Collaborative Adaptive Management Team Investigations on Understanding Population Effects and Factors that Affect Entrainment of Delta Smelt at State Water Project and Central Valley Project

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Executive Summary

In 2013, the United States District Court for the Eastern District of California granted a motion by the federal and state governments in the consolidated delta smelt and salmonid cases to extend the period to complete remanded biological opinions on the agreement that the involved parties would work collaboratively to develop a science and adaptive management program to address key uncertainties underlying the effects of the State Water Project (SWP) and Central Valley Project (CVP) on delta smelt and ESA-listed salmonids (CAMT 2014). The stated purpose of this adaptive management program is to have experts and scientists from the agencies, Public Water Agencies ('PWAs'), and environmental community develop information that will help inform the development and implementation of current, interim, and future, revised biological opinions (Lohoefener 2012 and included in O'Neill 2013). Following the issuance of the Court Order, a two-tiered organizational structure was established to implement CSAMP comprised of: (1) a Policy Group made up of agency directors and top-level executives from the entities involved in the litigation, and (2) the CAMT including designated managers and scientists to serve as a working group functioning under the direction of the Policy Group. The CAMT determined three priority topic areas for initial investigations: 1) Fall outflow management for delta smelt, 2) Old and Middle River (OMR) management and entrainment of delta smelt, and 3) South Delta salmonid survival. Scoping groups were formed for each topic area to provide additional guidance on the hypotheses and questions that should be tested and addressed for each topic area. Note, although the Court Order was recently reversed by the Ninth Circuit Court of Appeals, the parties have agreed to continue CSAMP/CAMT efforts in the mutual interest of conducting collaborative investigations to resolve scientific uncertainty underlying key management decisions of SWP and CVP operations.

In June 2014, the CAMT Delta Smelt Scoping Team (DSST) solicited study proposals from our investigator team to address a subset of questions and hypotheses (See CAMT Progress Report and Entrainment Workplan[1]) on the following topic areas: 1) Factors affecting entrainment (Proposals I and II) and 2) Population consequences of entrainment (Proposals III and IV). In collaboration with the DSST, we reviewed conceptual models and hypotheses underlying these topic areas and engaged in several discussions to refine study questions and define priorities to meet management objectives. The ultimate goal of the proposed investigations is to support a more confident assessment of delta smelt entrainment and, stemming from that greater understanding, to assess the efficacy of management actions used to operate the water projects in a manner consistent with the ESA. Note, due to time and budget constraints, the proposals focus on adult delta smelt entrainment dynamics. The investigator team recognizes the need for studies of larval and juvenile life stages to improve the overall knowledge of potential population consequences but was given direction from the CAMT DSST to focus on adult delta smelt entrainment dynamics for the first round of study proposals. Proposals on larval and juvenile delta smelt entrainment dynamics are anticipated in Year 2 or 3 investigations.

[1] Can be downloaded at http://www.sfcwa.org/category/projects/camt-projects/

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Management Relevance and Study Framework

Based on review of the CAMT Progress report and supporting background material, the investigator team worked with the DSST to identify four key areas of scientific uncertainty related to understanding adult delta smelt entrainment dynamics. The proposals as standalone investigations could yield useful results that would inform on a specific effect of entrainment. However, the proposals are designed to be integrated as a more holistic product, building information and results across studies to provide a more robust assessment of entrainment dynamics and subsequent management options (Figure 1).

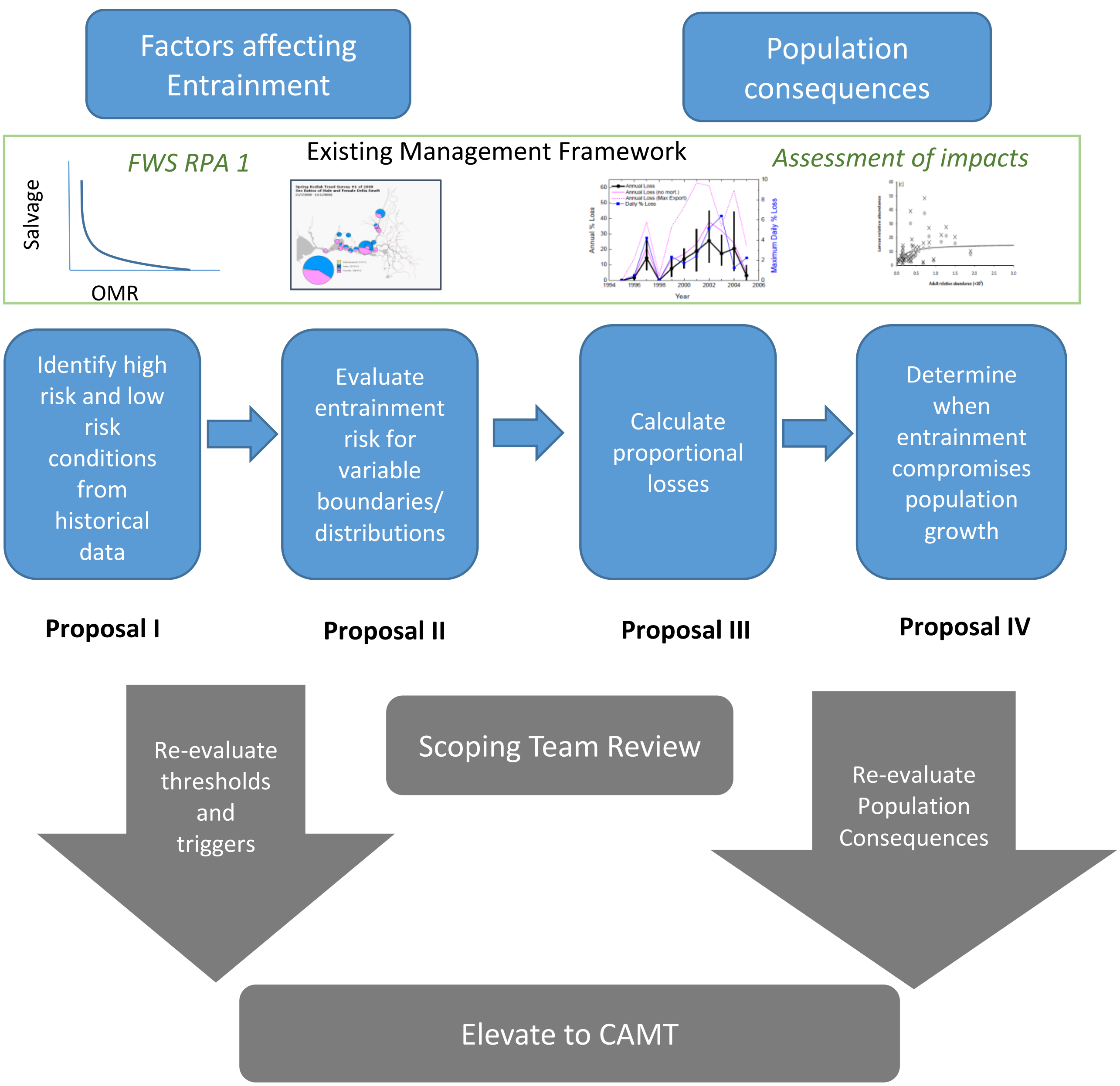

Figure 1. Management framework for incorporating information generated from adult delta smelt entrainment proposals.

The first study (Proposal I) is a retrospective analysis of historical data that aims to improve our understanding of factors that may affect entrainment risk. The first objective of this study is to revisit the existing conceptual models to determine if new studies or information (e.g., factors) can be used to better understand salvage patterns as an improvement from earlier investigations (e.g., Grimaldo et al. 2009). Following this review, factors believed to influence entrainment will be examined as explanatory variables in a multiple regression framework to determine what factors or interactions of factors best explain adult delta smelt salvage patterns. Results from this study could ultimately be used to characterize high risk and low risk scenarios for different management options. Additionally, information from this study could be used to inform the factors that might be explored using models described in Proposal II to explain behavior cues of adult delta smelt during upstream spawning movements (see below).

Proposal II proposes using a suite of hydrodynamic, water quality, and particle tracking models, referred to collectively as an individual-based model (IBM), to identify adult delta smelt behaviors that best explain movement towards SWP and CVP and entrainment. Statistical analysis will be used to identify and rank the best delta smelt behaviors evaluated in the modeling simulations. Assuming behaviors can be characterized successfully using the IBM, hypotheses can then be tested for how upstream movements are affected by different cues (i.e., changing turbidity vs salinity), how responses in entrainment relate to changes in boundary conditions (i.e., flows, sediment loads, exports, etc), or how effective the RPAs (Reasonable and Prudent Alternatives) from the delta smelt biological opinion would have been in reducing entrainment in the years simulated. Proposal II also proposes to develop new estimates for the two important “efficiency parameters” that are needed to expand the adult daily salvage data to daily entrainment estimates for the two south Delta fish facilities. The estimates for the salvage efficiency parameters are needed for the calculations of proportional entrainment losses proposed in Proposal III. Proposal III, therefore, relies heavily on results from Proposal II.

Under the category of Population Consequences, Proposal III represents our recommendation for the best approach to estimating adult delta smelt proportional losses to SWP and CVP entrainment. It proposes using the modeling tools described in Proposal II to estimate the efficiency parameters needed to expand salvage sampling data into entrainment estimates. Our basic approach to calculating proportional losses will be similar to previous work by Miller (2005c), Kimmerer (2008, 2011), and Miller (2011), but using what we believe will be improved estimates for both entrainment and populations. Our direct estimates of proportional losses also will extend over a much longer time period than previous direct estimates by including all water years from 1981 through 2014. The longer time series will be more effective for use as a covariate in the analysis of population-level effects of entrainment described in Proposal IV. We believe direct estimates of proportional losses are a more precise covariate for entrainment to use in models that assess population-level effects than covariates estimated by extrapolation backward in time using some type of regression analysis or covariates that are surrogates for entrainment such as the combined flows in Old and Middle Rivers (OMR).

Population consequences of entrainment have been examined using various statistical and life cycle model approaches with confounding interpretations of results based on input assumptions (Mac Nally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012; Rose et al. 2013a,b). Maunder and Deriso (2011) found that water temperature, prey, predators, and density-dependence are the most important factors controlling the population dynamics of delta smelt. They found weak support for adult entrainment and water clarity. Proposal IV will re-examine life cycle model results published by Maunder and Deriso (2011) using updated data sets (i.e., post 2005) and revised modeled assumptions. In particular, this study will test model sensitivity to the assumption of density dependence on survival relationships between life stages and use alternative values for process error variance. The secondary objective of this study is to develop a new set of covariates to be tested in the life cycle model based on information generated from Proposal I and III. Ultimately, the results from this investigation can be used to determine what levels of entrainment affects the viability of the delta smelt population.

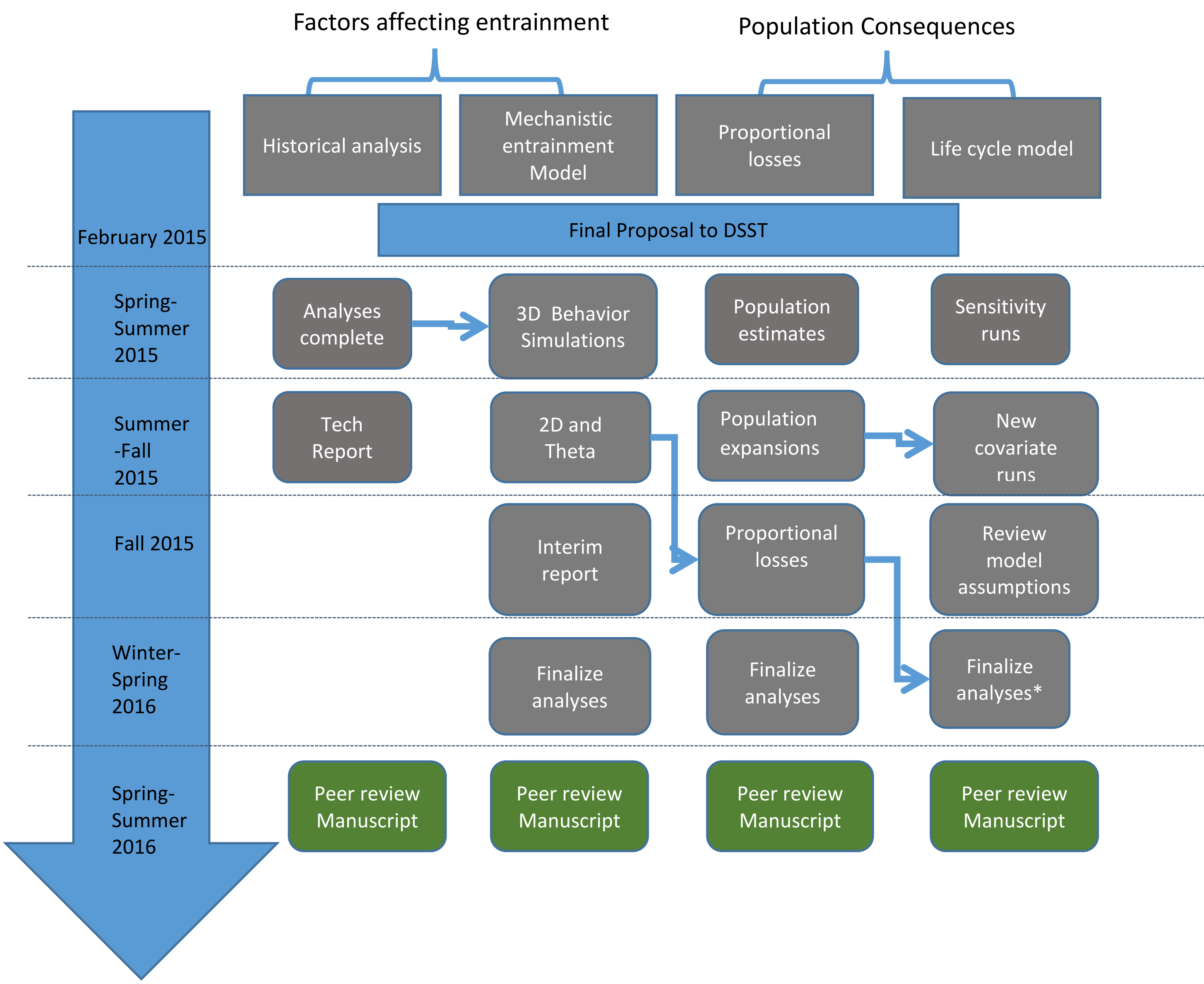

Figure 2. Timeline for key products and deliverables of CAMT entrainment proposals. Arrows denote where products from proposals are essential for completing products in other proposals.

Proposal I. Examining the factors that affect the magnitude, timing, and duration of adult delta smelt salvage at the SWP and CVP Fish Facilities: Identifying thresholds that define low and high risk entrainment conditions

Topic Area

This proposal addresses CAMT's workplan (3.2.1) for investigating new tools and potentially increasing the understanding of factors affecting entrainment**.**

Purpose Statement

The purpose of this proposal is to critically review the conceptual models (previous and present) that underlie adult delta smelt salvage and to subsequently determine through multi-regression models the best suite of variables that explain historical salvage patterns.

Key Investigators

Matt Nobriga (FWS)
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Josh Korman (Ecometrics)
Pete Smith (USGS retired)

Background

The 2008 Biological Opinion for Delta Smelt contains a Reasonable and Prudent Alternative (RPA) that includes two actions intended to protect adult delta smelt (Actions 1 and 2) from excessive entrainment. Actions are implemented through reductions in SWP and CVP water exports that reduce Old and Middle River (OMR) flows[2] to thresholds deemed protective of excessive entrainment risk. At question is whether the lower OMR thresholds for Actions 1 and 2, set at -2000 (14 days) and -5000 cfs respectively, confidently assess entrainment risk (NRC 2010) and whether new knowledge and information can be applied to improve identification of high risk and low risk entrainment periods.

