BUREAU OF RECLAMATION

Long-Term Operation – Biological Assessment

Appendix K – Summer and Fall Delta Outflow and Habitat

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Appendix K Summer and Fall Delta Outflow and Habitat

K.1 Introduction

Operation of Central Valley Project (CVP) and State Water Project (SWP) facilities changes flows entering, moving through, and exiting the Sacramento–San Joaquin Delta (Delta) and the flow-related habitat characteristics for Delta smelt. The summer and fall may represent a seasonal bottleneck for juvenile Delta smelt as freshwater flows reach their annual nadir and access to seaward habitat (e.g., Suisun Marsh) is lost, particularly during droughts (Hammock et al. 2022). The degree to which Delta smelt use these areas depends on salinity, temperature, and turbidity (Nobriga et al. 2008; Feyrer et al. 2011; Sommer and Mejia 2013). Other factors may affect their summer distribution such as *Microcystis* presence, prey density, bathymetric features, or other water quality constituents (Sommer and Mejia 2013). Summer and fall Delta outflow and habitat action is intended to increase the spatial overlap of key Delta smelt habitat attributes through moving the low salinity zone habitat westward by releases from reservoirs and limitations on exports, and by routing of freshwater flows for habitat connectivity and food web productivity.

This component includes the operation of the Suisun Marsh Salinity Control Gates (SMSCG) at times in addition to those required by the Suisun Marsh Preservation Agreement as well as Delta outflow for the location of two parts per thousand (ppt) isohaline water with the Delta. X2 refers to this location scaled as the distance in kilometers (km) from the Golden Gate Bridge.

K.2 Initial Alternatives Report

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K.2.1 Management Questions

The United States Department of the Interior, Bureau of Reclamation's (Reclamation) management questions for the formulation of an alternative include:

- Does the area of suitable habitat increase given salinity, turbidity, temperatures, and/or contaminants?
- Does the Summer-Fall Habitat Action increase food resources in historical Delta smelt summer and fall habitats from production and/or food transport?
- Does the Summer-Fall Habitat Action support migration of Delta smelt to areas of improved suitable habitat?

- Are effects on water supply different between habitat actions from SMSCG operations, export reductions, or reservoir releases?
- What are the effects on different Delta smelt life history strategies (i.e., freshwater, migratory, brackish water)?
- Does the Summer-Fall Habitat Action improve population recruitment and viability?

K.2.2 Initial Analyses

Reclamation solicited input for the knowledge base paper, *Summer and Fall Habitat Management Actions – Smelt*, *Growth and Survival*.

Reclamation completed a literature review.

Reclamation reviewed physical and biological modeling developed as part of Structured Decision Making done by the Delta Coordination Group in 2020–2022.

K.2.3 Initial Findings

K.2.3.1 Increased Delta Outflow

Reservoir releases vs Reservoir releases in combination with export reductions

- Moving the location of X2 downstream takes a considerable amount of freshwater and can be achieved in various ways. The primary means by which the summer-fall X2 action can be achieved is through reservoir releases because summer-fall months are generally dry. However, increasing Delta outflow can also be achieved with a combination of reservoir releases and reductions in export of water from the Delta. No evidence to date suggests that the response of Delta smelt to increased Delta outflow would differ based on how it is achieved. We generally expect that increased Delta outflow achieved with a combination of reservoir releases and export reductions would reduce the risk of negative impacts on winter-run Chinook salmon in a subsequent dry year.

X2 location: 80/81 in above normal water years; 80/74 in wet water years

- If X2 is located at 80–81 km, the daily average of depth-averaged salinity should be between 4 and 5 ppt in Suisun Marsh and most of Suisun Bay, resulting in that area falling within the low-salinity zone at least 96% of a given day (Delta Modeling Associates 2014).

K.2.3.2 Additional Operation of the Suisun Marsh Salinity Control Gate

4 ppt vs. 6 ppt

- Delta smelt prefer salinities less than 6 ppt (Sommer and Mejia 2013). Delta smelt habitat quantity and quality has been related to overlap of the low-salinity zone and favorable water velocity, water clarity conditions, and bathymetry, particularly in important rearing habitats including Suisun Marsh (Bever et al. 2016). The operation of the SMSCG during summer and fall is aimed at providing this overlap by maintaining low salinities within

Montezuma Slough with Suisun Marsh and Grizzly Bay. The salinity monitored at Belden's Landing has been used as the reference for meeting the salinity target.

Number of days operating in dry year (30 days vs. 60 days)

- The initiation and duration of gate operations influence how effective the SMSCG action is at maintaining a target salinity at Belden's Landing. Effectiveness can be defined as keeping the salinity as close to the target concentration as possible throughout the summer and fall or as achieving a maximum number of days below the target concentration during that time frame.

Temperature off-ramp in response to unsuitable temperatures

- Water temperature can affect Delta smelt in several ways, from gene response to mortality. Delta smelt occurrence in the field is almost non-existent at temperatures > 25° degrees Celsius (°C) (Nobriga et al. 2008), growth is hampered at >20°C (Lewis et al. 2021), and stress behaviors are also exhibited at 21°C (Davis et al. 2019b). These studies indicate that high temperature may be a limiting factor during the summer-fall period and reduce or erase the positive benefits conferred by flow actions, such as the SMSCG.
- Lab studies have determined a range of Delta smelt critical thermal maxima and chronic lethal thermal maxima (25.4°C–28.5°C) depending on acclimation temperatures and other study conditions (Swanson et al. 2000; Komoroske et al. 2014; Davis et al. 2019a). Meanwhile, observations from field survey data have found that Delta smelt are generally found below 22°C (Bennett 2005). Lab studies conducted across multiple life stages found that upper critical temperatures (CTmax) generally decreased with ontogenetic stage, with larval fish exhibiting higher CTmax, and post-spawning adults exhibiting lower CTmax (Komoroske et al. 2014). When CTmax was compared with corresponding temperatures experienced during each life stage, juveniles were least tolerant for warming conditions because they develop during the summer, when temperatures are warmest (Komoroske et al. 2014). Delta smelt can also experience sublethal effects from water temperature below their tolerances. At temperatures of 20°C and above, juvenile Delta smelt have exhibited an increase in oxygen consumption, as well as changes in genes associated with muscle function and growth and skeletal development, and changes in gene expression associated with ion regulation, and thus potentially osmoregulation (Jeffries et al. 2016). Warmer temperatures will also likely decrease the duration of the maturation window for juveniles, which could negatively affect reproductive potential, and the duration of the spawning window (15°C–20°C), which would result in smaller cohorts of adult Delta smelt (Brown et al. 2016a; Bennett 2005).

K.2.3.3 Food Web Enhancement Actions

With vs. without food web enhancement actions

- Directed, more localized flow pulses have the potential to be used to transport nutrients, phytoplankton, and zooplankton from more productive to less productive areas. Actions such as the North Delta Food Subsidies (NDFS) Study subsidize less productive areas from more productive freshwater regions, whereas an action such as the Sacramento River Deep Water Ship Channel would move artificially nutrient-enriched (i.e., fertilized) water to areas with favorable Delta smelt habitat conditions (e.g., the maximum turbidity zone). The impact of these actions at a population level are unknown and likely will depend on the distribution of Delta smelt, potential movement of Delta smelt to subsidized areas, the temporal and spatial extent of the action, and the resulting magnitude of prey subsidy.

- The NDFS Study creates a flow pulse with coordinated releases of agricultural drainage from the Colusa Drain Basin or diversion of Sacramento River water into the Yolo Toe Drain. This highly productive water is then transported downstream to subsidize Cache Slough. However, the source of water (agricultural drainage versus Sacramento River) may influence the effectiveness of the action. For example, agricultural drainage water contains higher concentrations of contaminants than Sacramento River water (Davis et al. 2022).

K.2.4 Subsequent Considerations

K.3 Public Draft Environmental Impact Statement Scenarios

Under the National Environmental Policy Act (NEPA), Reclamation compares action alternatives to a “no action” alternative. Under the Endangered Species Act (ESA), Reclamation’s discretionary actions over an environmental baseline determine the effects on listed species. No single environmental baseline to evaluate the effects under ESA or impacts under NEPA. ESA requires a comparison to the environmental baseline which is informed by ROR and Alternative 1. NEPA requires a comparison to NA.

K.3.1 Run of River

[Placeholder]

K.3.2 No Action

[Placeholder]

K.3.3 Alternative 1 – Water Quality Control Plans

[Placeholder]

K.3.4 Alternative 2 – Multi-Agency Deliberation

[Placeholder]

K.3.5 Alternative 3 – Unimpaired Flow

[Placeholder]

K.3.6 Alternative 4 – Reservoir Flexibility

[Placeholder]

K.4 Performance Metrics

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

K.4.1 Biological

Biological metrics consider direct observations and environmental surrogates including:

- **Abiotic Habitat (turbidity, salinity, current speed, temperature):** Various field-occupancy and laboratory studies have demonstrated Delta smelt association with a set of abiotic 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). 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 further downstream of the Delta. Operation of the SMSCG during the summer and fall is expected to increase suitable habitat in the marsh by lowering salinity (Sommer et al. 2020). However, food subsidy actions are not expected to have any measurable impact on the physical habitat of Delta smelt.

  A habitat suitability index (HSI) can include both physicochemical and biological conditions that support Delta smelt. One way to accomplish this is to calculate a weighted food availability score by multiplying the average zooplankton biomass in each region/month for a scenario by the HSI (California Department of Water Resources 2022). Including both physical habitat and zooplankton prey in a single index more directly evaluates the potential benefit of actions like the SMSCG, which should result in favorable changes in zooplankton species composition by altering salinity.

- **Food Availability (zooplankton abundance, biomass, and community composition):** The availability and quality of zooplankton prey has been identified as limiting juvenile and subadult Delta smelt growth and survival during the summer and fall (Figure K-1 and Figure K-2; Slater and Baxter 2014; Hammock et al. 2015). One of the objectives of the Summer-Fall Habitat Action is to create greater overlap between suitable physical habitat and sufficient, high quality zooplankton prey through flow actions that alter salinity or enhance zooplankton production and biomass and influence species composition (i.e., freshwater versus marine/brackish species). Diet composition and gut fullness differ across salinities. The freshwater zooplankton *Pseudodiaptomus forbesi* is an important prey item in both fresh water and the low-salinity zone (Slater et al. 2019). Gut fullness has been shown to differ along a salinity gradient (Slater et al. 2019) with evidence for relatively higher gut fullness in fresh water and the low-salinity zone during summer and fall, respectively (Hammock et al. 2017). Monitoring data has been used alone and in combination with modeling to predict and evaluate the effects of individual Summer-Fall Habitat Actions on zooplankton prey biomass and species composition (e.g., Hassrick et al. 2021; Section K.5.3, *Datasets*, and Section K.5.4, *Models*). However, the ability to statistically detect the effects of actions on zooplankton biomass tends to be limited by high variability in zooplankton abundances resulting in the need for large numbers of samples (Brandon et al. 2022). The regional focus of these actions is primarily the Suisun (i.e., Suisun Bay, Grizzly Bay, Suisun Marsh) and Cache Slough areas.

- **Population Abundance:** Delta smelt growth and survival have historically relied upon monitoring surveys (Hassrick et al. 2021; Section K.5.3, *Datasets*) for analysis of the population abundance. Fish collected in monitoring surveys have subsequently been processed in laboratory studies of health (Hammock et al. 2022) and growth (Xieu et al. 2021). However, continued decline in the population has made the capture of wild Delta smelt rare and made modeling a more resilient management tool for this performance metric. Delta smelt lifecycle models, population models, and growth models (Section K.5.4, *Models*) are used to model changes in Delta smelt growth and survival under different management actions. Data and model output generated to evaluate the 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 Summer-Fall Habitat Action scenarios.

K.4.2 Water Supply

Water supply metrics consider the multi-purpose beneficial uses of CVP Reservoir including:

- North-of-Delta agricultural deliveries (average and critical/dry years)
- South-of-Delta agricultural deliveries (average and critical/dry years)

K.4.3 National Environmental Policy Act Resources

Analysis of the range of alternatives as required by NEPA is anticipated to describe changes in the multiple resources areas. Key resources are anticipated to include surface water supply, water quality, aquatic resources, regional economics, socioeconomics, land use and agricultural resources, cultural resources, environmental justice, climate change, and power.

K.5 Methods Selection

In the spring of 2022, Reclamation solicited input for the knowledge base paper *Summer and Fall Habitat Management Actions - Smelt Growth and Survival*, included as Attachment K. Knowledge base 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. The methods for this appendix considered the knowledge base papers and determined the most relevant approach for Reclamation to answer management questions and evaluate options for potential alternatives.

Since implementation of the Record of Decision and Incidental Take Permit (ITP), summer-fall actions have not been implemented due to repeated dry conditions (2020–2022); however, baseline monitoring, models, and synthesis have been conducted. As a result of these activities and in coordination with the Summer-Fall Habitat Action Delta Coordination Group, Reclamation and California Department of Water Resources (DWR) 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 datasets, and guide Structured Decision Making. Documents include the following: Science and Monitoring Plan, updated annually; action-specific operations and science plans, updated every 1 to 3 years; summer-fall seasonal reports; Structured Decision Making process document and performance measure information sheets (California Department of Water Resources 2022 Appendix B); and 2022 and 2023 action plans (California Department of Water Resources 2022; California Department of Water Resources and Bureau of Reclamation 2023). These documents can serve as key references that collate information for the Summer and Fall Delta Outflow and Habitat action.

K.5.1 Literature

The following sections describe the literature.

K.5.1.1 History of Summer and Fall Habitat Management Actions by Regulatory Period

1950s–Early 1970s: Onset of Central Valley Project Operations
The C.W. "Bill" Jones Pumping Plant was constructed from 1947 to 1951. During this era, there were no Water Right Decisions that provided recommendations or regulatory requirements for a Summer-Fall Habitat Action or salinity management.

1978: 1978 Water Right Decision D-1485
Unlike the 1960s, during the 1970s exports began to occur year-round and were increasing in volume. State Water Resources Control Board (Water Board) Water Right Decision 1485 (D-1485) marked the beginning of environmental protections and management to outflow requiring standards for the protection of fish and wildlife. D-1485 was adopted in 1978 to establish water quality standards, including flows to be maintained for the protection of fish and wildlife, imposed as a condition to all of the CVP and SWP permits. The two documents adopted by the Water Board (a water quality control plan and a water right decision) represent a unified effort by the Water Board to develop and implement under its full authority a single comprehensive set of water quality standards to protect beneficial uses of Delta water supplies (State Water Resources Control Board 1978:6).

D-1485 provides the Water Board with flexibility to revise terms in the document covering areas including salinity control and protection of fish and wildlife. D-1485 explicitly calls Permittees to "report annually on methods for making more precise projections of salinity distribution in the Delta under varying inflow, outflow and export conditions" (State Water Resources Control Board 1978:28), to develop a better understanding of water quality including "predictive tools with emphasis on improving the understanding of flow/salinity/ phytoplankton relationships in the western Delta" (State Water Resources Control Board 1978:29), and to participate in research studies to determine "outflow needs in San Francisco Bay, including ecological benefits of unregulated outflows and salinity gradients established by them" (State Water Resources Control Board 1978:30). This Water Right Decision outlined Delta electrical conductivity for wildlife (striped bass and salmonid) protection by month for varying water year types. Additionally, electrical conductivity water quality standards are outlined for locations (e.g., Chipps Island, Prisoners Point) by month for varying water year types.

1980s: 1984 California Department of Water Resources Plan of Protection for the Suisun Marsh and 1987 Suisun Marsh Preservation Agreement

Suisun Marsh preservation agreement was first signed in 1987. Original purpose shifted. History on waterfowl and multispecies benefits. First recognition at confluence was the Suisun Marsh Preservation Agreement—management of the area to mitigate the impacts of CVP and SWP, described in the Suisun Marsh Environmental Impact Statement/Environmental Impact Report (Bureau of Reclamation et al. 2011:ES-2).

In 1987, Reclamation, DWR, California Department of Fish and Game, and Suisun Resource Conservation District signed the Suisun Marsh Preservation Agreement, which contains provisions for Reclamation and DWR to mitigate the adverse effects on Suisun Marsh channel water salinity from the SWP and CVP operations and other upstream diversions. It required Reclamation and DWR to meet salinity standards as specified in the then-current D-1485, set a timeline for implementing the Plan of Protection for the Suisun Marsh, and delineated monitoring and mitigation requirements.

Late 1990s and Early 2000s: D-1641, CALFED, CVPIA

By the early 1990s, agreements were in place allowing the California Department of Fish and Wildlife (CDFW) to monitor salvage operations providing further benefits to protected fish. During this era there were requirements set in place to address standards for fish and wildlife protection with written intent to restore the San Francisco Bay/Sacramento–San Joaquin Delta Estuary (Bay-Delta) ecosystem and improve water management. Among these requirements was consideration of the export rate restriction standard (E/I ratio). The Central Valley Project Improvement Act (CVPIA) passed mandating changes in CVP management specifically for "protection, restoration, and enhancement of fish and wildlife" (Section [b] [4] of CVPIA). There was organization of Federal and State agencies through CALFED. Water Board Water Right Decision 1641 (D-1641) outlined a long-term plan to limit pumping to protect juvenile Chinook salmonids.

- **D-1641:** In 2000, through adoption of D-1641, the SWP and CVP were mandated to comply with the objectives in the 1995 *Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary* (Bay-Delta WQCP). The requirements in D-1641 address standards for fish and wildlife protection, municipal and industrial water quality, agricultural water quality, and Suisun Marsh salinity. D-1641 also authorizes SWP and CVP to jointly use each other's points of diversion in the southern Delta, with conditional limitations and required response coordination plans.

  Salinity management and objectives were outlined in detail in D-1641 including the responsibility for meeting southern Delta salinity objectives. The 1995 Bay-Delta WQCP contained salinity objectives for the San Joaquin River at Vernalis and for three locations within the southern Delta (San Joaquin River at Brandt Bridge, Old River at Middle River, and Old River at Tracy Road Bridge) to protect agricultural beneficial uses of water. Reclamation was the only water right holder with responsibility of meeting objectives at Vernalis: a maximum 30-day running average of mean daily electrical conductivity of 0.7 millimhos per centimeter (mmhos/cm) April to August and of 1.0 mmhos/cm September to March of all water year types.

Late 2000s and 2010: U.S. Fish and Wildlife Service 2008 and National Marine Fisheries Service 2009 Reasonable and Prudent Alternatives

The U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) issued Biological Opinions in 2008 and 2009, which respectively recognized operations of the CVP and SWP were likely to adversely modify critical habitat for listed species and jeopardize some species' continued existence. Protections were put in place including management actions for listed fish protections.

- **National Marine Fisheries Service 2009 Biological Opinion:** There are no reasonable and prudent measures (RPMs) in the NMFS 2009 Biological Opinion for summer and fall X2 or Summer-Fall Habitat Action.
- **U.S. Fish and Wildlife Service 2008 Biological Opinion:** The USFWS 2008 Biological Opinion provided the first instance of a fall X2 action including an Effects section that used a lifecycle model perspective and assessed indirect effects related to habitat suitability and food supply. Habitat suitability was assessed using X2, total area of suitable abiotic habitat, and its predicted effect on Delta smelt abundance the following summer. Food supply was assessed based on evidence of entrainment of *Pseudodiaptomus forbesi,* a preferred prey for Delta smelt, due to summer export operations.

  The 2008 Biological Opinion presents five reasonable and prudent alternatives (RPAs) identified to minimize impact to and avoid likelihood of jeopardizing the continued existence of listed species or critical habitat. Maintenance of X2 is required by RPA Component 3: Improve Habitat for Delta Smelt Growth and Rearing. Specifically, Reclamation and DWR operations were to maintain X2 position at 74 km in September and October of wet years and at 81 km in above normal years.

Present Day: 2019 Reasonable and Prudent Measures, 2020 Record of Decision and 2020 Incidental Take Permit

Currently there are measures in place to provide continued protections for listed fish within Reclamation's 2020 Proposed Action via the 2020 Record of Decision and DWR's 2020 ITP. The Delta Smelt Summer-Fall Habitat Action was developed to improve overlap of Delta smelt food supply and habitat, thereby contributing to the recruitment, growth, and survival of Delta smelt. A Summer-Fall Habitat Action has occurred only once (2023) since the signing of the 2020 Record of Decision or implementation of the 2020 ITP in water years 2020 or 2021. Despite not taking a Summer-Fall Habitat Action previous to 2023, Reclamation provided seasonal reporting for the 2020–2022 water years: Delta Smelt Summer-Fall Habitat Seasonal Report for Water Year 2020; Delta Smelt Summer-Fall Habitat Seasonal Report for Water Year 2021; Delta Smelt Summer-Fall Habitat Seasonal Report for Water Year 2022.

The action is aimed at expanding the low salinity zone to create greater overlap of suitable abiotic habitat conditions and prey. In Suisun Marsh, prey densities (Brown et al. 2016b) and the body condition (Teh et al. 2020) of Delta smelt both have been shown to be relatively high compared to Suisun Bay. It includes operations to maintain an X2 position at 80 km in above normal and wet years and operation of the SMSCG in above normal, below normal and some dry years to maintain or increase low salinity habitat in Suisun Marsh and Grizzly Bay. It also includes food enhancement actions identified in the Delta Smelt Resiliency Plan (California

Natural Resources Agency 2016), specifically the NDFS and the Sacramento Deepwater Ship Channel studies. Both studies aim to subsidize Delta smelt rearing habitat by facilitating the downstream transport of more productive water, including zooplankton prey.

