Long-Term Operation – Initial Alternatives

Appendix P – Delta Habitat Restoration

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

Operation of the Central Valley Project (CVP) and State Water Project (SWP) includes implementing nonflow habitat-restoration actions to increase rearing habitat, including creation, expansion, and grading of floodplains and side channels, and enhancing foodweb connectivity through increasing tidal habitat. The nonflow habitat actions in the San Francisco Bay/Sacramento–San Joaquin Delta Estuary (Bay-Delta) are focused on foodweb support for Delta smelt and rearing habitat for outmigrating salmonids. These actions may also contribute to levee resilience and increase habitat connectivity to support a broad range of aquatic- and wetland-dependent species. These actions are also expected to restore ecosystem functions associated with tidal marshes, floodplains, and lowland grasslands by establishing unimpeded tidal connectivity, allowing exchange of water, sediment, nutrients, primary productivity, and aquatic organisms.

U.S. Bureau of Reclamation (Reclamation)'s management questions for the formulation of an alternative include:

- Where is a Delta habitat-limitation affecting Delta smelt and outmigrating salmonids?
- Does habitat restoration increase primary and secondary productivity and improve somatic growth of target species?
- What is the energy flow of habitat restoration productivity to different regions of the Delta, fish, and/or clams?
- Does habitat restoration provide refuge and improve survival for Delta smelt or salmonids?
- How does habitat restoration affect operations for flood conveyance, water supply, and/or water quality?

Tidal habitat restoration required in the U.S. Fish and Wildlife Service (USFWS) 2008 Biological Opinion was included within the 2020 Record of Decision (ROD) and its accompanying 2019 Biological Opinions. The *Yolo Bypass Salmonid Habitat and Fish Passage ROD* and the *Suisun Marsh Habitat Management, Preservation, and Restoration Plan ROD* implement additional Delta habitat actions. Contrary to other variable components, initial alternatives for tidal habitat restoration address whether to include or exclude habitat restoration from consideration, and not a range of options.

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2. Performance Metrics

Performance metrics describe criteria that can be measured, estimated, or calculated relevant to informing trade-offs for alternative management actions.

2.1 Habitat

Various field-occupancy and laboratory studies have demonstrated Delta smelt association with a set of physical conditions, such as turbidity, salinity, current speed, and temperature (Feyrer et al. 2011; Bever et al. 2016; Hasenbein et al. 2016; Davis et al. 2019a, Davis et al. 2019b). Consequently, suitable physical habitat for Delta smelt can be modeled based on appropriate ranges of these variables. Increase of suitable habitat was the basis of the fall X2 action, where the low-salinity zone is moved farther downstream of the Delta. Operation of the Suisun Marsh Salinity Control Gate during summer and fall is expected to increase suitable habitat in Suisun Marsh by lowering salinity (Sommer et al. 2020). However, food-subsidy actions are not expected to have any measurable effect on the physical habitat of Delta smelt.

2.2 Zooplankton Abundance, Biomass, and Community Composition

The availability and quality of prey have been identified as important drivers of juvenile and subadult Delta smelt and longfin smelt growth and survival (Figures 3, 4, 5). An objective of habitat restoration is creating more suitable physical habitat that enhances zooplankton production and biomass. The regional focus of these habitat restoration activities is primarily the Suisun (i.e., Suisun Bay, Grizzly Bay, and Suisun Marsh), Cache Slough, and Yolo Bypass.

A habitat suitability index can include both physical and biological conditions that support Delta smelt. One method is calculating a weighted food-availability score by multiplying the average zooplankton biomass in each region/month for a scenario by the habitat suitability index (California Department of Water Resources 2022). This method has been utilized for summer–fall habitat actions. Including both physical habitat and zooplankton prey in a single index more directly evaluates the potential benefit of habitat restoration projects.

2.3 Biological

Biological metrics consider direct observations and environmental surrogates.

- Smelt metrics (delta and longfin)
    - Survival rate

    - Growth rate
- Juvenile salmonid metrics (winter-run and spring-run Chinook salmon, steelhead)
    - Survival rate
    - Growth rate

2.4 Water Supply

Water supply metrics consider the multipurpose beneficial uses of Delta habitat restoration.

- South-of-Delta agricultural deliveries (average and critical/dry years).
- San Joaquin river exchange and settlement contracts and CVP Improvement Act refuge deliveries.
- Frequency of when Old and Middle River is controlling exports.

Water supply in the Delta can be affected by habitat restoration. CalSim II would support the evaluation of water supply metrics once project-specific design details are available.

2.5 National Environmental Policy Act Resource Areas

Considerations under the National Environmental Policy Act would include changes in multiple resource areas. Key resources are anticipated to include surface water supply, water quality, air quality, aquatic resources, terrestrial biological resources, regional economics, land use and agricultural resources, recreation, cultural resources, hazards and hazardous material, and climate change.

3. Methods

Although there was no knowledge-based paper for Delta habitat restoration, many of the datasets, literature, and models overlapped. These appendices considered the knowledgebase papers and additional literature and determined the most relevant approach for Reclamation in answering management questions and evaluating options for potential alternatives.

Since implementation of the ROD and Incidental Take Permit, Reclamation and CDWR have applied a series of non-flow, habitat-restoration actions within the Delta to improve spawning and rearing habitat and foodweb conditions. The *Long-Term Operations Habitat Restoration Seasonal Report,* updated annually or as needed, lists planned, under-construction, and recently completed habitat-restoration actions. Reclamation and California Department of have developed multiple documents that are being used to understand and monitor the effects of these actions, identify science and monitoring needs, identify relevant models and data sets, and guide structured decision making. Documents include the following: (1) Science and Monitoring Plan, updated annually; (2) action-specific operations and science plans, updated every 1 to 3 years; (3) structured decision-making process document and performance measure information sheets (California Department of Water Resources 2022, Appendix B); and (4) 2022 Action Plan (California Department of Water Resources 2022).

3.1 Datasets

Abiotic and biotic data used to assess habitat-restoration sites included publicly available monitoring data, as well as data collected specifically for each action. Data sets include sample-site geolocation data.

Multiple agencies collect continuous and discrete abiotic data, including DWR and U.S. Geological Survey (USGS). Continuous abiotic (e.g., hydrologic, temperature, turbidity) data are publicly available in real time on Bay Delta Live (https://www.baydeltalive.com), CDWR's California Data Exchange Center (https://cdec.water.ca.gov), and USGS and San Francisco Estuary Institute (SFEI) and the Aquatic Science Center's Data Integration Portal (https://www.sfei.org/sfeidata.htm). Discrete water quality data are publicly available on Environmental Data Initiative (EDI; https://environmentaldatainitiative.org) and Bay Delta Live. Suisun Marsh Monitoring Program Channel Water Salinity Reports are available on the California Natural Resources Agency website (https://resources.ca.gov), under Data and Resources.

Lower trophic (i.e., phytoplankton, zooplankton, benthic invertebrate) data are collected by multiple agencies and monitoring programs, including CDWR and California Department of Fish and Wildlife (CDFW). Data are publicly available on Bay Delta Live, EDI, and the CDFW File Transfer site (https://ftp.wildlife.ca.gov). CDFW and USFWS monitor Delta smelt and longfin smelt throughout the year, using multiple gear types. CDFW's 20-millimeter spring Kodiak trawl, summer townet, fall midwater trawl, bay study, and USFWS's Enhanced Delta Smelt

Monitoring (EDSM) program are some of the relevant datasets. CDFW's Fish Restoration Program also collects relevant data on physical and biological parameters at restoration sites. Data are publicly available on EDI and the CDFW File Transfer site and available on request from the agencies. Daily and weekly EDSM data are available on USFWS's Lodi website library (https://www.fws.gov/office/lodi-fish-and-wildlife). Many of the lower trophic datasets have been integrated into a single data set, using the R-package, Zooper (Bashevkin et al. 2022).

