Principles and Recommendations for Life Cycle Models

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Fish life cycle models are playing significant roles in the BDCP and the restoration of endangered species. Existing models present compelling, but different, explanations for the declines of Central Valley salmon and Delta smelt. However, the limited theory/data underling these models and the lack of a clear of evaluation process make it difficult to select between them. With the looming of model wars, a collaborative model development process is needed that encourages consensus and understanding. Drawing on experiences of veterans of review panels (NRC 2010, 2012; Rose, Anderson, McClure & Ruggerone 2011) I summarize issues and suggestions for the process of model development.

Philosophy–Life cycle models have varying degrees of mechanistic and statistical complexity which are ultimately determined by expert opinion. However, experience shows that neither expert opinion nor ability to fit data guarantees a model is correct or addresses relevant questions. To limit the modeling of myth alternative models should be developed and judged on their statistical and mechanistic aspects. Level of complexity should depend on the target audience: simple models inform the public on how the system works, forecast models assist managers and predictive models assist planners in designing futures.

Communication–A model is a logical structure combining ideas and data. Maintain a glossary of terms and concepts and a repository of data. Standardize documentation and public presentations. Publish the models in journals (SFWES).

Process–Modelers follow a process, which includes: identifying questions, reviewing existing models, synthesizing and summarizing data, formulating the structure and processes, coding, documentation, calibration, validation, sensitivity analysis and scenario evaluation. Each of these steps should be done in a collaborative and open manner. Models developed in isolation and reviewed in workshops and panels can lead to counterproductive model wars.

Ownership–Ultimately ownership belongs to the responsible agency but versions should be available to the target audiences: public, managers, planners.

Keywords: life cycle models, modeling process and evaluation

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Order 1

Application of a Winter Run Chinook Salmon Life Cycle Model to Evaluating Conservation and Management Actions

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Resource managers in the Central Valley are challenged to maintain stable or increasing populations of Chinook salmon in the face of increasing demand on the water resources and habitats that salmon depend on to complete their life cycle. Alternative management plans are often selected using professional opinion or piecemeal observations in place of integrated quantitative information that could reduce uncertainty in the effects of management plans on population dynamics. We developed a stochastic life cycle simulation model for winter run Chinook salmon in the Sacramento River with the goal of providing managers a tool for more effective decision making and demonstrating the utility of life cycle models for resource management. Sensitivity analysis revealed that the input parameters that influenced variation in salmon escapement were dependent on which age class was examined and their interactions with other inputs (egg mortality, Delta survival, ocean survival). Certain parameters (e.g. river migration survival, harvest) hypothesized to be important drivers of population dynamics were not identified in sensitivity analysis; however, there was a large amount of uncertainty in the value of these inputs and their error distributions. Thus, the model also was useful in identifying future research directions. Use of IOS for evaluating the BDCP has focused on entering modeled flow and temperature data for different scenarios and examining model output. However, this strategy does not take full advantage of model capabilities. Models like IOS can and should be used develop management scenarios by gaming different strategies. For example, the benefit of reducing harvest could be pitted against a reduction in exports or increases in river flow. To date, all scenarios have focused on early life stages of salmon and haven't addressed other life stage despite having management control over sources of adult mortality (harvest). The model presented provides an effective tool for decision making.

Keywords: Salmon

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Using OBAN and Decision Theory to Evaluate BDCP Alternatives

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Multiple anthropogenic and natural factors affect the population vital rates of Chinook salmon (*O. tshawytscha*). We developed a statistical framework entitled Oncorhynchus Bayesian Analysis (OBAN) to evaluate factors hypothesized to affect Chinook populations. To date we have applied this framework to winter and spring-run Chinook in the Sacramento River, CA. The OBAN framework is a state-space, stage-structured model that estimates the impact of hypothesized factors on the survival rates between stages. The impacts of factors are described by posterior probability distributions that characterize the uncertainty in the relationships between factors and stage-specific survival. The output of the OBAN model is a set of posterior probability distributions that can be used to forecast future abundances of Chinook as a function of hypothetical future factor levels (e.g., harvest rates, Yolo flooding, exports, etc.). The OBAN models have been used to evaluate Bay-Delta Conservation Plan (BDCP) alternatives in this context, producing probability of abundance and probability of quasi-extinction under different alternatives.