- **National Marine Fisheries Service 2019 Biological Opinion:** The NMFS 2019 Biological Opinion requires RPM 5.i.: "Reclamation and DWR shall coordinate with NMFS through the Sacramento River Temperature Task Group temperature planning processes and the coordination group for the Delta Smelt Summer-Fall Habitat Action regarding approaches to for using storage releases for the Delta Smelt Summer-Fall Habitat Action."
- **U.S. Fish and Wildlife Service 2019 Biological Opinion:** The USFWS 2019 Biological Opinion included as RPM 2. "Minimize the adverse effects of habitat degradation in summer and fall by studying the effectiveness of the Summer-Fall Habitat Action implementation. As appropriate, representatives from Reclamation, DWR, CDFW, NMFS and the Service will participate in the Delta Coordination Group as part of this planning process."
- **2020 Record of Decision/Proposed Action and 2020 Incidental Take Permit:** Proposed Action 4.10.5.11 addresses Delta smelt Summer-Fall Habitat Action (Bureau of Reclamation 2019:4-72) and Condition of Approval 9.1.3 addresses the Delta smelt Summer-Fall Habitat Action intended to improve food supply and habitat for Delta smelt in the low salinity zone (California Department of Fish and Wildlife 2020:115).

K.5.2 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, a substantial portion of the Delta smelt population has been recognized as residing year-round in the perennially freshwater Cache Slough Complex (Mahardja et al. 2019; Hobbs et al. 2019).

During the summer-fall period, sub-adult Delta smelt primarily rear in the west Delta, Suisun Bay, and Cache Slough Complex (Merz et al. 2011; Sommer and Mejia 2013; Interagency Ecological Program 2015). Note that while Delta smelt used to occur in the central and south 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; Sommer and Mejia 2013). Other factors that may affect Delta smelt summer distribution include prey abundance and distribution, *Microcystis* presence, bathymetric features, or other water quality constituents (Sommer and Mejia 2013).

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) and reduced subsidies of important, freshwater prey items such as *P. forbesi* (Kimmerer et al. 2019). 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. 2022). Additionally, X2 position (measured as specific conductance) during fall has shifted upstream over time, which has been attributed to water operations because the long-term trend in September through December runoff has not changed (Feyrer et al. 2007).

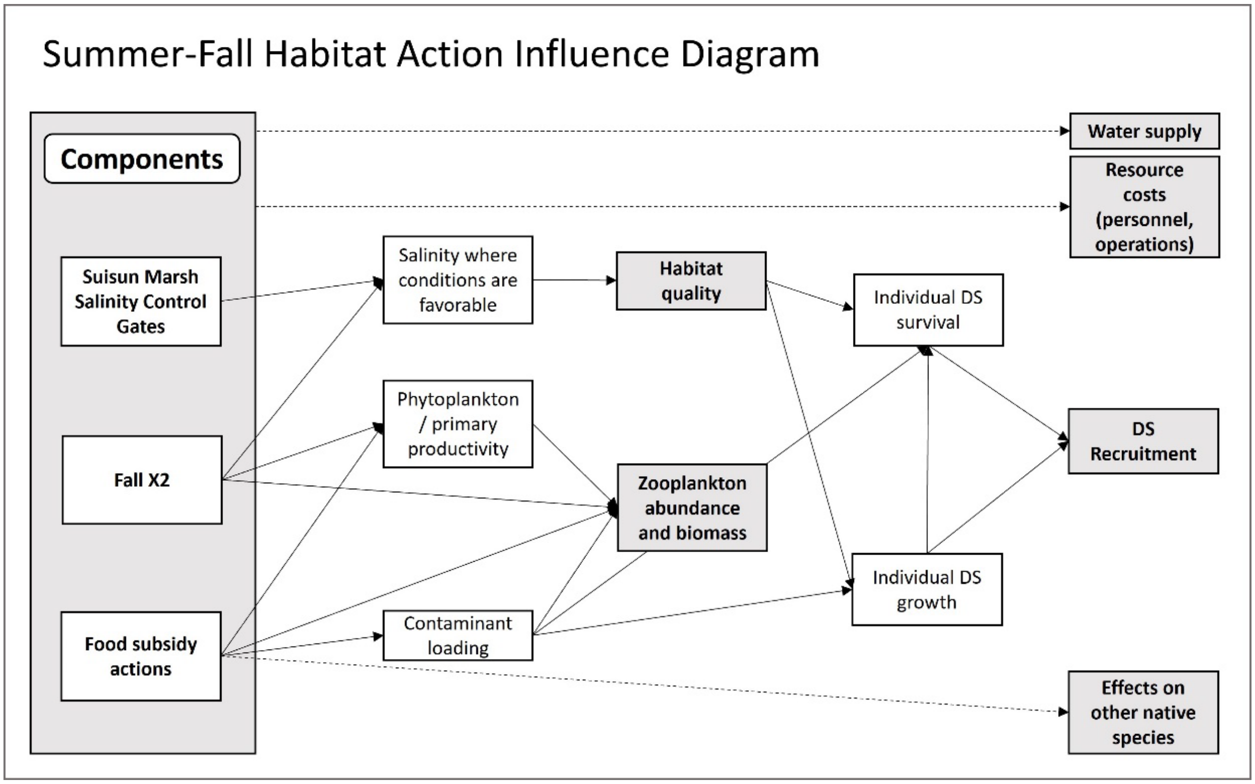
An analysis of changes in environmental conditions (e.g., turbidity, water clarity) and the position of X2 over time during fall, indicated that the confluence area and the lower Sacramento and San Joaquin Rivers have served as consistent and increasingly important low salinity zone habitat for Delta smelt (Feyrer at al. 2007; Nobriga et al. 2008). The interaction between this shift in low salinity zone location and multiple environmental factors, particularly water transparency and temperature, likely has contributed to long-term changes in habitat quality and Delta smelt distribution (Nobriga et al. 2008). Historically, Delta smelt juveniles and subadults likely benefited from migrating to the low salinity zone during summer, due to an overlap between turbidity levels, prey densities, and other environmental conditions. Hammock et al. (2017) found that Delta smelt foraging success and stomach fullness was higher in brackish water (2–-8 practical salinity units [psu]) and more turbid water compared to freshwater for most of the year, particularly during fall through spring. Hammock et al. (2019) also found a positive correlation between Delta smelt stomach fullness and tidal wetland area during summer and fall, due to both increased predation on larval fish and zooplankton.

Overall, the Delta smelt Summer-Fall Habitat Action is intended to increase the spatial overlap of key Delta smelt habitat attributes, and in the past had a focus on X2, Suisun Marsh, and experimental enhancements of prey supply from the Cache Slough Complex. Moving X2 downstream during the summer-fall period is hypothesized to benefit Delta smelt because under most conditions, it would manage low salinity habitat to overlap with turbid water and available food supplies, particularly in Suisun Marsh and Grizzly Bay when water temperatures are suitable. Additionally, it would manage low salinity habitat to overlap with turbid water and available food supplies, particularly in Suisun Marsh and Grizzly Bay when water temperatures are suitable. Additionally, it would establish contiguous fresh water to low salinity habitat from the Cache Slough Complex to the Suisun Marsh.

Meanwhile, operation of the SMSCG during the summer-fall months has the potential to provide an increase in low-salinity zone habitat for endangered Delta smelt, and to allow them to more frequently occupy Suisun Marsh, one of their most important rearing habitats (Sommer et al. 2020; Figure K-1). The Delta Smelt Summer-Fall Habitat Action also includes consideration of food enhancement actions, such as the NDFS Study (Frantzich et al. 2021), Sacramento Deep Water Ship Channel Food Web Study (Loken et al. 2022), and the Suisun Marsh managed wetland study (Figure K-1).

The specific hypotheses being tested by the different components of the Summer-Fall Habitat Action are (Figure K-1):

1. Decreasing X2 and/or operating the SMSCG during summer and/or fall will maximize the area of Delta smelt habitat with appropriate temperatures, turbidity, and salinity (e.g., Suisun Marsh, Grizzly Bay during gate operations), which will result in higher Delta smelt growth and survival;
2. Decreasing X2 and/or operating the SMSCG during summer and/or fall will increase biomass of calanoid copepods in the low salinity zone through increased transport of freshwater species from upstream and, during gate operation, into Suisun Marsh, which will result in higher Delta smelt growth and survival; and
3. Augmented flow pulses from areas of high primary and secondary production will transport nutrients, phytoplankton, and zooplankton from upstream to Delta smelt rearing areas; pulses that allow for longer water residence times will have greater potential to stimulate additional production downstream.



Source: Modified from California Department of Water Resources 2022.
The diagram shows causal links between the actions and the performance metrics.

Figure K-1. Summer-Fall Habitat Action Influence Diagram

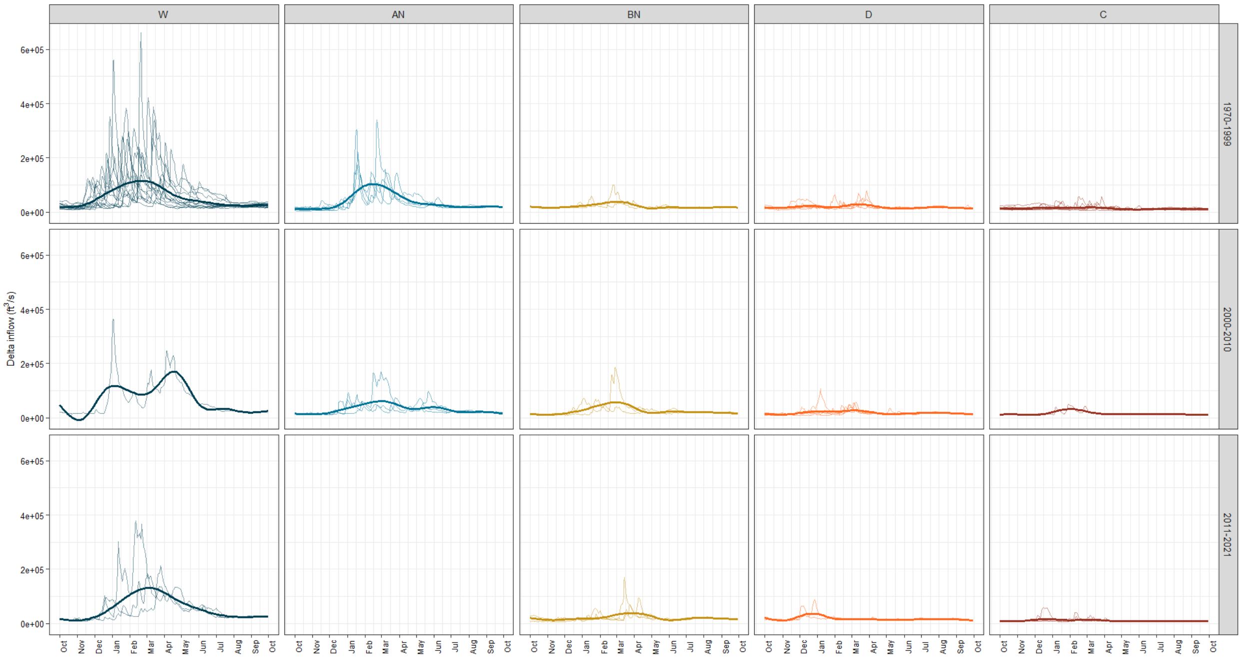
K.5.3 Datasets

Summer and fall habitat in the Bay-Delta is influenced by multiple factors including hydrology, water quality, and fish population abundance and distribution. Monitoring of hydrodynamics, water quality, and fish populations has been ongoing for over forty years, for some datasets, and covers the full spatial extent of the Bay-Delta. These data and the following plots serve as the foundation and to illustrate patterns of interannual variability in historical hydrology and trends in water quality. They also provide data and visualizations of trends in Federally listed native fish population abundances and distribution through the Sacramento River and Bay-Delta. The Directed Outflow Project evaluates the effects of X2 actions on the quantity and quality of habitat and food for Delta smelt and on Delta smelt growth and health indices. Action-specific study plans evaluate the effects of the SMSCG operation and the NDFS action on Delta smelt habitat and food quantity.

Presented in this section are three themes of empirical data: hydrodynamics, water quality parameters, and biological datasets. Hydrodynamics datasets (Section K.5.3.1, *Hydrodynamics*) include Delta inflow, Delta outflow, and export to inflow ratio. Water quality parameters (Section K.5.3.2, *Water Quality Parameters*) include X2, salinity, SMSCG operations, and turbidity. Invertebrate prey and fish datasets (Section K.5.3.3, *Biological Observations*) include total and preferred zooplankton prey and mysid shrimp, Delta Smelt abundance, and non-native aquatic fish composition and abundance.

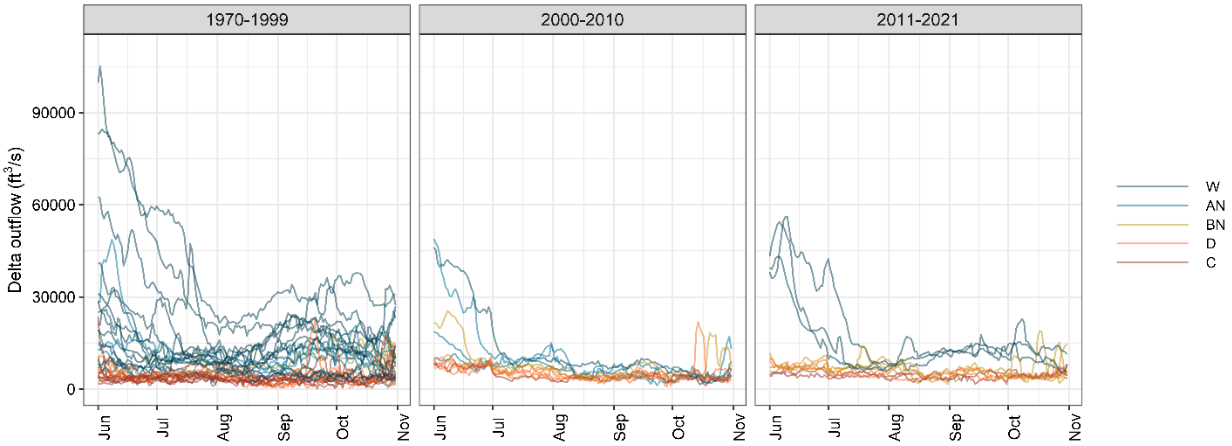
While some datasets include data gaps or shorter sampling efforts than others, overall a large body of historic monitoring data within the Bay-Delta is available. These data sets, in conjunction with modeled data (i.e., CalSim 3, DSM2, USRDOM), serve as inputs for models that can be used to understand and predict the effects of CVP and SWP operations on environmental conditions and fish growth and population recruitment and viability. Each data set is incorporated into one of multiple lines of evidence used to inform conclusions about both the magnitude and direction of differences among alternatives regarding hydrology and listed native fish populations abundance and distribution.

K.5.3.1 Hydrodynamics



Source: DAYFLOW Model.
ft^3/s = cubic foot per second; W = wet; AN = above normal; BN = below normal; D = dry; C = critically dry;
1970–1999 = pre-D-1641 and CALFED era;
2000–2010 = D-1641 and CALFED era;
2011–2021 = post-2008/2009 Biological Opinions.
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category’s dataset (which may include multiple water years).

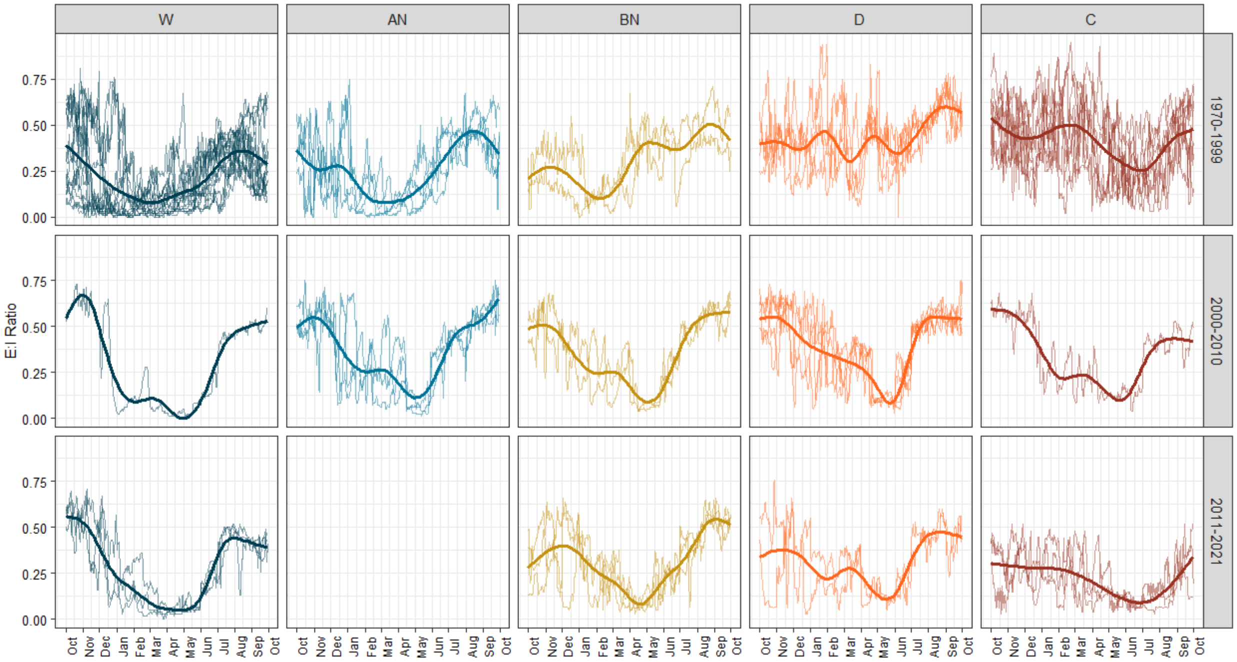
Figure K-2. Delta Inflow Data from 1970 to 2021, Plotted by Water Year Type from the Preceding Winter-Spring



Source: DAYFLOW Model.

ft^3/s = cubic foot per second; W = wet; AN = above normal; BN = below normal; D = dry; C = critically dry;
1970–1999 = pre-D-1641 and CALFED era;
2000–2010 = D-1641 and CALFED era;
2011–2021 = post-2008/2009 Biological Opinions.

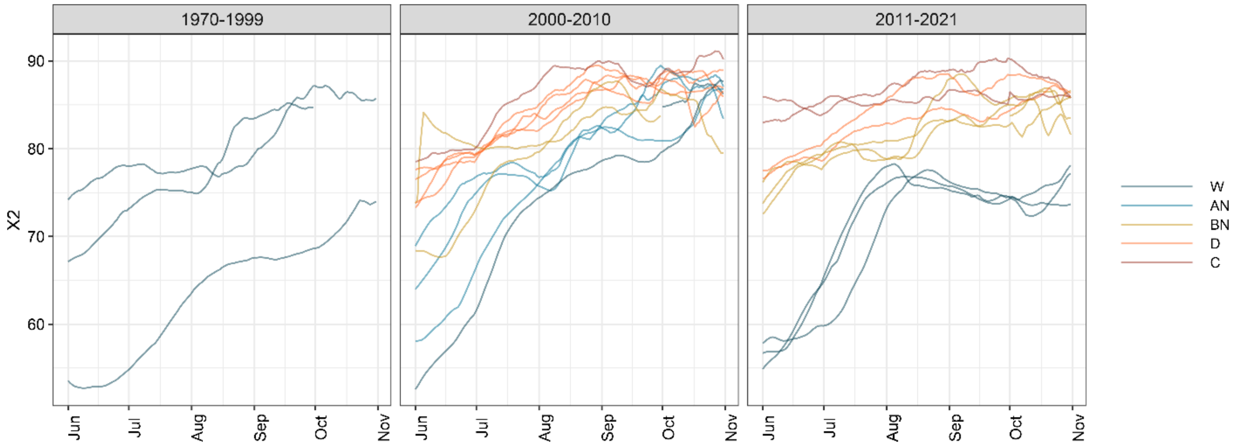
Figure K-3. Summer-Fall Delta Outflow Data from 1970 to 2021, Colored by Water Year Type from the Preceding Winter-Spring



Source: DAYFLOW Model.
E:I = export/import; W = wet; AN = above normal; BN = below normal; D = dry; C = critically dry;
1970–1999 = pre-D-1641 and CALFED era;
2000–2010 = D-1641 and CALFED era;
2011–2021 = post-2008/2009 Biological Opinions.
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category’s dataset (which may include multiple water years).

