Does Life History Diversity Provide Population Resilience in Delta Smelt?

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Problem Statement: The Delta Smelt (*Hypomesus transpacifics*) population has collapsed and may be approaching extinction. The resilience of the population appears to be dissipating as wetter years no longer provide the same degree of population "bounce-back". Delta Smelt exhibit a life history strategy termed partial migration, where the population consists of resident and migratory life history types. Thus attempts to understand the population dynamics in the low-salinity zone have largely ignored freshwater habitat and the smelt that reside in freshwater year-round.

Approach: In this study we evaluated the role partial migration provides to both population stability and population resilience using otolith strontium isotope ratios to determine the contribution of each life history type to the adult abundance.

Results: The migratory life history type comprised the majority of the population, although in some years the freshwater contingent comprised up to 40% of the adult population.

Conclusions: Unlike other species which exhibit partial migration, the migratory contingent provided population stability, while the freshwater contingent and brackish water contingents supported population resilience.

Keywords: Delta Smelt, Population Resilience, Population Stability, Partial Migration, Life History
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Session Time: Wednesday 1:35 PM – 3:15 PM, Room 307

Linking Temporal and Spatial Data Sets for Hierarchical Bayesian Network Analysis and Prediction of Delta Smelt Populations

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Abundance of delta smelt dropped by two orders of magnitude in this century. Studies with regression-based, life-cycle models have produced no generally accepted conclusions about the relative importance of different factors contributing to the decline. The prevailing conclusion of multiple causal factors provides little guidance on the choice and consequences of corrective actions. Bayesian Network methods, widely used elsewhere, may be useful in designing prediction/decision models for delta smelt. These methods are based on a conceptual model consisting of influence diagrams representing a hierarchical structure of interdependent factors.

Ideally, prediction methods are based on synchronous data, that is, data collected at the same time and place for the response variable (delta smelt abundance or density, in this case) and the factors thought to influence that variable. Unfortunately, routine Bay-Delta surveys do not produce such data. Several surveys sample for delta smelt and a few other factors influencing delta smelt. Other surveys sample the density of predaceous fish or shrimp, another the densities of delta smelt prey, and yet others the nutrients that affect delta smelt's food web. None of these surveys have the same sample locations and times, yet all produce useful information that cannot be ignored. Omitting an important factor because its data are non-synchronous runs the risk of attributing that variable's effects to an unimportant, included factor. This presentation presents one method for dealing with this problem of non-synchronous data.

The purpose of this presentation is to describe a method for "laminating" data from various surveys to produce data sets that approximate the synchronous ideal. This method would improve analyses directed at causal factors for many Bay-Delta ecosystem problems. Results of analyses of such data sets are applied to the prediction of delta smelt populations and are reported in a companion presentation by Oliver and Miller.

Keywords: merging data sets, data preparation, population dynamics, non-synchronous sampling
Session Title: Delta Smelt
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Predicting the Presence/Absence of Juvenile Smelt in the Bay Delta

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The author provides several Decision Analysis models for predicting time-dependent presence/absence of larval-juvenile delta smelt at 20 mm Survey stations within distinct sub-regions or zones in the Bay Delta. The models include seasonal influences such as temperature, month, previous year FMWT adult populations, Sacramento river flows, as well as prey, predators, ammonia concentrations, N/P ratios, and, in a well-defined pumping influence Zone (PI), the flows in Old and Middle rivers. A hierarchical Bayesian Network approach, heretofore unused in this or similar Bay-Delta problems, is based on the influences of predator/prey/river flows/sewage/nutrients and data collected during 1995-2009. These data, collected from several surveys, were laminated into a single data set that mimics temporally and spatially synchronous sampling at each 20 mm survey station. The authors develop a log-odds Bayesian factor or conditional score model that de-seasonalizes survey records and extracts meaningful signals from noisy data. By defining non-overlapping zones within the Delta, one can (1) predict seasonal time-dependent probabilities of presence/absence of delta smelt at individual survey stations, (2) identify and separate seasonal influences that mask influence of important nutrients, habitat factors and water exports, (3) conclude that pumping/export policies are modestly informative within the PI Zone, but (4) appear irrelevant to the prediction of delta smelt populations at all other stations in non-PI zones. Measures of performance and fit, Divergence, ROC curves, Gini Coefficients and Posterior Likelihoods are described and summarized. Results of these admittedly preliminary analyses suggest that management of Bay Delta water exports has little influence on the growth or decay of smelt populations and that much more attention must be given to management and control of water quality, nutrients and invasive predatory species. The models and methods of analysis may be useful in application to other Bay-Delta prediction and decision problems.

