT and DO were more influential than CH. In the winter, when the seasonal conditions are more benign, CH was the driver. Fourth, in order to reach the management goal, we calculated the conditions that would increase juvenile survival, adult survival, and a reduction in toxicological effects. The same process in this example should be applicable to the inclusion of multiple pesticides and to more descriptive population models such as those describing metapopulations.

Losee, J. P., Miller, J. A., Peterson, W. T., Teel, D. J., & Jacobson, K. C. (2014). Influence of Ocean Ecosystem Variation on Trophic Interactions and Survival of Juvenile Coho and Chinook Salmon. *Canadian Journal of Fisheries and Aquatic Sciences, 71*(11), https://doi.org/10.1139/cjfas-2014-0043

The community of trophically transmitted marine parasites of juvenile coho (Oncorhynchus kisutch) and Chinook (Oncorhynchus tshawytscha) salmon across 8 years (2002–2009) was related to indices of physical and biological ocean conditions and adult returns. When the biomass of lipid-poor, southern origin copepods in the coastal ocean was high during juvenile salmon outmigration from fresh water (April–June), yearling coho and Chinook salmon harbored a different trophically transmitted parasite fauna and exhibited lower survival compared with years when the southern copepod biomass was low. As copepods are key intermediate hosts in many marine parasite life cycles, these results support a trophic linkage between the copepod community and salmon prey. Interannual variation in the parasite community was correlated with survival ofcoho salmon (r = −0.67) measured 1 year later and adult returns ofUpper Columbia River summer and fall Chinook salmon (r = −0.94) 3 years from the time ofocean entry.

Lusardi, R. A., & Moyle, P. B. (2017). Two-Way Trap and Haul as a Conservation Strategy for Anadromous Salmonids. *Fisheries, 42*(9), https://doi.org/10.1080/03632415.2017.1356124

Dams are ubiquitous in the United States and have disconnected migratory fishes from important historical habitat. Trapping fish and moving them around dams (trap and haul) is a common strategy to manage Pacific coast salmonids. Usually, juveniles or adults are moved in one direction, but there is growing interest in two-way trap and haul (TH2), where both adults and out-migrating juveniles are captured and transported over dams. Despite recent technological advances, no TH2 program is an unequivocal success. Our review indicates that uncertainties associated with TH2 programs exist and include delayed effects from transportation, maintenance of above-dam populations, out-migrant capture efficiency, and the role of hatchery supplementation. Two-way trap and haul programs should (1) clearly define measurable and objective success metrics, such as the 10 we provide; (2) proceed experimentally under an adaptive management framework to determine risk–benefit trade-offs; and (3) be part of comprehensive conservation strategies that consider the entire life cycle of each species. Two-way trap and haul is proposed as a high-priority recovery strategy for Chinook Salmon Oncorhynchus tshawytscha populations in California. Our findings indicate that any such TH2 program should proceed with extreme caution.

Malick, M. J., Rutherford, M. B., & Cox, S. P. (2017). Confronting Challenges to Integrating Pacific Salmon into Ecosystem-Based Management Policies. *Marine Policy, 85*, https://doi.org/https://doi.org/10.1016/j.marpol.2017.08.028

Ecosystem-based management is an increasingly prominent paradigm for the management of living marine resources with a focus on maintaining ecosystem level properties and processes. Although highly migratory marine and anadromous fish species often disproportionately contribute to the structure and function of ecosystems, incorporating these species into ecosystem-based management policies remains difficult because they spend a considerable portion of time outside the boundaries that define a particular management area. In this paper, two case studies are used to examine how the challenges of ecosystem openness, imperfect information, and ecosystem complexity can impede efforts to integrate highly migratory Pacific salmon into ecosystem-based management policies. This analysis highlights three main factors that hinder more effective integration: (1) uncertainties about impacts of human activities and ecological processes that occur in geographically distant jurisdictional areas or at spatial scales larger than the ecosystem-based management area, (2) spatial asymmetries in the distribution of costs and benefits associated with management decisions (i.e., positive or negative externalities), and (3) static management policies that prevent updating management decisions in a timely manner when ecosystem conditions change or new information becomes available. Given these factors, two potential strategies to address migratory challenges are suggested. First, the creation of an international ecosystem synthesis group is recommended to facilitate the collection, analysis, and dissemination of ecological, social, and policy information across national and other jurisdictional boundaries. Second, the expanded use of dynamic in-season management policies is recommended, which allow for rapid updating of management decisions based on evolving information about ecosystem conditions.

Marin Jarrin, J. R., Teel, D. J., & Miller, J. A. (2016). Stock-Specific Movement and Distribution of Juvenile Chinook Salmon, Oncorhynchus tshawytscha, in Sandy Beach Surf Zones of Oregon and Washington, USA. *Estuaries and Coasts, 39*(3), https://doi.org/10.1007/s12237-015-0037-1

Sandy beach surf zones serve as alternative nursery habitats for juvenile Chinook salmon (0 age) during their early marine residency, a period considered critical due to high and variable mortality rates. Despite the importance of early marine residence, the extent of juvenile salmon surf zone use and movement along sandy beaches is not well understood. Juvenile Chinook salmon distribution and movement were studied in shallow surf zone habitats by sampling from 2006 to 2010 with a beach seine 11 beaches adjacent and distant to four estuary mouths in Oregon and Washington, USA. The estuary of origin of each juvenile was determined using genetic stock identification methods and coded wire tags. Surf zones sampled were within littoral cells, which are stretches of the coastline bordered by rocky headlands, and included estuaries with and without Chinook salmon populations. Juvenile salmonids were only collected at littoral cells with Chinook-inhabited watersheds. Most juveniles (95 %) were present at sandy beaches adjacent (<500 m from estuary mouth) to their estuary of origin. Few Chinook salmon (5 %) were collected at littoral cells that contained non-natal estuaries. These results indicate that juvenile Chinook salmon inhabiting surf zones mostly use beaches adjacent to their estuaries of origin, but some juveniles may reside in beaches distant from their point of ocean entry.

Maryoung, L. A., Blunt, B., Tierney, K. B., & Schlenk, D. (2015). Sublethal Toxicity of Chlorpyrifos to Salmonid Olfaction after Hypersaline Acclimation. *Aquatic Toxicology, 161*, https://doi.org/10.1016/j.aquatox.2015.01.026

Salmonid habitats can be impacted by several environmental factors, such as salinization, which can also affect salmonid tolerance to anthropogenic stressors, such as pesticides. Previous studies have shown that hypersaline acclimation enhances the acute toxicity of certain organophosphate and carbamate pesticides to euryhaline fish; however, sublethal impacts have been far less studied. The current study aims to determine how hypersaline acclimation and exposure to the organophosphate chlorpyrifos (CPF) impact salmonid olfaction. Combined acclimation and exposure to CPF was shown to impact rainbow trout olfaction at the molecular, physiological, and behavioral levels. Concurrent exposure to hypersalinity and 0.5 p.,g/L CPF upregulated four genes (chloride intracellular channel 4, G protein zgc:101761, calcium calmodulin dependent protein kinase II delta, and adrenergic alpha 2C receptor) that inhibit olfactory signal transduction. At the physiological level, hypersalinity and chlorpyrifos caused a decrease in sensory response to the amino acid L-serine and the bile salt taurocholic acid. Combined acclimation and exposure also negatively impacted behavior and reduced the avoidance of a predator cue (L-serine). Thus, acclimation to hypersaline conditions and exposure to environmentally relevant concentrations of chlorpyrifos caused an inhibition of olfactory signal transduction leading to a decreased response to odorants and impairment of olfactory mediated behaviors.

Matala, A. P., Allen, B., Narum, S. R., & Harvey, E. (2017). Restricted Gene Flow between Resident Oncorhynchus mykiss and an Admixed Population of Anadromous Steelhead. *Ecology and Evolution, 7*(20), https://doi.org/10.1002/ece3.3338

The species Oncorhynchus mykiss is characterized by a complex life history that presents a significant challenge for population monitoring and conservation management. Many factors contribute to genetic variation in O. mykiss populations, including sympatry among migratory phenotypes, habitat heterogeneity, hatchery introgression, and immigration (stray) rates. The relative influences of these and other factors are contingent on characteristics of the local environment. The Rock Creek subbasin in the middle Columbia River has no history of hatchery supplementation and no dams or artificial barriers. Limited intervention and minimal management have led to a dearth of information regarding the genetic distinctiveness of the extant O. mykiss population in Rock Creek and its tributaries. We used 192 SNP markers and collections sampled over a 5-year period to evaluate the temporal and spatial genetic structures of O. mykiss between upper and lower watersheds of the Rock Creek subbasin. We investigated potential limits to gene flow within the lower watershed where the stream is fragmented by seasonally dry stretches of streambed, and between upper and lower watershed regions. We found minor genetic differentiation within the lower watershed occupied by anadromous steelhead (FST = 0.004), and evidence that immigrant influences were prevalent and ubiquitous. Populations in the upper watershed above partial natural barriers were highly distinct (FST = 0.093) and minimally impacted by apparent introgression. Genetic structure between watersheds paralleled differences in local demographics (e.g., variation in size), migratory restrictions, and habitat discontinuity. The evidence of restricted gene flow between putative remnant resident populations in the upper watershed and the admixed anadromous population in the lower watershed has implications for local steelhead productivity and regional conservation.