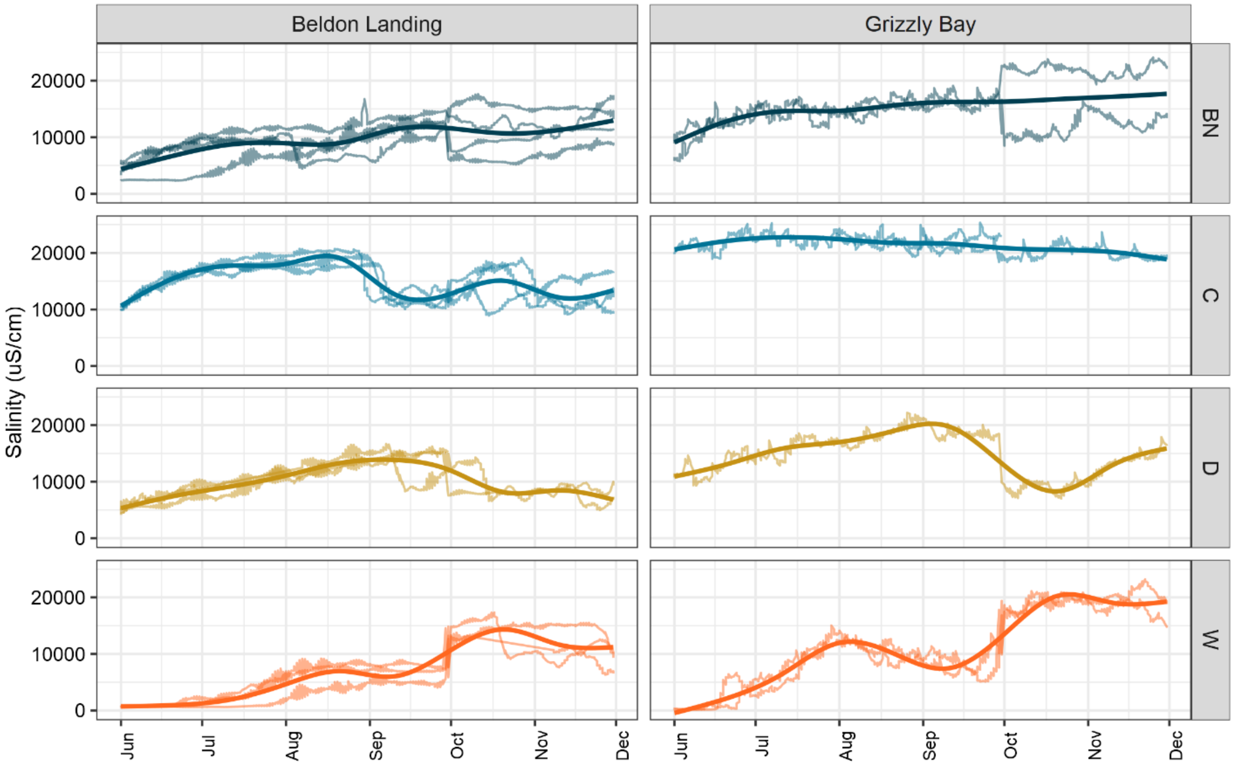
Figure K-4. Export to Inflow Ratio) Data from 1970 to 2021, Plotted by Water Year Type from the Preceding Winter-Spring

K.5.3.2 Water Quality Parameters



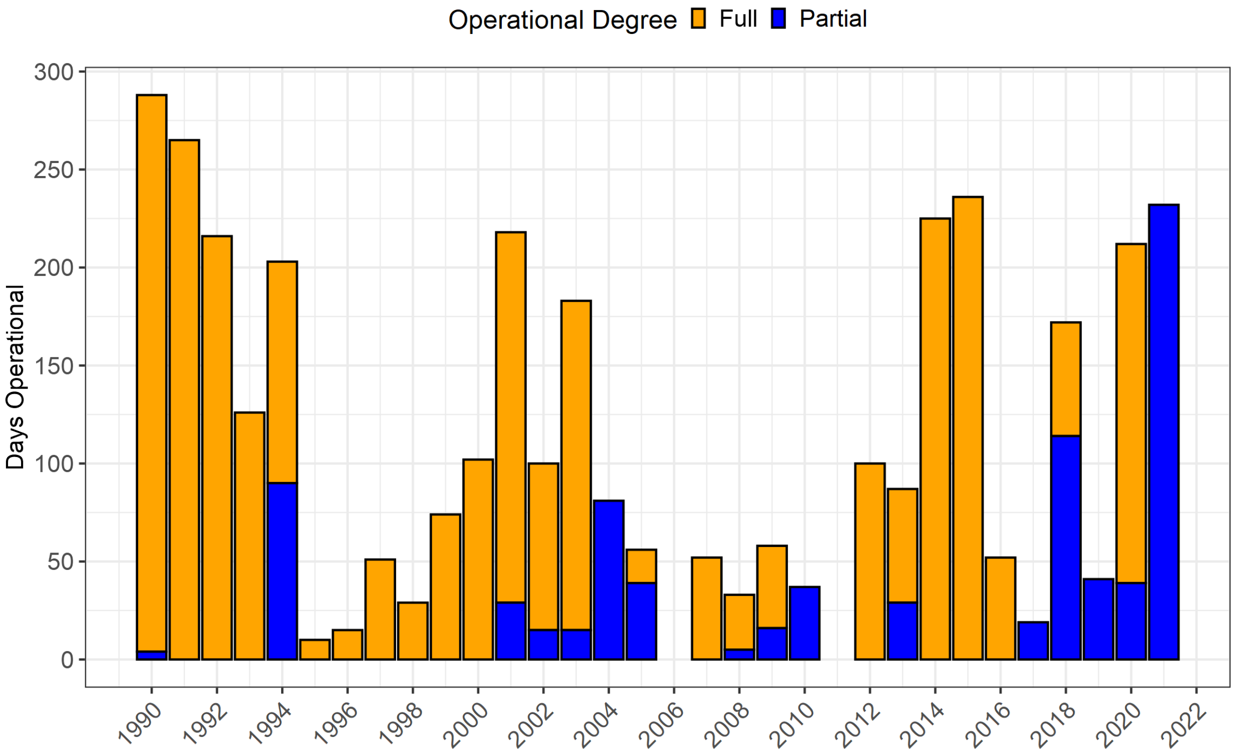
Source: DAYFLOW Model.
W = wet; AN = above normal; BN = below normal; D = dry; C = critically dry;
1970–1999 = pre-D-1641 and CALFED era;
2000–2010 = D-1641 and CALFED era;
2011–2021 = post-2008/2009 Biological Opinions.

Figure K-5. Summer-Fall 1997–2020 X2 Data for the Months of June through November from 1970 to 2021, Colored by Water Year Type from the Preceding Winter-Spring



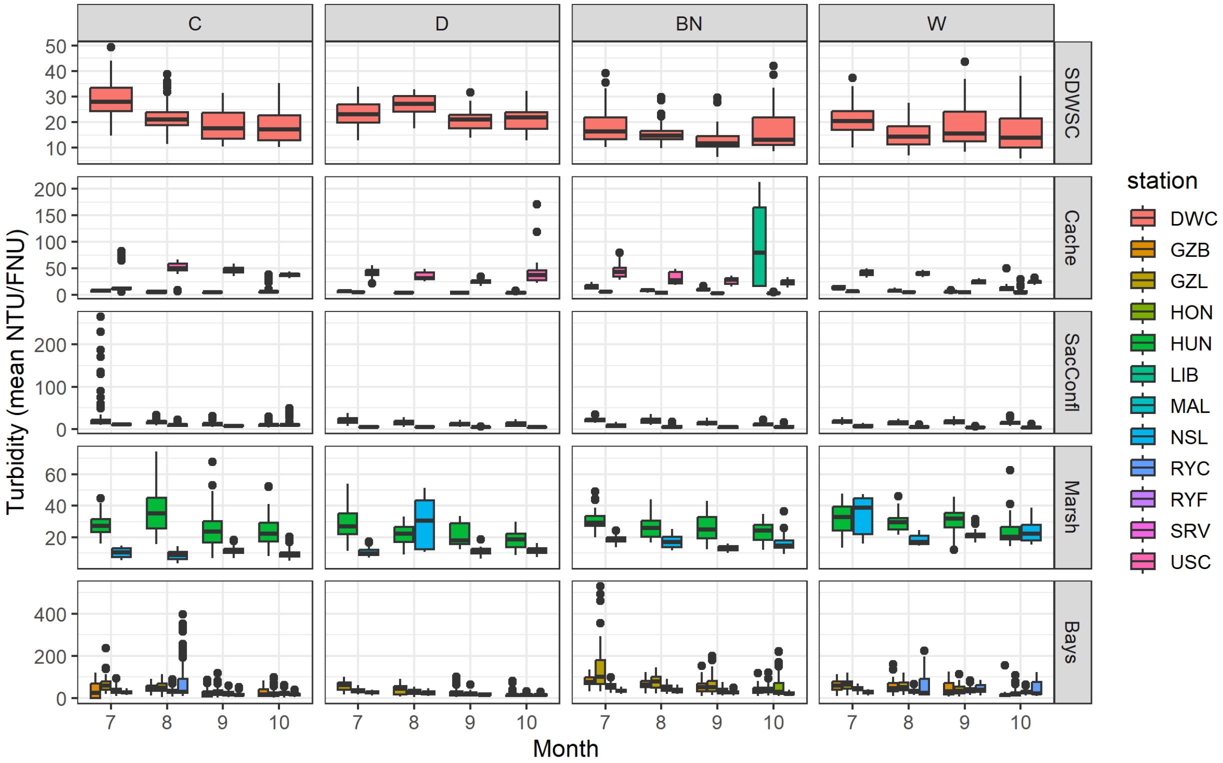
Source: California Data Exchange Center.
uS/cm = microsiemens per centimeter; W = wet; AN = above normal; BN = below normal; D = dry; C = critically dry.
Beldon Landing data are from Water Years 2009–2021 and Grizzly Bay (GZL) data are from Water Years 2015–2021.
Bolded line for each plot is a gam smooth across years of each station/water year type.

Figure K-6. Summer-Fall Salinity (Electrical Conductivity) Data for the Months of June through December from 1997 to 2020, Plotted by Water Year Type from the Preceding Winter-Spring



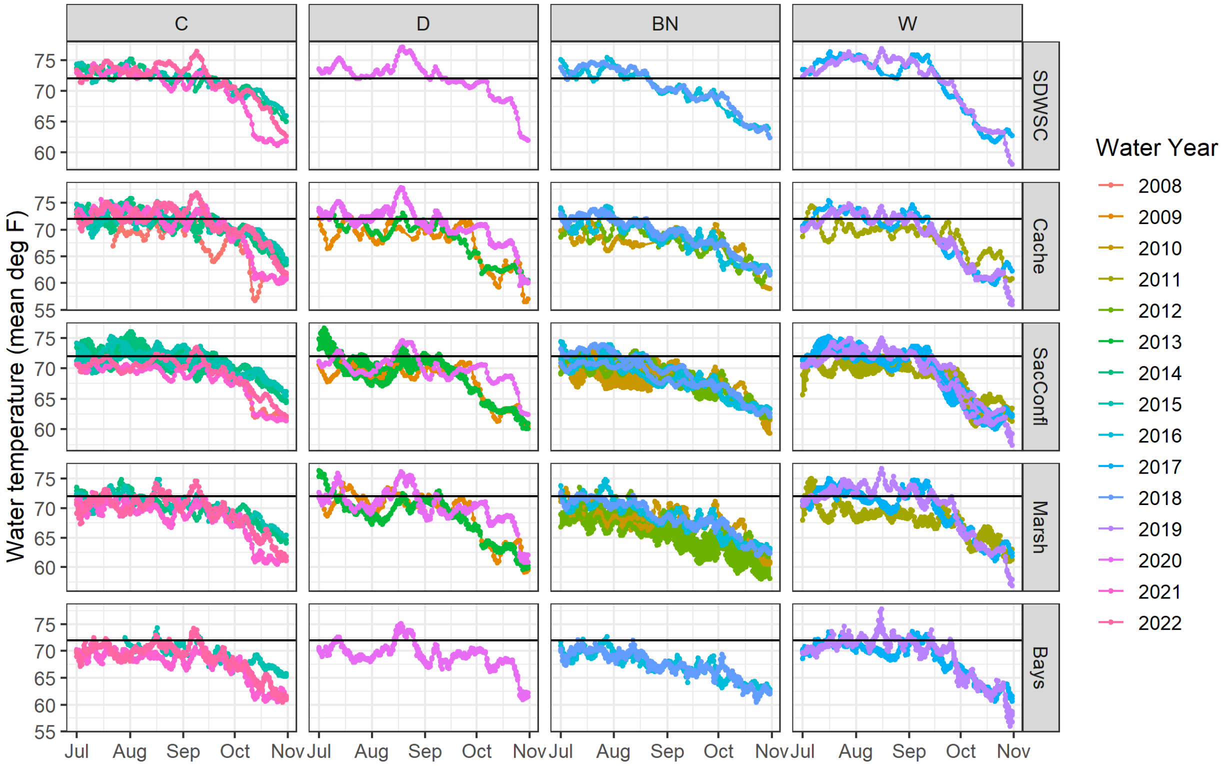
Source: Hartman et al. 2022.
Full operation (orange) indicates all the gates were in operation. Partial operation (blue) indicates either that at least one gate was not operating (open or closed), or that the gates were being manually operated.

Figure K-7. Suisun Marsh Salinity Control Gate Operations: Number of Days of Operation per Year, 1990–2021



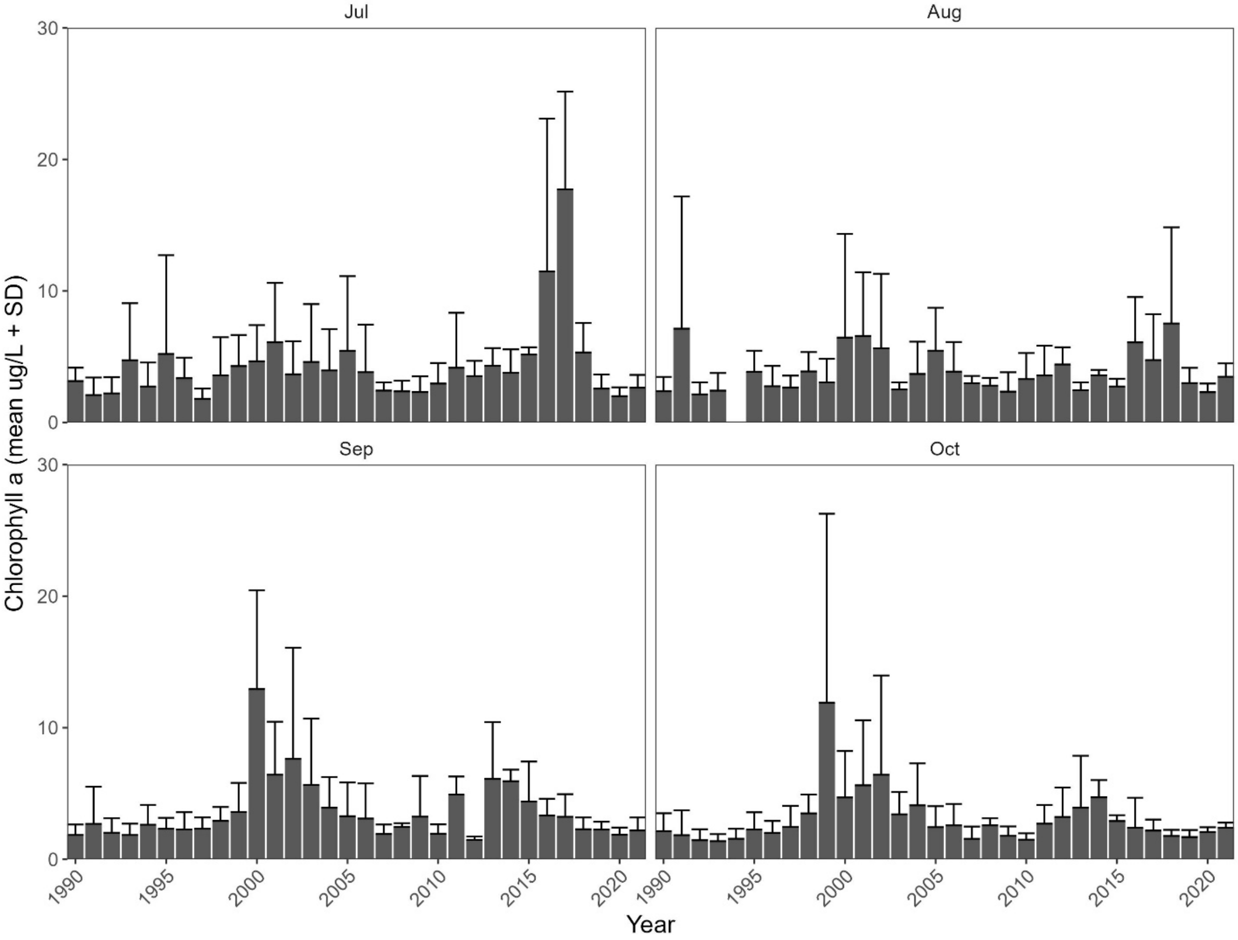
NTU = Nephelometric Turbidity Unit; FNU = Formazin Nephelometric Unit;
C = critically dry; D = dry; BN = below normal; W = wet;
SDWSC = Sacramento Deepwater Ship Channel (DWC = Deepwater Shipping Channel);
Cache = Cache Slough/Liberty Island (LIB = Cache Slough at South Liberty Island; RYF = Cache Slough above Ryer Island Ferry; UCS = Upper Cache Slough);
SacConfl = Lower Sacramento River and Confluence (MAL = Sacramento River at Mallard Island;
SRV = Sacramento River at Rio Vista);
Marsh = Suisun Marsh (HUN = Hunter Cut at Montezuma Slough; NSL = National Steel);
Bays = Suisun and Grizzly Bays (HON = Honker Bay; GZB = Grizzly Bay Buoy; GZL = Grizzly Bay;
RYC = Suisun Bay—Cutoff Near Ryer).
No years between 2008–2021 were classified as above normal water year types based on the Sacramento Valley Water Year Index. Data are from continuous monitoring stations operated by the U.S. Geological Survey (DWC, LIB, RYF, SRV, UCS) and California Department of Water Resources (all remaining).

Figure K-8. Mean Turbidity (NTU/FNU) in July, August, September, and October from 2008–2021 for Different Regions of the Delta Occupied by Delta Smelt by Water Year Type



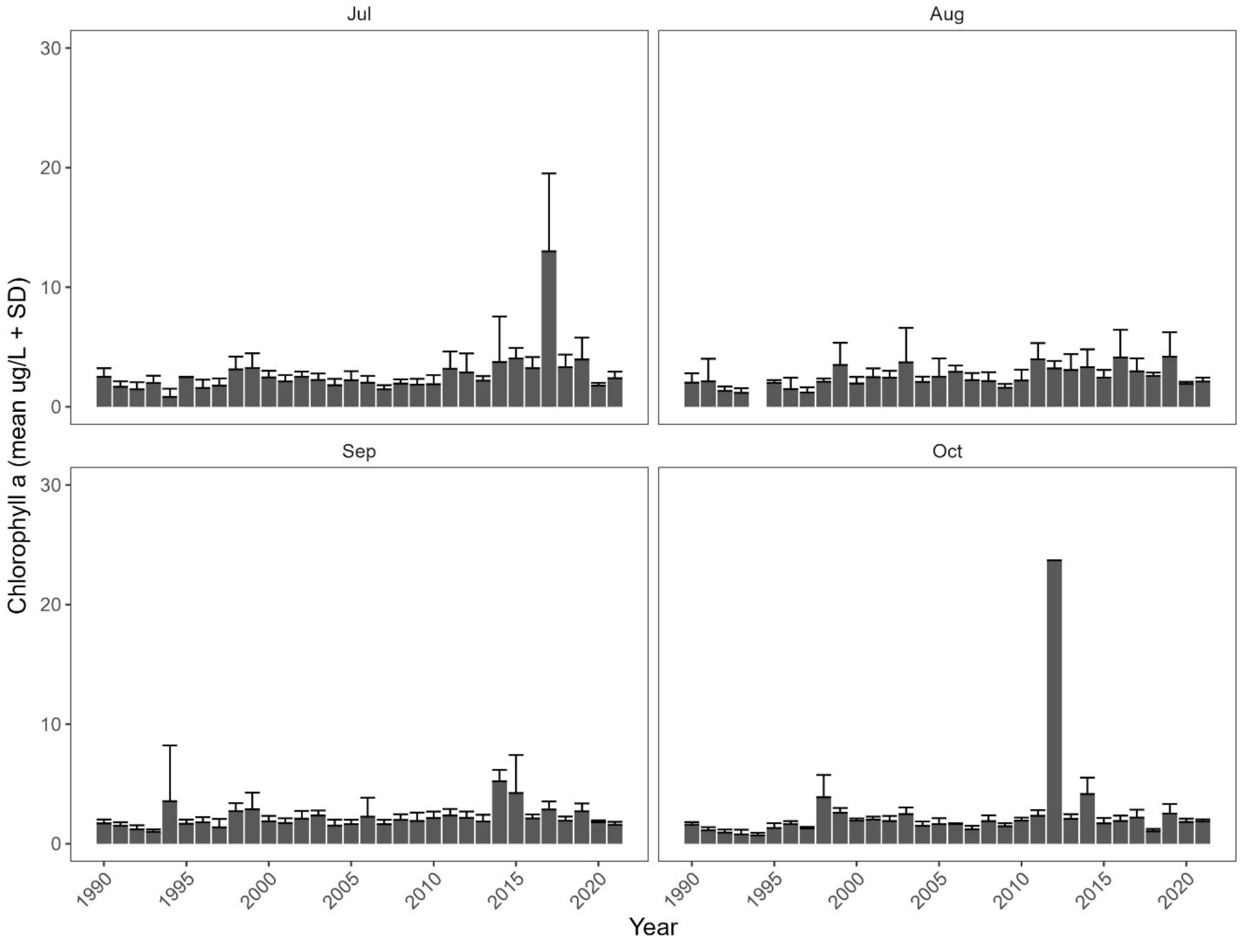
°F = degrees Fahrenheit; C = critically dry; D = dry; BN = below normal; W = wet;
SDWSC = Sacramento Deepwater Ship Channel (DWC = Deepwater Shipping Channel);
Cache = Cache Slough/Liberty Island (LIB = Cache Slough at South Liberty Island; RYF = Cache Slough above Ryer Island Ferry; UCS = Upper Cache Slough);
SacConfl = Lower Sacramento River and Confluence (MAL = Sacramento River at Mallard Island;
SRV = Sacramento River at Rio Vista);
Marsh = Suisun Marsh (HUN = Hunter Cut at Montezuma Slough; NSL = National Steel);
Bays = Suisun and Grizzly Bays (HON = Honker Bay; GZB = Grizzly Bay Buoy; GZL = Grizzly Bay;
RYC = Suisun Bay—Cutoff Near Ryer).
The horizontal lines at 72°F on each panel indicate a threshold above which temperatures have been shown to induce stress in Delta smelt. No years between 2008–2021 were classified as above normal water year types based on the Sacramento Valley Water Year Index. Data are from continuous monitoring stations operated by the U.S. Geological Survey (DWC, LIB, RYF, SRV, UCS) and California Department of Water Resources (all remaining).

