FINAL REPORT
CALFED SCIENCE PROGRAM PROJECT NUMBER: SCI-05-C106
PROJECT TERM: APRIL 1, 2006 THROUGH MARCH 31, 2009
PROJECT TITLE: MODELING THE DELTA SMELT POPULATION IN THE SAN FRANCISCO ESTUARY

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Funding Source: **CALFED Science Program**
Project Location: **Romberg Tiburon Center**
Brief Description of Project: This project is to develop and apply three classes of simulation models for the delta smelt population of the San Francisco Estuary. These models are: a particle-tracking model of movement; an individual-based population model; and a series of matrix models.

BUDGET SUMMARY

TASK/SUBTASK	% COMPLETE (BY DOLLARS)	AMOUNT INVOICED TO DATE (ALL YEARS)
Task 1 PTM	70	$177,502
Task 2 IBM	95	$366,189
Task 3 MAT	95	$250,059
Indirect		$83,205
Totals (with indirect)	88	$876,955

PROJECT STATUS TO DATE (BY TASK)

This project was terminated during the freeze of bond-funded projects, December 19, 2008. Despite a written request for an extension of the project end date beyond March 2009 to allow for the project to restart, we learned in May 2010 that the funds would not be forthcoming. The termination of this project was not attributable to any failure on our part. Previous semiannual reports had described reasonable progress and, as suggested by the budget summary above, at the time of termination the project was nearing completion.

This report is therefore the final report for the project, outlining the status of each task at the time of termination. Should funds for continuing the project become available, the PI's of this project would be interested in restarting it. Some adjustments to the scope and budget might be needed to allow for completion, because of changes in model characteristics outlined below and several changes in key personnel.

TASK 1: PARTICLE TRACKING MODEL (PTM)

Our early efforts focused on becoming familiar with the DSM2/PTM model, i.e., how to run the model and how to obtain necessary information for the IBM and other aspects of this project. During the course of this familiarization process, besides several minor issues with DSM2, we became aware of several major problems with the PTM:

(1) The PTM has never been properly calibrated. While some reports of limited comparison between PTM results and data are reported in several DWR reports, there has been no systematic evaluation of the quality of PTM results. This is of concern because the PTM is based on several major approximations of the real flows, most notably that mixing of particles is complete at junctions. To see the importance of this assumption, one can calculate the length of channel, L_m, required to mix particles across the channel via turbulent mixing as approximately $6W^2/D$, where W is the width and D is the depth. For a typical delta channel $W \approx 100$ m and $D \approx 10$ so that $L_m \approx 6$ km for a relatively narrow channel. This is longer than the distance between junctions for many delta channels, suggesting that shear flow dispersion in the PTM may be somewhat greater than in nature, since in oscillating shear flows often increasing the rate of transverse mixing can increase the longitudinal dispersion.

(2) The current java version of the PTM is limited in terms of the number of particles that can be handled because each particle requires a substantial memory allocation independent of the particle track itself. Moreover, compiled java is a relatively slow compared to structured languages like Fortran or C. The practical implication of this is that it is not currently feasible, either from the standpoint of execution speed nor memory, to run the large number of particles ($O(10^5)$) that is thought necessary for the IBM.

(3) To the best of our knowledge, there is no one at DWR tasked to maintain the PTM; the code's developers have since moved to other projects or have left DWR. As a result, there is little that can be done with the PTM other than run it in its current form. Moreover, there is virtually no documentation of the code, aside from general basic formulae for moving particles, formulae that are readily available in much of the extant literature dealing with particle tracking in general. There is no flow chart of how the code actually works, although given that java is an object-oriented language, constructing one be difficult. We note that a tree has been generated (presumably using standard software) that shows the important dependencies among the several dozen java code files that make up the PTM.

As the overall project proceeded, it became clear that a more interactive version of the PTM that can be built into the IBM, preferably written in Fortran, is needed. Given the central role that transport and entrainment are believed to play in Delta Smelt population dynamics, understanding the ability of the PTM to correctly model advection and dispersion seems imperative.

Our efforts therefore focused on developing the Fortran PTM (FPTM) code. The current version of the code, written in Fortran 90, has approximately 4500 lines and does the following:
(1) Reads in fixed data (channel areas, channel grid, etc.)
(2) Reads in time-varying input data (flows, boundary conditions)
(3) Reads in data from a DSM2-produced tide file
(4) Advects particles using a 4th order Runge-Kutta routine.
(5) Moves the particles vertically and laterally due to turbulent mixing using a random number generator.
(6) Moves particles through junctions either preserving position in the flow (for junctions with 3 channels) or randomizing the position after passage (all junctions, optional for 3 channel junctions).
(7) Moves particles into and out of open water areas. Each particle has an increasing probability of exiting the reservoir with time after it enters, so that 36% of the particles remain after a pre-defined residence time for the area.
(8) Writes out particle position data to a file every day of simulation.

We successfully tested basic components of the model (Sridharan 2008). This included various test cases with known analytical results, such as determining the distance to complete mixing downstream of the confluence of two channels. Subsequent development was needed to improve efficiency of the code and further test the code in realistic situations.

<u>Current status:</u> We have a working PTM but it has not yet been fully tested and calibrated. Additional tasks yet to be accomplished are to: finish code testing, calibrate the model versus field conditions, examine the consequences for particle movement of alternative particle movement rules at junctions, and prepare reports on the model and these results.