Since 2008, a number of studies have improved our understanding of the factors that affect entrainment risk and drivers of those factors (Grimaldo et al. 2009, Sommer 2011; Kimmerer 2011; Miller 2011; CAMT 2014). From these studies, several conceptual models have emerged to describe connections among ecosystem drivers, explanatory variables, fish behavior/movement and fish distribution (see CAMT progress report). Based on graphical presentation of data, many of these factors appear to have a threshold, below which the risk of significant entrainment appears low. Also, there is new awareness of the importance of the interaction between the factors. Yet to be completed, is a multiparameter testing of these variables to determine how entrainment risk, as measured by salvage, varies as a function of key variables of interest, including turbidity, fish presence, and distribution. The objective of this study is to provide a framework for including key variables of interest generated from the

[2] OMR flows index the zone of influence for entrainment risk as they incorporate river flows, exports, and tides (Grimaldo et al. 2009)

conceptual models (See Conceptual Model and Investigative Approach sections) and to explicitly test questions (see below) generated from the development of these conceptual models. The information used from this proposal will ultimately be used to establish thresholds for low and high entrainment risk conditions.

Management Relevance and Connections to other Entrainment Proposals

This study is intended to provide a more confident identification of entrainment risk thresholds by considering the interaction of physical and biological conditions. The variables determined to be important predictors of smelt entrainment from this element will be considered in the development of the mechanistic Individual Based Model (IBM) developed in Proposal II to maximize the explanatory fitting of behaviors evaluated and may inform Proposal III as well.

Conceptual Model on Factors Affecting Entrainment

Overarching conceptual model of delta smelt movements upstream:

Juvenile and adult delta smelt are strongly affiliated with turbid water (Feyrer et al. 2007; 2013; Bennett and Burau 2014). Delta smelt's winter movements are facilitated by tidal surfing; specifically, delta smelt use behaviors that keep them associated with the tidal and advective movements of turbid water (Feyrer et al. 2013; Bennett and Burau 2014). Delta smelt move in response to winter freshets that increase turbidity and decrease salinity in the upper estuary. The details of these movements are the subject of a current scientific debate (i.e., are they "migrating" or not; Sommer et al. 2011; Murphy and Hamilton 2013) so there has been a recent effort to understand how delta smelt move at tidal time scales (Feyrer et al. 2013; Bennett and Burau 2014). However, all of the authors listed above recognize that delta smelt expand their spatial distribution in response to winter flows. The primary difference between newer publications and older papers is that older papers suggested a very gradual migration starting in fall (Bennett 2005) or spring (Moyle et al. 1992) that was not explicitly associated with changing water quality conditions. The statistical analysis of environmental conditions and salvage that is proposed here should be unaffected by these alternative population-scale mechanistic hypotheses about how delta smelt move because both eastward migration and dispersal toward marsh habitats require that delta smelt use tidal surfing to remain associated with turbid water. In addition, both prevailing conceptual models recognize that delta smelt can move in any compass direction that the fish find suitable at the time.

The export of water from the Delta has little effect on the tidal dispersion of turbidity in most of the estuary (e.g., Ruhl and Schoellhamer 2004). However, the Delta Cross Channel gates and the magnitude of water exports relative to river inflows must have some influence on the dispersion of turbid water (and delta smelt that happen to surf with it) into the southern Delta because these water project operations affect the flow of Sacramento and San Joaquin river water into and through the southern Delta (e.g., Arthur et al. 1996; Monsen et al. 2007; Kimmerer and Nobriga 2008). This is the basis of any conceptual model that assumes there is a mechanistic reason why adult delta smelt salvage increases when OMR is negative and turbidity is high (e.g., Grimaldo et al. 2009; Deriso unpublished).

Peak delta smelt spawning occurs in association with water temperatures that most frequently occur during the spring (Bennett 2005; Rose et al. 2013a). However, most of the entrainment of adult delta smelt happens during the winter (Grimaldo et al. 2009). Therefore, the majority of adult delta smelt salvage observed the fish facilites cannot be related to spawning per se.

Conceptual model of factors and drivers of entrainment

The CAMT progress report and other background materials [3] provide a thorough overview of factors and drivers that might affect delta smelt entrainment dynamics. This study will use these conceptual models as the framework for including factors in the analyses. Additional variables may be included, or factors may be organized differently depending on their covaration with other factors (see PCA approach below). Nonetheless, the conceptual models provided by the CAMT provide the basis for the investigative approach (see below) developed for this study.

Study Questions generated from the CAMT Progress Report that will be addressed in this study element

1. Is there a relationship between Delta Smelt distribution and habitat conditions (e.g. turbidity, X2, temperature, food) during fall and subsequent distribution and associated entrainment risk in winter?

This question will be addressed in each of the study steps described below: Step 1 (review existing analyses that have evaluated this hypothesis), Step 2 (incorporate this hypothesis into a conceptual model) and Step 3: test the conceptual model.

2. What factors affect adult Delta Smelt salvage during and after winter movements to spawning areas?

This question will be addressed in each of the study steps described below: Step 1 (review existing analyses that have evaluated this hypothesis), Step 2 (incorporate this hypothesis into a conceptual model) and Step 3: test the conceptual model.

3. How should winter “first flush” be defined for the purposes of identifying entrainment risk and managing take of Delta Smelt at the south Delta facilities?

We will develop several alternative first flush definitions (as part of Step 2), test their covariation, and their relative utility as predictors of adult Delta Smelt salvage (as part of Step 3).

4.What habitat conditions (e.g. first flush, turbidity, water source, food, time of year) lead to adult delta smelt entering and occupying the central and south Delta?

See above – this question is an amalgam of the first three questions.

Investigative Approach

We propose three basic tasks: Step 1, critically review previously published and unpublished analyses of adult delta smelt salvage trends and the factors used to predict them, Step 2, develop a thoroughly annotated and updated conceptual model of the state of science on this topic, and Step 3, provide new analyses of the data as appropriate to test the elements of the ‘management’ conceptual model developed by the CAMT Delta Smelt Subgroup last year (See CAMT progress report). Analysis of

[3] See attached document from Scott Hamilton

scatterplots and multiple regression techniques will be used to determine entrainment risk at appropriate timescale relevant for managing actions in Step 3.

Data Sources and Metadata Documentation

We propose to summarize the following data sets: Delta Smelt trawl catch data and water quality data from Fall Midwater Trawl and Spring Kodiak Survey, Delta Smelt salvage data, DAYFLOW, Old and Middle river flow data, DCC gate operations data, turbidity and water temperature data from Clifton Court Forebay. We will generate summary tables that describe what data are missing from these data sets and what implications the missing data have for the interpretation of statistical tests.

We will perform a Principal Components Analysis on the DAYFLOW database using December 1 – March 31, 1993-2013 data that correspond to the time of year that most adult Delta Smelt salvage occurs. This analysis will inform us which if any variables in that data set can be considered independent and if any really are, the PCA will generate independent synthetic variables from the data. We will include the USGS OMR flow data and other time series data (e.g., Clifton Court Forebary inflow) deemed appropriate in this analysis. The synthetic variables may or may not prove useful to data analysis. This step is proposed mainly to help us thoroughly understand the colinearity of the Delta's numerous winter flow variables that can be extracted from DAYFLOW and CDEC.

Fish salvage facilities data:

The CVP and SWP fish facilities were designed to separate fish from diverted water (Brown et al. 1996). The CVP and SWP fish facilities are located near each other, but they are spatially separated and located in front of water diversions that export water differing in its fractional contributions of Sacramento and San Joaquin river water (Arthur et al. 1996). Each fish facility can be conceptualized as a large pump sampler, i.e., a type of fish sampling "gear". It is standard in fisheries science to correct fish catches for effort expended. In other words, to convert catch into catch per unit effort (CPUE), the effort expended by the fish facilities is two-factored: (1) the amount of water exported, and (2) the number of salvage counts each day. The salvage data come corrected for the latter as "expanded salvage". The former can be corrected for by dividing daily salvage by daily export volume daily exports at each facility, or seasonal salvage totals by seasonal export totals, etc.

If the fish facilities are effective sampling devices, their CPUEs should be correlated with independent surveys of delta smelt relative abundance. This possibility of a correlation between abundance and salvage has previously been addressed by creating a ratio of salvage to an abundance index – typically the Fall Midwater Trawl (FMWT) index (USFWS 2008; Fullerton unpublished). However, ratios can be difficult to interpret), so we propose to test other approaches as well. Because the FMWT index may be correlated with the salvage indices, we will treat relative abundance as a *cause* of variation in entrainment (salvage) by using the FMWT as an explanatory variable rather than creating a ratio of indices to use as a response variable.

The FMWT index for delta smelt is a sum of monthly CPUEs (Stevens and Miller 1983). Thus, it seems logical that the clearest comparison of survey relative abundance to fish facility relative abundance is to generate CVP and SWP abundance indices that are analogs to the FMWT index. This can be done by summing the daily adult delta smelt salvage CPUEs for the period December 1 through March 31 of each water year from 1993 through 2013. This predominantly winter period encompasses the vast majority of adult delta smelt salvage that occurs each year and avoids confounding the salvage of adults with the salvage of their offspring (Kimmerer 2008; Grimaldo et al. 2009). We propose to convert export volumes (reported in acre-feet) into units of 10,000 m^3 to put the fish facility CPUEs on the same scale that the SKT and 20-mm surveys use (e.g., Nobriga et al. 2004); in other words, to convert the data from each fish facility into units of salvage · 10,000 m^{-3}.

The effectiveness of all fish sampling gears varies in time and space (Peterson and Bayley 2004). The effectiveness of the fish facilities is known to be influenced by regional environmental conditions that affect how close the delta smelt population gets to the fish facilities (Grimaldo et al. 2009) and particularly for the SWP, by predation in Clifton Court Forebay (Castillo et al. 2012). For these reasons we propose to analyze the two fish facilities separately. Like all previous analyses of the salvage data, those proposed here must assume that – at the time scale analyzed - salvage is a representative index of entrainment. We recognize that this assumption cannot be validated because we do not have historical data on factors that would affect the salvage to entrainment relationship. Most notably, we do not know how prescreen predator loss rates have varied in the historical data nor do we know how louver efficiencies for Delta Smelt have varied under various conditions (e.g., aquatic debris loading). Nonetheless, inspection of annual salvage losses and entrainment estimates show they track each other fairly consistently throughout the time series (see Figure 12 in Kimmerer 2008)

Step 1. Critical review conceptual models and analyses performed to date

Previous evaluations of the adult delta smelt salvage data have plotted and/or statistically analyzed the data on daily to seasonal time steps (Kimmerer 2008; Grimaldo et al. 2009; Deriso unpublished; Manly unpublished; Fullerton unpublished). Note that in the case of adult delta smelt, analysis of the data at a seasonal time scale is approximately equivalent to an annual time scale analysis because the vast majority of adult delta smelt salvage occurs during a few months of the year centered on the winter months (Grimaldo et al. 2009). Plots of the data on a daily time step are useful for visualizing general patterns (Kimmerer 2008; Grimaldo et al. 2009; Deriso unpublished; Figure 1). However, statistical analyses of the data at a daily time step are extremely problematic because the salvage (or lack of salvage) of delta smelt on any given day (n) is correlated with the salvage on the prior day ($n - 1$) and likely to be correlated at multiple time lags. Daily salvage is also mechanistically linked to environmental conditions occurring both during and prior to the observed salvage – again, likely at multiple lagging time steps. This multifaceted temporal autocorrelation in the data is apparent in the 'contrails' made by certain groups of data points in plots of daily salvage vs OMR (Figure 1). Therefore, if an investigator wanted to link daily salvage to operational or environmental conditions in a statistically defensible manner, they would need to account for the daily and longer time scale autocorrelation in the salvage data and then find an objective way to link the left over variation in daily salvage to environmental and/or operational conditions potentially over yet another different time scale(s). Of itself this would be exceedingly difficult. The fact that a lot of key daily environmental and salvage data are missing, renders this approach inadvisable without assistance from validated particle tracking models, which are not currently available, but have been proposed as part of the CAMT entrainment proposal (see Proposal II).

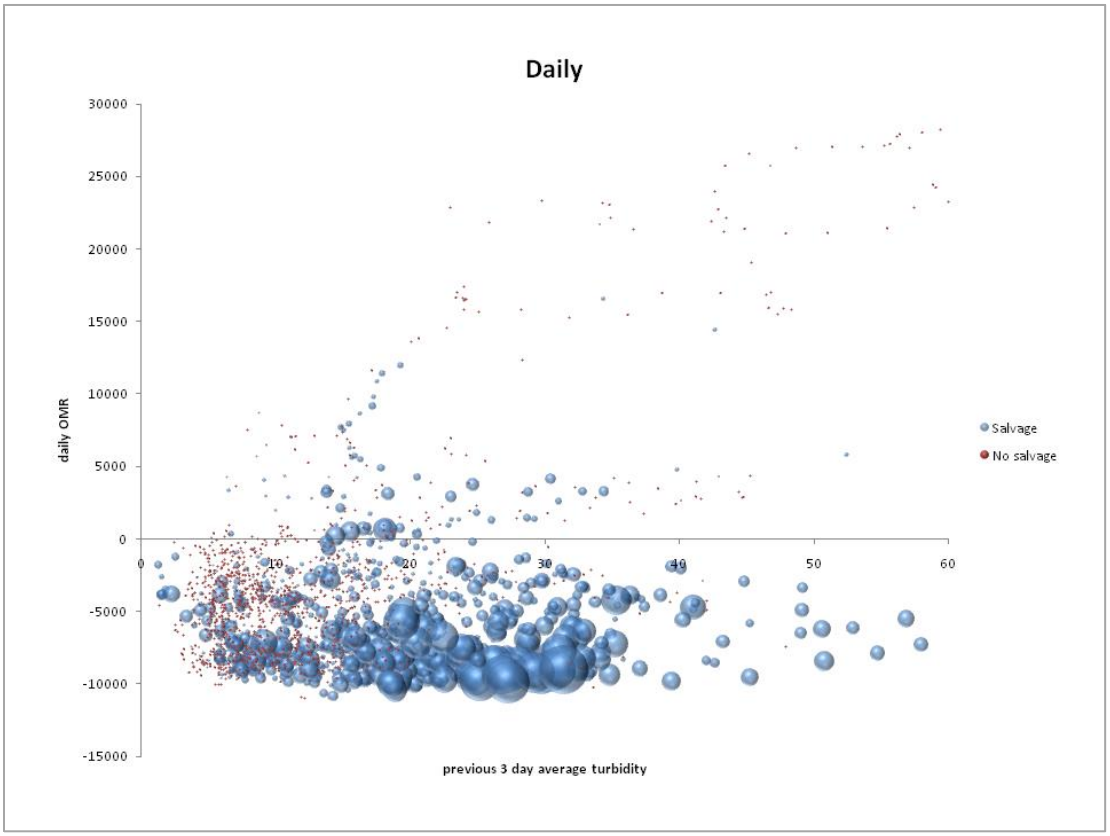

Figure 1. Recreation of Figure 3 from Deriso (2011; January 28, 2011 Declaration in support of Plaintiffs' request for injunctive relief in the delta smelt consolidated cases; court document # 772). Bubble plot of average turbidity (NTU at Clifton Court Forebay) for three days prior to a daily net flow in Old and Middle rivers (OMR). The blue datapoints are sized to reflect the co-occurring adult delta smelt salvage normalized to the Fall Midwater Trawl abundance index immediately preceding fall. Red data = no salvage on that day. The black line is a prediction line generated by the author and proposed as a guide to developing Project operating rules based on combinations of turbidity and OMR. December-March data for December 1988 through March 2009.

It is also apparent from Grimaldo et al.'s (2009) Figure 5 that the adult delta smelt salvage data are autocorrelated (on average) at a monthly time step meaning that salvage in month (*m*) is affected by what happened in the prior month (*m – 1*). The environmental and operational data are more reliable as monthly means because data are available to generate averages in most months. However, we do not propose to analyze the Delta Smelt salvage data at a monthly time step as initial analysis because many salvage events have straddled two or more calendar months. Thus, breaking these events into separate monthly averages could misrepresent the event both by parsing it and by including environmental data in calculations of monthly average conditions that had little or nothing to do with the salvage event. Intra-annual salvage trends can be examined after we have a better understanding of the autocorrelation in the time series of biological and environmental data.