Matala, A. P., Narum, S. R., Saluskin, B. P., Johnston, M. V., Newell, J. E., Fast, D. E., & Galbreath, P. F. (2019). Early Observations from Monitoring a Reintroduction Program: Return of Sockeye Salmon to a Nursery Lake of Historical Importance. *Transactions of the American Fisheries Society, 148*(2), https://doi.org/10.1002/tafs.10133

The historical distribution of Sockeye Salmon Oncorhynchus nerka in the Columbia River basin has been constrained by the species' dependence on nursery lakes for juvenile rearing. Several productive lake systems were impounded by dams during the last century leading to the extirpation of Sockeye Salmon from many nursery lakes in the region. Recent efforts to re-establish populations in historically natal areas are exemplified by the Cle Elum Lake reintroduction program. The program is founded on outplanting adult fish from two middle Columbia River donor populations with different adaptive potentials. We used genetic stock identification methods to differentiate stock origins between Osoyoos Lake (OSO) and Lake Wenatchee (WEN) donor stocks and to evaluate the relative productivity from two brood years (2011 and 2012) of natural spawning in the novel environment. Spawning ground surveys revealed assortative mating between earlier-spawning WEN fish that were more abundant farthest upstream and later-spawning OSO fish that were concentrated (82%) downstream nearest the lake. Hybrids accounted for only 5% of sampled smolts and 4% of adult returns. Smolts rearing in Cle Elum Lake were significantly larger overall (OSO, 140 mm; WEN, 129 mm) than smolts in either donor population (84 mm). However, the average size of OSO smolts varied among emigration years, and relative smolt abundances favored the WEN stock (70% overall), indicative of a rearing survival advantage. In relation, the WEN stock exhibited a better average rate of replacement (0.80) in adult-to-adult escapement compared with the OSO stock (0.17). Continued monitoring will focus on trends in productivity and potential demographic shifts that may arise in the Cle Elum Lake population and will provide managers with information concerning limiting factors in the environment that might affect similar approaches to reintroductions in other lake systems.

McCane, J., Adam, C., Fleming, B., Bricker, M., & Campbell, M. R. (2018). Fishgen.Net: An Online Genetic Repository for Salmon and Steelhead Genetic Baselines. *Fisheries, 43*(7), https://doi.org/10.1002/fsh.10105

FishGen is a final repository for Pacific salmon Oncorhynchus spp. and steelhead O. mykiss genetic data generated as part of the genetic stock identification and parentage-based tagging projects in the Columbia River basin and throughout the Pacific Coast of North America. Resource Data, Inc., developed this web-based, GIS - interfaced software, which is freely available to the public, with funding from the Pacific Coastal Salmon Recovery Fund and Bonneville Power Administration. FishGen currently houses genetic stock identification baselines for both Chinook Salmon O. tshawytscha and steelhead in the Columbia and Snake river basins, as well as hatchery, parentage-based, tagging baselines for both species in the Snake River basin. Because it has a userfriendly interface and protocol for submitting and storing standardized genetic and sample metadata, it is an excellent tool for supporting genetic research and monitoring projects throughout the region.

McHugh, P. A., Saunders, W. C., Bouwes, N., Wall, C. E., Bangen, S., Wheaton, J. M., . . . Jordan, C. E. (2017). Linking Models across Scales to Assess the Viability and Restoration Potential of a Threatened Population of Steelhead (Oncorhynchus mykiss) in the Middle Fork John Day River, Oregon, USA. *Ecological Modelling, 355*, https://doi.org/10.1016/j.ecolmodel.2017.03.022

Species conservation is often informed by the use of models evaluating the effect of different management strategies on the status of at-risk populations. For Pacific salmon and steelhead (Oncorhynchus sp.), which have complex life cycles spanning diverse environments and jurisdictions, life-cycle models (LCMs) have proven particularly useful for this task. Yet, most salmonid LCM applications to date have not been able to tie projections of population performance to specific tributary habitat management actions, which is integral to many recovery plans. Here we describe a modelling framework that links reach-scale stream habitat models with a basin-scale LCM, bridged by statistical extrapolation models, to evaluate recovery opportunities for an imperiled population of steelhead (O. mykiss) in the Middle Fork John Day River, USA. We parameterized a LCM by leveraging results from (1) a large-scale environmental monitoring program that supports ecohydraulic modelling and characterizes habitat quality (with a salmonid emphasis) within individual stream reaches (ca. 100–600 m segments), and (2) detailed demographic studies that provide estimates of survival, age structure, fecundity, etc. relevant to the model population. We then applied the model to quantify population performance under current/base (status quo) conditions and under two classes of restoration that aim to increase survival for juvenile steelhead: riparian revegetation, which reduces (otherwise limiting) stream temperatures during the warm summer months; and woody structure addition, which increases in-stream hydraulic complexity and thus juvenile rearing capacity. Status quo simulations produced abundance dynamics consistent with recent population monitoring data and the population's current threatened status. Our evaluation of these basic restoration scenarios revealed that while both strategies have the potential to improve the conservation status of steelhead, the benefits of woody structure addition were relatively minor compared to those resulting from stream temperature reductions. Together, our findings suggest that in thermally stressed systems the benefits of wood addition will be optimized if (1) structures are added at a considerably higher rate than is often done, focusing on reaches that are not thermally limited initially, and (2) these efforts are paired with extensive riparian planting (i.e., in reaches that have the highest potential for effective shading), which will address thermal limitations (if relevant) and offer a natural source for future wood recruitment. In addition to shedding light on effective strategies for recovering steelhead, our study illustrates the power of coordinated monitoring programs that can parameterize the relationships needed to integrate modelling possibilities across scales.

McIntyre, J. K., Lundin, J. I., Cameron, J. R., Chow, M. I., Davis, J. W., Incardona, J. P., & Scholz, N. L. (2018). Interspecies Variation in the Susceptibility of Adult Pacific Salmon to Toxic Urban Stormwater Runoff. *Environmental Pollution, 238*, https://doi.org/10.1016/j.envpol.2018.03.012

Adult coho salmon (Oncorhynchus kisutch) prematurely die when they return from the ocean to spawn in urban watersheds throughout northwestern North America. The available evidence suggests the annual mortality events are caused by toxic stormwater runoff. The underlying pathophysiology of the urban spawner mortality syndrome is not known, and it is unclear whether closely related species of Pacific salmon are similarly at risk. The present study co-exposed adult coho and chum (O. keta) salmon to runoff from a high traffic volume urban arterial roadway. The spawners were monitored for the familiar symptoms of the mortality syndrome, including surface swimming, loss of orientation, and loss of equilibrium. Moreover, the hematology of both species was profiled by measuring arterial pH, blood gases, lactate, plasma electrolytes, hematocrit, and glucose. Adult coho developed behavioral symptoms within a few hours of exposure to stormwater. Various measured hematological parameters were significantly altered compared to coho controls, indicating a blood acidosis and ionoregulatory disturbance. By contrast, runoff-exposed chum spawners showed essentially no indications of the mortality syndrome, and measured blood hematological parameters were similar to unexposed chum controls. We conclude that contaminant(s) in urban runoff are the likely cause of the disruption of ion balance and pH in coho but not chum salmon. Among the thousands of chemicals in stormwater, future forensic analyses should focus on the gill or cardiovascular system of coho salmon. Because of their distinctive sensitivity to urban runoff, adult coho remain an important vertebrate indicator species for degraded water quality in freshwater habitats under pressure from human population growth and urbanization.

Miller, J. A., Teel, D. J., Peterson, W. T., & Baptista, A. M. (2014). Assessing the Relative Importance of Local and Regional Processes on the Survival of a Threatened Salmon Population. *Plos One, 9*(6), https://doi.org/10.1371/journal.pone.0099814

Research on regulatory mechanisms in biological populations often focuses on environmental covariates. An integrated approach that combines environmental indices with organismal-level information can provide additional insight on regulatory mechanisms. Survival of spring/summer Snake River Chinook salmon (Oncorhynchus tshawytscha) is consistently low whereas some adjacent populations with similar life histories experience greater survival. It is not known if populations with differential survival respond similarly during early marine residence, a critical period in the life history. Ocean collections, genetic stock identification, and otolith analyses were combined to evaluate the growth-mortality and match-mismatch hypotheses during early marine residence of spring/summer Snake River Chinook salmon. Interannual variation in juvenile attributes, including size at marine entry and marine growth rate, was compared with estimates of survival and physical and biological metrics. Multiple linear regression and multi-model inference were used to evaluate the relative importance of biological and physical metrics in explaining interannual variation in survival. There was relatively weak support for the match-mismatch hypothesis and stronger evidence for the growth-mortality hypothesis. Marine growth and size at capture were strongly, positively related to survival, a finding similar to spring Chinook salmon from the Mid-Upper Columbia River. In hindcast models, basin-scale indices (Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO)) and biological indices (juvenile salmon catch-per-unit-effort (CPUE) and a copepod community index (CCI)) accounted for substantial and similar portions of variation in survival for juvenile emigration years 1998-2008 ($R2>0.70$). However, in forecast models for emigration years 2009-2011, there was an increasing discrepancy between predictions based on the PDO (50-448% of observed value) compared with those based on the NPGO (68-212%) or biological indices (CPUE and CCI: 83-172%). Overall, the PDO index was remarkably informative in earlier years but other basin-scale and biological indices provided more accurate indications of survival in recent years.