Data collected by the Directed Outflow Project (https://www.usbr.gov/mp/bdo/directed-outflow.html) include abiotic (i.e., physical and chemical) and lower trophic (i.e., phytoplankton and mesozooplankton) data collected simultaneously with USFWS's EDSM monitoring (U.S. Bureau of Reclamation and California Department of Water Resources 2022, Appendix E). Any Delta smelt that EDSM collects are then processed for dietary contents, growth and life-history strategy, and histological indices of health. Data are available on request from Reclamation or the University of California, Davis.

Data on habitat restoration acreage (completed and planned) is described in the *2021 Long-Term Operations Habitat Restoration Report* (U.S. Bureau of Reclamation 2021).

3.2 Literature

3.2.1 Chinook Salmon and Steelhead

Delta habitat restoration can affect the growth, survival, and life-history diversity of juvenile Central Valley Chinook salmon. Chinook salmon and steelhead use side-channel and floodplain habitat along Delta shorelines for feeding and growth, and the Delta can serve as a transition zone between freshwater rearing and saltwater entry. Figures 1 and 2 (below) provide conceptual models for effects of habitat conditions on fish responses during the transition from rearing to outmigrating in the Delta. Delta habitat restoration is expected to influence aspects of habitat conditions, including turbidity, structural complexity, connectivity, shallow-water habitat, and food production and retention.

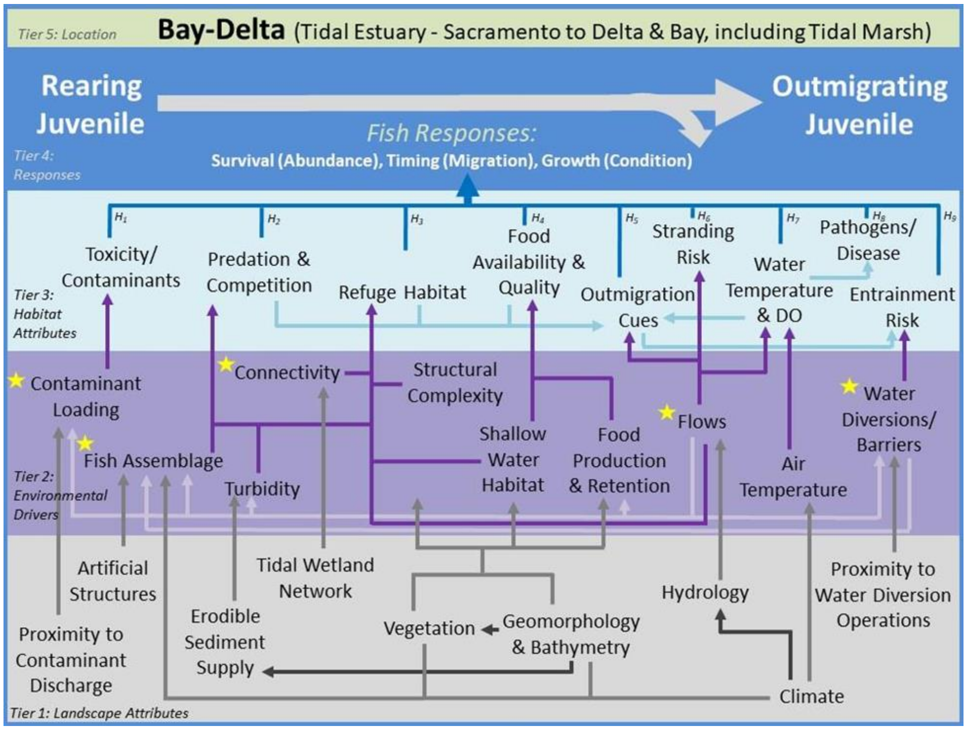


Figure 1. Conceptual model of attributes affecting the transition of winter-run Chinook salmon from rearing juvenile to outmigrating juvenile in the Delta (copied from Windell et al. 2017).

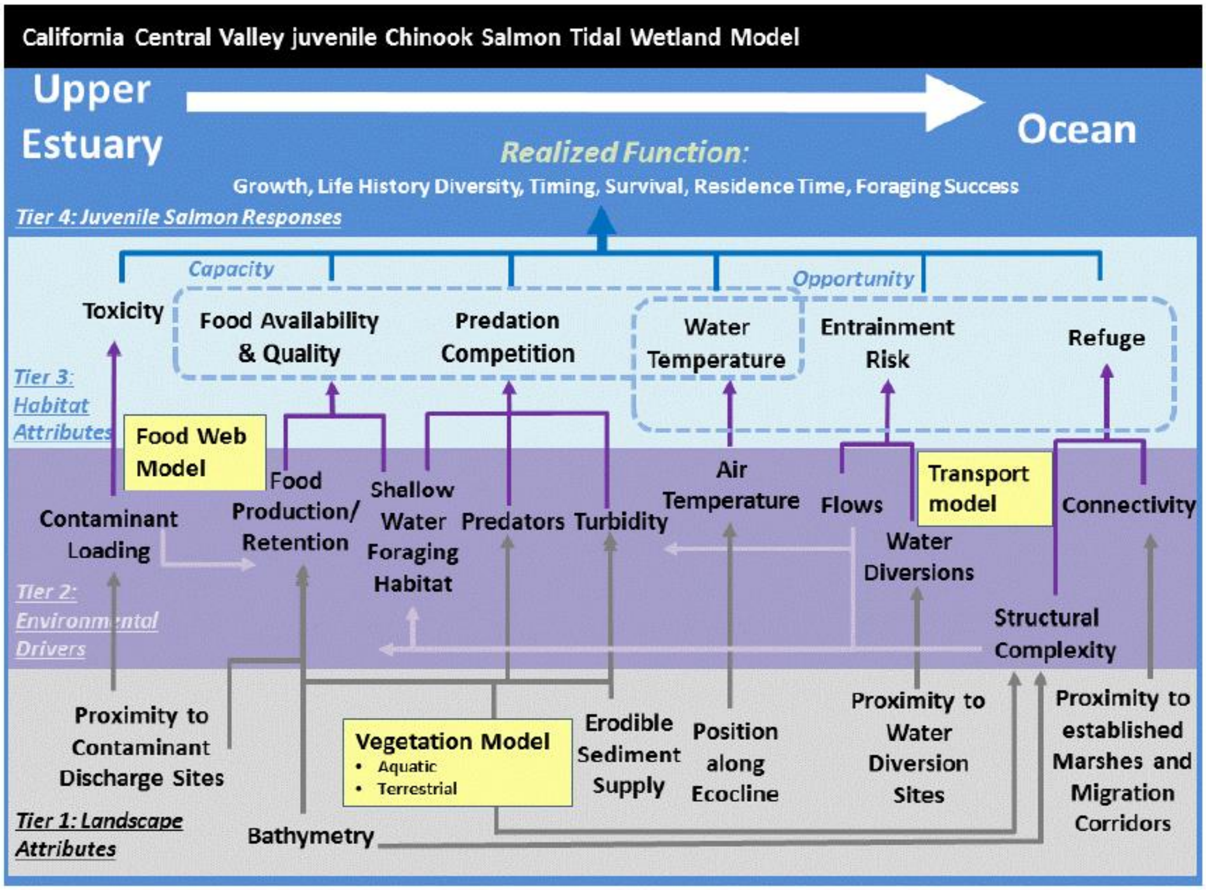


Figure 2. Central Valley Juvenile Chinook Salmon Tidal Wetland Conceptual Model. From Sherman et al. 2017.