Step 2 & 3. Developing and testing updated conceptual models using updated data sources and statistical approaches

An updated conceptual model will be provided after review of all existing information. This conceptual model may ultimately similar to those provided by CAMT. Nonetheless, it will provide the framework for testing updated or new variables. We will determine which parts of our working conceptual model, at which time steps, can be meaningfully tested in a statistical framework. We will use exploratory analyses and may use both bivariate and multiple regression techniques to address the study questions listed above. The following is a simple example of the proposed approach. For the reasons described above, we propose to start the analysis of each fish facility with a base model: $I_s \sim FMWT + \varepsilon$, where I_s is a log-transformed salvage index derived from SWP or CVP CPUE as described above, *FMWT* is the log-transformed Fall Midwater Trawl index for the water year corresponding to the adult salvage, and ε represents the variance in the modeled parameter estimates. Then, we propose to compare each fish facility's base model to several alternatives, for example:

$I_s \sim FMWT + ID + \varepsilon$
$I_s \sim FMWT + FF + \varepsilon$
$I_s \sim FMWT + ID + FF + \varepsilon$
$I_s \sim FMWT + ID + FF + Hab + \varepsilon$

where *ID* is one or more covariates depicting the initial distribution of Delta Smelt (study question 1), *FF* is one or more covariates depicting first flush conditions (study question 3), and *Hab* is one or more covariates describing habitat conditions associated with Delta Smelt salvage, possibly using event averaging[4]. Note, interactive terms will also be tested in this approach.

We will evaluate the comparative fit of the alternative candidate models using the information-theoretic approach based on the Akaike Information Criterion (AIC; Burnham and Anderson 1998) for each of the study questions above, and evaluate diagnostic plots of the best-fitting CVP and SWP models to determine how well statistical assumptions have been met. For instance, in the simple example provided above, we would compare the AIC of each model variation to the base model. If the AIC of any model variation was more than two units lower than the base model AIC, it would be considered a potentially better explanation of the data than the base model. However, we will also consider the *P*-values of individual covariates and the distribution of residuals based on diagnostic plots before making final conclusions about which regression model or models best explain variation in adult Delta Smelt salvage.

Investigative Challenges

The primary limitation of this investigation will be availability of data for factors that may influence entrainment risk (e.g., predator abundance estimates, appropriately time and space scaled distributional data, turbidity data, etc.) and missing data from key time series databases (e.g., OMR flow, salvage

[4] We propose testing event averaged covariates as part of our statistical analyses because it seems likely that environmental conditions occurring during the accelerating part of the seasonally accumulating salvage are the conditions that actually *caused the fish to occupy nearby channels in the south Delta* (e.g., Old and Middle rivers) and that during the decelerating part of seasonally accumulating salvage, the trend has less to do with operations than with the area occupied in the southern Delta. We will test for significant differences in covariate averages for accelerating versus decelerating salvage before making a final decision about this. (If the average covariate values do not differ significantly during accelerating versus decelerating salvage, then they may not be informative.)

observations, etc.). The model framework proposed under Proposal II can be used to test certain alternative hypotheses about smelt behavior that may affect their risk of entrainment.

Deliverables

A peer-review quality technical report with extensive supplemental documentation will be provided to the CAMT scoping group at the conclusion of the study In addition, presentations will be provided to the CAMT scoping group to demonstrate how the conceptual model was tested using different analytical methods and data sources. These sessions could be interactive to incorporate any alternative testing of the conceptual model by the scoping team. A peer-review manuscript may be generated from this investigation; however, the results may not be of sufficient general scientific interest to warrant publication.

Budget

The total budget for this study is $65,870. See attached task and timeline breakdown.

Timeline

The investigative approach outlined above and deliverables (not including the peer-review manuscript) should be completed by December, 2015.

Qualifications

See attached CV's

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Proposal II. Modeling delta smelt movement into the South Delta: Linking behavior, habitat suitability and hydrodynamics to better understand entrainment at the State Water Project and Central Valley Project

Topic Area

This proposal addresses CAMT's Workplan Element 3-2-1 for assessing factors affecting adult delta smelt entrainment. It will investigate factors affecting adult delta smelt entrainment using a combination of mechanistic modeling and statistical analysis.

Project Purpose and Overview

The primary purpose for this project is to evaluate hypothesized adult delta smelt swimming behaviors and how those behaviors driven by the environmental conditions of turbidity, salinity, and Delta flows, affect adult delta smelt entrainment at the south Delta export facilities. We propose using an approach based on a combination of mechanistic modeling and statistical analysis that will complement the data-driven investigation described in Proposal I.

A toolset of hydrodynamic, turbidity/suspended sediment, and particle-tracking models will be used to simulate adult delta smelt movement and behavior during four separate water years. The outputs from simulations with different hypothesized behaviors will be compared to field data for monthly delta smelt distributions and to daily numbers of adult delta smelt salvaged at the south Delta fish facilities. A statistical analysis will be applied to identify and rank the behaviors, or set of behaviors, that are most consistent with the observations.

Our plan is to immediately begin evaluating delta smelt behavior models using an existing set of two-dimensional (2D) depth-averaged models that includes a turbidity model to simulate water clarity rather than a more physically based, suspended sediment transport model. We also propose to progressively develop, test, and calibrate more mechanistic and sophisticated models to upgrade the toolset. First, a 2D suspended sediment transport model will be evaluated to replace the existing turbidity model. Then, a set of three-dimensional (3D) models, including a 3D sediment transport model, will be applied. When the three-dimensional models are applied, a more realistic representation of behavior is feasible. The three-dimensional behavior models will first be evaluated by comparison of predicted distributions in the lower Sacramento with the dataset of Bennett and Burau (2014) before application to Delta scale modeling of distribution and salvage.

After delta smelt behaviors are evaluated and the best behavior model(s) identified, the 2D model toolset will be used to demonstrate the factors affecting entrainment in the four water years simulated and to evaluate how effective the RPAs (Reasonable and Prudent Alternatives) from the delta smelt biological opinion would have been in reducing entrainment in those years.

Another purpose for this project is to apply the 2D modeling toolset, using the best delta smelt behavior, to estimate the salvage-sampling efficiencies for the two south Delta fish facilities. The two salvage efficiency parameters (referred to below as θ_1 and θ_2) will be used in our companion Proposal III for computing annual proportional entrainment losses at the facilities.

Previous experience with the kind of delta smelt behavior models discussed in this proposal is limited, and we are uncertain about the degree to which using these models will improve our understanding of factors affecting delta smelt entrainment. We are more confident that these models will prove useful for the purpose of improving estimates for the salvage efficiency parameters at the south delta fish facilities. Although we are hopeful we can make modest improvements in formulating delta smelt behaviors that are consistent with available observations, it could take years of additional development, calibration, and testing of fully three-dimensional models, and collection of additional field data to better understand the complexities of real-world delta smelt movement and behavior, before the predictive ability of these models are adequate to confidently address CAMT workplan hypotheses about entrainment. We believe that development and testing of these models is valuable and should be pursued with realistic expectations of what can be accomplished on the CAMT timelines.

Key Investigators

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Conceptual Model of Spawning Migration

A conceptual model of delta smelt life history and spawning migration has been provided in Proposal I and an even more detailed conceptual model is provided in CAMT (2014). Here we describe only the conceptual model relevant to the proposed modeling work.

Much of the delta smelt population occupies the oligohaline portion of the northern reaches of the San Francisco Estuary in winter (Sommer et al. 2011). During their spawning migration these delta smelt move landward (Sommer et al. 2011) and a portion remain in local tributaries and marsh regions with lower salinity (Murphy and Hamilton 2013). Observed salvage often has a peak following the first large influx of flow and sediment in the water year (Grimaldo et al. 2009). While the exact environmental conditions that cue the spawning migration are not conclusively established, Feyrer et al (2007) has shown that delta smelt are strongly associated with turbid water. Salvage of delta smelt is most strongly related to south Delta turbidity and the combined flow in Old and Middle Rivers (OMR). Salvage peaks generally occur during periods of high turbidity (> 12 ntu) and strongly negative (< -5,000 cfs) flows in OMR (Grimaldo et al. 2009).

Our conceptual model is that a landward migration of mature delta smelt in late fall or early winter is triggered by changes in turbidity distribution, or possibly salinity distribution. We hypothesize that delta smelt swimming may respond to the magnitude of spatial gradients in turbidity and salinity. While additional environmental cues, such as water temperature or food availability, may influence delta smelt movement, they will not be explored in our proposed work. Feyrer et al (2013) and Bennett and Burau (2014) have both provided evidence of vertical and lateral tidal migration behavior. Bennett and Burau (2014) conclude that their dataset is not adequate to distinguish between a turbidity cue or velocity cue for lateral migration behavior. Particle-tracking results suggest that tidal migration behaviors can plausibly accomplish the landward migration at the rate suggested by observations of delta smelt distribution and salvage (Sommer et al. 2011). In addition to the spawning migration, adult delta smelt are also believed to hold in regions of suitable habitat (Sommer et al. 2011).

In addition to entrainment at exports, natural mortality due to predation, temperature, reproductive costs and other influences affects adult delta smelt survival.

Key Questions

The key questions with respect to factors affecting entrainment have been identified by the CAMT Delta Smelt Scoping Team. These questions focus on the factors leading to adult delta smelt entrainment. We propose to address several questions, closely following the key questions identified in Workplan Element 3-2-1:

1. What are the environmental conditions that “trigger” spawning migration of delta smelt?
2. How does the distribution of adult delta smelt vary at time scales not resolved by surveys? In particular how does the distribution evolve during the spawning migration?
3. Which environmental conditions lead to adults entering the south Delta?
4. Which environmental conditions lead to adult delta smelt exiting the central and south Delta to regions with lower entrainment risk?
5. To what degree has implementation of the RPA reduced adult delta smelt entrainment?
6. What are the salvage efficiencies of the major water export facilities?

Background to Hydrodynamic Applications

A fairly small subset of the studies to estimate delta smelt abundance and entrainment have been spatially explicit modeling studies. The few studies that have done so have estimated movement and distribution of delta smelt by hydrodynamic transport, volitional movement or a combination of hydrodynamic transport and volitional movement (e.g. Rose et al. 2013, RMA 2009, Newman et al. 2014, Gross et al. 2010). Both hydrodynamics and volitional movement have been represented to various degrees and with different methods. A full review will not be provided but a few key examples will be cited.

One approach used to represent transport and distribution to date, particularly for larvae and post-larvae, has been to represent delta smelt as passive particles (e.g. Rose et al. 2013, Newman 2014). In the Delta Smelt Life Cycle Model (DSLCM) this is represented as monthly exchange among 4 regions in a “movement matrix” approach. Both of these examples use the one-dimensional DSM2 to provide a highly simplified representation of hydrodynamics and transport processes.

In contrast the simplest approaches for volitional movement ignore hydrodynamics altogether and determine the distribution of delta smelt based on specified movement such as the “stay in place” behavior alternative of the DSLCM or based on environmental cues (e.g. other hypothesized behaviors in the DSLCM). Rose et al. 2013 used a kinesis behavior with salinity as the environmental cue. This kinesis behavior specifies random and directed swimming behavior along the salinity gradient. Water velocity was ignored by Rose et al. (2013) for juveniles and adults.

Neither passive transport nor ignoring hydrodynamic velocities can provide a realistic representation of delta smelt movement in all locations. The velocity of fish movement at any moment is the superposition of hydrodynamic velocity and swimming velocity (e.g. Goodwin et al. 2006). Both these velocities are three-dimensional vectors. Furthermore the instantaneous velocities experienced by fish are turbulent velocities which have spatial scales on the order of meters and time scales on the order of seconds. The IRP LOBO review (Anderson et al. 2013) emphasized the importance of a more realistic representation of both hydrodynamic variability in velocity and delta smelt swimming behavior, stating that "developing an effective preemptive action (to reduce entrainment) requires understanding the behavior of delta smelt to their environmental cues during the migration" and that action "based on an incorrect model of delta smelt behavior may neither produce desired results nor be cost effective." A specific modeling approach for adult delta smelt behavior is proposed in the IRP LOBO review that is more detailed than other modeling approaches to date and at a finer spatial-temporal resolution than current modeling capability. In the IRP CAMT review of a draft of this proposal, the review panel stressed their preference of a highly mechanistic representation of behavior and turbidity, requiring the use of three-dimensional tools including a suspended sediment transport model. While a large gap exists between representation of fish movement in modeling studies to date and the instantaneous movement of delta smelt, some steps have been made towards more mechanistic and realistic modeling of delta smelt movement.

RMA has developed an adult delta smelt model that incorporates some elements of the current understanding of adult delta smelt behavior. RMA has applied the RMA2 depth-averaged hydrodynamic model and associated RMA PTRK particle tracking model (RMA 2009; RMA 2011). The turbidity model applied accounts for "first flush turbidity" resulting from inflow of sediment from Delta tributaries as this sediment is transported through the Delta and slowly settles out (RMA 2009). It did not account for local resuspension of sediment and relied on empirical coefficients representing the effect of net settling of sediment. The representation of adult delta smelt and their spawning migration from Suisun Bay into the Delta assumes turbidity and salinity and associated gradients trigger a tidal migration ("surfing") behavior. In regions of suitable salinity and turbidity, or small salinity and turbidity gradients, the modeled delta smelt move in random directions. The swimming behavior itself is not fully mechanistic but has been applied as a "velocity factor" applied to the hydrodynamic velocity. For example during landward spawning migration a fish may move 1.2 times faster than the hydrodynamic velocity vector (in the same direction) on flood tide and 0.5 times the hydrodynamic speed during ebb tide. This is a simplified approach, representing the expected net *effect* of a swimming behavior (moving up and down in the water column or laterally between channel and shoals) instead of a more mechanistic approach which would represent the swimming vector for delta smelt and require that lateral and vertical gradients in velocity be adequately resolved by a hydrodynamic model and associated particle-tracking model.

While the RMA approach is perhaps the most sophisticated approach for adult delta smelt movement modeling applied to date, substantial improvements are required to implement the more refined and mechanistic modeling approaches proposed by Anderson et al. (2013) and Anderson et al. (2014). The IRP conceptual model involves resuspension of sediment during the tidal cycle, which was not represented in the simplified turbidity model previously used in the RMA approach. The IRP CAMT review (Anderson et al. 2014) suggests a focus on the delta smelt behavior model hypothesized by Bennett and Burau (2014) which depends critically on lateral turbidity distribution. A full sediment transport model can be incorporated into the RMA approach with the depth-averaged tools. In addition, a three-dimensional hydrodynamic modeling approach is recommended to represent vertical variability in velocities, salinity and turbidity and a high resolution grid is recommended so that lateral variability in properties is resolved to the extent feasible. It should be noted that RMA's depth-averaged approach to date does not represent lateral variability in 1D channels in the south Delta. A staged approach to improve delta smelt modeling by making it increasingly mechanistic following IRP LOBO recommendations (Anderson et al. 2013) and DSP recommendations (Anderson et al. 2014) is described in the Investigative Approach of this proposal.

However, it should be noted that a more mechanistic representation of physical processes and refinement of swimming behaviors may or may not substantially improve comparison of model predictions and observations given currently available delta smelt survey observations. A more sophisticated approach will still rely on accurate model calibration for hydrodynamics, salinity, turbidity, and, perhaps most importantly, an appropriate behavior model with appropriate parameters (thresholds of turbidity, swimming speeds etc.). Since adult delta smelt behaviors are not well understood, neither the model nor appropriate values of these parameters are known. Instead they must be estimated, within realistic ranges, by evaluation of multiple models with different swimming behavior parameters. Due to substantial spatial and temporal variability in survey and salvage observations, different behaviors with different associated levels of entrainment may match observations approximately equally well. Therefore a statistical approach is required to evaluate alternative behaviors and indicate the level of confidence in distribution and entrainment predictions for each individual behavior model. It is not clear *a priori* whether such a statistical approach will suggest that substantial additional confidence in distribution and entrainment predictions will be gained from applying a more mechanistic and scientifically defensible three-dimensional hydrodynamic and sediment transport model. In the 3D stage of the proposed work, we will also incorporate the Bennett and Burau (2014) observations in our study which should allow increasing confidence in the representation of behavior.

