Delta Smelt Summer-Fall Habitat Seasonal Report for WY 2022

Central Valley Project and State Water Project

California

U.S. Department of the Interior and State of California

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Photo Credit: CDFW

Mission Statements

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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.

The mission of the California Department of Water Resources is to sustainably manage the water resources of California, in cooperation with other agencies, to benefit the state's people and protect, restore, and enhance the natural and human environments.

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United States Bureau of Reclamation
California Department of Water Resources

In coordination with the California's Department of Fish and Wildlife, United States Fish and Wildlife Service, National Marine Fisheries Service and Delta Coordination Group

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List of Abbreviations and Acronyms

Abbreviation	Definition
BPUE	Biomass per unit effort
CDFW	California Department of Fish and Wildlife
CVP	Central Valley Project
DCG	Delta Coordination Group
DOP	Directed Outflow Project
EDSM	Enhanced Delta smelt Monitoring Program
EMP	Environmental Monitoring Program
FMWT	Fall Midwater Trawl Survey
FCCL	Fish Conservation and Culture Laboratory
FNU	Formazin nephelometric units
GRI	Growth model index
GRP	Growth rate potential
NTU	Nephelometric Turbidity Units
NDFS	North Delta Food Subsidies/Colusa Basin Drain Study
ROD	Record of Decision
RMA	Resource Management Associates
RRDS	Roaring River Distribution System Food Subsidies Study
SDWSC	Sacramento River Deepwater Ship Channel Food Study
SWP	State Water Project
SCHISM	Semi-Implicit Cross-scale Hydroscience Integrated System Model
Water Board	State Water Resources Control Board
SDM	Structured decision-making
SMSCBG	Suisun Marsh Salinity Control Gates
STN	Summer Townet Survey
SFHA	Summer-Fall Habitat Action
D-1641	Water Rights Decision 1641
WY	Water Year
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

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Executive Summary

The delta smelt Summer Fall Habitat Action (SFHA) includes operational actions aimed to improve habitat and food for the species. WY 2022 was Critically dry, and no SFHA occurred. This followed the no-action years of WY 2021 and WY 2020. However, science and monitoring in Suisun and the North Delta regions was completed in 2022 to further establish a drought condition environmental baseline that can be contrasted with future action years. Overall, outflow, the location of X2, temperature, and turbidity in summer-fall of 2022 were similar to 2021 and other dry years, contiguous low-salinity habitat was not maintained between Cache Slough and the Suisun regions, and average salinity in the Suisun region may have precluded delta smelt from accessing habitat with other needed attributes.

The following describes findings and new activities during WY 2022:

- The Delta Coordination Group (DCG) completed the first iteration of Structured Decision Making (SDM) for SFHA with modeling improvements and expert elicitations.
    - As described in the 2022 SFHA Action Plan, if the WY was Below Normal the DCG recommended to implement reoperation of Suisun Marsh Salinity Control Gates (SMSCG) triggered by 4ppt at Belden's landing and the North Delta Food Subsidy Action (NDFS) redirecting Sacramento River water with low intensity flow rate (400 cfs) through the Yolo Bypass for a longer duration (4 weeks). If the WY was Dry, the DCG recommended only the NDFS action; however, conditions were critically dry, resulting in no action, and NDFS requires ESA coverage prior to implementation.
    - In post-SDM evaluation the DCG determined future SDM should not include SMSCG alternatives, and the expert elicitations may require improvements.
- Between July-September, delta smelt were detected in the Lower Sacramento River, Sacramento Deep Water Shipping Channel (SDWSC), and Suisun Marsh; catch was greater in summer-fall of 2022 compared to 2021. This was likely due to increased recruitment from the releases of 55,733 hatchery-reared delta smelt into the wild the previous winter, which increased the spawning stock of fish in the wild.
- Summer-Fall ecological monitoring indicated habitat conditions were similar to WY 2021's dry conditions. This likely reduced the probability of occupancy of delta smelt from large parts of Suisun Bay and Marsh.
    - Low salinity habitat (<6 ppt) generally did not extend west of the Sacramento-San Joaquin River confluence.
    - X2 was at approximately 85km at the start of the summer of 2022 and averaged 87 km over the course of the Summer and Fall. X2 during the summer and fall moved upstream as far as Three Mile Slough, or to approximately 90 km.
    - Average salinity in the Suisun regions was consistently > 6 ppt during the summer-fall. In September and October when the SMSCGs began operating to manage water quality for waterfowl, salinity declined but remained >6 ppt.
    - As is typically the case, average water temperature increased toward more landward freshwater areas and was generally lower than the delta smelt temperature stress

threshold used by the DCG (23.9°C). However, during the mid-September heat wave, several sampling events of Lower Sacramento, Cache Slough, and Sacramento Ship Channel exceeded 23.9°C.

- Average Chlorophyll *a* was greatest in Suisun Marsh followed by Suisun Bay, and SDWSC, and concentrations were lower in the Lower Sacramento and Cache/Liberty regions.
- Consistent with previous findings, zooplankton biomass and abundance was greatest in the North Delta regions compared to brackish water Suisun regions. However, most notable was zooplankton biomass and abundance during 2022 were lower in the SDWSC and Cache Slough compared to 2021, and most previous years for which data are available (except 2018 in SDWSC). However, these results are preliminary based on a reduced dataset and could change if the full dataset better captures short-term blooms of Cladoceran zooplankton.

Purpose

This 2022 Seasonal Report for the delta smelt Summer-Fall Habitat Action (SFHA) describes the operations of the Central Valley Project (CVP) and State Water Project (SWP) and delta smelt habitat conditions in water year (WY) 2022. This report may support adjustments, if necessary, to the delta smelt SFHA Guidance Document (Guidance Document) for WY 2023, and future operations, including delta smelt SFHA plans, by documenting the environmental conditions that occurred in the absence of an action. The structure of the Seasonal Report for the delta smelt SFHA will be modified for years when the action is implemented, and those modifications will be subject to DCG review. This document also fulfills commitments under the 2020 Record of Decision (ROD) signed by the Bureau of Reclamation (Reclamation) for the Reinitiation of Consultation on the Coordinated Long-Term Operations of the CVP and SWP, and acts as the delta smelt SFHA report (Condition of Approval (COA) 9.1.3.1) outlined in the California Department of Fish and Wildlife (CDFW) Incidental Take Permit (ITP) for the Long-Term Operation of the California SWP issued to the California Department of Water Resources (DWR). Additionally, this Seasonal Report will be used to support the development of Reclamation's Annual Report on the Long-Term Operation of the CVP and SWP for WY 2022. Finally, this document will inform independent reviews required by the 2020 ROD and ITP (ITP Adaptive Management Plan; Attachment 2). Compliance with the Incidental Take Statements, including the Reasonable and Prudent Measures and associated Terms and Conditions in the 2019 Biological Opinions from the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) adopted by the aforementioned 2020 ROD will be documented in the Annual Report and not in this document. This document strives to provide an integrated view of the factors affecting the low salinity zone and adjacent habitats within the Sacramento- San Joaquin Delta with regard to their suitability to support delta smelt growth and survival. The results and discussion sections are focused on available delta smelt summer and fall habitat in WY 2022 with inclusion of data from WY 2021 that have become available since the last annual report.

Data Quality

Seasonal SFHA reporting requires compiling available data to help inform the following year's management decisions on action implementation. The variables and data highlighted in this report were selected based on past delta smelt conceptual model work and the general understanding of delta smelt biology. However, some habitat information deemed important characterizing the food web in the summer and fall (e.g., phytoplankton, benthic invertebrates, etc.) of 2022 were not yet available upon the completion of this report. In addition, the majority of 2022 data that are included in this report may not have undergone final quality assurance and quality control procedures. Thus, information presented in this report should be interpreted as preliminary. A more complete, final dataset from WY 2022 will be captured in the seasonal report for WY 2023.

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Background

The delta smelt SFHA provides for operational actions that are hypothesized to improve habitat and food availability for delta smelt. Operational actions include use of the Suisun Marsh Salinity Control Gates (SMSCG) in the summer months, Delta outflow augmentation, and several optional food enhancement actions that could include the Sacramento Deep Water Ship Channel Food Web Study (SDWSC), North Delta Food Subsidies-Colusa Basin Drain Study (NDFS) and the Suisun Marsh and Roaring River Distribution System Food Subsidies Study (RRDS).

Most delta smelt complete their entire life cycle within or immediately upstream of the estuary's low salinity zone (Merz et al. 2011). Scientific research has generally shown that reducing salinity in Suisun Marsh and other areas within the Sacramento-San Joaquin Delta is beneficial for the delta smelt population due to increased distribution, foraging opportunities, and habitat complexity (Sommer and Mejia 2013, Sommer et al. 2020). The highest quality habitats in this large geographical region include areas with complex bathymetry, in deep channels close to shoals and shallows, and in proximity to extensive tidal or freshwater marshlands and other wetlands (Pg. 1 and 2, Guidance Document) (Bever et al. 2016, Hammock et al. 2019). Therefore, the 2020 ROD and ITP included a delta smelt SFHA intended to improve delta smelt's access to prey aggregations and other important physical habitat attributes, which is believed to increase the growth, survival, and recruitment of delta smelt (Pg. 33, ROD; Pg. 113 ITP). The delta smelt SFHA will investigate summer-fall habitat to better quantify and integrate information on how food, turbidity, salinity, water velocity, and temperature interact to contribute to improved overall recruitment (Pg. 1, Guidance Document). Overall, the delta smelt SFHA is intended to increase the spatial overlap of Delta smelt habitat attributes with a focus on Suisun Marsh and to experiment with potential enhancements of prey supply in the Cache Slough Complex.

The current prevailing hypothesis is that abiotic habitat conditions for delta smelt in the San Francisco Bay-Delta are generally better in years when the low salinity zone in the summer and fall (as indexed by X2) is located further downstream (Brown et al. 2013, IEP MAST 2015). Three commonly measured water quality parameters form the underlying basis for this hypothesis: salinity, water temperature, and turbidity (Nobriga et al. 2008, Mac Nally et al. 2010, Feyrer et al. 2011, Bever et al. 2016). Abiotic habitat attributes within suitable ranges for delta smelt are defined in this report as low salinity conditions of 6 ppt or less, turbidity higher than 12 NTU, and water temperatures below 75°F (~23.9°C) based on Brown et al. (2016).

Delta smelt has been described as a semi-anadromous species. The species spawns in freshwater and most individuals migrate into the low-salinity zone where they spend large parts of their life cycle (Hobbs et al. 2019). Delta smelt physiological stress response to high salinity (Komoroske et al. 2016), and studies that demonstrated the species' higher occurrence in low salinity habitat (Feyrer et al. 2007, Nobriga et al. 2008) are the reasons why size and location of the low salinity zone have been described as helpful indicators of delta smelt habitat suitability.

Evidence of delta smelt's sensitivity to warm water temperature has come from both laboratory and field studies. Critical thermal maxima of juvenile delta smelt appear to range somewhere between 25 to 29°C in a controlled laboratory setting (Swanson et al. 2000, Komoroske et al. 2014, Davis et al. 2019), a temperature range that is observed in the field at times. High summer temperature was also found to have a negative impact on juvenile delta smelt survival from spring to fall based on a multivariate autoregressive model work and life cycle modeling (e.g., Mac Nally et al. 2010, Polansky et al. 2021). Moreover, occurrence of postlarval and juvenile delta smelt peaks near 20 degrees Celsius, indicating that warmer temperatures are increasingly stressful (Nobriga et al. 2008, Sommer and Mejia 2013, Komoroske et al. 2014).

Turbidity is also believed to be a key determinant factor in the occurrence and abundance of delta smelt in the field (Feyrer et al. 2007, Nobriga et al. 2008, Hasenbein et al. 2016).

Food availability is another essential component of delta smelt habitat, but how much is needed is difficult to evaluate in the field because prey densities that are needed to sustain growth vary as a function of physical habitat conditions (Smith and Nobriga unpublished data). Food quality can also be impacted by harmful algae blooms (Lehman et al. 2010; Acuña et al. 2012) and access to otherwise available food may be impacted by competition between delta smelt and other fishes (IEP MAST 2015).

Although chlorophyll concentration and phytoplankton abundance in the summer-fall period do not directly explain concurrent variation in delta smelt abundance or survival (Mac Nally et al. 2010), these phytoplankton indices are correlated with calanoid copepod abundance, which historically were the most frequently consumed prey of delta smelt (Mac Nally et al. 2010; Bollens et al. 2011; though see Jungbluth et al. 2021; Kimmerer et al 2018) and describing chlorophyll patterns provides a more holistic understanding of conditions in the summer-fall of 2022.

Figure 1 Map of the Sacramento- San Joaquin Delta (Credit: Google Earth, downloaded Jan 2023)

Environmental and biological goals for summer and fall (June through October) of below normal, above normal and in wet years are (Pg. 4-72, BA):

(1) Maintain low salinity habitat in Suisun Marsh and Grizzly Bay when water temperatures are suitable;
(2) Manage the low salinity zone to overlap with turbid water and available food supplies; and
(3) Establish contiguous fresh water- low salinity habitat from Cache Slough Complex to the Suisun Marsh (Pg. 2 and 15, Guidance Document).

Management Actions

Operation of the SMSCG to maintain low salinities in Suisun Marsh during the summer and fall has the potential to allow delta smelt to more frequently occupy Suisun Marsh, which can meet multiple habitat needs when salinities are suitable (Hammock et al. 2015; 2019; Sommer et al. 2020). To accomplish the goals listed above, Reclamation and DWR will implement SMSCG operations for 60 additional days (not necessarily consecutive) from June 1st through October 31st. Reclamation intends to meet Delta outflow augmentation in the fall primarily through export reductions as they are the operational control with the most flexibility in September and October (Pg. 4, Guidance Document). Storage releases from upstream reservoirs may be used to initiate the action by pushing the salinity out further in August and early September; however, the need for this initial action will depend on the hydrologic, tidal, storage, and demand conditions at the time (Pg. 4, Guidance Document). In addition, storage releases may be needed in combination with export reductions during (Pg. 4, Guidance Document).

The delta smelt SFHA also includes optional food enhancement actions, e.g., those included in the Delta Smelt Resiliency Strategy to enhance food supply (CNRA 2016), including the SDWSC, NDFS and the Suisun Marsh and RRDS (see ITP COA 3.9.1).

- **Sacramento Deep Water Ship Channel Food Study** is a federal and local partnership between Reclamation and City of West Sacramento and West Sacramento Area Flood Control Agency to determine the feasibility of repairing or replacing the West Sacramento lock system to hydraulically reconnect the ship channel with the mainstem of the Sacramento River. Combined with nutrient augmentation and other adaptive management measures, a reconnected ship channel has the potential to boost food production for delta smelt residing in the ship channel and to export surplus food resources into other parts of the North Delta.
- **North Delta Food Subsidies – Colusa Basin Drain Study** monitors and evaluates the effects of managed flow pulses on the food web in the North Delta. The NDFS action may redirect agricultural return water or Sacramento River water into Yolo Bypass for up to two to four weeks to generate a moderate flow pulse of 20-25 thousand acre-feet (i.e., a managed ‘flow action’). This pulse flow temporarily generates a net downstream flow in the Yolo Bypass Toe Drain that moves locally generated planktonic organisms downstream, which in turn is hypothesized to enhance the quantity and quality of food for delta smelt in the North Delta (Frantzich et al. 2021). The North Delta region is relatively rich in zooplankton compared to many other parts of the Estuary, but during summer and fall net negative flows result from local water diversions. This tends to result in high plankton densities that are “trapped” in small channels that delta smelt do not frequently occupy. The action takes an adaptive management approach to planning and implementing annual augmented flow pulses (or not) in summer or fall based on a combination of factors including evaluation of past results, predicted WY type, water availability and collaboration with supporting stakeholders.
- **Suisun Marsh Food Subsidies Study** will determine whether it is feasible to coordinate managed wetland flood and drain operations is to flush food rich waters of the managed wetlands into Grizzly Bay where delta smelt will have access to them. This Suisun Marsh Managed Wetlands Food Subsidies is conducting scientific research to evaluate the

feasibility of using managed wetlands currently maintained for waterfowl habitat in Suisun Marsh to increase production and transport of phytoplankton and zooplankton.

The 2019 USFWS Biological Opinion and 2020 CDFW ITP require annual reports documenting the planning, implementation, and monitoring of the delta smelt SFHA. In years that an action will be implemented, Reclamation and DWR shall provide a draft of the implementation plan to USFWS by May 1 and a final report of the action by May 1 of the following year, whereas DWR shall provide a draft of the plan to CDFW by May 15 and a final report of the action by February 28 of the following year (ITP COA 9.1.3.1). Since 2022 was a critically dry year, Reclamation and DWR notified the USFWS and CDFW through the Delta Coordination Group (DCG) that it was a non-action year. A draft plan was developed for the WY 2022 to be used as a template for years where implementation occurs and is available on the internet at 2022 SFHA Action Plan - Final 05.10.22.pdf.

Delta Coordination Group

The Guidance Document (Pg. 4 and 5) identified a Collaborative Planning Process to implement the delta smelt SFHA. In June 2020, Reclamation and DWR formed the DCG to coordinate planning of the delta smelt SFHA with USFWS, NMFS, CDFW, and representatives from federal and state water contractors. The DCG uses SDM to evaluate which actions to undertake in a given year. Although 2022 was a critically dry year, the DCG committed to a formal SDM process for evaluating SFHA alternatives in Below Normal and Dry water years for learning purposes (see SFHA Action Plan for further information). In brief, the 2022 SDM process was guided by contracted consultants. Facilitator Jennie Hoffman from Adaptation Insight, in collaboration with Compass Resource Management, guided the exchange information between the DCG SDM process and the Collaborative Science and Adaptive Management Program SDM process. The DCG revisited and improved the scope of the decision objective, built-out action alternatives, refined and scored performance metrics using best available science and two expert elicitations. The DCG technical workgroups (Science and Monitoring Working Group and Hydrology and Operations Work Group) assisted the DCG in technical evaluation, scoring performance metrics and expert elicitations related to SFHA.

Decision Support Models and Tools

The delta smelt SFHA is informed by several conceptual models (Brown et al. 2014, IEP 2015, FLOAT 2019). For example, the Fall Low Salinity Habitat conceptual model suggested that delta smelt habitat should include salinity conditions ranging from fresh to low salinity (0-6 ppt), minimum turbidity of approximately 12 Nephelometric Turbidity Units (NTU) for adults, water temperatures below 23.9°C, and qualitatively described food availability and bathymetric complexity.

In support of the DCG's SDM effort, information sheets were developed for each performance metric. The information sheets included a specific definition of the metric, an influence diagram illustrating expected impacts of the action on the performance metric, the methods (i.e., data, model(s), expert elicitation) used to calculate scores under different alternatives, assumptions, and uncertainties, see the 2022 SFHA Action Plan for additional detail. While scoring the performance metrics during the 2022 SDM, the DCG and DCG technical teams determined that overall, the performance metrics are useful as measures of what they are intended to represent. Some metrics and scoring criteria have potential for improvement but mechanisms to do so have not been determined. For example, how to weight information based on quantitative models versus expert elicitation. The DCG discussed the integration of information from multiple quantitative tools for scoring population-level performance metrics (e.g., stage-structured and individual-based life cycle models); however, the group decided not to pursue this in 2022 or 2023 SDM. More specific recommendations included using the Delta Simulation Model II (DSM2) hydrologic models to estimate water supply cost (as volume) as opposed to CalSim. Further, the volume of water re-routed during actions (e.g., NDFS) is non-consumptive and was not included in water cost. Another recommendation was to base contaminant effect scoring on toxicity to zooplankton and delta smelt instead of loading or concentration. The DCG observed that output from the abiotic and copepod biomass models were not as useful as they could be for scoring suitable habitat and food due to concerns over modeling limitations and assumptions. A delta smelt habitat suitability index was calculated using the Semi-implicit Cross-scale Hydroscience Model (SCHISM). The delta smelt growth performance metric was calculated as the difference in potential growth as predicted by the bioenergetics model included in the delta smelt Individual-Based Model (Rose et al. 2013a,b) between conditions representing no action and conditions representing each alternative. Performance metrics for the learning objective were not scored during the first prototype. The DCG discussed a possible scoring system based on value of information analysis of different science actions (e.g., data collection and analysis or modeling), but concluded it scores may not be objective and therefore not helpful as a new metric. The next iteration of SDM for WY 2023 will be aimed at refining and scoring some performance metrics, including repeating expert elicitations for effects of SFHA alternatives on other species (e.g., salmonids) and effects of contaminants on plankton and delta smelt growth.

Delta Outflow

Delta water operations during June of 2022 were controlled by D-1641 as modified by the Water Board's Temporary Urgent Change Order (April 2022 TUCO). However, Delta outflow exceeded the TUCO minimum every day in June and as monthly averages, the July-September minima set by D-1641 (Figure 2).

During the summer and fall the CVP and SWP exports were limited by the 2022 TUCO to a combined 1,5000 cubic feet per second (cfs). Exports increased following the expiration of the 2022 TUCO at the end of June. Exports were generally maintained from 3,000 cfs to 3,500 cfs for the remainder of the summer and fall period, July through October, see Figure 3, below.

The summer and fall of 2022 experienced lower Delta outflow than recent water years. However, the rates of Delta outflow were similar to other dry and critically water years (Figure 4 and 5). These patterns were naturally reflected in X2 data as well. Throughout the summer and fall X2 was located similarly to other dry and critical water years (Figure 4 and 5). The average position of X2 during Summer and Fall of WY 2022 was 87 km. Overall, water year 2022 was critically dry, with X2 and outflow were comparable to 2020 and 2021, which were similarly dry (Figure 4 and 5).

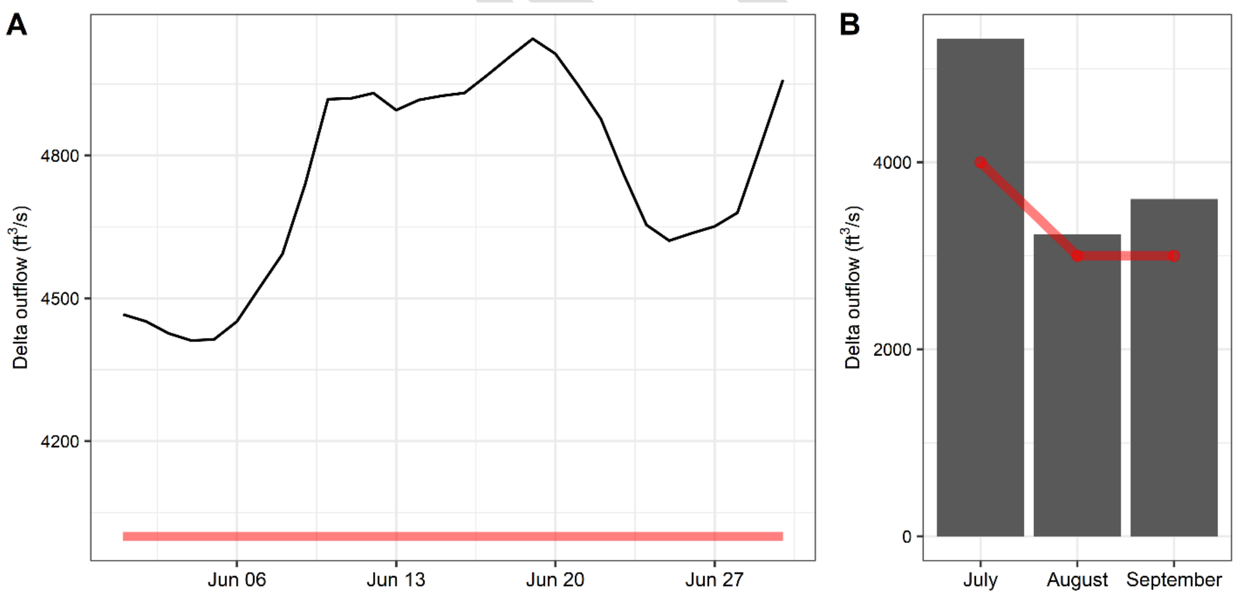

Figure 2 Delta Outflow (Black line and black bars) and SWRCB's D-1641 Outflow Standards for a critically dry year including 2022 TUCOs (Red Line). For June (A), Delta Outflow was calculated as a 14-day rolling average, while monthly average values were used for July to September (B).

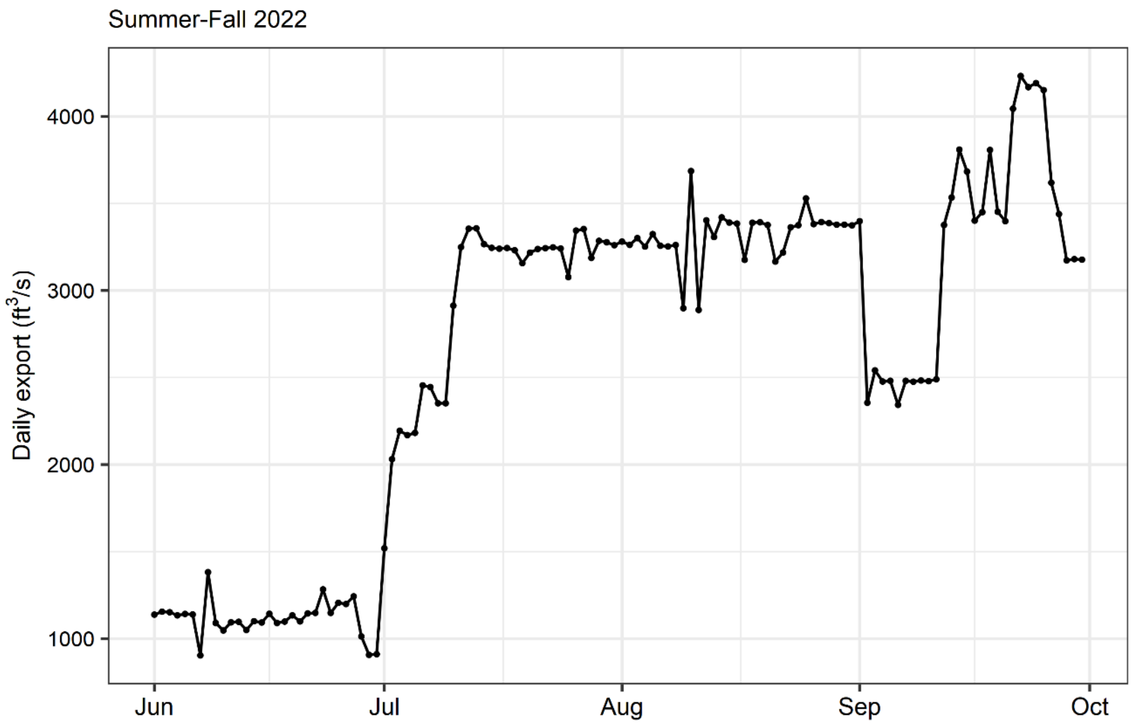

Figure 3 Delta Exports at SWP and CVP pumping facilities.

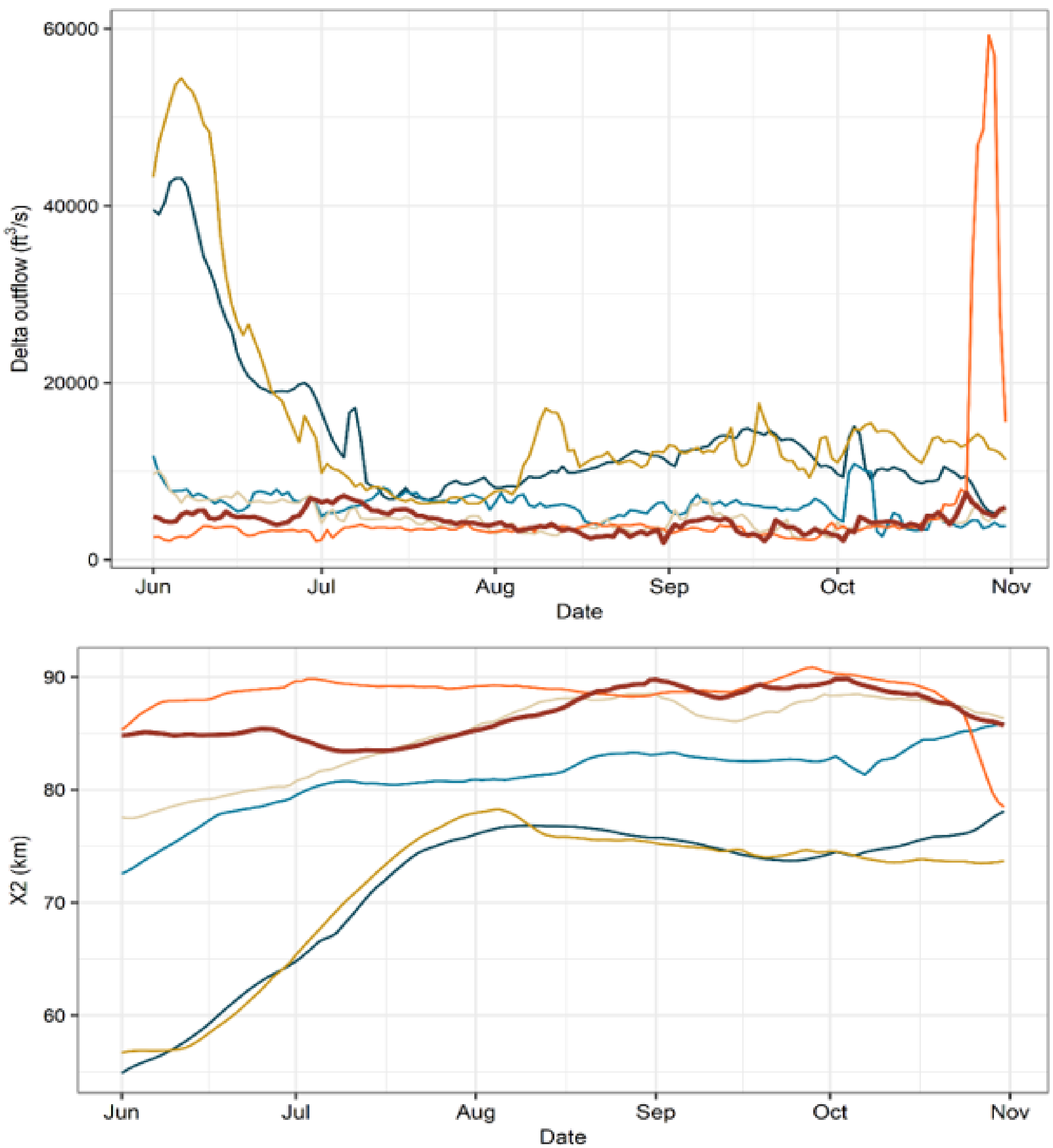

Figure 4 Top: Modeled daily Delta outflow from DWR Dayflow model from 2017 to 2021, plotted alongside 2022 Net Delta Outflow Index (NDOI) from DWR. Bottom: Modeled daily X2 from DWR Dayflow model (with the exception of 2022), plotted alongside calculated X2 for 2022 using X2 equation used in Dayflow and NDOI data (bottom). Dark red bold line indicates the year 2022.