Delta habitat restoration can affect the growth of juvenile salmon through modifications to water temperature, food availability, and competition for resources. Shallow Delta habitats, including wetlands and floodplains, typically exhibit greater temperatures, higher residence times, and greater production and retention of macroinvertebrates, with resulting positive effects on growth rates relative to channeled habitat (Schemel et al. 2003; Jeffres et al. 2008).

Delta habitat restoration can affect juvenile salmon by providing greater food resources and increasing cover or bathymetric heterogeneity as refugia from predators (Rahel and Stein 1998; Hering et al. 2010). Increased connectivity and habitat heterogeneity also can allow salmon to adapt and move in response to locally stressful conditions (Armstrong et al. 2013).

3.2.2 Delta Smelt

The Bay-Delta’s Mediterranean climate means that, in a typical year, Delta smelt experience wet conditions (i.e., high precipitation and flows) during the winter and spring months, and dry and low flow conditions in the summer–fall months. Delta smelt occur primarily in the low-salinity and freshwater portions of the Bay-Delta. Historically, the center of distribution of Delta smelt closely followed the location of the low-salinity zone (as approximated by X2; Sommer et al. 2011). However, in more recent years, there is growing recognition that a substantial portion of the Delta smelt population can reside year-round in the perennially freshwater Cache Slough Complex (Mahardja et al. 2019; Hobbs et al. 2019).

During the summer–fall period, subadult Delta smelt primarily rear in the western Delta, Suisun Bay, and Cache Slough Complex (Merz et al. 2011; Sommer and Mejia 2013; Interagency Ecological Program 2015). Although Delta smelt used to occur in the central and southern Delta during the summer–fall months, this is no longer the case (Nobriga et al. 2008). The degree to which Delta smelt use these areas depends on salinity, temperature, and turbidity (Nobriga et al. 2008, Feyrer et al. 2011); other factors may affect their summer distribution, such as the presence of *Microcystis* blooms and prey density, bathymetric features, or other water-quality constituents. Periods of low outflow are thought to be stressful for Delta smelt because the volume of physically suitable habitat becomes restricted by encroaching salinity (Feyrer et al. 2011). As such, the summer–fall period may represent a seasonal bottleneck for the species as freshwater flows reach their annual nadir, and access to seaward habitat (e.g., Suisun Marsh) is lost, particularly during droughts (Hammock et al. 2021).

Habitat restoration is aimed toward increasing food subsidies for Delta smelt. During the spring and summer, Delta smelt rear in the low-salinity zone. Thus, restoration projects that target areas adjacent to rearing areas (e.g., western Delta, Suisun Bay, Cache Slough Complex) and create suitable conditions for Delta smelt are expected to benefit Delta smelt.

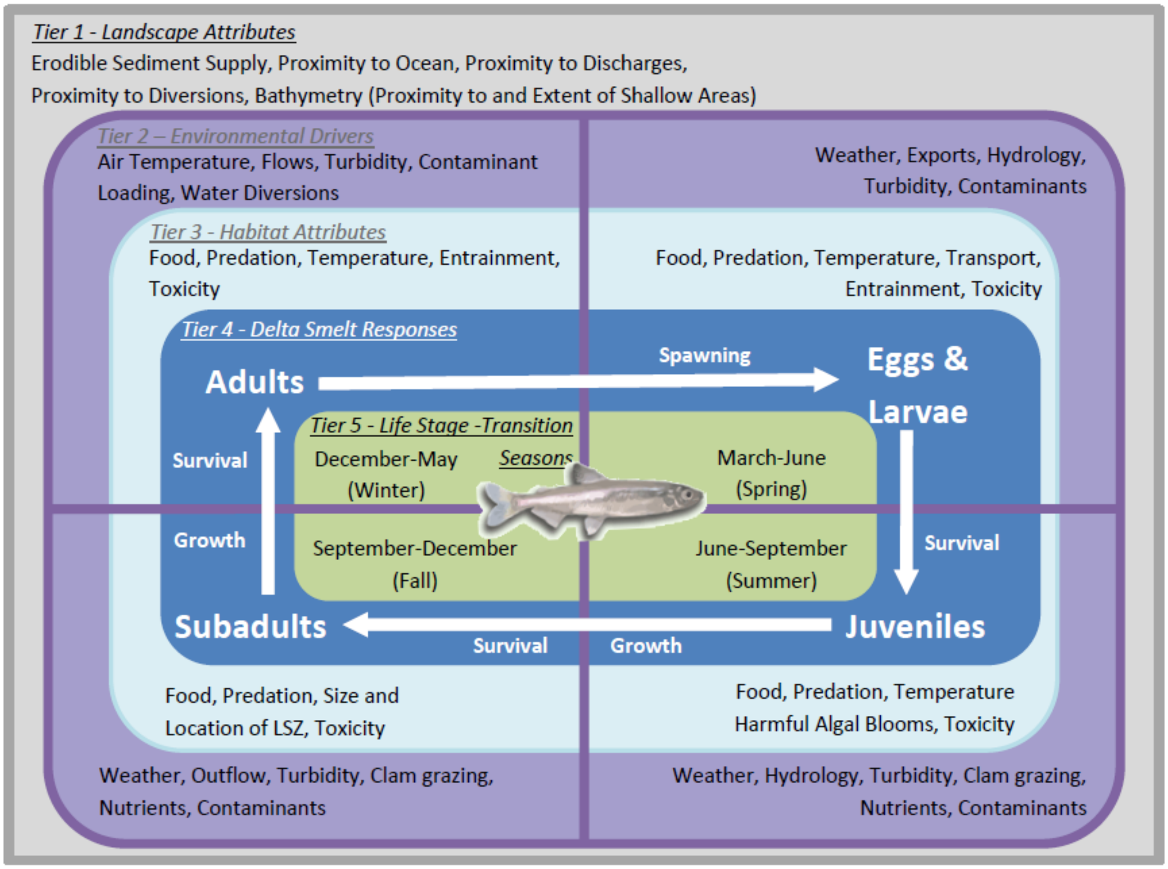


Figure 3. Delta Smelt Conceptual Model. From Interagency Ecological Program 2015.

