Appendix 4A

Attachment 5: DSM2 ECO-PTM Documentation

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4A-5.1 Introduction

ECO-PTM is based on DSM2-PTM. DSM2-PTM simulates the transport and fate of individual neutrally buoyant particles through the Delta. DSM2-PTM can simulate neutrally buoyant particles' responses to the changes in the Delta hydrodynamic system, but the simulation does not represent the response of juvenile salmonids without modifications to account for fish behaviors. The goal of ECO-PTM is to improve the model accuracy in simulating juvenile salmonid migration and survival through the Delta by attaching fish behaviors to the neutrally buoyant particles.

4A-5.2 ECO-PTM Description

ECO-PTM implements three types of behaviors: swimming, routing, and survival. These behaviors are mathematically described by a set of statistical models (behavior modules) that were developed by fitting the models to tag data.

The swimming behavior module describes behaviors such as tidal confusion (swimming in the opposite direction toward the ocean), diel holding (holding during daytime), selective tidal stream transport (holding during flood tides), and differential swimming velocities at different times for different juvenile salmonids. A set of equations with stochastic variables were formulated to represent these behaviors. The behavioral parameters for the equations were calibrated using a simulated maximum likelihood approach within the context of a particle swarm optimization routine to fit ECO-PTM simulated travel times to the travel times of acoustically tagged juvenile salmonids. The goal of the calibration is to select an optimized set of parameters that ECO-PTM can utilize to simulate juvenile salmonid travel times under a wide variety of hydrodynamic conditions and salmonid behavioral responses.

Simulating accurate fish travel time is important because the routing and survival modules rely on the travel time to calculate routing and survival probabilities. An accurate travel time offers correct timing for fish particles to arrive a junction, and also provides reasonable duration estimates for the fish particles to migrate through the Delta channel. Both the timing and duration are crucial to correctly calculate routing and survival probabilities.

The routing behavior module is a set of statistical models that use hydrodynamic and other junction conditions as covariates to calculate routing probabilities at junctions. Utilizing the available tag data, three general fitted models from the statistical analyses of the data were implemented for the four junctions: Sutter Slough (Sut. Sl.), Steamboat Slough (Stm. Sl.), Delta Cross Channel (DCC), and Georgiana Slough (Geo. Sl.). The first statistical model is for the Geo. Sl. junction and can only be applied to high-flow periods when Sacramento River (Sac. R.) flows entering the junction are greater than 14,000 cfs and the direction of the flows are always toward the ocean (no reverse flows). The model was developed from two-dimensional (2D) tracks of acoustic tagged juvenile salmon. The 2D data allowed the development of a statistical model based on the critical streakline entrainment zone hypothesis (see Box 3 in Perry et al. 2016) to explore the effects of such factors as fish distribution across the channel, streakline location, and fish positions relative to the streakline. The statistical model consists of two parts: (1) a beta regression model to characterize the cross-stream distribution of fish, and (2) a logistic regression model to determine the routing probability based on the relative position of fish to streakline. The covariates of the statistical model include the probability of a fish particle's relative position to the streakline, hydrodynamic variables (junction inflow, flow split, etc.), time of day, and operation of a non-physical barrier. The second model is the generalized linear model (GLM) developed by Perry et al. (2015). Perry et al. fitted multinomial regression models to the tag data that identified when the tagged fish in Sac. R. entered the branches. The probability of an individual fish entering a given branch or remaining in Sac. R. was modeled as a multivariate Bernoulli random variable. Then, a logit link function was used to model routing probabilities as a linear function of the covariates. The covariates include: (1) discharge in Sac. R.; (2) discharge entering Geo. Sl. or DCC; (3) the flow rate of change in Sac R.; and (4) flow direction in Sac R. Time of day was considered at the beginning of the analysis but was eliminated from the model because likelihood ratio tests showed no significant improvement of model fitness. The GLM is applied to the DCC and Geo. Sl. junctions. For the Geo. Sl. junction, because the higher flow conditions (greater than 14,000 cfs) are covered by the first model, the second model is only applied to the inflows less than or equal to 14,000 cfs. The third statistical model is a similarly structured GLM (Romine et al. 2017) but applied for the junctions of Sac. R. with Sut. Sl. and Stm. Sl. For all other junctions where the tag data for routing analysis were not available, routing probabilities were calculated using the default routing probability calculation sub-model in DSM2 PTM, which routes particles proportional to flow split ratios at channel junctions.

The survival behavior module is based on the recently published model by Perry et al. (2018). For the ECO-PTM, the logit link function used by Perry et al. (2018) was replaced with an XT model to calculate fish survival probability through the Delta channels. The XT model is a predator-prey model that expresses survival of migrating juvenile salmon as a function of both distance traveled (X) and travel time (T). The model was fitted to the tag data from juvenile late-fall Chinook salmon migrating through the Delta during the winters of 2007–2011. To estimate model parameters, the XT model is incorporated into a Bayesian mark-recapture model that estimated both travel times and survival probabilities of tagged fish. The XT model parameters were reach specific. The Delta was divided into nine reaches according to the locations of acoustic telemetry receiving stations for the tag studies (Perry et al. 2018). The nine reaches represent different migration routes and Delta conditions (riverine, transitional, and tidal). The parameters were estimated for each reach. Using the XT model, survival probabilities of individual fish were calculated at the end of each reach. The population survival rate for each reach was calculated according to the percentage of fish survived among the detected fish at the end of the reach. The end reach survival rates were then used to calculate survival rate for each route. There are five routes for fish to migrate from Freeport to Chipps Island (Figure 4A-5-1). The total survival rates were calculated by combining survival rates from all routes.