Figure K-9. Mean Daily Temperature (°F) in July, August, September, and October from 2008–2021 for Different Regions of the Delta Occupied by Delta Smelt by Water Year Type



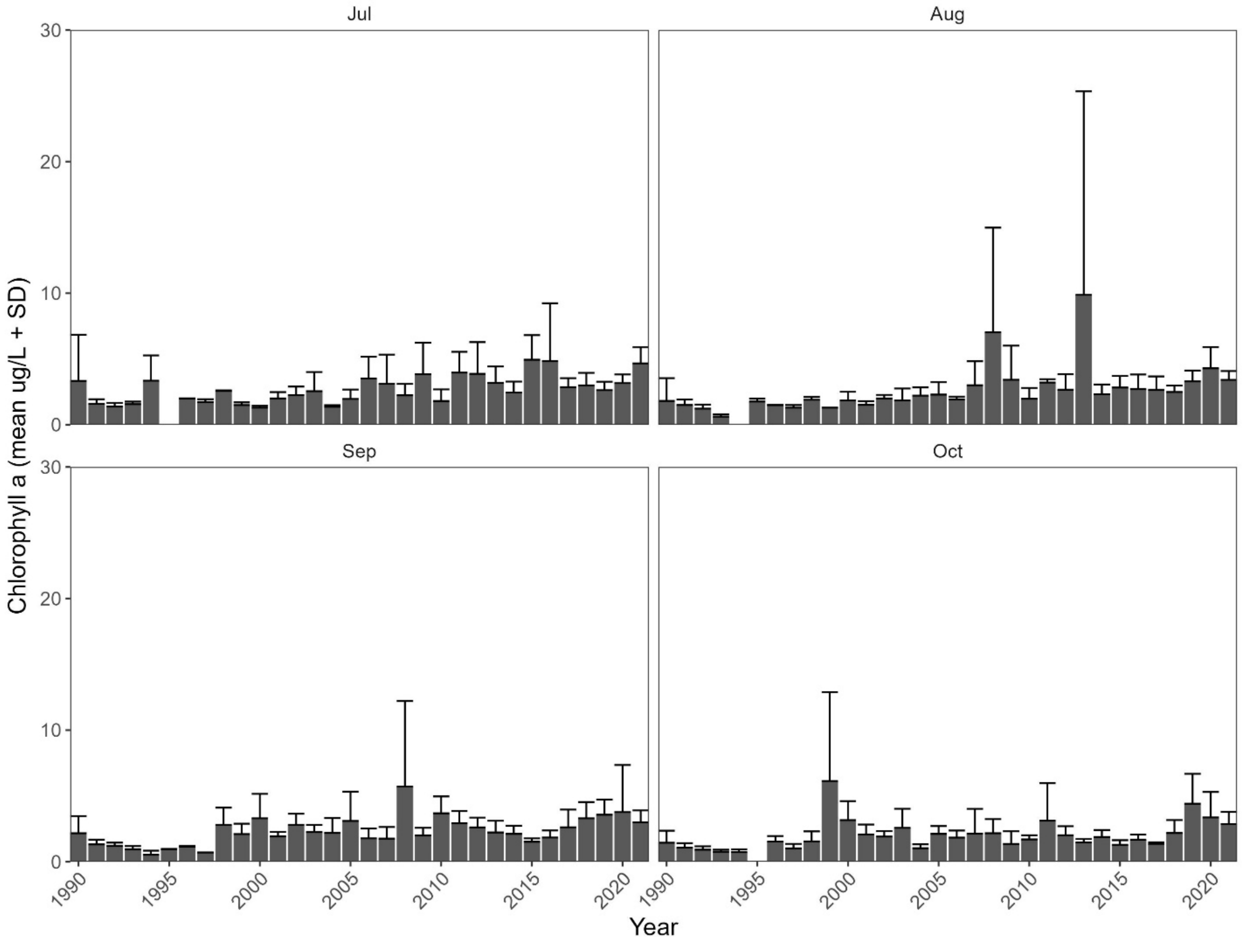
Source: Data downloaded and plotted using Zooper package in R.
ug/L = micrograms per liter; SD = standard deviation; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

Figure K-10. Freshwater Zone Chlorophyll a Mean Monthly Concentration Measured by the Environmental Monitoring Program from March through June of Each Year, 1990–2021



Source: Data downloaded and plotted using Zooper package in R.
ug/L = micrograms per liter; SD = standard deviation; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

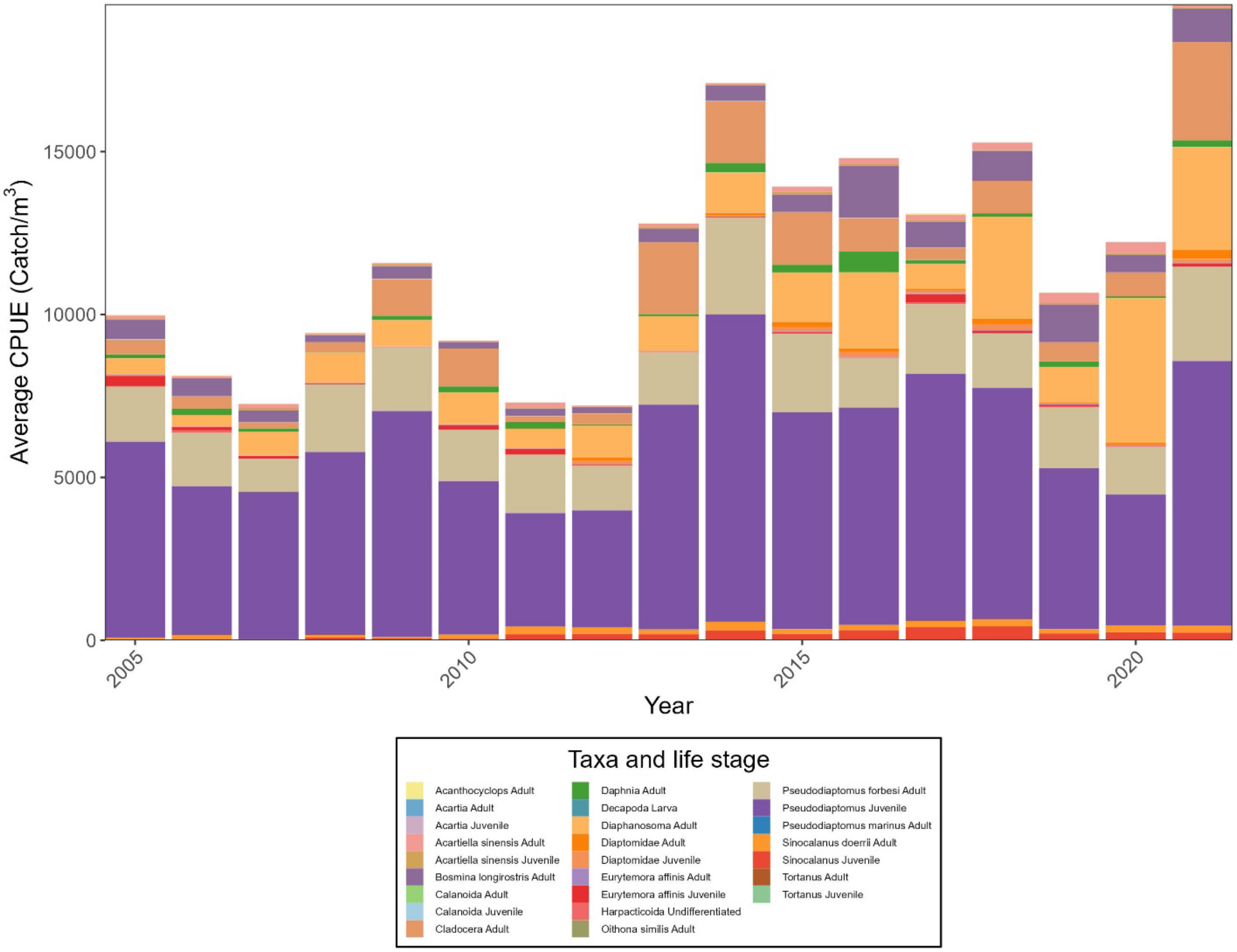
Figure K-11. Low Salinity Zone Chlorophyll a Mean Monthly Concentration Measured by the Environmental Monitoring Program from March through June of Each Year, 1990–2021



Source: Data downloaded and plotted using Zooper package in R.
ug/L = micrograms per liter; SD = standard deviation; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

Figure K-12. High Salinity Zone Chlorophyll a Mean Monthly Concentration Measured by the Environmental Monitoring Program from March through June of Each Year, 1990–2021

K.5.3.3 Biological Observations



Sources: Data collected by the California Department of Water Resources and Bureau of Reclamation Environmental Monitoring Program, California Department of Fish and Wildlife (CDFW) Summer Townet Survey, and CDFW Fall Midwater Trawl Survey; data downloaded and plotted using Zooper package in R.

CPUE = catch per unit effort; catch/m^3 = number of individuals per cubic meter; psu = practical salinity unit.

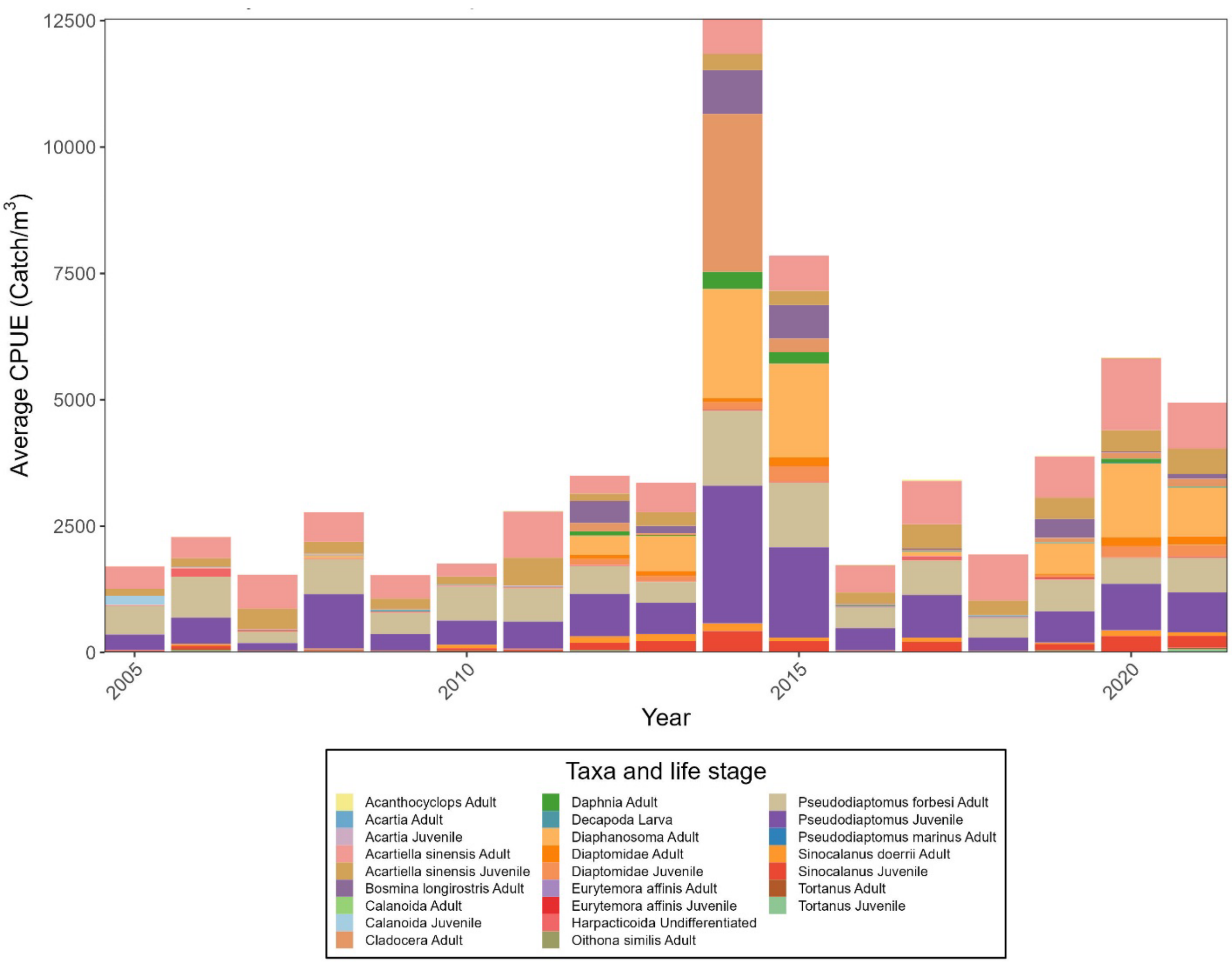
Salinity zones are defined as follows, based on surface salinity:

<0.5 psu, freshwater;

0.5-6.0 psu, low salinity zone;

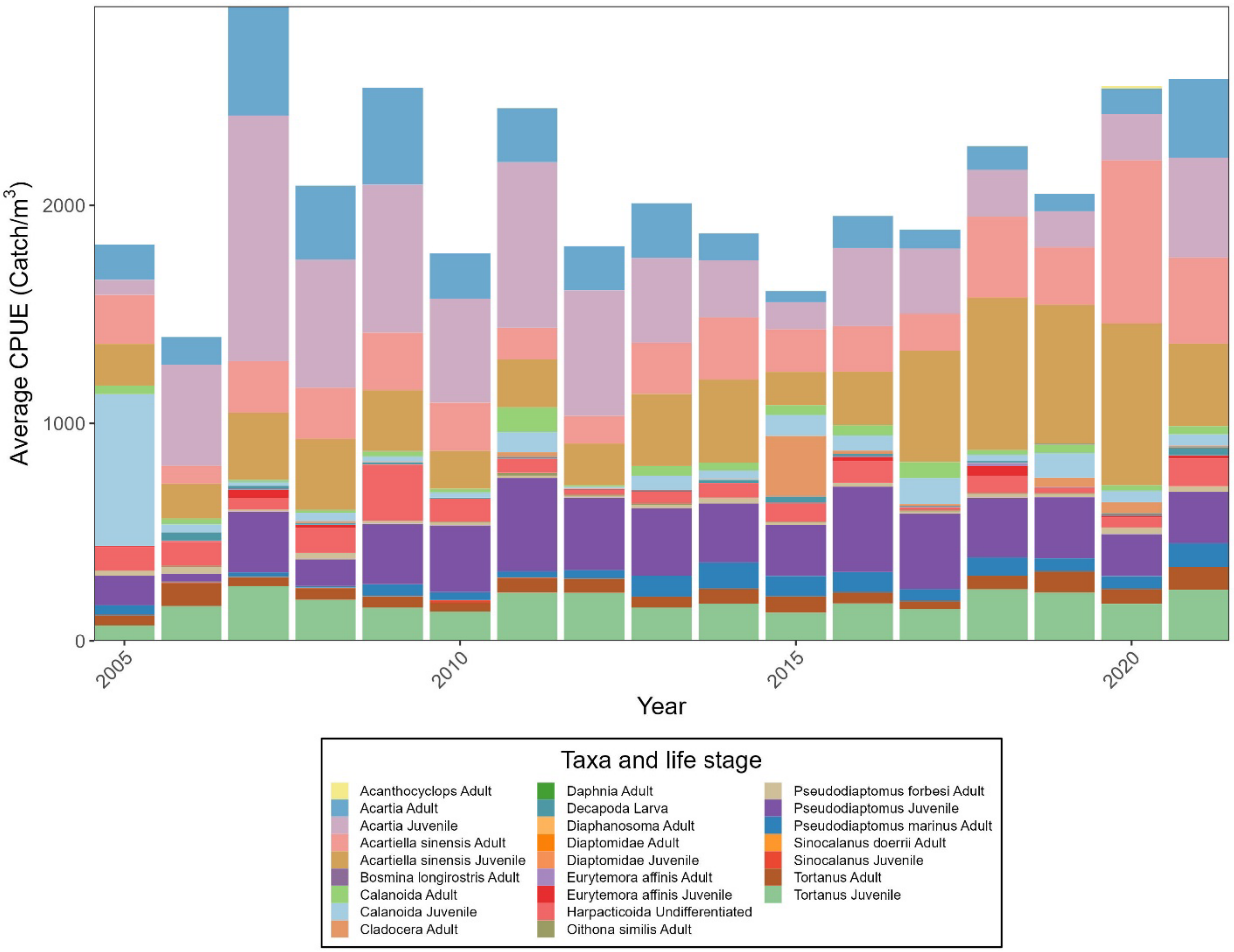
>6.0 psu, high salinity zone.

Figure K-13. Freshwater Zone Meso-Zooplankton Mean Annual Relative Abundance from July through October of Each Year, 2005–2021



Sources: Data collected by the California Department of Water Resources and Bureau of Reclamation Environmental Monitoring Program, California Department of Fish and Wildlife (CDFW) Summer Townet Survey, and CDFW Fall Midwater Trawl Survey; data downloaded and plotted using Zooper package in R.
CPUE = catch per unit effort; catch/m^3 = number of individuals per cubic meter; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

Figure K-14. Low Salinity Zone Meso-Zooplankton Mean Annual Relative Abundance from July through October of Each Year, 2005–2021



Sources: Data collected by the California Department of Water Resources and Bureau of Reclamation Environmental Monitoring Program, California Department of Fish and Wildlife (CDFW) Summer Townet Survey, and CDFW Fall Midwater Trawl Survey; data downloaded and plotted using Zooper package in R.

CPUE = catch per unit effort; catch/m^3 = number of individuals per cubic meter; psu = practical salinity unit.

