Long-Term Operation – Initial Alternatives

Appendix J – Spring Pulses and Delta Outflow - Smelt, Chinook Salmon, and Steelhead Migration and Survival

Central Valley Project, California

Interior Region 10 – California-Great Basin

U.S. Department of the Interior **September 2022**

Mission Statements

The U.S. Department of the Interior protects and manages the Nation’s natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1. Introduction

Outflow from the Sacramento-San Joaquin Delta (Delta) integrates the effects of runoff, storage, releases, and diversions. In the spring months, native and other fish complete their most sensitive life stages. Juvenile Chinook salmon migrate from natal tributaries through the Delta and rear along the way to the ocean. Spring pulse flows provide outmigration cues for juvenile Chinook salmon and help to enhance likelihood of Central Valley (CV) steelhead anadromy. Portions of the Delta smelt and longfin smelt populations spawn in the freshwater area of the Delta, and their larvae and juveniles migrate toward Suisun Marsh and Bay. State Water Resources Control Board Decision-1641 (D-1641) implemented the water quality objectives from the 1995 Bay-Delta Plan and assigned certain responsibilities to the Central Valley Project (CVP) and State Water Project (SWP).

Bureau of Reclamation’s (Reclamation’s) management questions for the formulation of an alternative include the following:

- During the spring, what is the proportion of primary and secondary productivity supplied to the Delta from tributary inflows, Yolo Bypass, and other floodplain inundation versus productivity within the Delta?
- Does the inundation of Yolo Bypass and other floodplain areas change the productivity compared to in-channel and shallow tidal habitat within the Delta?
- What is the proportion of spring primary and secondary productivity passed to Suisun Marsh and Bay versus removed by CVP and SWP exports versus captured; e.g., clams?
- Can spring exports and tributary releases stimulate phytoplankton blooms and/or disperse central Delta phytoplankton biomass to habitats that are likely occupied by Delta smelt and longfin smelt?
- Can spring exports and tributary releases stimulate detrital-based zooplankton production and/or disperse central Delta food resources to habitats that are likely occupied by Delta smelt and longfin smelt?
- Does maintenance of low-salinity zone connectivity to Suisun Marsh and San Pablo Bay for Delta smelt and longfin smelt bolster spring survival?
- How much does spring export reductions, tributary releases, and/or both improve migratory conditions for Chinook salmon and steelhead?
- Do spring Delta outflows driven by tributary releases reduce the need for Old and Middle River management?
- What are the costs of Delta outflow actions to the current year’s water supply, storage, water quality, and/or hydropower?

Delta outflow is influenced by CVP and SWP storage, releases, and diversions as well as uncontrolled runoff and diversion by non-project water users. Recent efforts to balance the need to build a coldwater pool through storing water in reservoirs with the needs for instream flows and Delta outflow require a more detailed understanding of how different actions might perform.

2. Performance Metrics

2.1 Biological

Biological metrics consider direct observations and environmental surrogates as follows.

Smelt metrics (Delta and Longfin):

- Survival and
- Physical habitat quality and quantity

Food web metrics:

- Zooplankton (prey availability)

Salmon metrics:

- Juvenile survival probability to Chipps Island
- Juvenile physical habitat quality and quantity

2.2 Water Supply

Water supply metrics consider the multipurpose beneficial uses of CVP reservoirs including:

- North of Delta agricultural deliveries (average and critical/dry years)
- South of Delta agricultural deliveries (average and critical/dry years)
- Bay-Delta Water Quality Control Plan (D-1641) Standards

2.3 National Environmental Policy Act Resource Areas

Major considerations under the National Environmental Policy Act will include changes in multiple resource areas. Key resources are anticipated to include: surface water supply, water quality, groundwater resources, power, aquatic resources, terrestrial biological resources, regional economics, land use and agricultural resources, recreation, cultural resources, socioeconomics, environmental justice, and climate change.

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3. Methods

Reclamation solicited input for the knowledge-based paper *Spring Pulse and Delta Outflow-Smelt, Chinook Salmon, and Steelhead Migration and Survival* which is included as Attachment J. Knowledge-based papers compile potential datasets, literature, and models for analyzing potential effects from the operation of the CVP and SWP on species, water supply, and power generation. From the knowledge-based papers, Reclamation and California Department of Water Resources (DWR) organized the best available information for evaluating the impacts of spring pulse and Delta outflow as described below.

3.1 Datasets

- U.S. Fish and Wildlife Service Enhanced Delta Smelt Monitoring Program. Monitors all life stages of Delta smelt year-round throughout the species' range and collects longfin smelt. See: https://www.fws.gov/project/enhanced-delta-smelt-monitoring-program
- California Department of Fish and Wildlife Spring Kodiak Trawl survey. Monitors adult Delta smelt and adult longfin smelt during winter and spring. Available from: https://wildlife.ca.gov/Conservation/Delta/Spring-Kodiak-Trawl
- California Department of Fish and Wildlife 20-mm Survey. Surveys larval and early juvenile Delta smelt and juvenile longfin smelt during spring to early summer. Available from: https://www.dfg.ca.gov/delta/projects.asp?ProjectID=20mm
- California Department of Fish and Wildlife Smelt Larva Survey. Surveys larval and early juvenile longfin smelt and larval Delta smelt in the winter and early spring. Available from: https://www.dfg.ca.gov/delta/projects.asp?ProjectID=SLS
- California Department of Fish and Wildlife San Francisco Bay Study. Surveys a variety of species, including adult longfin smelt, monthly, year-round. Available from: https://wildlife.ca.gov/Conservation/Delta/Bay-Study
- California Department of Water Resources Yolo Bypass Fish Monitoring Program. Includes rotary screw trap and beach seine data that occasionally captures adult Delta smelt and longfin smelt. Available from: https://portal.edirepository.org/nis/mapbrowse?packageid=edi.233.2
- Bashevkin, S.M., R. Hartman, M. Thomas, A. Barros, C.E. Burdi, A. Hennessy, T. Tempel, and K. Kayfetz. 2022. Interagency Ecological Program: Zooplankton abundance in the Upper San Francisco Estuary from 1972-2020, an integration of five long-term monitoring programs ver 3. Environmental Data Initiative. https://doi.org/10.6073/pasta/89dbadd9d9dbdfc804b160c81633db0d.