For more information on the development of ECO-PTM, see the ECO-PTM Model Development chapter in the 40th Annual Progress Report titled *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh* (Wang 2019).

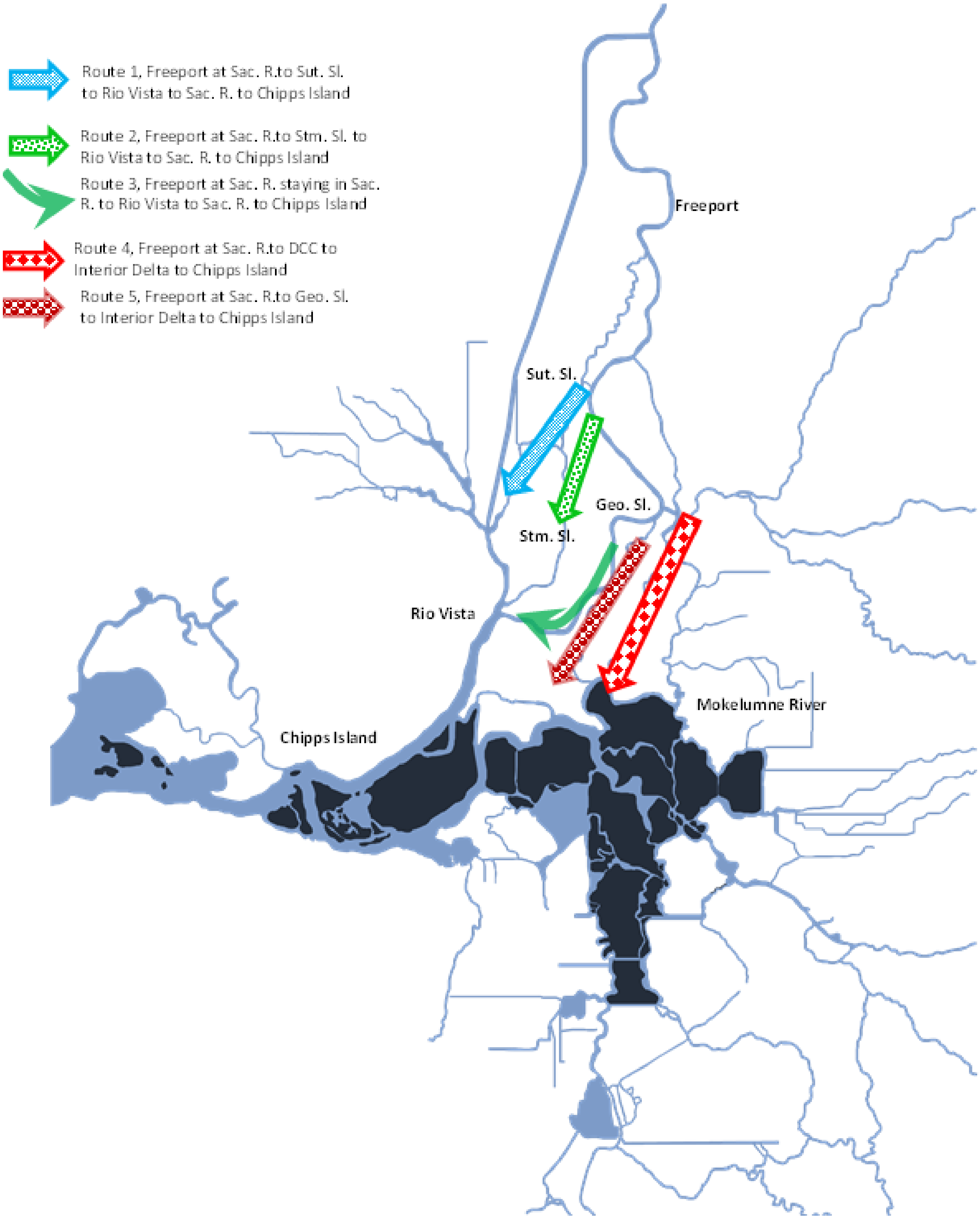

Figure 4A-5-1. Juvenile Salmonid Migration Routes from Freeport to Chipps Island

4A-5.3 Non-physical Barriers

With the performance of historical simulations (baseline) examined, ECO-PTM was applied to evaluate the effectiveness of non-physical barriers. DWR is planning for non-physical barriers to guide fish to more favorable survival routes. There are five routes for fish migration from Freeport to Chipps Island as shown in Figure 4A-5-1. Route 2 via Stm. Sl. and Route 3 remaining in the mainstem of Sac. R. are considered better routes for survival than the routes entering the interior Delta (Route 4 and Route 5). To guide fish to the more favorable routes, DWR is considering installing a non-physical barrier at the junction in the Sac. R. at Geo. Sl. The barrier at the Geo. Sl. junction could decrease the number of fish entering the interior Delta.

To simulate the functions of the barrier, which is to reduce the routing probability into Geo. Sl. and otherwise direct fish downstream through the mainstem only, ECO-PTM was programed to allow users to input a percentage either to increase or to reduce route probabilities based on the historical routing probability calculation. This percentage is fixed throughout the simulation period. Dynamic operations of a fish barrier will be incorporated into a future version of ECO-PTM.

Two factors were applied to simulate the effect of a non-physical barrier:

1. Multiplying calculated Geo. Sl. routing probability by constant 50%.
2. Multiplying calculated Geo. Sl. routing probability by constant 33%.

4A-5.4 References

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