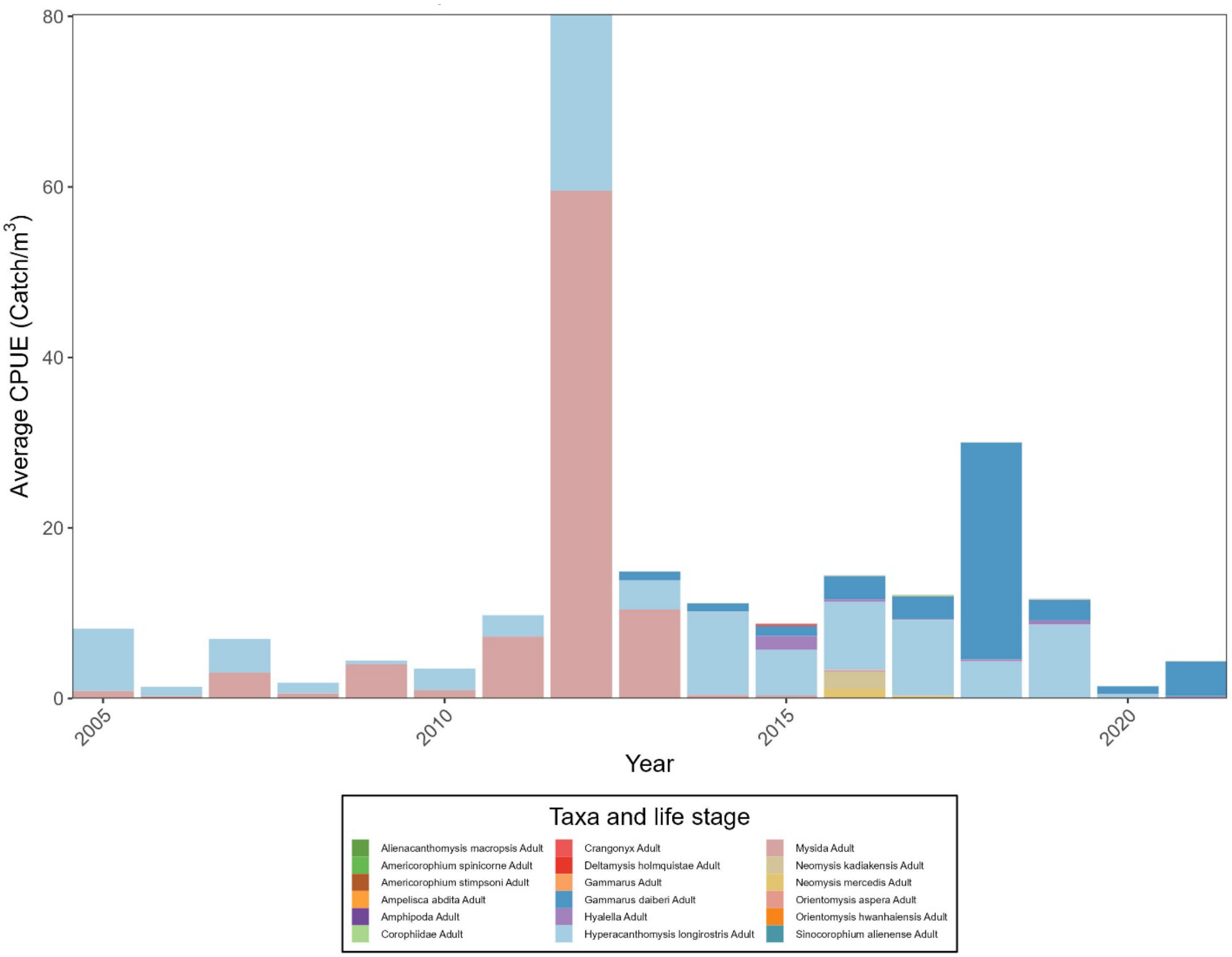
Salinity zones are defined as follows, based on surface salinity:

<0.5 psu, freshwater;

0.5-6.0 psu, low salinity zone;

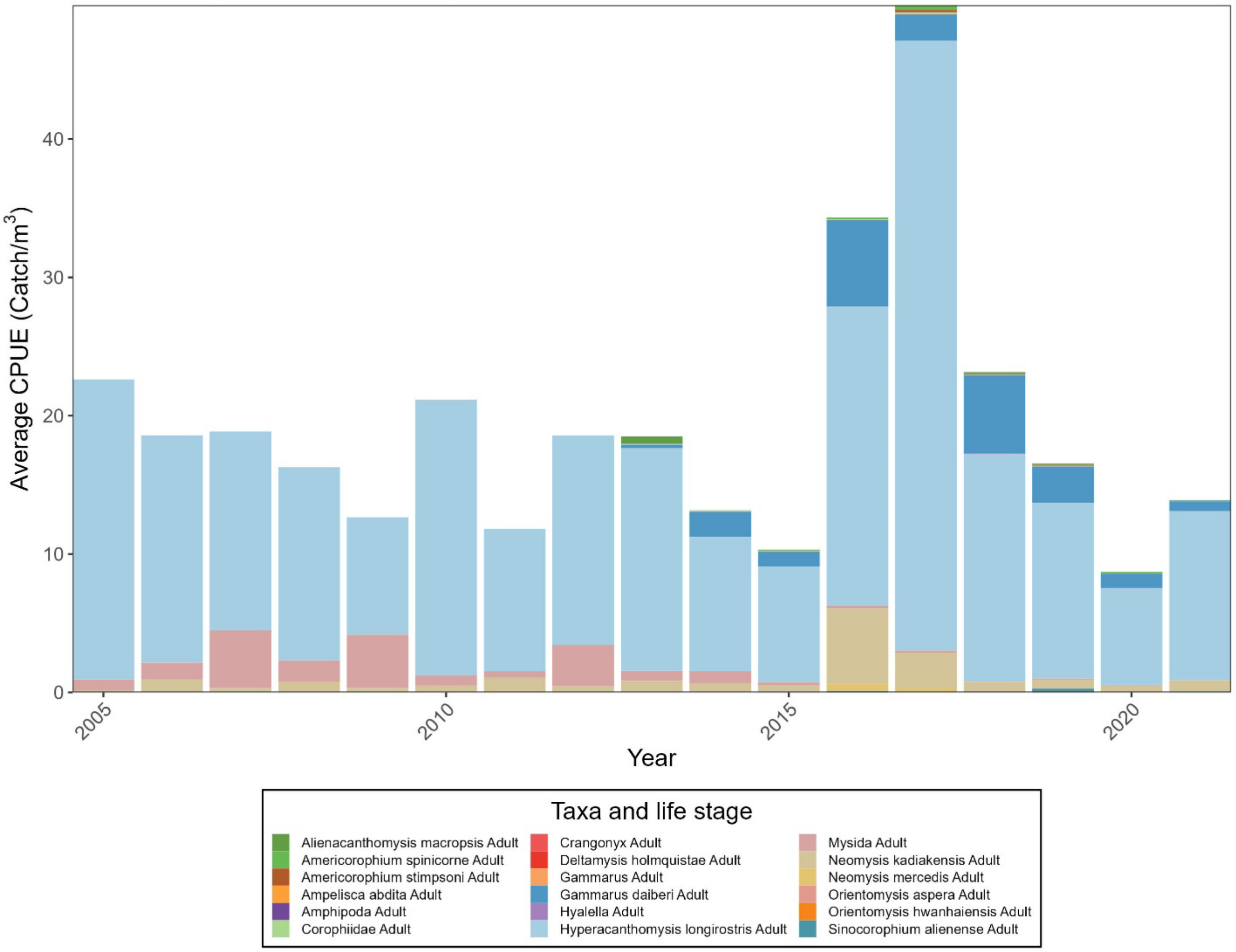
>6.0 psu, high salinity zone.

Figure K-15. High Salinity Zone Meso-Zooplankton Mean Annual Relative Abundance from July through October of Each Year, 2005–2021



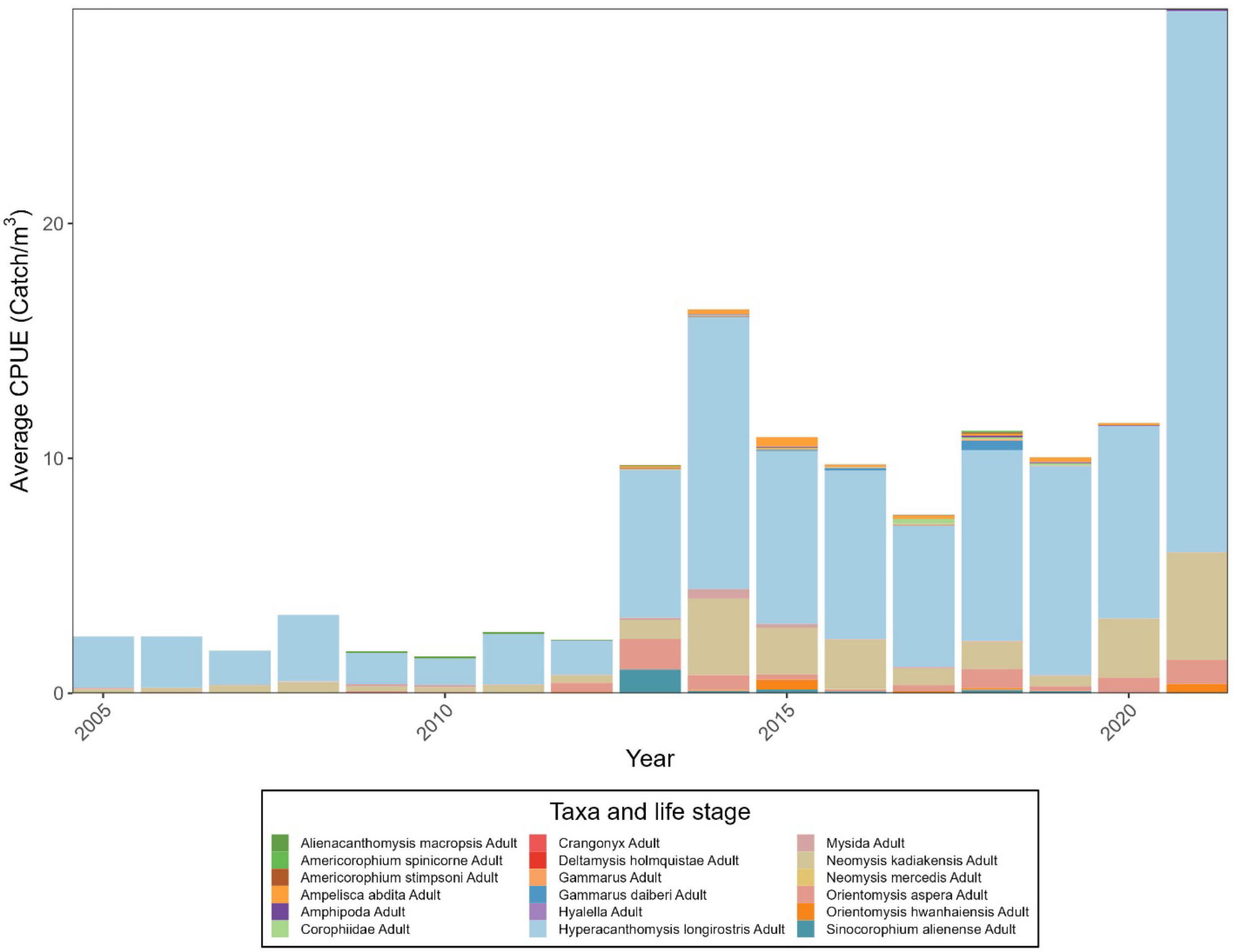
Sources: Data collected by the California Department of Water Resources and Bureau of Reclamation Environmental Monitoring Program, California Department of Fish and Wildlife (CDFW) Summer Townet Survey, and CDFW Fall Midwater Trawl Survey; data downloaded and plotted using Zooper package in R.
CPUE = catch per unit effort; catch/m^3 = number of individuals per cubic meter; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

Figure K-16. Freshwater Zone Macro-Zooplankton Mean Annual Relative Abundance from July through October of Each Year, 2005–2021



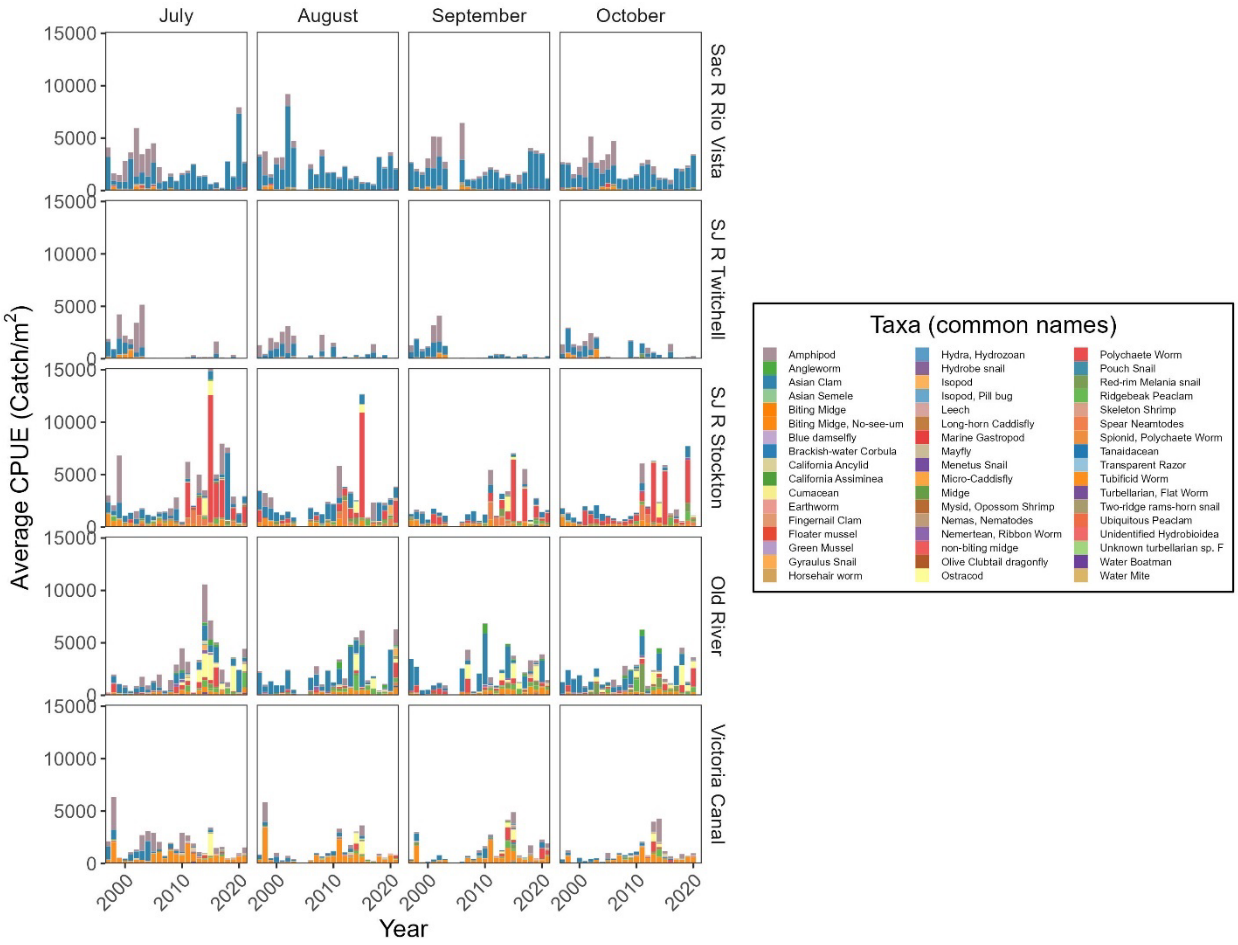
Sources: Data collected by the California Department of Water Resources and Bureau of Reclamation Environmental Monitoring Program, California Department of Fish and Wildlife (CDFW) Summer Townet Survey, and CDFW Fall Midwater Trawl Survey; data downloaded and plotted using Zooper package in R.
CPUE = catch per unit effort; catch/m^3 = number of individuals per cubic meter; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

Figure K-17. Low Salinity Zone Macro-Zooplankton Mean Annual Relative Abundance from July through October of Each Year, 2005–2021



Sources: Data collected by the California Department of Water Resources and Bureau of Reclamation Environmental Monitoring Program, California Department of Fish and Wildlife (CDFW) Summer Townet Survey, and CDFW Fall Midwater Trawl Survey; data downloaded and plotted using Zooper package in R.
CPUE = catch per unit effort; catch/m^3 = number of individuals per cubic meter; psu = practical salinity unit.
Salinity zones are defined as follows, based on surface salinity:
<0.5 psu, freshwater;
0.5-6.0 psu, low salinity zone;
>6.0 psu, high salinity zone.

Figure K-18. High Salinity Zone Macro-Zooplankton Mean Annual Relative Abundance from July through October of Each Year, 2005–2021

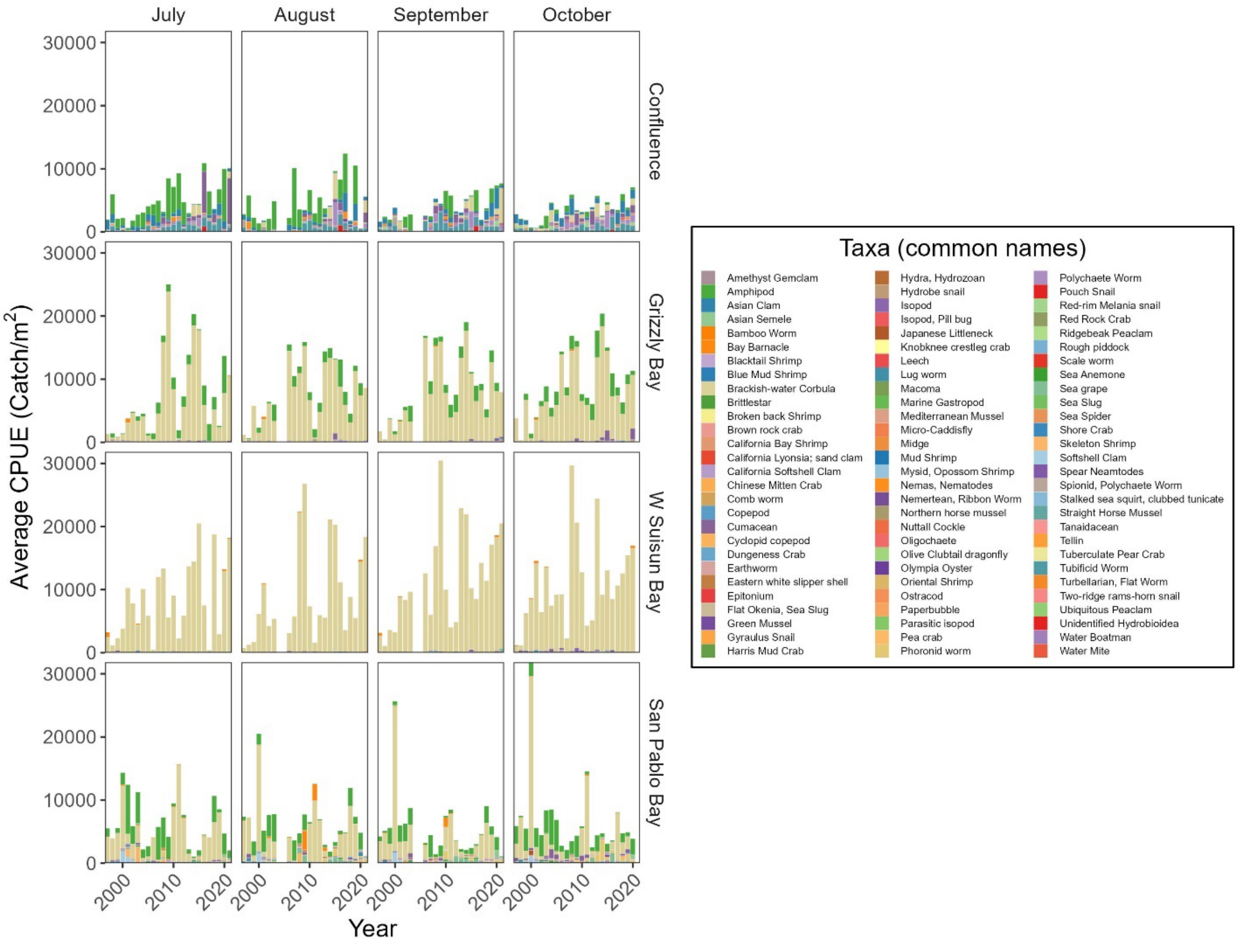


Source: Samples were collected by the Environmental Monitoring Program; data were downloaded from the Environmental Data Initiative on December 23, 2022.

CPUE = catch per unit effort; catch/m^2 = number of individuals per square meter; Sac R = Sacramento River; SJR = San Joaquin River.

Taxonomic groups provided as common names. Note the y-axis scales differ between the plot for the fresher regions and the brackish regions.