3.2 Literature

CVP and SWP operations can potentially influence the growth and survival of foraging and migrating smelts in Delta habitats. Figures 1, 2 and 3 show conceptual models for how smelt growth and survival may be affected by spring outflow conditions modified by hydrology and diversions.

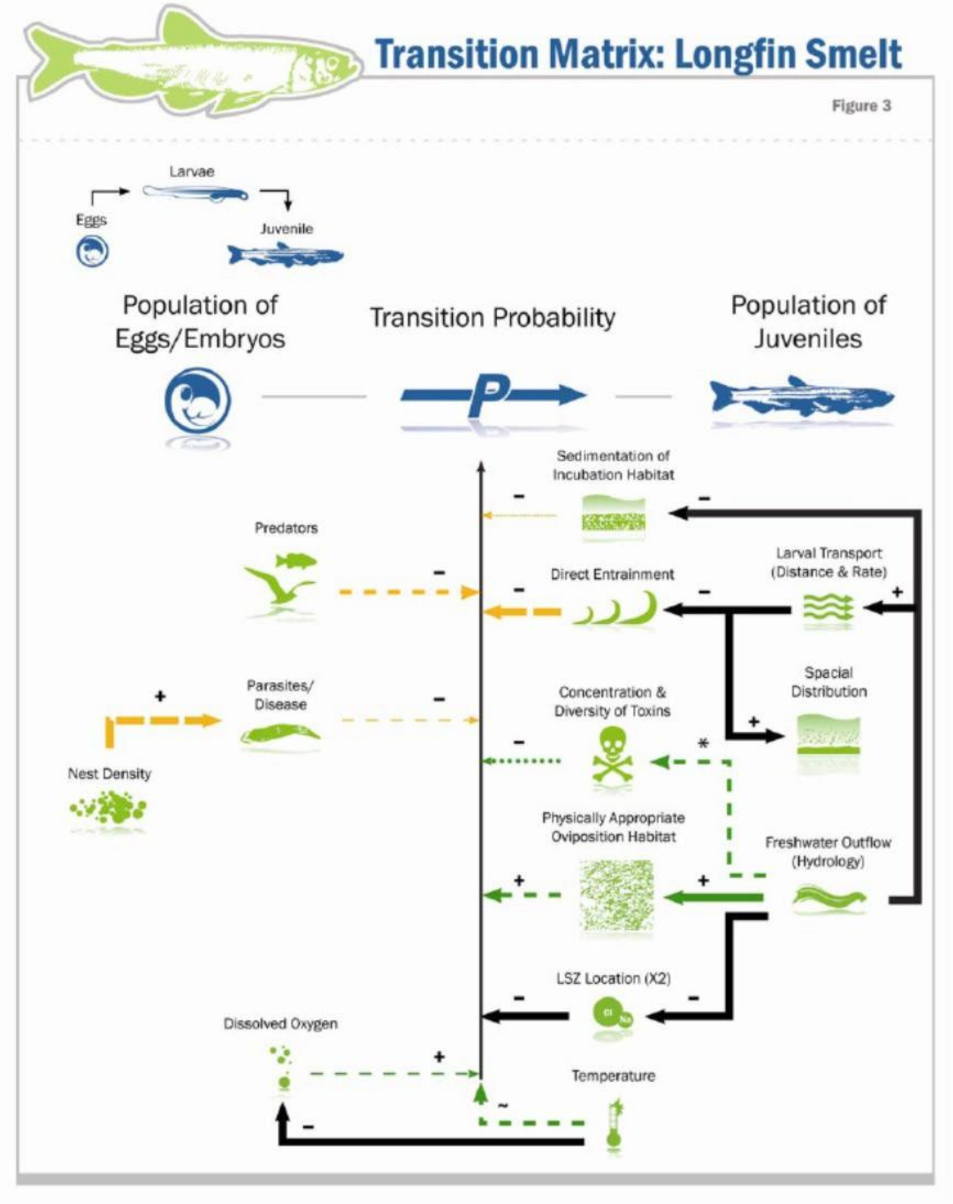

Figure 1. Transition Matrix of the Juvenile Life Stages of Longfin Smelt (Rosenfield 2010)

River flows can potentially influence the growth and survival of rearing salmonids in riverine habitats. Figures 2 and 3 show conceptual models for how adult and juvenile salmonid survival may be affected by pulse flows from dam releases on the Sacramento River. Pulse flows affect habitat attributes resulting in outmigration cues, which can result in changes in juvenile salmonid survival.

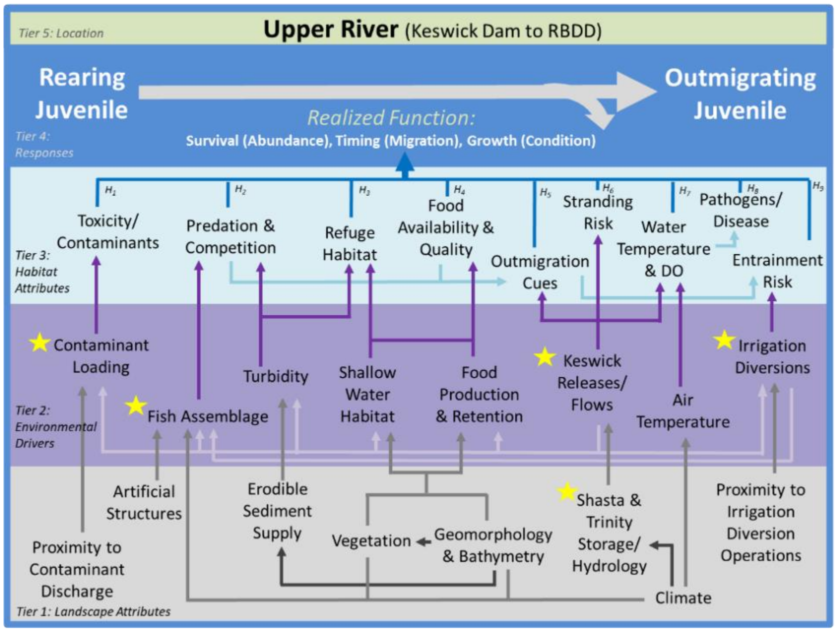

Figure 2. Conceptual Model of Juvenile Winter-Run Chinook Salmon Affected by Releases/Flows in Central Valley Tributaries (Windell et al. 2017)