Investigative Approach

The investigative approach can be discussed as several distinct components as follows. First a small number of conceptual models of delta smelt swimming behaviors will be developed and all assumptions and free parameters will be described. In developing these conceptual models, the relevant literature will be considered including Bennett and Burau (2014), Feyrer et al. (2013) and Andersen et al. (2013. 2014). Furthermore the hydrodynamic and turbidity fields predicted by UnTRIM/Sedimorph and RMA2 for previous simulations periods will be inspected to qualitatively understand some likely effects of hypothesized behavior which may allow rejection or refinement of some behaviors. The expected valid range of parameters and distinct sets of parameters in these ranges which define the behavior scenarios to be evaluated will be defined. A portion of these behavior models will then be incorporated into a set of depth-averaged modeling tools. A statistical approach will be developed to allow each behavior to be evaluated by comparison of predictions to survey and salvage observations. The best performing model(s) will be used to evaluate the effectiveness of the RPA in reducing entrainment. Additional models will be incorporated in a three-dimensional individual based model which uses hydrodynamic and turbidity fields from a three-dimensional hydrodynamic and suspended sediment transport model. Increasingly realistic and mechanistic representation of behavior will be evaluated first by comparison to the observations of Bennett and Burau (2014) then by comparison to Spring Kodiak Trawl (SKT) observations and salvage observations. A more detailed description of each component of this investigation is provided below.

Because the distribution of adult delta smelt, and associated entrainment, results from the combination of hydrodynamic velocities and swimming behaviors, answering the key questions about the factors that affect entrainment requires identification of adult delta smelt behaviors that lead to distribution and salvage predictions most consistent with available observations. These behaviors are likely related to environmental cues including hydrodynamics, salinity and turbidity. Possible additional environmental conditions that may influence delta smelt movement have been identified by CAMT but will not be considered in this proposal. As suggested in the DSP review (Anderson et al. 2014) the first logical step in the individual based modeling work is to describe explicit behavior models consistent with observations reported from recent field studies (Bennett and Burau 2014, Feyrer et al. 2013). Anderson et al. (2014) provide an example conceptual model for behavior(s) consistent with the Bennett and Burau (2014) observations. Furthermore it recommended that proposed models should attempt to be realistic "based on first principles of the animal's perceptive, cognitive and physiological capabilities DSP review (Anderson et al. 2014)." The references cited therein suggest that this realism could include considering a nonlinear relationship between environmental cues and stimulus intensity, accounting for acclimatization to environmental conditions and introducing stochasticity in behavioral responses (e.g., Goodwin et al. 2014). In our initial task of defining behavior models we will define what range of complexity we believe is appropriate in the behavior modeling given the limitations of available observations. This will be not just a conceptual model but also a quantitative model for behavioral responses to stimuli, such as the model described by Goodwin et al. (2014). We will define the parameters of the proposed models and valid ranges of these parameters and outline sets of parameters comprising individual models to be tested. The development of these models may involve further interactions with members of the Delta Science Panel, Bill Bennett and possibly others. The range of behaviors explored will vary both in complexity and in parameter values chosen.

The proposed investigative approach will apply several existing tools and datasets. We expect the two tracks of work described below to commence simultaneously. Due to the time sensitivity of the CAMT process, initial simulations of large scale distribution and salvage of delta smelt will utilize the existing RMA tools for depth-averaged modeling. This will allow the statistical approach to be developed and applied early with the initial model results. In the three-dimensional work, which will begin simultaneously, mechanistic tidal surfing models will first be applied in a reach of the lower Sacramento River and compared with the channel reach scale observations of Bennett and Burau (2014). Then the resulting candidate behaviors will be applied at the Delta scale and evaluated against survey and salvage observations using the same statistical approach applied with the depth-averaged modeling tools described below.

The existing model by RMA uses the RMA2 depth-averaged hydrodynamic model and associated RMA PTRK particle tracking model (RMA 2009). The model domain used in previous simulations extended from Martinez through the Delta but the RMA software will be applied to the full Bay-Delta model domain in the proposed work. The turbidity model applied to date accounts for "first flush turbidity" resulting from inflow of sediment from Delta tributaries as this sediment is transported through the Delta and slowly settles out (RMA 2009). It does not account for wind and current driven local resuspension of sediment which is a particularly important process in shallow open water regions. A sediment transport model accounting for local resuspension (RMA 1998) has been applied to the Bay-Delta by RMA but has not been used in the adult delta smelt modeling to date. We will evaluate whether a suspended sediment modeling approach, with a limited calibration effort imposed by timelines of the CAMT process, improves turbidity predictions and incorporate it in the modeling approach if it is an improvement. The behaviors explored to date assume turbidity and salinity and associated gradients trigger a tidal migration ("surfing") behavior. In regions of suitable salinity and turbidity, or small salinity and turbidity gradients, delta smelt swimming is randomly directed.

Due to the computational efficiency of this depth-averaged modeling framework, several simulations periods can be considered and sensitivity of predictions to different behavioral triggers/thresholds and swimming speeds can be explored more rapidly than in a three-dimensional modeling framework. We propose to simulate hydrodynamics and turbidity for 4 periods each of approximately 6 months duration and for each of these periods (corresponding to different water years) simulate approximately 10 to 20 alternative behaviors.

RMA's existing adult delta smelt model has similarities and differences relative to the adult delta smelt model proposed by the IRP (Anderson et al. 2013). Behaviors are triggered by turbidity and salinity and associated spatial gradients consistent with IRP recommendations. Key areas of improvement identified in the IRP review of a previous application of this approach are 1) use of a sediment transport model to improve predictions of turbidity, particularly by allowing tidal time scale resuspension; 2) using a swimming velocity vector instead of a "velocity factor" approach described in the Background section; 3) use of a three-dimensional hydrodynamic model and three-dimensional behaviors; and 4) resolution of lateral velocity gradients to the extent feasible. The first recommendation can be addressed by using a depth-averaged sediment transport model to predict turbidity. Conversion of suspended sediment to turbidity is discussed in the Appendix. The second key recommendation can be partially addressed by applying different swimming behaviors and superimposing the swimming velocity and hydrodynamic velocity to estimate delta smelt movement. This movement cannot be accurate in one-dimensional channels however because lateral gradients in velocity are not resolved in those locations.

A statistical approach will be applied to evaluate alternative behaviors by comparing model predictions of abundance and salvage with observations from fish surveys and recorded salvage. The main objective of this element of the proposal is to rank alternative behavior models based on the consistency between predictions and observations. Alternative behavior models may lead to large differences in estimates of entrainment, and a ranking or scoring of models based on their fit to observations is essential to determine the likelihood of various levels of entrainment.

For brevity, we will refer to the combination of hydrodynamic model, suspended sediment (turbidity) model, particle tracking model and adult delta smelt behavior model as an individual-based model (IBM). In order to compare IBM based entrainment estimates to observed salvage, pre-screen losses due to mortality and salvage efficiency must be estimated. These can be combined and represented as an "efficiency ratio" (θ) defined by Kimmerer (2008) as $\theta=1/(E*S)$ where E is louver efficiency and S is fraction of fish entrained that enter the facility, which accounts for pre-screen losses. θ will be estimated individually for the SFPF (θ_1) and TFCF (θ_2). Pre-screen losses due to predation in Clifton Court Forebay of the SWP are known to be large and variable (Castillo et al. 2012). Therefore θ_1 will be estimated from a constant salvage efficiency (E_1) and a daily estimate of pre-screen losses that depends on the hydraulic residence time (T) of Clifton Court Forebay (CCF) for antecedent flow conditions. So two parameters, a salvage efficiency (E_1) and a daily mortality rate (m_{CCF}), will be estimated to represent the efficiency ratio for the SFPF/SVP, $\theta_1=1/(E_1*\exp(-m_{CCF}*T))$.

Due to the computational expense of IBM simulations, sampling of behavior parameters in a Bayesian inference or maximum likelihood framework, requiring thousands of individual model runs, is not feasible. However, several parameters that do not affect particle trajectories can be fit subsequent to the IBM simulations. These parameters include E_1, m_{CCF}, θ_2, m, and n_i, where m is natural mortality and n_i is initial regional abundance for each region (i) at the beginning of the simulation period, which is not required to be at the time of a SKT survey.

For each adult delta smelt IBM (each representing a different behavior model) predicted distributions will be compared with Spring Kodiak Trawl (SKT) survey observations and salvage observations via a statistical model. Fall Midwater Trawl (FMWT) survey observations will likely also be used to better constrain the fitting of initial distribution of delta smelt or perhaps to directly specify an initial distribution. The IBM results will be summarized in a movement matrix, which represents the proportion of particles from a given region (spatial unit) that remain in that region or move to other (of approximately 10) regions. The statistical model will use maximum likelihood to estimate the natural mortality rate and entrainment proportions (θ) that result in the best fit between predicted and observed abundances by region on each survey date and daily salvage. The overall fit of the model is summarized in the total likelihood that is maximized during the estimation. This likelihood consists of survey fit and salvage fit components. Alternate behavior models can be compared based on differences in total likelihoods among models. Uncertainty in entrainment and estimates of θ for any model can be described based on changes in the likelihood as a function of alternate parameter values. This statistical fitting approach will be applied to both depth-averaged and three-dimensional IBMs. The details of the observation models for trawl data and salvage data are provided in the Appendix.

After the best performing behavior model (or models) is identified, key questions on factors affecting adult delta smelt entrainment will be addressed by analysis of predictions utilizing that behavior model. The effectiveness of Biological Opinion Reasonable and Prudent Alternatives (RPA's) in reducing entrainment will be evaluated using the best performing behavior model, or possibly with an ensemble of behavior models. The same model(s) will be used to estimate salvage efficiency at the State Water Project's (SWP) Skinner Fish Protective Facility (SFPF) and Central Valley Project's (CVP) Tracy Fish Collection Facility (TCFC).

Consistent with the IRP LOBO (Anderson et al. 2013) and IRP CAMT (Anderson et al. 2014) recommendations, a three-dimensional set of tools will also be applied to investigate additional behaviors depending on vertical distribution of velocity, turbidity and salinity and allow better representation of lateral gradients in velocity and turbidity. The UnTRIM Bay-Delta model (MacWilliams et al. 2007, 2008, 2009, 2015) has been previously applied together with the SWAN (SWAN Team 2009a) wave model and the SediMorph sediment transport and seabed morphology model (BAW 2005), as a fully-coupled hydrodynamic-wave-sediment transport model of the San Francisco Estuary in numerous previous studies (e.g., Delta Modeling Associates, 2014; Bever and MacWilliams 2013; Bever et al. 2014). As a result this coupled modeling system provides a ready-to-go 3-D hydrodynamic and sediment transport model that will not require any additional development for application to the CAMT project. The formulation and applications of these three-dimensional tools, which include a well-established sediment transport model that can be used for prediction of turbidity, have been published in peer-reviewed journals (e.g. Casulli and Walters 2005; Casulli and Zanolli 2005; MacWilliams and Gross 2013; Kimmerer et al. 2013, Kimmerer et al. 2014; Bever and MacWilliams 2014). This phase of work will focus on testing variations of the behavior (conceptual) model hypothesized by Bennett and Burau (2014).

Three-dimensional simulations will be performed with the UnTRIM hydrodynamic model (Casulli and Walters 2000; Casulli and Zanolli 2005) to provide hydrodynamics, salinity, and turbidity predictions and the FISH-PTM (MacWilliams and Gross 2013; Kimmerer et al. 2014) will be applied to represent three-dimensional delta smelt trajectories and associated distribution and entrainment resulting from the combination of hydrodynamics and swimming behaviors. The mechanistic and relatively well-established sediment transport modeling approach used with the three-dimensional tools, discussed in the Appendix, is more robust and scientifically defensible than both the simplified turbidity prediction approach and the RMA sediment transport and may allow substantial improvements in entrainment predictions. The three-dimensional FISH particle-tracking model naturally incorporates information on stratification and both vertical and lateral shear in particle tracking simulations and allows vertical and lateral tidal migration behaviors to be explored (Kimmerer et al. 2014). This is particularly important for exploring the behavior hypothesized by Bennett and Burau (2014).

In the three-dimensional delta smelt IBM work, the initial phase will be application of mechanistic behavior models in December 2010 to predict tidally-varying delta smelt distribution in the lower Sacramento River. We will statistically compare predictions from the IBM with the observations of Bennett and Burau (2014). Predictions will be classified into the frequency of particles in shoal and channel areas during ebb and flood tides. These predictions will then be compared to the frequency of Delta Smelt present in beach seine and Kodiak trawl samples in the Bennett and Burau (2014) data, respectively. An observation model will be constructed to translate predictions from the particle tracking model into presence-absence type observations (as in Bennett and Burau, 2014). There are two fundamental uncertainties associated with this effort. First, a subsampling routine will be necessary to translate predicted particle densities by area (shoal vs. channel) and time period (ebb vs. flood) into presence-absence observations. Second, it is uncertain whether a model that predicts shoal vs. channel distributions will make accurate predictions at larger longitudinal scales needed for the main particle tracking model and entrainment assessment. For example the lateral distribution of turbidity and delta smelt in the study region of Bennett and Burau (2014) may be substantially influenced by junctions including Threemile Slough and other local bathymetric features that are not representative of other locations in the Delta. Ideally, we would like to identify behavioral models that represent distributions at both spatial scales. This effort will help determine whether models predicting finer scale distribution patterns can also produce larger scale distributions which are consistent with the spring Kodiak trawl and entrainment datasets.

After a set of candidate behavior models are identified using data from the Bennett and Burau (2014) study period and location, the distribution and salvage of delta smelt will be simulated for one of the high entrainment periods for those behaviors using the observations and fitting approach used with the depth-averaged tools.

The fitting approach will identify which behavior models are most consistent with observations for each year of historic conditions simulated by the depth-averaged and three-dimensional modeling tools and quantify uncertainties in distribution and entrainment predictions. Ranking candidate behavior models for each year of simulation will lead to an improvement in our understanding of behavior and effects on entrainment. Once the best performing behavior(s) has been identified and its uncertainty in prediction of historic entrainment has been quantified, the parameters and results of this behavior model can be analyzed to directly answer the Key Questions identified by the CAMT Delta Smelt Scoping Team. A model-averaging approach can be used to provide a final estimate of entrainment and proportional losses.

Addressing Key Questions

For Key Question 1 "What are the environmental conditions that "trigger" spawning migration of delta smelt?" the selected behavior model(s) itself will provide insight. This behavior model will necessarily have one or more parameter that initiates the spawning migration. For example this could be a combination of calendar date and a turbidity threshold. If the same behavior model is ranked the highest in each of the four years simulated this would suggest some confidence in that model, at least relative to other candidate behavior models. A possible outcome is that two models are consistently ranked high and differ only in the turbidity threshold parameter, suggesting that turbidity does trigger the spawning migration but that the exact turbidity threshold required is uncertain.

Key Question 2 is "How does the distribution of adult delta smelt vary at time scales not resolved by surveys? In particular how does the distribution evolve daily and weekly during the spawning migration?" This can be explored by direct examination of the predictions of distribution from the best performing behavior model(s). To be consistent with the spatial scale at which the delta smelt IBM has been compared with observations, regional abundances in the approximately 10 different regions of our analysis can be estimated and documented on various dates, most likely at a weekly interval, to provide insight to short time scale changes in distribution. A portion of the uncertainty in predicted distribution can be represented by Monte Carlo sampling from the posteriors of relevant parameters (n_i, m) determined in the fitting approach.