National Marine Fisheries Service. (2016). *Viability Assessment for Pacific Salmon and Steelhead Listed under the Endangered Species Act : Southwest*. https://doi.org/10.7289/V5/TM-SWFSC-564

This report from the Southwest Fisheries Science Center covers 10 ESA-listed Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) that lie wholly or partially in California. In this review, we consider 1) new information relevant to the delineation of ESU/DPS boundaries, and 2) new information on status and trends in abundance, productivity, spatial structure and diversity specifically addressed by viability criteria previously developed by Technical Recovery Teams (TRTs). These viability assessments summarize current information (through the 2014-2015 spawning year where available) with respect to the viability criteria developed by the TRTs. Consequently, the current assessments consider not only changes in populations that have occurred since the 2010 assessments but also the status of populations and ESUs/DPSs in relation to the viability criteria developed by the TRTs. For eight of the ESUs/DPSs (Southern Oregon/Northern California Coho Salmon, Central California Coast Coho Salmon, California Coastal Chinook Salmon, Northern California Steelhead, Central California Coast Steelhead, South-central California Steelhead, Southern California Steelhead, and California Central Valley Steelhead) the new information suggests that there has been no change in extinction risk since 2010 viability assessments. For two ESUs (Central Valley Spring-run Chinook Salmon, and Sacramento River Winter-run Chinook Salmon) the new information suggests a change in extinction risk. The viability of Central Valley Spring-run Chinook salmon appears to have improved since the 2010 assessment, but this ESU is far from being viable and is still facing relatively high extinction risk. The viability of Sacramento River Winter-run Chinook Salmon has been reduced and the ESU faces greater extinction risk since the 2010 assessment.

National Marine Fisheries Service. (2018). *Using Integrated Population Models to Evaluate Fishery and Environmental Impacts on Pacific Salmon Viability*. https://doi.org/http://doi.org/10.7289/V5/TM-NWFSC-140

Age- or stage-structured population models, also known as life cycle models, are a mainstay of applied ecology and conservation, particularly in fisheries management. The data available to inform parameters in such models are, however, often limited and variable in quality. Ad-hoc, piecemeal approaches to parameter estimation can lead to biased inference about key processes, such as the strength of density dependence and the magnitude of environmental variability in recruitment. Recent statistical advances have facilitated a more rigorous, comprehensive approach to fitting life cycle models by combining all relevant data into a joint likelihood function. Such integrated population models (IPMs) have been widely applied in marine fisheries stock assessment, but are less familiar in salmonid management. We developed a multipopulation IPM for Pacific salmon (Oncorhynchus spp.) that accounts for spatial and temporal variability in adult recruitment and age structure, the presence of hatchery-origin spawners, and observation error in abundance, age-composition, and hatchery-fraction data. The method is analogous to traditional spawner-recruit modeling based on brood-table reconstruction, but the model is fitted to the "raw" data and distinguishes between process and observation error. We applied the model to 29 populations of spring/summer Chinook salmon in the Snake River and Upper Columbia River Evolutionarily Significant Units (ESUs), and used the estimated parameters and states to simulate the impact of fishery exploitation rate on future abundance and quasi-extinction risk. As expected, predicted abundance declined and quasi-extinction risk increased across a range of fixed harvest rates from 0-0.3. The slope of the decline in abundance, relative to population-specific carrying capacity, was inversely related to intrinsic productivity. Large-scale environmental fluctuations (e.g., ocean conditions and hydrosystem operations, represented by the shared process error) were at least as important as harvest in determining long-term population viability. If future environmental conditions are relatively poor, and especially if they are assumed to have undergone a persistent state shift at some point in the last 60 years, then quasi-extinction risks are dramatically elevated even in the absence of harvest. We see potential for the further development of IPMs (e.g., the inclusion of more detailed stage structure) and their application to salmon conservation problems throughout the Pacific Northwest.

National Marine Fisheries Service. (2019). *Salmon Habitat Status and Trends: Monitoring Protocols*. (Report NMFS-NWFSC-PR-2019-03). https://doi.org/10.25923/w8y2-vj33

In 2014 and 2015, we began a habitat status and trend monitoring program for the Puget Sound Chinook, Hood Canal Summer Chum, and Puget Sound Steelhead Evolutionarily Significant Units (ESUs), covering large river, floodplain, delta, and nearshore habitats. The purpose of this monitoring program is to provide consistent habitat data for evaluating trends in the habitat listing factor at each 5-year status review for the listed ESUs. As part of the monitoring program, we developed protocols for delineating floodplain, delta, and nearshore boundaries, and measuring habitat features and calculating monitoring metrics. In 2018 we expanded the monitoring program to the Oregon Coast Coho salmon ESU. Funding was reduced at the end of 2018. In this report, we summarize the protocols for delineating analysis area boundaries, and for measuring habitat features and calculating habitat metrics.

Nyqvist, D., McCormick, S. D., Greenberg, L., Ardren, W. R., Bergman, E., Calles, O., & Castro-Santos, T. (2017). Downstream Migration and Multiple Dam Passage by Atlantic Salmon Smolts. *North American Journal of Fisheries Management, 37*(4), https://doi.org/10.1080/02755947.2017.1327900

The purpose of this study was to investigate behavior and survival of radio-tagged wild and hatchery-reared landlocked Atlantic Salmon Salmo salar smolts as they migrated past three hydropower dams equipped with fish bypass solutions in the Winooski River, Vermont. Among hatchery-reared smolts, those released early were more likely to initiate migration and did so after less delay than those released late. Once migration was initiated, however, the late-released hatchery smolts migrated at greater speeds. Throughout the river system, hatcheryreared fish performed similarly to wild fish. Dam passage rates varied between the three dams and was highest at the dam where unusually high spill levels occurred throughout the study period. Of the 50 fish that did migrate downstream, only 10% managed to reach the lake. Migration success was low despite the presence of bypass solutions, underscoring the need for evaluations of remedial measures; simply constructing a fishway is not synonymous with providing fish passage.

Payton, Q., Hostetter, N. J., & Evans, A. F. (2019). Jointly Estimating Survival and Mortality: Integrating Recapture and Recovery Data from Complex Multiple Predator Systems. *Environmental and Ecological Statistics, 26*(2), https://doi.org/10.1007/s10651-019-00421-8

Identifying where, when, and how many animals live and die over time is principal to understanding factors that influence population dynamics. Capture–recapture– recovery (CRR) models are widely used to estimate animal survival and, in many cases, quantify specific causes of mortality (e.g., harvest, predation, starvation). However, the restrictive CRR framework can inhibit the consideration and inclusion of some types of recovery data. We developed an extension to the CRR framework to allow for the incorporation of recoveries from indeterminate temporal or spatial origin. This model jointly estimates cause-specific mortality and survival probabilities across multiple spatial and temporal scales, while accounting for differences in mortality-specific reporting and recovery rates. We fitted the model to data on a group of juvenile steelhead trout (Oncorhynchus mykiss) marked with passive integrated transponder tags in the Columbia River basin, USA. Following tagging and release, fish were detected alive at up to six downstream locations and/or recovered dead on one of nine bird colonies during seaward migration. We estimated that, in aggregate, avian predators consumed 31% of juvenile steelhead during outmigration to the ocean (95% CRI: [27, 36]). Colony-specific predation rates ranged from < 1 to 14% among river reaches, with avian predation accounting for > 95% of all steelhead mortality within some reaches. This integrated modelling approach provides a flexible framework to integrate multiple recapture and recovery data sources, providing a more holistic understanding of animal life history, including direct comparisons of cause-specific mortality factors and the cumulative impact of multiple mortality factors across time or space.

Prince, D. J., O’Rourke, S. M., Thompson, T. Q., Ali, O. A., Lyman, H. S., Saglam, I. K., . . . Miller, M. R. (2017). The Evolutionary Basis of Premature Migration in Pacific Salmon Highlights the Utility of Genomics for Informing Conservation. *SCIENCE ADVANCES, 3*(8), https://doi.org/10.1126/sciadv.1603198

The delineation ofconservation units (CUs) is a challenging issue that has profound implications for minimizing the loss of biodiversity and ecosystem services. CU delineation typically seeks to prioritize evolutionary significance, and genetic methods play a pivotal role in the delineation process by quantifying overall differentiation between populations. Although CUs that primarily reflect overall genetic differentiation do protect adaptive differences between distant populations, they do not necessarily protect adaptive variation within highly connected populations. Advances in genomic methodology facilitate the characterization of adaptive genetic variation, but the potential utility of this information for CU delineation is unclear. We use genomic methods to investigate the evolutionary basis of premature migration in Pacific salmon, a complex behavioral and physiological phenotype that exists within highly connected populations andhas experienced severe declines. Strikingly, wefind that prematuremigration is associatedwith the same single locus across multiple populations in each of two different species. Patterns of variation at this locus suggest that the premature migration alleles arose froma single evolutionary event within each species and were subsequently spread to distant populations through straying and positive selection. Our results reveal that complex adaptive variation can depend on rare mutational events at a single locus, demonstrate that CUs reflecting overall genetic differentiation can fail to protect evolutionarily significant variation that has substantial ecological and societal benefits, and suggest that a supplemental framework for protecting specific adaptive variation will sometimes be necessary to prevent the loss of significant biodiversity and ecosystem services.