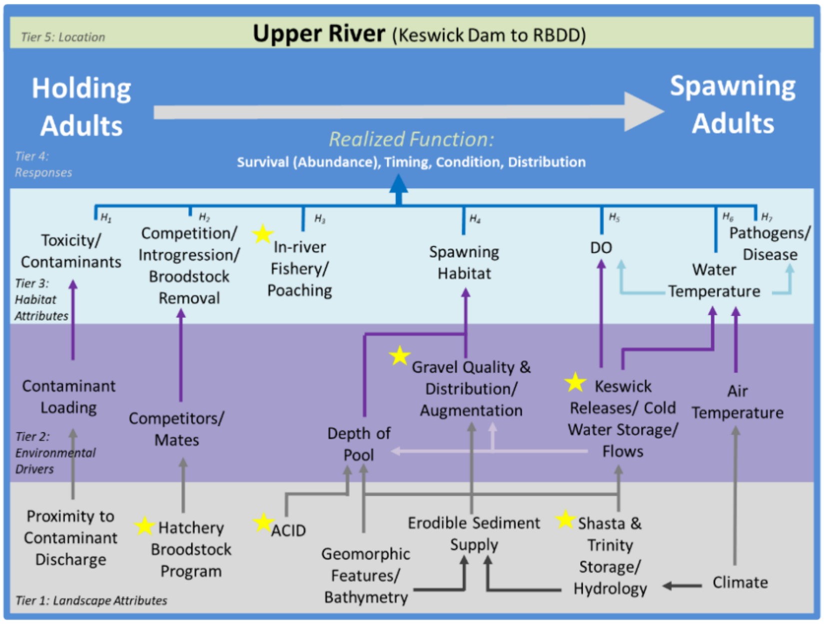

Figure 3. Conceptual Model of Adult Winter-Run Chinook Salmon Affected by Releases/Flows in Central Valley Tributaries (Windell et al. 2017)

3.2.1 Delta Smelt

Delta smelt is primarily an annual species with spawning occurring in springtime within the freshwater portion of the San Francisco Bay-Delta. By March, most adult Delta smelt that reared in the low-salinity habitat would have made their migration into freshwater (IEP MAST 2015). Note that a subset of the Delta smelt population appear to reside in freshwater year-round, mostly within the Cache Slough Complex region (Sommer et al. 2011, Hobbs et al. 2019). Delta smelt have a protracted spawning season given their life span. Spawning can occur from late January through June, while larvae can be seen from late February through early May (Moyle et al. 2016). Food availability, predation risk associated with turbidity, entrainment risk, and temperatures associated with the spawning window have all been considered as factors that can affect spawning and larval recruitment success (IEP MAST 2015, Brown et al. 2016) (Figures 4, 5). There has been less emphasis on the positive impacts of high spring outflow on Delta smelt relative to the summer-fall period. However, low outflow years are generally associated with a decline in Delta smelt abundance (IEP MAST 2015, Mahardja et al. 2021) and there is some evidence that higher spring outflow can improve recruitment for Delta smelt (Polansky et al. 2020)

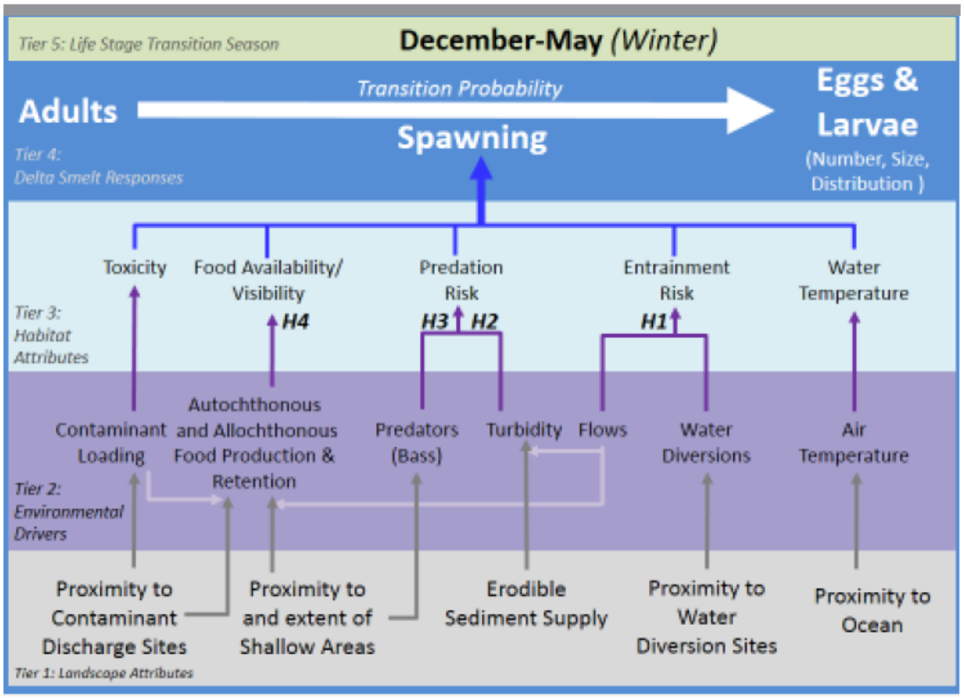

Figure 4. Conceptual Model of Adult Delta smelt during the Winter-Spring (MAST 2015).