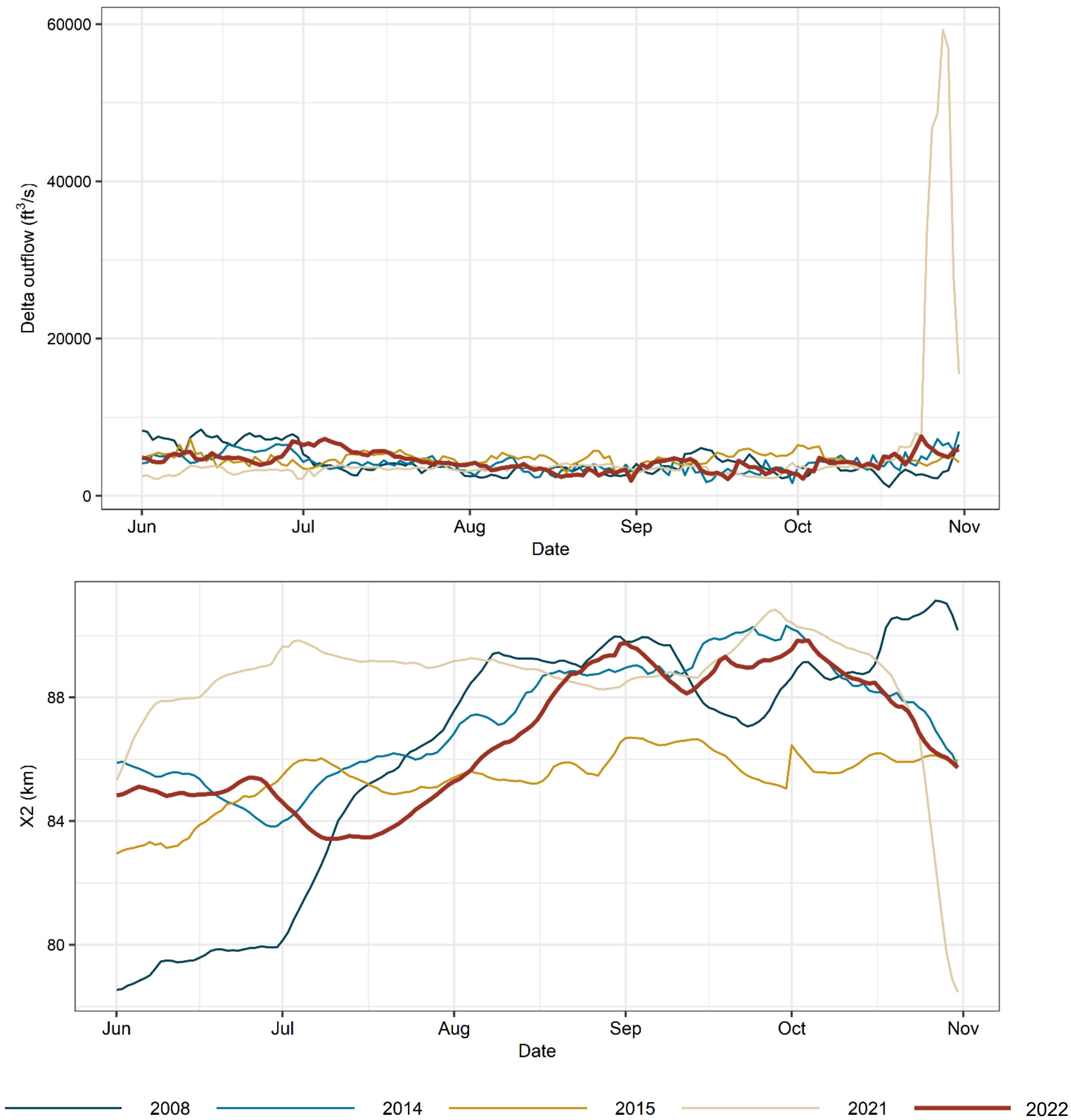

Figure 5 Top: Modeled daily Delta outflow from DWR Dayflow model for all critically dry years since 1997 (with the exception of 2022), plotted alongside 2022 NDOI from DWR. Bottom: Modeled daily X2 from DWR Dayflow model (with the exception of 2022), plotted alongside calculated X2 for 2022 using X2 equation used in Dayflow and NDOI data (bottom). Dark red bold line indicates the year 2022.

General Environmental Monitoring

Extent of Contiguous Low Salinity Habitat

In years of high net Delta outflow, habitat suitable for delta smelt may extend contiguously from the freshwater habitat of Cache Slough Complex to Suisun Bay and Suisun Marsh (Figure 6). Conditions in Suisun Bay and Suisun Marsh are suitable for delta smelt when salinity is 6ppt or less, which generally occurs when X2 is less than about 75 km (FLOAT-MAST 2021). However, based on the 2022 X2 location estimates and salinity data from continuous water quality stations, Delta smelt may have been excluded from large parts of Suisun Bay and Suisun Marsh for the majority of 2022 (Figures 4 and 5). X2 was at approximately 85km at the start of the summer and averaged 87 km over the course of the Summer and Fall (Figures 4 and 5). During parts of early September and early October, X2 moved upstream as far as Three Mile Slough, approximately 90 km from the Golden Gate Bridge.

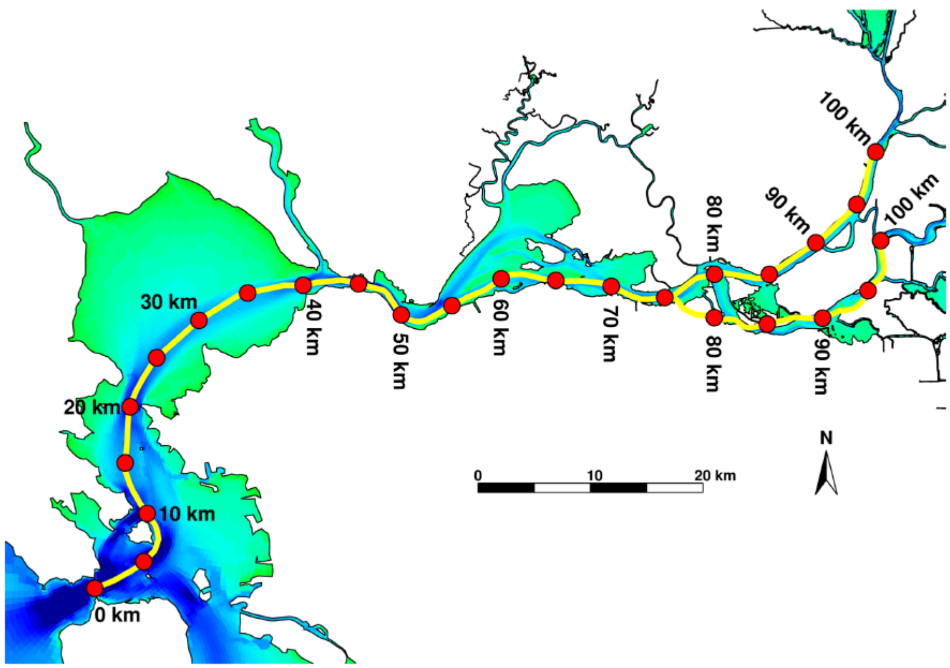

Figure 6 Map of the San Francisco Bay-Delta depicting location of X2 based on distance from the Golden Gate Bridge according to UnTRIM Bay-Delta model taken from MacWilliams et al. (2015). Green-blue shading shows water depth.

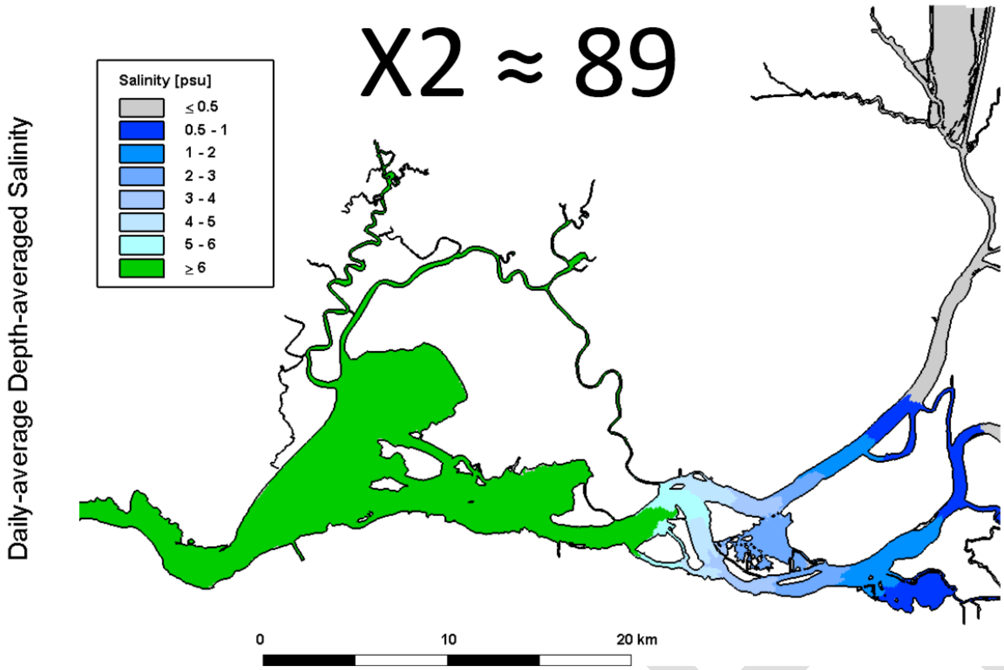

Figure 7 Daily- Average Depth-averaged Salinity when X2 is located at 89km (Delta Modeling Associates 2014), the maximum X2 value between June and October 2021 based on the X2 calculation with CDEC DTO station data.

Contiguous fresh water to low salinity water conditions did not extend from Cache Slough into Suisun Bay during the summer and fall in 2022. The low outflow resulted in Suisun Bay salinities typical of critical water years. This resulted in a low-salinity zone that was largely restricted to the legal Delta. During the summer and fall, salinity in Grizzly Bay, Honker Bay and the western part of Suisun Marsh was too high to provide high suitability habitat opportunities for delta smelt. Figure 7 shows modeled low salinity habitat (<6 ppt) under conditions similar to those that occurred in summer and fall of WY2022. The model results indicate the actual low-salinity zone was similarly located in the lower Sacramento and San Joaquin Rivers. Salinity conditions in 2022 were similar to 2021.

Again, one of the goals of the delta smelt SFHA is to establish contiguous low salinity habitat from Cache Slough Complex to the Suisun Marsh. However, as no action was taken in the offramped 2022 water year, this goal was not met.

Discrete Water Quality

The water quality in the low salinity zone, Suisun Marsh, and lower Sacramento River region are monitored by routine and long-standing surveys such as the Environmental Monitoring Program (http://www.water.ca.gov/iep/activities/emp.cfm), which collects water quality, phytoplankton, zooplankton and benthic invertebrate samples on a monthly basis (IEP et al. 2020a).

Salinity

In WY 2022, mean salinity in the Suisun regions among Directed Outflow Project (DOP), Summer Townet Survey (STN), and Environmental Monitoring Program (EMP) sampling sites was consistently above 6 ppt during the summer and fall (Appendix-A Figure 2). Salinity in Suisun Marsh dropped in September and October when the SMSCGs began operating, though it remained above 6 ppt. The Lower Sacramento Region was also slightly brackish, with salinities over 5 ppt on some sampling occasions. The same patterns were seen in the continuous water quality plots where salinity in the Marsh and Suisun Bay remained high throughout the summer until dropping when the SMSCGs began operating (Appendix-A Figure 1)

Temperature

Brown et al (2016) suggests that the number of days with mean daily water temperature above 24°C will limit Delta Smelt growth and survival in the summer and fall. In both the summer and fall of 2022, water temperature measured by STN, Fall Midwater Trawl (FMWT), DOP, and EMP generally increased toward more landward freshwater areas and was generally lower than the delta smelt temperature stress threshold (23.9°C; Brown et al. 2016) (Appendix-A Figure 5). However, several sampling events for the freshwater regions of Lower Sacramento (four out of 35 days with observations with temperatures over 23.9°C), Cache Slough (five out of 23 days with observations with temperatures over 23.9°C), and Sacramento Ship Channel (seven out of 22 days with observations with temperatures over 23.9°C) had readings over the delta smelt temperature threshold, many of these observations occurred during the mid-September heat wave.

Water temperatures did not vary substantially between fixed stations with continuous sondes (relative to turbidity and salinity) and mean daily temperature generally stayed under 23.9°C for most of the summer and fall period. The mid-September heat wave likely impacted the delta smelt population to some extent and was most noticeable at the Suisun Marsh and Rio Vista stations. Rio Vista had 38 days out of the 153 day period with a mean temperature above 23.9°C, and stations in Suisun Marsh had occasional days with mean temperatures above 23.9°C (Appendix Figure 6, Table 1). All stations had maximum temperatures surpassing 23.9°C on a regular basis (Table 1). Based on the upper thermal limit for delta smelt suitable habitat used in this document (23.9°C, 75°F), water temperature may have limited delta smelt survival or distribution in freshwater regions of the northern Delta during summer of 2021 (Figure 30 and Appendix-A Figure 5, Table 1).

Table 1. Number of days where each sampling station had maximum temperatures above 23.9°C and mean temperatures above 23.9°C out of 153 days from June-October.

cdec_code	Days with Max Temperature > 23.9°C	Days with Mean Temperature >23.9°C
BDL	30	5
GZB	18	0
GZL	21	1
GZM	39	5
HUN	30	4
MAL	8	0

cdec_code	Days with Max Temperature > 23.9°C	Days with Mean Temperature >23.9°C
NSL	28	1
RVB	65	38

Turbidity

In both the summer and fall of 2022, turbidity from discrete samples taken by long-term monitoring programs was highest in Suisun Marsh, with a mean of 32.3 NTU and a maximum of 192 (Appendix A, Figure 4). Turbidity was also comparatively high in Suisun Bay and the SDWSC (mean of 20.7 NTU and 17.6 NTU). Turbidity was lowest in the Cache/Liberty complex (mean of 3.75 NTU).

Continuous sondes showed similar trends (Appendix A, Figure 3), with the highest turbidity in Grizzly Bay and Suisun Marsh, and the clearest water at Rio Vista.

Chlorophyll

In both the summer and fall of 2022, the average and upper range of Chlorophyll a measured by DOP was greatest in Suisun Marsh (max of 30.5, mean of 4.8 ug/L) (Figure 8), followed by Suisun Bay (Max of 19.5 Mean of 3.4), this agrees with the continuous water quality sondes (Figure 23). Concentrations were much lower in the Sacramento and Cache/Liberty regions than Suisun Regions (mean of 1.87ug/L and 1.37 ug/L respectively) with mid-range chlorophyll in the SDWSC (mean of 2.33 ug/L).

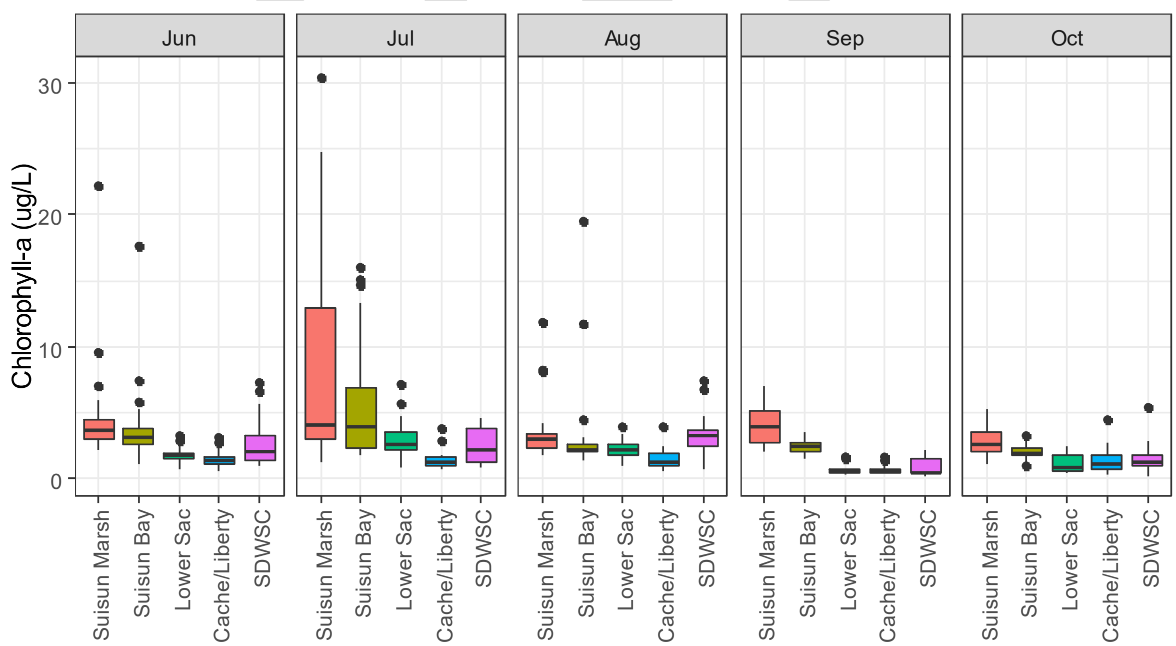

Figure 8 Variation in Chlorophyll a (µg/l) across regional strata as measured during 2021 DOP and EMP sampling.

Microcystis

Microcystis is a genus of cyanobacteria often associated with harmful algal blooms in the San Francisco Bay-Delta. *Microcystis* is one of the most common toxogenic cyanobacteria in the Delta, and presents both environmental and human health concerns because it can produce the toxin microcystin. Microcystins have detrimental effects to the health of humans, their pets, fish, and wildlife. *Microcystis* blooms have occurred annually during the summer and fall since 1999, particularly between July and September, and they often increase in magnitude with high water temperature, low Delta inflow and brackish water conditions encroaching into the legal Delta, all of which are associated with drought (Lehman et al. 2008, 2017, 2018, Kurobe et al. 2018). Microcystis is harmful to many fish and invertebrates (Ger et al. 2018; Acuña et al. 2012; Lehman et al. 2010); and can impact community composition and abundance of beneficial phytoplankton. Therefore, areas high in *Microcystis* and other harmful algal blooms are likely to provide poor habitat for delta smelt (IEP 2015).

Microcystis is surveyed in the region by visual observations conducted by CDFW's STN, Reclamation's DOP, and the EMP. Field staff rank *Microcystis* presence/absence on a scale of 1 to 5, with 1 being absent and 5 being very high. We integrated these data sets and assessed relative frequency of high *Microsystis a*bundance between regions of the estuary. These data indicate that 2022 had lower occurrence of Microcystis than 2020 and 2021, but higher levels than the wet years of 2017 and 2019 (Figure 9). Thus, the patterns described by Lehman et al. continue to hold.

Variation in *Microcystis* among regional strata largely followed a similar trend between seasons (Figure 10). *Microcystis* presence and overall intensity was lowest in Suisun Marsh and highest in the Lower Sacramento and Suisun Bay.

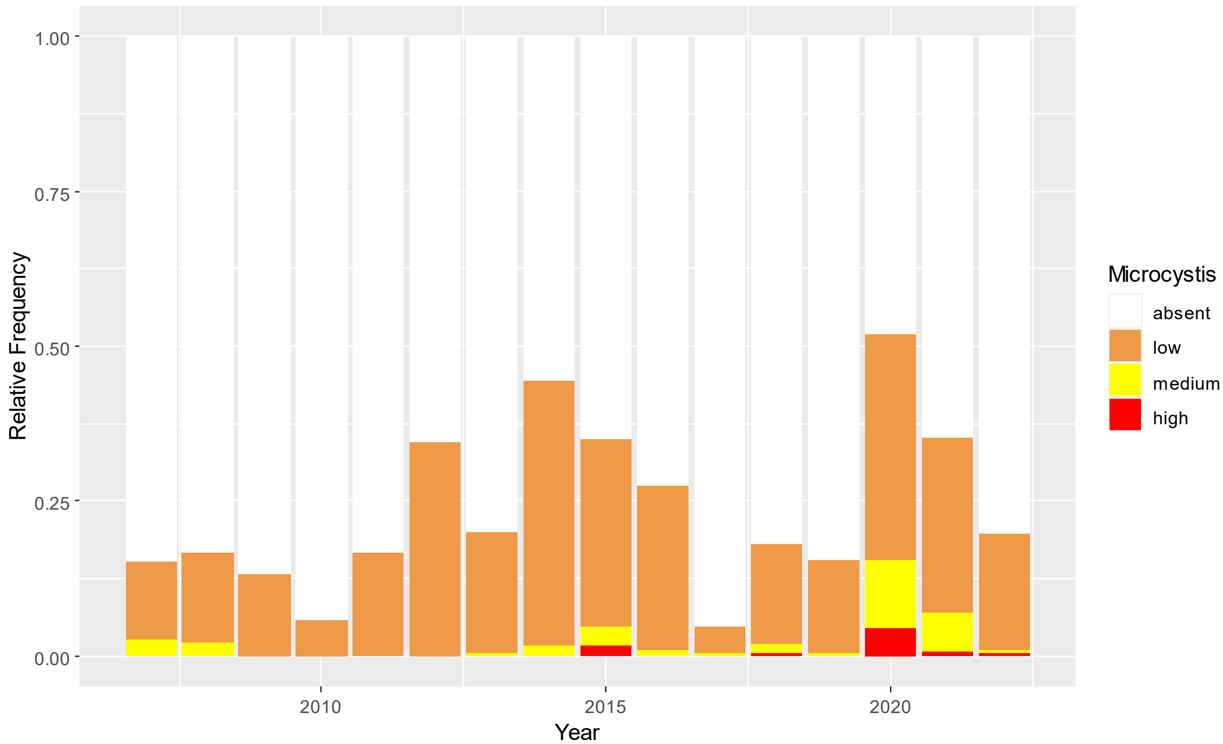

Figure 9 Summer-Fall Microcystis bloom intensity based on visual ranking data from EMP, Summer Townet, and FMWT comparing previous years to 2021. These data were only from stations within regions shown in (Figure 11). Microcystis bloom presence and intensity are measured on a qualitative scale with 5 categories: absent, low (widely scattered colonies), medium (adjacent colonies), high (contiguous colonies), and very high (concentration of contiguous colonies forming mats/scum).

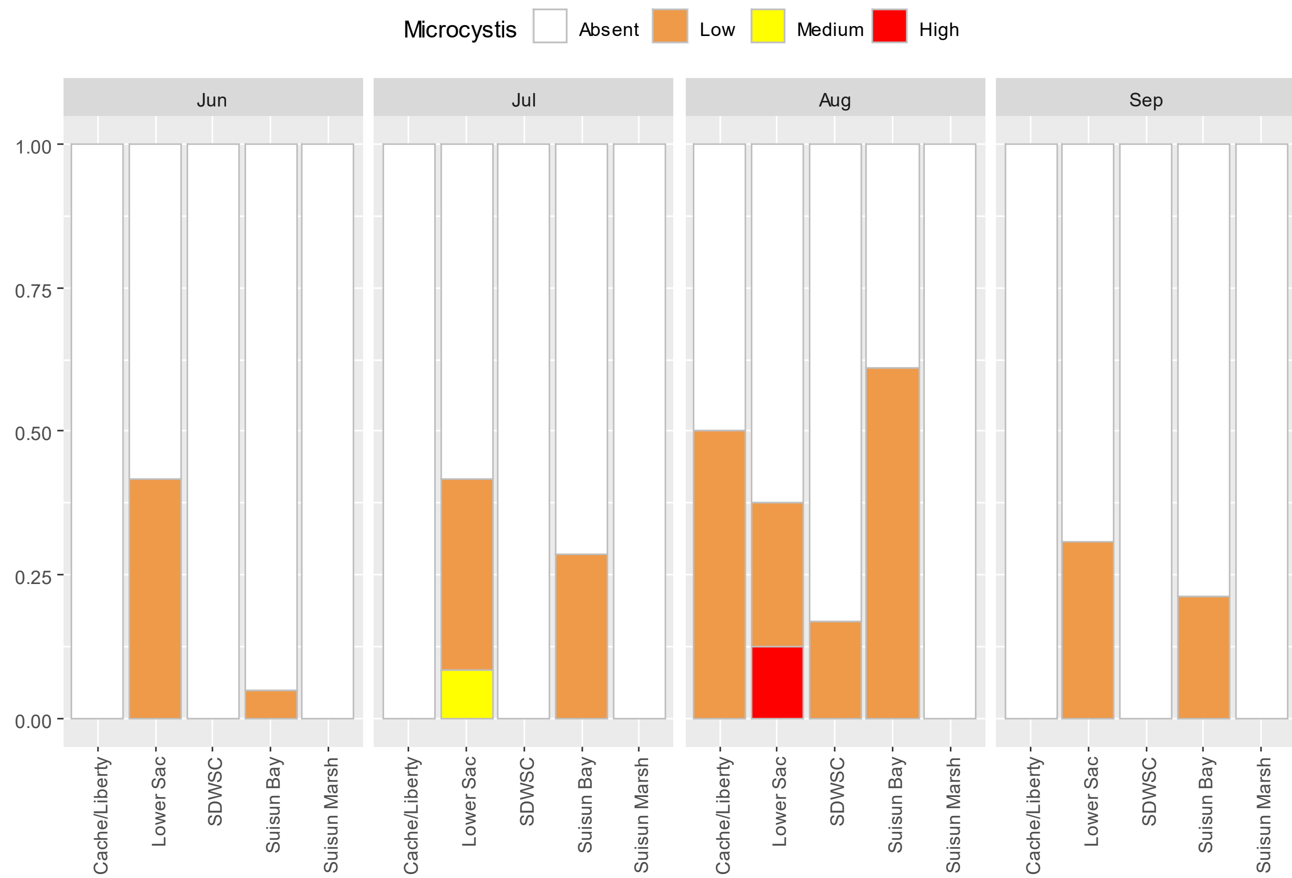

Figure 10 Variation in visually detected Microcystis blooms among regional strata as measured during 2022 EMP, FMWT, NCRO, and STN sampling. Microcystis presence and intensity were measured on a qualitative scale with 5 categories: absent, low (widely scattered colonies), medium (adjacent colonies), high (contiguous colonies), and very high (concentration of contiguous colonies forming mats/scum). No "very high" observations were recorded in 2022

Phytoplankton

The Directed Outflow Project (DOP) (https://www.usbr.gov/mp/bdo/directed-outflow.html), established in 2016, collects data on water quality, phytoplankton, zooplankton, and fish (Schultz 2019). Like EDSM, DOP conducts stratified random sampling instead of sampling at fixed station. The DOP uses a generalized random-tessellation stratified sampling design (Stevens and Olsen 2004; Starcevich et al. 2016; also used by the current EDSM program) to select three sampling sites within each regional sampling stratum within the full study area per weekly sampling period. DOP habitat monitoring occurs during the majority of the delta smelt rearing-stage period (April – November; start date coincides with start of EDSM 20-mm sampling). The DOP study area (Figure 13) includes the North Delta Arc (Moyle et al. 2016), an area consistently occupied by a large portion of the delta smelt population.

Phytoplankton data from 2020-2022 are not yet available.

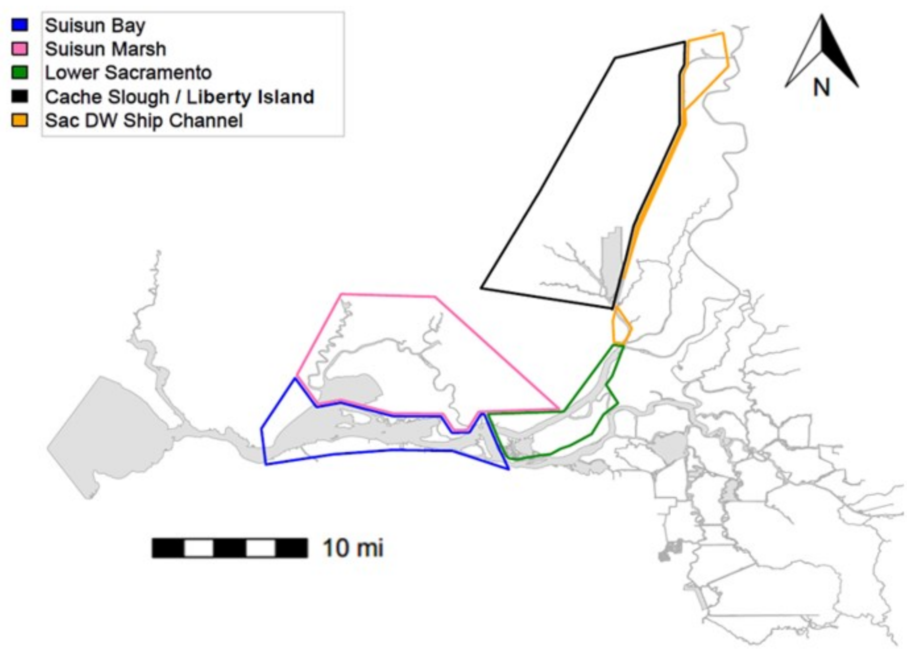

Figure 11 Map of the Directed Outflow Project Study Area depicting sampling strata

Zooplankton

Zooplankton data from regions across the Bay-Delta are collected by DOP and other programs. Data for 2021 have been updated from the 2021 seasonal report to include all of DOP's weekly samples (Table 2). Preliminary data for 2022 are a subset of the total number of samples collected that includes samples collected every other week during June through end of October (Table *2*).

