Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 1
PTM Fish Behavior Development Workshop

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1 PTM Fish Behavior Development Workshop

1.1 Introduction

This chapter summarizes the Particle Tracking Model (PTM) Fish Behavior Development Workshop held at DWR on January 8, 2015. This workshop was attended by PTM developers from National Marine Fisheries Service (NMFS), U.S. Geological Survey (USGS), and California Department of Water Resources (DWR). The leads for the three agencies were Doug Jackson (NMFS), Russel Perry (USGS), and Xiaochun Wang (DWR).

1.2 Background

NMFS and DWR staff, for the most part, have been independently developing fish behavior PTMs with USGS staff providing expertise on developing methodologies for calibration and fish behavior submodels. The purpose of this technical workshop was to establish a plan for coordinating NMFS and DWR PTM behavior development efforts.

In the workshop, the participants from the three agencies learned the background of the development efforts, reviewed differences in the development goals and objectives between NMFS and DWR, discussed technical details of methodologies, provided updates on development status, and identified opportunities for collaboration.

1.3 Goals and Objectives

NMFS and DWR both seek to develop a PTM with fish behaviors assigned to the neutrally buoyant particles to evaluate possible impacts on fish migration through the Delta because of project operations and new construction in the Delta. However, the NMFS and DWR PTM behavior developments differ in scope. The NMFS PTM behavior development has a specific goal and a targeted species. As a part of the NMFS Central Valley Chinook Life Cycle Model, the NMFS PTM will provide smolt mortality rate for the life cycle model during smolt migration through the Delta. Therefore, its development is focused on Chinook smolts. In addition, because of the tight time frame for the scheduled release of the Chinook Life Cycle Model in March 2015, and the specifically targeted fish species, model reusability, flexibility, and scalability are not emphasized.

DWR intends to develop a PTM with fish behaviors that is more flexible and scalable, that is a model that accommodates various species and environmental conditions and is more accessible to the general public. In addition, because fish behavior research is an active field, DWR's model development will take into consideration reusability for future development.

Although NMFS and DWR have differences in the scope of the development, the workshop participants agreed that coordinating development efforts of the two agencies would be mutually beneficial. Therefore, it was decided that NMFS and DWR will merge the current development and work collaboratively in the future to produce a single set of behavior submodels for Chinook smolts.

1.4 Methodologies

The methodologies being used by the two agencies to calibrate the behavior submodels are being developed primarily by USGS (Russell Perry's group). Three types of behaviors are needed to make a particle "fish-like": swimming, survival, and route selection. The following sections provide brief explanations of the methods used to implement the three behaviors into PTM.

1.4.1 Swimming Velocity Calibration

Both NMFS and DWR calibrate the particle swimming velocities from field-observed acoustic telemetry tag data using optimization techniques. However, there are major differences in the optimization methods and swimming behavior submodels.

NMFS employs an optimization method that is based on a Bayesian framework and a Markov Chain Monte Carlo algorithm. This method requires repeated sampling, on the order of thousands of samples, of PTM outputs under different parameterizations. Generating this large number of PTM realizations by running the PTM directly would be impracticable. To address this issue, emulators of the PTM outputs are constructed. Once these emulators are constructed, they allow for nearly instantaneous estimates of the PTM outputs for any arbitrary parameterization. However, there is a substantial upfront cost to generate the emulators, as it requires the PTM to be run numerous times across a range of parameter values. There is also significant expertise required to tailor this framework to a specific data set, making this approach inaccessible to most DSM2 users.

In contrast, DWR's method allows users to couple an optimization routine with PTM simulations. Users can plug in a specific set of observed data and obtain the swimming parameters tailored for this set of data. This will be a powerful tool for fish biologists who are interested in finding behavior patterns for a specific fish species under specific environmental conditions. Then again, there is a cost for the flexibility. It requires more development effort, and it is computationally more expensive. Currently, USGS and DWR are working on applying an efficient optimization method called Particle Swarm Optimization (PSO) to PTM. PSO is a population-based stochastic optimization technique. Since its development in 1995, PSO has demonstrated it can find a global optimum faster and cheaper than many other optimization methods.