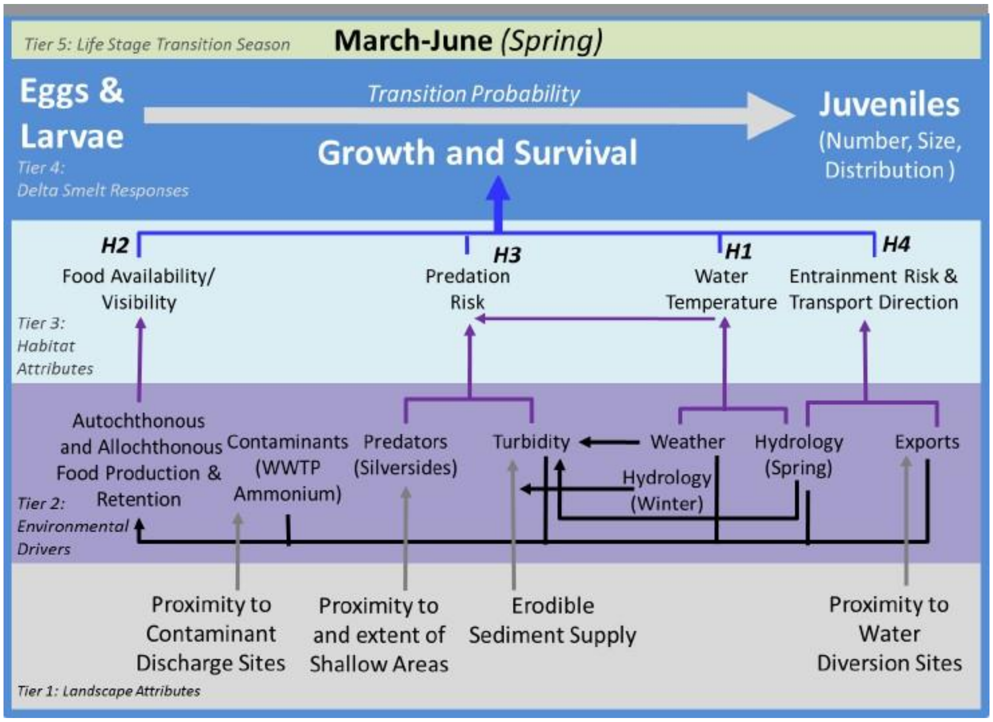

Figure 5. Conceptual Model of Early Life Stages of Delta Smelt during the Spring (MAST 2015).

3.2.2 Longfin Smelt

Water temperature can similarly impact longfin smelt. The critical thermal maximum is 24.8 degrees Celsius (°C) for larvae and 25.6°C for juveniles, and low densities of longfin smelt greater than 21°C–22°C indicate low field tolerance for these temperatures (Rosenfield 2010, Jeffries et al. 2016, Pasparakis personal communication). Sublethal effects exhibited by longfin smelt are similar to those of Delta smelt. At temperatures of 20°C and above, juvenile longfin smelt have exhibited changes in genes associated with muscle function and growth and skeletal development, changes in gene expression associated with ion regulation, and pronounced cellular stress response, indicating acute thermal stress (Jeffries et al. 2016). Water temperatures also influence the initiation of spawning and the duration of the spawning window, which occurs between 8°C–14°C (Wang 2007W, Grimaldo et al. 2017). In laboratory studies, embryos and yolk-sac larvae experience reduced hatch success, body length, growth rates, and earlier mass mortality at temperatures of 15°C compared with at 9°C and 12°C, thus indicating an optimal temperature of 9°C–12°C for culturing longfin smelt (Yanagitsuru et al. 2021).

3.3 Models

3.3.1 Hydrodynamics

3.3.1.1 Particle Tracking Model

The Particle Tracking Model (PTM) is a component of the Delta Simulation Model II to simulate the particle movement throughout the Bay-Delta network. The PTM model uses the hydrodynamics calculated from the DSM2-HYDRO model and extrapolates the one dimension (1D) average velocity in a channel to a pseudo three dimension (3D) velocity with assumed certain cross-sectional velocity profiles. The velocity profiles assume faster velocity at channel center and slower velocity near the channel bank and bottom. Field data are used to guide the selection of the velocity profiles and to calibrate the PTM.

Currently, two applications are commonly used with PTM. One is to estimate the particle residence time. When a certain number of particles (e.g., 1,000) are inserted at a certain location, the time for 25%, 50% and 75% of the particles to exit the system is estimated. The other is to estimate particle traces. For example, the percentage of particles released at Vernalis into the San Joaquin River and diverted into the SWP and CVP after 90 days can be used to represent the likelihood of fish entrainment.

Applications are available at: https://water.ca.gov/Library/Modeling-and-Analysis/Bay-Delta-Region-models-and-tools/Delta-Simulation-Model-II. PTM can be used to evaluate the movement and distribution of smelt eggs and larvae performance metric.

3.3.1.2 Bay-Delta SCHISM

The Bay-Delta Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) model is a three-dimensional numerical modeling system for the San Francisco Bay Delta estuary that is based on an unstructured grid numerical model known as SCHISM (Chao et al. 2017a,b; Zhang et al. 2008, 2016, 2019). The model can predict salinity and temperature in the Bay-Delta. Bay-Delta SCHISM can be used along with Bever et al. (2016) to evaluate physical habitat quality and suitability for Delta and longfin smelt.