Figure K-19. Benthos Mean Monthly Relative Abundance by Enhanced Delta Smelt Monitoring Program Region: Fresher Regions, from July through October of Each Year, 1996–2021

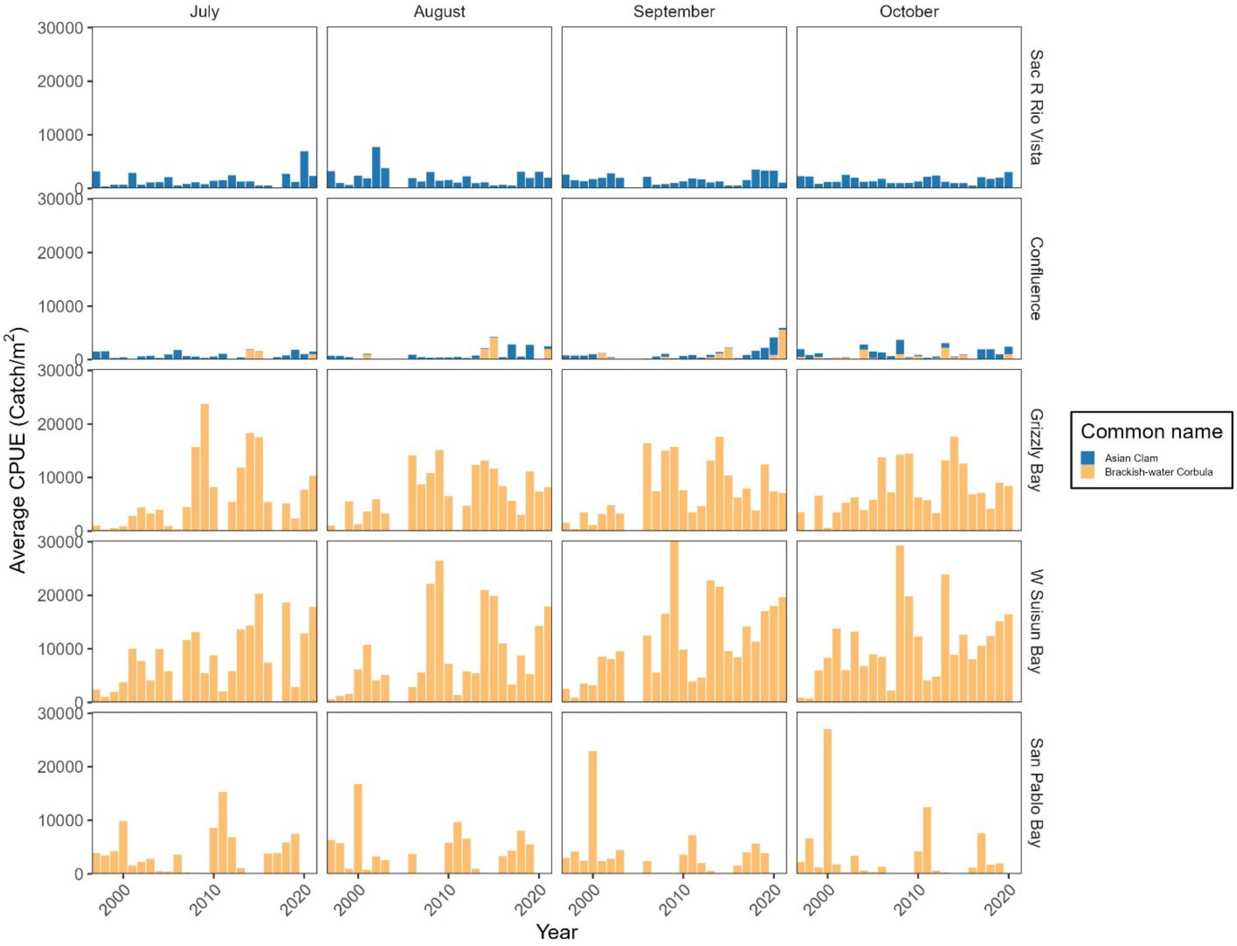


Source: Samples were collected by the Environmental Monitoring Program; data were downloaded from the Environmental Data Initiative on December 23, 2022.

CPUE = catch per unit effort; catch/m^2 = number of individuals per square meter.

Taxonomic groups provided as common names. Note the y-axis scales differ between the plot for the fresher regions and the brackish regions.

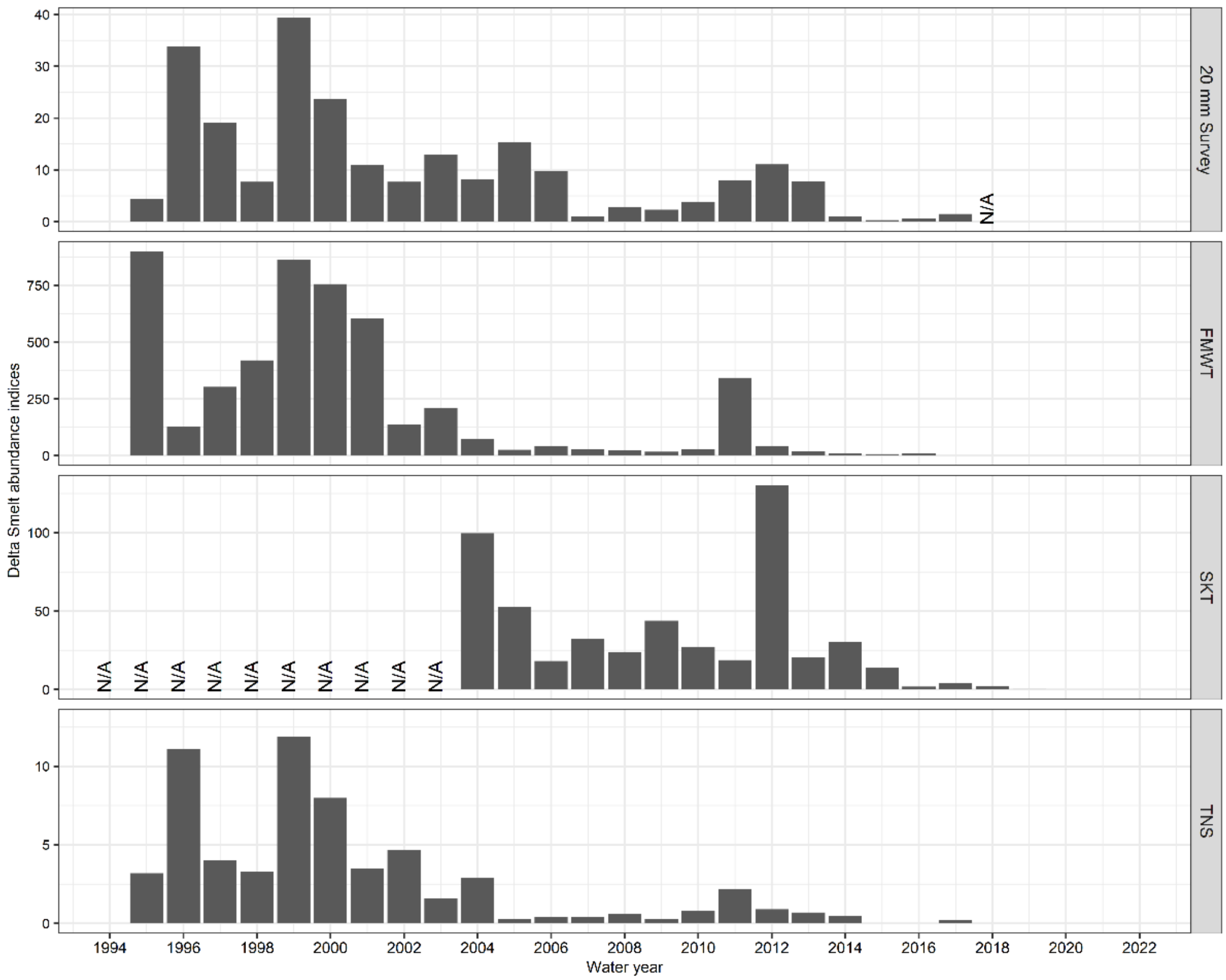
Figure K-20. Benthos Mean Monthly Relative Abundance (by Enhanced Delta Smelt Monitoring Program Region: Brackish Regions, from July through October of Each Year, 1996–2021



Source: Samples were collected by the Environmental Monitoring Program; data were downloaded from the Environmental Data Initiative on December 23, 2022.

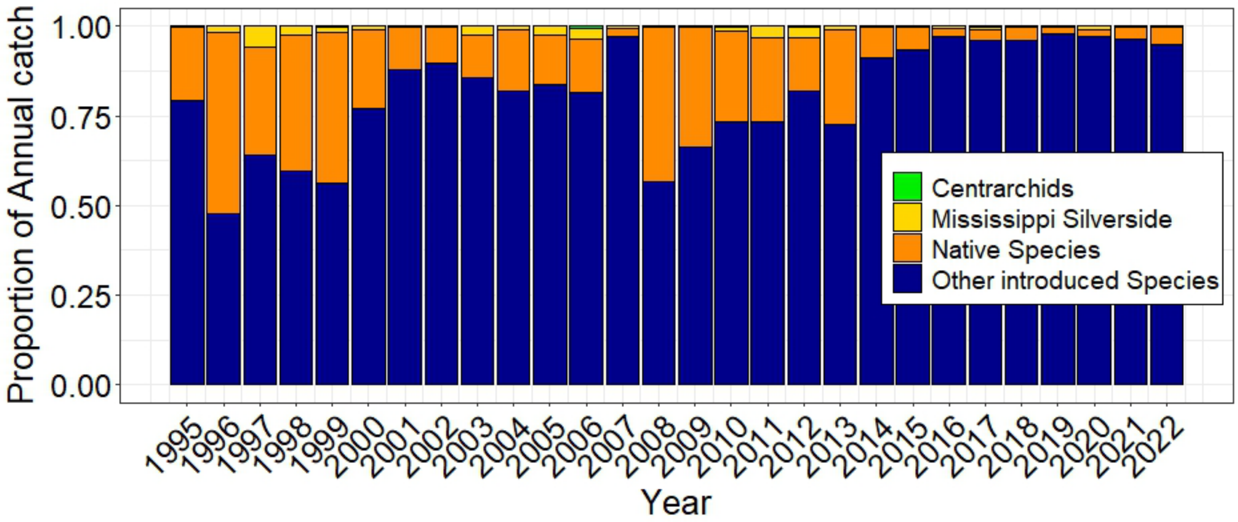
CPUE = catch per unit effort; catch/m^2 = number of individuals per square meter; Sac R = Sacramento River. Taxonomic groups provided as common names.

Figure K-21. Invasive Clam Mean Monthly Relative Abundance by Enhanced Delta Smelt Monitoring Program Region, from July through October of Each Year, 1996–2021



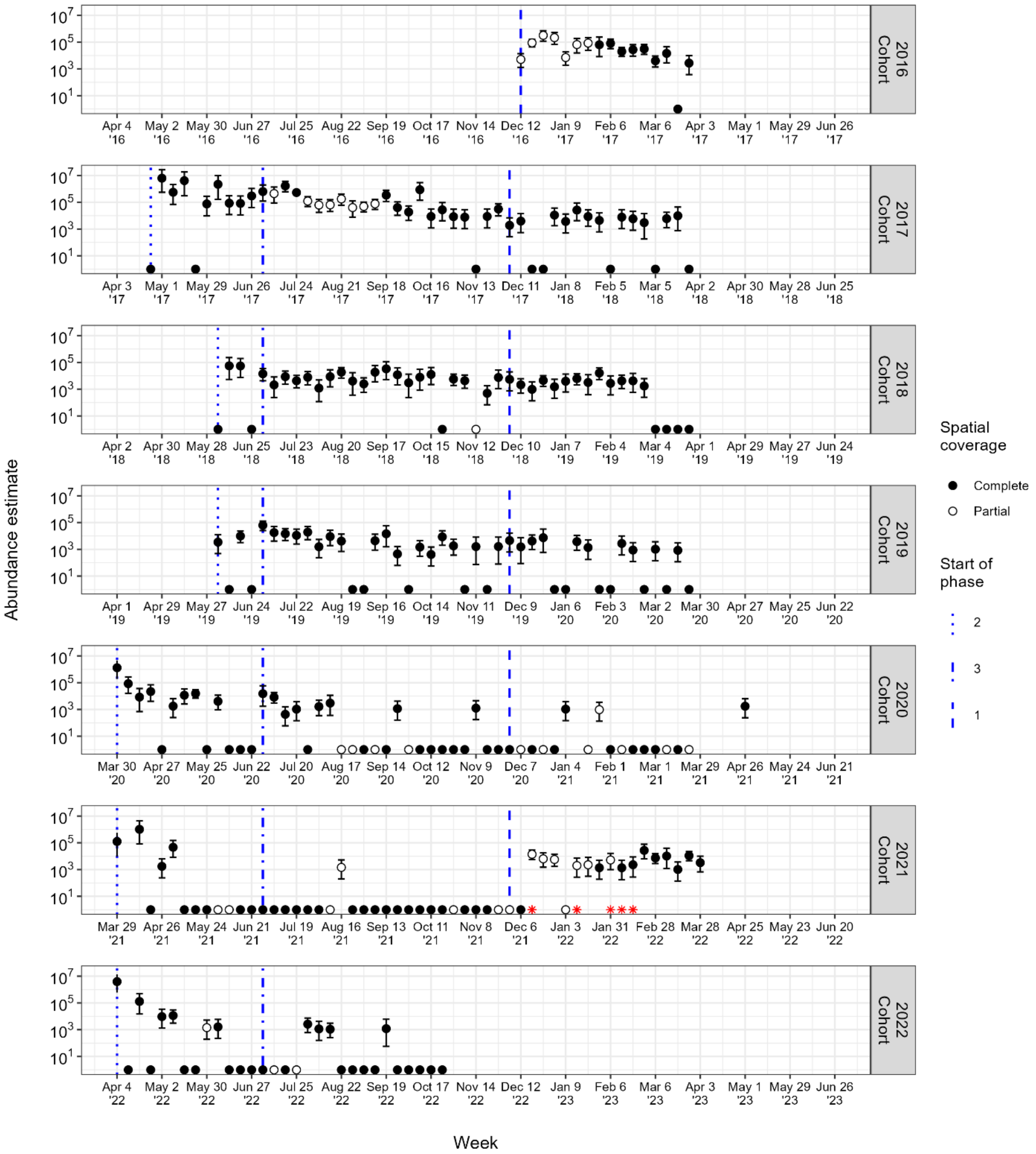
20 mm Survey = 20-mm Larval Delta Smelt Survey; FMWT = Fall Midwater Trawl Survey;
SKT = Spring Kodiak Trawl Survey; TNS = Summer Townet Survey.
For more information on each survey, see Tempel et al. (2021).

Figure K-22. Indices of Delta Smelt Abundance from Long-running Fish Surveys in the Delta



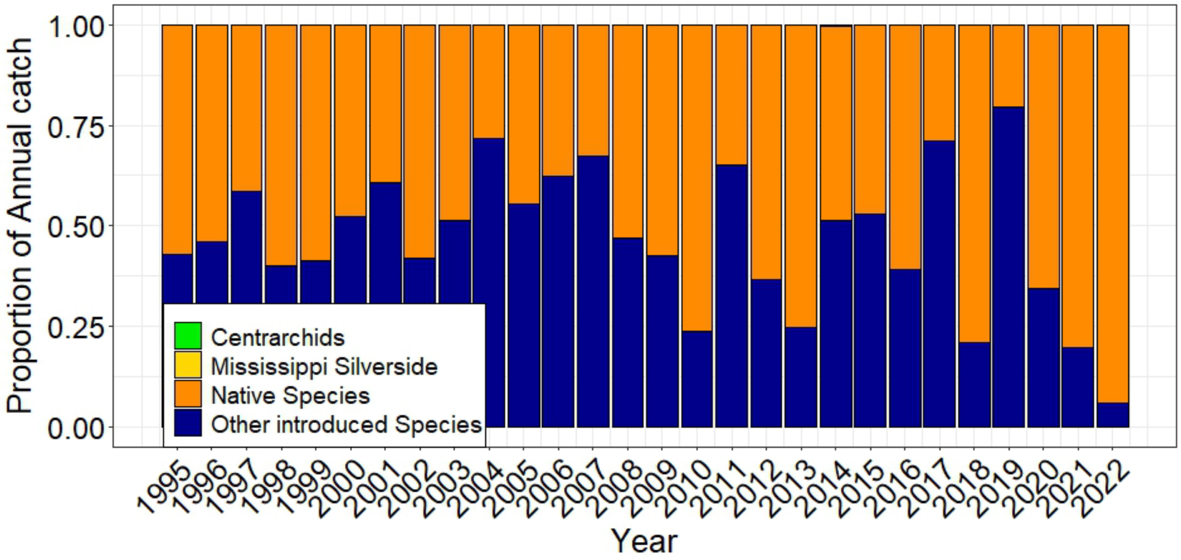
Centrarchids and Mississippi silversides are separated as noted competitors or predators of native fishes like Delta smelt.

Figure K-23. Summer Townet Survey Estimated Proportion of Annual Catch of Fishes



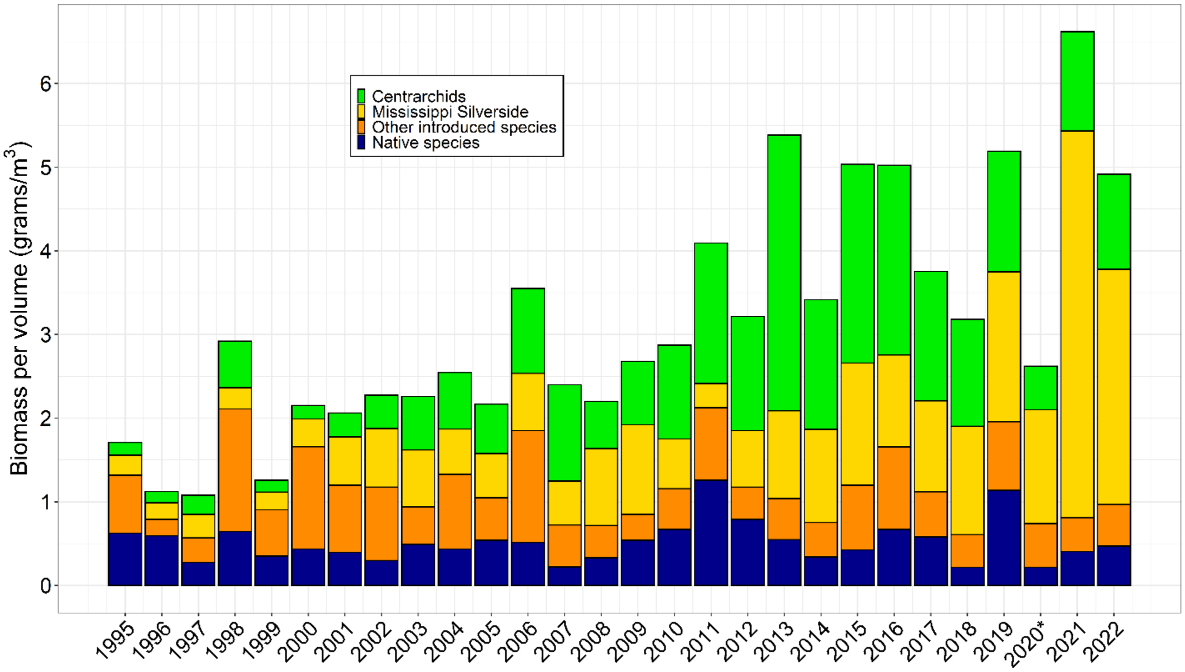
Phase 1 uses Kodiak trawl to sample adult Delta Smelt during spawning and entrainment season. Phase 2 uses 20-mm larval net to sample larval and early juvenile Delta Smelt. Phase 3 uses Kodiak trawl to sample rearing subadult Delta Smelt. Abundance estimates were calculated using zero-inflated negative binomial model for phase 1 and 3, and using design-based method for phase 2. Red stars indicate weeks with supplemental releases. Note that data from the latest phase has not yet been QA/QC'ed,

Figure K-24. Time Series of Enhanced Delta Smelt Monitoring Program Weekly Delta Smelt Abundance Estimates (y-axis, log scale) for 2016 through 2022 Cohorts



Centrarchids and Mississippi silversides are separated as noted competitors or predators of native fishes like Delta smelt. Abundance of northern anchovy is driving high proportion of native fishes.

Figure K-25. Fall Midwater Trawl Estimated Proportion of Annual Catch of Fishes



Source: Based on March-August Beach Seine Catch Data from the Delta Juvenile Fish Monitoring Program as calculated in Mahardja et al. (2017).
grams/m^3 = grams per cubic meter.
*Reduced sampling in 2020 due to COVID-19 pandemic.

Figure K-26. Estimated Annual Mean Biomass per Volume of Nonnative Nearshore Fishes

K.5.4 Models

Numerous quantitative models can be used to evaluate the environmental impacts of the CVP and SWP on listed fishes. A standardized set of criteria was applied to identify the suite of models used in our effects analysis. The necessary criteria include: (1) models are accessible and model output can be reproduced by an independent party, (2) model structure is well documented including model assumptions, (3) model functions are responsive to changing operations such as flow, and (4) model output informs performance metrics. In addition, models also preferably include: (1) focus on target species and/or run-timing group, (2) data collected after 2008, (3) an open and participatory development process, and (4) recent application in regulatory context (e.g., Biological Assessment, Biological Opinions).

K.5.4.1 Delta Smelt Habitat and Food and Growth Potential

- Reclamation considered the Bioenergetics-Based Habitat Suitability, from the Individual-Based Model in R (Rose et al. 2013a, 2013b; Smith 2021) but would not be able to easily translate the CalSim output to the model, so it was not selected.

- The Habitat Suitability Model (Bever et al. 2016) as published and with the addition of a temperature threshold was calculated using SCHISM output.

- Reclamation considered the Resources Management Associates (RMA) Bay-Delta Model and concluded that the additional information would not change the ESA effects analysis nor the NEPA Impact determinations, so it was not selected.

- Reclamation considered the Kimmerer Copepod Box Model (Kimmerer et al. 2019) and subsequent application by Hassrick et al. (2023) and concluded that the modeling approach requires empirical field data. A different approach would need to be developed to conduct a comparable evaluation of different alternatives.

- RMA Copepod BPUE Model (Calanoid copepod analysis addendum; https://dshm.rmanet.app/overview/rma_calibration_reports/USBR_LTO_copepod_addendum.pdf) Reclamation considered the RMA Copepod BPUE Model and did not select it because it is still undergoing peer review.