Key Question 3 is "Which environmental conditions lead to adults entering the south Delta?" The similar Key Question 4 is "Which environmental conditions lead to adult delta smelt exiting the central and south Delta to regions with lower entrainment risk?" Again the selected behavior model itself will provide some insight. For example the selected behavior selected may use turbidity gradients to guide direction of "tidal surfing" and require a minimum turbidity threshold to enter a region. This would suggest that the environmental conditions to enter the south Delta are turbidity above the chosen threshold and a gradient of turbidity increasing from the west Delta into the south Delta. Similarly the conditions leading to exit from the south Delta in this case would be turbidity in the south Delta decreasing below the minimum turbidity threshold or turbidity increasing from the south Delta to the central Delta. Of course another major factor for entry and exit from the south Delta is transport by net flows which can be inferred by analysis of net flows from the hydrodynamic model along with delta smelt distribution predictions from the IBM. For example exit from the south Delta may be found to occur primarily when Old River and Middle River flow is toward the central Delta.

The IBM can be used to estimate entrainment for alternative hydrodynamic scenarios. The effect of implementing the RPA on entrainment (Key Question 5) will be evaluated by introducing RPA-compliant operations in a high entrainment year prior to the RPA. We will assume that only export flows (not Delta tributary flows) change and simulate the reduction in entrainment afforded by the this hypothetical reoperation of water projects. A portion of the uncertainty in predicted entrainment can be quantified by Monte Carlo sampling from the posteriors of the parameters (θ_2, θ_2, n_i, m) determined in the fitting approach. If multiple behavior models perform similarly well, the evaluation of reduction in entrainment resulting from RPA-compliant operations can be estimated using an ensemble of IBM simulations, each with Monte Carlo sampling of the parameters determined in their respective fitting.

More specific insights to the conditions leading to entrainment may be gained from analysis of model results that cannot be anticipated at this time. These insights may include correlative relationships between modeled conditions and entrainment at exports. However the four years of conditions that will be simulated might not span enough hydrodynamic and environmental conditions to develop reliable correlations.

The IBM will also be used to provide salvage efficiency parameters for the proposed work on estimating proportional losses. This will follow the fitting procedure already discussed but will probably employ a shorter simulation period starting near a SKT survey, in order to start with a known distribution, and proceeding through a short period of substantial salvage in order to maximize the salvage “signal” in the fitting period.

Several criteria should be selected in choosing the four specific years to simulate delta smelt distribution. Spring Kodiak Trawl observations are required for the proposed fitting approach, which limits the candidate years to 2002 or later. For the estimate of salvage efficiency parameters, significant salvage is desired. However, for the exploration of behavior models, it is also desired that the simulation conditions span a range of hydrodynamic and environmental conditions, including conditions leading to low salvage. At this point we propose to simulate 2002, 2004 and 2005, which are all years of substantial salvage desired for the estimation of salvage efficiency. We leave the final year to be decided based on guidance from the CAMT DSST.

Investigative Challenge

The hydrodynamic modeling and particle tracking tools and datasets that will be used in the CAMT investigations are already well-established. The sediment transport (turbidity) models have also been developed and applied though in fewer studies. The adult delta smelt swimming behaviors and the spatial resolution required to appropriately resolve the effects of these behaviors are still quite uncertain, as reflected by the various approaches recently applied (Rose et al. 2013, RMA 2009) and recommended (Anderson et al. 2013), but there is an increasing amount of empirical information available to guide our choices (Feyrer et al. 2013; Bennett and Burau 2014). However, all behaviors suggested to date can be explored in the three-dimensional modeling framework proposed using the highest spatial resolution currently feasible with these tools, allowing for an explicit evaluation of model sensitivity to alternative assumptions about smelt behavior.

The survey and salvage datasets themselves may not be adequate to distinguish between fine details of adult behavior models. Several specific limitations can be identified in advance. The monthly interval of SKT surveys does not resolve the changing distribution during the spawning migration which occurs over roughly 1 to 4 weeks (Sommer et al. 2011). High uncertainty may remain in comparison with observed salvage due to uncertain salvage efficiency (Kimmerer 2011; Castillo et al. 2012). A limited sample size of trawls to represent delta smelt density within modelled regions for a given survey, and a high frequency of 0 catches, may make the SKT data relatively uninformative. This in turn may lead to difficulties in getting the statistical model to converge and provide reliable parameter estimates and consistent measures of fit to the data. These challenges can be resolved by reducing the spatial resolution of the model (e.g., using 5 rather than 10 regions) or by constraining the parameter estimates by using minimally informative prior distributions.

The initial distribution determined by fitting may not be well constrained by the survey data. In this case an alternative approach starting with an assumed initial distribution based on FMWT survey observations may be explored. The initial abundance and the natural mortality estimated by fitting may be confounded variables. In that case we may fit natural mortality as described in Proposal III.

Similarly the Bennett and Burau (2014) dataset may not be adequate to distinguish fine details of behavior, including the exact cue that triggers a lateral migration behavior. Specifically the scarcity of information on the spatial distribution of turbidity during the Bennett and Burau (2014) study may be limiting. While the 3D modeling tools will predict lateral turbidity gradients there are not adequate observations to validate those predictions. Furthermore, the “first flush” that occurred during the Bennett and Burau (2014) study did not generate high sediment load or turbidity. Therefore, successfully reproducing spatial distribution trends observed during the Bennett and Burau (2014) study would not guarantee that the same behavior would reproduce large scale spatial distribution of delta smelt during a year with higher sediment load.

The hydrodynamic, sediment transport, and particle tracking tools require substantial computation for each scenario explored. This computation is limited by performing particle tracking offline (with saved hydrodynamic and turbidity information) so that the hydrodynamic and sediment transport simulations are only performed once for each period simulated. However, given the computational expense of particle tracking scenarios there is no guarantee that an optimal set of parameters for the behavior model can be determined. Instead we will attempt to minimize the number of parameters used and possibly present an ensemble of predicted distribution and entrainment for a multiple sets of parameters.

The three-dimensional hydrodynamic and sediment modeling tools are particularly computationally intensive. For this reason, we propose initially simulating 2 winter-spring period with the three-dimensional tools. The first period will include December 2010 to allow comparison with the Bennett and Burau (2014) observations and the second period will be one of 2002, 2004, 2005. Use of these observations will allow testing and refinement of hypothesized behaviors prior to application at the full Delta scale. Though the three-dimensional tools are clearly more realistic and defensible, the variance in catch in trawls and uncertainty in salvage efficiency may make it difficult to identify clear improvements in regional abundance and salvage predictions of the three-dimensional tools. However, even in this case, comparisons between the depth-averaged predictions and three-dimensional predictions for scenarios with the same delta smelt behavior may be informative. Furthermore the analysis using the three-dimensional tools will be far easier to publish in a peer-reviewed journal because it is a more mechanistic approach using tools that have a strong publication record.

One known major approximation will be introduced by the computational grid applied. Whether three-dimensional or depth-averaged, this computational grid will not resolve the hydrodynamic and turbidity field at the scale of delta smelt but at a scale of roughly ten to hundreds of meters in the horizontal direction and 1 meter in the vertical dimension in the case of the 3D model. In addition, some aspects of the environment that are likely to affect delta smelt behavior will not be represented at all. For one example, we do not propose to represent the distribution of aquatic vegetation although this distribution may influence delta smelt behavior and, thereby, distribution and entrainment. Similarly, spatial variation in sources of mortality will not be represented. Spatial variation in mortality could be incorporated into the IBM at a later time.

Applications of Findings to Management

The results of this study will help determine the link between smelt movements with environmental conditions and entrainment risk, particularly during critical first flush periods. Because the study offers a mechanistic approach for resolving behaviors, the model can be applied to test hypotheses about how smelt may respond to different environmental conditions or boundary conditions. Additionally, depending on how well the fitting explains movements, this model could be potentially be used as a tool for evaluating entrainment risk for real-time management. This proposal provides an improved approach (relative to previous approaches) for estimating salvage efficiencies for proportional loss estimates (Proposal III). Ultimately, more accurate estimates of proportional loss estimates can help management determine appropriate levels of allowable entrainment for improved conservation of the species (see Proposal III and IV).

Technology Transfer

Several tools and products of the analysis can also be made available including

- Complete description of adult delta smelt behavior model and all parameter values
- Movement matrices determined from IBM results for the selected behavior model(s)
- AD Model Builder code and results

The 3-D particle tracking applications will make use of the existing UnTRIM Bay-Delta model and the existing FISH-PTM particle tracking model, neither of which will be included as products of this work. The behavioral model, which sets swimming speeds based on environmental conditions, that will developed for the CAMT project will be made publicly available for review and provided as one of the products of this work. The FISH-PTM model itself will not be provided as a product of this work though it could possibly be made publically available at some point in the future. The hydrodynamic and suspended sediment results from UnTRIM will be available to DMA and RMA for further use in further CAMT or related projects funded by SFCWA or other state and federal agencies but will not be made publicly available.

Schedule and Deliverables

Both 2D and 3D modeling tasks are expected to begin concurrently. Therefore the schedule given below necessarily has overlapping periods. One critical output of this proposal is salvage efficiency parameters which will be used in proposal III. These will be provided in month 8 of the proposal II work.

3D modeling tasks during months 1-6

- Incorporation of SSC and Turbidity into UnTRIM FISH_PTM output
- Hydrodynamic, SSC and turbidity modeling for fall-winter of water year 2011
- Develop adult behavior model in 3D IBM
- Individual based modeling and comparison with Bennett and Burau (2014) observations

2D modeling tasks during months 1-10

- Simulate 4 years of hydrodynamics and turbidity using simplified turbidity approach

- Evaluate the 2D sediment transport model for estimation of turbidity
- Develop fitting approach for evaluation/ranking of behaviors
- Run IBM for a set of behavior scenarios and apply fitting approach to evaluate each scenario
- Estimate salvage efficiency parameters
- Simulate RPA scenarios
- Document 2D modeling results

3D modeling tasks during months 4-12

- Hydrodynamic , SSC and turbidity modeling for year in early-mid 2000's
- Run IBM and apply fitting approach
- Prepare manuscript or peer-review quality report

The findings will also be presented in at least two presentations at local conferences, most likely the Interagency Ecological Program Workshop or Delta Science Conference.

Budget

The total budget requested for this study is $654,836.

Qualifications

See attached resumes of investigators.

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Investigative Approach Appendix

Three-Dimensional Modeling Tools

The UnTRIM Bay-Delta model (MacWilliams et al. 2007, 2008, 2009, in review) has been applied together with the SWAN (SWAN Team 2009a) wave model and the SediMorph sediment transport and seabed morphology model (BAW 2005), as a fully-coupled hydrodynamic-wave-sediment transport model of the San Francisco Estuary. This coupled modeling system has been used previously to predict sediment transport throughout the Bay-Delta system, as part of two projects for the U.S. Army Corps of Engineers (USACE) to investigate how sea level rise and a reduced sediment supply to the Delta impacted the sediment routing through the Bay-Delta system and the sediment deposition within Suisun and San Pablo Bays (MacWilliams et al. 2012; Bever and MacWilliams 2014). The coupled models were also used to investigate the effects of breaching Prospect Island on regional turbidity and sediment dynamics in the north Delta and Cache Slough region (Delta Modeling Associates, 2014). Other applications of the sediment transport model include simulations of dredged material dispersal in Northern San Francisco Bay (MacWilliams et al. 2012) and South San Francisco Bay (Bever and MacWilliams 2014; Bever et al. 2014) to determine the fate of dredged material and investigate if open water placements can potentially be used to augment mudflat and marsh sedimentation. Bever and MacWilliams (2013) have also applied the coupled modeling system to investigate wave shoaling and sediment fluxes between the channel and shoals in San Pablo Bay.

Sediment transport simulations using the UnTRIM San Francisco Bay-Delta Model include multiple sediment classes, an initial sediment bed based on over 1300 observed seabed grain size distributions within the Bay and Delta and sediment input from ten Bay-Delta tributaries. By simulating suspended sediment processes directly, both tidal variability in sediment re-suspension, and re-suspension generated by strong wind wave events are both explicitly evaluated. The hydrodynamic model results will be saved for use in the PTM as velocity, salinity, and total suspended sediment concentration (SSC). The total suspended sediment concentration will also be used to develop spatially and a temporally variable turbidity field in three-dimensions, using a spatial transformation from SSC to turbidity based on relationships derived from USGS measurements of turbidity and observed suspended sediment concentrations at the fixed monitoring stations, as was done in the analysis of turbidity effects for the Prospect Island Tidal Restoration study (Delta Modeling Associates, 2014).

Observation Models

We expect to use a zero-inflated Poisson model, zero-inflated Poisson model with extra variation or zero-inflated lognormal model to describe the variation in density across tow locations within each region. Given the sparseness in the data, individual means and variances for each region may be challenging to estimate. We may need to use a hierarchical model where we assume that the means and variances of catch densities for each region are random variables drawn from common hyper-distributions. Estimates of the mean and variance in fish density for each region will be used to estimate the expected density, which will be converted to an “abundance” for the region based on the ratio of the average tow volume to the estimated habitat volume for the region. A key assumption of our model is that the ratio of the volume sampled to the habitat volume of the region correctly represents the fraction of the regional abundance that is sampled. We are therefore assuming that delta smelt are uniformly distributed through the volume of water in the region over a fixed depth, and that they are not avoiding or being attracted to the trawl. Kimmerer (2008) assumed that delta smelt occupy the top 4 meters of the water column. This assumption or a similar assumption will be applied in our regional abundance estimates.

The salvage observation model that will assume that the number of fish salvaged over a specific time interval (day) is a random variable drawn from a binomial distribution that depends on the total number entrained (as predicted by the PTM) and the proportion of those entrained fish that are captured in the fish collection facility. That is,

$$n_s \sim dbin(1/\theta, n_e)$$

Where n_e is the number entrained as predicted by the IBM, n_s is the observed number salvaged, and $1/\theta$ is the proportion of the entrainment which is collected at the pumps through salvage. If there is evidence of overdispersion in the fit of the salvage model, we will use an overdispersed distribution. We will use two alternate models to describe θ:

$$\text{Logit}(\theta)=b_0$$

$$\text{Logit}(\theta)=b_0+b_1*T$$

Where b_0 represents a constant salvage-entrainment proportion while the latter assumes the ratio depends on the residence time (T) in Clifton Court Forebay due to mortality (m_{CCF}), as described previously. A logit transformation will be used so that θ estimates are restricted to >0 and <1.

Proposal III. Estimating Adult Delta Smelt Proportional Losses to State Water Project and Central Valley Project Entrainment.

Topic area

The proposed investigation falls under the topic area Population Consequences (Workplan Element 3.2.2).

Project Purpose

The purpose for the proposed project is to estimate proportional losses from entrainment of adult delta smelt at the SWP and CVP export facilities in the south Delta. Proportional losses refer to the percentage decrease in the delta smelt population over a specified period of time caused by entrainment loss. Natural mortality that occurs to delta smelt also will be estimated. The project is part of a larger effort aimed at assessing population-level effects of delta smelt entrainment at the south Delta export facilities.

The proposed approach will be a significant improvement to the approach used by Kimmerer (2008, 2011) and will extend the time period for estimates of proportional losses to include water years 1981-2014.[5] It should eliminate the possible causes of bias toward overestimating entrainment raised by Miller (2011) in his critique of the work by Kimmerer (2008). Wherever possible (and as time permits), we will examine the sensitivity to specific assumptions made in the estimates of proportional loss and attempt to quantify uncertainties. As stated above, we expect this work will increase scientific consensus on entrainment and proportional losses and that our estimates for proportional loss will be useful as covariates in any analyses of population-level effects of entrainment.