3.3.1.3 Water Temperature (HEC-5Q)

Over the past 15 years, various temperature models were developed to simulate temperature conditions on the rivers affected by CVP and SWP operations (Sacramento River Water Quality Model [SRWQM], San Joaquin River HEC-5Q model) (Reclamation 2008). Recently, these models were compiled and updated into a single modeling package called the HEC-5Q model. Further updates were performed under the Long-Term Operation Environmental Impact Statement modeling that included improved meteorological data and subsequent validation of the Sacramento and American River models, implementation of the Folsom Temperature Control Devices and low-level outlet, implementation of the Trinity auxiliary outlet, improved temperature targeting for Shasta and Folsom Dams, improved documentation and streamlining of the models, and improved integration with the CalSim II model (Reclamation 2015). A summary of previous model calibration and validation details can be found at the following link: DWR-1084 RMA 2003 SRWQM.pdf (ca.gov)

HEC-5Q can inform juvenile and adult salmon survival as a function of river temperature.

3.3.2 Food Web

Several models are available for assessment of food web performance metrics. The density of the key smelt zooplankton prey *Eurytemora affinis* is significantly negatively related to mean March through May X2 and a general linear model to analyze this for different outflow scenarios is available from Greenwood (2018). X2 is the distance, expressed in kilometers from the Golden Gate Bridge, at which channel bottom water salinity (isohaline) is 2 parts per thousand (2 ppt). Regression equations from Hennessy and Burris (2017) are available that predict *E. affinis* density and mysid shrimp *Neomysis mercedis* density in the low-salinity zone as a function of March through May Delta outflow as well as an equation predicting the density of the smelt zooplankton prey *Pseudodiaptomus forbesi* in Suisun Bay as a function of mean June through September Delta outflow, although this is minimally overlapping the spring Delta outflow period).

3.3.3 Delta Smelt

3.3.3.1 Delta Smelt Individual-Based Model

For Delta smelt, an Individual-Based Model (IBM) was developed by Rose et al. (2013a, 2013b) and updated in 2022. This model simulates reproduction, movement, growth, and mortality of Delta smelt based on a combination of the approaches described by Rose et al. (2013a). It was calibrated to entrainment mortality, abundances, and growth rates estimated from the wild Delta smelt population between 1995 and 2015.

Delta smelt IBM can be used to evaluate the movement and distribution and survival probability performance metrics for Delta smelt. This model can combine Delta Simulation Model II flow data from the Sacramento and San Joaquin Rivers with export level values from the pumping facilities.

3.3.3.2 Delta Smelt State-Space Models

Several state-space statistical models have been developed for Delta ssmelt, including by U.S. Fish and Wildlife Service (Polansky et al. 2021, Smith et al. 2021) and by Maunder and Deriso (2011) These may be applicable to scenario data given assumptions regarding covariates for which the effects of management actions are not predictable.

3.3.3.3 Longfin Smelt Outflow-Abundance Model

Various statistical models are available linking to longfin smelt abundance indices to winter-spring Delta outflow. A recently developed model uses a Bayesian model-stacking approach to predict the longfin smelt fall--midwater trawl abundance index as a function of Delta outflow during March through May and December through May; the fall-midwater trawl abundance index two years prior (as an index of parental stock size); and a term indicating ecological regime (i.e., *Potamocorbula amurensis* invasion and pelagic organism decline). This modeling approach was developed to address concerns such as lack of parental stock terms in simpler X2-abundance approaches (Kimmerer 2002a) or uncertainty in density-dependence and use of models for predictions rather than to test hypotheses (Nobriga and Rosenfield 2016). The model is described by DWR (California Department of Water Resources 2022) (Appendix 12B).

3.3.4 Chinook Salmon

3.3.4.1 SacPAS Fish Migration Model

The SacPAS fish model allows estimation of juvenile Chinook salmon survival in Sacramento reaches downstream of the Red Bluff Diversion Dam (http://www.cbr.washington.edu/sacramento/fishmodel/). Survival, passage time, and estimated counts of juvenile passage at reference sites between the Red Bluff Diversion Dam and Freeport is based on the mean free-path length model (i.e., XT model), in which juvenile survival in the Sacramento River reaches is modeled as a function of reach length, passage time, and flow rate based on expected interactions with predators (Anderson et al. 2005). Parameters for the XT model were estimated using acoustic telemetry data from releases of juvenile late fall-run Chinook salmon, obtained from the Coleman National Fish Hatchery, in water years 2013 and 2014 (Steel et al. 2020).

3.3.4.2 STARS Models

The STARS model estimates the movement and survival of outmigrating smolts from Freeport to Chipps Island as a function of hydrodynamics and fish arrival date at Freeport (Perry et al. 2018). The model was parameterized using mark-recapture studies conducted on release groups of late fall-run Chinook salmon in the Sacramento River between 2006 and 2011.

Caveats for the SacPAS and STARs models include the reliance on flow as the only environmental covariate, with no formal consideration of other effects, including temperature and habitat capacity. The XT model also assumed all reaches to be free flowing, without consideration of any impoundments. Furthermore, recalibration of parameters for the XT model using more recent acoustic telemetry data from winter-run Chinook salmon is recommended but not yet underway (Hassrick et al. 2022). The current implementation of the STARS model may also be updated to reflect recent acoustic telemetry data from winter-run Chinook salmon in the Delta (Hance et al. 2021).

The SacPAS Fish Model can be used in concert with the STARS model to evaluate survival to Chipps Island performance metrics for winter-run Chinook salmon. These models can incorporate historical or simulated flow data, like those generated from CalSim II, and initial numbers of juveniles passing the Red Bluff Diversion Dam as model input.

3.3.5 Other Species

A number of general linear models are available which link spring Delta outflow or X2 to abundance or survival of fish and shrimp species occurring within the Delta. Relationships predicting abundance or survival were developed by Kimmerer et al. (2009) and recently applied by DWR (California Department of Water Resources 2022, Appendix 12B) for the following species:

- Striped bass (separate models based on bay otter trawl abundance index, bay midwater trawl abundance index, fall-midwater trawl abundance index, summer townet abundance index, and summer townet survival index).
- American shad (separate models for bay midwater trawl abundance index and fall-midwater trawl abundance index).

- Starry flounder and California bay shrimp (models based on bay otter trawl abundance indices).