The OBAN framework can potentially be limiting, however, because forecasts of future abundances cannot easily accommodate hypothetical alterations to the ecosystem, such as the proposed North Delta diversions. Yet, there is the potential to use decision theory alongside Bayesian analyses (Berger, J. 1991, Statistical Decision Theory and Bayesian Analysis, Springer) as a coherent framework for incorporating subjective probability distributions of future interventions in the forecasted system. Importantly, the objective shifts from forecasting realistic distributions of abundances to developing robust decisions. We describe how we have coupled the OBAN models and the decision framework to provide evaluations of BDCP alternatives under hypothetical alterations to the Bay-Delta ecosystem.

Relevance: We combine a retrospective statistical model (OBAN) with a decision theory framework to facilitate decision-making under hypothetical alterations to the ecosystem as part of the BDCP process.

Keywords: Bayesian analysis, OBAN, Chinook, decision analysis, BDCP

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A Flexible, Multi-Input Life Cycle Model for Chinook Salmon in the Central Valley of California

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Recognizing that multiple factors affect survival and capacity across a gradient of habitat types and for a variety of life stages, we are developing a flexible life cycle model for Chinook salmon in the Central Valley of California. The model combines empirical data relating water temperature and flow levels to survival, with capacity estimates based on channel roughness, water depth, and velocity. These inputs are used to estimate life-stage- and river-reach-specific survival and capacity in the Species Life-cycle Analysis Module (SLAM) modeling framework. The initial versions of the model will focus on comparing salmon population dynamics given current, historical, and future scenarios (assuming BDCP-based changes in habitat and hydrology). Present limitations of the model are due, in large part, to a lack of empirical data on survival and/or capacity for various life-stage/habitat-type combinations. We are presently working on alternate methods to estimate these parameters, particularly fry survival in the Delta using modifications to the Particle Tracking Module of DSM-II. The flexible framework developed for this model means that new data (e.g., turbidity) and/or factors (e.g., hatchery fish) can be easily assimilated, and that diverse scenarios can be explored within a single modeling framework. However, even in its present form, the model provides a means to compare Chinook population dynamics under alternate scenarios and evaluate effects of specific management actions.

Keywords: Chinook Salmon, Life Cycle Model, Survival, Capacity, HEC-RAS

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Sacramento River Chinook: Modeling the Influence of Environmental Variability in a Stock Complex

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Chinooksalmon (*O. tshawytscha*) populations spawning in the Sacramento River (CA) and its tributaries have demonstrated high variability, and in some cases significant declines in spawning abundance, during the past 40 years despite restrictions to commercial and recreational fishing activities. Concern over the sustainability of Sacramento River Chinook populations has driven our inquiry into the environmental drivers of survival during specific life-stages and competition amongst stocks at likely points of interaction. We are in the process of developing a stage-structured population dynamics model that will permit hypotheses to be tested regarding the impact of environmental factors on productivity and capacity in various life-stages, the influence of hatchery production on the survival of natural stocks, and competition amongst co-migrating and co-rearing natural and hatchery-produced groups. Environmental factors under investigation may be broadly categorized as: 1) the result of natural changes in marine productivity, or 2) arising from anthropogenic influences in the system including changes to water flow and temperature, access to rearing habitat, and water exports or diversions for agriculture and urban use. We estimate the direction and magnitude of influence from the suite of environmental factors by fitting models to historical time series of abundance and environmental data (~1970+). Competition is evaluated between Spring, Winter and Fall-run Chinook from the Sacramento mainstem, as well as naturally reared and hatchery produced stocks from tributaries throughout the watershed.

The purpose of this research is to provide a quantitative framework for assessing the influence of both environmental and anthropogenic factors on the survival of threatened and endanger Chinook salmon populations in the Sacramento River, California, and a means for estimating future changes in abundance under alternative ecological and water use policy scenarios.

Keywords: life-cycle, modeling, Chinook, Sacramento, productivity, capacity, hatchery

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Hierarchical Spatial-temporal Modeling of Delta Smelt Population Dynamics

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A spatially explicit, hierarchical state space model has been formulated and fit to predict delta smelt population dynamics. Delta smelt are a species listed as threatened under the Federal Endangered Species Act and listed as endangered under the California Endangered Species Act. This model was developed primarily to provide resource managers a tool for assessing and predicting the effects of various management actions, particularly actions aimed at restoring the population, on the population dynamics. We are using fish, other biota, and physical data from multiple sources in an integrated manner to estimate the parameters of the model. Management actions can be translated into changes in model input variables or covariates, which in turn affect model processes such as survival. Alternatively, management actions can be translated more directly as changes in a model process, e.g., survival is adjusted up or down by some specified amount. We show how this structure and fitting procedure yields model outputs of direct interest to managers, such as population viability or recovery analyses. This tool is of direct relevance for quantitatively evaluating how different actions might affect the survival of delta smelt and potential for recovery.