Table 2. Number of zooplankton samples processed in 2021 and 2022 for relative abundance and biomass.

Season	2021	2022
Summer (June – August)	484	188
Early Fall (September – October)	287	110
Total	771	298

To assess regional foraging conditions, meso-zooplankton relative abundance and biomass are shown for 2021 and 2022 calculated from meso-zooplankton tows conducted by the DOP in the summer (June-August) and early fall (September-October). Data for 2021 are updated from the 2021 seasonal report to include all weekly samples (Table 2; Figure 12 and Figure 14). Preliminary data for 2022 were calculated from a subset of the total number of samples collected that includes samples collected every other week during June through end of October (Table 2; Figure 13 and Figure 14). This dataset only used tows conducted at the channel surface and channel "deep". Channel deep tows were not conducted when sampling sites were less than 20 feet deep. The remaining 2022 meso- and macro-zooplankton data from the DOP will not be available in time for this 2022 seasonal report.

Total meso-zooplankton biomass and abundance were greatest in the SDWSC during summer and early fall, followed by Cache Slough in the summer (Figure 12 and Figure 13). Meso-zooplankton relative abundance and, to a lesser extent, biomass were lowest in Suisun Bay and Suisun Marsh during the summer and early fall. This is consistent with previous studies showing lower zooplankton biomass in brackish water, and Suisun Marsh in particular (Hammock et al. 2017; Sommer et al. 2020). In the Sacramento Deepwater Shipping Channel and Cache Slough regions, zooplankton relative abundance and biomass were approximately four times lower in fall compared to summer, which is a well described seasonal phenology for zooplankton in the estuary. Zooplankton biomass and abundance during 2022 were lower in the Sacramento Deepwater Ship Channel and Cache Slough compared to 2021, particularly during the summer (Figure 12 and Figure 13), and compared to all previous years, except 2018 in the Sacramento Deepwater Ship Channel (Figure 14).

In both 2021 and 2022, zooplankton taxonomic composition transitioned from a more brackish-tolerant zooplankton community in Suisun Marsh and Bay to a freshwater community in Cache Slough and the Sacramento Deepwater Ship Channel. Community composition in Suisun Bay and Marsh was dominated by the calanoid copepods *Acartiella sinensis* and *Tortanus spp*. (Figure 12 and Figure 13), which have been observed, based on DOP data, to occur at mean salinities of 4.03 ppt and 9.24 ppt, respectively (Amy Wong, ICF, unpublished data). Similar to 2021, *Tortanus spp*. dominated zooplankton biomass in both regions during summer and in Suisun Bay during fall of 2022; *A. sinensis* dominated biomass in Suisun Marsh during fall 2022 (Figure 13). While taxonomic composition was similar in the two freshwater regions sampled (Sacramento Deepwater Ship Channel and Cache Slough), the relative proportion of each group differed between 2021 and 2022 (Figure 12 and Figure 13). In summer and fall of 2021, Cache Slough samples were dominated in number and biomass by *Pseudodiaptomus forbesi* subadults, a calanoid copepod (Figure 12). In the Sacramento Deepwater Ship Channel region in the summer of 2021, relative abundance and biomass were dominated by “other prey” (Figure 12), which comprised *cladocerans* from the families *Sididae* and *Daphniidae.* In the fall of 2021 and both summer and fall of 2022, relative abundance and biomass in the freshwater sites were more evenly distributed among P. *forbesi* adults, *Pseudodiaptomus* spp. subadults, and *Sinocalanus doernni*, another calanoid copepod (Figure 12 and Figure 13). Based on DOP data, both *P. forbesi* and *S. doernii* tend to occur at lower salinities around 0.29 ppt and 0.23 ppt, respectively (Amy Wong, ICF, unpublished data). *Sididae* spp. dominated the “other prey” category in the Sacramento Deepwater Ship Channel region during the summer and fall of 2022 and the Cache Slough region during the summer of 2022. The lower meso-zooplankton abundances observed in the freshwater regions in 2022 compared to 2021, was observed across taxonomic groups, although the difference was greatest for the “other prey” group in the Sacramento Deepwater Ship Channel between the summers of 2021 and 2022. These taxonomic patterns likewise followed well-known patterns of species turnover along the estuarine salinity gradient (Kimmerer 2004).

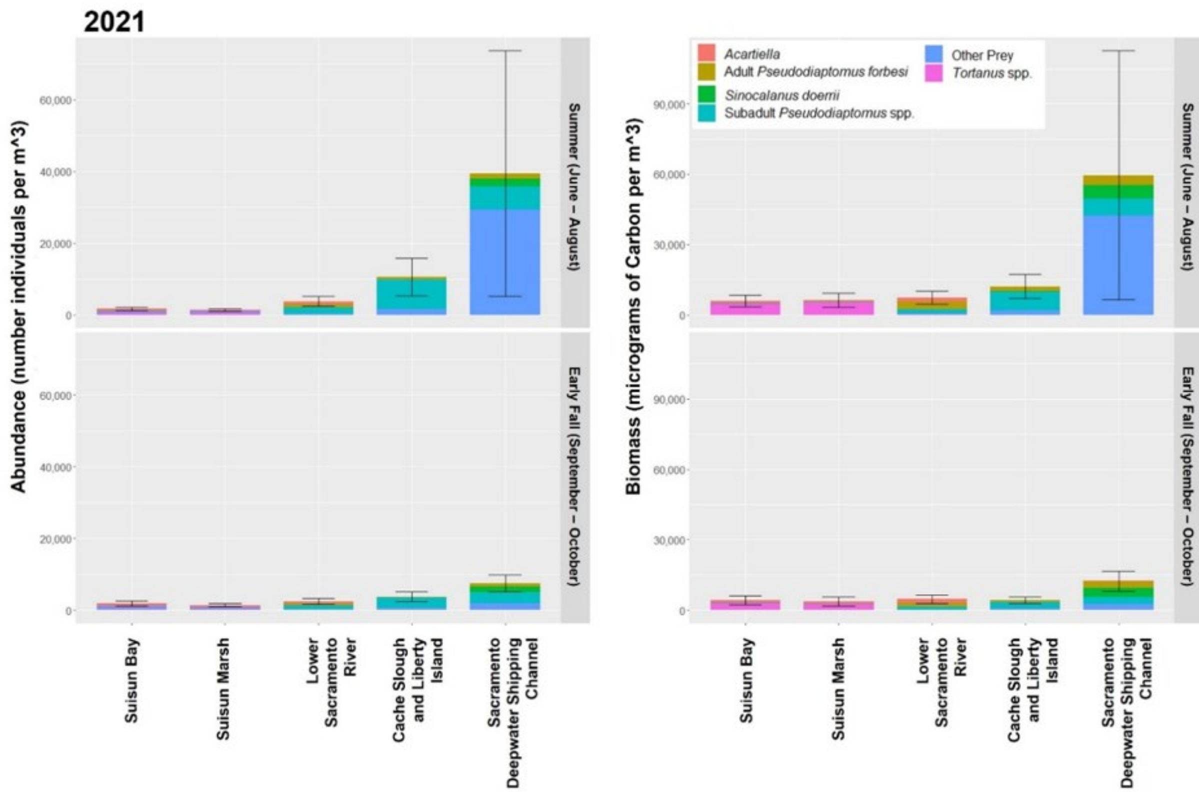

Figure 12 Variation in monthly zooplankton abundance (number of individuals/meter3) and biomass (mean micrograms of Carbon/meter3) across regional strata as measured during 2021 DOP sampling.

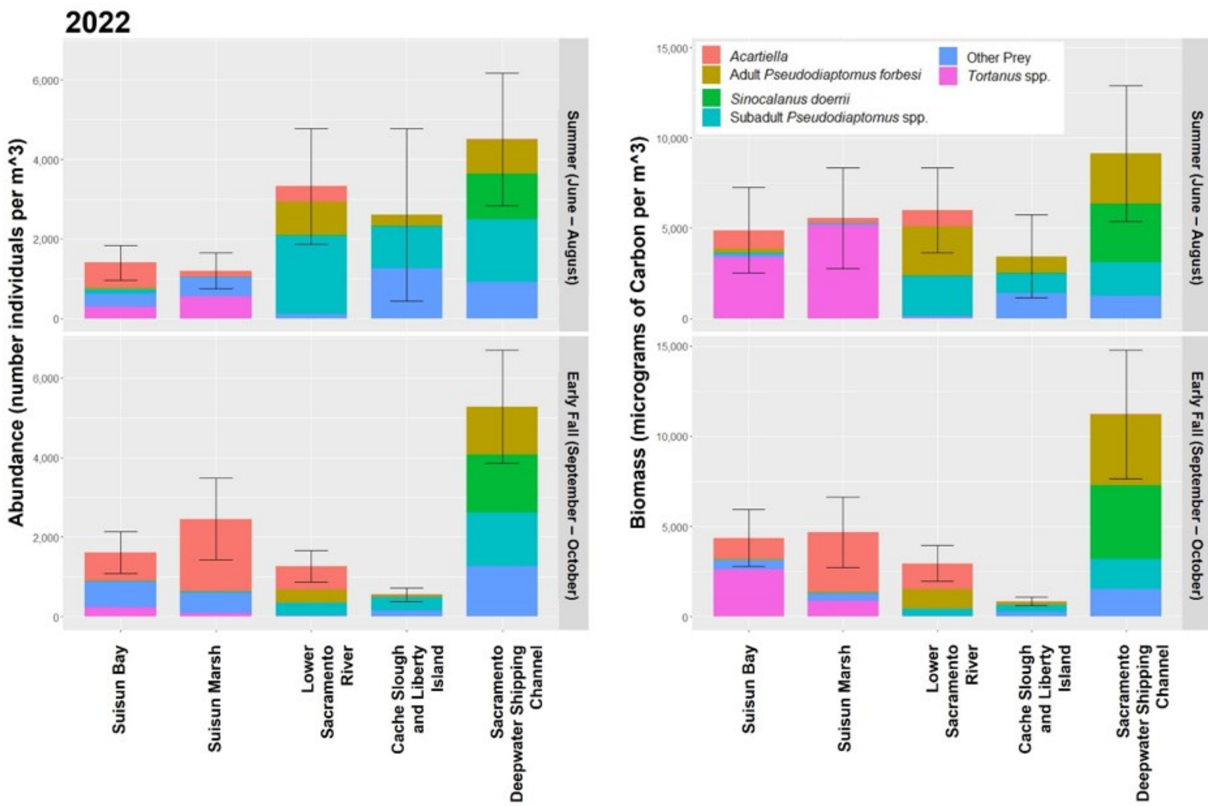

Figure 13 Variation in monthly zooplankton abundance (number of individuals/meter3) and biomass (mean micrograms of Carbon/meter3) across regional strata as measured during 2022 DOP sampling.

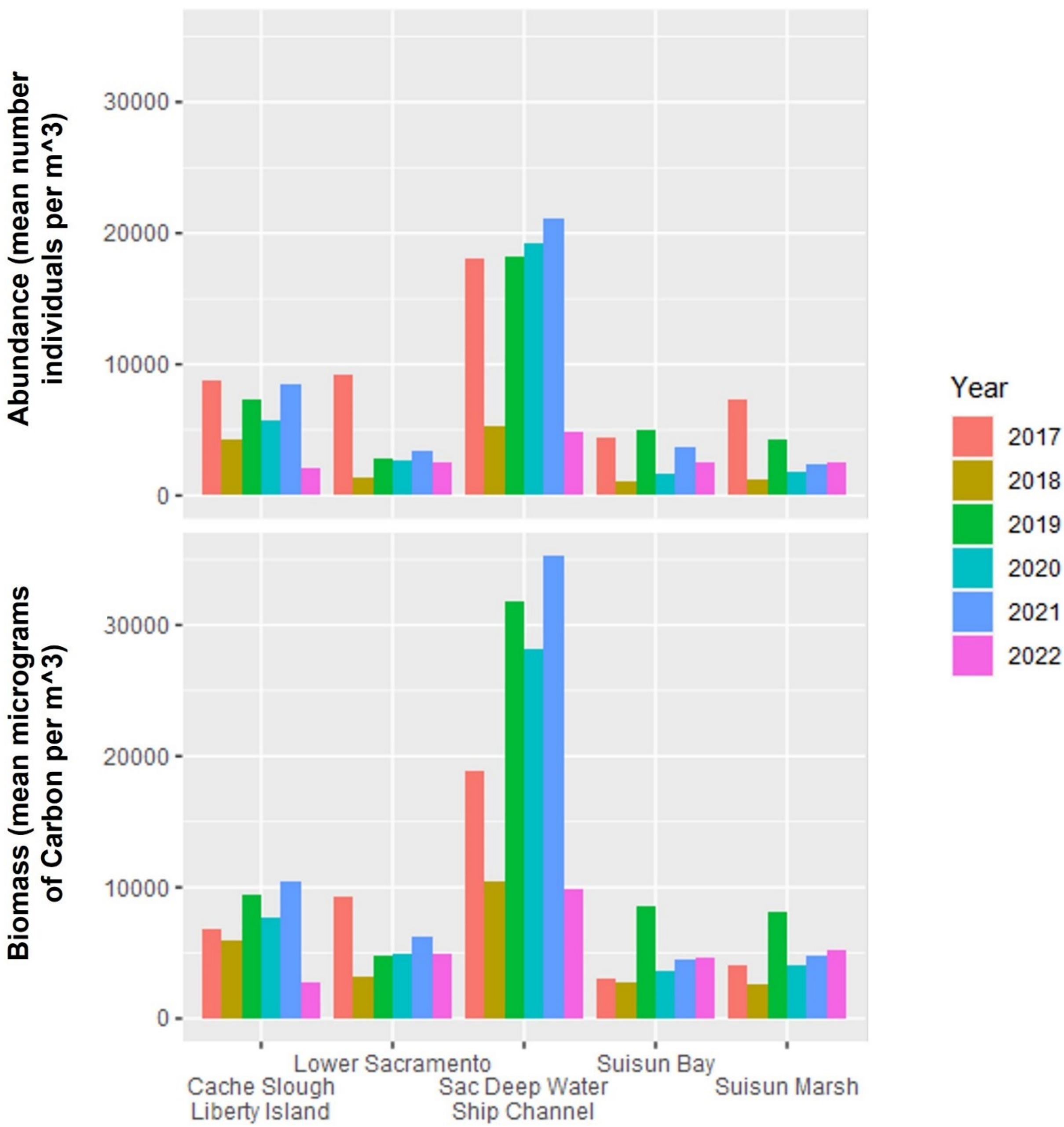

Figure 14 Variation in mean annual zooplankton abundance (number of individuals/meter3) across regional strata as measured during 2017-2022 DOP sampling.

Fish

Fish monitoring efforts that are utilized in this seasonal report include existing surveys conducted by IEP, specifically the CDFW's STN, FMWT, as well as the UC Davis Suisun Marsh Survey and USFWS Enhanced Delta smelt Monitoring Program (EDSM; USFWS et al. 2022). Because monitoring relies entirely on existing monitoring programs, each of which has limited sampling, statistical analysis of community composition between action years and non-action years may not be possible until multiple action years are combined.

Delta smelt Status

Abundance

The STN and FMWT have historically provided abundance indices for delta smelt in the summer and fall periods, respectively. However, delta smelt numbers have declined below the detection limits of both surveys. The STN delta smelt abundance index for 2022 was 0. The 2022 Fall Midwater Trawl Survey did not captured any delta smelt at their fixed index stations, making a 0 index for this survey as well. Unlike some recent years, survey efforts in WY2022 were not reduced due to COVID or wildfire smoke.

EDSM delta smelt catch in summer-fall period 2022 was higher than summer-fall of 2021. It is likely that a large portion of the 2022 cohort was produced by the hatchery-reared delta smelt released in the winter of 2021-2022 (Figure 15).

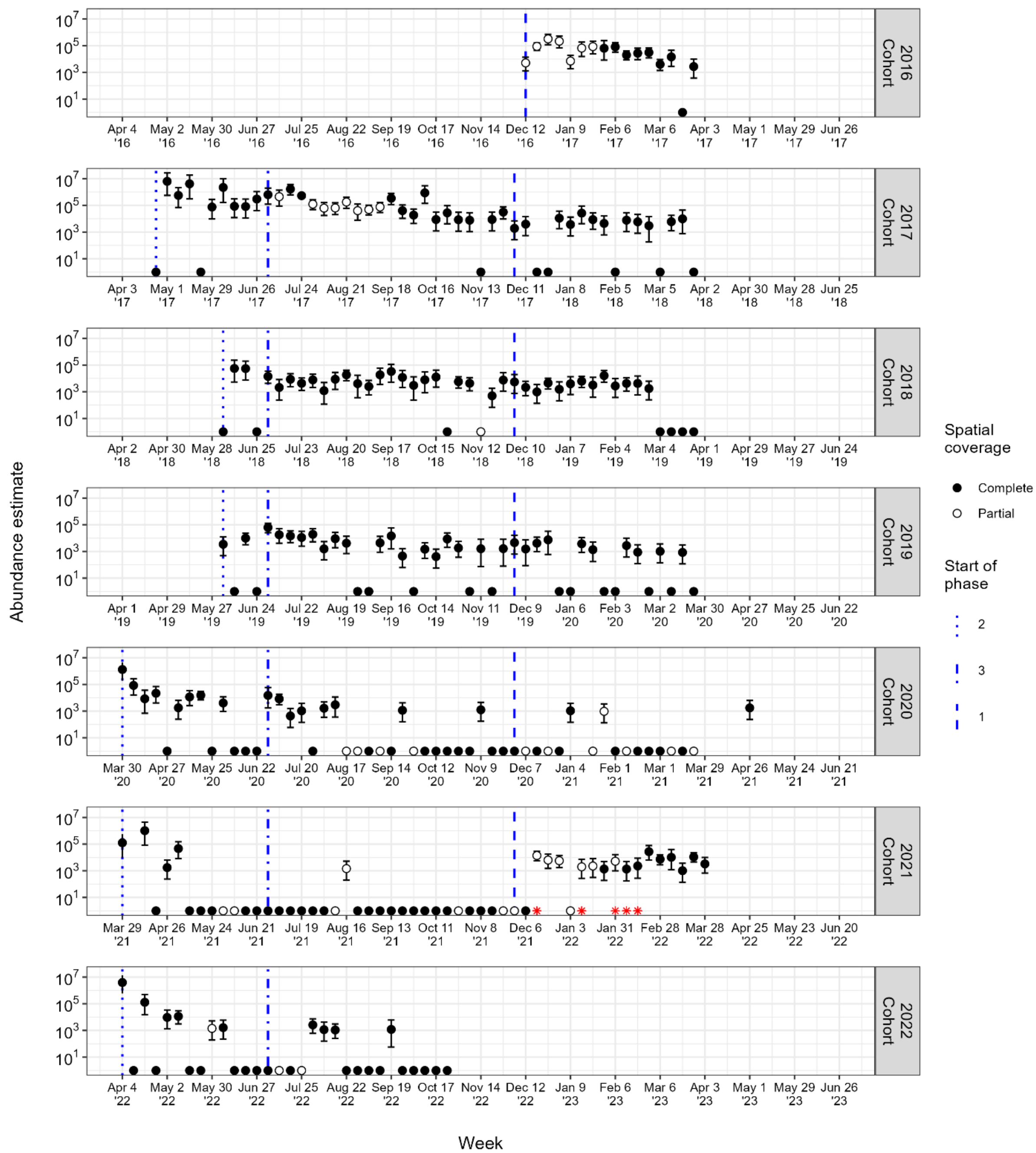

Figure 15. Time series of weekly delta smelt abundance estimates from EDSM survey. Phase 1 of EDSM runs from December through March and focuses on adult delta smelt. Phase 2 sampling takes place from April through June and targets post-larval and juvenile delta smelt. Phase 3 runs from July through November and targets juvenile and sub-adult 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 was provided by Lara Mitchell (USFWS).

Distribution

Between the start of phase 3 sampling in early July and the end of September 2022, EDSM has caught a total of six delta smelt on 484 different sampling events. Delta smelt were observed at the Lower Sacramento River, the Sacramento Deep Water Shipping Channel, and Suisun Marsh.

Delta smelt Supplementation

Annual supplementation of Delta smelt using cultured-reared fish from the University of California Davis, Fish Conservation and Culture Laboratory (FCCL) was proposed in Reclamation's 2019 Biological Assessment and analyzed in the 2019 BiOp (USFWS 2019). Supplementation was proposed to begin between 2022 to 2025; however, continued declines in population abundance and lack of wild delta smelt broodstock collections for the refuge population at FCCL the last couple years expedited supplementation efforts. To plan, coordinate and implement experimental releases of hatchery delta smelt, the USFWS led Experimental Release Technical Teams (ERTT) in collaboration with CEQA lead CDFW, DWR, USBR, USGS, FCCL and academic experts with the goal to provide an initial evaluation of logistical operations, techniques, science, and information needs and resources.

The first experimental releases of hatchery delta smelt into the wild began in WY2022 (Year 1). A total of 55,733 marked hatchery delta smelt were transported and released in the Delta and Suisun Marsh at >200 days post hatch, in 5 release events, from December 2021 to February 2022 (Table 3). Year 1 releases exceeded the initial production estimate of 40,000 fish, and the total delta smelt (across all life stages) caught in WY 2022 was 113 across all monitoring programs (including 1 in salvage), which was the highest catch since 2017 and 2018. The 2021 ERTT study plan (USFWS 2021) and summary of activities report (USFWS 2022) for experimental releases are available upon request. Plans and reports include further detail on objectives and procedures for high-priority learning areas including production, genetics, tagging, transport, release, and monitoring (many of which pertain to goals outlined in the FWS Supplementation Strategy (USFWS 2020)), and recommendations for future years given lessons learned in Year 1.

Table 3 Summary of hatchery delta smelt transported and released during Year 1 (2021/2022) of experimental releases. Only one 'soft' release occurred, and observed mortalities are noted following transport in carboys or following 24 h acclimation in soft-release enclosures. Table modified from 2021 ERTT summary report (USFWS 2022).

Release Event	Site	Date(s)	Hard Release	Soft Release	Carboy (Mortalities)	Acclimation (mortalities, 24 h)	Total Released
1	Rio Vista	14-15 Dec 2021	6,400	6,400	1	~60	12,800
2	Rio Vista	11-12 Jan 2022	12,800	N/A	2	N/A	12,800

Release Event	Site	Date(s)	Hard Release	Soft Release	Carboy (Mortalities)	Acclimation (mortalities, 24 h)	Total Released
3	SDWSC	3 Feb 2022	6,400	N/A	0	N/A	6,400
4	Montezuma Slough	9-10 Feb 2022	12,800	N/A	1	N/A	12,800
5	SDWSC	16-17 Feb 2022	10,933	N/A	2	N/A	10,933
Year 1 Total	N/A	N/A	49,333	6,400	6	~60	55,733

Given the success of Year 1 releases, Year 2 releases will follow similar methodologies with modifications. In brief, all fish will be VIE tagged with the tag color and tag location varied by release type (hard or soft-enclosure release) and release site. Due to resource limitations surrounding tagging and space capacity at FCCL, only three experimental release events are planned for Year 2. The first occurred in late November. The subsequent releases are planned for January 2023. Fish will be released at Rio Vista and in the Sacramento Deepwater Ship Channel (SDWSC). As of November 1, 2022, Year 2 experimental release schedule and details are described in Table 4.

Table 4 Tentative summary of hatchery delta smelt to be transported and released during Year 2 (2022/2023) of experimental releases. Physical tag locations will be either posterior (PD) or anterior (AD) of the dorsal fin. Asterisks indicate (*) ERTT will discuss the best location option for release event 3 based on release 1 and 2 outcomes, and (**) extra fish may be added to the release event 3 dependent on survival through January of 2023.

Release Event	Site	Date(s)	Hard Release	Soft Release	Hard-release tag	Soft-release tag	Approximate Released
1	Rio Vista	28 Nov 2022	6,875	6,875	Left (red)/AD	Right (blue)/PD	13,750
2	SDWSC	9 Jan 2023	6,875	6,875	Right (green)/PD	Left (orange)/AD	13,750
3	Rio Vista*	23 Jan 2023	13,750	N/A	Right (orange)/PD (or ad-clip)	N/A	13,750 + 1,300 **
Year 2 Total	N/A	N/A	27,500	13,750	N/A	N/A	42,550

Based on the existing literature and monitoring information for delta smelt, we expect 2022 environmental conditions to be mostly detrimental to the species due to the combination of high salinity, low turbidity, high temperatures, low prey densities, and high incidence of HABs. However, over 1,500 Wakasagi (Hypomesus nipponensis) were caught in Summer-Fall period of 2022, with the majority of catch coming from the Sacramento Deep Water Ship Channel (where Delta smelt also occurred). Wakasagi is an introduced smelt species in the same genus as delta smelt with similar life history and habitat requirements (Davis et al. 2022). Although additional studies are clearly needed, the high numbers of Wakasagi in 2022 may offer some hope that there may be remnant suitable habitat for delta smelt in the Cache Slough Complex during a critically dry year. However, increased Wakasagi in delta smelt habitat may alternatively negatively affect delta smelt through competition.

Fish Assemblage

Native vs Non-Native Fish Species

The Delta Plan listed percentage of native fish biomass or relative abundance as a performance measure in the Delta. This metric is based on the Delta Juvenile Fish Monitoring Program beach seine survey data that has demonstrated an increase in non-native fish numbers over the past two decades (Mahardja et al. 2017b, IEP et al. 2020b). Biomass of native fishes in the nearshore habitat continued to be considerably low relative to introduced fishes in WY2022 (Figure 16). Mississippi silverside (*Menidia audens*) and centrarchid species make up a substantial portion of this introduced fish biomass. Mississippi silverside may be a significant competitor and intraguild predator to delta smelt and thus their consistently high numbers in WY2022 are likely to limit the production of delta smelt (Bennett 2005; Schreier et al. 2016). Centrarchids such as largemouth bass (*Micropterus salmoides*) are known to be associated with submerged aquatic vegetation (SAV). Delta smelt seem to avoid SAV or the clearer water conditions with which it is often associated (Nobriga et al. 2005). If and when they cannot avoid vegetated habitats, they may experience higher rates of predation (Ferrari et al. 2014). The increasing dominance of these introduced littoral species may be a chronic drain on the declining delta smelt population (Figure 16).

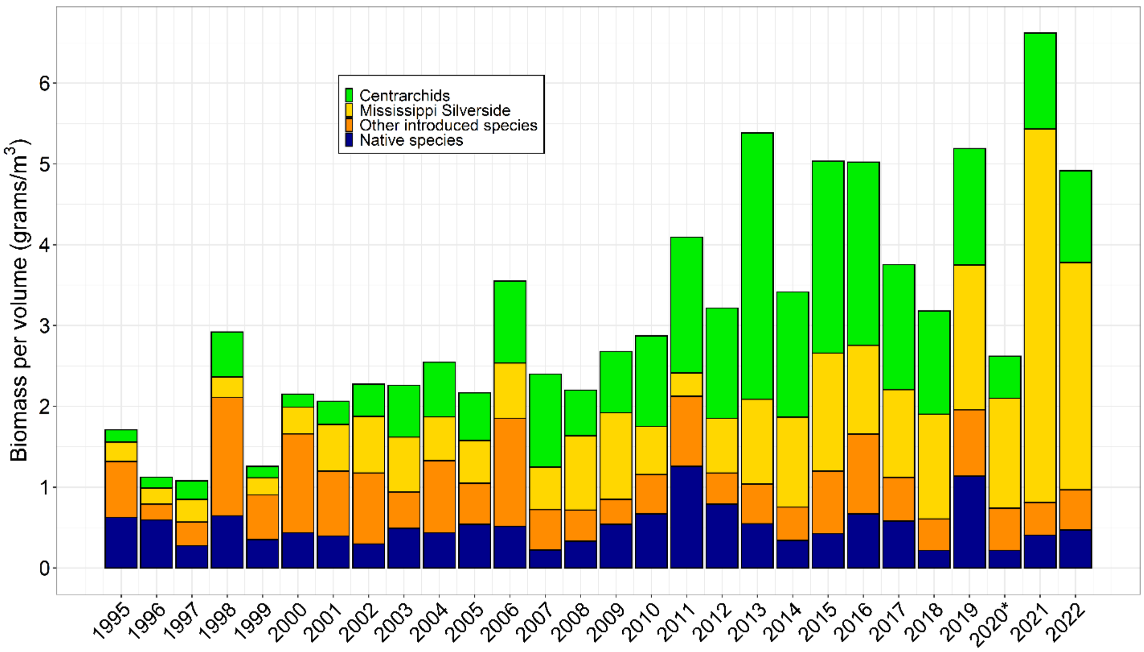

Figure 16 Estimated annual mean biomass per volume of nearshore fishes based on March-August beach seine catch data as calculated in Mahardja et al. (2017). *Reduced sampling in 2020 due to COVID-19 pandemic.

Abundance of POD Species

The steep decline of delta smelt that occurred in the early 2000s was a part of the Pelagic Organism Decline (POD) event, in which at least four pelagic fish species experienced simultaneous, abrupt declines in abundance (Thomson et al. 2010). These simultaneous declines were believed to have been caused by a common factor or factors but subsequent data analysis was not able to confirm that hypothesis (Mac Nally et al. 2010). Like the littoral fishes described above, the POD fishes are likely competitors and predators of delta smelt (Feyrer et al. 2003; Nobriga and Smith 2020). The 2022 status of two introduced species listed in the POD, striped bass (*Morone saxatilis*) and threadfin shad (*Dorosoma petenense*), are reviewed in this report to compare and contrast their responses to delta smelt under this critically dry year condition. Age-0 striped bass numbers in the summer and fall based on long-term surveys appear to be somewhat correlated with water years (Figure 17), with 2022 catch so far being lower than recent wet years (e.g., 2011, 2017, 2019). Unlike delta smelt and striped bass, threadfin shad numbers in 2022 were comparable to the past few years for the STN and higher than the more recent dry years for the FMWT (Figure 18).