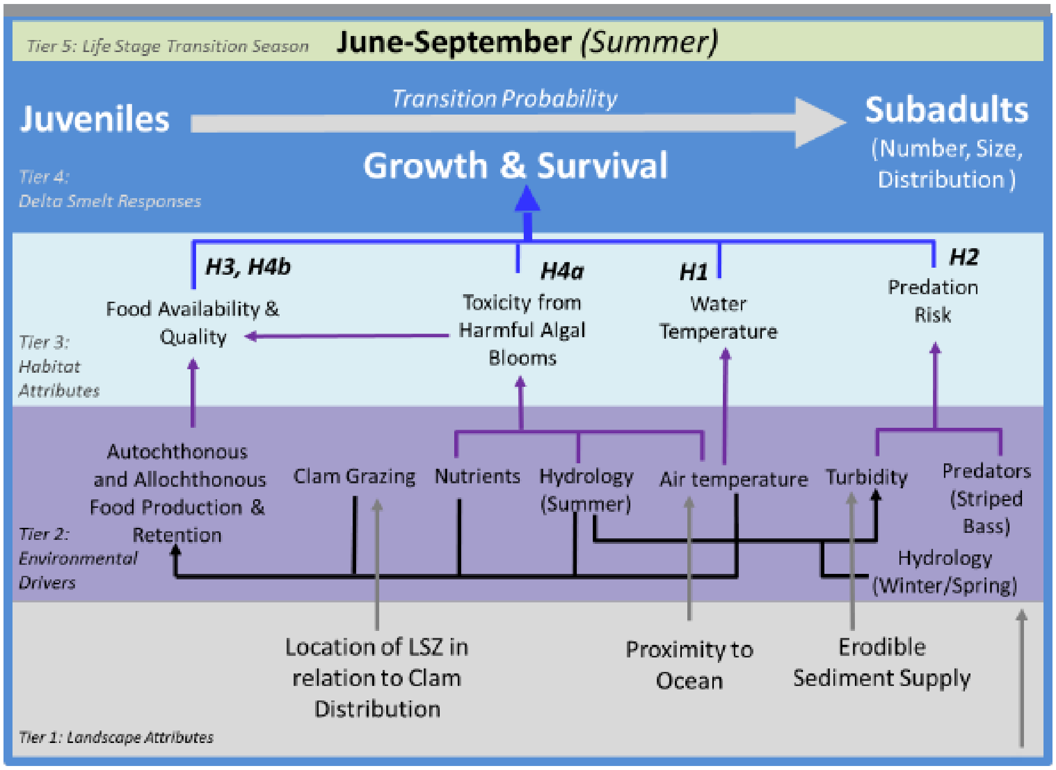


Figure 4. Juvenile to Subadult Delta Smelt Conceptual Model. From Interagency Ecological Program 2015.

Habitat restoration is designed primarily to increase food availability and quality, leading to increased growth and survival. Site selection and design characteristics are important for determining water temperature, turbidity, and nutrients and can also influence predation risk, clam grazing, and nutrient availability, all of which would affect survival of Delta smelt.

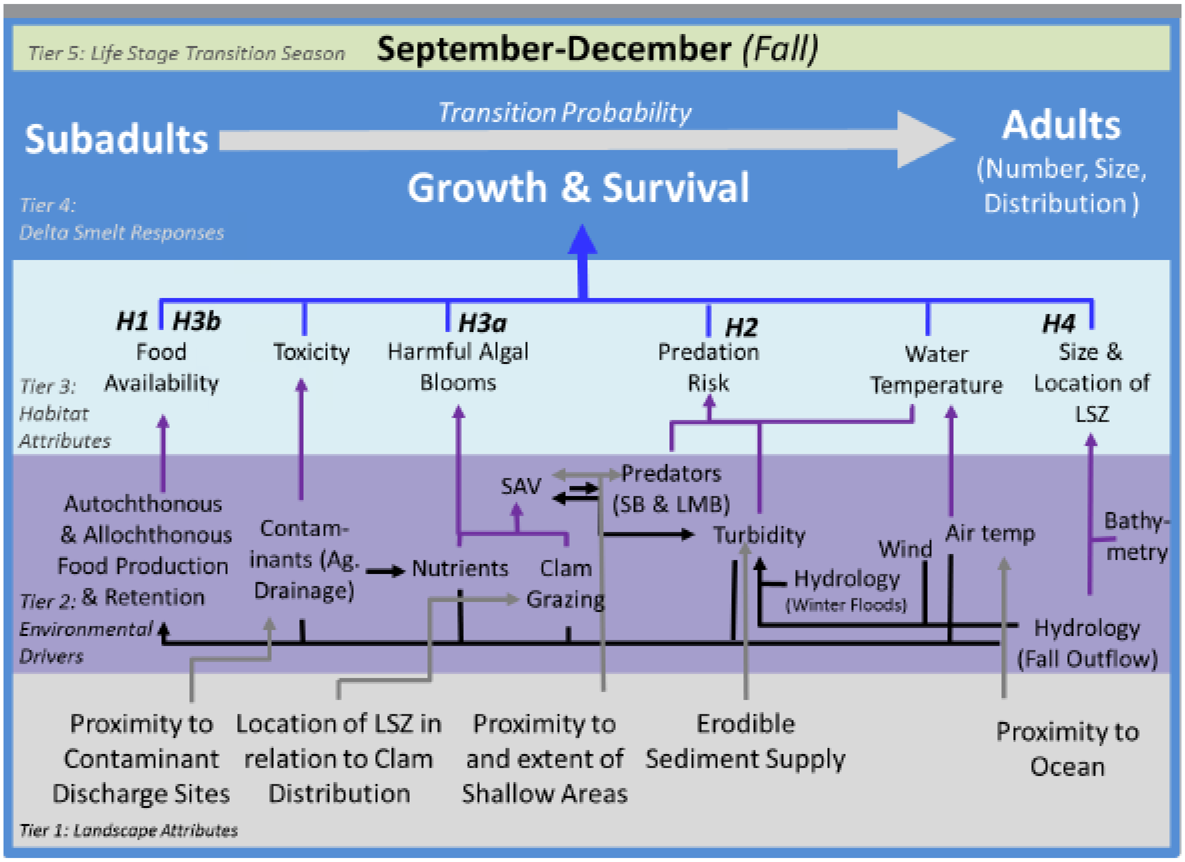


Figure 5. Subadult to Adult Delta Smelt Conceptual Model. From Interagency Ecological Program 2015.

Habitat restoration is designed primarily to increase food availability, leading to greater growth and survival. Site selection and design characteristics are important for determining water temperature, turbidity, and nutrients and can also influence predation risk, submerged aquatic vegetation, clam grazing, and nutrient availability, all of which would affect survival of Delta smelt.