General linear models are also available linking white sturgeon year class strength (based on capture by otter trawls by the San Francisco Bay Study) to March through July and April through May Delta outflow (California Department of Water Resources 2022 [Appendix 12B]).

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4. Initial Options Analysis

Scoping and coordination with agencies and interested parties identified potential subcomponents for Old and Middle River that may be combined into options for components of initial alternatives. Different options may omit, substitute, combine and/or modify subcomponents. Detailed text is provided under the options section. A summary of subcomponents moving forward from scoping include:

- Additional Delta Outflow above D-1641
  - Export to Delta Inflow Adjustment (E:I Ratio) through restriction in exports
  - San Joaquin River Inflow to Export Ratio (San Joaquin I:E Ratio) through restriction in exports
    - 2:1 during March through May
    - 1:1 during mid-April through mid-May
  - Export reduction of 125 thousand acre-feet (TAF)
  - Exports under D-1641 I:E ratio
- Additional Inflow above D-1641
  - Sacramento River inflow increased by 200 TAF releases (all years, certain years)
  - San Joaquin River inflow increased by 50 TAF releases (all years, certain years)
  - 65% uninterrupted flow January through June
- Flow-Abundance Delta Outflow Objective
- Scheduled Export Limitation (combined exports no more than XX cubic feet per second [cfs])

The detailed text for each of the subcomponents is provided under each option.

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5. Initial Alternative Effects Assessment Options

5.1 Effect of Spring Inflow and Outflow on Ecosystem Productivity

Ecosystem productivity in the Delta, integrating both primary production and densities of zooplankton like *Eurytemora affinis*, reflects a balance of numerous forcing factors, including riverine carbon inputs (i.e., detritus), floodplain inundation, salinity conditions, water residence time, turbidity, and inorganic nutrient loading. Of these forcing factors, the effects of turbidity and inorganic nutrient availability will be minimally affected by spring outflow. Given plentiful nutrients in the Delta, light availability due to high turbidity historically has been a limiting factor for primary productivity in the Delta, and increased spring outflow is not necessarily expected to affect this constraint (Jassby et al. 2002).

Supply of detrital-based organic carbon from river inflows to the Delta can match or exceed carbon produced by local phytoplankton, depending on annual river flow. High freshwater inflow has been correlated with dominance of detrital or river-based carbon in Suisun Bay (Jassby et al. 1993). Detrital matter has been observed to be only weakly linked to the Delta's pelagic food web due to its reliance on the microbial loop to be made bioavailable (Sobczak et al. 2002; Sobczak et al. 2005).

Changes in spring outflow due to floodplain inputs can temporarily increase riverine ecosystem productivity in riverine floodplain habitats like the Yolo Bypass. Primary production in the Yolo Bypass, as measured by chlorophyll a, was observed to increase rapidly after flooding and subsequent draining back to the level of the perennial channel (Schemel et al. 2004). These levels of primary production were approximately two times (or more) greater than levels in the main Sacramento River channel (Lehman et al. 2008). Copepod and cladoceran densities did not appear to vary meaningfully between floodplain and channel habitat, but floodplain habitat supported higher densities of Diptera and terrestrial invertebrates (Sommer et al. 2004). High biomass can remain in the Yolo Bypass for several weeks before decreasing to pre-flooding levels. The floodplain habitat can contribute substantial loads of primary producer biomass and, particularly, biomass of wide-diameter diatoms and green algae, to downstream reaches of the Sacramento River entering the north and west Delta (Lehman et al. 2008). Results from this research suggest that multiple flooding and draining cycles will maximize transport of primary production downstream of the Yolo Bypass. The minimum necessary flood pulse, as measured in river flow, to inundate the Yolo Bypass floodplain was estimated to be 2,000 cfs; the estimated flow necessary to flood the entire bypass was 8,000 cfs (Williams et al. 2009). The expected contributions of Yolo Bypass productivity to overall productivity in the Delta is unknown.

Effects of spring outflow on the Delta include changing the distribution of salinity (e.g., the low-salinity zone and X2). There is a strong negative relationship between X2 and Delta outflow (Jassby et al. 1995). Specific relationships between Delta outflow, X2, and the corresponding low-salinity zone are modeled by past studies (Kimmerer et al. 2013; MacWilliams et al. 2015); these studies found that X2 changes more rapidly at higher Delta outflows. Therefore, the ability to meaningfully influence X2 with relatively low additional Delta outflows may be limited.

Past research has tested the hypothesis that species abundance varies with the volume of low-salinity habitat and documented a negative relationship between focal copepod species like *E. affinis* and X2 (Kimmerer 2002a). This relationship is also supported by model predictions that pulse spring flows in dry water years can increase copepod biomass near Suisun Bay (Hamilton et al. 2020). Other recent analyses have provided additional support for higher smelt copepod and mysid prey with greater spring Delta outflow (Hennessy and Burris 2017; Greenwood 2018). However, as shown by Reclamation and DWR (2021:2-11), there are more significantly negative relationships of zooplankton to spring Delta outflow than positive relationships at the scale of the regions sampled by the Environmental Monitoring Program and 20-Millimeter Survey.

Primary productivity in the Delta is influenced by the water residence time. At higher river inflows, water residence time in most of the estuary decreases. Decreased residence time limits the buildup of primary producers and typically results in lower plankton biomass (Kimmerer 2004; Jassby 2008). Conversely, very high residence times associated with lower river inflow may be offset by losses from water diversions. The effects of residence time on primary productivity in areas in the Delta, like Suisun Bay, appear muted by the grazing pressure of the invasive clam *Potamocorbula amurensis* (Jassby 2008; Kimmerer et al. 2012; Kimmerer and Thompson 2014). Grazing from clams and zooplankton has exceeded net phytoplankton growth in some regions, requiring a subsidy from other regions. However, the probability of spring blooms of primary productivity in Suisun Bay, rare in recent decades, may be enhanced by maintaining sufficient river flows to dilute anthropogenic sources of ammonium and simultaneously preventing washout of primary productivity at higher river flows (Dugdale et al. 2012; Glibert et al. 2014). The role of ammonium has been debated, and one recent study suggested that high ammonium loading is not a driver of the lower productivity in the San Francisco Bay Delta (Strong et al. 2021).

In total, increased spring outflows from the Delta can expand the area and volume of the low-salinity zone with potential ramifications for zooplankton distribution and abundance; but the extent of expansion will be muted at lower levels of outflow. High spring outflow may increase zooplankton biomass, and particularly zooplankton preferred by Delta and longfin smelt, in more habitats occupied by these species. Increased outflows are not necessarily expected to increase primary productivity via nutrient supplementation, due to existing nutrient availability, or via effects on light availability. Spring flows that are too high may decrease primary productivity by decreasing water residence time, while low spring outflow alternatives may increase the proportion of productivity that is removed by exports. The response of zooplankton production to increased, river-based detrital inputs may be minimal; and transport of primary production from one area of the Delta to another may be limited (Kimmerer et al. 2018).

5.2 Effect of Spring Outflow on Water Quality

Spring outflows have varying effects on important aspects of water quality in the Delta, including temperature, salinity, turbidity or sedimentation, oxygen, nutrients, contaminants, and organic and inorganic particle load (Schoellhamer et al. 2016).

Freshwater inflow into the Delta has limited direct effects on temperatures in the Delta after winter storms and runoff events cease by the end of February (Wagner et al. 2011). Water temperatures in the Delta are usually driven by surface heat fluxes, and any effects of altered spring freshwater inflow will diminish rapidly (i.e., in less than a month) (Monismith et al. 2009; Wagner et al. 2011). However, outflow-based effects on Delta hydrology may have indirect effects on temperature patterns throughout the Delta (Gleichauf 2015) as springtime surface water temperature is typically colder when inflow is higher (Bashevkin and Mahardja 2022).

The effects of spring outflows on salinity in the Delta have been described in part in the previous analysis, but additional nuances in the relationship between outflow and salinity can be described here. Modeling efforts have observed that X2 responds more rapidly to increases in flow than decreases (Chen et al. 2015), which supports the value of spring outflow pulses for improving Delta habitat as it relates to salinity. However, pulse flows are expected to require a larger total volume of flow to maintain a given X2 than a steady flow corresponding to the same X2 (Monismith 2017).

Turbidity levels in the upper Delta respond strongly to high winter and spring river inflows associated with storm runoff (Schoellhamer et al. 2012), but the effects of spring outflow pulses from reservoirs appear to be poorly understood. Releases from reservoirs are relatively clear and are not expected to contribute substantial suspended sediment loads to downstream reaches. Sedimentation patterns throughout the Delta may be affected indirectly by flows as changing salinity levels in the Delta can alter hydrology and sediment transport (Shellenbarger et al. 2013).

Effects of spring river inflow and exports (which result in outflow) on oxygen, nutrients, contaminants, and particle load are less understood. Spring river inflow may indirectly maintain sufficient oxygen levels for normal ecosystem function by decreasing residence time and reducing occurrences of high biological oxygen demand (i.e., large phytoplankton blooms) (Monsen et al. 2007; Baxter et al. 2008). Spring outflow may reduce the effect of contaminants on ecosystems by reducing water residence time (Schoellhamer et al. 2016). In this case, the operations to improve outflows may affect water residence time differently. Reducing exports to increase outflow may not reduce residence times similar to how greater inflows reduce water residence times. Direct effects of river inflow on concentrations of contaminants are incompletely understood. For example, Kimmerer et al. (2002b) reports competing hypotheses that increased river flows either dilute existing contaminants or increase loading of contaminants, potentially through increased terrestrial habitat connections and runoff.

5.3 Effects of Spring Outflow on Migratory Conditions

Spring outflow has important effects on migratory conditions, through impacts on factors such as water quality and food availability. Water quality effects of spring outflow—such as temperature, salinity, turbidity or sedimentation, oxygen, nutrients, and contaminants (Schoellhamer et al. 2016)—are included in the conceptual models of juvenile winter-run Chinook salmon (Figure 1) from Windell et al. (2017). High river inflows in the spring provide connectivity to off-channel habitat such as floodplains (Takata et al. 2017). Floodplains increase aquatic food availability, and juvenile salmon growth is highest in these habitats. Measurement of fall-run Chinook growth in the Delta compared to the natal stream (American River) from 2014 through 2016 showed that growth in the Delta was faster than in the natal stream in 2016, but not in the drought years of 2014 and 2015 (Coleman at al. 2022). Differences were attributed to factors such as food availability and density-dependent competition that are affected by lower river inflows in drought years.

Flow has important effects on salmonid migratory behavior. Downstream migration and arrival of juveniles at Knights Landing in the Sacramento River is correlated with the timing of the first high flows in spring (del Rosario et al. 2013). Migratory travel times of Sacramento River salmon smolts decreases with increasing river discharge (Michel et al. 2013; Steel et al. 2020; Hance et al. 2022). There are positive relationships between river inflow and juvenile Chinook salmon migration survival in the rivers upstream of the Delta (Henderson et al. 2019, Michel et al. 2021, Hassrick et al. 2022) and in the Delta, primarily in the riverine reaches; whereas, inflow has less effect as tidal action becomes the predominant force controlling water velocity and direction of flow (e.g., in the Sacramento River downstream of Georgiana Slough (Perry et al. 2018; Hance et al. 2022). The magnitude of river inflow influences predation risk within the Delta and entry into the interior Delta increases with decreasing flow (e.g., at the Sacramento River–Georgiana Slough junction (Perry et al. 2018; Hance et al. 2022). Exports are not identified to influence predation risk within the Delta nor entry into Georgiana Slough, so increased outflow by reducing exports may not affect predation risk or routing at Georgiana Slough. Differences in the survival and migratory success of different life stages of Chinook (e.g., fry, smolt, juvenile) may have different relationships to water year types and managed flow regimes (Sturrock 2015 and 2020). Reach-specific pulse flow events also have been observed to increase survival, particularly in low flow years (Henderson et al. 2019; Hassrick et al. 2022). Additional research to quantify how much spring export reductions, tributary releases, and/or both improve migratory conditions will be forthcoming

An acoustic telemetry study of steelhead released in the San Joaquin River upstream of the head of Old River found no association between migratory survival from the head of Old River to Chipps Island and south Delta exports, and only weak support for an association between migratory survival and CVP proportion of combined exports (Buchanan et al. 2021). This finding would suggest that spring management may have limited effects on migratory conditions for steelhead. However, this study was conducted during a period with relatively low variability in export levels, making it difficult to detect potential survival effects. Survival in the upstream reaches of the Delta was associated with river discharge into the Delta, while survival through the lower reaches of the Delta was associated with migration routes (Buchanan et al. 2021). For fall-run Chinook salmon released upstream of head of Old River, Buchanan and Skalski (2020) found survival from the head of Old River to Chipps Island was positively related to the volume of Old River flow (regardless of flow direction) in the strongly tidal interior Delta, but was not related to San Joaquin River flow either entering the Delta from upstream or measured in the Delta near the riverine/tidal interface. However, survival in the upstream, more riverine region of the Delta was positively associated with San Joaquin River flow in the Delta. Buchanan and Skalski (2020) noted that their finding of generally limited effects of flow and south Delta exports on survival was generally similar to the findings of Zeug and Cavallo (2013), who studied the effects of those predictors as reflected in survival of juveniles to capture in ocean fisheries.

Another migrating species, white sturgeon, has a positive relationship between year class strength and Delta outflow (Fish 2010). Among several Delta outflow periods examined, similar magnitudes of positive correlation with year class strength were found for November through February, April alone, July alone, and March through July (Fish 2010). Fish (2010) suggested that fall and winter river inflows provide stimuli for adult migration and gonadal maturation, with spring flows providing stimuli for spawning; increased survival of eggs, larvae, and early juveniles; and transport of juveniles to the estuary.

5.4 Effect of Spring Inflow and Outflow on Delta Fish Abundance

Various fish-flow relationships have been established in the San Francisco Bay-Delta and have been reviewed in a recent publication (Tamburello et al. 2019). However, some questions remain regarding which flow metrics are most correlated with fish abundance metrics/indices. Analysis was done for a few fish-flow relationships using more recent data to see if R^2 values of these ordinary least squares (OLS) regressions from previous studies are improved or worsened by the use of different flow metrics. Below is a table that summarizes R^2 based on the different flow metrics and species used to construct OLS regression.

Species	X2	Delta Outflow	Delta Inflow	Unimpaired Runoff
Longfin smelt	0.67	0.64	0.64	0.51
Striped bass	0.00	0.00	0.00	0.02
Splittail	0.25	0.30	0.30	0.13

The longfin smelt and splittail relationships are from Kimmerer (2002a). The striped bass relationship is a recreation of Stevens (1977)T with the full-time series, using the data from Tamburello et al. (2018)(https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lno.11037). Data and code can be found at https://github.com/bmahardja/flow-fish-relationship/blob/main/R_VariousFlowMetrics. Note that the exact month range that was used in the original analyses cannot be recreated for unimpaired runoff since there is no runoff in the drier months of June and July. Therefore, combined water year runoff value was used.

Longfin smelt has a relationship with all the variables given that the Bay-Delta hydrology is mainly driven by climate. However, it also makes sense that outflow and X2 have a better fit with longfin smelt considering that longfin smelt are distributed downstream of the confluence most of the time. That is, underlying mechanism would be related to X2 or outflow instead of unimpaired runoff. Note, however, that some other modeling approaches have found unimpaired runoff to have a higher correlation with longfin smelt population dynamics than Delta outflow (Maunder et al. 2015). In addition to Delta outflow, indices of parental stock size have also been shown to have good correlations with longfin smelt abundance indices, and the intercept of flow-abundance relationships has shifted downward over time (Nobriga and Rosenfield 2016; California Department of Water Resources 2022:Appendix 12B,pp.12B-99–12B-104).

It also makes sense that splittail has a good fit even with inflow given that the floodplains splittail use to spawn are upstream of the export facilities. This is the mechanism underlying the correlation that was suggested by Kimmerer (2002a). Other species occurring in the Bay-Delta with statistically significant relationships with Delta outflow and X2 include American shad, starry flounder, and California bay shrimp (Kimmerer et al. 2009; Tamburello et al. 2018).

Delta smelt generally have not been shown to have statistically significant relationships with spring Delta outflow using linear models (Kimmerer et al. 2009), although more complex state-space modeling has found evidence for the spring E:I ratio being negatively related to Delta smelt recruitment (i.e., the transition from adult to the subsequent larvae) (Polansky et al. 2021).

6. Summary

- Spring Delta outflow can affect numerous attributes of water quality. There is a well-established relationship between outflow and salinity incursion into the Delta, with increasing outflow leading to decreased salinity. Increasing riverine inflow to meet outflow may decrease Delta water temperatures indirectly, though atmospheric influences predominate. Reducing exports to meet outflow are likely to result in longer residence times, which are likely to result in warmer water temperatures. There remains uncertainty about sources of spring outflow and oxygen, contaminants, and sediment.

- Changes in spring Delta outflow due to changes in river inflow can increase primary productivity and fish growth in migratory habitats by inundating seasonal floodplain habitat like the Yolo Bypass. Changes in spring Delta outflow due to exports has not been shown to have similar effects. Effects of spring Delta outflow on ecosystem productivity in the tidally-influenced estuarine Delta regions are less clear. Modifying spring Delta outflow may affect productivity primarily by changing the volume and distribution of low-salinity habitat as well as changing water residence time.

- Changes in spring Delta outflow through increased riverine inflow increases survival of juvenile salmonids through the Delta.

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