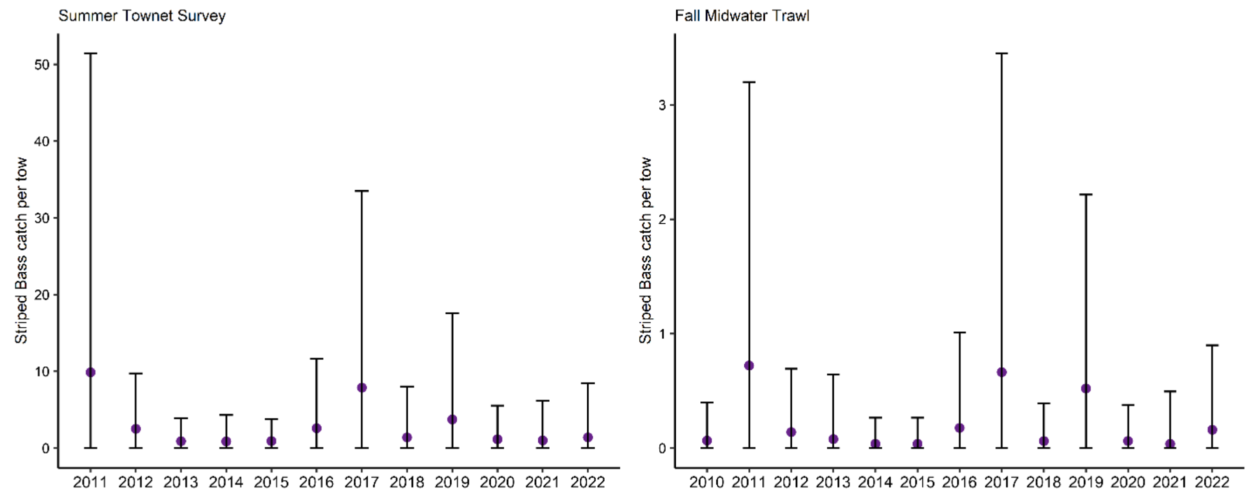

Figure 17 Mean striped bass catch per tow and standard deviation (error bars) from the CDFW Summer Townet Survey from all stations for each year since 2011 (left) and from the CDFW Fall Midwater Trawl Survey from all stations for each year since 2010 (right). Only data from September and October surveys were used for Fall Midwater Trawl Survey to ensure consistency with 2022 data.

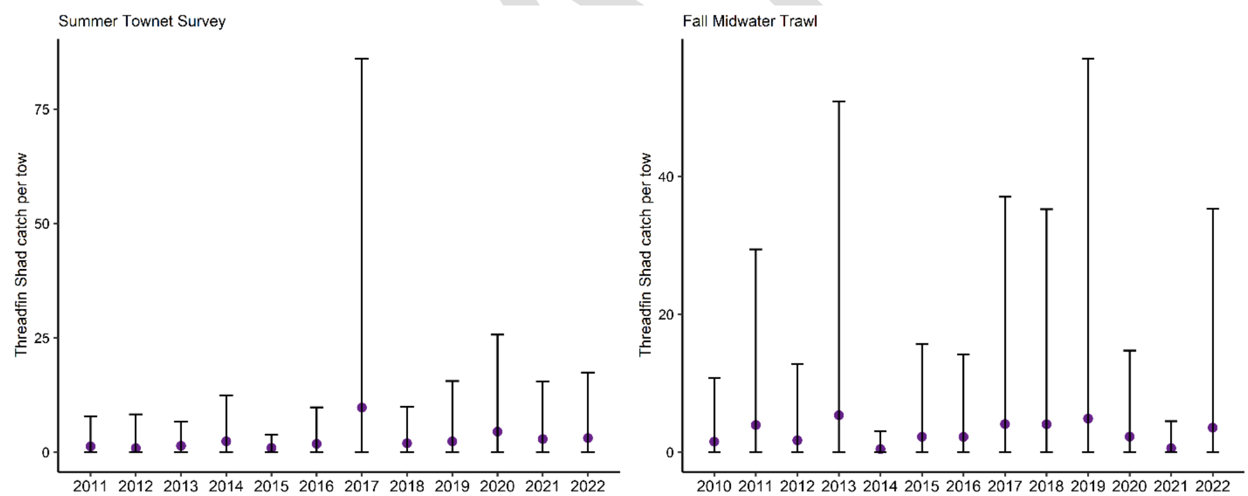

Figure 18 Mean threadfin shad catch per tow and standard deviation (error bars) from the CDFW Summer Townet Survey from all stations for each year since 2011 (left) and from the CDFW Fall Midwater Trawl Survey from all stations for each year since 2010 (right). Only data from September and October surveys were used for Fall Midwater Trawl Survey to ensure consistency with 2022 data.

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Suisun Marsh Salinity Control Gates Action

The SMSCG was not operated pursuant to the SFHA action during 2021 or 2022.

Operations

The SMSCG were not operated from June through August, two out of the three gates were held open, and one was closed for refurbishment. SMSCG operations began September 1st for the purposes of meeting the channel water salinity standards for the Suisun Marsh outlined in the Suisun Marsh Preservation Agreement (SMPA 2015). Flashboard Status indicates if they are installed or removed. Boat Lock Status indicates if it is closed or in operation.

Table 5 2022 Suisun Marsh Salinity Controls Gate Operations

Date	Gate Status	Flashboard Status	Boat Lock Status	Notes
9/1/21 – 9/2/21	2 Operational 1 Closed	Installed	Operational	N/A
9/3/21 – 9/12/21	Closed	Installed	Operational	Mechanical problem
9/13/21 – 11/9/21	2 Operational 1 Closed	Installed	Operational	N/A
11/10/21 – 11/28/21	2 Open 1 Closed	Installed	Operational	N/A
11/29/21 – 12/20/21	2 Operational 1 Closed	Installed	Operational	N/A
12/21/21 – 2/10/22	2 Open 1 Closed	Installed	Operational	N/A
2/11/22 – 3/7/22	2 Operational 1 Closed	Installed	Operational	N/A
3/8/22 – 4/6/22	2 Open 1 Closed	Installed	Operational	N/A
4/7/22 – 5/31/22	2 Operational 1 Closed	Installed	Operational	N/A
6/1/22 – 8/2/22	2 Open 1 Closed	Installed	Operational	N/A
8/3/22 – 8/25/22	Closed	Installed	Operational	Gates closed for refurbishment
8/26/22 – 8/30/22	1 Open 2 Closed	Installed	Operational	Gate 1 removed for refurbishment Gate 2 opened Gate 3 closed for calibration testing
9/1/22 – 9/7/22	2 Open 1 Closed	Installed	Operational	N/A

Date	Gate Status	Flashboard Status	Boat Lock Status	Notes
9/8/22	1 Operational 1 Open 1 Closed	Installed	Operational	Gate 3 failed to operate; remained open
9/9/22 – 10/31/22	2 Operational 1 Closed	Installed	Operational	Gate 3 repaired

The SMSCG tidal operations are reflected in the salinity measurements at Belden's Landing. There was a decrease in salinity following implementations of operations, see Figure 19 below.

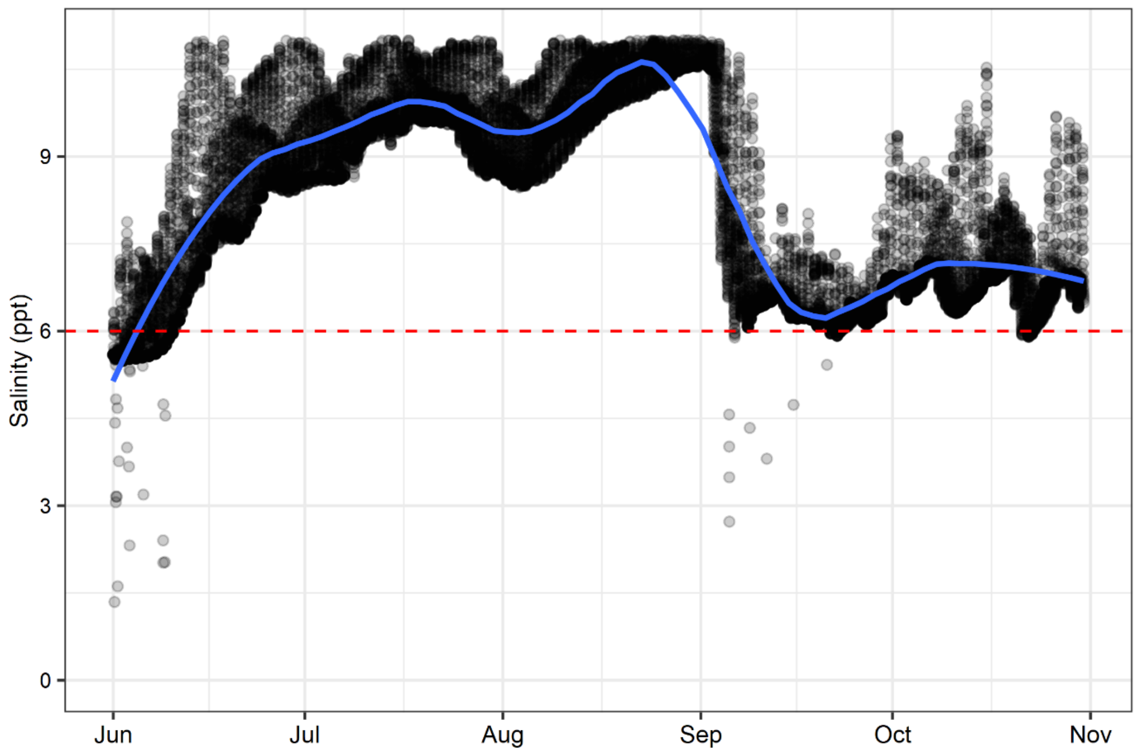

Figure 19 Salinity at Belden's Landing from June through October (Station BDL at CDEC).

Water Quality

The water quality in the spatially variable low salinity zone, as well as the geographically fixed Suisun Marsh, and lower Sacramento River region are relatively well-monitored by a number of water quality stations. Several continuous water quality stations that cover the downstream range of delta smelt were selected in order to provide a general overview of the abiotic habitat conditions in the summer and fall of 2022 (Figure 20). Stations Grizzly Bay West (GZL), Grizzly Bay East (GZB), and Tule Red (TRB) were used to evaluate conditions in Grizzly Bay. Stations at the mouth of Montezuma Slough (GZM), Hunter's Cut (HUN), Belden's Landing (BDL), and National Steel (NSL) were used to describe conditions within Suisun Marsh. To evaluate conditions along the Sacramento River, data from stations at Mallard Island (MAL), Decker Island (SDI), and Rio Vista (RVB) were used.

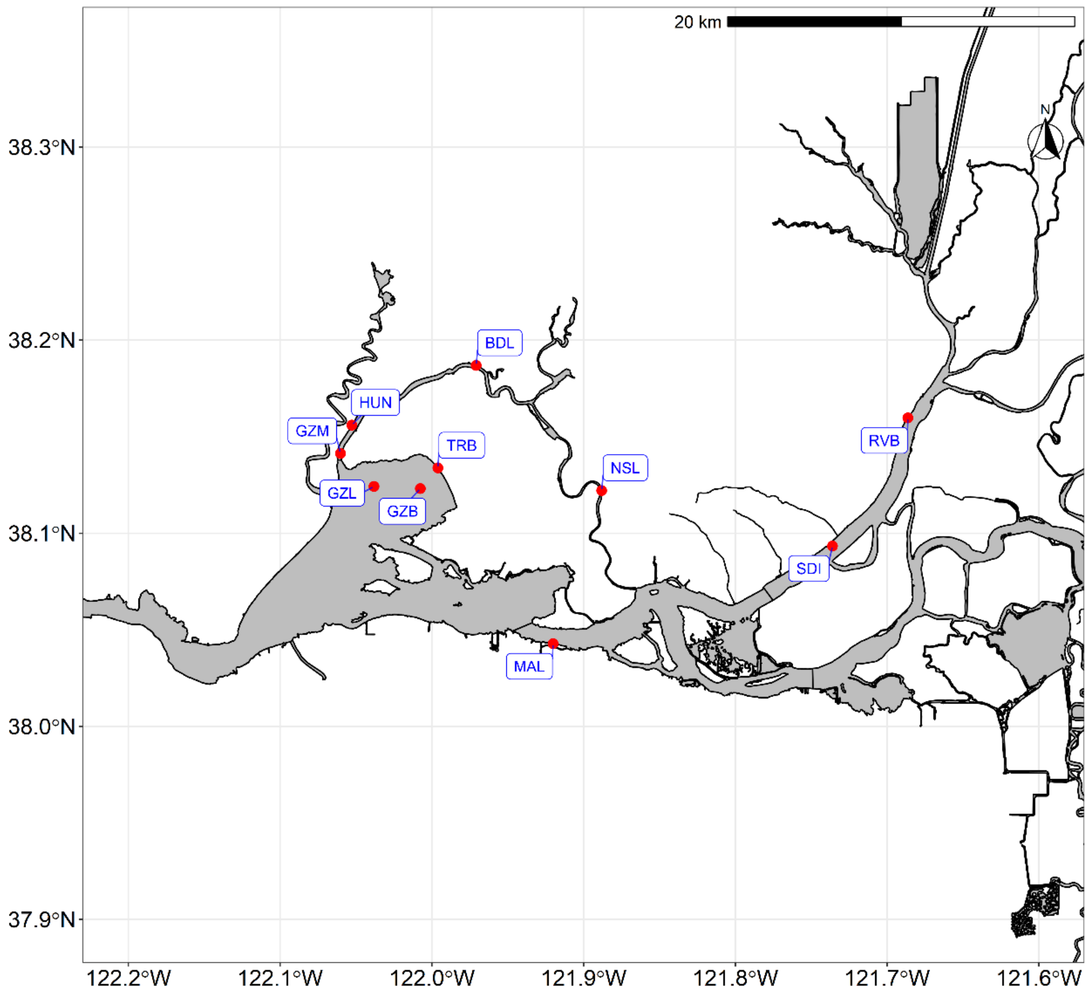

Figure 20 Map of the general low salinity zone within the San Francisco Bay-Delta and the CDEC stations used to create figures in this document. HUN = Hunter's Cut, BDL = Belden's Landing, NSL = National Steel, GZL = Grizzly Bay West, GZB = Grizzly Bay Buoy East, TRB = Tule Red, GZM = Grizzly Bay at Montezuma Slough, MAL = Sacramento River at Mallard Island, SDI = Sacramento River at Decker Island, RVB = Sacramento River at Rio Vista.

Abiotic habitat attributes within suitable ranges for delta smelt are defined in this report as low salinity conditions of 6 ppt or less, turbidity higher than 12 NTU, and water temperatures below 75°F (~23.9°C) based on Brown et al. (2014). To illustrate conditions for delta smelt at the various stations, proportion of time in each day deemed suitable for delta smelt based on each water quality parameter threshold was calculated and plotted in a summary heat map (Figure 21). Based on the general understanding of delta smelt biology, unsuitable condition based on just a single parameter (e.g., salinity), may preclude most delta smelt from the area. More detailed discussion on each water quality parameter can be found below.

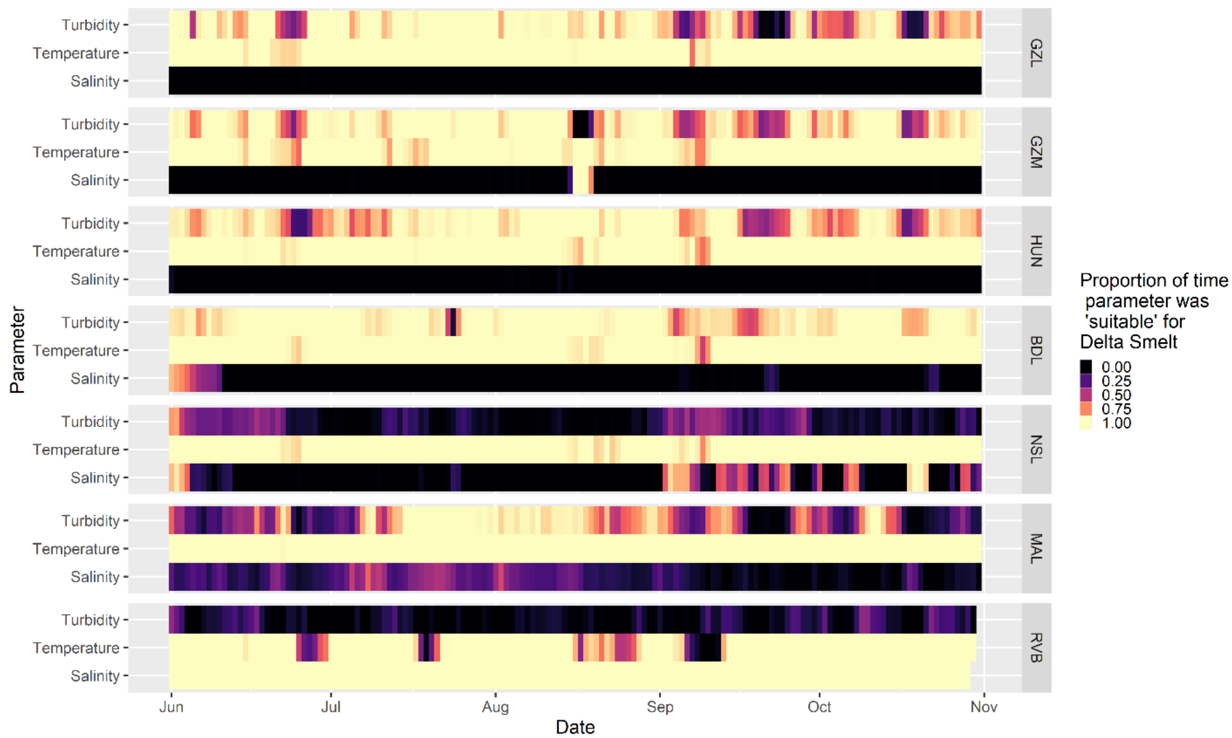

Figure 21 Heat map demonstrating proportion of time in each day that each water quality parameter was suitable for delta smelt at the continuous water quality stations (i.e., salinity ≤ 6 ppt, turbidity ≥ 12 NTU, temperature ≤ 23.9°C). Note that data has not undergone quality control/check and that stations may actually record formazin nephelometric units (FNU) instead; however, the general turbidity patterns observed should remain valid.

Salinity

In 2022, salinity within Suisun Marsh was generally highest downstream around Grizzly Bay and lowest at Rio Vista upstream (Figure 21 and Appendix-A Figure 1 and 2). Sites within Suisun Marsh exhibited the general pattern of a slight increase in salinity between June and September, followed by a larger decline in salinity in early- to mid-September that continued into October, though it remained above 6 PSU. It is likely that salinity was a limiting factor in Suisun Marsh for delta smelt for the majority of the 2022 Summer-Fall period (>6 ppt). As expected based on NDOI pattern (Figure 5), the MAL station showed a pattern of increasing salinity over time from June to October of 2022. Delta smelt were not likely to be present around the vicinity of MAL station for the entirety of summer-fall period of 2022; however, salinity upstream of the confluence between Sacramento and San Joaquin Rivers remained suitable for delta smelt based on the RVB station at Rio Vista.

Salinity at Belden's Landing (BDL), a monitoring station central to the additional operation of the SMSCG, was above 6 ppt from June to September based on extrapolation of existing data

(Figure 19). After September, salinity at BDL declined, coincident with the beginning of SMSCG operations, but remained above 6 ppt. Overall, there was higher salinity in 2022 relative to 2021.

Of the three new sites in Grizzly Bay (Figure 22), specific conductance measured at continuous water quality sondes across Grizzly Bay and Suisun Marsh. GZL, and GZB had very similar patterns of salinity, without a significant increase in information given by having both stations. Station GZM aligned very closely with the other Grizzly Bay stations during the summer when the gates were not operated, but was slightly less saline when gate operation began in September. Several logistical problems prevented a continuous data stream from TRB over the summer of 2022, so it is unclear how much additional information is provided by that station.

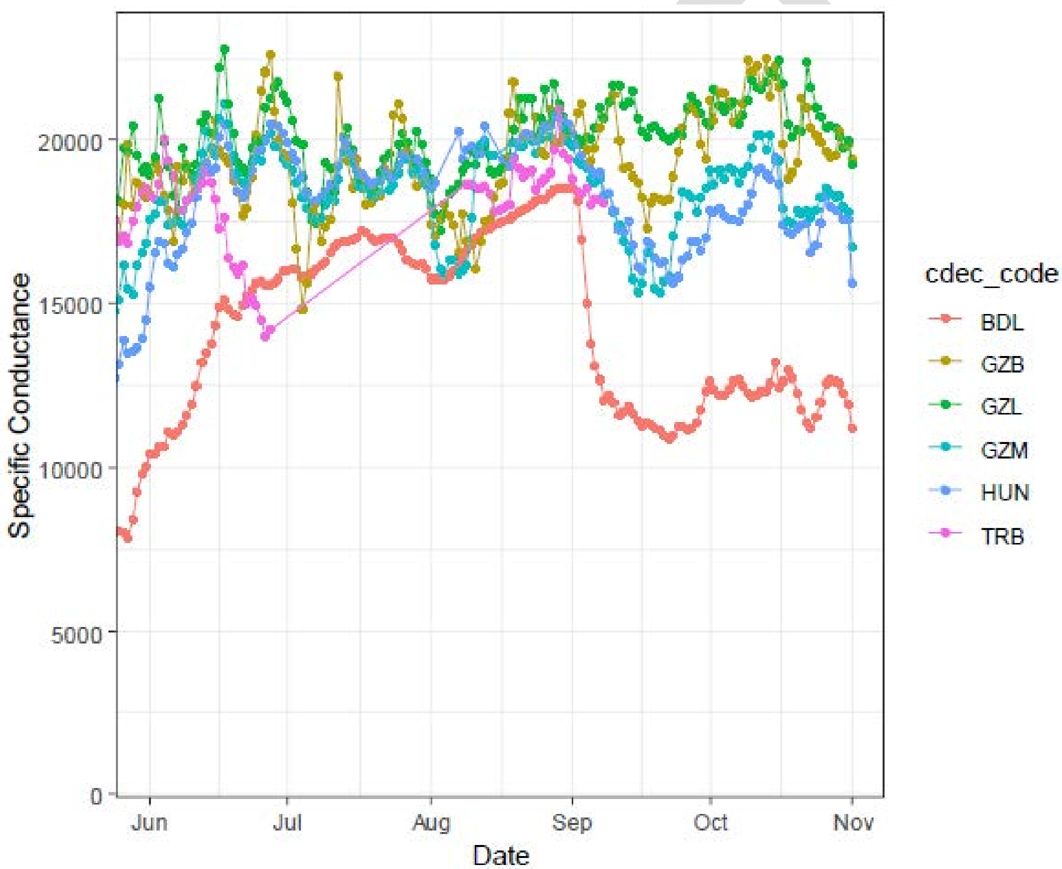

Figure 22 Specific conductance measured at continuous water quality sondes across Grizzly Bay and Suisun Marsh.

Temperature

Water temperatures in the Suisun Marsh region remained generally high for most of the 2022 summer and fall period until mid-September. Although mean water temperatures were below 23.9°C for most stations, there were frequently timepoints within the day when conditions were warmer than this threshold (Appendix Figure 5). Based on the upper thermal limit for delta smelt suitable habitat used in this document (23.9°C, 75°F), water temperature may have limited delta smelt survival or distributions in summer of 2022, especially in freshwater regions of the northern Delta (Figure 21 and Appendix-A Figure 5).

Turbidity

In summer and fall of 2022, western Suisun Marsh sites saw generally higher turbidity relative to eastern sites closer to the confluence (NSL, MAL, and RVB) (Figure 21 and Appendix A Figure 3). The observed low turbidity (<12 NTU) in these more upstream sites may have been a limiting factor for delta smelt in this region during summer and fall of 2022. It should be noted that reported readings in this document are in NTU but collected data from continuous water quality stations may be in FNU instead (DWR Memorandum). Nevertheless, the relative turbidity patterns observed should remain valid as both units (FNU and NTU) are very similar (DWR's June 5, 2020 Memorandum; Morgan-King and Schoellhamer 2013).

Chlorophyll

Continuous water quality stations (Figure 20) varied in Chlorophyll fluorescence with several short, localized spikes during the summer and fall. (Figure 23). Average Chlorophyll fluorescence was highest at the MAL station in the beginning of the summer, but levels at MAL dropped in August and stations in Suisun Marsh had higher chlorophyll than MAL later in the summer. Chlorophyll fluorescence was lowest at the RVB stations, with the latter never ranging above three fluorescence units.

Figure 23 Daily average Chlorophyll fluorescence (converted to an estimate of ug/L Chlorophyll) from continuous sondes in 2022.

Phytoplankton

Phytoplankton data are from the Summer Townet Survey, Fall Midwater Trawl, and EMP (Figure 24). Four regions, including Suisun Bay, western Suisun Marsh, eastern Suisun Marsh, and the Lower Sacramento River/Confluence, were monitored twice per month during July to October. The 2020 and 2021 data are complete and presented in this report. Phytoplankton data for 2022 were not available in time for this report. Phytoplankton monitoring methods are further detailed in Appendix B.

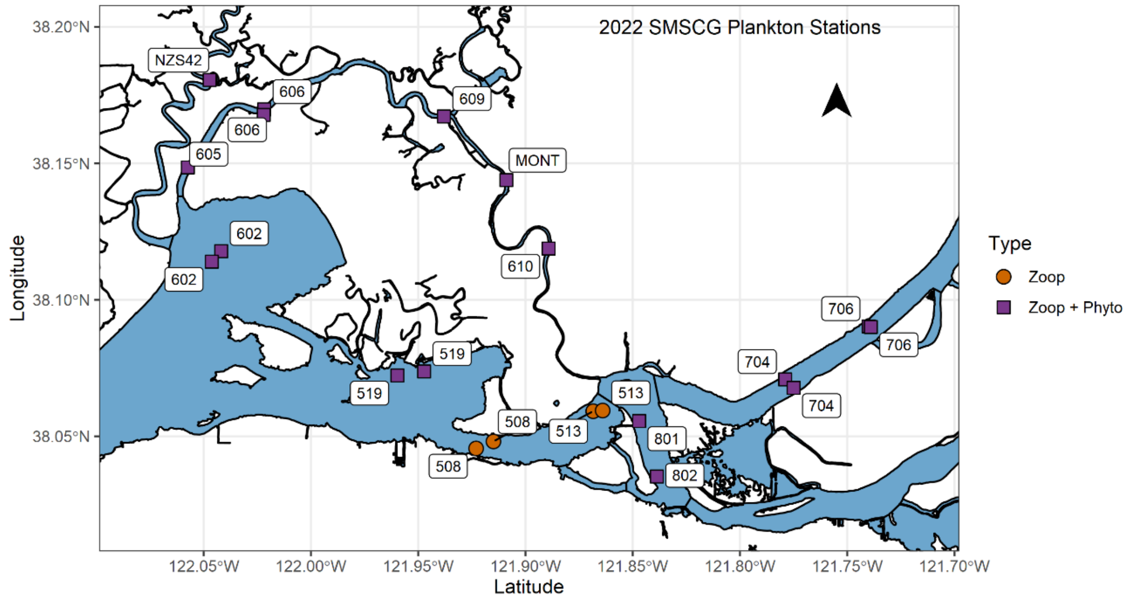

Figure 24. Map of stations for monitoring phytoplankton and zooplankton around the Suisun Marsh Salinity Control Gates.

Data from 2020 and 2021 showed phytoplankton biovolume did not differ among the three regions examined ($p = 0.67$; Lower Sacramento River, eastern Suisun Marsh, western Suisun Marsh) or among the four months examined ($p = 0.53$; July – October) (Figure 25, Figure 26). However, phytoplankton biovolume in 2020 was 2.1× higher than in 2021 ($p < 0.0001$; 2020: mean = 0.0018 $mm^3\ mL^{-1}$, SD = 0.0024 $mm^3\ mL^{-1}$; 2021: mean = 0.0008 $mm^3\ mL^{-1}$, SD = 0.0015 $mm^3\ mL^{-1}$).

Diatom biovolume did not differ among months ($p = 0.66$) but did differ among regions ($p = 0.03$) and years ($p < 0.0001$) (Figure 25, Figure 26). Specifically, diatom biovolume in western Suisun Marsh was 2.2× higher than in the Lower Sacramento River (Lower Sacramento River: mean = 0.0005 $mm^3\ mL^{-1}$, SD = 0.0010 $mm^3\ mL^{-1}$; eastern Suisun Marsh: mean = 0.0008 $mm^3\ mL^{-1}$, SD = 0.0015 $mm^3\ mL^{-1}$; western Suisun Marsh: mean = 0.0011 $mm^3\ mL^{-1}$, SD = 0.0023 $mm^3\ mL^{-1}$). Diatom biovolume in 2020 was 1.7× higher than in 2021 (2020: mean = 0.0010 $mm^3\ mL^{-1}$, SD = 0.0019 $mm^3\ mL^{-1}$; 2021: mean = 0.0006 $mm^3\ mL^{-1}$, SD = 0.0015 $mm^3\ mL^{-1}$). Diatoms comprised 54.8 and 70.3 percent of total phytoplankton biovolume in 2020 and 2021, respectively.

It was hypothesized that both total phytoplankton biovolume and total diatom biovolume would be highest in western Suisun Marsh and lowest in the Lower Sacramento River. Only diatom biovolume matched this hypothesis, but statistical power is limited with only two years of data.

In 2021, a pilot sampling effort took place at two stations in Grizzly Bay (Figure 26), but there were too few data to include in the statistical analysis.