Roegner, G. C., Weitkamp, L. A., & Teel, D. J. (2016). Comparative Use of Shallow and Deepwater Habitats by Juvenile Pacific Salmon in the Columbia River Estuary Prior to Ocean Entry. *Marine and Coastal Fisheries, 8*(1), https://doi.org/10.1080/19425120.2016.1227889

The degree to which fine-scale habitat use by salmonid species and stocks varies within habitat types such as estuaries is not fully resolved. We sampled shallow shoreline and deeper main-stem channel habitats in the Columbia River estuary over 3 years to compare salmon species composition, migration timing, density, size, and production type (hatchery or natural). Results indicated a high degree of spatial heterogeneity in habitat occupancy by the five salmonid species that are native to the basin. Salmonid communities at two channel habitat sites were much more similar to each other than to the community at a shoreline site. Salmonids sampled at the shoreline site were primarily subyearling Chinook Salmon Oncorhynchus tshawytscha and Chum Salmon O. keta and yearling Coho Salmon O. kisutch, with few other salmonids present. In contrast, channel habitat contained a higher diversity of salmon species, with samples representing all species of anadromous salmonids, including Sockeye Salmon O. nerka and steelhead O. mykiss. Salmonids in deeper channel habitat were generally larger than salmonids found along the shore, and the proportion of hatchery-origin salmon was also higher in deep channel habitats. On a per-area basis, we also found much higher densities of salmon along the shoreline than in channel habitats. For Chinook Salmon, habitat use also differed by genetic stock of origin: upper-river stocks primarily used deeper channels, while lower-river populations used both channel and shoreline areas. We concluded that sampling at both habitat types is required to fully encompass the migration patterns of all salmon evolutionarily significant units in the Columbia River basin. These spatial and temporal variations in salmon timing and density have ramifications for feeding, growth, and competitive interactions. This study provides information that is relevant for conservation efforts targeting specific fish populations and efforts to evaluate the potential impacts of in-water activities in the Columbia River estuary.

Roon, S. R., Alexander, J. D., Jacobson, K. C., & Bartholomew, J. L. (2015). Effect of Nanophyetus Salmincola and Bacterial Co-Infection on Mortality of Juvenile Chinook Salmon. *Journal of Aquatic Animal Health, 27*(4), https://doi.org/10.1080/08997659.2015.1094150

The freshwater trematode Nanophyetus salmincola has been demonstrated to impair salmonid immune function and resistance to the marine pathogen Vibrio anguillarum, potentially resulting in ocean mortality. We examined whether infection by the parasite N. salmincola similarly increases mortality of juvenile Chinook Salmon Oncorhynchus tshawytscha when they are exposed to the freshwater pathogens Flavobacterium columnare or Aeromonas salmonicida, two bacteria that juvenile salmonids might encounter during their migration to the marine environment. We used a two-part experimental design where juvenile Chinook Salmon were first infected with N. salmincola through cohabitation with infected freshwater snails, Juga spp., and then challenged with either F. columnare or A. salmonicida. Cumulative percent mortality from F. columnare infection was higher in N. salmincola-parasitized fish than in nonparasitized fish. In contrast, cumulative percent mortality from A. salmonicida infection did not differ between N. salmincola-parasitized and nonparasitized groups. No mortalities were observed in the N. salmincola-parasitized-only and control groups from either challenge. Our study demonstrates that a relatively high mean intensity (>200 metacercariae per posterior kidney) of encysted N. salmincola metacercariae can alter the outcomes of bacterial infection in juvenile Chinook Salmon, which might have implications for disease in wild fish populations.

Rub, A. M. W., Som, N. A., Henderson, M. J., Sandford, B. P., Van Doornik, D. M., Teel, D. J., . . . Huff, D. D. (2019). Changes in Adult Chinook Salmon (Oncorhynchus tshawytscha) Survival within the Lower Columbia River Amid Increasing Pinniped Abundance. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(10), https://doi.org/10.1139/cjfas-2018-0290

Considerable effort towards conservation has contributed to the recovery of historically depleted pinniped populations worldwide. However, in several locations where pinnipeds have increased, they have been blamed for preventing the recovery of commercially valuable fish species through predation. Prompted by increasing pinniped abundance within the Columbia River (CR), USA, over a 6-year period, we used passive integrated transponder tags to measure the survival of adult spring-run Chinook salmon (Oncorhynchus tshawytscha) through the estuary and lower CR to Bonneville Dam (river kilometre 234). We estimated 51 751 – 224 705 salmon died annually within this reach from sources other than harvest. Mixed-effects logistic regression modelling identified pinniped predation as the most likely source of this mortality. The odds of survival was estimated to decrease by 32% (95% CI: 6%–51%) for every additional 467 sea lions (Zalophus californianus and Eumetopias jubatus) present within the CR and to increase by 32% (95% CI: 8%–61%) for every increase of 1.5 in the log of American shad (Alosa sapidissima), a potential prey item for sea lions.

Satterthwaite, W. H., Andrews, K. S., Burke, B. J., Gosselin, J. L., Greene, C. M., Harvey, C. J., . . . Sobocinski, K. L. (2019). Ecological Thresholds in Forecast Performance for Key United States West Coast Chinook Salmon Stocks. *Ices Journal of Marine Science, 77*(4), https://doi.org/10.1093/icesjms/fsz189

Preseason abundance forecasts drive management of US West Coast salmon fisheries, yet little is known about how environmental variability influences forecast performance. We compared forecasts of Chinook salmon (Oncorhynchus tshawytscha) against returns for (i) key CaliforniaOregon ocean fishery stocks and (ii) high priority prey stocks for endangered Southern Resident Killer Whales (Orcinus orca) in Puget Sound, Washington. We explored how well environmental indices (at multiple locations and time lags) explained performance of forecasts based on different methods (i.e. sibling-based, production-based, environment-based, or recent averages), testing for nonlinear threshold dynamics. For the California stocks, no index tested explained >50% of the variation in forecast performance, but spring Pacific Decadal Oscillation and winter North Pacific Index during the year of return explained >40% of the variation for the sibling-based Sacramento Fall Chinook forecast, with nonlinearity and apparent thresholds. This suggests that oceanic conditions experienced by adults (after younger siblings returned) have the most impact on sibling-based forecasts. For Puget Sound stocks, we detected nonlinear/threshold relationships explaining >50% of the variation with multiple indices and lags. Environmental influences on preseason forecasts may create biases that render salmon fisheries management more or less conservative, and therefore could motivate the development of ecosystem-based risk assessments.

Snow, C. G. (2016). Survival of Age-0 Hatchery Summer-Run Chinook Salmon Is Enhanced by Early Release. *North American Journal of Aquaculture, 78*(1), https://doi.org/10.1080/15222055.2015.1090505

Subyearling (age-0) hatcherysummer-run ChinookSalmonOncorhynchus tshawytscha have been released into the Columbia River in mid-June from Wells Fish Hatchery, Washington, since 1993, but release-to-adult survival (SAR) under this strategy has been low. I used paired releases of four broods of coded-wiretagged age-0 Chinook Salmon released in mid-May (early release [ER] group) and mid-June (late release [LR] group) to evaluate whether advancing the release date could improve SAR. Additionally, passive integrated transponder tags implanted in a subsample of each release group were used to estimate emigration rate and release-to-McNary Dam survival of juvenile fish. Mean migration rate from release to McNary Dam was significantly faster forLRfish thanforERfish.Noamong-yeardifferenceinmean survival from release to McNary Dam was observed between ER and LR groups, although differences were observed within years. Mean overall SAR was significantly greater for ER fish than for LR fish. These results suggest that altering the release date of age-0 Chinook Salmon at Wells Hatchery would enhance return survival.

Sol, S. Y., Hanson, A. C., Marcoe, K., & Johnson, L. L. (2019). Juvenile Salmonid Assemblages at the Mirror Lake Complex in the Lower Columbia River before and after a Culvert Modification. *North American Journal of Fisheries Management, 39*(1), https://doi.org/10.1002/nafm.10249

This study examined salmonid assemblages upstream of a culvert connecting the Mirror Lake Complex with the lower Columbia River before and after the culvert was modified to improve habitat connectivity and fish passage. Initially the culvert limited water flow between the Columbia River and the Mirror Lake Complex. The outlet and interior of the culvert were reconfigured to create a more "natural" and suitable passageway for salmonids through the removal of riprap and the strategic placement of boulders, cobbles, gravels, baffles, and weirs. Prior to the culvert modification, three sites were sampled

monthly between April and August of 2008, 5.0 and 0.5 km upstream of the culvert and immediately downstream of the culvert. After the culvert modification, the same sites were sampled from 2009 to 2012, with two additional sites added in 2010. Sites near the culvert supported Chinook Salmon Oncorhynchus tshawytscha, Coho Salmon O. kisutch, and Chum Salmon O. keta, while sites further from the culvert supported unmarked Coho Salmon and Rainbow Trout O. mykiss, steelhead (anadromous Rainbow Trout), and Cutthroat Trout O. clarkii. Clear trends in salmonid occurrence were not observed, although densities of Chinook Salmon tended to be higher in years postmodification than before modification. Culvert modifications should focus on alleviating site-specific fish passage conditions to result in substantial changes to habitat connectivity.