3.2.3 Food Web/Transport

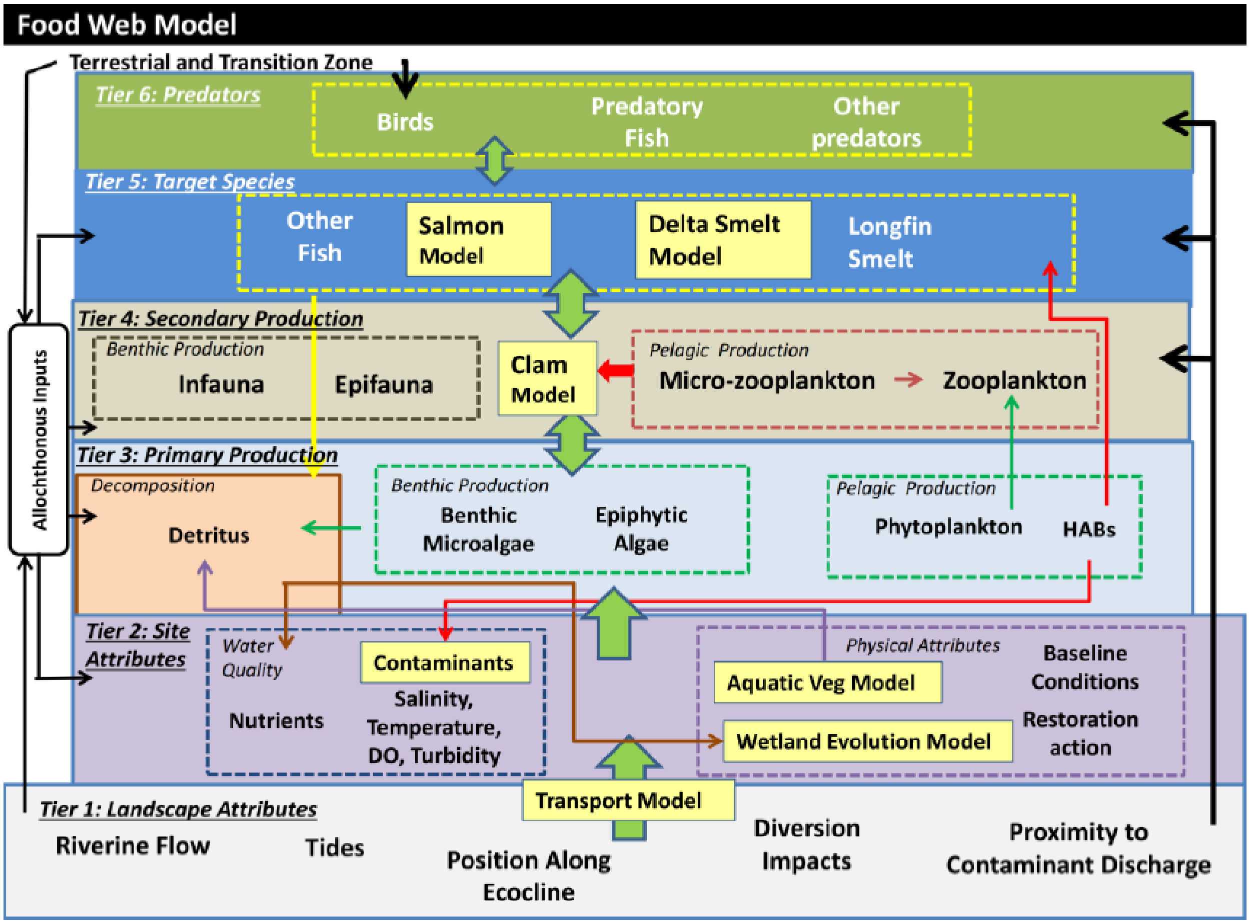
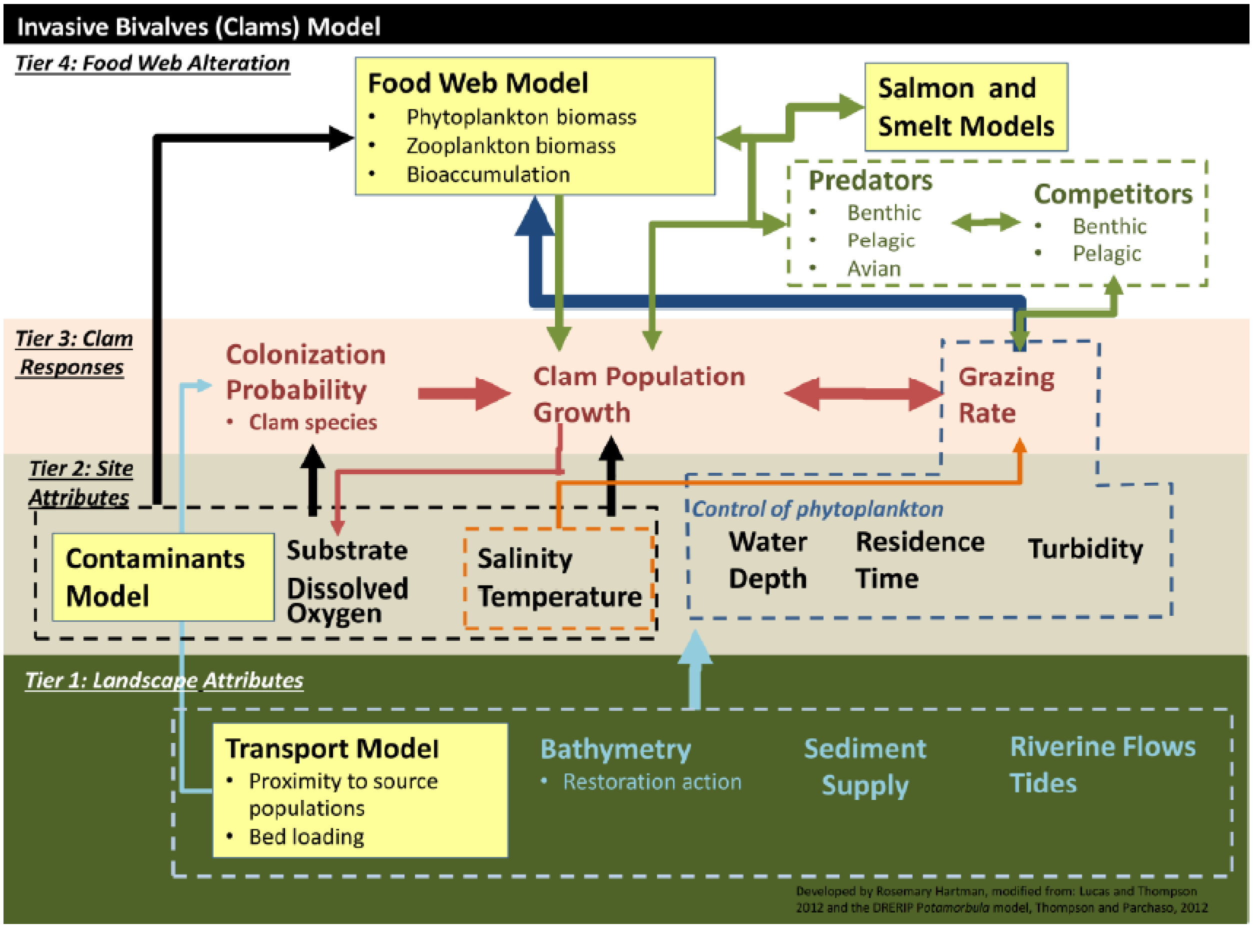


Figure 6. Foodweb Conceptual Model. The foodweb conceptual model describes the foodweb structure in tidal wetlands, with a focus on Species of Concern. Arrows indicate relationships between variables. All variables surrounded by boxes influence each other. The model links to other tidal wetland conceptual models as indicated by yellow boxes. From Sherman et al. 2017.