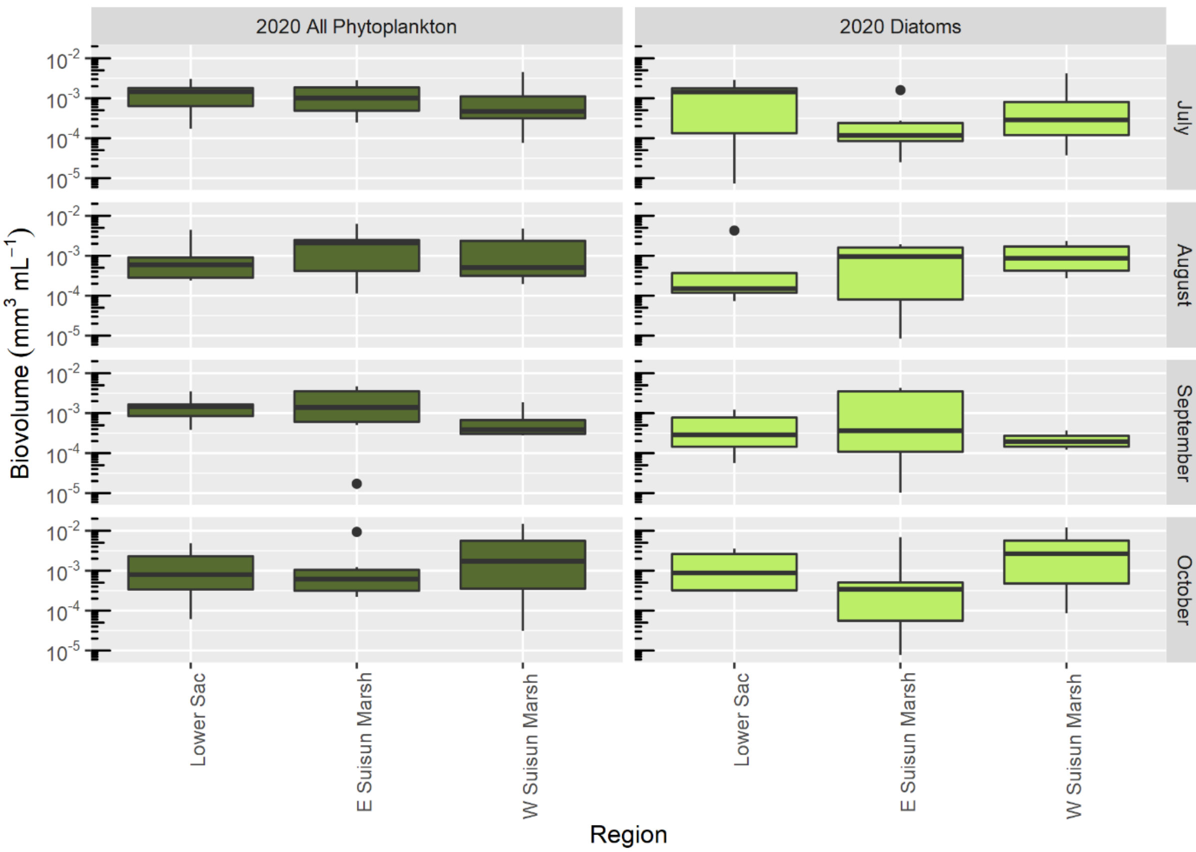

Figure 25 Estimated biovolume of all phytoplankton (left) and diatoms (right) based on samples collected during 2020 by the Environmental Monitoring Program, Summer Townet Survey, and Fall Midwater Trawl Survey. Sample sizes range 4-7 for each month by year combination.

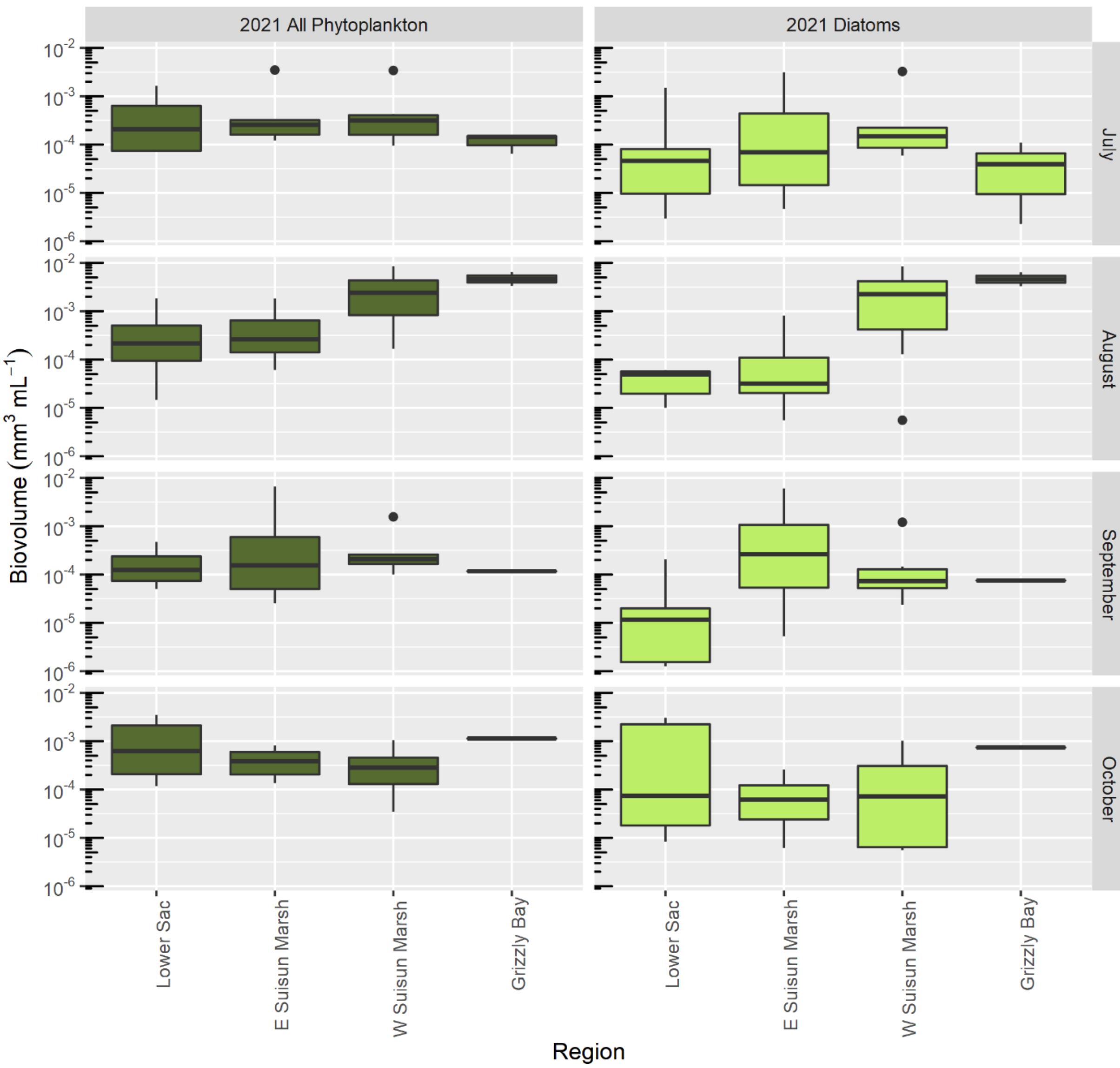

Figure 26 Estimated biovolume of all phytoplankton (left) and diatoms (right) based on samples collected during 2021 by the Environmental Monitoring Program, Summer Townet Survey, and Fall Midwater Trawl Survey. Sample sizes range 6-7 for each month by year combination except for Grizzly Bay, which had sample sizes 1-3.

Zooplankton

Zooplankton data are from the Summer Townet Survey, Fall Midwater Trawl, and EMP (Figure 24). Four regions, including Suisun Bay, western Suisun Marsh, eastern Suisun Marsh, and the Lower Sacramento River/Confluence, were monitored twice per month during July to October. Data for 2022 were not available in time for this report. However, we present data from previous years, including 2021, which was not included in the previous report. Zooplankton monitoring is further detailed in Appendix B.

The 2021 samples were distributed across four regions, including the Lower Sacramento River/Confluence ($n = 36$), Eastern Suisun Marsh ($n = 24$), Western Suisun Marsh ($n = 16$), and Suisun Bay ($n = 14$).

Zooplankton biomass for 2021 did not differ from that of any of the previous three years (all $p > 0.1$). Across months and years, the River region had the highest biomass compared to the other three regions (all $p < 0.001$). Western Suisun Marsh and Suisun Bay exhibited similar biomass ($p = 0.99$). Eastern Suisun Marsh had the lowest biomass (all $p < 0.01$). Across years and regions, the months of July and August showed similar biomass ($p = 0.77$), and these two months showed higher biomass (all $p < 0.05$) compared to September and October, which did not differ from one another ($p = 0.55$). There were no significant interactions among year, region, and month (all $p > 0.1$). In 2021, Suisun Bay and Western Suisun Marsh were dominated by *Tortanus,* and to a lesser extent, *Acartiella* (Figure *27*). In Eastern Suisun Marsh and the River region, the community was dominated by *Acartiella,* followed by *Tortanus* and *Pseudodiaptomus* (Figure *27*).

Figure 27 Mean biomass per unit effort of major zooplankton taxa contributing to delta smelt diets in regions surrounding the SMSCG.

Clams

The vast majority of bivalves found in Suisun Marsh belong to two non-native species, the brackish-water *Potamocorbula amurensis* (Nichols et al. 1990) and the more freshwater-adapted *Corbicula fluminea* (Brown et al. 2016). Both species have been presumed to impact delta smelt by reducing food availability (Mac Nally et al. 2010, Kimmerer and Thompson 2014). The density and biomass of these two clam species are important parameters to monitor for the management of delta smelt. Benthic invertebrate data is routinely collected by EMP and was supplemented by a special investigation of clams in Suisun Marsh beginning in 2018 to further investigate the Marsh's habitat value.

DWR staff conducted bivalve surveys at twenty-eight sites in July and September of 2021, matching the survey months and sample sites of earlier years 2018 - 2020. All samples taken from 2018-2021 have been processed, and the data from 2018-2021 is presented below as well as published on EDI. No sampling was conducted in summer 2022; the similarity of 2022 to other water years indicated that little new information would be added to the patterns of distribution already established. At each site, a Ponar dredge was used to collect a sample of benthic sediment, which was rinsed and preserved in ethanol. All *C. fluminea* and *P. amurensis* individuals were identified, counted, and shell measured to the closest millimeter shell length using either a micrometer or handheld calipers. Biomass and grazing rates of each clam species were estimated for all Suisun Marsh sites sampled using log-log regressions of shell biomass on shell length constructed from additional samples of clams collected at two reference sites (methodology outlined in Thompson et al. 2008). Clam Density and Biomass monitoring is further detailed in Appendix B.

Analysis of clam data from 2018-2021 revealed a few predominant patterns. First the distribution of the two clam species followed the estuarine salinity gradient in Suisun Marsh (Figure 28), and each species' biomass varied depending on several other variables. *Corbicula fluminea* had higher biomass at sites with gravel sediment ($p<<0.001$), in sloughs compared with larger rivers and channels ($p<0.001$), at deeper water depths ($p<<0.001$), and at lower salinities ($p<<0.001$) (Figure 29A). *Potamocorbula amurensis* had higher biomass in clay/silt sediment than in sediment with high organic content ($p=0.02$), at sites with deeper water depth ($p<<0.001$), and at higher salinities ($p=0.008$) (Figure 29B). When we examined the total grazing of both species added together, the salinity effect largely cancelled out. Total grazing rates were higher at deeper water depths ($p<<0.001$) (Figure 30A) and lower in sites with sediment characterized by large amounts of organic matter ($p<<0.001$) (Figure 30B). The pattern of fewer clams in sites with shallower water has been noticed before in Suisun Marsh (O'Rear and Moyle 2014, 2017); we note that this seems to be especially pronounced in shallow sites with a high proportion of organic matter in their sediment.

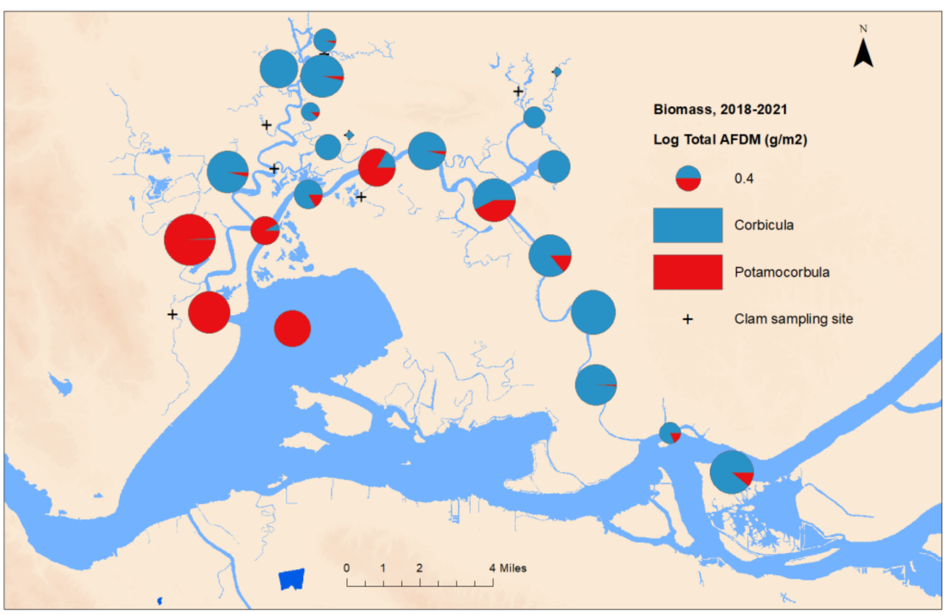

Figure 28 Map showing average biomass of invasive bivalves Corbicula fluminea and Potamocorbula amurensis in Suisun Marsh from 2018-2021.

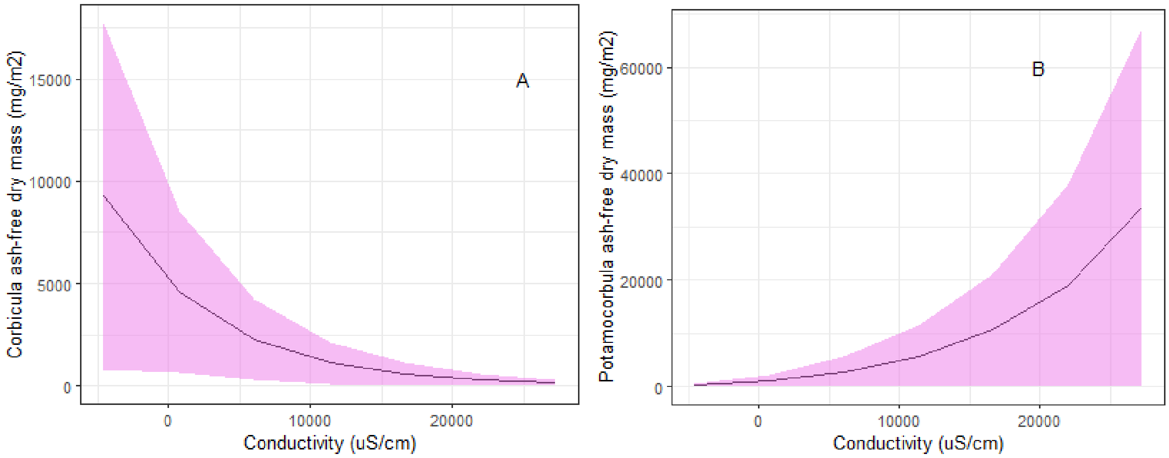

Figure 29 Salinity as a driver of A) Corbicula fluminea and B) Potamocorbula amurensis biomass in Suisun Marsh 2018-2021

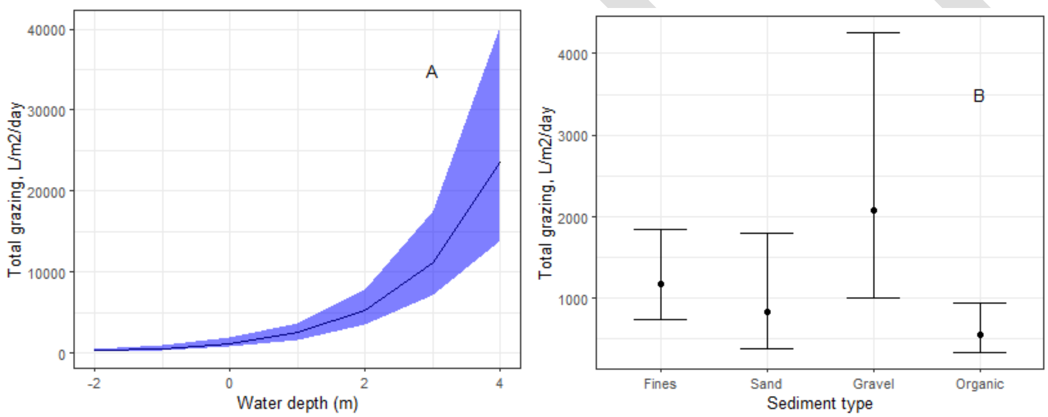

Figure 30 Total clam grazing as a function of A) water depth and B) sediment type in Suisun Marsh 2018-2021.

Discussion

The SMSCG action did not occur during either 2021 or 2022, so the gates were not operated during the June to August periods. Consequently, environmental conditions in Suisun Marsh were likely to have low suitability for delta smelt during June to August, particularly because of high salinity (> 6 ppt).

Phytoplankton and zooplankton data for 2022 were not available in time for this report. During July – October of 2021, phytoplankton biovolume was low and comprised of a higher proportion of diatoms compared to 2020. In 2021, the biomass of zooplankton taxa that contribute to delta smelt diets was similar to other recent years. This zooplankton community was dominated by *Tortanus,* a higher salinity tolerant taxon, followed by *Acartiella,* and *Pseudodiaptomus.* Overall, these plankton results likely reflect the high salinity in Suisun Marsh during the summer months of 2021.

Clams were not surveyed in 2022 due to the similarity of this water year to other recent water years. Across 2018-2021, patterns of composition were similar, with *Corbicula fluminea* at higher abundances in fresher areas and *Potamocorbula amurensis* at higher abundances in saltier areas. Total grazing rates were similar across the region despite the variation in community composition.

There will be a more detailed discussion of results for this management action during years in which the management action occurs.

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North Delta Food Subsidies Action

Background

The NDFS action redirects agricultural drain water or Sacramento River water into the Yolo Bypass Toe Drain to create positive net flow during the summer or fall when flows are typically net negative to transport food for delta smelt into the North Delta, including Cache Slough Complex and potentially the lower Sacramento River. This is accomplished by generating a larger than normal flow pulse of 20-25 thousand acre-feet in the Yolo Bypass Toe Drain during the summer or fall period for up to four weeks, which has been shown to transport lower trophic plankton and potentially trigger a phytoplankton bloom downstream in some years (Frantzich et al. 2018, 2021; Twardochleb et al. 2021b).

Two types of flow actions (i.e., managed flow pulse) have been conducted to date: a Sacramento River action and an agricultural return action. During flow actions, DWR alters the operation of the Knights Landing Outfall Gates (KLOG) and Wallace Weir (near Knights Landing, CA) to increase fall agricultural return flows or re-direct Sacramento River water into the Yolo Bypass Toe Drain to create aflow pulse large enough to sustain positive daily average net flow measured at Lisbon Weir. Study operations can begin in mid-to late-July for Sacramento River actions and are coordinated among DWR, Reclamation, and local irrigation and reclamation districts and require increased pumping of Sacramento River water into Colusa Basin Drain and Knights Landing Ridge Cut (Ridge Cut). Agriculture return actions begin in mid- to late-August, depending on suitable water allocations and water quality within the Colusa Basin Drain, Ridge Cut, and Yolo Bypass as determined by DWR and monitoring by reclamation districts. This type of action relies on coordinated releases of rice field drainage into Colusa Basin Drain to sustain the pulse flow once the water reaches the Toe Drain.

Each year, DWR monitors continuous and discrete water quality parameters, phytoplankton, and zooplankton before, during, and after the NDFS flow pulse at sites upstream in the Colusa Basin Drain and Yolo Bypass and downstream in the Cache Slough Complex and lower Sacramento River. Sampling begins in July or August and continues through November in years with non-managed flow pulses or agriculture actions. In years with Sacramento River actions, sampling occurs from June through September. Water quality parameters include temperature, dissolved oxygen (DO), conductivity, pH, turbidity, and secchi depth. Water samples for nutrients, phytoplankton, and zooplankton are collected concurrently with water quality measurements.

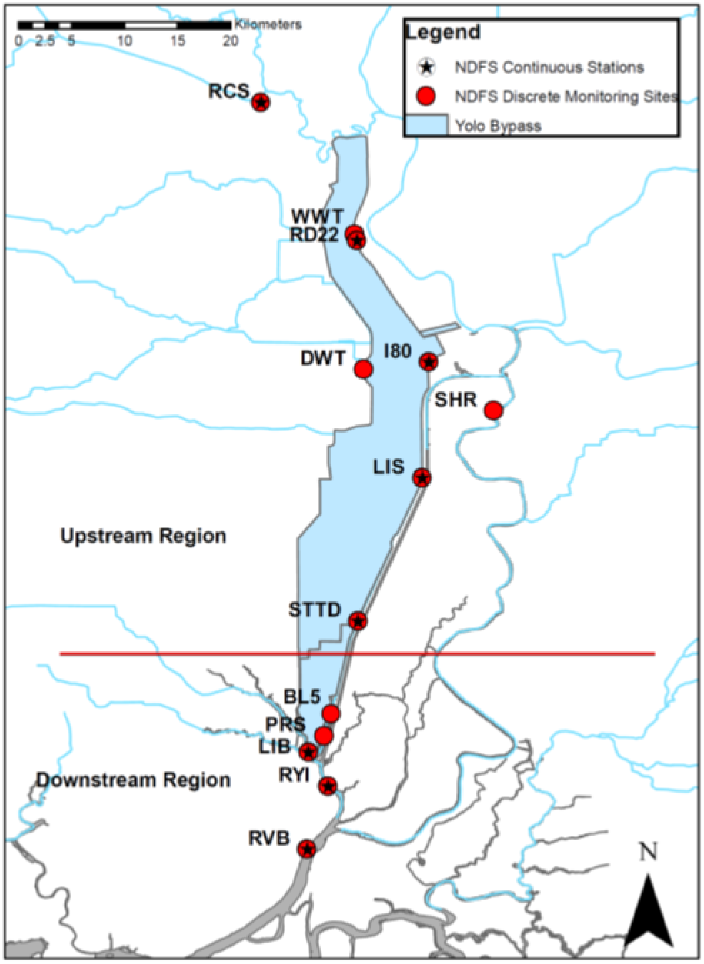

Figure 31 Map of the NDFS study area. Red circles indicate monitoring sites for discrete water quality and biological responses to flow pulses. Circles with stars indicate sites that were monitored for continuous water quality. The red line separates monitoring sites into Upstream and Downstream regions. Upstream region sites for monitoring include Rominger Bridge (RMB), Ridge Cut Slough at Highway 113 (RCS), Woodland Wastewater Treatment (WWT), Toe Drain at Road 22 (RD22), Davis Wastewater Treatment (DWT), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), and Screw Trap at Toe Drain (STTD). Downstream region sites include Below Toe Drain in Prospect Slough (BL5), Liberty Island (LIB), Ryer Island (RYI), and Sacramento River at Rio Vista Bridge (RVB). Sacramento River at Sherwood Harbor (SHR) is a control site for biological monitoring. RMB and RCS are alternative sites for sampling the agricultural source water.

Operations

An NDFS flow action (i.e., managed flow-pulse) was not implemented in 2022 due to the critically dry water year and additional ESA consultation that is underway. Historically low proportion of rice field acreage planted in the Colusa Basin resulted in reduced agricultural return flow in the Yolo Bypass such that during the study period there were only two consecutive days (September 21st and 22nd) between June and October 2022 for which flow in the Yolo Bypass Toe Drain at Lisbon Weir was net positive (Figure 32). As with other dry and critically dry water years (2020 and 2021), net flow in the Yolo Bypass Toe Drain remained negative for most of the 2022 study period. Mean daily discharge during June to October was –54.63 ± 67.64 cfs, -55.27 ± 185.60 cfs, and –82.42 ± 36.80 cfs in 2020, 2021 and 2022, respectively (Figure 33). In 2019, however, a wet year in which an experimental managed flow action was conducted, mean daily discharge was 128.40 ± 273.56 cfs.

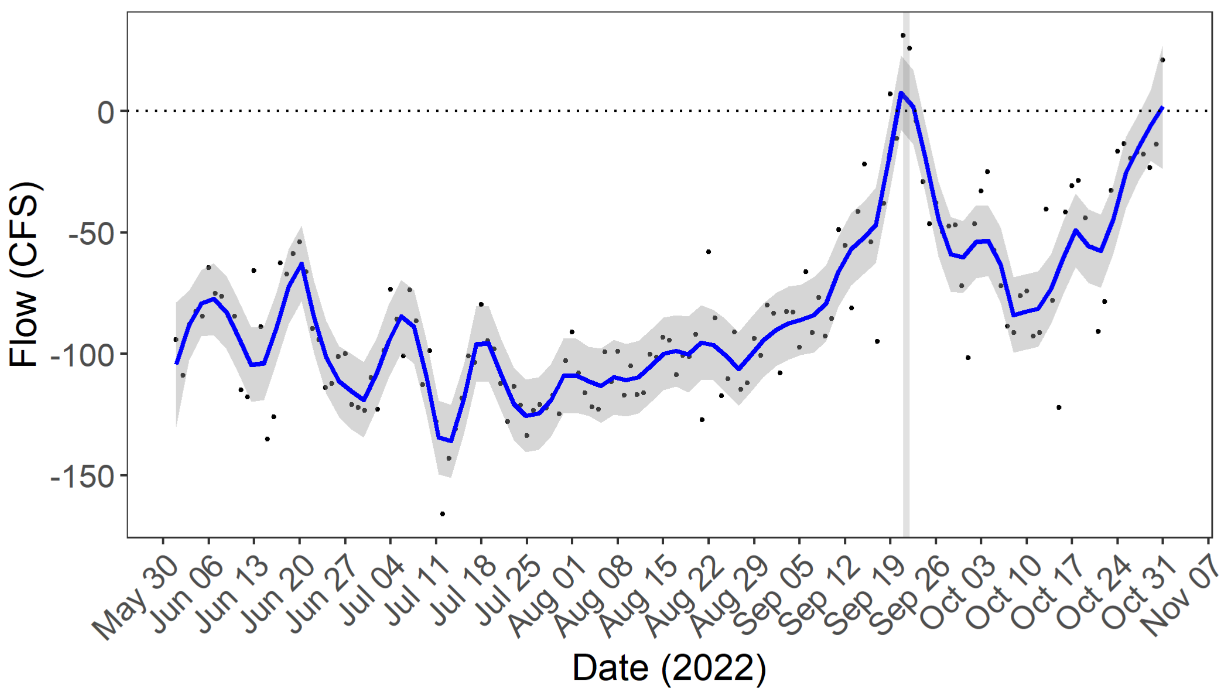

Figure 32 CDEC flow data from Lisbon Weir in the Yolo Bypass Toe Drain (station LIS) from June 1st through October 31st, 2022, taken at 15-minute intervals. Blue line indicates LOESS smoothing line ± 1 SE of daily average flow. Points represent daily average flow, the horizontal dashed line at 0 CFS indicate the threshold for positive flow (downstream), and the grey box highlights the two-day non-managed flow pulse that occurred September 21st and September 22, 2022, during which daily average flow was 31.1 CFS. Data from CDEC are provisional, did not undergo QA/QC and are subject to change.

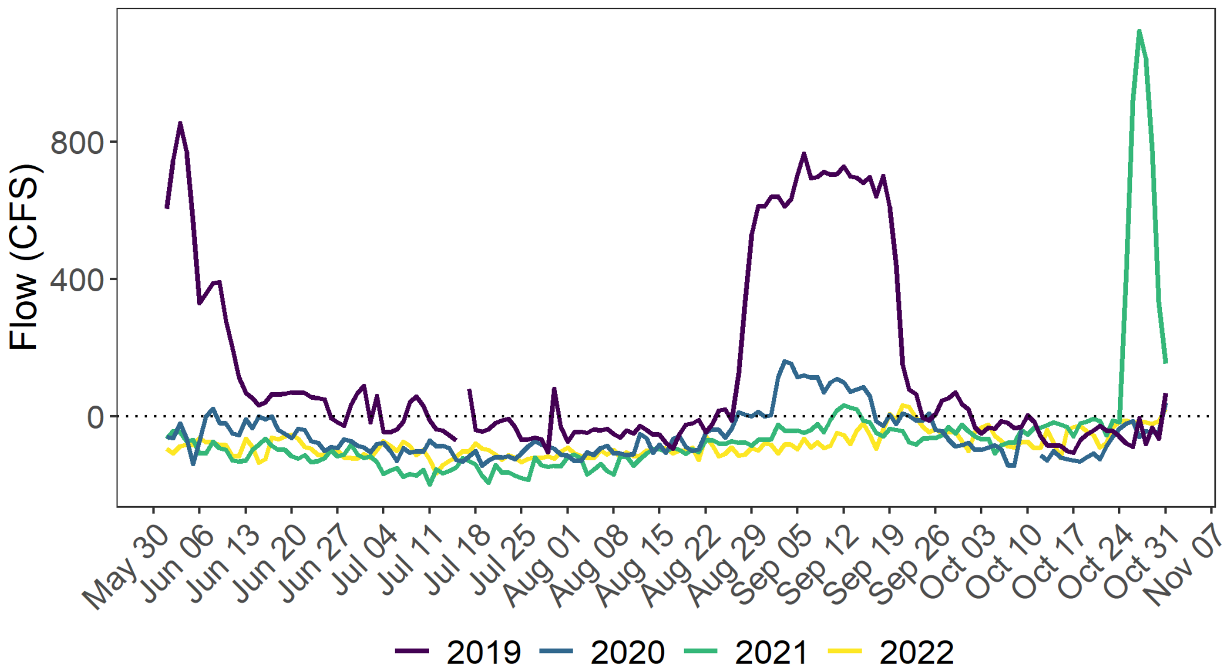

Figure 33 CDEC flow data from Lisbon Weir in the Yolo Bypass Toe Drain (station "LIS") from June 1st through October 31, 2019 – 2022, taken at 15-minute intervals. The horizontal dashed line at 0 CFS indicates the threshold for positive flow (downstream). The managed flow action in 2019 was experimental. Flow pulses in 2020, 2021 and 2022 were non-managed. Data from CDEC are provisional, did not undergo QA/QC and are subject to change.