Teel, D. J., Burke, B. J., Kuligowski, D. R., Morgan, C. A., & Van Doornik, D. M. (2015). Genetic Identification of Chinook Salmon: Stock-Specific Distributions of Juveniles Along the Washington and Oregon Coasts. *Marine and Coastal Fisheries, 7*(1), https://doi.org/10.1080/19425120.2015.1045961

We used microsatellite DNA data and genetic stock identification methods to delineate the temporal and spatial distributions of juvenile Chinook Salmon Oncorhynchus tshawytscha occupying coastal habitats extending from central Oregon to northern Washington. Juveniles were collected in trawl surveys conducted during spring, summer, and autumn over 15 years. Distributions (mean latitude and distance from shore) differed between yearling and subyearling life history types and between stocks; many of these differences were consistent across years. Yearlings were nearly all (98%) from Columbia River sources, and only 6% were naturally produced. In late May, yearlings from the lower Columbia and Willamette rivers were farther north than other yearlings, likely due to the early spring timing of their releases from hatcheries and subsequent out-migration from the Columbia River. However, yearling distributions in late June reflected known migration behaviors. Yearlings from interior Columbia and Snake River sources were farthest north by June, whereas yearlings from other stocks were more spread out in latitude. Subyearlings sampled in early summer were also largely from the Columbia River (98%), but greater percentages of subyearlings from coastal rivers were present during the fall (24%). In contrast to yearlings, natural production accounted for nearly one-third of subyearlings. Subyearlings of most stocks tended to remain relatively near their point of sea entry throughout the summer. Subyearlings from the Snake River fall-run stock and upper Columbia River summer–fall-run stock exhibited diverse distributions that included both southward and northward dispersal. Overall, distributions of Chinook Salmon stocks and life history types reflected differences in migration behavior but also reflected the influence of environmental factors and hatchery practices.

Temple, G. M., Newsome, T., Webster, T. D., & Coil, S. W. (2017). Evaluation of Rainbow Trout Abundance, Biomass, and Condition Following Coho Salmon Reintroduction in Taneum Creek, Washington. *Northwest Science, 91*(1), https://doi.org/10.3955/046.091.0107

Reintroducing fish to previously occupied habitats appears promising for recovery of extirpated fish populations in cold water systems. Uncertainty still exists surrounding the ecological effects of reintroductions however, particularly when they involve historically sympatric taxa. We initiated a study to estimate any potential impacts to rainbow/steelhead trout (Oncorhynchus mykiss) that may arise from reintroducing coho salmon (O. kisutch) in Taneum Creek, Washington, following their extirpation approximately 100 years ago. Prior to reintroducing coho salmon into Taneum Creek, we conducted a formal risk assessment to predict potential impacts to rainbow trout that might result from restoring coho salmon natural production in this stream. Following the assessment, adult coho salmon were released to spawn naturally in experimental reaches in Taneum Creek during a five year period, 2008–2012. Rainbow trout abundance, average size, condition, and growth were not reduced in our experimental reaches relative to control locations following the reintroduction of coho salmon; a result predicted from our ecological risk assessment. Our findings validate the utility of the ecological risk assessment for predicting and reducing undesirable effects of reintroductions involving historically sympatric salmonids.

Trammell, J. L. J., Fast, D. E., Hatch, D. R., Bosch, W. J., Branstetter, R., Pierce, A. L., . . . Frederiksen, C. R. (2016). Evaluating Steelhead Kelt Treatments to Increase Iteroparous Spawners in the Yakima River Basin. *North American Journal of Fisheries Management, 36*(4), https://doi.org/10.1080/02755947.2016.1165767

Steelhead Oncorhynchus mykiss are iteroparous, distinguishing them from Pacificsalmon Oncorhynchus spp. that are semelparous. In this study we evaluated enhancement techniques that exploit this life history strategy to facilitate species restoration and recovery. In the Columbia River basin, where the natural ecosystem has been substantially altered over several decades due to human influence, all steelhead populations are listed as threatened or endangeredunder the U.S. Endangered Species Act. One factor believed to be limiting survival of Columbia River kelt (postspawned) steelhead is poor migration success to the ocean past several dams. We evaluated three treatments for kelts captured in the Yakima River basin from 2002 to 2011: (1) transport and release below Bonneville Dam (to provide unimpeded access to the ocean); (2) short-term reconditioning (holding and feeding in an artificial environment to facilitate gonad maturation) with transport; and (3) long-term reconditioning. These treatments were compared with an in-river migration control group to identify differences in the rate at which kelts survived and returned to Prosser Dam for potential repeat spawning (hereafter repeat spawners). The long-term reconditioning treatment exhibited the highest return rate of repeat spawners (range, 11.5–17.6%). The short-term reconditioning treatment with transport downstream from Bonneville Dam had a 3.2% return rate. The transport only treatment exhibited the lowest return rate (0.9%); this was only onethird of the control group's return rate (2.7%). Our results indicate that long-term steelhead kelt reconditioning is more successful than either transportation or in-river migration alternatives at increasing potential repeat spawner abundance and providing recovery benefits in river systems that have experienced substantial losses in natural productivity due to loss of habitat and habitat connectivity.

U.S. Army Corp of Engineers. (2014). *Estimating Iteroparity in Columbia River Steelhead Using Records Archived in the Columbia River Pit Tag Information System (Ptagis) Database*. Retrieved from https://www.salmonrecovery.gov/Files/APR/Section%202%20Literature%20Cited/Keefer%20and%20Caudill%202014_steelhead-iteroparity.pdf

We used steelhead PIT-tag detection data archived in the Columbia River PTAGIS database to

estimate the incidence of repeat spawning migration (i.e., iteroparity) in the multi-stock metapopulation upstream from Bonneville Dam. We evaluated migration histories from 53,282 adult steelhead detected

at Bonneville Dam over 11 adult migration years (2000-2010). The dataset included winter- and summer-run life history types, wild- and hatchery-origin fish, and were from a wide variety of populations and management groups.

U.S. Bureau of Land Management. (2016). *Final Programmatic Environmental Impact Statement (Peis): Vegetation Treatments Using Aminopyralid, Fluroxypyr, and Rimsulfuron on Bureau of Land Management Lands in 17 Western States*. Retrieved from https://eplanning.blm.gov/epl-front-office/eplanning/planAndProjectSite.do?methodName=dispatchToPatternPage&currentPageId=103601

This Final Programmatic Environmental Impact Statement (PEIS) analyzes the potential direct, indirect, and cumulative impacts associated with the Bureau of Land Management's (BLM's) use of the herbicides aminopyralid, fluroxypyr, and rimsulfuron on the human and natural environment. These three herbicides would be added to the BLM's list of approved active ingredients and integrated into the vegetation management program that was analyzed in an earlier PEIS released in 2007. Alternatives analyzed in the PEIS include the No Action Alternative, or a continuation of use of 18 currently approved herbicides. In addition, three action alternatives were evaluated: 1) the Preferred Alternative, which would allow the BLM to use aminopyralid, fluroxypyr, and rimsulfuron in addition to the currently approved herbicides; 2) an alternative that would prohibit aerial spraying of the three new herbicides; and 3) an alternative that would only allow the BLM to add the two new herbicides without acetolactate synthase-inhibiting active ingredients (aminopyralid and fluroxypyr). Under all alternatives (including the No Action Alternative), projected maximum total use of herbicides would be the same, at 932,000 acres annually.

U.S. Bureau of Land Management. (2016). *Record of Decision : Vegetation Treatments Using Aminopyralid, Fluroxypyr, and Rimsulfuron on Bureau of Land Management Lands in 17 Western States Programmatic Environmental Impact Statement*. Retrieved from https://www.biodiversitylibrary.org/item/245930

This Record of Decision (ROD) approves the U.S. Department of the Interior (USDOI) Bureau of Land Management's (BLM's) proposed use of the herbicide active ingredients aminopyralid, fluroxypyr, and rimsulfuron to treat vegetation on BLM-administered lands in the western U.S. These three herbicides are being added to the BLM's list of active ingredients available for use on public lands under previously approved vegetation management programs.