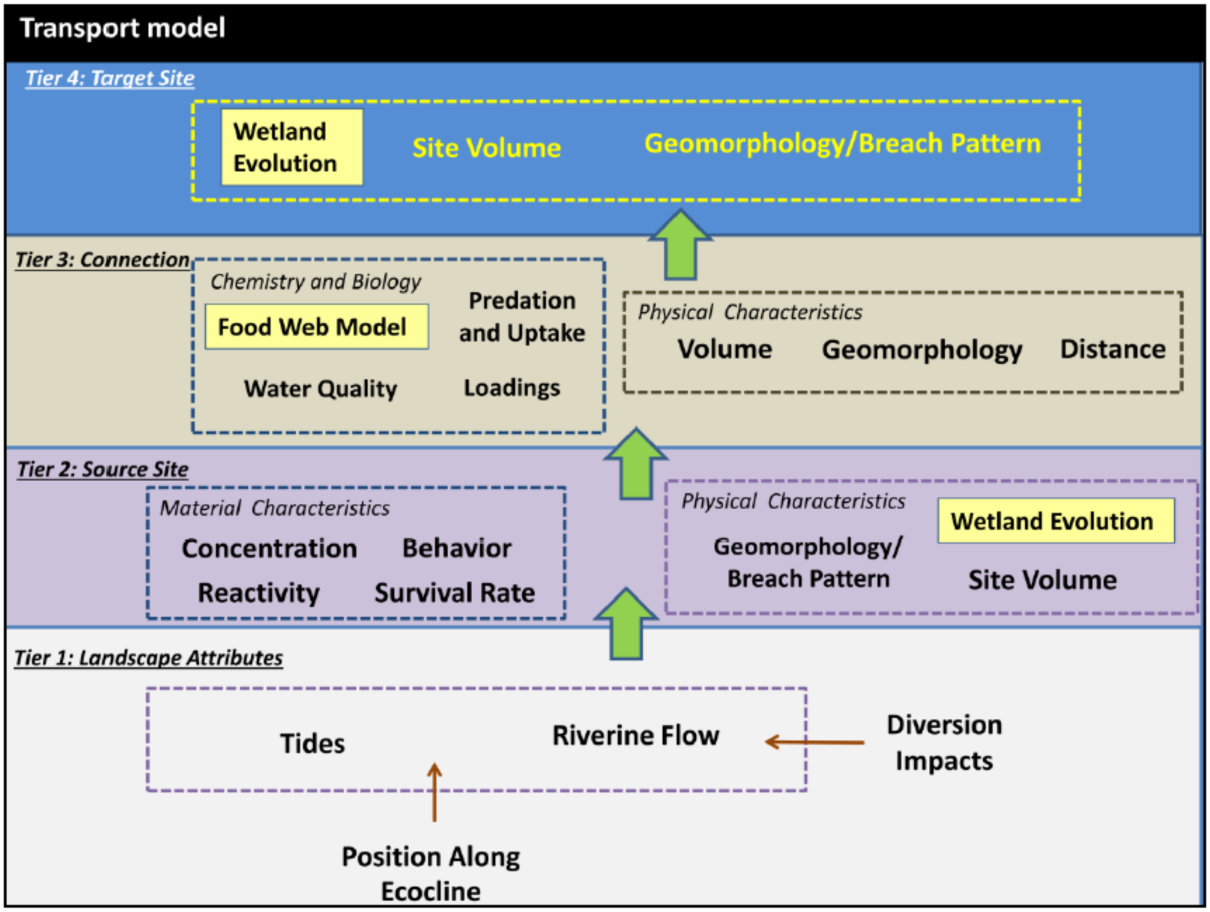
Delta restoration aims to increase food availability for fishes. Site selection and design characteristics can influence the water quality and presence of aquatic vegetation, which would, in turn, influence primary production, secondary production, and, thus, fish growth. Aquatic vegetation and environmental conditions may also influence the presence of predators, which can influence Delta smelt survival.



Developed by Rosemary Hartman, modified from: Lucas and Thompson 2012 and the DRERIP *Potamorbula* model, Thompson and Parchaso, 2012

Figure 7. Invasive Bivalve Conceptual Model. Arrows indicate relationships where variables influence other variables. All variables surrounded by boxes influence each other. The model links to other tidal-wetland conceptual models (i.e., Foodweb Model, Contaminants Model, and Transport Model), as indicated by yellow boxes. (Present model developed by Rosemary Hartman, modified from Lucas and Thompson 2012 and the DRERIP Potamocorbula model, Thompson and Parchaso 2012). From Sherman et al. 2017.

Site selection and restoration design may affect the colonization of a site by invasive clams. Restoration designs that can balance residence time with tidal and riverine flows may influence clam population and growth, which affects the productivity of the food web, and, thus, fish growth and survival.

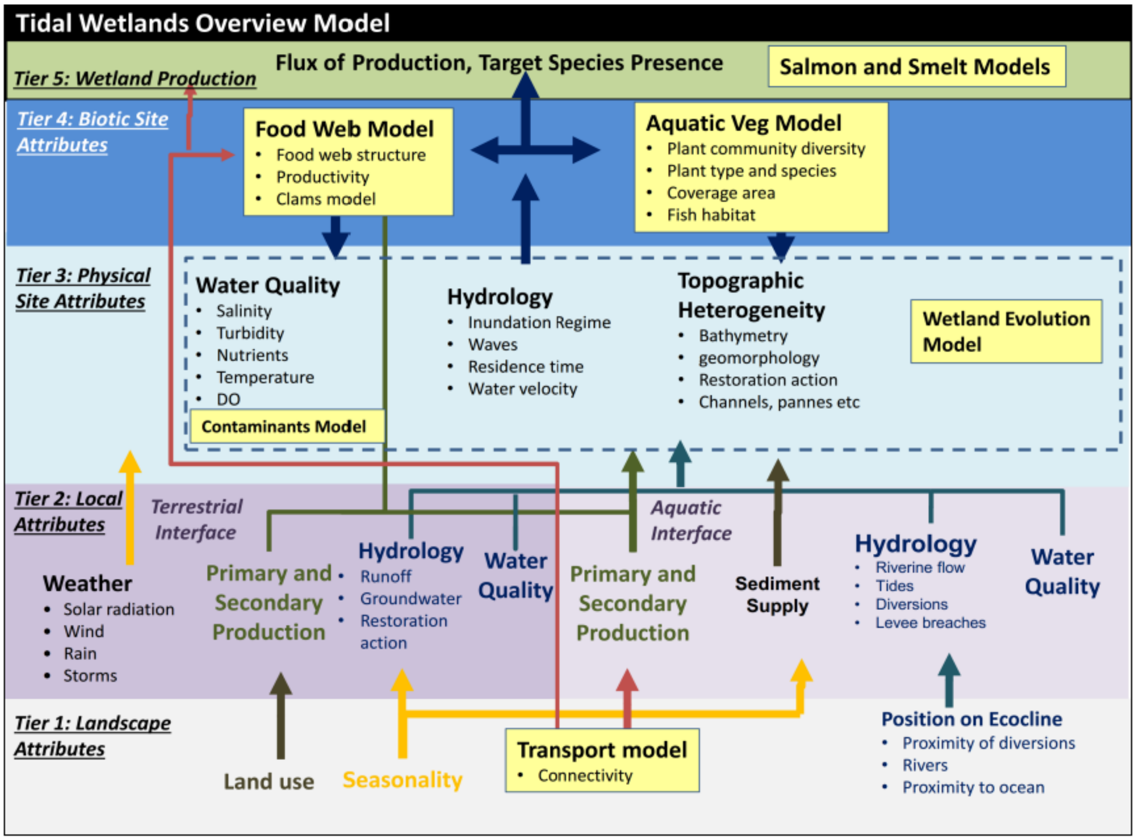


Note: This model depicts a general framework of how materials are exchanged between regions of a tidal estuary. Arrows indicate relationships between variables. All variables surrounded by boxes influence each other. The model links to other tidal wetland conceptual models (Food Web Model and Wetland Evolution Model), as indicated by yellow boxes.

Figure 8. Transport Conceptual Model. From Sherman et al. 2017.

Site selection and design for restoration would determine the effectiveness of food transport. The geomorphology and volume of the entire transport pathway would affect how food is transported into the target site, influencing the habitat conditions, productivity, and ability of fish to access any food created by restoration.

3.2.4 Habitat



Note: Arrows indicate relationships between variables. All variables surrounded by boxes influence each other. The model links to sub-models, as indicated by yellow boxes.

Figure 9. Tidal Wetlands Overview Conceptual Model. This conceptual model emphasizes processes that may influence restoration trajectories and affect ecosystem responses. From Sherman et al. 2017.