K.5.4.2 Habitat

Bever et al. (2016) Habitat Suitability Index

During the summer-fall period, sub-adult Delta smelt primarily rear in the west Delta, Suisun Bay, and Cache Slough Complex (Merz et al. 2011; Sommer and Mejia 2013; Interagency Ecological Program 2015). The degree to which Delta smelt use these areas depends on salinity, temperature, turbidity, and current speed (Nobriga et al. 2008; Feyrer et al. 2011; Sommer and Mejia 2013; Bever et al. 2016). Bever et al. (2016) developed an HSI for Delta smelt using long-term data from the CDFW's Fall Midwater Trawl (FMWT) Survey along with three-dimensional hydrodynamic modeling using the 3D UnTRIM Bay-Delta Model. They developed a statistical model using salinity (percent of time < 6 psu), velocity (maximum depth-averaged current speed over a 4-month period), and turbidity (0.5 meter Secchi depth threshold) metrics to predict a catch station index, which is the relative ranking of FMWT stations based on Delta smelt catch. This index was validated using Delta smelt data from the CDFW Bay Study survey, indicating general applicability of the index throughout the Delta (Bever et al. 2016). Bever et al. (2016)

concluded that the index is useful for predicting the favorability of environmental conditions among years and, specifically, that historical Delta smelt catch was higher at locations with overlapping conditions of low salinity, low maximum velocity, and high turbidity.

For this analysis HSI was calculated using a methodology derived from Bever et al. (2016) and RMA (2021), with model runs performed using the 3D Bay-Delta SCHISM Model. The HSI represents spatially- and temporally-averaged suitability of habitats within the delineated subregions in the Bay-Delta shown in Figure 1. Spatial averaging was performed both vertically over depth and horizontally over the area of each subregion. The temporal averaging was performed biweekly from June to November. The HSI is based on the four abiotic variables discussed above: salinity, temperature, turbidity, and current speed. Turbidity (NTU) was used instead of Secchi depth with a threshold of 12 NTU, based on Sommer and Mejia (2013). A temperature threshold of 22ºC was used based on sub-lethal physiological and behavioral effects described in Komoroske et al. (2015, 2021), Davis et al. (2019, 2022), Lewis et al. (2021), and Hammock et al. (2022).

K.5.5 Lines of Evidence

K.5.5.1 Habitat Modeling and Analysis

The area of suitable habitat for Delta smelt increases by increasing the low salinity zone's physical area through pushing X2 further downstream in the wider areas (Grizzly Bay) than the confluence of the Sacramento and San Joaquin Rivers (Feyrer et al. 2011; Bever et al. 2016; Hobbs et al. 2019). This should increase connectivity between the more turbid downstream waters with low salinity fresh waters upstream. However, this relationship is based primarily on the expected salinity change to the system and to some extent, turbidity and water velocity (Bever et al. 2016). Delta smelt do not appear to persist upstream of Jersey Point (Polansky et al. 2018), likely because habitat is inhospitable in the San Joaquin River and fish can be advected to water export facilities (Kimmerer 2008, 2011).

While increased flow or lower X2 in the summer-fall may increase turbidity, the erodible sediment pool from rivers has been depleted, resulting in sudden clearing in the early 2000s (Schoellhamer 2011). Furthermore, the expansion of invasive submersed aquatic vegetation in the Delta has caused an even further decline in turbidity within the Delta (Hestir et al. 2016).

Operation of the SMSCG decreases salinity and increases physical habitat suitability in Suisun Marsh. Bay-Delta SCHISM output for a below normal water year type was used to calculate the HSI for two different gate operation schedules to achieve 4 ppt at Belden's Landing and for a scenario in which the gates are not operated for the Summer-Fall Habitat Action. On a scale of 0 to 1, HSI increased 13%–40% from 0.36 when gates are not operated to between 0.41-0.5, depending on operation schedule.

The relationship between summer-fall outflow and water temperature is even less clear. While there is a negative correlation between fall Delta inflow and water temperature (i.e., higher flow is associated with cooler temperature), the causal link for this relationship is not well understood (Bashevkin and Mahardja 2022). Moreover, summer and fall water temperatures have been increasing due to climate change (Bashevkin et al. 2022) and will progressively get warmer (Dettinger et al. 2016). Region-specific summer-fall actions (e.g., NDFS, SMSCG) for Delta smelt may not be successful if the water temperature becomes unsuitably warm at these locations in the near future.

Contaminant loading may fluctuate under high flow conditions, as pollutants are mobilized and transported downstream within waterways. However, there is a lot of uncertainty regarding the effects of flow on contaminants and the associated risk to aquatic resources including Delta smelt (Stillway et al. 2021). For instance, complex biogeochemical processes (e.g., photo-redox, absorption by phytoplankton, adsorption/desorption, complexation) control the speciation and partitioning of some trace metals or organic contaminants between the dissolved, colloidal and particulate fractions (Bourg 1987; Rogers 1993; Turner 1996; Turner and Millward 2002; Abdou et al. 2022) and thus their availability through direct or trophic pathways. Because flow affects a number of biotic and abiotic drivers (e.g., salinity, suspended sediments, particulate and dissolved organic matter, phytoplankton production and concentration) involved both in those processes and in controlling the distribution, abundance, growth, survival, and reproductive success of aquatic organisms, its potential impacts on individual contaminants (or interactive effects of contaminant mixtures), their bioavailability and toxicity, go beyond direct hydrological effects such as mobilization, transport or dilution and are challenging to predict. Connon et al. (2019) recognize some of those sources of uncertainty, knowledge gaps and challenges in the current state of ecotoxicological monitoring and regulatory frameworks. They offer recommendations to integrate the latest research and technology advances into enhanced monitoring programs that should provide actionable information to guide management and mitigate risk to Bay-Delta aquatic resources, including Delta smelt.

Bever et al. (2016) Habitat Suitability Index

Bever et al. (2016) HSI values (henceforth Bever HSI) and Bever HSI modified with a 22°C temperature threshold values (henceforth 22C HSI) were calculated for the Delta (i.e., averaged across all subregions), subregions targeted by the summer and fall habitat X2 and SMSCG actions (Yolo, Lower Sacramento River, Confluence, Suisun Marsh, Northwest Suisun), and each subregion.

- **Drivers of Variation:** Differences among alternatives in Bever HSI are due to salinity and current speed; differences among alternatives in 22C HSI are due to salinity, current speed, and temperature. Among water year types, salinity was influenced by hydrology and whether the SMSCG were operating. Water temperatures were influenced by the air temperatures used in SCHISM. For example, air temperatures and therefore water temperatures were relatively warm in 2019, used to model the wet water year, compared to 2010, used to model the above normal water year.
- **Calibration:** The Bay-Delta SCHISM Model has previously been calibrated and validated by Ateljevich et al. (2014). Prior to applying SCHISM to evaluate the different alternatives outlined above, its capability was further validated in this study for each water year type using a historical water year with a similar Sacramento River Index and ample observed data (flow, salinity, and temperature) for comparison.
- **Uncertainties:** Using historical turbidity values for a given water year type is the largest source of uncertainty, as we have very poor predictive power for turbidity. Actual turbidities occurring in the modeled years may be quite different from previous years. Also, model predictions are subject to limitations in the climate datasets used, and

methodologies used to derive the boundary conditions, as well as CalSim 3 assumptions and uncertainties in the flows that are used as boundary conditions to SCHISM. The range of water temperatures during July through November span the 22°C and 24°C temperature thresholds used to modify Bever et al. (2016). This causes HSI calculations using these thresholds to be very sensitive to both the temperature threshold used for calculating HSI and the source of air temperature used for the SCHISM simulations.

- **Performance Measure Comparisons (Biological Assessment):** Mean Bever HSI ranged from 0.39 to 0.51 for the Delta, with differences among alternatives < 0.009. Mean Bever HSI ranged from 0.40 to 0.65 for the summer and fall habitat regions, with differences among alternatives ≤ 0.024. Any differences between the alternative two components and the no action alternative are most likely due to differences in salinity and current speed among alternatives for each water year. Higher mean Bever HSI values in the above normal water are likely due to operation of the SMSCG and the timing of inflow during the summer. Mean 22C HSI ranged from 0.11 to 0.38 for the Delta, with differences among alternatives ≤ 0.008. Mean 22C HSI ranged from 0.13-0.14 for the summer and fall habitat regions, with differences among alternatives ≤ 0.012. Any differences between the alternative two components and the no action alternative are most likely due to small differences in salinity and water temperature among the no action alternatives and Alternative 2 components for each water year. Differences among water year types were driven by temperature and salinity. Bever HSI values across the alternative two components were similar to those of the no action alternative at all levels of spatial organization (Delta, summer and fall habitat subregions together, individual subregions). For the Delta and summer and fall habitat subregions, percent changes were slightly negative; for each subregion, percent changes were either zero or slightly negative (> -8.5%), except for the Confluence in the critical water year.

Table K-1. Means and Standard Deviations of the Habitat Suitability Index Calculated using Bever et al. (2016) for Each Alternative and Water Year Type

Water Year Type	**Region**	**EXP1**	**EXP3**	**NAA**	**Alt2w TUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**
Wet	Summer-Fall	0.383 +/- 0.13	0.509 +/- 0.157	0.585 +/- 0.172	0.579 +/- 0.172	0.576 +/- 0.171	0.58 +/- 0.172	0.58 +/- 0.172
	Delta	0.385 +/- 0.135	0.439 +/- 0.149	0.484 +/- 0.17	0.481 +/- 0.169	0.479 +/- 0.167	0.481 +/- 0.169	0.481 +/- 0.169
Above Normal	Summer-Fall	0.489 +/- 0.182	0.593 +/- 0.165	0.645 +/- 0.158	0.645 +/- 0.158	0.645 +/- 0.158	0.647 +/- 0.158	0.65 +/- 0.157
	Delta	0.427 +/- 0.168	0.49 +/- 0.172	0.51 +/- 0.182	0.508 +/- 0.182	0.508 +/- 0.182	0.51 +/- 0.183	0.512 +/- 0.184
Below Normal	Summer-Fall	0.343 +/- 0.109	0.525 +/- 0.159	0.588 +/- 0.18	0.574 +/- 0.181	0.574 +/- 0.181	0.583 +/- 0.181	0.583 +/- 0.181
	Delta	0.366 +/- 0.13	0.45 +/- 0.148	0.467 +/- 0.181	0.461 +/- 0.177	0.461 +/- 0.177	0.464 +/- 0.178	0.464 +/- 0.179

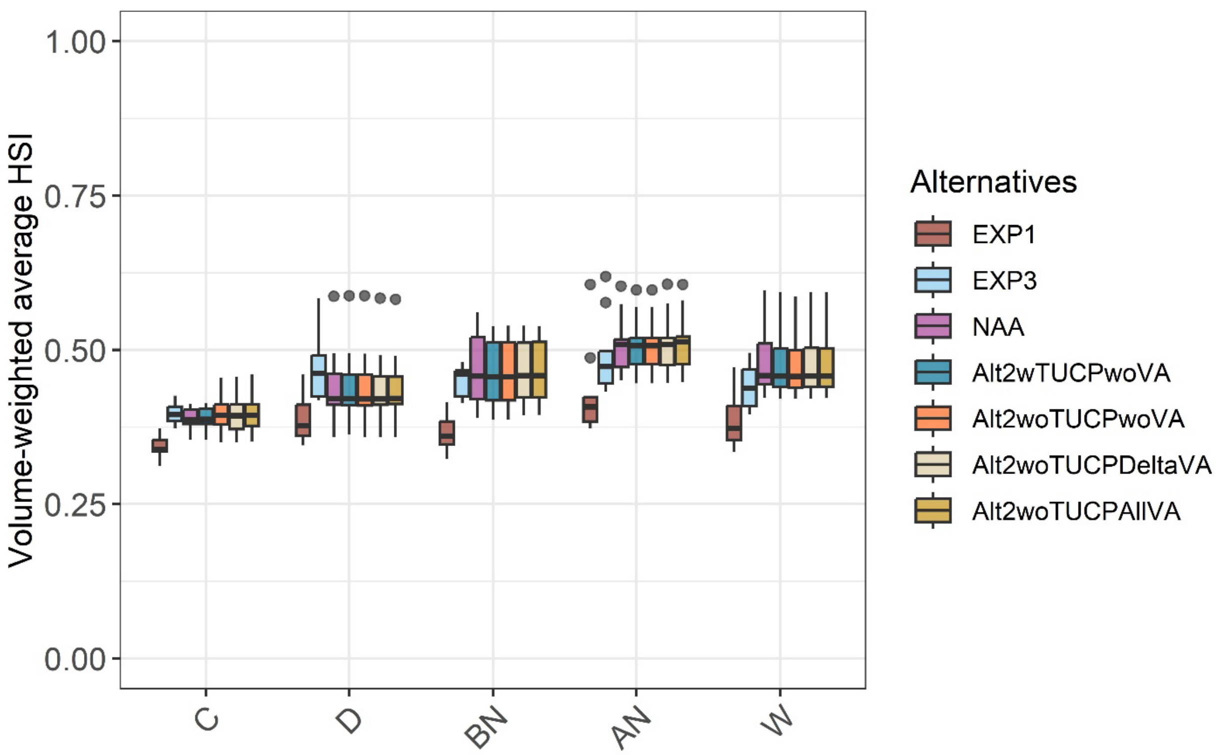
Dry	Summer-Fall	0.398 +/- 0.142	0.562 +/- 0.168	0.515 +/- 0.176	0.514 +/- 0.176	0.513 +/- 0.176	0.513 +/- 0.176	0.515 +/- 0.176
	Delta	0.39 +/- 0.141	0.469 +/- 0.163	0.438 +/- 0.168	0.438 +/- 0.168	0.437 +/- 0.168	0.436 +/- 0.167	0.436 +/- 0.167
Critically Dry	Summer-Fall	0.286 +/- 0.045	0.429 +/- 0.138	0.4 +/- 0.133	0.402 +/- 0.134	0.424 +/- 0.157	0.418 +/- 0.155	0.422 +/- 0.155
	Delta	0.341 +/- 0.116	0.397 +/- 0.14	0.387 +/- 0.137	0.388 +/- 0.137	0.397 +/- 0.145	0.395 +/- 0.144	0.397 +/- 0.144

Sources: Bever et al. 2016; California Department of Water Resources 2010 (above normal water years), 2019 (wet water years).

Table K-2. Means of the Habitat Suitability Index Calculated using Bever et al. (2016) for Each Alternative and Water Year Type

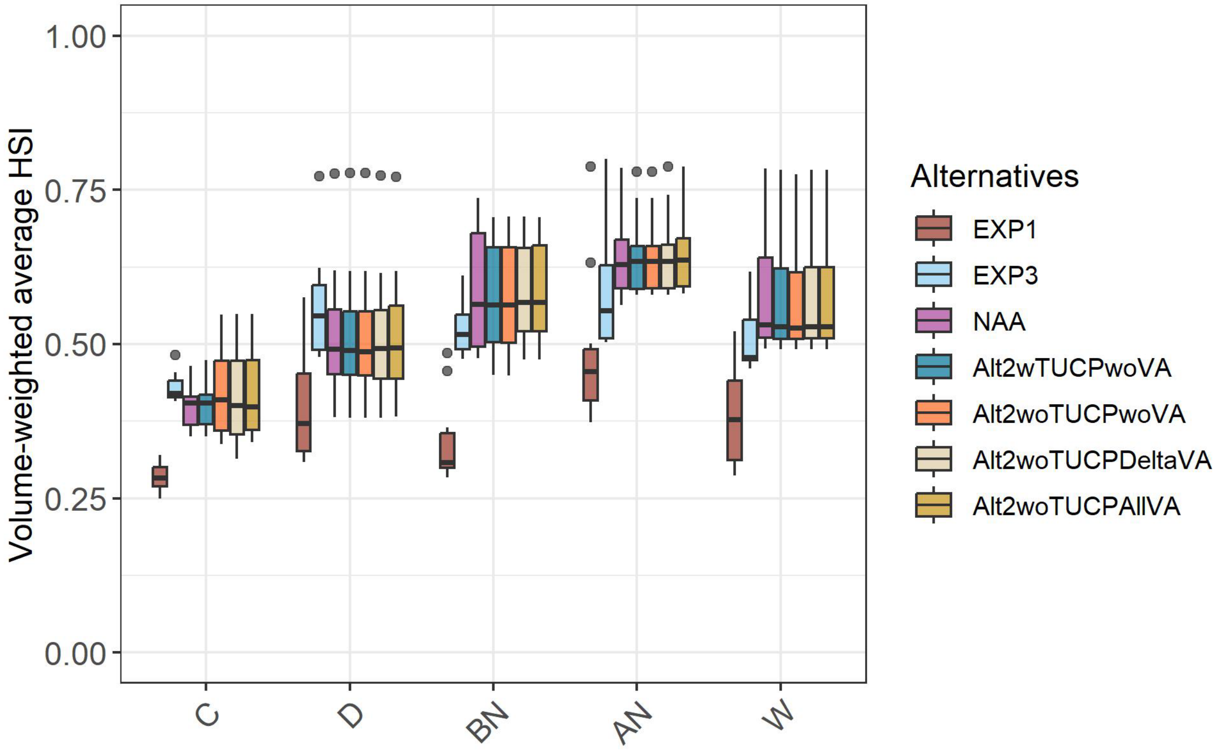
Water Year Type	**Region**	**EXP1**	**EXP3**	**NAA**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**
Wet	Summer -Fall	0.383 (0.345)	0.509 (0.13)	0.58	0.579 (0.01)	0.576 (0.015)	0.58 (0.009)	0.58 (0.009)
	Delta	0.385 (0.205)	0.439 (0.093)	0.48	0.481 (0.006)	0.479 (0.01)	0.481 (0.006)	0.481 (0.006)
Above Normal	Summer -Fall	0.489 (0.242)	0.593 (0.081)	0.64	0.645 (0)	0.645 (0)	0.647 (-0.003)	0.65 (-0.008)
	Delta	0.427 (0.163)	0.49 (0.039)	0.51	0.508 (0.004)	0.508 (0.004)	0.51 (0)	0.512 (-0.004)
Below Normal	Summer -Fall	0.343 (0.417)	0.525 (0.107)	0.59	0.574 (0.024)	0.574 (0.024)	0.583 (0.009)	0.583 (0.009)
	Delta	0.366 (0.216)	0.45 (0.036)	0.47	0.461 (0.013)	0.461 (0.013)	0.464 (0.006)	0.464 (0.006)
Dry	Summer -Fall	0.398 (0.227)	0.562 (-0.091)	0.52	0.514 (0.002)	0.513 (0.004)	0.513 (0.004)	0.515 (0)
	Delta	0.39 (0.11)	0.469 (-0.071)	0.44	0.438 (0)	0.437 (0.002)	0.436 (0.005)	0.436 (0.005)
Critically Dry	Summer -Fall	0.286 (0.285)	0.429 (-0.072)	0.40	0.402 (-0.005)	0.424 (-0.06)	0.418 (-0.045)	0.422 (-0.055)
	Delta	0.341 (0.119)	0.397 (-0.026)	0.39	0.388 (-0.003)	0.397 (-0.026)	0.395 (-0.021)	0.397 (-0.026)

Sources: Bever et al. 2016; California Department of Water Resources 2010 (above normal water years), 2019 (wet water years).



Sources: Bever et al. 2016; California Department of Water Resources 2019 (air temperatures).
HSI = habitat suitability index; C = critically dry; D = dry; BN = below normal; AN = above normal; W = wet.
The median is shown as the horizontal line, the box indicates the 25th and 75th percentiles, the vertical lines indicate the 25th and 75th percentiles plus 1.5 times the interquartile range, and the dots indicate potential outliers.

Figure K-27. Bever et al. (2016) Delta-wide Habitat Suitability Indices for Each Alternative and Water Year Type for July 1–November 18



Sources: Bever et al. 2016; California Department of Water Resources 2019 (air temperatures).
HSI = habitat suitability index; C = critically dry; D = dry; BN = below normal; AN = above normal; W = wet.
The arc includes subregions Confluence, Lower Sacramento River, northwest Suisun Bay, and Suisun Marsh. The median is shown as the horizontal line, the box indicates the 25th and 75th percentiles, the vertical lines indicate the 25th and 75th percentiles plus 1.5 times the interquartile range, and the dots indicate potential outliers.

Figure K-28. Bever et al. (2016) Habitat Suitability Indices in the Summer and Fall Habitat Arc for Each Alternative and Water Year Type for July 1–November 18

Table K-3. Means and Standard Deviations of the Habitat Suitability Index Calculated using Bever et al. (2016) Modified with a 22°C Temperature Threshold for Each Alternative and Water Year Type

Water Year Type	**Region**	**EXP1**	**EXP3**	**NAA**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**
Wet	Summer-Fall	0.167 +/- 0.221	0.182 +/- 0.233	0.205 +/- 0.237	0.204 +/- 0.237	0.203 +/- 0.237	0.204 +/- 0.237	0.204 +/- 0.237
	Delta	0.156 +/- 0.203	0.166 +/- 0.208	0.193 +/- 0.206	0.193 +/- 0.206	0.193 +/- 0.206	0.193 +/- 0.206	0.193 +/- 0.206
Above Normal	Summer-Fall	0.364 +/- 0.18	0.439 +/- 0.2	0.513 +/- 0.191	0.515 +/- 0.188	0.515 +/- 0.188	0.524 +/- 0.189	0.525 +/- 0.19
	Delta	0.262 +/- 0.186	0.32 +/- 0.215	0.373 +/- 0.21	0.373 +/- 0.207	0.373 +/- 0.207	0.38 +/- 0.212	0.381 +/- 0.213
Below Normal	Summer-Fall	0.246 +/- 0.124	0.352 +/- 0.189	0.412 +/- 0.186	0.402 +/- 0.187	0.402 +/- 0.187	0.412 +/- 0.194	0.412 +/- 0.195
	Delta	0.206 +/- 0.153	0.262 +/- 0.191	0.296 +/- 0.185	0.291 +/- 0.183	0.291 +/- 0.183	0.296 +/- 0.187	0.296 +/- 0.188
Dry	Summer-Fall	0.242 +/- 0.193	0.305 +/- 0.226	0.273 +/- 0.192	0.272 +/- 0.192	0.272 +/- 0.191	0.272 +/- 0.193	0.274 +/- 0.195
	Delta	0.196 +/- 0.184	0.235 +/- 0.214	0.212 +/- 0.19	0.212 +/- 0.19	0.212 +/- 0.189	0.211 +/- 0.19	0.212 +/- 0.19
Critically Dry	Summer-Fall	0.105 +/- 0.109	0.155 +/- 0.188	0.137 +/- 0.161	0.137 +/- 0.16	0.134 +/- 0.155	0.129 +/- 0.145	0.131 +/- 0.148
	Delta	0.102 +/- 0.136	0.123 +/- 0.172	0.118 +/- 0.161	0.118 +/- 0.161	0.117 +/- 0.159	0.115 +/- 0.156	0.117 +/- 0.157

Sources: Bever et al. 2016; California Department of Water Resources 2010 (above normal water years), 2019 (wet water years).
°C = degrees Celsius.