U.S. Geological Survey. (2019). *Fish and Habitat Assessment in Rock Creek, Klickitat County, Washington 2016–2017*. (2019-1092). https://doi.org/10.3133/ofr20191092

Intermittent streams are important and productive for salmonid habitat. Rock Creek, in southeastern Washington, flows south to the Columbia River at river kilometer (rkm) 368 and is an intermittent stream of great significance to the Yakama Nation and to the Kah-miltpah (Rock Creek) Band in particular. Historically, native steelhead (anadromous form of rainbow trout [Oncorhynchus mykiss])

and bridgelip sucker (Catostomus columbianus) populations were used by the Kah-miltpah Band for sustenance, trade, and traditional practices. Anadromous salmonid populations currently present and being monitored in the Rock Creek subbasin include Coho (O. kisutch) salmon and steelhead. Resident rainbow trout are also present and monitored (rainbow trout and steelhead will be collectively referred to as O. mykiss throughout this report). Streamflow is a limiting habitat factor in this system, but despite this, steelhead and Coho salmon still successfully return to spawn, rear, out-migrate, and survive over-summer in many of the isolated pools. We completed habitat surveys during 2015–17 to assess the perennial pools during lowflow conditions. The lower river sections (rkm 2–13) had proportionately more dry sections than the upper river sections (rkm 14–22) for all years surveyed and had higher variability among habitat types across years. The surveyed dry sections within the lower river ranged from 44 to 57 percent, with 2015 (a drought year) as the highest and 2017 the lowest. The percentage of pool habitat in the lower river was 21−24 percent, with 2015 as the lowest and 2016 and 2017 both at 24 percent. The upper river sections had a relatively high percentage of non-pool wet habitat (49−51 percent), followed by dry (33−36 percent) and pool habitat (17−18 percent). In Walaluuks Creek, the percentage of pool habitat was the most consistent across the years, ranging from 10 to 13 percent.

Van Doornik, D. M., Beckman, B. R., Moss, J. H., Strasburger, W. W., & Teel, D. J. (2019). Stock Specific Relative Abundance of Columbia River Juvenile Chinook Salmon Off the Southeast Alaska Coast. *Deep Sea Research Part II: Topical Studies in Oceanography, 165*, https://doi.org/10.1016/j.dsr2.2019.05.008

Migration patterns of juvenile Columbia River Chinook salmon (Oncorhynchus tshawytscha) differ among stocks and life history types, creating diverse marine distributions of these fish. This results in different stocks being subject to different ocean conditions during their first summer of marine residence, a time that is critical for their survival. Understanding their early marine distributions, and the conditions that affect their survival, may enhance conservation efforts for these stocks, many of which are protected under the Endangered Species Act. We analyzed juvenile Chinook salmon samples collected in trawls made from 2011 to 2015 off the southeastern (SE) Alaskan panhandle, and off the coasts of Washington and Oregon. We used genetic stock identification techniques to estimate stock proportions of juvenile Chinook salmon in each of these areas. Results indicated that most juvenile Chinook salmon in our SE Alaska coast study area in July originate from Columbia River springrun stocks. We found a significant relationship in catch per unit effort (CPUE) over all stocks between the SE Alaska and the Washington and Oregon coast samples. In 2011, CPUE for Columbia River spring-run stocks for the SE Alaska coast was lower than for the Washington and Oregon coast, suggesting a differing level of marine mortality that year. We also found a significant relationship between juvenile CPUE of interior Columbia River spring-run stocks off the SE Alaska coast and adult counts at Bonneville Dam two years later. Our results provide marine life history, performance and survival information that supports management and recovery efforts for Columbia River Chinook salmon.

Van Doornik, D. M., Hess, M. A., Johnson, M. A., Teel, D. J., Friesen, T. A., & Myers, J. M. (2015). Genetic Population Structure of Willamette River Steelhead and the Influence of Introduced Stocks. *Transactions of the American Fisheries Society, 144*(1), https://doi.org/10.1080/00028487.2014.982178

Conservation genetics studies are frequently conducted on Pacific salmon Oncorhynchus spp. to delineate their population structure and to quantify their genetic diversity, especially for populations that have experienced declines in abundance and are subject to anthropogenic activities. One such group of salmonids is steelhead O. mykiss (anadromous Rainbow Trout) from the Willamette River, a tributary of the Columbia River. Within the Willamette River there are multiple steelhead life history and run-timing types, some of which originated from nonnative populations. Late winter-run steelhead and Rainbow Trout are native to the Willamette River, whereas early winter-run and summer-run steelhead have been introduced into the system via releases from artificial propagation efforts. We conducted genetic analyses of Willamette River steelhead to determine the effect that nonnative steelhead released into the Willamette River basin have had on the genetic population structure of native steelhead. We found genetic differentiation among the samples that separated steelhead into four population groups that corresponded to run type. Possibly due to local adaptation, the native run type has retained its genetic distinctiveness from the introduced types, despite there being opportunities for gene flow among all types. Introduced early winter-run steelhead appear to be the origin of steelhead inhabiting certain Willamette River tributaries where native steelhead did not historically spawn.

Vizek, A., & Nielsen-Pincus, M. (2017). Landowner Attitudes toward Conservation Easements: Balancing the Private and Public Interest in Land. *Society & Natural Resources, 30*(9), https://doi.org/10.1080/08941920.2017.1331486

Private land conservation provides an opportunity to address problems of habitat fragmentation and biodiversity loss caused by an increase in the development and parcelization of private land. Conservation easements (CEs) are used to protect significant natural qualities of private land. In this study, we explore landowner attitudes toward CEs through the implementation of a mixed-mode survey to private landowners in the Whychus Creek Watershed (Deschutes County, Oregon). The results of an exploratory factor analysis suggest there are two dimensions to landowner attitudes toward CEs, an internal dimension and an external dimension. We found that positive external attitudes are primarily influenced by environmental beliefs, whereas positive internal attitudes are influenced by a suite of factors, including financial beliefs and perceived risk to private ownership. Awareness of CEs may also play a role in attitude development. Through this research, we argue that CEs may be beneficial in reintegrating the public good into private property.

Wall, C. E., Bouwes, N., Wheaton, J. M., Saunders, W. C., & Bennett, S. N. (2015). Net Rate of Energy Intake Predicts Reach-Level Steelhead (Oncorhynchus mykiss) Densities in Diverse Basins from a Large Monitoring Program. *Canadian Journal of Fisheries and Aquatic Sciences, 73*(7), https://doi.org/10.1139/cjfas-2015-0290

Substantial research effort has been devoted to understanding stream-dwelling salmonids' use of summer rearing and growth habitat, with a subset of studies focusing on foraging position selection and the energetic trade-offs of differential habitat use. To date, however, cost–benefit analyses for most foraging model studies have focused on small sampling areas such as individual habitat units. To address this knowledge gap, we applied a mechanistic foraging model to 22 stream reaches (100–400 m) from two watersheds within the Columbia River Basin. We found a strong, positive correlation ($R2 = 0.61$, $p < 0.001$) between predicted carrying capacities and observed fish densities. Predicted proportion of

suitable habitat was weakly correlated with observed fish density (R2 = 0.18, p = 0.051), but the mean net rate of energy intake prediction in sampling reaches was not a significant predictor of observed fish biomass. Our results suggest spatial configuration of habitat, in addition to quantity and quality, is an important determinant of habitat use. Further, carrying capacity predicted by the model shows promise as a habitat metric. We also evaluated the feasibility of applying this data-intensive modeling approach in a large-scale monitoring program to examine habitat quality and quantity. Though the approach can be computationally expensive, we feel the model's ability to integrate physical habitat metrics (e.g., depth, velocity) with important biological considerations like food availability and temperature is a benefit that far outweighs associated costs. We feel this modeling approach has great potential as a tool to help understand habitat use in drift-feeding fishes.

Walters, C., English, K., Korman, J., & Hilborn, R. (2019). The Managed Decline of British Columbia's Commercial Salmon Fishery. *Marine Policy, 101*, https://doi.org/10.1016/j.marpol.2018.12.014

Commercial salmon harvests have declined dramatically for all Pacific salmon species in British Columbia, mainly over the period 1995–2000. Much of this decline is attributable to declining abundance, but some of it has been due to deliberate reduction in allowable exploitation rates. Various reasons have been given for this reduction, but the main rationale appears to have been concern about declines in a few relatively small and unproductive stocks that are intercepted in mixed-stock fisheries. Reductions in exploitation rate have generally not been followed by the increases in stock size that would be expected if overfishing had been the main cause of the declines. Current procedures for setting exploitation rate goals do not appear to involve explicit analysis of the risk-reward trade off relationship between mixed stock exploitation rates and yields.

Ward, E. J., Anderson, J. H., Beechie, T. J., Pess, G. R., & Ford, M. J. (2015). Increasing Hydrologic Variability Threatens Depleted Anadromous Fish Populations. *Glob Chang Biol, 21*(7), https://doi.org/10.1111/gcb.12847

Predicting effects of climate change on species and ecosystems depend on understanding responses to shifts in means (such as trends in global temperatures), but also shifts in climate variability. To evaluate potential responses of anadromous fish populations to an increasingly variable environment, we performed a hierarchical analysis of 21 Chinook salmon populations from the Pacific Northwest, examining support for changes in river flows and flow variability on population growth. More than half of the rivers analyzed have already experienced significant increases in flow variability over the last 60 years, and this study shows that this increase in variability in freshwater flows has a more negative effect than any other climate signal included in our model. Climate change models predict that this region will experience warmer winters and more variable flows, which may limit the ability of these populations to recover.

Washington State Recreation and Conservation Office. (2015). *Salmon Recovery Grant Funding Report*. Retrieved from https://www.rco.wa.gov/grants/eval_results.shtml#srfb

The Legislature created the Salmon Recovery Funding Board (SRFB) in 1999 to provide grants to protect and restore salmon habitat. The SRFB works closely with local watershed groups known as lead entities1 and the eight salmon recovery regions to identify and approve projects for funding. The Recreation and Conservation Office has administered more than $805 million of state and federal funds to help finance nearly 3,000 salmon recovery projects and activities statewide. This report presents information on the process used to review the 2015 applications, the SRFB Review Panel project evaluations, and staff analysis for the SRFB to consider at its December 9 and 10, 2015 meeting in Olympia.

Washington State Recreation and Conservation Office. (2016). *Salmon Recovery Grant Funding Report*. Retrieved from https://www.rco.wa.gov/grants/eval_results.shtml#srfb

Since 1999, the Salmon Recovery Funding Board (SRFB) has been distributing state and federal money to protect and restore salmon habitat. Honoring the "Washington Way" of ground-up salmon recovery decision-making, the SRFB works closely with local watershed groups known as lead entities1 to identify projects for funding, and regional organizations to prioritize funding. This partnership has resulted in the SRFB distributing nearly $836 million for nearly 3,000 projects and activities statewide, all aimed at bringing salmon back from the brink of extinction. This report presents information on the process used to review the 2016 applications and develop funding recommendations for the SRFB to consider at its December 8, 2016 meeting in Olympia.

Washington State Recreation and Conservation Office. (2017). *Salmon Recovery Grant Funding Report*. Retrieved from https://www.rco.wa.gov/grants/eval_results.shtml#srfb

Since 1999, the Salmon Recovery Funding Board (SRFB) has been distributing state and federal money to protect and restore salmon habitat. Honoring the "Washington Way" of ground-up salmon recovery decision-making, the SRFB works closely with local watershed groups known as lead entities1 to identify projects for funding, and regional organizations to prioritize funding. Lead entities and regions rely on their approved recovery plans to prioritize projects for funding requests to the SRFB. This partnership has resulted in the SRFB distributing nearly $867 million for more than 3,030 projects and activities statewide, all aimed at bringing salmon back from the brink of extinction. This report presents information on the process used to review the 2017 applications and develop funding recommendations for the SRFB to consider at its December 7, 2017 meeting in Olympia.

Washington State Recreation and Conservation Office. (2018). *Salmon Recovery Grant Funding Report*. Retrieved from https://www.rco.wa.gov/grants/eval_results.shtml#srfb

Since 1999, the Salmon Recovery Funding Board (SRFB) has been distributing state and federal money to protect and restore salmon habitat. Honoring the "Washington Way" of ground-up salmon recovery decision-making, the SRFB works closely with local watershed groups known as lead entities1 to identify projects for funding, and regional organizations to prioritize funding. Lead entities and regions rely on their approved recovery plans to prioritize projects for funding requests to the SRFB. This partnership has resulted in the SRFB distributing nearly $825 million for more than 2750 projects statewide, all aimed at bringing salmon back from the brink of extinction. This report presents information on the process used to review the 2018 applications and develop funding recommendations for the SRFB to consider at its December 5, 2018 meeting in Olympia.

Washington State Recreation and Conservation Office. (2018). *State of Salmon in Watersheds Executive Summary*. Retrieved from https://www.rco.wa.gov/doc_pages/other_pubs.shtml#monitoring

The 2018 State of Salmon in Watersheds is the State's biennial report on salmon, their habitat, and the progress of statewide salmon recovery efforts. In 1991, the federal government declared the first salmon in the Pacific Northwest endangered under the Endangered Species Act. In the next few years, 14 additional species of salmon and steelhead and 3 species of bull trout were listed as at-risk of extinction. By the end of the decade, wild salmon had disappeared from about 40 percent of their historic breeding ranges in Washington, Oregon, Idaho, and California. In Washington, the numbers had dwindled so much that salmon, steelhead, and bull trout were listed as threatened or endangered in nearly three-fourths of the state. Today, nearly 20 years later, we see that salmon recovery efforts have been instrumental in helping some species turn the corner towards recovery and have slowed the decline of several other species; however too many others remain precariously close to the brink of extinction.

Weber, M. A. (2015). Navigating Benefit Transfer for Salmon Improvements in the Western Us. *Frontiers in Marine Science, 2*, https://doi.org/10.3389/fmars.2015.00074

A perennial problem in environmental resource management is targeting an efficient level of resource provision that maximizes societal well-being. Such management requires knowledge of both costs and benefits associated with varying management options. This paper illustrates the challenge of estimating the benefits of an improvement in a marine resource when secondary data must be used, and when total economic benefits include non-use values. An example of non-use values is existence value, which is not contingent on resource extraction nor recreational activities. State of the art techniques for adapting secondary data, or "benefit transfer," are reviewed in the context of increasing anadromous salmon for an example Western US policy scenario. An extensive summary of applicable primary studies is provided, compiling observations from several studies surveying several thousand Western US households. The studies consistently indicate a high willingness to pay for increased salmon abundance. Analytical techniques for transferring data are described, with calculation examples using published tools, focusing on meta-regression and structural benefit transfer. While these advanced benefit transfer tools offer perspective on benefits beyond what can be learned by relying on a single study, they also represent a variety of challenges limiting their usefulness. While transparently navigating these issues, a monetized estimate of increased salmon for the policy case is provided, along with discussion on interpreting benefit transfer techniques and their results more generally. From this synthesis, several suggestions are also made for future original salmon valuation studies.

Weber, N., Bouwes, N., Pollock, M. M., Volk, C., Wheaton, J. M., Wathen, G., . . . Jordan, C. E. (2017). Alteration of Stream Temperature by Natural and Artificial Beaver Dams. *Plos One, 12*(5), https://doi.org/10.1371/journal.pone.0176313

Beaver are an integral component of hydrologic, geomorphic, and biotic processes within North American stream systems, and their propensity to build dams alters stream and riparian structure and function to the benefit of many aquatic and terrestrial species. Recognizing this, beaver relocation efforts and/or application of structures designed to mimic the function of beaver dams are increasingly being utilized as effective and cost-efficient stream and riparian restoration approaches. Despite these verities, the notion that beaver dams negatively impact stream habitat remains common, specifically the assumption that beaver dams increase stream temperatures during summer to the detriment of sensitive biota such as salmonids. In this study, we tracked beaver dam distributions and monitored water temperature throughout 34 km of stream for an eight-year period between 2007 and 2014. During this time the number of natural beaver dams within the study area increased by an order of magnitude, and an additional 4 km of stream were subject to a restoration manipulation that included installing a high-density of Beaver Dam Analog (BDA) structures designed to mimic the function of natural beaver dams. Our observations reveal several mechanisms by which beaver dam development may influence stream temperature regimes; including longitudinal buffering of diel summer temperature extrema at the reach scale due to increased surface water storage, and creation of cool-water channel scale temperature refugia through enhanced groundwater-surface water connectivity. Our results suggest that creation of natural and/or artificial beaver dams could be used to mitigate the impact of human induced thermal degradation that may threaten sensitive species.

Weil, J., Duguid, W. D. P., & Juanes, F. (2019). A Hyperiid Amphipod Acts as a Trophic Link between a Scyphozoan Medusa and Juvenile Chinook Salmon. *Estuarine, Coastal and Shelf Science, 223*, https://doi.org/10.1016/j.ecss.2019.01.025

Gelatinous zooplankton (GZ) can impact productivity of marine ecosystems through competition with small pelagic fish and predation on early life history stages of species from multiple trophic levels. Nevertheless, GZ do not always represent 'trophic dead ends.' Some predators directly consume GZ, and many species host parasitoids which in turn are prey for other organisms. We characterized trophic relationships between the fried-egg jellyfish Phacellophora camtschatica, its hyperiid amphipod parasite (Hyperia medusarum), and juvenile Chinook Salmon Oncorhynchus tshawytscha in the Salish Sea. Hyperia medusarum occurred in 29–47% of Chinook Salmon stomachs over 3 years and were observed in high abundance on P. camtschatica medusae (mean = 428 individuals per medusa). Light and transmission electron microscopy confirmed the presence of morphologically similar nematocysts in the foreguts of H. medusarum from both medusae and Chinook Salmon stomachs. Occurrence of H. medusarum in Chinook Salmon diets was also positively related to an index of P. camtschatica abundance. Chinook Salmon stomachs contained almost exclusively mature female H. medusarum while males and juveniles were common on medusae. Size and sex ratio differences between hyperiids in Chinook Salmon diets and on medusae could reflect predator selectivity or sex and/or life-stage specific differences in H. medusarum behavior. Our results support previous speculation that GZ abundance may facilitate predation on hyperiids by Pacific Salmon. Hyperiid-mediated energy flow from GZ to fish is not limited to medusa-associated fish species and should be considered in studies of marine food webs.

Weitkamp, L. A., Goulette, G., Hawkes, J., O'malley, M., & Lipsky, C. (2014). Juvenile Salmon in Estuaries: Comparisons between North American Atlantic and Pacific Salmon Populations. *Reviews in Fish Biology and Fisheries, 24*(3), https://doi.org/10.1007/s11160-014-9345-y

All anadromous fishes, including juvenile salmon, encounter estuarine habitats as they transition from riverine to marine environments. We compare the estuarine use between juvenile Atlantic salmon (Salmo salar) in the Penobscot River estuary and Pacific salmon (Oncorhynchus spp.) in the Columbia River estuary. Both estuaries have been degraded by anthropogenic activities. Atlantic and Pacific salmon populations in both basins rely heavily on hatchery inputs for persistence. Pacific salmon, as a group, represent a continuum of estuarine use, from species that move through rapidly to those that make extensive use of estuarine habitats. While Atlantic salmon estuarine use is predominantly similar to rapidly moving Pacific salmon, they can exhibit nearly the entire range of Pacific salmon estuarine use. Both slow and rapidly migrating Atlantic and Pacific salmon actively feed in estuarine environments, consuming insect and invertebrate prey. Interactions between juvenile salmon and estuarine fish communities are poorly understood in both estuaries, although they experience similar avian and marine mammal predators. Estuaries are clearly important for Atlantic and Pacific salmon, yet our understanding of this use is currently insufficient to make informed judgments about habitat quality or overall estuary health. This review of salmonid migration through and residency within estuaries identifies actions that could hasten restoration of both Atlantic and Pacific salmon populations.

Weitkamp, L. A., Teel, D. J., Martin, L., Hinton, S. A., Doornik, D. M. V., & Bentley, P. J. (2015). Stock-Specific Size and Timing at Ocean Entry of Columbia River Juvenile Chinook Salmon and Steelhead: Implications for Early Ocean Growth. *Marine and Coastal Fisheries, 7*(1), https://doi.org/10.1080/19425120.2015.1047476

Juvenile salmon transitioning from freshwater to marine environments experience high variation in growth and survival, yet the specific causes of this variation are poorly understood. Size at and timing of ocean entry may contribute to this variation because they influence both the availability of prey and vulnerability to predators. To explore this issue, we used stock assignments based on genetic stock identification and internal tags to document the stock-specific size and timing of juvenile hatchery and presumed wild Columbia River Chinook Salmon Oncorhynchus tshawytscha and steelhead O. mykiss at ocean entry during 2007–2011. We found that juvenile salmon and steelhead had consistent stock-specific capture dates, with lower-river stocks typically having earlier timing than those originating farther upstream. Mean size also varied among stocks and was related to hatchery practices. Hatchery yearling Chinook Salmon and steelhead were consistently larger than wild fish from the same stocks, although timing in the estuary was similar. In contrast, hatchery subyearling Chinook Salmon were of similar size to wild fish but entered the ocean up to a month earlier. We evaluated the potential importance of these traits on early marine growth by estimating stock-specific growth rates for Chinook Salmon caught in estuarine and ocean habitats. Growth rates were related to relative ocean entry timing, with lower growth rates for stocks that had only recently arrived in marine waters. Our results demonstrate that stocks within a single basin can differ in their size and timing of ocean entry, life history traits that contribute to early marine growth and potentially to the survival of juvenile salmon. Our results also highlight the necessity of considering stock-specific variation in life history traits to understand salmon ecology and survival across the entire life cycle.

Westley, P. A. H., Dittman, A. H., Ward, E. J., & Quinn, T. P. (2015). Signals of Climate, Conspecific Density, and Watershed Features in Patterns of Homing and Dispersal by Pacific Salmon. *Ecology, 96*(10), https://doi.org/10.1890/14-1630.1

It is widely assumed that rates of dispersal in animal populations are plastic in response to intrinsic and extrinsic cues, yet the factors influencing this plasticity are rarely known. This knowledge gap is surprising given the important role of dispersal in facilitating range shifts that may allow populations to persist in a rapidly changing global climate. We used two decades of tagging and recapture data from 19 hatchery populations of Oncorhynchus tshawytscha (Chinook salmon) in the Columbia River, USA, to quantify the effects of regional and local climate conditions, density dependence, watershed features such as area and position on the landscape, and direct anthropogenic influence on dispersal rates by adult salmon during the breeding season. We found that the probability of dispersal, termed "straying" in salmon, is plastic in response to multiple factors and that populations showed varied responses that were largely idiosyncratic. A regional climate index (Pacific Decadal Oscillation), water temperatures in the mainstem Columbia River that was commonly experience by populations during migration, water temperatures in local subbasins unique to each population during the breeding season, migration distance, and density dependence had the strongest effects on dispersal. Patterns of dispersal plasticity in response to commonly experienced conditions were consistent with gene by environment interactions, though we are tentative about this interpretation given the domesticated history of these populations. Overall, our results warn against attempts to predict future range shifts of migratory species without considering population-specific dispersal plasticity, and also caution against the use of few populations to infer species-level patterns. Ultimately, our results provide evidence that analyses that examine the response of dispersal to single factors may be misleading.

Wilhere, G. F., Atha, J. B., Quinn, T., Tohver, I., & Helbrecht, L. (2017). Incorporating Climate Change into Culvert Design in Washington State, USA. *Ecological Engineering, 104*, https://doi.org/10.1016/j.ecoleng.2017.04.009

Road crossings at rivers or streams are known to create barriers to fish movement when they are improperly designed or constructed. Over the next 50–100 years climate change is projected to cause major changes in hydrology and channel morphology across Washington State. If culverts built today cannot accommodate future channel conditions, then climate change could indirectly create barriers to fish movement and consequent loss of fish habitats. To inform managers and engineers about the potential impacts of climate change on fish passage through culverts, we determined changes in bankfull width from projected changes in bankfull discharge. These changes were estimated from an ensemble of 10 statistically downscaled global climate models. The spatial resolution of these regional projections was 1/16◦ grid cells (≈33 km2), and the spatial extent was Washington State. Projections of bankfull width for two future time periods, 2040s and 2080s, were compared to bankfull width estimated from simulations of historical bankfull discharge. Our projections indicate that in both time periods bankfull discharge and bankfull width will increase in about 80% of Washington State, although the magnitude of change varies by ecoregion. In the Pacific Maritime Mountain Ecoregion Division, for instance, the mean across all grid cells of the mean projected percent change in bankfull width was 12.1% in the 2080s but near zero (0.2%) in the Columbia Basin for the same time period. Because statistically valid ways to express uncertainty associated with climate change projections are currently lacking, our metric of uncertainty was the number of models that agree on the sign of change in bankfull width. In the 2080s, the percentage of grid cells with a majority of models projecting an increase in bankfull width was 69%, and 26% of grid cells had majority of models projecting a decrease. We also present some graphical depictions of our results to help managers and engineers understand climate-related uncertainty and risk in culvert design. We explain how our results can be used in culvert design through a case study.

Winans, G. A., Allen, M. B., Baker, J., Lesko, E., Shrier, F., Strobel, B., & Myers, J. (2018). Dam Trout: Genetic Variability in Oncorhynchus mykiss above and Below Barriers in Three Columbia River Systems Prior to Restoring Migrational Access. *Plos One, 13*(5), https://doi.org/10.1371/journal.pone.0197571

Restoration of access to lost habitat for threatened and endangered fishes above currently impassable dams represents a major undertaking. Biological monitoring is critical to understand the dynamics and success of anadromous recolonization as, in the case of Oncorhynchus mykiss, anadromous steelhead populations are reconnected with their conspecific resident rainbow trout counterparts. We evaluate three river systems in the Lower Columbia River basin: the White Salmon, Sandy, and Lewis rivers that are in the process of removing and/or providing passage around existing human-made barriers in O. mykiss riverine habitat. In these instances, now isolated resident rainbow trout populations will be exposed to competition and/or genetic introgression with steelhead and vice versa. Our genetic analyses of 2,158 fish using 13 DNA microsatellite (mSAT) loci indicated that within each basin anadromous O. mykiss were genetically distinct from and significantly more diverse than their resident above-dam trout counterparts. Above long-standing natural impassable barriers, each of these watersheds also harbors unique rainbow trout gene pools with reduced levels of genetic diversity. Despite frequent releases of non-native steelhead and rainbow trout in each river, hatchery releases do not appear to have had a significant genetic effect on the population structure of O. mykiss in any of these watersheds. Simulation results suggest there is a high likelihood of identifying anadromous x resident individuals in the Lewis and White Salmon rivers, and slightly less so in the Sandy River. These genetic data are a prerequisite for informed monitoring, managing, and conserving the different life history forms during upstream recolonization when sympatry of life history forms of O. mykiss is restored.

Zhang, X., Li, H. Y., Deng, Z. Q. D., Leung, L. R., Skalski, J. R., & Cooke, S. J. (2019). On the Variable Effects of Climate Change on Pacific Salmon. *Ecological Modelling, 397*, https://doi.org/10.1016/j.ecolmodel.2019.02.002

Water temperature has manifold effects on the biology of Pacific salmon. Thermal optima enable Pacific salmon to maximize growth while temperatures above thermal optima can induce stress and lead to mortality. This study investigated the impacts of climatic changes and water management practices on Chinook and Steelhead smolts in the Columbia River Basin using an integrated earth system model and a multiple regression model that incorporated nonlinear survival responses to water temperature. Results revealed that the effects would vary significantly with the species, location, and climate change scenario. Mean survival rates may increase by more than 10% in Upper Columbia River, while reduce by 1 similar to 13% and 2 similar to 35% for Chinook and Steelhead smolts respectively, in the Lower Columbia River by 2080s. This study highlights the importance of integrating the nonlinear response of survival rate to river temperature and water management effects in climate change vulnerability analysis for salmonid stocks.