3.3 Models

3.3.1 Delta Smelt

3.3.1.1 Delta Smelt Life Cycle Models

Delta smelt growth and survival historically have relied on monitoring surveys (see Section 3.1, *Datasets*) for analysis of the population abundance. Fish collected in monitoring surveys have subsequently been processed in laboratory studies of health (Hammock et al. 2021) and growth (Xieu et al. 2022). However, continued decline in the population has made the capture of wild Delta smelt rare and modeling a more resilient management tool for this performance metric. Delta smelt life-cycle models, population models, and growth models are used to model changes in Delta smelt growth and survival under different management actions. Data and model output generated to evaluate habitat suitability and zooplankton prey–performance metrics can be incorporated into some of these models to predict individual (e.g., Delta smelt bioenergetics) and population-level (e.g., Delta Smelt Individual-Based Model) responses to different restoration projects.

- Hamilton and Murphy (2018) limiting factors model
- Maunder and Deriso (2011) state-space model
- Polansky et al. (2020) state-space model
- Smith et al. (2021) state-space model with entrainment

3.3.1.2 Delta Smelt Population Models

- Kimmerer and Rose (2018): Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary III. Effects of Entrainment Mortality and Changes in Prey
- Rose et al. (2013a, 2013b): Individual-based modeling of Delta smelt population dynamics in the upper San Francisco Estuary I and II

3.3.1.3 Delta Smelt Growth

- Bioenergetics-based habitat suitability, from the Individual-Based Model in R (Rose et al. 2013a, 2013b; Smith 2021)
- Delta Smelt Individual Based Model in R (Rose et al. 2013a, 2013b; Smith 2021
- Bioenergetics-based growth model (Fujiwara et al. 2015)

3.3.1.4 Delta Smelt Habitat and Food

- Hamilton and Murphy Smelt Habitat Model (Hamilton and Murphy 2020**Error! Bookmark not defined.**)
- Habitat Suitability Model (Bever et al. 2016)
- Feyrer and Manly Models (Three models very similar, with spatial differences; Feyrer et al. 2011, 2016; Manly et al. 2015).
- Nobriga Presence-Absence model (Nobriga et al. 2008)
- Delta Simulation Model II water cost model (https://data.cnra.ca.gov/dataset/methodology-for-flow-and-salinity-estimates-in-the-sacramento-san-joaquin-delta-and-suisun-marsh)
- Bay-Delta Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) (Ateljevich et al. 2014; Chai et al. 2017a, 2017b; Zang et al. 2008, 2016, 2019).
    - Zhang, Y. and A.M. Baptista 2008. SELFE: A semi-implicit Eulerian- Lagrangian finite-element model for cross-scale ocean circulation, Ocean Modelling, 21(3-4), 71-96.

- Resources Management Associates (RMA) Bay-Delta model, RMA San Francisco Estuary UnTRIM Model (https://dshm.rmanet.app/overview/rma_calibration_reports/USBR_LTO_Summer_Fall_Delta_Smelt_Habitat.pdf)
- Kimmerer Copepod Box Model (Kimmerer et al. 2018)
- RMA Copepod BPUE model (*Calanoid copepod* analysis addendum; https://dshm.rmanet.app/overview/rma_calibration_reports/USBR_LTO_copepod_addendum.pdf)
- Bayesian Network Relative Risk model for contaminant toxicity on Delta smelt (Landis 2021)
- Soil and Water Assessment Tool for contaminant fate (Chen et al. 2017; https://swat.tamu.edu/)

3.3.2 Habitat

The habitat suitability index for Delta smelt can be calculated using a methodology derived from Bever et al. (2016), Resources Management Associates 2021 (2021), and Bay-Delta SCHISM output California Department of Water Resources 2022, Appendix B). The index represents spatially and temporally averaged suitability of habitats within the Bay-Delta.

3.3.3 Zooplankton

Delta habitat restoration is aimed at creating high-quality, productive habitat for salmon and smelt. To evaluate this action, the Zooper package, with integrated zooplankton data, can be used to calculate zooplankton abundance near different types of habitats.

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4. Lines of Evidence

Reclamation’s management questions for the formulation of an alternative include the following.

4.1 Where is a Delta habitat limitation affecting Delta smelt and outmigrating salmonids?

SFEI characterized expected rearing-habitat availability in the Delta for juvenile Chinook salmon and steelhead using available data and broke down habitat availability by spatial region (San Francisco Estuary Institute 2020). These efforts revealed gaps or limitations in rearing-habitat availability in the Sacramento River Mainstem, San Joaquin Mainstem north of Stockton, Georgiana Slough and North Mokelumne River, and south Delta. The SFEI analysis further estimated that an additional 9,500 hectares of marsh and other floodplain habitats would be needed for salmon rearing in the Delta, beyond habitat that already exists or is planned for restoration. A separate analysis by Cramer Fish Sciences estimated that 11,200 and 4,600 acres of suitable rearing habitat are necessary in the Lower Sacramento River and Lower San Joaquin River, respectively, to achieve Anadromous Fish Restoration Program doubling goals, based on territory size (California Department of Water Resources 2016).

One of the major stressors implicated in the decline of Delta smelt is the loss of productive wetland habitat (Sherman et al., 2017). Although there is little information available about Delta smelt spawning habitat and the attributes needed for successful spawning (Interagency Ecological Program 2015), wetlands are expected to provide some spawning habitat, and other life stages of Delta smelt appear to benefit from proximity to tidal wetland habitat and other long residence–time habitat (Hammock et al. 2019; Sommer and Mejia 2013). Restoration projects are thus focused on creating areas for rearing and refuge and for increasing and transporting food subsidies to adjacent open-water habitats Delta smelt inhabit (Sherman et al. 2017).

Juvenile Delta smelt are most affected by habitat limitation because their life stage overlaps with warmer temperatures, and Delta smelt are sensitive to high water temperatures. In the field, they are rarely found above 25 degrees Celsius (°C; Nobriga et al. 2008), and they experience sublethal effects above 20°C (Jeffries et al. 2016). During the summer, there is also greater incidence of harmful algal blooms, and more food is needed to meet energetic demands. Delta smelt are also particular to specific ranges of salinity and turbidity (Dege and Brown 2004; Feyrer et al. 2007; Nobriga et al. 2008; Swanson et al. 2000), and development and climate change are likely to alter these parameters and decrease the amount of suitable habitat in the future (Feyrer et al. 2011). Although less is known about longfin smelt, juvenile and adult longfin smelt are also stressed by temperatures and food availability (Rosenfield 2010).

Delta smelt and longfin smelt migrate throughout the course of the year, so different regions of the Delta may benefit the fishes at different times of the year (Sommer et al. 2011). Juvenile life stages are found in the North Delta Arc, between the Cache Slough Complex and the Suisun Bay and Marsh. Although tidal marsh and shallow, flooded habitat is in the Suisun Marsh, many of these habitats are not connected to the rest of the estuary. Restoration targeting barrier removal and areas adjacent to areas occupied by smelt can increase access to food subsidies for smelt (Hobbs et al. 2017). In the Cache Slough Complex and Yolo Bypass, increasing habitat (through flows) and tidal wetland restoration could also provide food and habitat for smelt (Hobbs et al. 2017).

4.2 Does habitat restoration increase primary and secondary productivity and improve somatic growth of target species?

Primary and secondary productivity depends on restoration design and environmental conditions and can be highly variable, even between similar sites (Lucas et al. 2002, 2009; Sherman et al. 2017). Restoration sites that are shallow and have high residence times are predicted to create higher primary productivity (Sherman et al. 2017; Sommer and Mejia 2013), and when these shallow productive habitats are adjacent to deeper and less-productive channels, they may subsidize food production in pelagic areas (Lucas et al. 2009). Other factors, such as the quality of food (i.e., phytoplankton species), presence of harmful algal blooms, aquatic vegetation densities, nutrient concentrations, and, especially, clam grazing, can interact with and significantly decrease primary productivity and be hard to predict or control in a new restoration site (Cloern and Dufford 2005; Lucas et al. 2002; Sherman et al. 2017; Sommer and Mejia 2013).