Keywords: delta smelt, Interagency Ecological Program, hierarchical model, Bayesian, MCMC

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Bay Delta Ecosystem Diagnosis and Treatment

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Numerous stressors on the Bay Delta ecosystem have resulted in an impaired presentation in numerous dimensions. Ecosystem-based management of the Bay Delta, though well supported in the policy arena and thoroughly discussed in the scientific literature, seems complicated by the diverse and sometimes competing requirements of threatened and managed species that make use of these commons. The initiative to compoundly optimize the system for water exports and aquatic ecology has resulted in a sophisticated suite of models and management tools for seasonal and water-year based resource allocation. More recent planning efforts have included habitat restoration efforts aimed to relax limiting factors affecting delta smelt (*Hypomesus transpacificus*) and other species. There remains, however, some distance between the prescriptions of management and the prognosis of existing and new treatment plans that are operating on numerous and sometimes disparate scales. I describe an application of the medical model to the Bay Delta Ecosystem aimed to support long-term (20 year) diagnosis and treatment through integrated plans, actions, and outcomes. Bay Delta Ecosystem Diagnosis & Treatment (BDEDT) builds upon implementations of the medical model in the tributaries to the Bay Delta, and leverages the comparison between patient (i.e. current) and template (i.e. system potential) presentations of the system as these would be perceived through the eyes of delta smelt. I describe the benchmark performance of a Lefkovitch stage based model for delta smelt, spatio-temporal aspects of various life-history trajectories through the delta, species-habitat relationships, and the potential sensitivities to limiting factors based on existing published literature. I present these modeling elements within the Ecosystem Diagnosis & Treatment analytical framework with an emphasis on its application to habitat restoration and management.

Keywords: Fish

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Models as Tools for Learning: Room for Many in the Sandbox

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Predicting population trajectories of endangered species is difficult. We used a systems modeling approach to simulate the delta smelt lifecycle to explore smelt population behavior. Several smelt life stage attributes and environmental co-variates are included in the model. We used several model versions in comparison as a logical, learning-by-doing exercise for evaluating potential steps for recovery. We suggest agencies place increased emphasis on quantitative and semi-quantitative systems modeling and learning. We encourage simple systems simulation as supplement to consultant- or investigator-driven model building and "problem solving." The use of models as learning tools stems from the idea that models are disposable, quick, cheap, and useful for only a short period of time and for a limited set of questions.

Keywords: Systems Modeling, smelt, population, simulation

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A Lower Trophic Level Food Web Model for Simulating Dynamics in the Low Salinity Zone (LSZ) of the San Francisco Estuary

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A version of the comprehensive aquatic systems model (CASM) was developed to simulate daily growth processes and food web interactions over one year among important lower trophic level (LTL) populations in the low salinity zone (LSZ) of the San Francisco Estuary. The LTL food web is comprised of two phytoplankton populations and nine consumer groups that include multiple populations of particle-feeding zooplankton, a predatory copepod, *Corbula* clams, mysids, and a pelagic fish group. Daily population growth is determined by bioenergetics-based equations, and daily inputs for light, temperature, depth, nutrients, suspended sediments, and particulate organic matter differentially modify maximum photosynthesis and consumption of the populations. Field data and outputs generated for 2004 by EFDC hydrodynamic and water quality models were used as model inputs, and daily predicted biomasses for the populations were calibrated to biomass data collected by the Interagency Ecological Program using an automated program called PEST. PEST adjusted the bioenergetic parameters of the populations to best fit the predicted and the observed biomasses. The PEST-calibrated parameters were then manually fine-tuned to produce a realistic set of values that provided reasonable diet composition and degrees of coupling among the populations within the food web. The calibrated LTL food web showed that phytoplankton growth was severely light-limited in 2004 and had to be subsidized from outside the LSZ in order to support the food web. The calibrated model was used to evaluate changes in energy cycling and food web responses, as well as potential changes in food supply (particle-feeding and predatory zooplankton) for delta smelt, due to bottom-up changes in primary production and top-down effects from clam grazing. The CASM can evaluate a variety of bottom-up effects of water quality and restoration measures on production and distribution of the LTL populations in the San Francisco Estuary.

Keywords: lower trophic level food web, low salinity zone, model

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