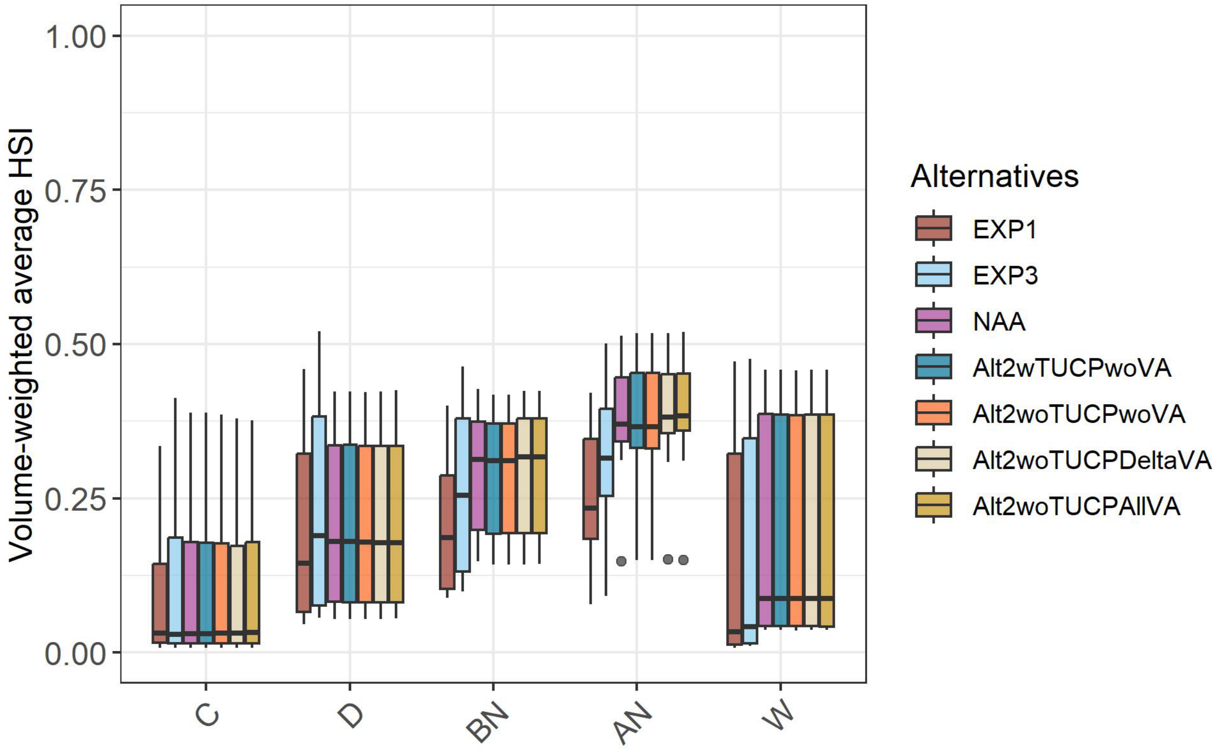
Table K-4. Means of the Habitat Suitability Index Calculated using Bever et al. (2016) Modified with a 22°C Temperature Threshold for Each Alternative and Water Year Type

Water Year Type	**Region**	**EXP1**	**EXP3**	**NAA**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**
Wet	Summer-Fall	0.167 (0.185)	0.182 (0.112)	0.205	0.204 (0.005)	0.203 (0.01)	0.204 (0.005)	0.204 (0.005)
	Delta	0.156 (0.192)	0.166 (0.14)	0.193	0.193 (0)	0.193 (0)	0.193 (0)	0.193 (0)
Above Normal	Summer-Fall	0.364 (0.29)	0.439 (0.144)	0.513	0.515 (-0.004)	0.515 (-0.004)	0.524 (-0.021)	0.525 (-0.023)
	Delta	0.262 (0.298)	0.32 (0.142)	0.373	0.373 (0)	0.373 (0)	0.38 (-0.019)	0.381 (-0.021)
Below Normal	Summer-Fall	0.246 (0.403)	0.352 (0.146)	0.412	0.402 (0.024)	0.402 (0.024)	0.412 (0)	0.412 (0)
	Delta	0.206 (0.304)	0.262 (0.115)	0.296	0.291 (0.017)	0.291 (0.017)	0.296 (0)	0.296 (0)
Dry	Summer-Fall	0.242 (0.114)	0.305 (-0.117)	0.273	0.272 (0.004)	0.272 (0.004)	0.272 (0.004)	0.274 (-0.004)
	Delta	0.196 (0.075)	0.235 (-0.108)	0.212	0.212 (0)	0.212 (0)	0.211 (0.005)	0.212 (0)
Critically Dry	Summer-Fall	0.105 (0.234)	0.155 (-0.131)	0.137	0.137 (0)	0.134 (0.022)	0.129 (0.058)	0.131 (0.044)
	Delta	0.102 (0.136)	0.123 (-0.042)	0.118	0.118 (0)	0.117 (0.008)	0.115 (0.025)	0.117 (0.008)

Sources: Bever et al. 2016; California Department of Water Resources 2010 (above normal water years), 2019 (wet water years).

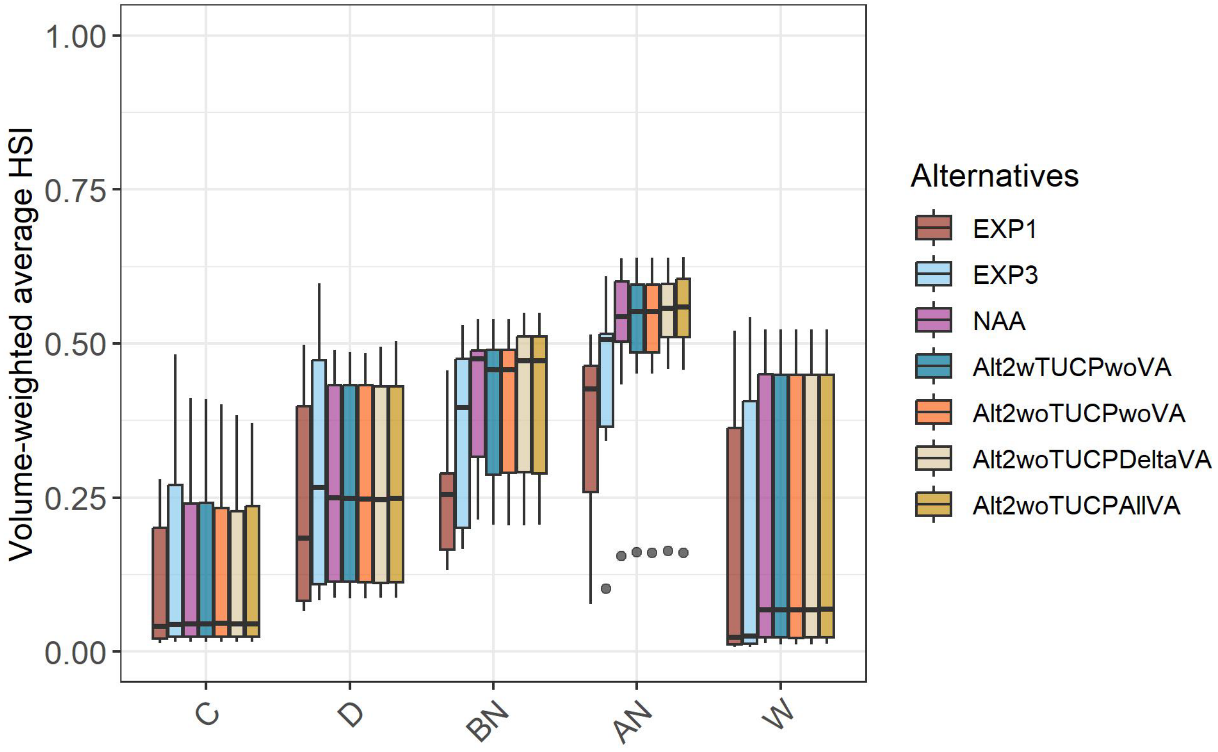
°C = degrees Celsius.

Percent change of each mean compared to the No Action Alternative mean is indicated in parenthesis.



Sources: Bever et al. 2016; California Department of Water Resources 2019 (air temperatures).
HSI = habitat suitability index; C = critically dry; D = dry; BN = below normal; AN = above normal; W = wet; °C = degrees Celsius.
The median is shown as the horizontal line, the box indicates the 25th and 75th percentiles, the vertical lines indicate the 25th and 75th percentiles plus 1.5 times the interquartile range, and the dots indicate potential outliers.

Figure K-29. Bever et al. (2016) Delta-wide Habitat Suitability Indices Modified by a 22°C Threshold for Each Alternative and Water Year Type for July 1–November 18



Sources: Bever et al. 2016; California Department of Water Resources 2019 (air temperatures).
HSI = habitat suitability index; C = critically dry; D = dry; BN = below normal; AN = above normal; W = wet; °C = degrees Celsius.
The arc includes subregions Confluence, Lower Sacramento River, northwest Suisun Bay, and Suisun Marsh. The median is shown as the horizontal line, the box indicates the 25th and 75th percentiles, the vertical lines indicate the 25th and 75th percentiles plus 1.5 times the interquartile range, and the dots indicate potential outliers.

Figure K-30. Bever et al. (2016) Habitat Suitability Indices Modified by a 22°C Threshold in the Summer and Fall Habitat Arc for Each Alternative and Water Year Type for July 1–November 18

K.5.5.2 Flow-Food Relationships During Summer and Fall

The steep decline in zooplankton abundance due to the introduction of invasive clams in the 1980s has been purported to be one of the main drivers of Delta smelt decline (Kimmerer and Rose 2018). The clam species is an indirect competitor to Delta smelt, consuming zooplankton prey and the phytoplankton resources needed for zooplankton. However, the distribution of the clam is restricted to the more saline portions of the estuary (Thompson and Parchaso 2010). Food availability in the low salinity zone during summer and fall is likely subsidized by the transport of zooplankton prey, particularly the calanoid copepod *Pseudodiaptomus forebsi*, from more productive freshwater habitat upstream (Kimmerer et al. 2018, 2019; Hassrick et al. 2023). Analysis by Hamiliton et al. (2020) predicted decreases in calanoid copepod biomass with increased flows during September and October. However, Hassrick et al. (2023) used a box-model approach to show that augmented outflow aimed at moving the position of X2 seaward can increase *P. forbesi* subsidies to the low salinity zone, doubling it between an X2 of 85 km and 74 km and tripling it between an X2 of 85 km and 67 km. Although this level of outflow augmentation is infeasible given the water and financial costs, Hassrick et al. (2023) concluded that increases in *P. forbesi* abundance in the low salinity zone in response to smaller outflow augmentations could increase fish feeding rates. In contrast, an analysis of zooplankton monitoring data from 2011-2017, Schultz et al. (2019) did not detect an increase in or higher zooplankton densities during wet years (2011, 2017), when the low salinity zone overlapped with Suisun Bay and Marsh and when outflow was augmented during fall to shift X2 seaward towards 75 km. One explanation for these observations are modifying river flows redistributes copepods. Monitoring has shown zooplankton biomass varies by month and location, and generally into areas of lower biomass downstream than upstream (Hamilton et al. 2020). Another explanation may be related to the monitoring itself as a statistical power analysis based on current zooplankton monitoring methods in the Upper San Francisco Estuary showed limited power to detect changes in zooplankton biomass in response to an augmented outflow X2 action, unless the effect was large (> 150%) (Brandon et al. 2022).

Although the distribution of Delta smelt has been restricted in recent years, Delta smelt were known to reside in fresh water year-round within the North Delta region, especially during dry years (Sommer et al. 2011; Mahardja et al. 2019; Lewis et al. 2022). Phytoplankton blooms occurred in the North Delta during the summer-fall period of 2011 and 2012 following flow pulses through the Yolo Bypass Toe Drain, leading to the idea of using such flow pulses to augment zooplankton/food for Delta smelt (i.e., the NDFS action; Frantzich et al. 2018). The NDFS actions showed consistent increases in phytoplankton and chlorophyll; however, these effects have been mostly localized and only occasionally followed by a subsequent increase in zooplankton (Davis et al. 2022). Similar to an augmented outflow X2 action, the power to detect differences in zooplankton catch per unit effort in response to an NDFS action is low, even for a relatively large effect (Brandon et al. 2022). A larger food web response from the NDFS action has been somewhat inconsistent, and preliminary results from the Delta smelt Individual-Based Modeling effort showed little effect on the growth and survival of Delta smelt even under the most ideal scenarios (Resources Management Associates 2021; California Department of Water Resources 2022). For example, increases in Delta smelt growth increment under different NDFS implementation scenarios ranged from 0.21–0.63 millimeters (mm) when modeled for a below normal water year type (California Department of Water Resources 2022). However, the NDFS action may have led to a zooplankton increase in 2016 and it is thought that the timing and type of water used for the NDFS action (agricultural return water vs. Sacramento River water) can largely affect the type of phytoplankton and zooplankton response (Frantzich et al. 2021).

In light of the box-model, zooplankton biomass observation, and fish observations, food subsidies should be expected to be scaled to the magnitude of inflow contributing to the low salinity zone and reflect the regions where water is being distributed. Flow pulse actions in other areas in the Bay-Delta (e.g., Sacramento Deep Water Ship Channel) and managed flooding and drainage of wetlands in Suisun Marsh are being studied and considered as other ways to augment food at a variety of spatial scales for the increasingly rare Delta smelt.

K.5.5.3 Delta Smelt Behavior, Distribution, and Habitat Analysis

The distribution of larval Delta smelt is primarily driven by the local hydrodynamics and geography in the region in which they hatched until they grow to approximately 20 mm total length (TL), when they become free swimming and can retain their position in the estuary (Interagency Ecological Program 2015). A large portion of the population exhibits a migratory life history in which they are transported or actively migrate towards the low salinity zone, while some remain and complete their life cycle in fresh water (Hobbs et al. 2019). Delta smelt in the low salinity zone or brackish habitat remain there until environmental cues trigger them to move upstream towards fresh water for spawning. Because of its timing, the Summer-Fall Habitat Action is most relevant to the rearing juvenile and subadult life stage of Delta smelt.

Based on observed relationships between salinity, temperature, and turbidity with the probability of catching Delta smelt (Nobriga et al. 2008; Feyrer et al 2007), the intrusion of salinity along with changes in water clarity and rising temperatures in the Delta may limit access to otherwise supportive habitat. Merz et al. (2011) used historical pelagic fish monitoring data to evaluate the spatial distribution of juvenile and sub-adult Delta smelt during the summer and fall. Based on Summer Townet Survey data from 1995–2009, the average frequency of juvenile Delta smelt occurrence was approximately 45% in the low-salinity zone (Suisun Bay, Suisun Marsh, Grizzly Bay, confluence, lower Sacramento River), 73% in Grizzly Bay, and 19% in Suisun Marsh between June and August, compared to an average frequency of occurrence of 8% in the other regions sampled (Merz et al. 2011, Table 7). Based on FMWT Survey data for September through December, 1995-2009, the average frequency of juvenile Delta smelt occurrence was approximately 15% in the low-salinity zone, 15% in Grizzly Bay, and 23% in Suisun Marsh, compared to an average frequency of occurrence of 2% in the other regions sampled (Merz et al. 2011, Table 7). The average frequency of occurrence of sub-adult Delta smelt collected by the FMWT during the same months and years was approximately 20% in the low-salinity zone, 20% in Grizzly Bay, and 27% in Suisun Marsh, compared to an average frequency of occurrence of 5% in the other regions sampled (Merz et al. 2011, Table 7). More recently, analysis by Hendrix et al. (2023) found that region was not a primary driver of occupancy during the fall, rather it was a combination of salinity and temperature.

Summer-Fall Habitat Actions aim to alleviate this constriction in action years by increasing the physical extent of lower salinity conditions in areas with higher turbidity, lower temperatures, and other favorable characteristics (e.g., complex bathymetry, sufficient prey availability). Thus, Delta juveniles and subadults may have access to more suitable habitat in areas including Suisun Marsh and Grizzly Bay than if no action was taken. By December and January, Delta smelt conduct their spawning migration using tidal movement (Bennett and Burau 2015). Whether

Delta smelt can exhibit this tidal surfing behavior to access more suitable habitat in the summer-fall months is somewhat uncertain; however, evidence so far suggests that Delta smelt can indeed track the low salinity zone in fall months (Sommer et al. 2011) and that some Delta smelt were able to access Suisun Marsh in 2018 when the first SMSCG action was conducted (Sommer et al. 2020).

K.5.5.4 Habitat Use and Delta Smelt Life History Strategies

Using otolith isotope chemistry, three different life history strategies have been generally identified for Delta smelt (Hobbs et al. 2019): migratory, freshwater resident, and brackish water resident life histories. Some relationships between environmental factors and the prevalence of these life histories have been proposed. Lewis et al. (2022) observed freshwater residents as most abundant during cool and dry conditions while migratory and brackish residents were more commonly observed in warm and wet years. Furthermore, recent work suggests adaptive genetic variants for life history are present in the population (Campbell et al. 2022). These observations of life history, in the context of the habitat and population dynamics, have implications for resilience that are further complicated by the near extirpation of wild Delta smelt and subsequent experimental releases. Therefore, if and how Summer-Fall Habitat Actions affect fish expressing any of the three life histories is currently difficult to assess. However, we can surmise that if the Summer-Fall Habitat Actions offer benefits to Delta smelt, the X2 and SMSCG actions would primarily affect the migratory and brackish water resident portion of the population, while the NDFS action (if beneficial) would likely affect the freshwater resident portion of the population.

K.5.5.5 Effects of the Summer-Fall Habitat Actions on Delta Smelt Population Recruitment and Viability

Using a nonlinear stage-structured state-space model for Delta smelt, Polanksy et al. (2020) identified that recruitment was most influenced by adult food, temperature, and the approximate location of X2 the previous fall. Rose et al. (2013) used the Delta smelt Individual-Based Model to identify the effects of factors that resulted in lower or higher population growth rates. They found that juvenile growth rates in late fall through winter had the greatest influence on population growth rates. Juvenile growth rates were influenced by multiple factors, including water temperature and zooplankton densities during summer through early spring (Rose et al. 2013). These models support the hypothesis that Summer-Fall Habitat Actions that couple increased area of suitable habitat with enhanced prey quality and/or quantity should improve Delta smelt population recruitment and viability. Smith et al. (2021) found as June-August outflow declined, estimated mortality of post-larval Delta smelt during summer increased significantly, and found juvenile mortality (during fall) was significantly less than during summer and suggest ecosystem management actions may be more effective earlier in the year.

Hammock et al. (2022) observed that Delta smelt hepatosomatic index and condition factor are typically the lowest during the fall period and therefore fall may represent a seasonal bottleneck for Delta smelt. Delta smelt growth and survival in the summer-fall months are expected to increase based on anticipated increases in zooplankton prey abundance, possible changes in the zooplankton community composition to more nutritious prey, and greater suitable habitat area that connects different regions of the Delta (Feyrer et al. 2011; Kimmerer and Rose 2018). This was recently supported by a correlation between greater pelagic productivity and increases in hepatosomatic index and condition factor in fish collected in the fall (Hammock et al. 2022).

Greater survival and growth in the summer-fall period should generally lead to higher fecundity and therefore recruitment in the subsequent spring. However, the magnitude of positive impacts from these actions with respect to the distribution and movement of Delta smelt at the population level will depend on the magnitude (i.e., spatial extent and temporal duration) of the summer-fall actions. For summer-fall actions to produce a measurable benefit to the Delta smelt population, it would also require the actions to be successful in their intended objectives (e.g., food subsidy action produces food) and not compromised by other limiting factors (e.g., warm water temperatures, low spring-summer survival, etc.).

K.6 Uncertainty

To inform reliability and value of information regarding summer and fall X2, special studies include Summer-Fall Habitat Action for Delta smelt. This is described in the Proposed Action 9.8 Species Studies.

K.7 References

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