TASK 2: INDIVIDUAL-BASED MODEL

Early on in the design of the new IBM of delta smelt population dynamics, we decided to implement two modifications to the IBM as originally described in the proposal:
1) Derive daily growth rates of individuals dynamically through a bioenergetics sub-model with individual consumption based on zooplankton densities.
2) Instead of using transition probabilities from the PTM to move individuals through the big boxes of the IBM, we plan to implement the IBM on the same spatial grid as the PTM. Working closely with the Stanford University group developing the PTM, we intend to incorporate the PTM as a sub-model to the IBM allowing for the movement of individuals to be tracked throughout their entire life history. Particle-tracking would be

used for early life stages, behavorial movement for juveniles and adults, and some mix for larvae. In doing so, we hope to provide a more realistic change from larvae as passive particles moved within the flow to more active fish that can determine their own location within the delta.

Several key features of the model are:

1. It runs with a simplified, embedded PTM that uses DSM2 HYDRO output files. The PTM that we coded is very similar to the PTM used by DWR.
2. It is set up to run water years 1995-2005, because of the good availability of data for those years.
3. Environmental data are developed for 11 spatial boxes, which are taken to have uniform parameters for environmental data.
4. Salinity and temperature data are taken from continuous monitoring stations and interpolated.
5. Secchi depth and zooplankton biomass in several taxonomic categories were analyzed for mean and variance by box. These values are then used to produce values for each channel within the box; thus the model fish are exposed to similar variability as is seen in samples from the field.

The IBM has been coded and the code verified. In preparing for the October 2008 CALFED Science Conference, we thoroughly exercised the model in various modes and resolved several tricky coding problems. We also explored several scenarios related to hypotheses about food, export losses, and the "big mama" hypothesis, but uncovered several unforeseen problems. Work to resolve those problems was progressing but had not been completed at the time of the funding freeze. We are currently resolving these issues on our own time in order to complete the IBM and prepare manuscripts.

Current status: The table below shows the status of each of the major model elements. The goals for the remainder of the project were to complete testing of the model, run several scenarios for feeding, diversion effects, and the effect of spring pumping schedules, and write two papers on the results. The first paper was to describe the model's structure and calibration, and the second the results of the scenarios.

Model Feature	Basic Coding	Calibration	Validation
Bookkeeping	X	X	X
Growth	X	X	X
Mortality	X	X	X
Reproduction	X	X	X
Movement – PTM	X	X	
Movement - active	X	X	

TASK 3: MATRIX MODEL

Initial work on the stage-based matrix projection modeling component has focused primarily on re-examining assumptions and parameter estimates used in developing the preliminary matrix model that was reported in Bennett (2005). The periodic stage-based approach (Caswell 2001) used in this preliminary model tracked the relative survival of early-spawn and late-spawn cohorts based on the dynamics of three seasonal matrices, roughly representing the spring (spawning season), fall, and winter of an annual life cycle. However, the scientific basis for adding cohort structure to this model was limited to best judgment because, at the time Bennett developed the preliminary model, we knew little about individual life history strategies for spawning and cohort structure of delta smelt. Furthermore, preliminary estimates of survival and fecundity also needed refinement given a variety of new sources of information. Therefore, initial work on this project has focused on improving the scientific basis for our prior assumptions concerning spawning and cohort structure, as well as

recently on the accuracy of survival parameters. This work has been particularly valuable in developing the IBM. We planned on coupling the IBM and new matrix models by using IBM output to estimate parameters of a spatially-explicit matrix model, whose general structure was recently described in Hunter and Caswell (2005). We could then use eigenvalue analysis to quickly determine the sensitivity of the population growth rate of delta smelt to changes in growth, mortality, reproduction, and movement.

Current status: Preliminary (stage-based, single spatial box) modeling has been completed. Additional matrix modeling work awaits completion of some of the IBM work to provide parameters for exploration in the cohort matrix model, and for seeding the spatially-explicit version of the matrix model.

PROJECT-WIDE STATUS

ACHIEVED OBJECTIVES, FINDINGS, AND CONTRIBUTIONS: Findings are described above. Oral and written reports include:

Kimmerer, W. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. Vol. 6, Issue 2 (June 2008), Article 2. (This paper acknowledges support of this contract for work on estimating loss rates of delta smelt to the south Delta export facilities, and analysis of the relationship of food biomass to summer-fall survival. Work on other parts of this paper was funded by other sources).

Edwards, Karen. 2006. Modeling the delta smelt population of the San Francisco Estuary. Presentation to the Estuarine Ecology Team, August 2006.

Rose, K.A. 2008. Delta Smelt Population Modeling: Development of a spatially-explicit, individual-based, full-life cycle model. CALFED Science Conference, Sacramento, October 2008

Kimmerer, W.J. 2008. Delta Smelt Population Modeling: Preliminary Results of Simulations with an Individual-Based Model. CALFED Science Conference, Sacramento, October 2008

Sridharan, V. K. 2008. Delta Smelt Modeling Project: The Development of a Particle Tracking Model to Study Discontinuous Scalar Fields in the Delta.

PROBLEMS OR DELAYS ENCOUNTERED: The project was terminated following the December 2008 freeze.

DELIVERABLES: None to report

PERSONNEL CHANGES: All personnel terminated from the project and have moved on to other activities.

CONTRACT MODIFICATIONS: Contract was terminated

NOTES/OTHER: None

Literature Cited

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San

Francisco Estuary, California. San Francisco Estuary and Watershed Science. 3(2): 71pgs. (http://repositories.cdlib.org/jmie/sfews/ vol3/iss2/art1/)

Caswell, H. 2001. Matrix Population Models: Construction, Analysis, and Interpretation, Second edition. Sinauer, Sunderland MA.

Hunter, C.M.,and H. Caswell. 2005. The use of the vec-permutation matrix in spatial matrix population models. Ecological Modelling 188: 15-21.