Two holding behavior submodels are used to calibrate swimming velocities. They are selective tidal stream transport (STST), where there is fish hold position if the upstream flow exceeds a specified threshold, and diel-holding submodels. NMFS' STST submodel uses 1) a velocity threshold, 2) the net direction of flow over one or more tidal cycles, and 3) a probability of confusion, which is a function of a signal-to-noise ratio (the mean flow over the standard deviation of flow), to decide whether a particle is holding or swimming. In contrast, DWR's submodel only uses a velocity threshold (a fitting parameter) to make this decision.

For the holding behavior during a diel period, NMFS' submodel only allows particles to swim during a specified period centered on midnight. DWR's submodel uses sunrise and sunset to determine daytime and nighttime. All particles swim during nighttime. During daytime, whether or not a particle swims is determined by a probability calculated from the percentage of the particles allowed to swim. The percentage is a fitting parameter.

1.4.2 Particle Route Selection Submodel

In the original PTM, the probability of a particle selecting a certain route, either a branch or the main stem of a river, at a river junction is based on the flow split proportion to the route. The higher the flow into the route, the higher the probability a particle selects the route. When a particle's swimming velocity is superimposed on a river velocity, the net velocity, which decides the direction of the particle's movement, may not be in the same direction as the river flow. In turn, this may cause numerical errors and the PTM to crash. To solve this problem, NMFS' route selection submodel prohibits the particle from selecting the route when there is a directional conflict in the net velocity and the river flow. DWR's submodel has a different approach; a swimming flow (swimming velocity multiplied by the channel cross-sectional area) is superimposed on the river flow. The probability of the route selection is then calculated using the original flow split method. By superimposing swimming flow, the higher the combined river and swimming flows, which relate to the swimming velocity and channel cross-sectional area, the higher probability a particle will enter the route.

Using flow splits to calculate route selection probabilities is a simple model that may not match actual fish routing dynamics, but is general enough to be used at any river junction. In contrast, generalized linear models fit to telemetry data at a specific junction may describe routing dynamics well, but cannot be generalized across junctions. Therefore, DWR, NMFS, and USGS are working toward developing a set of routing models that are general enough to apply to river junctions where no telemetry data exists, but are specific enough to capture the primary mechanisms affecting migration routing.

1.4.3 Particle Survival Submodel

NMFS uses an XT model to calculate smolt survival rates. The XT model relates smolt survival through the Delta to the smolt travel distance (X) and time (T). The XT model is implemented in PTM and the two model parameters, λ and ω, are calibrated using acoustic telemetry tag data.

DWR implements a survival model developed by USGS that relates the smolt survival rates to river discharge. The parameters were estimated from observed acoustic telemetry tag data.

1.5 Collaboration Plan

The workshop participants carefully examined the different methodologies and discussed technical details of each method. The discussion took into consideration the two agencies' goals and objectives. It was decided that the current development work from NMFS and DWR will be integrated by taking the best of both efforts and only one set of behavior submodels for Chinook smolts will be developed. After weighing the pros and cons in terms of ecological, fish-biological, and software developmental merits for the different methods, the participants agreed that NMFS will adapt DWR's route selection and diel holding submodels. DWR will use NMFS' STST and calibrated XT submodels.

Because of the differences in development goals, it was also agreed that both NMFS and DWR will keep their own optimization method so that DWR will have a general, data-driven model to release to the public domain while NMFS will have a more specific PTM for the life cycle model to meet the release schedule. The other added benefit to using different optimization methods to calibrate the PTM parameters is that the parameters can be compared from the different methods to ensure the consistency and quality of the PTM calibration.

The workshop action items for USGS, NMFS, and DWR were:

1) DWR and NMFS will exchange and review the PTM codes.

2) NMFS will implement DWR's route selection and diel-period-holding submodels.

3) DWR will implement NMFS' STST and calibrated XT submodels.

4) USGS will develop a PSO routine to be implemented in PTM.

The timeline for completing the above list is April-May, 2015. For future collaboration, DWR will schedule quarterly technical meetings so that the involved parties can be updated on each other's development status.

In summary, the PTM Behavior Development Workshop was very productive. The technical issues, arising from the development of the software to simulate smolt behaviors, were thoroughly discussed, the tasks were finalized and assigned, the timeline to complete the tasks was set, and future collaborations were planned. The group will submit a proposal for future PTM development at the next meeting.