Water Quality

Discrete monitoring data for the NDFS Study in 2021 (water quality, nutrients, phytoplankton, zooplankton) that were not available for the 2021 seasonal report are presented here. Discretely measured physical water quality parameters and nutrient samples were collected in 2021 on three occasions before, once during, and twice after the small, non-managed pulse flow. In 2021, most physical water quality parameters did not differ between regions and across flow pulse periods (Figure 34). Two-way ANOVAs (type 3 for unbalanced sampling design) were performed to analyze the effect of region (i.e., upstream or downstream) and pulse period with sampling station included as a random effect, on physical water quality parameters. Region had a significant effect on dissolved oxygen (mg/L, $F_{10.65, 63}=12.5$, p=0.005), pH ($F_{10.60, 63}=7.72$, p=0.012), secchi depth (m, $F_{10.68, 58}=55.07$, p<0.001), temperature (º C, $F_{13.78, 63}=5.88$, p=0.030), and conductivity (µS/cm at 25 ºC, $F_{13.85, 63}=5.72$, p=0.032). Flow pulse period also significantly affected dissolved oxygen (mg/L, $F_{55.0}=4.75$, p=0.012), secchi depth (m, $F_{50.75}=5.55$, p=0.007), and temperature (º C, $F_{55.28}=71.30$, p<0.01). There were no significant interactive effects of region and flow pulse period. In addition, no significant differences between individual contrasts were detected in physical water quality post hoc tests.

Nutrient levels qualitatively differed between upstream and downstream regions throughout all sampling periods in 2021; concentrations were notably higher with greater variability upstream (Figure 35). Similar to water quality analyses, two-way (type 3) ANOVAs were conducted to analyze the effect of region and pulse period, with sampling station included as a random effect, on ammonia, nitrate and nitrite, ortho-phosphate, and silica concentrations. Region had a significant effect on silica (µmol, $F_{12.28, 66}=7.95$, $p=0.015$) and ortho-phosphate (µmol, $F_{12.09, 66}=5.97$, $p=0.031$) concentrations; both silica and ortho-phosphate concentrations remained higher upstream. Flow pulse period only significantly affected nitrate/nitrite concentrations upstream (µmol, $F_{12.06, 66}=5.36$, $p=0.007$). Nitrate+Nitrite concentrations progressively increased following the flow pulse in the upstream region. There were no statistically detectable differences in ammonia concentrations between region or flow pulse periods and there were no significant differences between individual contrasts in nutrient concentration post hoc tests.

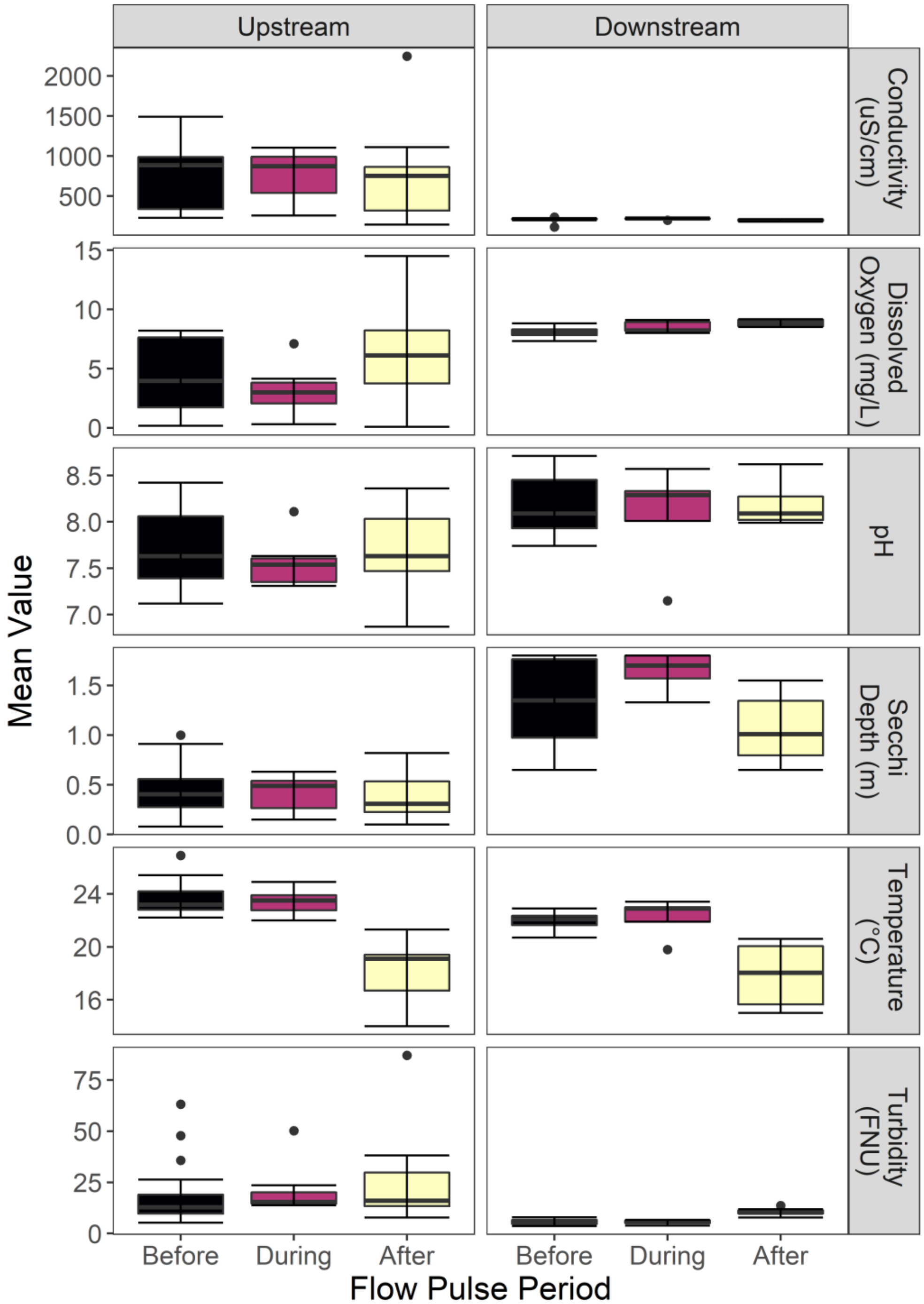

Figure 34 North Delta Food Subsidies study discrete water quality measurements in 2021 from upstream and downstream regions before, during and after the non-managed flow pulse. Mean values (±1 SD) for dissolved oxygen (mg/L), pH, specific conductivity (um/cm at 25 °C), water temperature (°C), and turbidity (FNU) were measured with a YSI ProDSS.

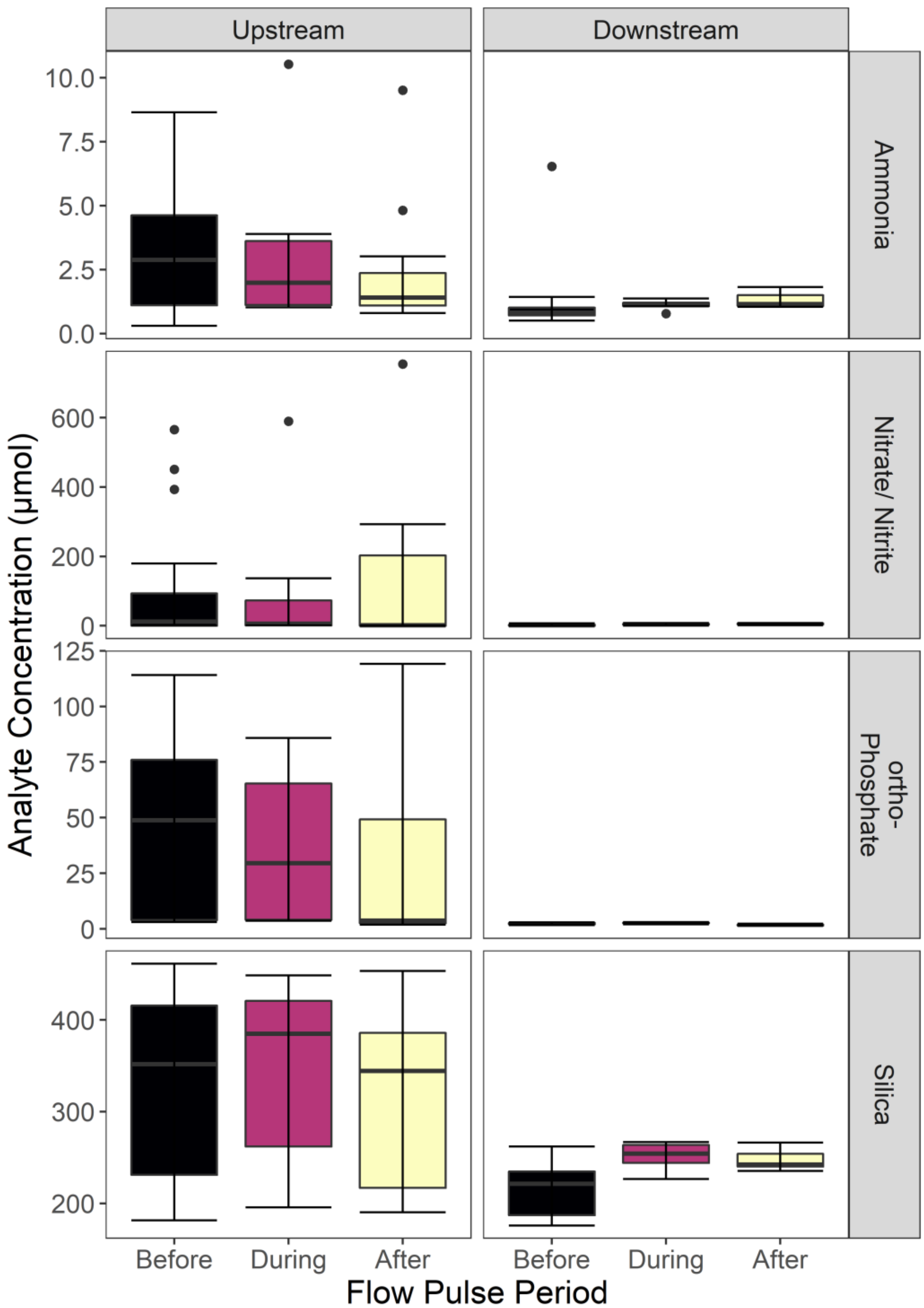

Figure 35 North Delta Food Subsidies study nutrient concentrations in water from the upstream and downstream study regions, before, during, and after the 2021 non-managed flow pulse. Mean concentrations (µmol±1 SD) are shown for dissolved ammonia, dissolved nitrate + nitrite, dissolved ortho-phosphate, and Silica. Nutrient levels were assessed by the Dugdale-Wilkerson Lab at San Francisco State University. The lab is not ELAP accredited and thus levels should be interpreted with caution.

Phytoplankton and Zooplankton

The 2021 phytoplankton and zooplankton monitoring indicated that phytoplankton biovolume (log of mean, μm3/mL) did not differ among upstream and downstream regions or sampling periods (two-way [type 3] ANOVA; Table 6; Figure 36 2021 NDFS mean phytoplankton and zooplankton monitoring data. a) Log of mean phytoplankton biovolume (μm3/mL ± 1 SD) and b) log of mean zooplankton CPUE (catch per unit effort, number/m2 ± 1 SD) by NDFS study region and sampling period for six transects across August, September, and October before, during and after the 2021 small, non-managed flow pulse.

Similarly, zooplankton CPUE (log of mean catch per unit effort, number/m3) was similar across regions and sampling periods (two-way [type 3] ANOVA; Table 6; Figure 36 2021 NDFS mean phytoplankton and zooplankton monitoring data. a) Log of mean phytoplankton biovolume (μm3/mL ± 1 SD) and b) log of mean zooplankton CPUE (catch per unit effort, number/m2 ± 1 SD) by NDFS study region and sampling period for six transects across August, September, and October before, during and after the 2021 small, non-managed flow pulse.

A visual examination of zooplankton CPUE and phytoplankton biovolume by functional group suggested that there were not strong differences between upstream and downstream regions or interactions between region and flow pulse period. Therefore, we tested for effects of flow pulse period only using one-way ANOVA [type 2] and found no significant differences in phytoplankton biovolume or zooplankton CPUE (except calanoid copepods) for any functional groups across flow pulse periods (one-way ANOVA [type 2]; Table 6; 37).

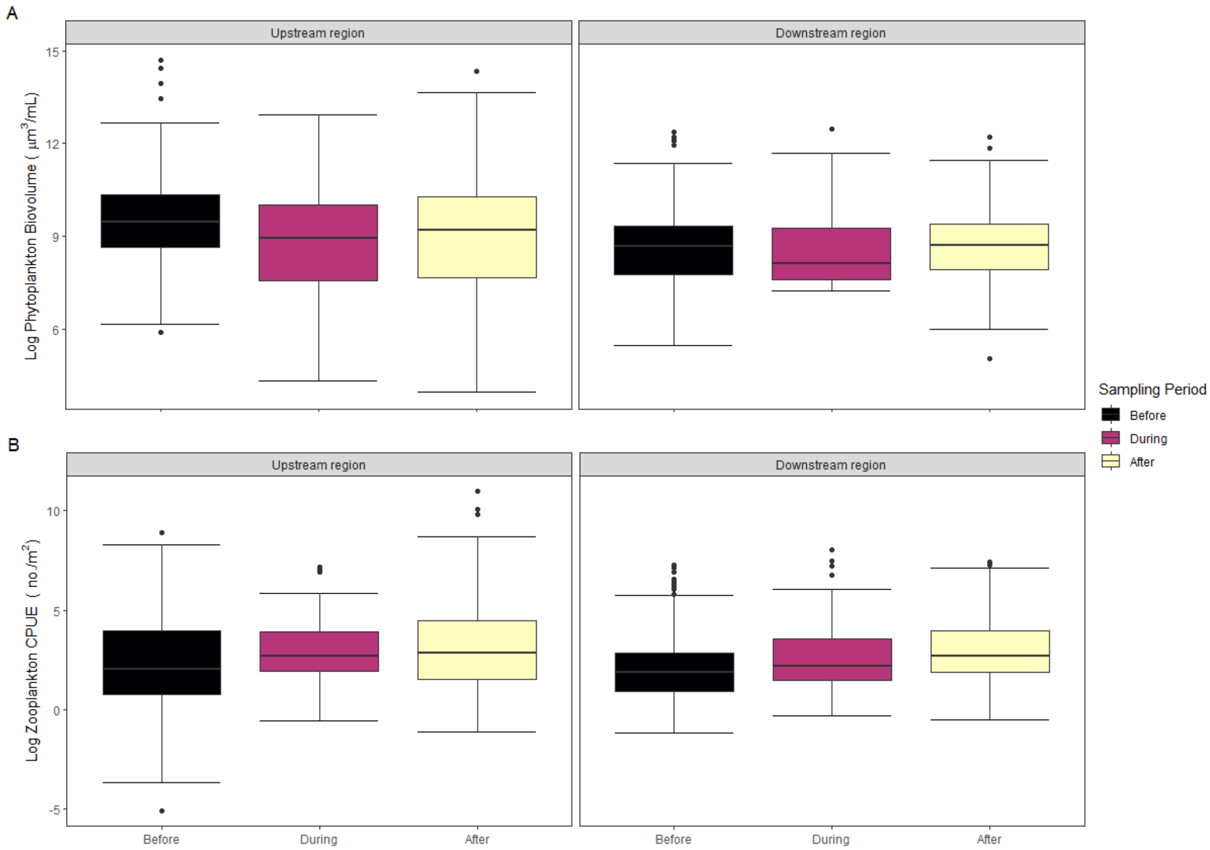

Figure 36 2021 NDFS mean phytoplankton and zooplankton monitoring data. a) Log of mean phytoplankton biovolume (µm3/mL ± 1 SD) and b) log of mean zooplankton CPUE (catch per unit effort, number/m2 ± 1 SD) by NDFS study region and sampling period for six transects across August, September, and October before, during and after the 2021 small, non-managed flow pulse.

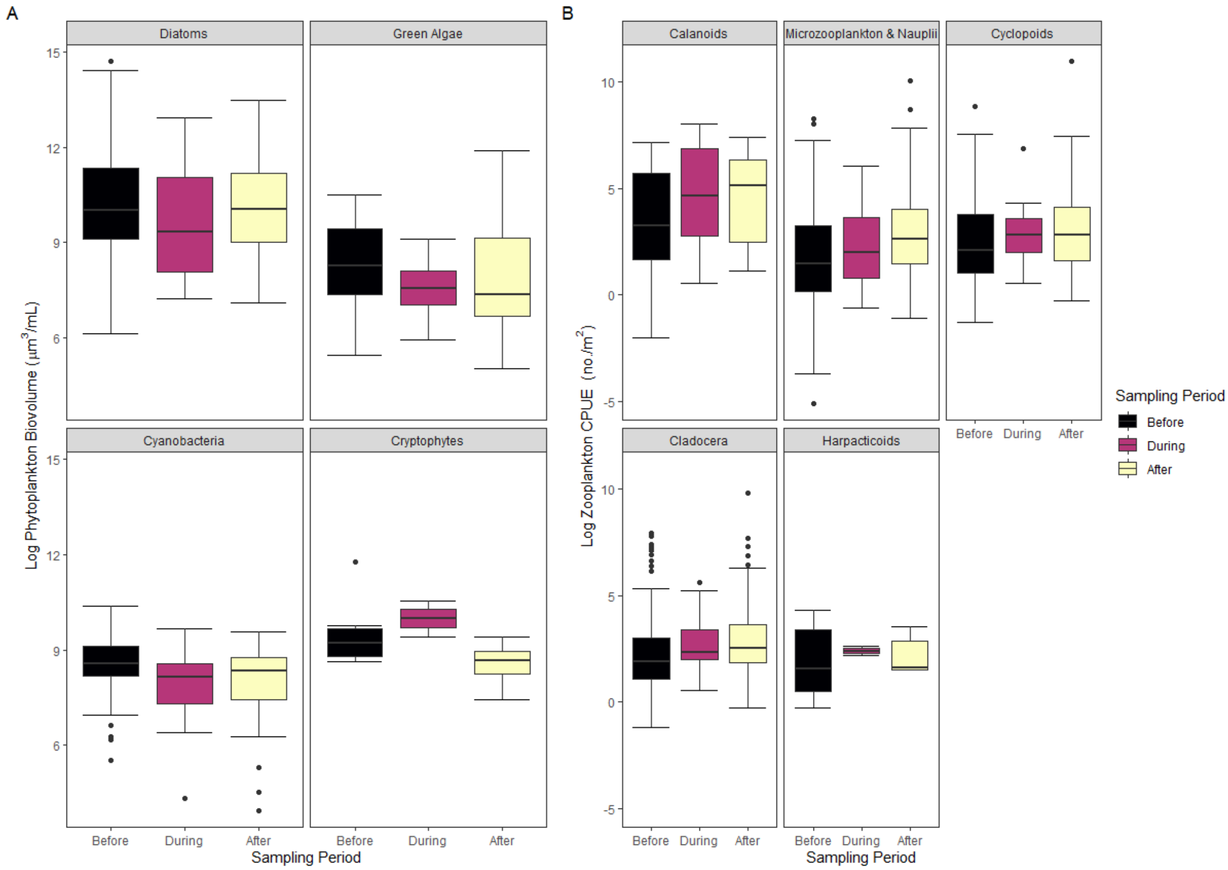

Figure 37 2021 NDFS phytoplankton and zooplankton monitoring data by taxonomic group. a) Log of mean phytoplankton biovolume (µm3/mL ± 1 SD) by phytoplankton taxonomic group and b) log of mean zooplankton CPUE (catch per unit effort, number/m2) by zooplankton taxonomic group from six transects across August, September, and October before, during and after the 2021 small, non-managed flow pulse.

Table 6 2021 NDFS zooplankton and phytoplankton model results. Two-way ANOVAs were conducted for the mean phytoplankton biovolume and mean zooplankton CPUE. In these two-way ANOVAs flow pulse period, region, and their interaction, were included as fixed effect predictors, while station nested within region was included as a random effect. For these analyses the 'Test Statistic' column displays chi-square statistic values. We also ran one-way ANOVAs to test for differences in phytoplankton biovolume and zooplankton CPUE of individual taxonomic groups across flow pulse periods. For these analyses the 'Test Statistic' column displays F-statistic values. Significant model terms (α = 0.05) are shown in bold.

Model	Model Term	Test Statistic	df (term, residuals)	p-value
Mean Phytoplankton Biovolume	**Intercept**	**419.383**	**1, 14**	**<0.001**
Mean Phytoplankton Biovolume	Flow Pulse Period	1.674	2, 14	0.433
Mean Phytoplankton Biovolume	Region	1.785	1, 14	0.376
Mean Phytoplankton Biovolume	Interaction (Flow Pulse Period x Region)	0.147	2, 14	0.929
Mean Zooplankton CPUE	**Intercept**	**24.366**	**1, 12**	**<0.001**
Mean Zooplankton CPUE	Flow Pulse Period	3.725	2, 12	0.155
Mean Zooplankton CPUE	Region	0.597	1, 12	0.440
Mean Zooplankton CPUE	Interaction (Flow Pulse Period x Region)	1.461	2, 12	0.482
Diatoms	Flow Pulse Period	0.741	2, 22	0.488
Cryptophytes	Flow Pulse Period	0.924	2, 8	0.436
Cyanobacteria	Flow Pulse Period	1.587	2, 24	0.225
Green Algae	Flow Pulse Period	0.047	2, 14	0.955
Calanoids	**Flow Pulse Period**	**4.193**	**2, 22**	**0.029**
Cladocera	Flow Pulse Period	0.467	2, 22	0.633
Cyclopoids	Flow Pulse Period	1.038	2, 22	0.371
Harpacticoids	Flow Pulse Period	0.278	2, 22	0.760

Model	Model Term	Test Statistic	df (term, residuals)	p-value
Microzooplankton & Nauplii	Flow Pulse Period	0.324	2, 22	0.727

A majority of baseline information collected by the NDFS study in 2022 (e.g., nutrients, contaminants, phytoplankton, zooplankton, etc.) are not yet available for this 2022 seasonal report. Chlorophyll a fluorescence data from continuous water quality stations (Figure 38), suggest that that there was an increase in chlorophyll levels at two upstream stations (I80 and LIS) during and after the small non-managed flow pulse in the Yolo Bypass Toe Drain during September 2022 (Figure 38). Chlorophyll levels increased at I80 during the flow pulse and at LIS two days after the flow pulse. No other changes in chlorophyll fluorescence were detected during or after the flow pulse relative to before.

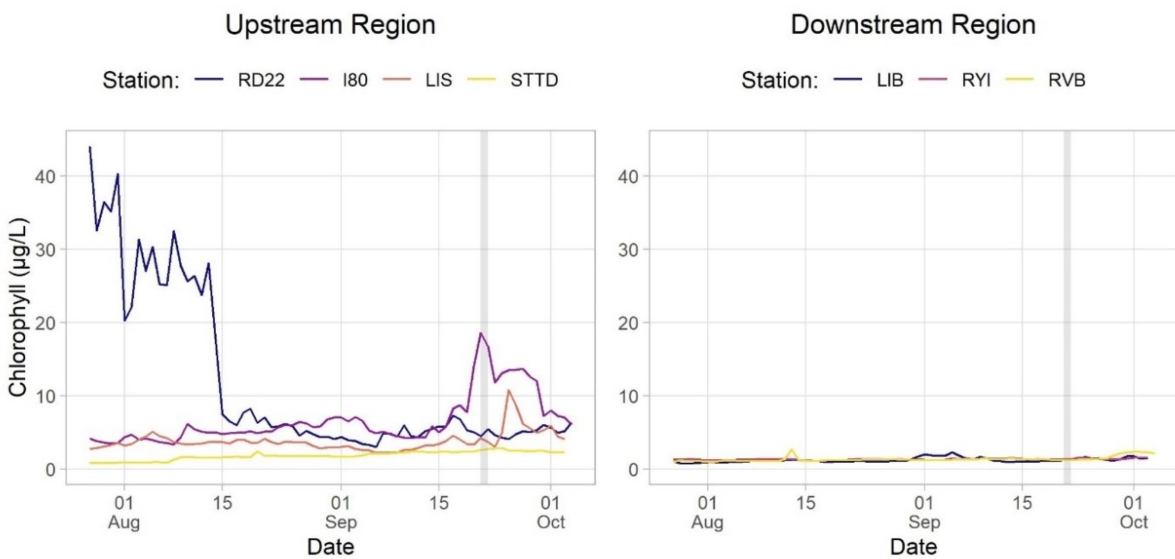

Figure 38 2022 NDFS chlorophyll fluorescence data from continuous water quality stations. Stations shown in order from most upstream site to downstream: Toe Drain at Road 22 (RD22), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), Screw Trap at Toe Drain (STTD), Liberty Island (LIB), and Sacramento River at Rio Vista Bridge (RVB) between July and October of 2022. Chlorophyll data are daily averaged. Shaded area indicates the days of the flow action (9/21-9/22). Upstream sites were QA/QC'd using procedures from the Resources Assessment Branch WQES Field Manual (06/2020). Note that LIB, RYI (downloaded from USGS NWIS) and RVB (DWR EMP) data have not undergone QC.

Discussion

During the 2021 North Delta Food Subsidies Study regional differences in physical water quality and nutrient concentrations were obvious, however differences between flow pulse periods (in a no-action year) were less conspicuous. Measures of physical water quality and nutrient concentrations were consistently higher in the upstream region across flow periods. Although temperature differed between pulse periods these results may be confounded by a seasonal effect as air and water temperature cools during the fall. Interestingly, during the small 2021 pulse flow, dissolved oxygen decreased notably upstream, yet increased downstream both during and after the pulse flow likely resulting from seasonal declines in temperature increasing oxygen solubility (Figure 34). During several previous high-flow pulse years (2016, 2018, and 2019), observations of pH, turbidity, and specific conductivity indicated that flow pulses were effective at transporting water downstream (Davis et al. 2022); yet in 2021, consistent with dry water year types (2013 and 2014), physical water quality parameters differed between the upstream and downstream regions during all sampling periods and the non-managed flow pulse only changed physical water quality locally, within the upstream region (Figure 34). This pattern likely resulted from minimal water transport downstream during the small, non-managed pulse flow in 2021.

In 2021, as indicated by secchi depth and turbidity measurements, there was greater light penetration downstream with an increased euphotic zone, whereas the upstream region remained light limited (Figure 34). Phytoplankton blooms occur during rapid increases in growth rate caused by nitrate uptake during improved light conditions in the presence of low ammonia concentrations (Wilkerson et al. 2006); however, in 2021, light conditions did not sufficiently improve in the upstream region during the 2021 sampling season to increase phytoplankton productivity, despite higher nutrient concentrations. Consistent with other low-flow years (2013 and 2014) silica, an important element for phytoplankton growth, increased slightly during the small, non-managed pulse flow period downstream despite the negligible transport from the upstream region (Figure 35Figure 35). Counter to most previous NDFS study years, ammonia concentrations in 2021 were greater in the upstream region rather than downstream where higher concentrations were historically observed (Davis et al. 2022). Further, during dry periods concentrations of ammonia generally increase, inhibiting nitrate uptake and growth by phytoplankton (Wilkerson et al. 2006). Yet mean ammonia concentrations in 2021 generally remained below 4 µmol/L. Ammonia concentrations less than 4 µmol/L are not known to inhibit phytoplankton from accessing nitrate pools (Wilkerson et al. 2006, Dugdale 2007), but there was still no detectable increase in phytoplankton productivity (2021 Delta smelt Summer-Fall Habitat Seasonal Report). Notable decreases in ammonia concentrations in 2021 can likely be attributed to the implementation of a new Biological Nutrient Removal project by the Sacramento Regional County Sanitation District that removes large amounts of ammonia from regional wastewater (Regional San, 2021).

Consistent with previous years, chlorophyll fluorescence levels in summer-fall 2022 were higher in the upstream study region compared to downstream, and levels before the small, non-managed flow pulse (from local agriculture drainage) resembled levels in previous years (e.g., 2020, 2021) (Frantzich et al. 2021; Davis et al. 2022). As predicted in a no-action year, chlorophyll levels were unchanged in the downstream region following the small, non-managed flow pulse;

however, local increases in chlorophyll were observed at upstream sites following the small pulse (Figure 38). In 2018 and 2019 large agricultural flow actions caused noticeable changes in chlorophyll fluorescence in the upstream study region (Frantzich et al. 2019, Twardochleb et al. 2021a). In both 2018 and 2019, during and after the flow actions, chlorophyll levels decreased in the upstream region, but levels were unchanged downstream. (Frantzich et al. 2019, Twardochleb et al. 2021a). During the 2016 Sacramento River action, chlorophyll levels in the upstream region generally dropped during the flow action while levels rose at downstream sites after the action (Frantzich et al. 2021).

The localized response in chlorophyll in 2022 is likely due to the critically dry conditions, with low flow due to reduced acreage planted and irrigated (estimated 1% of normal rice planted) resulting in very little water released to redistribute nutrients and phytoplankton from upstream to downstream sites (Figure 38). The chlorophyll responses in 2022 were even lower than in 2020 and 2021, both non-managed flow years with dry conditions in which chlorophyll levels increased in the Yolo Bypass but not downstream in the Cache Slough Complex following the small, non-managed flow pulse (2020 Delta smelt Summer-Fall Habitat Seasonal Report). Field staff noted aquatic vegetation increased in density during the recent ongoing drought (2020-2022) and may have reduced phytoplankton responses to the small pulse flow by shading the water column and consuming available nutrients.

The small, non-managed flow pulse in 2021 had few observed effects on phytoplankton biovolume or zooplankton CPUE. Only CPUE of calanoid copepods varied significantly across the study period (Figure 37; Table 6). As in other years of the NDFS study calanoid densities increased over time, which may have been due to seasonal changes in populations (Davis et al. 2022). Moreover, phytoplankton and zooplankton communities responded similarly in 2021 as they had to previous higher pulse flows in 2018 and 2019 (Frantzich et al. 2019; Davis et al. 2022). These results contrast responses to the high flow, 2016 Sacramento River managed flow pulse, when both phytoplankton biovolume and zooplankton density increased following the pulse (Frantzich et al. 2019).