Investigators

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[5] Kimmerer (2008) estimated proportional losses for water years 1995 to 2006. Our selection of the period 1981 to 2014 was chosen to extend the length of the time series for estimating adult proportional losses to include the two prominent declines in delta smelt abundance that occurred during the early 1980s and during the years of the Pelagic Organism Decline (2000-2005). This longer time period also encompasses a wider variety of water year types including the drought of 1987-1992 when winter exports were high but adult delta smelt entrainment was mostly low. There is an adequate sample size of at least 8 to 10 years during the period 1981-2014 when high numbers of adult delta smelt were observed in the winter salvage. The hope is that the 34-year time series will be long enough so that life-cycle modeling (Proposal IV) or regression analyses can be effective at differentiating whether a population-level effect from entrainment has occurred or has not. We decided not to extend the time series back in time through the 1970s because data during that period is even sparser than the 1980s and less is known about how the hydrodynamics of the Delta and other factors might have affected delta smelt abundance and entrainment

Background

The purpose of this investigation is to redo the proportional entrainment loss calculations for adult delta smelt by Kimmerer (2008, 2011) using a significant upgrade to the approach employed in his work and to extend the calculations to include water years 1981 to 2014. Our approach involves initially estimating entrainment in the four years (2002-2005)[6] when data for monthly delta smelt catch distributions are available from the Spring Kodiak Trawl Survey (SKTS)[7] and when estimates of fall delta smelt abundance and observed adult delta smelt salvage (a measure of entrainment at the south Delta fish facilities) were both relatively high. The estimates will be made from simulations using an "Individual-Based Model (IBM)" that includes a hydrodynamic, turbidity, and particle-tracking model with adult delta smelt swimming behaviors assigned to particles. This is in contrast to the approach employed by Kimmerer, which was to estimate entrainment as the catch per unit volume of delta smelt measured once monthly in the south Delta multiplied by the combined flow in Old and Middle Rivers. Our companion modeling proposal (Proposal II) provides details on the IBM approach and how it will be used to estimate entrainment and the two "efficiency" parameters, θ_{SWP} and θ_{CVP}, that are needed to expand daily salvage of delta smelt measured at the south Delta fish facilities (the SWP's Skinner Fish Facility and the CVP's Tracy Fish Collection Facility) to an estimate of daily entrainment. The Appendix to this proposal clarifies the difference in our proposed approach and the approach used by Kimmerer (2008) and summarizes the advantages of the new approach. Once the θ values are estimated using the IBM applied to the four water years selected, they will then be used to expand the adult daily salvage data to daily entrainment for all water years by assuming that the estimated values are representative over the longer time period. The adult entrainment estimates will be accumulated daily over the entrainment season each year to give the entrainment loss value that will be the numerator in the proportional loss fraction.

Our proposal to upgrade the analyses for determining θ values using the IBM approach will address bias issues raised by Miller (2011) in a published critique of the work by Kimmerer (2008). Miller (2011) considered four assumptions underlying Kimmerer's estimates of adult proportional entrainment and concluded that there was a bias in each of those assumptions that resulted in overestimating the magnitude of entrainment. According to Miller (2011), three of the four assumptions resulted in overestimation because of how the efficiency parameter (θ) for the salvage facilities was determined.[8] In response to Miller (2011), Kimmerer (2011) mostly argued his assumptions did not introduce upward bias in his calculation of θ, although he did revise downward his estimate of θ from 29 to 22.[9] Miller

[6] The selection of these four years is preliminary. The CAMT Delta Smelt Scoping Team has discussed eliminating one of these "high entrainment" years and replacing it with a more recent "low entrainment" year so as to provide a better test for the model under a range of conditions and when better turbidity monitoring data are available. If that happens, 2003 would be the water year most likely to be eliminated because the January Spring Kodiak Trawl Survey is missing from that year. The decision to limit our proposal to modeling four years is arbitrary and only reflects the need to meet CAMT timelines and budgets.

[7] Data from the SKTS are available starting from 2002.

[8] Kimmerer (2008) used only one efficiency parameter, θ, to apply to the combined SWP and CVP fish facilities.

[9] The downward revision of Kimmerer's (2008) estimate of θ resulted from a point raised by Miller (2011) that there were too many zeros in the delta smelt catch data to assume they were a Poisson-distributed random variable. Kimmerer (2011) re-fit his equation for θ with a zero-inflated Poisson model using a Bayesian approach and arrived at a revised estimate of $\theta = 22$ with 95% confidence limits of 13 and 33. The revised estimate for θ was 76% of the previous estimate.

(2011) argued the value for θ should be closer to 18 or even less. The years 2002-2005 were the water years analyzed by Kimmerer.

In order to estimate proportional loss, the population size of delta smelt that existed each year prior to entrainment must be estimated along with entrainment. Miller (2011) raised concern that Kimmerer (2008) may have underestimated the monthly adult delta smelt populations calculated from the SKTS data during years 2002-2005 because his populations were not adjusted to account for potentially high numbers of delta smelt in the unsampled Sacramento Deep Water Ship Channel (and potentially Liberty Island).[10] We will investigate this potential bias using the IBM and also by analyzing available data for flows in Cache Slough, sediment loads entering the Delta from the Sacramento River during first flush, and delta smelt sampling from the SKTS in the Sacramento DWSC and Cache Slough Complex. We will also test various assumptions regarding fish density in the DWSC and determine how that affects population estimates. A key question is whether it is likely that the percentage of the adult delta smelt population in the Sacramento DWSC would have been high leading up to and during the large first-flush and entrainment events that occurred in the years of 2002-2005. During those years, the magnitudes of the first-flush events (in terms of the size of the sediment loads entering the Delta) and the elevated turbidity levels they caused throughout the Delta were higher than any years we have had since then, so the question may be difficult to answer from the data alone. We do not know, for example, if it is only when turbidity is low elsewhere in the Delta that delta smelt become more concentrated in the DWSC.

As we point out in more detail below in our discussion of investigative approach, there is a significant overall discrepancy between Kimmerer (2008) and Miller (2005b, 2011) regarding their monthly population estimates determined from expanding the catch per unit effort (CPUE) data for delta smelt from the SKTS for the years 2002 to 2005. These are the years for which they both made population estimates that can directly be compared. Miller (2005b) used a spatially stratified approach in which the mean CPUE per trawl for 14 sub-regions of delta smelt habitat were expanded by the volume of each sub-region over the surface 4 meters (Miller actually used 12 feet) and summed to get an index of total abundance (population) for each monthly survey. Alternatively, Kimmerer (2008) did not use sub-regions for his expansions, but instead calculated the mean catch per unit volume in all survey samples for each month and multiplied by the volume over the upper 4 meters of the entire area of delta smelt habitat sampled. Miller's estimates for sub-region volumes were calculated by hand from NOAA nautical charts and documented in Miller (2005a). The calculations by Miller (2005b) for populations were checked by Manly (2006). Kimmerer (2008) used a value of 0.9×10^9 cubic meters for his expansion volume, but did not specify how it was determined or the exact boundaries of delta smelt habitat it included. The cause of the discrepancy between population estimates from the two investigators is unclear, but because it is so large, new abundance (population) estimates for all years of the SKTS will be done as part of our proposed work. A stratified approach will be used, but with new sub-region boundaries and with water depth data used to compute expansion volumes taken from the latest (2011) 10-m bathymetric grid and DEM (Digital Elevation Model) for the Bay-Delta developed by DWR. Interactive software (called GrBathCalc) available from USGS now makes it easy to accurately compute these volumes.

[10] It was not until the second (late-February) SKTS of 2005 that station 719 in the Sacramento DWSC was added to the core list of sampling sites and incorporated into the Delta-wide survey. This was after the entrainment event that happened mostly in January of 2005.

As described in the companion Proposal II, we will account for sampling error in estimating abundances (populations) by using a zero-inflated Poisson model (or zero-inflated Poisson model with over dispersion) to describe the variation in CPUE across the multiple sample locations within each sub-region. Estimates of the mean and variance in CPUE for each sub-region will be used to estimate the expected CPUE, which will then be expanded to the abundance for the sub-region. At least initially, we will follow Kimmerer (2008) and Miller (2005b) and use the volume of the surface 4 meters of each sub-region as the weighting factor to expand mean CPUE from the surface sampling locations[11] to the estimate of abundance in each sub-region, but we are open to considering other weightings and calculating the affect they have on population estimates. The 4-meter assumption is not meant to imply that in the deepwater (> than 4-m deep) channels of the Delta and Bay that delta smelt only reside in the surface four meters of the water column or that they are distributed uniformly either vertically or laterally over the surface 4 meters. It simply proposes that the volume of the surface 4 meters is the best estimate for a weighting factor to expand the average density of fish measured near the surface and during the daytime at center-channel locations to an estimate of total abundance in each sub-region. As more data of the type recently obtained by Feyrer et al (2013) and Bennett and Burau (2014) are collected at additional locations in the Bay-Delta and under a variety of environmental conditions this assumption should be checked.

Because delta smelt populations before the start of the SKTS in 2002 are needed for proportional loss calculations in earlier years, they will be estimated also. For use in estimating these (pre-SKTS) populations, both Miller (2005c, Fig 2) and Kimmerer (2008) fit a relationship between their estimates of delta smelt populations from the SKTS and a measure of delta smelt abundance from the previous FMWT survey[12]. They then used the relationship to estimate the populations for the earlier years. Those relationships are dramatically different for reasons explained in more detail below. During some years, such as 1996, 2000, and 2001, they give differences in the estimates of population size in the range 400% to 900%. The estimates by Kimmerer (2008) are mostly much higher than those by Miller (2005c). For our work, a new relationship will be developed relating the 13 years of SKT population estimates to the FMWT abundance Index. That relationship will be used to estimate population size for years when the FMWT index is approximately 300-400 and less. Because of the great uncertainty in extrapolating for population sizes to years when the FMWT index is greater than 400, direct estimates of populations from the FMWT survey data during those years will be attempted using some variations (different sub-regions and expansion volumes) to the methods of Newman (2008) and using new data from gear-comparison field studies to estimate FMWT net efficiencies.

Overall, we believe the work proposed here will significantly improve and extend the estimates of proportional loss provided in the various papers by Kimmerer and Miller and will be useful to determine the relative magnitude of entrainment losses under different biological and physical conditions. We expect this work will increase scientific consensus on entrainment and proportional losses and lead to better strategies for managing mortality associated with water project operations. Our estimates for proportional losses should be useful as covariates in any revised analyses of population effects of delta smelt entrainment as proposed in our companion Proposal IV using the life-cycle model by Maunder and Deriso (2011), or in updated regression analyses by Miller et al (2012), or for the new life-cycle model by

[11] The Kodiak trawl fishes the top 1.8-meters of the water column and mostly in the center of the channel being sampled.

[12] The FMWT survey data are available dating back to 1967.

Newman et al (2013, in progress), which includes spatial partitioning of the Delta into four regions and a finer (monthly) temporal resolution than earlier models.

Key Questions

This proposal addresses the adult delta smelt component of *Key Question a* from Work Element 3-2-2 of the 2014 CAMT Progress Report. This question requires first estimating adult delta smelt entrainment and populations for water years 1981 to 2014, and then using those to estimate proportional loss. *Key question a* is:

What is the magnitude (e.g. % of population) of adult and larval/juvenile delta smelt entrainment across different years and environmental conditions?

The work proposed here, in combination with the work proposed for the companion Proposal II, will address additional questions defined in the CAMT progress report:

1. What is the best feasible method for estimating the number of adults entrained by the water projects?
2. What is the relationship between salvage and entrainment and how variable is the relationship, and what factors influence that variability?
3. What new tools would provide a better understanding of adult entrainment levels?

The approach proposed here is mostly a response to question 1 above.

Our investigative team has not yet decided on a satisfactory approach for investigating larval/juvenile delta smelt entrainment, but we intend to develop an approach, and prepare a proposal for an investigation, as part of the work proposed for this study. The low catches for delta smelt in the 20-mm survey, the absence of counts in the salvage sampling for delta smelt smaller than 20-mm in length, the presumed lower quality of salvage sampling for juvenile delta smelt prior to the early 1990s (before which skilled biologists were not used to identify salvaged fish and the identifying of fish to species was done much less frequently than every two hours), and the lack of data available from the 20-mm survey before 1995 are all obstacles to any simple estimation of larval and juvenile entrainment and proportional losses that includes the period of 1981-2014. While particle-tracking modeling is more straightforward[13] with larval and early juvenile delta smelt than for adults, estimating entrainment may require particle-tracking modeling for every year to improve on the approach of Kimmerer (2008). The investigator team does believe it is necessary to consider larval/juvenile proportional losses of delta smelt if the overall population-level effect of entrainment is to be assessed.

Hypotheses

This proposal is needed to contribute toward testing the following two hypotheses from the CAMT workplan:

(H1): Delta Smelt are entrained at Project facilities at levels that are likely to affect the long-term abundance of the delta smelt population.

[13] During the larval stage, it is thought that large-scale movements of delta smelt in interior Delta channels can mostly be approximated by simulations with neutrally buoyant particle-tracking models.

(H2): There are circumstances under which the losses of delta smelt to entrainment are sufficient to cause a demonstrable impact on population viability.

Investigative Approach

Outlines of the approach that will be used in our investigation were given above in the section on Background, so here we only add a few details.

Our approach is to calculate proportional loss for the period 1981 to 2014 by estimating adult delta smelt entrainment from the salvage data for each water year and then dividing that entrainment by an estimate of the population before entrainment loss occurred (typically late-December or early January). The approach requires four main steps:

1. Estimating entrainment losses for 1981-2014
2. Estimating populations for the period 2002-2014 using data from the SKTS
3. Estimating populations for the period 1981-2001 when no SKTS data are available
4. Estimating adult proportional losses for 1981-2014

We provide details on each of these steps below.

1. Estimating entrainment losses

Estimates of adult delta smelt entrainment losses will be straightforward to calculate once the values for the two salvage "efficiency" parameters, θ_{SWP} and θ_{CVP}, are estimated by the IBM as described in the companion Proposal II. These parameter values will be used to expand the adult daily salvage data to daily entrainment for all water years by assuming that they are representative for the entire time period from 1981 to 2014. The daily values for entrainment will be accumulated over the entrainment season each year to give the entrainment loss value that will be the numerator in the proportional loss fraction.

Our investigative team is well aware that the values for the two efficiency parameters are not constant from year to year even if we account for the effect of residence time (as outlined in Proposal 2) in the Clifton Court Forebay (CCFB) on the value of θ_{SWP}. We are hopeful that the IBM will reveal something about the magnitude of the variability in these values even though only four years will be simulated. Mark-recapture experiments conducted since the 1970's in CCFB using experimental fish (Gingras 1997, Clark et. al. 2009, Castillo et. al. 2012) suggest there is significant variability in predation losses of fishes across the Forebay, although in all the experiments the losses are still considered high.[14] Variability in these losses would cause variability in the efficiency parameter (θ_{SWP}) for the SWP. If our study with the IBM proves useful in estimating the efficiency parameters, the model could be applied to additional years to better assess the variability of the parameters.

2. Estimating populations from the SKTS data (2002-2014)

Populations for the period 2002-2014 will be estimated monthly during Jan-May by expanding the CPUE of delta smelt measured by the SKTS. Our approach will mostly follow the same procedure as Miller

[14] Castillo et al (2012) discusses potential sources for bias in the results from CCFB mark-recapture experiments. Because of potential bias, some caution is advised in the interpretation of the precise numerical results from these experiments.

(2005b) in expanding the CPUE data for delta smelt from the survey using a spatially stratified approach in which the mean CPUE per trawl for 10 to 20 sub-regions of delta smelt habitat will be expanded by the volume of each sub-region over the surface 4 meters and summed to get an index of total abundance (population) for each monthly survey. We will use sub-regions as defined for the Delta Smelt Life Cycle Model project (Newman et al 2013), rather than those used by Miller (2005a), and use volumes for each sub-region as calculated accurately by computer software using water depth data from the Bay-Delta bathymetric data base. We will first calculate the population estimates directly from the raw CPUE data, and then process it statistically to account for sampling error and to quantify the uncertainty from that error. A zero-inflated Poisson model will be used to describe the variation in CPUE across the multiple sample locations within each sub-region. Estimates of the mean and variance in CPUE for each region will be used to estimate the expected CPUE, which will then be expanded to the abundance for the sub-region. To distinguish cases of "certain zeros" in the sampling data from cases when zero delta smelt are caught but are likely present in the sampled water, we will consider models based on water transparency, specific conductance, and flow[15].