Keywords: Juvenile Smelt, Prediction, Scoring; Hierarchical Bayesian Models; Seasonal Factors
Session Title: Delta Smelt
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A Life Cycle Model and Population Viability Analysis for Wild Delta Smelt

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Delta smelt (*Hypomesus transpacificus*) are a native and endangered fish residing in the interior San Francisco Bay-Delta. Despite intensive study and management actions aimed at their protection and recovery, delta smelt abundances continue to decline. This is due in part to difficulties in studying their reproduction and survival in the wild. Past and proposed management actions to protect and recover delta smelt include manipulating interior Delta flow regimes, but the effectiveness of such actions remains a topic of scientific debate. To quantify the effects of flows, habitat volume, and food on delta smelt population dynamics, we first built a life cycle model that described recruitment and life-stage specific survival as functions of salient covariates. Life stages consisted of larva, juvenile, sub-adult, and adult. The resulting nonlinear, non-Gaussian state-space model was fit in a Bayesian framework using estimates of life-stage specific abundances, derived from long term monitoring survey data collected between 1995-2015. General findings were consistent with qualitative understanding: recruitment was enhanced when water temperatures were optimal, while increases in flow and habitat volume had positive effects on survival of other life stages. The fitted model served as the basis for a population viability analysis, in which we studied population growth rates and the risk of extinction across a range of time horizon, flow, and habitat volume scenarios. These results provide quantitative information on mechanisms driving delta smelt population dynamics and chances for survival, and it is hoped that such quantitative conservation biology can make more precise the comprehensive qualitative understanding about this species.

Keywords: Delta smelt; life cycle model; population viability analysis; state-space model
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A Delta Smelt Life Cycle Model: Separating Entrainment from other Sources of Mortality

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Management of the Sacramento-San Joaquin River's endangered delta smelt population is limited by the lack of a unified quantitative framework with which to explore consequences of potential water and environmental management actions. The Delta Smelt Life Cycle Model (LCM) is an effort by the United States Fish and Wildlife Service to assess present and past delta smelt population status, quantify drivers of population dynamics, and find long-term, resilient solutions to conserve delta smelt in the Bay-Delta. As a critical nexus between water users and environmental managers, water operations and entrainment in the South Delta and their effects on endangered species are of primary conservation interest; however, the per capita risk of delta smelt entrainment and the factors associated with higher risk have not been quantified. The LCM quantified the relative effects of water operations on delta smelt abundance patterns by incorporating Central Valley and State Water Project salvage data as an index of direct entrainment and treating direct entrainment and other sources of mortality as competing risks. Incorporation of salvage data mirrored the treatment of fishery catch in fishery stock assessment models. Twenty Millimeter, Fall Midwater Trawl, and Spring Kodiak Trawl Surveys were used to estimate juvenile, subadult, and adult abundances, and environmental, trophic, and water operations covariates were used to estimate annual variation in survival and reproduction. Merits of this approach were the separation of direct entrainment from other sources of mortality and the derivation of salvage observation probability as a function of mortality rates; however, strong assumptions regarding the ratio of salvage to entrainment and the average of other sources of mortality were required.

Keywords: Delta smelt, population dynamics, entrainment, stock assessment, state-space model
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