Sacramento Deep Water Ship Channel Food Web study

The SDWSC study is investigating the feasibility of exporting phytoplankton, zooplankton and other food web resources from the upper relatively productive reaches of the ship channel to the lower reaches of the ship channel and Cache Slough. The study focuses on improving understanding of physical and ecological processes including measurement of plankton growth rates, nutrient dynamics (including bottom sediment processes) and ecosystem metabolism and how the fish community varies between open channel and littoral habitat and varies with water quality and plankton standing stock. These data will be used to develop enhance models for use in comparing the performance of multiple flow-nutrient management scenarios as they affect environmental conditions, food supply and delta smelt.

Export of planktonic food web constituents would be managed adaptively in part by controlling inflow from the Sacramento River at West Sacramento. Presently, inflow is limited to the small amount of flow (~3 cfs) that leaks through the Stone Lock facility sector gates which are inoperable and locked in their closed position. Reconnecting the ship channel with the river at West Sacramento could also supply the lower Sacramento River mainstem with a ‘seed source’ capable of taking advantage of the higher nitrogen concentration in the lower river. This concept is thus similar to the strategy being implemented by the North Delta Food Subsidies action. Experimentally manipulating flow into the ship channel cannot occur until the required infrastructure is approved, constructed and permitted for operation as part of the city of West Sacramento’s effort to address flood risks at the Stone Locks facility. The authorizing legislation stipulates that the City shall achieve 200-year protection by 2025. As part of its urban development planning process the City of West Sacramento (2020) evaluated multiple alternatives for achieving this level of protection and ranked repairing the sector gates of the Stone Lock facility highly. Adaptive management of the ship channel action could include operating the Lock facility gates to enhance thermal stratification and adding liquid fertilizer to boost phytoplankton production.

The ship channel comprises three hydrodynamic zones: a zone of relatively rapid water exchange with the mainstem Sacramento River downstream of CM56: a zone of low exchange represented by long-term monthly discrete sampling stations CM62 and CM66; and a no-exchange zone represented by four stations in the uppermost reach of the channel (Figure 38). This longitudinal gradient in hydrodynamic conditions is largely responsible for the longitudinal variation in plankton production. Another important habitat feature of the ship channel is its longitudinal variation in suspended solids concentration and turbidity. The length of the ship channel exceeds the maximum tidal excursion length, and its flood tides are stronger than ebb tides. These characteristics result in the formation of a Turbidity Maximum Zone (TMZ) in the low-exchange zone (Lenoch et al. 2021). Here, total suspended solids concentration averages ~20 mg/L and turbidity ~30 NTU, some 3-times higher than in the upper reaches. Surveys conducted by the California Department of Fish and Wildlife Summer Tow Net Survey indicate that delta smelt catch at the TMZ station was consistently higher than at its sampling station in the no-exchange zone.

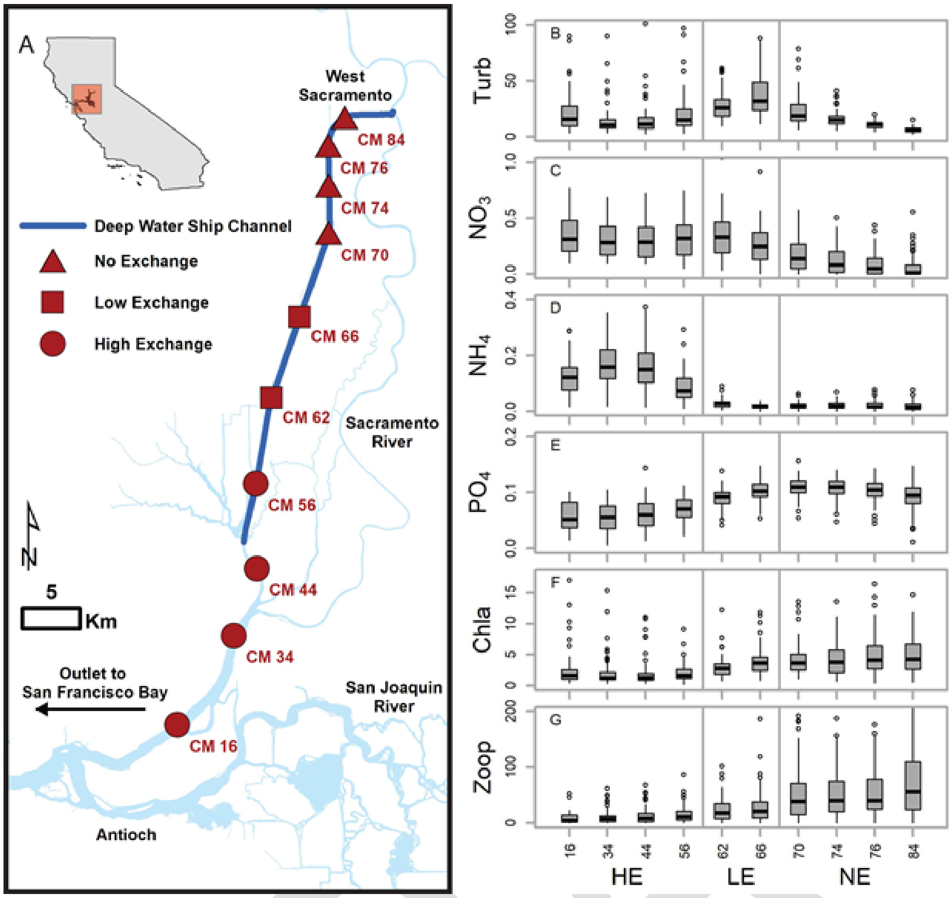

Figure 39 Location of sampling stations (designated by channel markers; CM). b-g) Turbidity (NTU), nitrate concentration (mg N L-1), ammonium (mg N L-1), phosphate (mg P L-1), chlorophyll-a (µg L-1), and total zooplankton biomass Location of sampling stations (designated by channel markers; CM). b-g) Turbidity (NTU), nitrate concentration (mg N L-1), ammonium (mg N L-1), phosphate (mg P L-1), chlorophyll-a (µg L-1), and total zooplankton biomass (µg dw L-1) at each sampling station, including all sampling dates (2012-2019). Sampling stations on the x-axes are ordered from seaward to landward, and gray vertical lines denote site groupings based on hydrodynamic exchange zones (HE, LE, NE). (Figure prepared by Adrianne Smits, UC Davis)

Monthly grab sampling resumed in 2022 and continuous monitoring of specific conductance, temperature, turbidity, dissolved oxygen concentration, pH and chlorophyll fluorescence was conducted as an element of the fish monitoring component of the ship channel food web study that began in May 2021 (Reclamation 2021). This fish monitoring effort is being conducted using the Aquatic Habitat Sampling Platform (Platform) developed by Cramer Fish Sciences under a grant from the Reclamation. The Platform samples the fish community by guiding fish through a live well outfitted with video cameras and so does not require fish handling, an important consideration when sampling areas where delta smelt and other species of concern are known to reside. This effort includes near-shore and channel as well as day and night sampling.

Continuous monitoring data recorded at the USGS station at CM72, which indicated fairly comparable turbidity in WY2021, WY2022, and the beginning of WY2023, although turbidity was generally higher in WY2021 than WY2022 during February through March (around day 120-180; Figure 40).

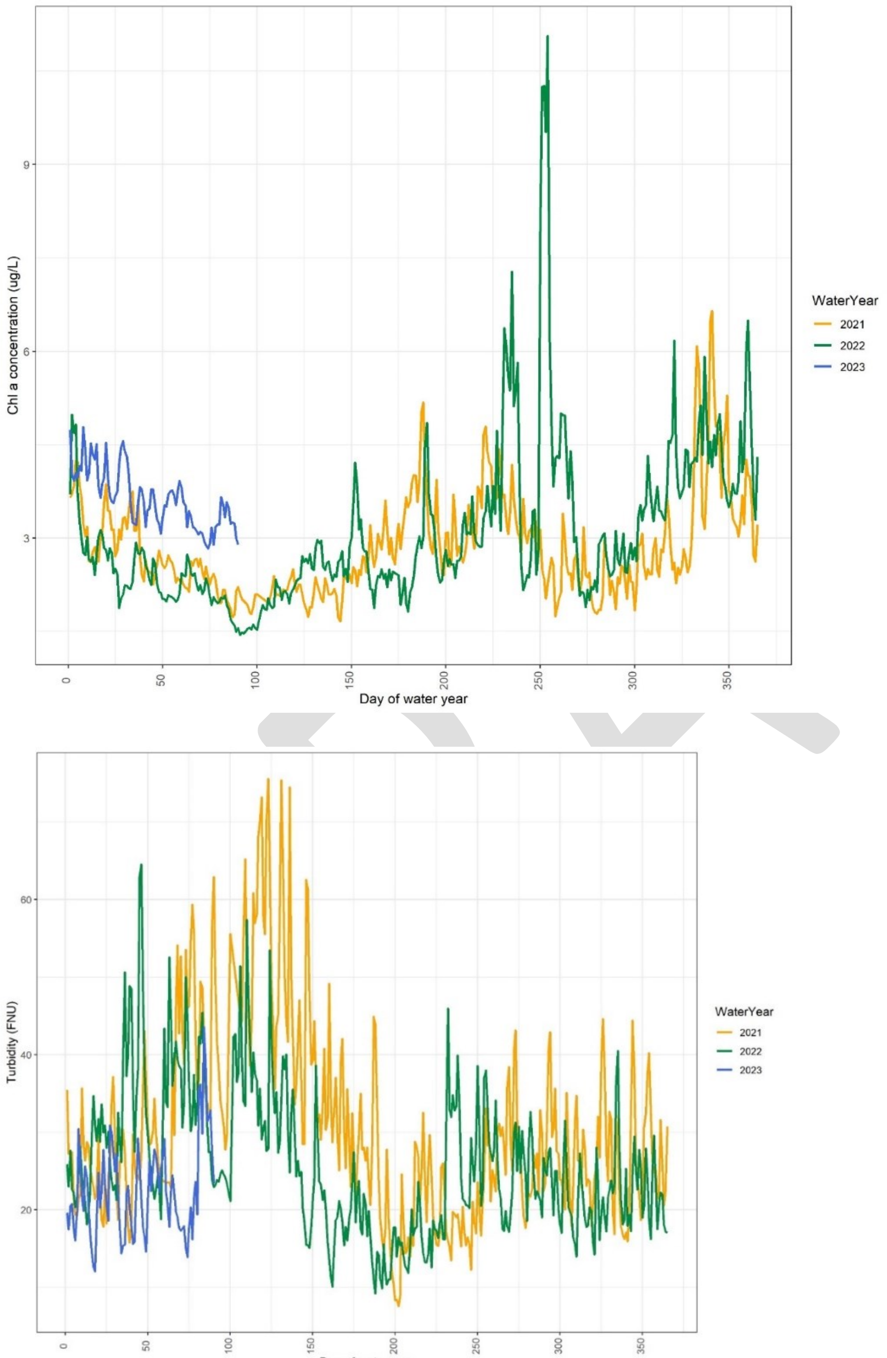

Figure 40 Comparison of chlorophyll concentration and turbidity at USGS continuous monitoring station at CM72 in the low-exchange zone of the ship channel. Missing data interval coincides with COVID-19 shut down period. Data are provisional.

Chlorophyll export

If net flow can be restored to the ship channel and manipulated experimentally to adaptively manage food web productivity, it will be important to determine how much algal biomass and other forms of biologically available organic carbon it exports to the lower Sacramento River and how the magnitude of this exported material compares to organic carbon fluxes at stations up- and downstream. For this purpose, Reclamation funds USGS to maintain continuous monitoring stations in the Sacramento River at Walnut Grove and Decker Island, in Cache Slough and in the San Joaquin River at Jersey Point (Figure 39Figure 41). The stations at Toland (TOL) and Jersey Point (JPT) represent the chlorophyll fluxes from the northern and southern Delta into the low salinity zone, respectively. The station at Walnut Grove (WGA) represents flux from upper Sacramento River and the station at Cache Slough (RYFCC) represents the flux from the Cache Slough complex making it possible to separate their relative contribution to the flux into Suisun Bay via TOL.

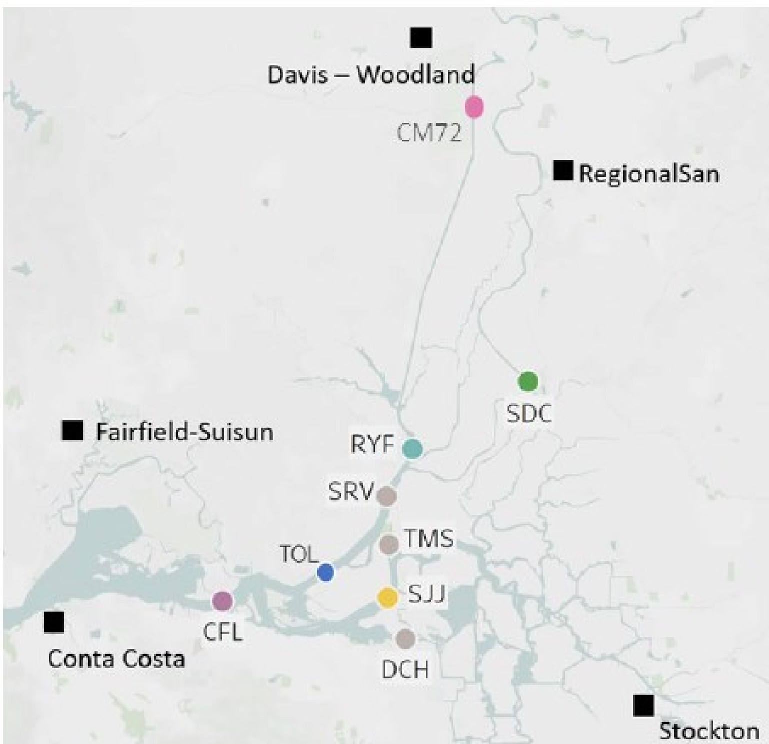

Figure 41 Continuous Monitoring Stations - with nitrate and chlorophyll fluorescence – for September 2021. Sacramento River below Toland (TOL) replaced the Decker Island station (decommissioned in April 2021). Report also includes station data collected at Walnut Grove (SDC), Cache Slough (RYF), Jersey Point (SJJ), Confluence (CFL, Sacramento Deep Water Shipping Channel Marker 72 (CM72). Flow stations used to estimate flux at CFL include SJJ, Rio Vista (SRV), Three Mile Slough (TMS), and Dutch Slough (DCH). TOL does not yet have a discharge rating – for the purpose of this report, the SRV discharge is used to estimate flux at TOL. Black boxes indicate wastewater-derived nitrogen input. Source: Brian Bergamaschi, USGS.

Due to the isolation of its relatively productive uppermost reach and lack of net outflow, the ship channel did not function as a net exporter of chlorophyll during 2020, 2021, or 2022. On the contrary, the net chlorophyll flux in the no-exchange zone during the third and fourth quarters of both water years may have been slightly negative (landward). By comparison, the net chlorophyll flux from the Cache Slough complex during those same periods was slightly positive. The average chlorophyll flux conveyed into the North Delta by the Sacramento River at Walnut Grove during July-September of 2022 was approximately 4.4 metric tons, the equivalent of 180 tons of phytoplankton carbon. This value is slightly greater than the net negative chlorophyll flux at the confluence (~ -2.7 metric tons) indicating a sink of phytoplankton biomass in the confluence area.

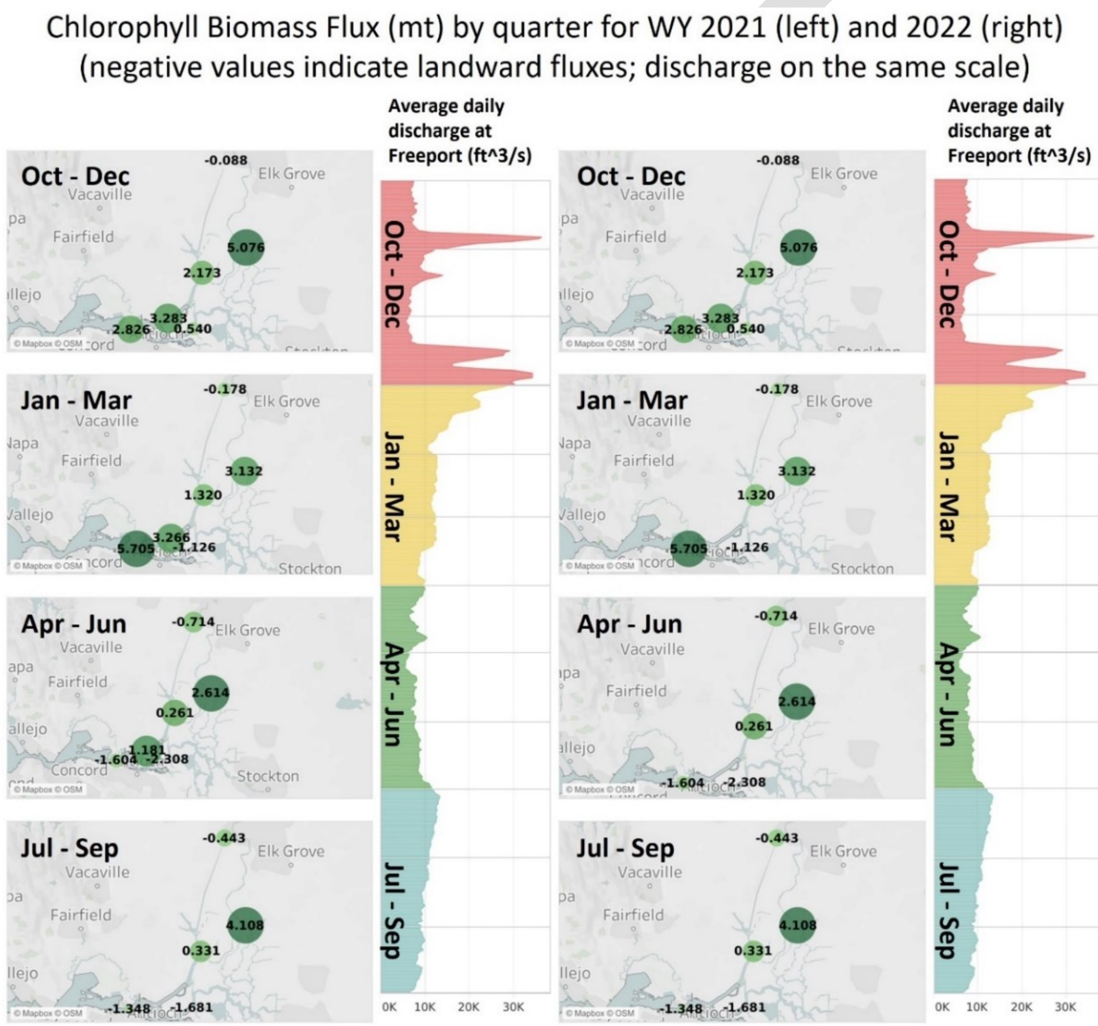

Figure 42 Comparison of seasonal chlorophyll flux at USGS continuous monitoring stations in the Sacramento-San Joaquin Delta. Fluxes are expressed in metric tons of chlorophyll a per quarter (value within circle) with negative numbers signifying landward fluxes (stations are: CM72, SDC, RYF, TOL, SJJ, and CFL [see Figure 41]). Multiplying chlorophyll by 41 yields an estimate of phytoplankton carbon (Source: Brian Bergamaschi, USGS). Data are provisional.

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Roaring River Distribution System and Other Suisun Marsh Food Subsidy Studies

The RRDS Study would use the existing infrastructure on Grizzly Island to drain water that may be food-rich from the Roaring River canal into Grizzly Bay under the hypothesis this will augment delta smelt food supplies in that area. This management action may attract delta smelt into the shallows of Grizzly Bay in greater numbers, reducing use of the deeper, less food-rich Suisun Bay habitats (CNRA 2016). Modified operations for the study will require extensive coordination with private landowners as the majority of managed wetlands are private property. Infrastructure repairs may also be needed. Due to these constraints, RRDS was not implemented in 2022, feasibility assessments have been postponed, and the action will not be considered for implementation likely within the terms of 2019 BiOp and 2020 ITP. However, a new focused study investigating if and how managed wetlands in Suisun Marsh may increase plankton production and food availability as a prospective delta smelt SFHA action was supported by the DCG and began in late 2022. The Suisun Marsh managed wetland study will compare phytoplankton and zooplankton production, and identify drivers of production in wetlands across seasons and across the landscape. The study will observe three wetland types (tidally restored, muted tidal, and managed) over the next two water years to understand how different management schemes may affect the ability to locally augment pelagic food production.

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Modeling

SCHISM-Based Habitat Suitability Model

DWR has developed a model to assess the area of habitat with appropriate salinity, water temperature, and turbidity for delta smelt using the Bay-Delta SCHISM model, which is based on the Semi-Implicit Cross-scale Hydroscience Integrated System Model (SCHISM) (Zhang et al. 2016). Prior SCHISM modeling for the Incidental Take Permit produced two metrics of delta smelt habitat area. First, the spatial area of habitat below 6 ppt. Second, the area below 6 ppt that also has a Secchi disk depth of 0.5 m or less (higher turbidity) and water temperature of 25°C or lower. In the modeling, salinity and water temperature were produced by the model and turbidity was interpolated from continuous sondes. Following improvements in the continuous turbidity monitoring network close to Suisun Bay and Marsh, modelers have translated the current index from Secchi depth to turbidity (using a 12 NTU threshold) to take advantage of better temporal resolution, which has been the accuracy limiter in prior work.

For 2022, Bay-Delta SCHISM 3D forecast simulations were performed by DWR and Reclamation to predict potential habitat availability in the marsh over the summer-fall period for different management actions. The simulations were performed to support the DCG's 2022 SFHA work. The methodology and results from the analyses are detailed in the 2022 SFHA action plan and only summarized herein. Habitat suitability was quantified using the habitat suitability index (HSI) developed by Bever et al. (2016) and modified by RMA (2021a,b) and DWR/Reclamation for the forecasts (see 2022 SFHA plan). Spatiotemporal averages of HSI's were predicted for the subregions in Figure 43. Averaging was performed vertically and horizontally in space, and on a monthly basis from July to September. Since 2022 was a no-action year, no hindcast simulations were performed.

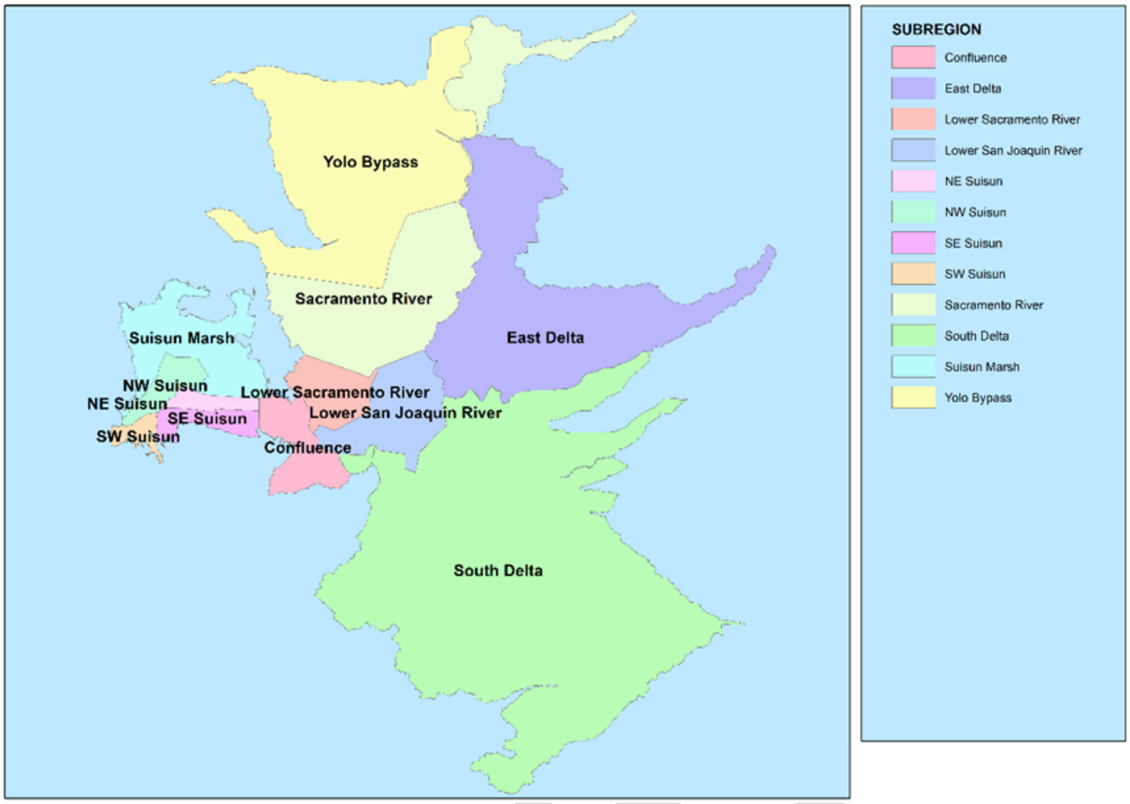

Figure 43. Habitat Suitability Index (HSI) subregions

Prior to performing the forecasts, we verified our adapted Bever et al./RMA methodology by comparing its *HSI* predictions for 2020 with *HSI*'s determined with the conventional Bever et al. (2016)/RMA (2020) methodology that does not rely on historical quantiles (Figure 44). The comparison is done for the period between 08/01/2020 and 08/14/2020 for the area in and around Suisun Bay/Marsh. The quantile-based approach predicts a similar trend in habitat suitability, with high HSI values in Montezuma Slough, from Belden's Landing to the SM control gates. HSI values in Grizzly Bay are also similar, between 0.3 and 0.4, indicative of ideal low flow velocities yet somewhat high salinity. The lowest HSI values (<0.3) are found primarily in areas along the main channel stem with high flow velocities and high salinity. A similar range in HSI (0.5-0.8) is also observed in Honker Bay for both approaches, where there is a good range of low flow velocities and near-threshold salinities. The largest difference in HSI is to the west of the confluence of the Sacramento and San Joaquin rivers, with quantile-based HSI values between 0.6 and 0.8, and conventional-based HSI values between 0.3 and 0.6. The sensitivity of the HSI to the approach used in this region suggests a variability in turbidity about the suitability threshold from year to year that markedly affects predictions (at least for the period examined; further analyses are needed to investigate further).

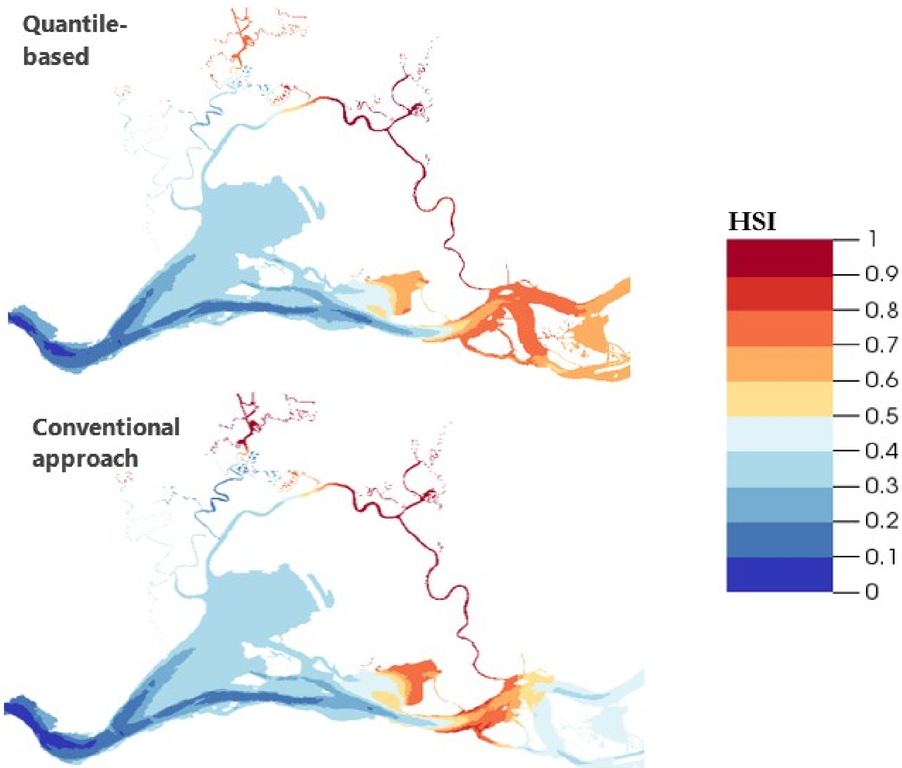

Figure 44. HSI predicted with our quantile-based approach (top) and conventional approach (bottom)

Typical relative suitabilities (on a scale of 0-1) of each of the four factors in the adapted Bever et al./RMA approach are presented in Figure 45. The salinity and current speed suitabilities are the *S* and *V* indices computed in Equation 1, while the turbidity and temperature suitabilities are the fraction of time they do not exceed 12 NTU and 24 ºC, respectively. For turbidity, this is the same as the fraction of time HSI is calculated without a penalty for low turbidity. Temperature is generally suitable most of the time, although, as noted in last year's report, there may be short critical periods where the threshold is exceeded. Current speed is most suitable in the Grizzly and Honker bays, and in Montezuma Slough.