After individual monthly populations are estimated for the first five months of each water year, a daily population model that accounts for daily exponential mortality and daily entrainment loss will be fit to the five monthly data points. Two parameters in the model will be estimated during the fitting process: an "initial population" in mid-December of each water year before any salvage is observed, and a coefficient of exponential mortality[16]. Daily entrainment estimates needed in the population model will be determined by expanding the daily salvage. The fitted model will be used to estimate the population each year of the SKTS for the period immediately before entrainment loss occurred. The model will be fitted in a "least-squares" sense so there is no conceptual difficulty if occasionally the estimate for population size is found to increase from one month to the next. The model itself will, of course, require that populations trend downward each succeeding month, reflecting a continuous natural mortality of delta smelt and mortality from entrainment. In the monthly SKT populations estimated by Miller (2005b), he found that only once (during Feb 2002) did a calculated population increase over the prior month's value.

3. Estimating populations for the period 1981-2001

Populations for the water years 1981-2001 must be estimated differently from those of water years 2002 -2014 because no data from the SKTS are available. For each of these years, we will first estimate the mid-December population using a regression curve relating the estimates we derive for mid-December populations from the SKTS data to the previous FMWT index. A population model will then be used with an assigned natural mortality rate to estimate the population for the approximate date each year that salvage begins.

[15] By use of the term "flow" here, we mostly mean very high flows. We will assume that delta smelt are not present during very high flow conditions in locations within the Delta where no flood tides are occurring and where down-estuary water currents over the entire tidal cycle are greater than delta smelt can swim upstream against. Thus, in these locations, any zeros in sampling will be considered "certain zeros." There have been a few occasions, such as late-Feb of 2004, when significant entrainment events have occurred during these types of very high flow conditions, so they are not irrelevant to our analyses. The assumption is that the landward extent of delta smelt distributions are constrained by very high flows.

[16] The estimates for coefficients of exponential mortality discussed here will be redundant with estimates made from the four years of individual-based modeling described in Proposal II. This will be useful. The values derived from the two methods will be compared for consistency.

We are unsure if the regression curve will provide a reliable estimate for the initial (mid-December) adult delta smelt population during years when the value of the FMWT Index is greater than approximately 300-400. This is because those estimates will require extrapolation beyond the range of data from which the regression equation will have been derived. We are especially worried about populations estimates for the years 2001, 2000, and 1981, which have high previous FMWT indexes and are considered years of potentially high proportional entrainment losses (for both adults and juveniles). For these three water years (and possibly others), we expect to use direct estimates of populations from the FMWT survey data calculated using new sub-regions and different expansion volumes than those used by Newman (2008) in his previously published delta smelt populations from the FMWT survey data. We also intend to use data from recent gear-comparison field studies to estimate FMWT net efficiency, which is vital to making accurate population estimates using that survey data because the efficiency is known to be especially low (unlike the SKTS). We will not directly use the population estimates in Newman (2008) because they are considered too low.

4. Estimating adult proportional losses for the period 1981-2001

The final step in estimating the time series of adult proportional losses for the period 1981 to 2014 will simply involve dividing the accumulated entrainment losses calculated in step 1 for each water year by the appropriate population estimated in either step 2 or 3.

Additional Comments on Related Work

For this investigation, one reason we consider it necessary to re-do the estimates of delta smelt populations from the SKTS done previously by Kimmerer (2008) and Miller (2005b, 2011) is to try and resolve the differences in their estimates. Figure 1 is a graph of the estimates made by the two authors using the SKTS data for years 2002-2005. On average, the estimates differ by almost a factor of two with the estimates by Kimmerer being equal or higher in all months.

Kimmerer (2008) and Miller (2005c) also each estimated populations before 2002 from a regression curve relating SKT population size to a measure of FMWT abundance. Miller (2005b) used the full FMWT index and the February SKT population estimate (not index) as his measures of abundance and Kimmerer (2008) used mean CPUE for only the last two months (November and December) of the FMWT survey as his measure of abundance to relate to a January SKT population estimate. Although this seems to be a relatively innocuous difference in the assumption each investigator made, it turned out to have a major effect on their population estimates for the period 1995-2001 as shown in Fig 2. During some years (1996, 1998, 2000, and 2001), the differences in the estimates of population size between each investigator are in the range 400% to 900%. The regression equation derived by Miller (2005c) is plotted in Fig 3a and that derived by Kimmerer (2008) is plotted in Fig 3b. Unfortunately, one data point, water year 2002, influenced immensely the differences in their regression equations. During that particular water year, delta smelt catches in the FMWT survey (for fall of calendar year 2001) were very high in September and October but low in November and December, and then relatively high again in January and February of the SKT survey. This caused the plotting position of that data point to shift dramatically between Fig 3a and 3b. Fig 3c shows an estimate for the regression equation that might have been derived by Kimmerer if he had used the full FMWT index as the covariate in his regression. Because of the high month-to-month variability observed in the individual (monthly) values composing the FMWT index, our investigative team believes it is generally best not to parse the index into sub-parts involving only one or two months. We will avoid that in our work. By using the additional data from the

SKTS through 2014 (13 years of data total), we are confident our proposed work will provide a different and better-defined regression curve than those derived by Kimmerer and Miller based on only 4 or 5 points.

Investigative Challenges

There are challenges to some of the analyses we are proposing:

- We will need to be careful that any inaccuracies in modeling adult delta smelt behavior using the IBM does not introduce bias in the estimation of the efficiency parameters (θ_{SWP} and θ_{CVP}) needed for this proposal. If particle behavior in the IBM is too close to neutrally buoyant, it might over-estimate entrainment. If the IBM does not move particles into the south Delta correctly against a turbidity gradient, it might underestimate entrainment. Fortunately, we are fairly confident we can avoid these problems.
- If there are large and unknown variations in the parameter values of θ_{SWP} and θ_{CVP} between years, it will be a source of unknown error in our entrainment estimates. We believe it is likely there are significant yearly and seasonal variations in these parameters, but we have no estimate of their magnitude. Variations that would be important to our analyses will be those occurring between the years of high proportional entrainment losses. Unfortunately, there is little we can do about this source of error except to include more years of modeling to directly estimate the parameters.
- The SKT survey does not sample San Pablo Bay (only the lower Napa River and eastern Carquinez Strait) so we do not plan to include that large volume of water in the expansion of fish densities into population estimates. Unless Delta outflows in winter are very high, we believe adult delta smelt do not generally reside in San Pablo Bay because they prefer water of lower salinity. We are fortunate that periods of very high Delta outflows generally do not correspond with periods of high delta smelt entrainment (with the one possible exception being late-Feb/early Mar of 2004, which may be a period we will need to review our assumptions for).
- There was no sampling in the Sacramento DWSC during 2002-2004 (and during the first flush event in Jan 2005) so we will need to test various assumptions regarding fish density in the channel to see how much difference it makes in our population estimates and proportional loss calculations.
- Fitting a population model, as planned, to only 5 monthly data points (populations) each year of the SKT survey will be crude, but is still expected to prove helpful so that we are not relying on any one month of data.
- Estimating adult delta smelt populations and proportional losses for key high-entrainment years (such as 2001, 2000, and 1981) when no SKTS data are available but when the previous FMWT index is high, may prove challenging as described earlier in the proposal. We are cautiously optimistic we can make reasonable estimates of proportional losses for these years, but our estimates will almost certainly have greater uncertainty than other years.
- Estimating populations directly from the FMWT data (as we anticipate we will do) will be challenging because the efficiency of the FMWT gear for catching delta smelt is so low and not accurately known.

Applications of Findings to Management

We believe the work proposed here will be useful to determine the relative magnitude of entrainment losses under the very wide range of historical biological and physical conditions. It should improve scientific consensus on entrainment and proportional losses and lead to improvements in managing mortality associated with water project operations. Our estimates for proportional losses should be useful as covariates in any new revised analyses of population effects of delta smelt entrainment such as those done previously by Maunder and Deriso (2011) and Miller et al (2012), or for new analyses such as by Newman et al (2013), in progress.

Technology Transfer

Everything possible will be made available:

- GIS layers and scripts for subregions and population calculations
- GrBathCalc (Java) software for computing volumes with Bay-Delta bathymetry input file.
- Volumes, populations, and proportional loss estimates will be released in short memorandum reports.
- The exact survey data will be provided in the form used in GIS analysis
- R and WinBugs codes will be provided
- One or more presentations will be given
- A paper on proportional loss estimates will be planned for a peer reviewed journal, but only in a second year of the study (and with additional funding) after all collaborative work is completed and an outline is developed and authorship roles are established.

Schedule and Deliverables

Months 1-3

- Decide on sub-regions and calculate volumes for 2-meters, 4-meters, 10-meters, and full depth.
- Download and process latest SKT survey and FMWT survey data files. Load data into GIS software.
- Update daily salvage file through 2014. .
- Make population estimates from SKT observations before statistical analysis
- Investigate expansions for FMWT survey data
- If requested, development of a juvenile delta smelt proportional losses investigation proposal will begin

Months 4-17

- Fit exponential mortality equation to monthly SKT populations estimates. Develop software with estimates for θ_{SWP} and θ_{CVP} while waiting for IBM results to become available.
- Make population estimates from SKT observations after statistical analysis (Korman, LaTour)
- Attempt abundance estimates from Fall Midwater Trawl surveys
- Estimate pre-SKT populations from regression of FMWT with SKT.
- Calculations for θ_{SWP} and θ_{CVP} made available
- Make entrainment and proportional loss estimates.
- Sensitivity analysis

Deliverables:

Technical Memos

Presentation at local conference

Proposal for a manuscript to be prepared in a second year of this project to a peer-reviewed journal.

Budget

The total budget for this study is $267,360. Task and timelines are provided in the attached budget spreadsheet.

Qualifications

See attached

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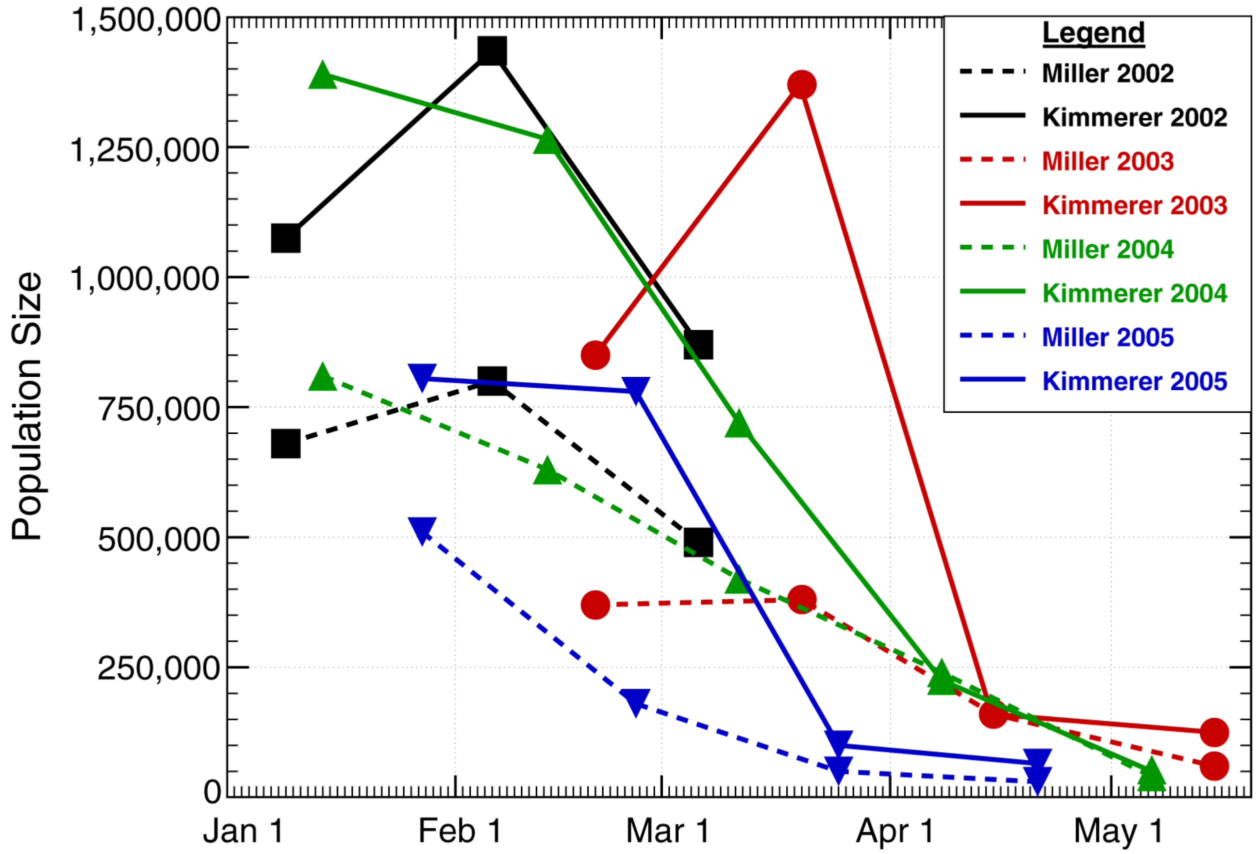

Figure 2. Monthly adult delta smelt population estimates computed from the Spring Kodiak Trawl Survey for the years 2002 to 2005 by Kimmerer (2008, Fig 11a) and Miller (2005b, Table 2). Each symbol represents the estimate for a given month. The solid lines are Kimmerer's estimates and the dashed lines are Miller's estimates. The populations shown for Miller are those calculated without using the supplemental surveys in the Sacramento Deep Water Ship Channel. Both investigators assumed the Spring Kodiak Trawl sampling is 100% efficient and expanded the catch per unit volume data using the volume of the surface 4-meters of the estuary. Miller expanded by sub-regions and Kimmerer did not.

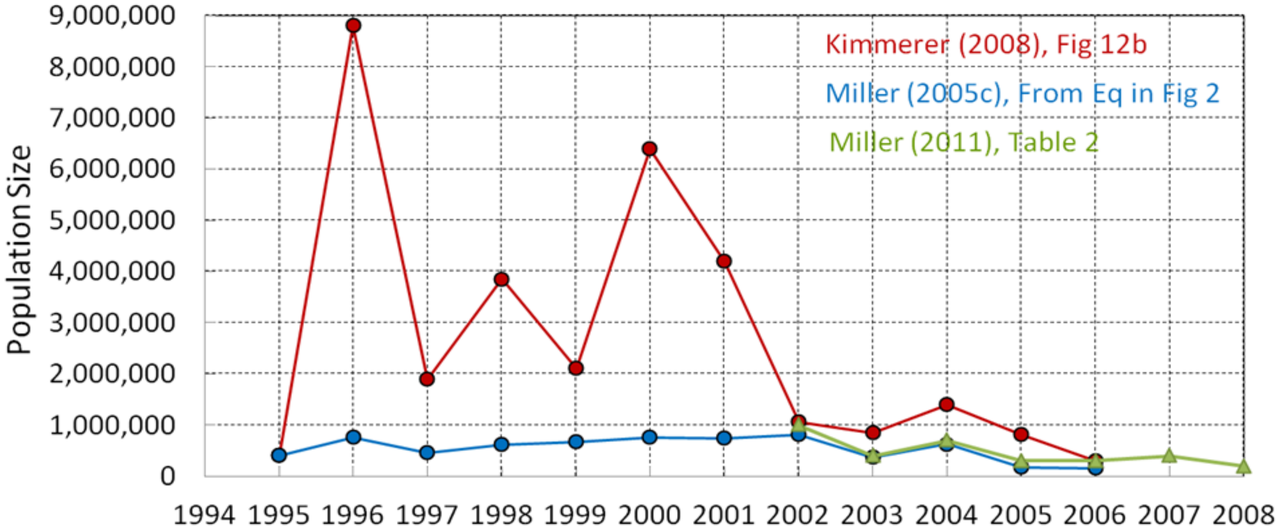

Figure 3. Adult delta smelt population estimates for January of each year by Kimmerer (2008) and for February of each year by Miller (2005b, 2005c) and Miller (2011). Estimates for the years 2002 and after were estimated directly from the Spring Kodiak trawl data. Estimates prior to 2002 were from a regression equation (see Fig 3). During some years, such as 1996, 1998, 2000, and 2001, the differences in the estimates of population size between each investigator are in the range 400% to 900%.

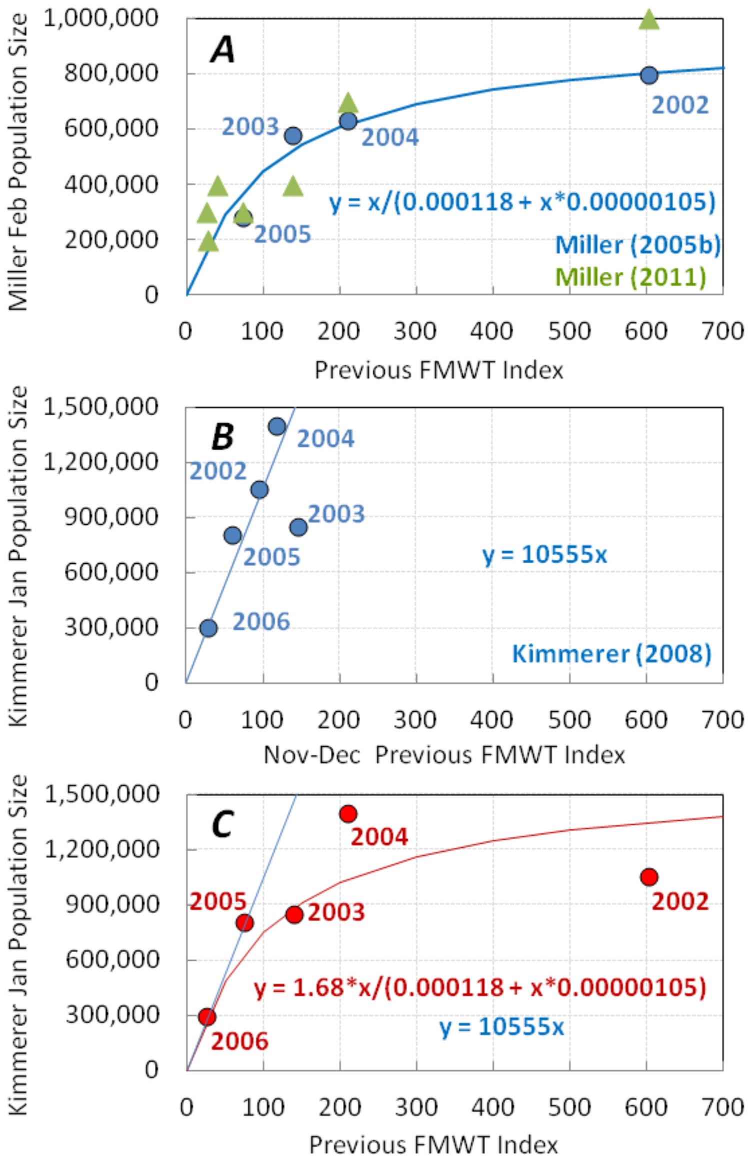

Figure 4. (***A***) Regression equation used by Miller (2005c, Fig 2) to estimate population sizes before 2002 based on the previous FMWT Index, (***B***) Regression equation (approx) used by Kimmerer (2008) to estimate population sizes before 2002 based on the previous Nov-Dec FMWT Index, (***C***) Estimated regression equation (in red) based on Kimmerer's populations if he had used the previous FMWT Index as his covariate.

Proposal III Appendix

Difference in the proposed approach from Kimmerer (2008)

Our proposed method will not use equation 16 from Kimmerer (2008) to compute θ. This equation was the source of most of the criticism by Miller (2011) that Kimmerer introduced upward bias into his estimates of θ. We are proposing an upgraded approach that addresses the criticisms by Miller (2011). Equation 16 from Kimmerer (2008) is:

$$\frac{N_{SD}Q_{SD}}{V_{SD}} = \theta\left(\widehat{N}_{d1} + \widehat{N}_{d2}\right)$$

where

N_{SD} = Total delta smelt caught in Kodiak trawl samples at four south Delta stations (902, 906, 914, and 915) during a survey

V_{SD} = Total volume filtered at the four south Delta stations (using an average volume per sample of all stations) (m^3)

Q_{SD} = Daily combined flow in Old and Middle Rivers (m^3d^{-1})

$\widehat{N}_{d1}$, $\widehat{N}_{d2}$ = Daily salvage at SWP and CVP (d^{-1})

Although the Kodiak trawl samples are only collected monthly, Kimmerer applied this equation on a daily basis for the years 2002-2005 assuming the catch density was constant over the month. The only unknown in the above equation is θ so it was estimated by fitting to the daily data assuming an appropriate error distribution for N_{SD}.

If we assume that the efficiency of the Kodiak Trawl sampling is 100 percent, the above equation is simply a statement that

$$(Daily\ Calculated\ \#\ of\ Delta\ Smelt\ Entrained)_{method\ 1}$$
$$= (Daily\ Calculated\ \#\ of\ Delta\ Smelt\ Entrained)_{method\ 2}$$

Our proposal is to replace Kimmerer's method for estimating daily numbers of adult delta smelt entrained on the left-hand-side of the above equation with daily estimates derived from the IBM model discussed in Proposal II:

$$\frac{N_{SD}Q_{SD}}{V_{SD}} = \theta\left(\widehat{N}_{d1} + \widehat{N}_{d2}\right)$$

Note: Our proposal is to replace this term with daily estimates of delta smelt entrainment calculated with a hydrodynamic, turbidity (or sediment transport), and particle-tracking model with delta smelt behavior applied to the particles. (We also will use individual values of θ for the SWP and CVP.)

The use of an IBM (although admittedly involving a lot more work) has the following advantages over the approach used by Kimmerer:

- Time-of-travel from the sampling stations to the fish facilities will be accounted for.
- The model will not assume that monthly estimates of the south Delta population for delta smelt based on Kodiak survey catch apply to the entire month when sampling occurred. (The temporal variations in populations in the south Delta will be continuously simulated at a tidal time scale accounting for movement, entrainment, and natural mortality.)
- Delta smelt behavior will be assigned to particles so entrainment will be proportional to turbidity, and turbidity gradients, and not only the combined southward flow in Old and Middle Rivers as assumed by Kimmerer. (This will reduce estimates of entrainment when south Delta turbidity is low and OMR flow is negative, and allow for the occurrence of entrainment when OMR flow is positive and south Delta turbidity is high.)
- In fitting the IBM model to Kodiak Trawl sampling data for delta smelt, actual sample volumes that are known for each station for each survey will be used in contrast to the average volume sampled per station for all surveys as used by Kimmerer.

Proposal IV. Determining Sensitivity of Delta Smelt Life Cycle Model Results to Revised Model Assumptions and Covariate Selection

Topic Area

This proposal addresses CAMT's workplan for understanding the effects of entrainment to the delta smelt population.

Background

Life cycle models are an essential tool in evaluating factors influencing populations of management concern (Buckland et al. 2007). They can evaluate multiple factors that simultaneously influence different stages in the presence of density dependence. They also link the population dynamics from one time period to the next propagating the information and uncertainty. This link allows information relating to one life stage (i.e., abundance estimates) to inform processes influencing other life stages and is particularly important when data is not available for all life stages for all time periods. The life cycle model should be fit to the available data to estimate the model parameters, including parameters that represent density dependence, and determine the data-based evidence of the different factors that are thought to influence the population dynamics. Finally, the model should be used to direct research or provide management advice.

Using a state-space multistage life cycle model, Maunder and Deriso (2011) found that delta smelt life stage dynamics food abundance, temperature, predator abundance, and density dependence were the most important factors controlling the population dynamics of delta smelt. Survival is positively related to food abundance and negatively related to temperature and predator abundance. Maunder and Deriso also found some support for a negative relationship with water clarity and adult entrainment and a positive relationship with the number of days where the water temperature was appropriate for spawning. The first variables to be included in the model were those related to survival from larvae to juveniles, followed by survival from juveniles to adults, and finally the stock-recruitment relationship. Mac Nally et al. (2010) also found that high summer water temperatures had an inverse relationship with delta smelt abundance. Thomson et al. (2010) found exports and water clarity as important factors. Adult entrainment was not one of the main factors contributing to juvenile recruitment. More importantly, the coefficient was unrealistically high and highly correlated with the coefficient for water clarity. Mac Nally et al. (2010) and Thomson et al. (2010) only used the FMWT data and did not look at the different life stages, which probably explains why the factors supported by their analyses differ from what was found in Maunder and Deriso (2011).

Since Maunder and Deriso (2011) was published, a number of new conceptual models about the factors that affect delta smelt population dynamics have arisen (Miller et al. 2012; Rose et al. 2013; MAST 2014). In addition, there have been eight more years of data collected (Maunder and Deriso used trawl data up to 2006), including a year when the population made a significant rebound in numbers (MAST 2014). The objective of this proposal is determine if the findings of Maunder and Deriso (2011) differ when alternative covariates based on a higher-order mechanistic underpinning of variables or updated data are used in the analysis. We also propose to investigate how the selected covariates change when the assumption of an adult to juvenile density-dependence relationship is modified to a density-independent relationship and when a different value is assumed for the process error variance.

Key Investigators

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Project Purpose

The primary purpose of this proposal is to determine if sensitivity of state-space multiple life cycle results (Maunder and Deriso 2011) vary to alternate model assumptions, updated data and alternative covariates.

Key Questions

The key questions about population consequences were developed by the CAMT DSST. These questions focus on the effects of entrainment to population viability and demographics:

What are the effects of entrainment on the population?

How do updated data and new model assumptions affect life cycle model results published in Maunder and Deriso (2011)?

Does incorporating alternative covariates in the life cycle model change results and interpretation from Maunder and Deriso (2011)?

Hypotheses

This proposal addresses or can be used to address the following hypotheses from the CAMT workplan:

(H1): Delta Smelt are entrained at Project facilities at levels that are likely to affect the long-term abundance of the delta smelt population.

(H2): There are circumstances under which the losses of delta smelt to entrainment are sufficient to cause a demonstrable impact on population viability.

Investigative Approach

Density independent juvenile to adult survival

Maunder and Deriso (2011) estimated Ricker type density dependent survival between juveniles and adults in their delta smelt life cycle model. This relationship was heavily dependent on three consecutive years of high juvenile abundance. It has been suggested that the low survival of these year classes may have been due to environmental conditions and not density dependence. A sensitivity analysis that ignores density dependence in survival from juvenile to adults will be conducted to determine if the results (e.g. the covariates chosen) are sensitive to this density dependence. The sensitivity analysis will be run on covariates used in Maunder and Deriso (2011), possibly incorporating data up through 2013 (see below).

Alternative values for the process error penalty variance parameter

The life cycle model of Maunder and Deriso (2011) is a state-space model in that it models both observation and process error. Due to computational demands of integrating over the state-space, a penalized likelihood approach was used to approximate the integration. The process error variance (which is used in the distributional based penalty) controls how much survival can vary from the underlying covariate and density dependent relationships. It can be difficult to estimate the process error variance using penalized likelihood so Maunder and Deriso (2011) fixed it at what they considered a reasonable value. The results (e.g. the covariates chosen) may be sensitive to the value of the process error variance. Sensitivity analyses using different values for the process error variance will be conducted to determine if the results (e.g. the covariates chosen) are sensitive its value. The sensitivity analysis will be run on covariates used in Maunder and Deriso (2011), possibly incorporating data up through 2013 (see below).

Addition of the spring Kodiak survey data to estimate observation error

The life cycle model of Maunder and Deriso (2011) assumes that the observation error variance used in the likelihoods for the survey data are known. Their values were based on the random sampling error (e.g. by bootstrapping the data). Variation could also be caused by changes in catchability caused, for example, by changes in environmental conditions. Therefore, the observation error variances may be under estimated and influence the covariate model selection process since observation variation will be interpreted by the model as process error (survival) variation. Multiple observations on the same quantity can be used to calculate observation error. Maunder and Deriso (2011) did not use the spring Kodiak survey trawl data in their model because the time series was short. The spring Kodiak trawl survey measures the abundance of adults, which are also measured by the Fall Midwater Trawl, and now with more years of data that may facilitate the estimation of the observation error variance. A sensitivity analysis that includes the spring Kodiak survey trawl data and estimates the observation error variance will be conducted to determine if the results (e.g. the covariates chosen) are sensitive to its value. This would require updating all the survey and covariate data to include additional years. Alternatively, analyses could be conducted with different assumptions about the observation error variance.

Updated data

Sensitivity analyses will be conducted with the most recent data to determine if the results (e.g. the covariates chosen) are sensitive or improved with the addition of new data. This will require updating the analyses used to construct the surveys indices and their variances and the covariates.

Alternative covariates

Sensitivity analyses will be conducted with alternative covariates as recommended by other researchers. A team will formed in March 2015 to help investigators develop a set of covariates most appropriate for model selection. The purpose of this group will be to select and specify values for covariates to be used in life cycle modeling for delta smelt. This work will occur in the following steps:

1. The group meets with the modelers to determine the kinds of covariates required for life cycle modeling and to develop the specifics of each covariate. Specifics will include the following:
    - Areas over which each covariate is to be estimated.
    - Periods of the year (or life stages) over which each covariate is to be estimated.

- The manner by which relevant minimums and maximums within each time period will be dealt with.
- The manner in which co-occurrence with proportions of the delta smelt population will be dealt with.
- The possibility of combining some covariates (turbidity and predation, for example) will be dealt with.
- Other issues that arrive in discussions of the group and the modelers.

The product of this meeting will be a table listing the covariates and the specifics of each covariate, with notes as necessary to address special considerations of each covariate (for example, co-occurrence and minimums/maximums).

2. The group meets to determine the following:
   - The source(s) of data to be used in specifying each covariate.
   - How to deal with gaps in data, including the need for hindcasting and forecasting.
   - How to deal with uncertainties in the values of each covariate.
   - Identification of persons who will obtain the raw data and process it as the first step in quantifying each covariate.
   - Identification of persons who will be responsible for taking the initially processed data and estimating the values of each covariate.

   The product of this meeting will be a table listing each covariate, the sources of data for each covariate, methods for dealing with uncertainty, hindcasting, and forecasting, and the identification of persons responsible for initial data processing and for estimating covariate values.

4. The work of initial data processing and covariate estimation is carried out. The product of this step will be a table of values of each covariate for each area and time period, including notes for each covariate dealing with uncertainties and these uncertainties could be dealt with in the use of each covariate in modeling. This table is reviewed by the Covariate Specification Group, and any necessary changes are made. The table is transmitted to the DSST.

Applications of Findings to Management

Although this life cycle model has already been used to estimate adult delta smelt entrainment effects (Maunder and Deriso 2011), testing the existing covariates with new model assumptions could be informative for understanding the robustness of the conclusions about entrainment effects from original runs. The results from this study can be used to determine the population consequences of entrainment relative to other key stressors.

Deliverables

The findings of this study will be described in a technical report and a portion of the findings submitted in a manuscript to a peer reviewed journal.

Budget

The total budget requested for this study is $133,600. It should be noted that this study can be funded in stages per the timeline indicated in Table 1.

Qualifications

See attached CV's.

References

Maunder, MN, and Deriso, RB. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to Delta Smelt (*Hypomesus transpacificus*). Canadian Journal of Fisheries and Aquatic Sciences 68:1285–1306.