Studies of habitat restoration effects in the Delta are rare for salmon and steelhead, but insights may be obtained from monitored restoration efforts in other highly modified estuarine systems. Studies in Washington estuaries observed differing diet composition among restored and reference sites, but similar salmon growth rates (Cordell et al. 2011; David et al. 2014; Woo et al. 2017). Estimated invertebrate productivity from restored mudflat habitat in Washington was comparable to reference sites three years after establishment, and growth rates of juvenile Chinook salmon were similar between restored and reference sites (Davis et al. 2017). These studies suggest that restored sites can result in secondary productivity and fish growth rates similar to similar reference sites (e.g., from a habitat type that did not require restoration). Limited information is available on primary productivity. These findings on restoration and productivity can also inform expected growth of Delta smelt.

Few studies document the effects of habitat restoration on productivity and growth for smelt. In Blacklock Marsh, restored wetland had lower productivity and fish diversity and higher invasive species, as compared with nearby sloughs and managed wetlands (Williamshen et al. 2021). Preliminary studies at the Liberty Island Ecological Reserve indicated that habitat diversity may be beneficial for increasing prey diversity, which may allow smelt to diversify their feeding strategies when pelagic zooplankton are in low abundance (Hartman et al. 2019; Whitley and Bollens 2014). Other studies have also targeted restoration habitat types and areas. In Suisun Marsh, one study found that stomach fullness in delta smelt increased with increases in tidal wetland areas, attributed mainly to increased predation on larval fish, but also increased predation on zooplankton, and another found that nursery habitat adjacent to shallow, warm water produced larval smelt of higher condition and higher densities of Delta smelt (Hammock et al. 2019; Hobbs et al. 2006). These results indicate that restoration of shallow habitats may benefit feeding opportunities for smelt when adjacent to smelt habitat. Studies in the Yolo Bypass, where restoration is planned, have found greater phytoplankton and insect concentrations in the floodplain, compared with the mainstem river, and greater insect densities during flooding of floodplain habitat (Benigno and Sommer 2008; Sommer et al. 2004).

4.3 What is the energy flow of habitat restoration productivity to different regions of the Delta, fish, and/or clams?

Comparisons of phytoplankton biomass, production, and growth rates among depth strata in the Bay-Delta indicate that transport and consumption are meaningful controls on local phytoplankton biomass (Lopez et al. 2006). Transport processes are determined by the nature of the material, the structure of the source and target sites, and the nature of the connecting channels, and can be influenced by tidal cycles and outflow, which influence the water-residence time and flushing rates (Enright et al. 2013; Sherman et al. 2017). Transport of plankton outside of the tidal exchange zone is likely limited. For smelt, productivity transfer is most likely to provide benefits where open waters adjacent to shallow, productive habitats have smaller volumes, so that any productivity created is not diluted (Herbold et al. 2014). Areas colonized by the invasive clam *Corbicula fluminea* functioned as food sinks, due to consumption, whereas uncolonized areas may serve as food sources. Effects of habitat-restoration actions may require a regional perspective to capture connectivity among other habitats, and site-specific design understanding transportation is important for supporting phytoplankton reaching targeted species and reducing the effect of nonnative species competing and consuming these food resources (Herbold et al. 2014).

4.4 Does habitat restoration provide refuge and improve survival for delta smelt or salmonids?

Limited information is available about the effects of estuary restoration on juvenile Chinook salmon or steelhead survival in general, let alone in the Delta. Survival of rearing fry, in particular, is a knowledge gap. One study suggests that survival of wild migrant fry Chinook salmon was higher in pocket-estuary habitat (i.e., areas with less saline water near creek mouths or coastal embayments) in Washington estuaries, which could serve as structural and salinity-based refugia (Beamer et al. 2006). Restoration of similar low-flow habitats in the Delta could provide a similar benefit. The importance of the Delta as a transition zone before saltwater entry suggests that increased habitat availability and capacity via restoration may have indirect, positive effects of survival (del Rosario et al. 2013). Habitat restoration that increases bathymetric heterogeneity may also provide refugia and increase access to preferred depths for rearing fry across tidal cycles (McLain and Castillo 2009; Hering et al. 2010).

Limited information is also available about the effects of estuary restoration on Delta smelt and longfin smelt. There is some evidence of higher abundances of longfin smelt in restored tidal wetlands in the San Francisco Bay (Lewis et al. 2020); however, smelt, especially Delta smelt, are rarely caught in surveys, and take is limited. Thus, many evaluations of restoration success are more focused on increasing productivity. Habitat restoration may improve survival where sites meet the habitat requirements of species (e.g. water quality), where there are few predators, contaminants, clams, and invasive species, where sites are far from export facilities, and where there is potential to accommodate sea-level rise (Herbold et al. 2014; Sherman et al. 2017; Sommer and Mejia 2013). Restoration outcomes can be very different, though, depending on the physical configuration of projects (U.S. Geological Survey et al. 2020). Restoration is most likely to provide benefits where open waters adjacent to shallow, productive habitats have smaller volume, so any productivity created is not diluted (Herbold et al. 2014).

4.5 How does habitat restoration affect operations for flood conveyance, water supply, and/or water quality?

Habitat restoration is constrained by flood conveyance, water supply, and water quality and can contribute to increasing flexibility in each factor. For example, the flood-conveyance baseline continually changes as river beds downgrade from sediment movement without replacement. The downgraded condition becomes the new baseline for subsequent habitat projects, which limits the scope of the project. When habitat projects can expand flood conveyance laterally, they can increase habitat, while maintaining and potentially increasing conveyance capacity. These same projects can increase the amount of time that water remains on streamside areas, thus increasing groundwater storage for the future.

Habitat projects can be designed to provide suitable habitats at flow regimes with less variability than the historic habitats experienced. Downcutting of river mainstems has disconnected off-channel habitat, such as side channels and floodplains. Restored habitats can be developed to inundate in lower-flow conditions and result in less water needed to maintain suitable habitats.

Habitat restoration can improve water quality by providing backwater areas for suspended sediment to settle out, resulting in cleaner water and fertile soils for riparian or marsh vegetation establishment.

5. Conclusions

Most Delta restoration projects have just been completed or are about to break ground, so there is limited information on the direct effect of Delta habitat restoration on growth and survival of fishes or ecosystem function. There is also limited information on the effects of Delta habitat restoration on salmon, steelhead, or smelt. For juvenile salmon and steelhead, current estimates of habitat availability suggest that rearing habitat in some regions may be limiting in some regions of the Delta. The low populations of smelt also makes it difficult to directly quantify survival, abundance, and growth of these species.

Tidal marsh restoration successes in other regions of the United States provides a reasonable basis for assuming that Delta habitat-restoration actions may benefit target species and ecosystem processes. For example, projects in Washington estuaries restored wetlands and other intertidal habitats that provided comparable levels of secondary productivity to similar reference sites with suitable habitat for rearing juvenile salmon and steelhead. However, Delta habitat is highly complex, and the success of restoration actions would depend on a variety of factors. For example, restoration effect on total food subsidies is strongly affected by grazers, such as clams, and dependent on the hydrology and design of the site, which effect the transport of these food subsidies.

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