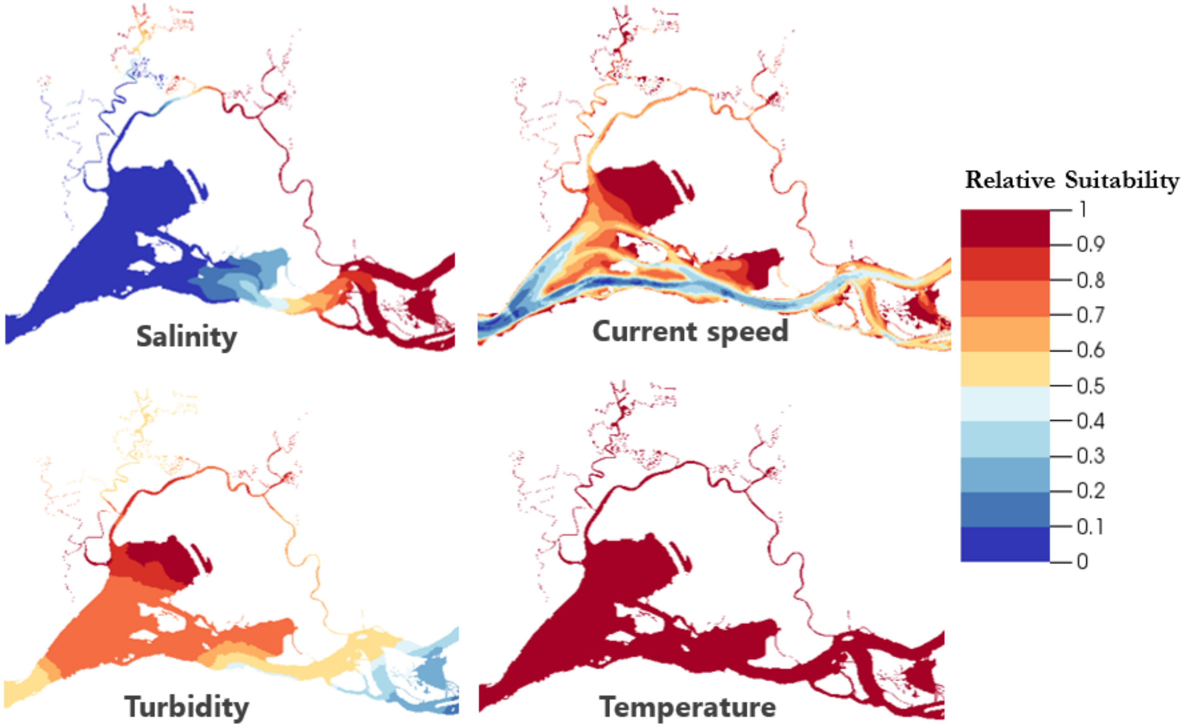

Figure 45. Relative suitability of the four factors used to verify the adapted HSI approach

Examples of temperature and turbidity quantiles are presented in Figure 46 and 47 for August and September for Suisun Marsh/Bay. The quantiles shown are monthly averages of the quantiles used in the forecast runs. Both turbidity and temperature reduce as the months progress from summer to fall. For a majority of the time, they are suitable in the bay and marsh. By using the quantile approach to predict HSI, we largely account for the fraction of time that these factors are suitable and not suitable. In other words, on a given day, we consider the probability that habitat is suitable based on past observations. This, in part, addresses one of the previous challenges encountered with the use of hard thresholds for quantifying habitat suitability, where uncertainties arise when prevalent temperatures and turbidities hover around their respective thresholds (see 2021 Summer Fall Habitat report). Since in the hard threshold approach, a 0 or 1 approach is used (i.e. habitat is either suitable or not), when a factor hovers around the threshold, the accuracy of suitability classification is questionable given uncertainties in both model predictions and observations as well as the thresholds themselves.

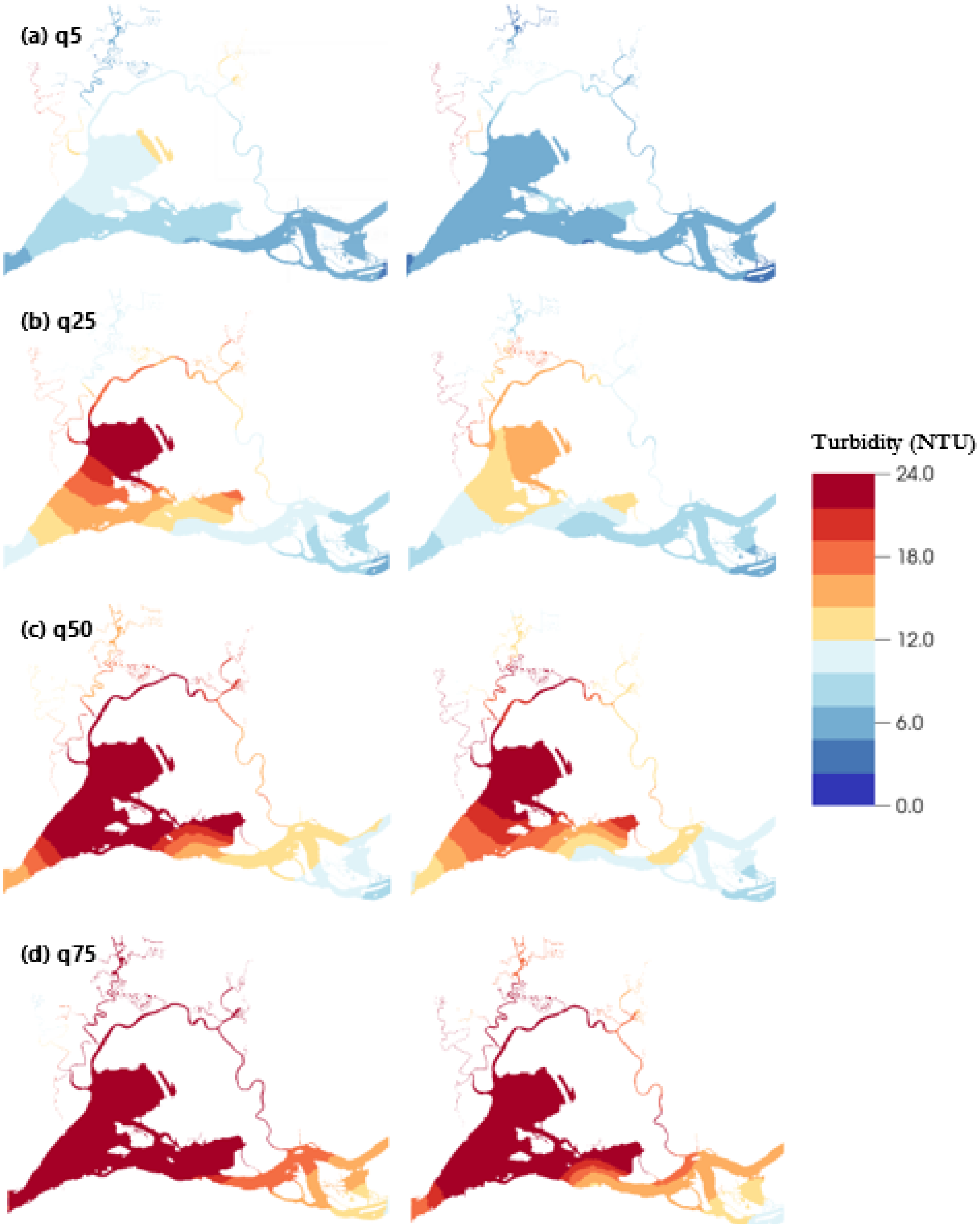

Figure 46. Sample monthly averaged turbidity quantiles (5th, 25th, 50th, 75th) for August (left) and September (right)

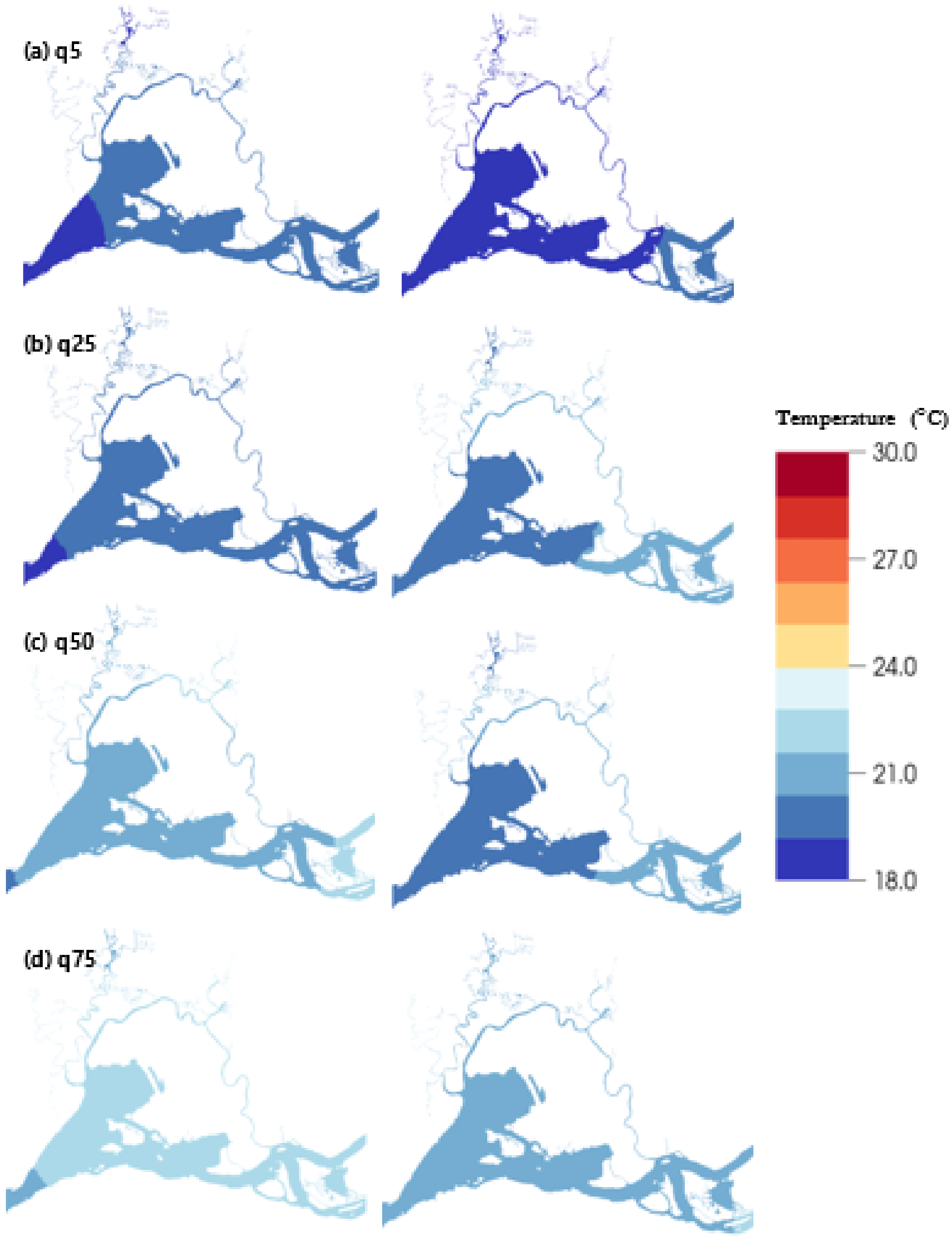

Figure 47. Sample monthly averaged temperature quantiles (5th, 25th, 50th, 75th) for August (left) and September (right)

The forecasted monthly spatial averaged HSI's in the subregions are reported in the 2022 SFHA plan for eight scenarios: a no action scenario and seven management actions covering various SMSCG and NDFS actions. Overall habitat suitability for delta smelt had the largest change in the Suisun Marsh region compared to other regions in the estuary in a BN year. Operations of SMSCG increased HSI, particularly in August and September. The salinity trigger of 4 ppt had greater benefit for smelt habitat than the 6 ppt trigger. NDFS alternatives had no effect on HSI.

Modeling for SMSCG showed salinity at Belden's Landing reached 4 ppt in mid-June for the Dry year no-action alternative and mid-July for the Below Normal year no-action alternative. Operating the gates with a 4 ppt trigger resulted in salinity at Belden's fluctuating above and below 4 ppt for the duration. Operating the gates with a 6 ppt trigger made it difficult to decrease salinity in the Marsh below 4 ppt with the modeled timing. Future modeling may need to assess other alternative gate operation schedules.

In 2022 an emergency drought barrier was installed upstream in False River, similar to 2021 and several previous drought years. Modeling conducted in 2021 suggests the physical effect of the emergency drought barrier on LSZ habitat is detectable but small, resulting in a change in mean salinity during the period August 15-28, 2021 given equal hydrology and some changes in habitat acreage due to salinity and temperature.

Rose et al. (2013) bioenergetics model

The DCG chose to use predictions of delta smelt growth rate as one of several performance metrics in its SDM process for summer-fall habitat actions (SFHA). The current performance metric compares predictions of delta smelt growth rates to average growth rates observed during the summer-fall of 1999-2005. The tool used to predict growth is a modified version of the bioenergetics model (BEM) presented by Rose et al. (2013). For the DCG, the BEM was used to index the suitability of aquatic habitat to support successful delta smelt foraging (BEM-based HSI; Smith and Nobriga *in review*). The BEM-based HSI was used to predict the cumulative growth of delta smelt, assuming occupancy of a given region of the estuary and a set of physical habitat conditions and prey densities unique to each region.

Regional conditions driving the expected growth of delta smelt were water temperature, turbidity, and prey density. The growth predicted from the BEM-based HSI (growth potential) resulting from different SFHA were compared to an average rate of growth and the growth expected if no action were taken. The average growth was defined externally by fitting a von Bertalanffy growth model to size at age of wild delta smelt. If BEM-predicted growth was lower than average growth, regional conditions were considered insufficient to support robust delta smelt growth. The difference between BEM-based growth, given no change to water temperature, turbidity, and prey density (no action) and given SFHA effects, represented the expected benefit of the action.

Starting with a July 1 assumed length of 30 mm FL, all combinations of conditions explored (region x year type x scenario) could produce at least an average growth rate by the end of October (Table *7*). With no simulated action, the difference between the most energetically favorable region (Marsh) and the least energetically favorable region (Lower Sacramento) was 3.4 mm of potential growth in a dry year and 3.6 mm of potential growth in a below normal year.

The incremental benefit of each scenario (action – no action) was much smaller than the regional differences, ranging from zero to 0.43 mm (Table 8). Predicted growth was highest in Suisun Marsh, with the SMSCG action triggered at 4ppt.

Decomposition of the predicted foraging limitations into the three component effects due to temperature, turbidity, and day length demonstrated that the greatest predicted limitation resulted from low turbidity. Though turbidity declined over the time period analyzed, its effect was less in the fall than the summer because the model assumed that fish became less sensitive to turbidity during the same time period as they grew from 30 to 45 mm FL.

Table 7. Bioenergetics model (BEM)-predicted and reference (external von Bertalanffy growth model) lengths at the end of October, assuming a July 1 length of 30 mm TL.

Region	Year Type	BEM-based (No action)	Reference
Yolo	Below Normal	56.42	58.91
Lower Sac	Below Normal	56.05	58.91
Confluence	Below Normal	56.73	58.91
Marsh	Below Normal	59.20	58.91
Yolo	Dry	56.16	58.91
Lower Sac	Dry	55.80	58.91
Confluence	Dry	56.41	58.91
Marsh	Dry	58.81	58.91

Table 8. Growth increment (performance measure) for each region-year type-scenario combination. Growth increment was the difference between BEM-predicted growth with simulated action minus predicted growth with no action (Table 7).

Region	Year Type	AgLong-Low	AgShort-High	Sac Ag	SacLong-Low	SacShort-High	SMSCG-4ppt	SMSCG-6ppt
Yolo	Below Normal	0.26	0.20	0.58	0.32	0.21	0	0
Lower Sac	Below Normal	0.04	0.04	0.06	0.04	0.04	0	0
Confluence	Below Normal	0	0	0	0	0	0	0
Marsh	Below Normal	0	0	0	0	0	0.41	0.31
Yolo	Dry	0.37	0.30	N/A	N/A	N/A	N/A	N/A
Lower Sac	Dry	0.06	0.06	N/A	N/A	N/A	N/A	N/A
Confluence	Dry	0	0	N/A	N/A	N/A	N/A	N/A
Marsh	Dry	0	0	N/A	N/A	N/A	N/A	N/A

Conclusions

Abiotic Limiting Factors

Based on abiotic habitat attributes alone, delta smelt distribution in Suisun Marsh was likely limited in Summer-Fall of 2021 due to encroachment of high salinity (> 6 ppt) water over time, while delta smelt's presence within the freshwater reaches of the Delta may have been limited by low turbidity and high-water temperatures (Figure 21).

The overall abiotic habitat conditions in summer and fall of 2022 for delta smelt were similar to what can be expected based on a critically dry, non-action year (i.e., stressful throughout much of the species' typical range). Outflow and X2 in summer and fall of 2022 fell within the range of other critically dry years from the past two decades (Figure 6). Based on outflow and X2 calculations for summer and fall of 2022, salinity levels within the Suisun Marsh and Suisun Bay were comparable to previous critically dry years (Figure 4 and 5). Salinity at Belden's Landing and within the western portion of Montezuma Slough was likely_to contribute to constraining the western distribution of Delta smelt for large parts of the season. Salinity at the BDL station largely stayed above 6 ppt starting in June. Brief periods of low turbidity were also observed at the BDL station (Figure 19); this combination of factors likely imposed additional stress for any delta smelt in this area.

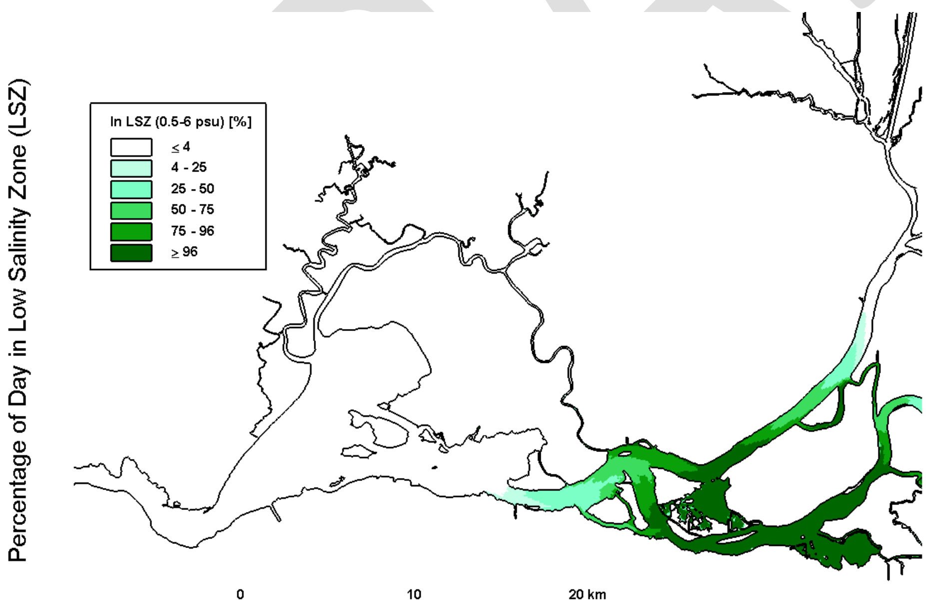

Figure 48 Percentage of Day in the low salinity zone when X2 is located at 89km (Delta Modeling Associates 2014)

Delta smelt low salinity habitat in late summer and fall 2021 was most likely similar to Figure 48, above.

The San Francisco Bay-Delta system has seen a long-term reduction in turbidity over the past several decades (Schoellhamer et al. 2011, Hestir et al. 2013, Bever et al. 2018); however, some regional differences persist. Within the range of delta smelt, the Suisun region and the North Delta have generally seen the highest turbidity, along with the general area of low salinity zone where X2 is located. Turbidity in 2022 appeared to be similar to other dry years where the Lower Sacramento River and upstream sites remained less turbid than shallower downstream areas. The SDWSC had highly variable turbidity. Summer and fall water temperature in 2022 were generally under the 23.9°C threshold, but daily mean temperatures exceeded 23.9°C multiple times at several locations ranging from 1-38 days throughout the historical range of delta smelt (Table 1), which may have been detrimental to delta smelt population.

Biotic Limiting Factors

Previous studies have shown the factors that lead to decline of delta smelt are multifaceted and often operate simultaneously. As such, it is difficult to determine the limiting biotic factors that drive delta smelt abundance and distribution in any year and 2022 was no exception, especially given that the majority of biotic data remain unavailable at the time of this report's publication. Based on the available data so far, phytoplankton and zooplankton productivity were similar to other dry years in the past two decades. There was a large, concentrated harmful algal bloom in the central/south Delta in July of 2022, but toxicity was relatively low, and the bloom did not extend into the primary Delta smelt habitat areas in the North Delta or Suisun Marsh/Suisun Bay (USGS data: https://tableau.usgs.gov/views/SFBD_Data_Portal/Mapping2018and2020). However, the effects of long-term biotic changes to the system that are believed to be detrimental to delta smelt (e.g., reduction of food due to invasive clams, shifts in the zooplankton community) have continued to persist and are therefore likely chronic stressors.

The extent to which delta smelt abundance and distribution was driven by biotic habitat factors in WY2022 is still not clear, as the majority of biotic data remain unavailable at the time of this report's publication. However, we note that chlorophyll levels remain much lower than historic (pre-1986) levels throughout both the Delta and Suisun, with the highest chlorophyll in areas of lower flow (Sacramento Deep Water Ship Channel) and greater hydrodynamic complexity (Suisun Marsh), such Figure 34). Cyanobacteria blooms have been increasing in the Delta over the past 20 years, and 2022 both high incidences of *Microcystis* in visual assessments, especially in the Lower Sacramento (Figure 9), though this was lower than in 2020 or 2021. *Microcystis* thrives in high water temperatures, high nutrient, and low flows (Lehman et al. 2018), and the combination of high temperatures and harmful algae may have been detrimental to smelt.

The data from 2021 and other previous years indicate that food for delta smelt, particularly the calanoid copepod *Pseudodiaptomus*, is highest in Suisun Marsh during higher outflow years (Figure 23). Few *Pseudodiaptomus* were found in Suisun Marsh during 2020, probably due to lower transport and of these freshwater taxa from upstream and mortality from clams (Kimmerer et al. 2018). However, the response of delta smelt to encroaching salinity is to retract their distribution to the east, which on average is expected to keep them associated with their typical low-salinity prey taxa. However, warm, relatively clear water in the legal Delta can hinder delta smelt's ability to forage effectively (Tables 9-10). Clam biomass tended to be lower within the small sloughs of Suisun Marsh (Figure 28) suggesting lower grazing rates, supporting this as a region of beneficial food production in the future.

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Management Summary

We were unable to attain the goals for the summer-fall actions due to critically dry conditions and lack of action implementation. The average outflow and the location of X2 during WY 2022 was similar to other critically dry years as defined by the Sacramento Valley Hydrologic Classification (as per D-1641). Delta smelt abundance was likely lower the last few years. It is likely that salinity was a limiting factor in Suisun Marsh and Suisun Bay for Delta smelt for the majority of the 2022 Summer-Fall period (>6 ppt), precluding the species from access the majority of the habitat. Abiotic habitat was available in the Sacramento River and north delta, but productivity (as measured by chlorophyll) in these regions was very low, temperatures occasionally exceeded delta smelt's thermal limits, and harmful algal blooms were widespread.

References

Acuña S, Baxa D, Teh S. 2012. Sublethal dietary effects of microcystin producing Microcystis on threadfin shad, Dorosoma petenense. Toxicon. 60:1191-1202.

Bennett, W.A., 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science, 3(2).

Bever, A. J., MacWilliams, M. L., Herbold, B., Brown, L. R., & Feyrer, F. V. 2016. Linking Hydrodynamic Complexity to Delta smelt (Hypomesus transpacificus) Distribution in the San Francisco Estuary, USA. San Francisco Estuary and Watershed Science, 14(1). https://doi.org/10.15447/sfews.2016v14iss1art3

Bever, A. J., MacWilliams, M. L., & Fullerton, D. K. 2018. Influence of an Observed Decadal Decline in Wind Speed on Turbidity in the San Francisco Estuary. Estuaries and Coasts, 41(7), 1943–1967. https://doi.org/10.1007/s12237-018-0403-x

Bollens, S. M., et al. 2011. "Mesozooplankton of the lower San Francisco Estuary: spatio-temporal patterns, ENSO effects and the prevalence of non-indigenous species." Journal of Plankton Research 33(9): 1358-1377.

Brown LR, Baxter R, Castillo G, Conrad L, Culberson S, Erickson G, Feyrer F, Fong S, Gehrts K, Grimaldo L, et al. 2014. Synthesis of studies in the fall low-salinity zone of the San Francisco Estuary, September-December 2011. http://pubs.er.usgs.gov/publication/sir20145041.

Brown, L.R., Kimmerer, W., Conrad, J.L., Lesmeister, S. and Mueller–Solger, A., 2016. Food webs of the Delta, Suisun Bay, and Suisun Marsh: an update on current understanding and possibilities for management. San Francisco Estuary and Watershed Science, 14(3).

Brown, L.R., Komoroske, L.M., Wagner, R.W., Morgan-King, T., May, J.T., Connon, R.E. and Fangue, N.A., 2016. Coupled downscaled climate models and ecophysiological metrics forecast habitat compression for an endangered estuarine fish. PloS one, 11(1), p.e0146724.

California Natural Resources Agency (CNRA). 2016. Delta smelt Resiliency Strategy. California Natural Resources Agency, Sacramento, CA. http://resources.ca.gov/delta-smelt-resiliency-strategy/

City of West Sacramento 2020. Stone Lock Water Quality and Ecosystem Enhancement Project. Alternatives Analysis Technical Memorandum. Prepared by Jacobs for the City of West Sacramento, February 28, 2020. 81 pp.

Davis, B., Adams, J., Bedwell, M., Bever, A., Bosworth, D., Flynn, T., Frantzich, J., Hartman, R., Jenkins, J., Kwan, K., MacWilliams, M., Maguire, A., Perry, S., Pien, C., Treleaven, T., Wright, H., Twardochleb, L. 2022. North Delta Food Subsidy Synthesis: Evaluating Flow Pulses from 2011-2019. Department of Water Resources, Division of Integrated Science and Engineering. Draft.

Davis, B.E., Cocherell, D.E., Sommer, T., Baxter, R.D., Hung, T.C., Todgham, A.E. and Fangue, N.A., 2019. Sensitivities of an endemic, endangered California smelt and two non-native fishes to serial increases in temperature and salinity: implications for shifting community structure with climate change. Conservation physiology, 7(1), p.coy076.

Davis B.E., Adams J. B., Lewis L.S., Hobbs J.A., Ikemiyagi, N., Johnston C., Mitchell L., Shakya A., Schreier B.M., Mahardja B. 2022. Wakasagi in the San Francisco Bay Delta Watershed: Comparative trends in distribution and life-history traits with native Delta smelt. San Francisco Estuary and Watershed Science, 20(3).

Delta Modeling Associates, 2014. Low Salinity Zone Flip Book, Version 2.0, December 31, 2014.

Department of Water Resources, June 5, 2020, Memorandum: DWR YSI Turbidity Sensor Measurement Units (DWR Memorandum)

Dugdale, R. C., Wilkerson, F. P., Hogue, V. E., & Marchi, A. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science, 73(1–2), 17–29. https://doi.org/10.1016/j.ecss.2006.12.008

FLOAT-MAST (Flow Alteration - Management, Analysis, and Synthesis Team). 2019. Synthesis of data and studies relating to Delta smelt biology in the San Francisco Estuary, emphasizing water year 2017. IEP Technical Report Draft. Interagency Ecological Program, Sacramento, CA

FLOAT-MAST (Flow Alteration - Management, Analysis, and Synthesis Team). 2021. Synthesis of data and studies relating to Delta Smelt biology in the San Francisco Estuary, emphasizing water year 2017. IEP Technical Report 95. Interagency Ecological Program, Sacramento, CA

Ferrari MCO, Ranåker L, Weinersmith KL, Young MJ, Sih A, Conrad JL. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. Environ Biol Fishes. 97(1):79–90. doi:10.1007/s10641-013-0125-7.

Feyrer, F., Herbold, B., Matern, S.A. and Moyle, P.B. 2003. Dietary shifts in a stressed fish assemblage: consequences of a bivalve invasion in the San Francisco Estuary. Environmental Biology of Fishes, 67(3), pp.277-288.

Feyrer, F., Nobriga, M. L., & Sommer, T. R. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences, 64, 723–734. https://doi.org/10.1139/F07-048

Feyrer, F., Newman, K., Nobriga, M., & Sommer, T. 2011. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries and Coasts, 34(1), 120–128. https://doi.org/10.1007/s12237-010-9343-9

Frantzich J, Sommer T, Schreier B. 2018. Physical and Biological Responses to Flow in a Tidal Freshwater Slough Complex. San Francisco Estuary and Watershed Science, 16(1).

Frantzich et al. 2019. Investigation Yolo Bypass as a Fall Food Web Subsidy for the Delta. CDFW Contract Agreement Report (no. D168300100). Department of Water Resources.

Frantzich J, Davis BE, MacWilliams M, Bever A, Sommer T. 2021. Use of a Managed Flow Pulse as Food Web Support for Estuarine Habitat. San Francisco Estuary and Watershed Science. 19(3):art3. https://doi.org/10.15447/sfews.2021v19iss3art3.

Ger KA, Otten TG, DuMais R, Ignoffo T, Kimmerer W. 2018. In situ ingestion of Microcystis is negatively related to copepod abundance in the upper San Francisco Estuary. Limnology and Oceanography. 63(6):2394-2410.doi:https://doi.org/10.1002/lno.10946.

Hasenbein, M., Fangue, N.A., Geist, J., Komoroske, L.M., Truong, J., McPherson, R. and Connon, R.E. 2016. Assessments at multiple levels of biological organization allow for an integrative determination of physiological tolerances to turbidity in an endangered fish species. Conservation Physiology, 4(1).

Hammock, B.G., Hobbs, J.A., Slater, S.B., Acuña, S. and Teh, S.J. 2015. Contaminant and food limitation stress in an endangered estuarine fish. Science of the Total Environment, 532, pp.316-326.

Hammock, B. G., S. B. Slater, R. D. Baxter, N. A. Fangue, D. Cocherell, A. Hennessy, T. Kurobe, C. Y. Tai, and S. J. Teh. 2017. Foraging and metabolic consequences of semi-anadromy for an endangered estuarine fish. Plos ONE 12(3):e0173497. 10.1371/journal.pone.0173497

Hammock BG, Hartman R, Slater SB, Hennessy A, Teh SJ. 2019. Tidal Wetlands Associated with Foraging Success of Delta smelt. Estuaries and Coasts. https://doi.org/10.1007/s12237-019-00521-5.

Hestir, E.L., D.H. Schoellhamer, T. Morgan-King, S.L. Ustin. 2013. A step decrease in sediment concentration in a highly modified tidal river delta following the 1983 El Niño floods. Marine Geology 345:304–313.

Interagency Ecological Program (IEP), M. Martinez, J. