Status of Sacramento River Winter Run Chinook Salmon: What is Needed to Achieve Viability?

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Sacramento River Winter Run Chinook Salmon (SRWRC) are listed as Endangered under the US Endangered Species Act. They exist as a single population restricted from their historical spawning area, in a heavily managed and modified river, dependent on cold-water releases from Lake Shasta. Following listing and a series of conservation actions, SRWRC increased from critically low to moderate abundance levels, but have since declined during a period of poor ocean conditions and prolonged drought. Recent modeling advances reviewed here give deeper insight into the interacting causes of SRWRC's vulnerability to extinction and add further support to the need for the high-priority actions identified in the SRWRC recovery plan. These actions include restoring access to headwater spawning areas that would provide refuge in droughts, and to rearing areas that would increase the productivity of the population.

Keywords: Sacramento River Winter Chinook; Viability; Drought; Modeling
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There and Back Again:
Winter Run Chinook Salmon Drought/Temperature Management from 1988-2013

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This presentation will focus on the history of management actions directed towards Winter Run Chinook salmon taken in the upper Sacramento River from the mid 70's to 2016. Winter run chinook salmon have gone through several major droughts in 1977-76, 1988-92 , and 2013-2016 where environmental conditions were extremely poor. Management actions designed to protect and restore the population have varied from doing nothing during the first drought to nearly cutting 100+ year old sacrosanct water rights in recent years. Management actions during the second drought focused on improving fish passage at Red Bluff Diversion Dam and improving in-river water temperatures during spawning. Additional regulatory actions through conditioning of water rights and the issuance of several ESA Biological Opinions were also important towards the protection of winter run. The development of a winter run conservation hatchery starting in the late 1980's whose success in recent years has played a critical role in the protection of the species. In recent years, additional efforts in monitoring as well as improving the science behind survival modeling have assisted in making improved management decisions. With each new drought, new insights are realized and additional levels of management actions are taken or proposed using an ever-increasing science based knowledge base.

Keywords: Red Bluff Diversion Dam Water Temperatures Sacramento River Biological Opinions
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Coupling Headwaters, Reservoirs, and Rivers to Model Water Flows and Temperatures

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Winter-run Chinook salmon is an endangered species largely dependent on regulated water flows and temperatures for survival during their initial and finale life cycle stages. The most southerly remaining run of Chinook rely on the cold-water discharge from California's largest storage reservoir, Shasta Reservoir, in the Sacramento River Watershed to provide suitable conditions from egg to fry development. Drought conditions, however, have put added strain on the multi-use resource of Shasta Reservoir and resulted in Chinook redds being exposed to above than desirable temperatures even after the reservoir was outfitted with a temperature control device to selectively withdraw colder water from deeper regions when needed. Lessons from the ongoing drought have highlighted the potential benefits of improved forecasting capabilities of temperature dynamics above, within, and below Shasta Reservoir for better management of cold-water resources. Therefore, to better understand factors affecting flows and temperature discharges into the Sacramento River downstream from Shasta Reservoir, we coupled hydraulic models of Shasta Reservoir headwaters (i.e. Sacramento, McCloud, and Pit Rivers), Shasta Reservoir, its downstream forebay Keswick Reservoir, and the upper Sacramento River. Models were forced with local meteorological data and scenarios of different reservoir operations examined. Factors observed to affect temperature dynamics will be discussed in the context of cold-water resource management.

Keywords: Hydraulic modeling, Water temperature, Winter-run Chinook
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Why Lab-Derived Estimates of Thermal Tolerance Failed to Predict Survival of Winter-Run Eggs in the Sacramento River and What We Can Do About It

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Predicting species responses to climate change is a central challenge in ecology, with most efforts relying on lab derived phenomenological relationships between temperature and fitness metrics. We tested one of these models using the embryonic stage of the endangered Sacramento River winter-run Chinook. We parameterized the model with laboratory data, applied it to predict survival in the field, and found that it significantly underestimated field-derived estimates of thermal mortality. We used a simple biophysical model based on mass-transfer theory to show that the discrepancy was due to the differences in water flow velocities between the lab and the field. This mechanistic approach provides testable predictions for how the thermal tolerance of embryos depends on egg size and flow velocity of the surrounding water. We found strong support for these predictions across more than 180 fish species, suggesting that flow and temperature mediated oxygen limitation is a general mechanism underlying the thermal tolerance of embryos. We conclude that descriptive models of thermal tolerance can drastically underestimate species responses to climate change and that simple mechanistic models can explain substantial variation in the thermal tolerance of species.

Keywords: Thermal tolerance, salmon, model, temperature, embryo, survival, oxygen, flow
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Impacts of Shasta Dam Water Operations on Endangered Winter-Run Chinook Salmon

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Sacramento River Winter run Chinook salmon are listed under the Endangered Species Act and have a very restricted stretch of spawning habitat on the Sacramento River below Keswick Dam. The quality of this habitat is heavily impacted by water operations, particularly by the amount and temperature of water released from Shasta Lake, the largest reservoir in the state. We have developed science-based decision-support tools to evaluate how water operations impact winter run salmon populations in the past, present, and future, to improve our management decision process. These support tools consist of a series of linked physical models the track the movement of water and heat through the system from the watershed to the ocean. The output from these models can then used to estimate the impact on various life stages, such as developing salmon eggs on the Sacramento River. Our initial results indicate that some years, temperature dependent mortality can be as high as 78% for winter run salmon eggs. These tools allow us to estimate the physiological responses to key environmental stressors, such as the ongoing drought, through science-based management strategies to protect fish populations.

Keywords: modeling, decision support, temperature, flow, reservoir, salmon
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Genetic Evaluation of Sacramento River Winter-Run Chinook Salmon

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Sacramento River Winter-run Chinook salmon were largely blocked from their historical freshwater habitat by an impassible dam and were listed as "endangered" under the Endangered Species Act in 1994. A conservation hatchery program for this species was initiated in 1989 at an existing facility, and was subsequently moved to Livingston Stone National Fish Hatchery in 1998. Since its inception, the Winter-run Chinook salmon program has operated under an integrated hatchery paradigm, and has incorporated several measures to minimize genetic risks of hatchery propagation to the population. In order to prevent inadvertent hybridization with other populations of Chinook salmon, all fish collected as potential broodstock at Livingston Stone National Fish Hatchery were screened with either microsatellite or single nucleotide polymorphism markers. The genetic samples and data collected during this screening process provide an opportunity for evaluating change in the population over time. Here we present an overview of how the genetic profile of the population has changed over time as well as how the role of genetic data in hatchery operations has continued to evolve.

Keywords: Winter Run Chinook Salmon, Genetic assignment, effective population size
Session Title: Winter-Run Chinook Salmon Science and Management in a Changing Climate II
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Potential Impacts of *Ceratonova shasta* and *Parvicapsula minibicornis* Infection on Survival of Natural Sacramento Juvenile Chinook Salmon: Comparison to Rivers of Known Infectivity

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Infection by the myxozoan parasites, *Ceratonova* (previously *Ceratomyxa*) *shasta* and *Parvicapsula minibicornis*, has been observed in all Sacramento River adult runs, and juvenile fall and winter-run Chinook. In 2014, infections were lethal for over half of the spring out-migrants sampled from the lower river. In fall of 2015, sentinel juvenile salmon, held above Red Bluff diversion dam, incurred a high prevalence of severe infection. In contrast, only 15% prevalence of early stage infections were observed in juvenile Winter-run Chinook collected at the dam. Drought conditions (lower winter flows, higher spring and summer temperatures) appear to increase parasite infectivity. The effect of different river conditions in 2016 will be compared to 2015 data. Reduced juvenile salmon survival due to *C. shasta* has been documented in both the Klamath and Feather Rivers. Characteristics of these systems on the life cycle and infectivity of *C. shasta* will be discussed in the context of the Sacramento River.

Keywords: winter-run Chinook, disease
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Predator Swamping and Movement under High Flows: Comparing Winter-Run Chinook Juveniles Released only Days Apart

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Predator swamping is a form of reproductive synchrony thought to reduce the fraction of prey taken by a predator. For salmon in a natural system increased river flow from rainstorms is the environmental cue that causes synchronous mass out-migration of juveniles. However, for hatchery raised fish, this takes the form of a mass release with thousands of fish released all at once. In 2015, the Livingston Stone National Fish Hatchery released 200,000 winter-run pre-smolts each night for three days on the Sacramento River in Redding. In the first and third release there were 249 and 318 pre-smolts implanted with Juvenile Salmon Acoustic Telemetry System (JSATS) transmitters. Movement and survival of these two groups of acoustic tag fish were compared at several reaches using detections from an array of JSATS receivers. The predator swamping hypothesis would predict that the fish in the third release will have higher survival because fish from the first and second release have satiated all available predators. Survival of both release groups for the first 15 river km was nearly perfect. High river flow reduced detection efficiency of the tagged fish in the third release group for the next 140 river km making survival comparisons uncertain. In the next three river reaches covering the area of the river from Hamilton City to Colusa survival for tagged fish in the third release group was higher, supporting the possibility of predator swamping for those reaches. The range of arrival times to receiver locations was affected by flow conditions, with a narrow range during low flow conditions and a broader range during high flow conditions. The high resolution data generated by acoustic tagging is useful for identifying areas where predation is a problem and is helpful to hatchery managers to optimize releases of fish with natural or managed river flows.

Keywords: Winter-run Chinook salmon, juveniles, smolt, acoustic tag, survival, predator, swamping
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Otolith Chemistry Reveals the Diverse Rearing Habitats of Winter-Run Chinook Salmon

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Protecting or restoring the juvenile rearing habitat of winter-run Chinook salmon (WRCS) will be critical to recovery of the species. However, identifying where important rearing habitats occur with current juvenile monitoring is challenging because 1) the length-at-date criteria does not reliably distinguish WRCS from the other Central Valley Chinook (CCV) salmon stocks, and 2) habitats outside the sampling area will not be considered. Indeed, the importance of non-natal rearing habitats—here defined as rearing occurring somewhere other than the Sacramento River between the spawning grounds and Knight's Landing—are not likely to be recognized because WRCS using these habitats will either go unsampled or be misidentified as another CCV stock. Further, non-natal habitats may provide important safe-havens from degraded conditions in the mainstem Sacramento River (e.g. high temperatures, predator density). Therefore, we used strontium isotopes in WRCS spawning adult otoliths to reconstruct their juvenile rearing habitats. The strontium isotope signatures of the Sacramento River are geographically variable, allowing for differentiation between mainstem Sacramento River reaches, tributary streams, and the Delta. We found that of the WRCS spawning adults sampled from escapement years 2007 – 2009, 64%, 65%, and 47% reared as juveniles in non-natal habitats, respectively. Non-natal habitats that could be identified were the Mt. Lassen tributaries (used by 56%, 19%, and 15% of all non-natal rearing fish from escapement years 2007-2009), the American River (22%, 40%, and 38%), and the Delta (11%, 36%, and 32%). The time period spent within the non-natal habitats ranged from approximately 2 to 16 weeks. These results suggest the extent of WRCS juvenile rearing habitat is likely under sampled and that non-natal habitats are potentially contributing significantly to the WRCS spawning population. Thus, we believe protecting and restoring non-natal rearing habitats can play an important role in recovering the winter-run Chinook salmon population.

Keywords: life-history diversity, life-history strategy, migration, restoration, rearing habitat, otoliths, strontium
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Effects of Out-Migration Size and Timing on Early Marine Survival of Chinook Salmon in the Ocean

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The first period at sea is a critical time for Chinook salmon during which recruitment strength is typically set. Ultimately, the productivity of the shelf ecosystem is tied to the survival and growth of the out-migrating salmon. However, the impact of the environment is not equally shared across all members of the out-migrating population. For example, the timing of out-migration is linked to survival; those fish that migrate following the development of a diverse forage base have a greater likelihood of success than those that migrate early relative to the development of a productive shelf ecosystem. As well, larger out-migrating individuals, when faced with an unproductive ecosystem, have a greater likelihood of survival. I demonstrate that a dominant agent of mortality on these out-migrating salmon is predation. Namely, during periods of reduced forage availability, seabirds change their foraging behavior which has the effect of increasing their interactions with juvenile salmon. Freshwater discharge can be tied to the growth and timing dynamics of out-migrating salmon and, therefore, their survival on the shelf ecosystem. Ultimately, I demonstrate an ecosystem analysis across the life-cycle of the salmon that demonstrates management of freshwater, forage fishes, and protected seabirds in the context of a variable environment is critical to the success of salmon recovery efforts.

Keywords: forage fish, seabird, predation, shelf ecosystem, survival
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