### Juvenile Chinook Salmon: A Need for Population-Specific Bioenergetics Models?

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Growth of juvenile salmonids is a critical variable affecting survival and recruitment to successive life history stages, essentially affecting the strength of subsequent cohorts. Consumption and temperature are key variables affecting growth for fishes in general. Temperature dictates the metabolic efficiency of prey conversion to production, and is thus a primary variable affecting growth. However, temperature optima and thresholds are variable for Pacific salmon populations. Yet many researchers using bioenergetic approaches to understand growth use temperature-dependent equations and coefficients for Chinook Salmon published in Steward & Ibarra (1991), which is based on adults from Lake Michigan, and uses coefficients from other salmonid species. To address this problem, we are using an approach using several lines of evidence to better understand relationships between temperature and growth. We focus this effort on juvenile Chinook Salmon used in the San Joaquin River Restoration Program, which seeks to restore the southern-most run in North America. Our approach includes a meta-analysis of growth rate and temperature relationships for wild populations, simulations with inSTREAM and bioenergetics models, and hatchery data sets. Results from these multiple lines of evidence suggest that juvenile Chinook Salmon growth rates in southern rivers are quite robust, despite the degraded conditions of these ecosystems. Our broader main objectives are to generate population and habitat specific bioenergetics algorithms and encourage a broader use of population-specific relationships of temperature and growth rate. A focus on these approaches can help fisheries managers set realistic expectations for restoration projects.

**Keywords:** Juvenile Chinook Salmon, Bioenergetics, Restoration, Fish Growth Rates
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## The Central Valley Spring-Run Chinook Life Cycle Model: A Tool to Manage the Recovery of Threatened Salmon Populations

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Spring-run Chinook salmons were once a major component of the Central Valley Chinook stock, with annual catches of over a half million fish in the 1880's. Today, wild populations of spring-run Chinook thought to be self-sustaining survive only in three tributaries of the Sacramento River: Mill, Deer and Butte Creeks (Lindley *et al.*, 2007; Yoshiyama *et al.*, 1998). Since 1999 Central Valley spring-run Chinook salmon are state and federally listed as a threatened species. In order to better manage these stocks for future recovery, understanding their life history strategies is necessary in gaining insight into where and how these fish are facing adversity.

We developed a life cycle model describing the dynamics of these populations at different life stages throughout a range of various rearing, feeding and spawning habitats. This model includes management variables (e.g. flow, water temperature, fishery harvest rates) in both the aquatic and marine stages of the life cycle in order to assess their impact on the survival, movement and rearing strategies. For instance, water flow in the spawning habitat is shown to strongly influence the timing and proportion of fry dispersing from natal reaches to downstream habitats soon after their emergence. Moreover, results from an acoustic tagging study performed recently on spring-run smolts are used in the model to inform the survival of spring-run juveniles migrating to the Ocean and the factors affecting this survival. We will present the model predictions obtained for different water management and climate change scenarios and discuss the implications for Central Valley spring-run Chinook salmon recovery.

**Keywords:** life cycle model, spring-run Chinook salmon, population management
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## Life-cycle Models for Evaluating the effects of Hydromanagement on Chinook Salmon in the Central Valley

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Balancing competing desires for fisheries, flood control, water supply and other ecosystem goods and services is a durable natural resource management challenge. The ongoing efforts to develop and approve new water project operating plans and WaterFix require models to evaluate how complex and interacting management actions affect salmon populations. Our general approach is to link existing physical (e.g., HEC-RAS) and biological models (e.g., enhanced Particle Tracking Model) to a stage-structured life-cycle model through stage-transition coefficients. In the model described here, we consider both developmental stage and geographic location (upper river, lower river, yolo, delta, bay, ocean) to define the state (e.g., fry in the upper mainstem river). Transitions among states then reflect survival, reproduction and movement among habitat areas at a monthly time step. Calibration is difficult due to the management focus of the model and the limited life-stage and geographic observations of abundance. Calibration of the model can occur through manual "tweaking" of coefficients or alternatively through statistical fitting of the model to the observations. We performed maximum likelihood estimation via numerical optimization to obtain coefficients of the transition functions in the life-cycle model that maximized the similarity of model predictions and observed data. For the winter-run life-cycle model, we used hatchery and natural origin escapement, juvenile abundance at Red Bluff Diversion Dam, catches of winter-run sized fish at Knights Landing, and abundance at Chipps Island. We found that average monthly temperatures above approximately 13.5 C during spawning had negative impacts in egg to fry survival; Wilkins Slough flow triggered movement past Knights Landing; export and flow effects were captured in ePTM survival; and different patterns of river, yolo, and delta habitat use under historical conditions. Furthermore, the calibration provided coefficients for running the life-cycle model prospectively to evaluate management actions such as restoration and hydrologic diversions under WaterFix.

**Keywords:** winter-run, hydromanagement, life-cycle model, calibration, estimation, WaterFix, scenario, decision analysis
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## Quantifying Uncertainty in Estimates of Juvenile Salmoinid Loss at the Central Valley and State Water Projects

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Mortality of juvenile salmonids at the Central Valley Project (CVP) and State Water Project (SWP) has been hypothesized to negatively impact special status populations. Both the CVP and SWP contain facilities that salvage entrained fishes and return them to the delta. However, mortality occurs in the diversion facilities and during the salvage process. This mortality is referred to collectively as "loss". In the National Marine Fisheries Service 2009 biological opinion on the long term operation of the CVP and SWP, loss per volume of water diverted was used as the metric to trigger actions in the Reasonable and Prudent Alternative. However, data are only collected on fish salvaged, not fish lost. Multiple reviews of the current method of calculating loss from salvage have been strongly critical of assumptions and methods, pointing out that they do not accurately represent the process of loss, cannot estimate loss when salvage is zero, and cannot properly incorporate the uncertainty in model parameters. We developed a Partially Observed Markov Process (POMP) model for estimating loss that addresses these issues and provides a flexible framework for estimation at both facilities. Using the POMP model and sound statistical inference we can estimate entrainment, loss, and salvage at time scales relevant for management decisions (*i.e.*, daily, annually), including the probability that triggers have been reached. Model results indicate that there is high uncertainty in loss estimates at both facilities. Uncertainty in model parameters estimated from experiments, and the lack of empirical entrainment estimates entirely, often accounts for over 50% of the variance in loss estimates. These results suggest that experiments designed specifically to inform loss estimates are needed and that operational decisions are currently based on highly uncertain loss estimates. The effectiveness of using of triggers to define operations should be reevaluated in light of these findings.

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## A Road Map for Designing and Implementing a Biological Monitoring Program

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Biological monitoring programs, such as status and trends monitoring, are commonplace in most natural resource agencies and can be a large fraction of management costs. However, the relevance and importance of the resulting data to resource management is sometimes questionable. In the worst case data are collected but never analyzed or used, and in other cases the data are inadequate due to biased collection procedures or failure to collect the right kind of data., Clarity is needed before a monitoring program is initiated to determine whether or not monitoring is in fact needed, and if it is needed, clarity is needed about exactly what data should be collected, how it should be collected, and how it should be used to assist with management decision making. To facilitate such clarity and to increase the value of biological monitoring programs, we have developed a how-to-monitor guide, a "Road Map" for monitoring. The Road Map has 10 steps of which only one step involves actual data collection. Other steps include components of structured decision making, sampling and monitoring designs, data analysis and modeling, and connecting analysis results to management decision making. The utility of the Road Map will be illustrated in application to the development of a monitoring program focused on entrainment of Delta Smelt.

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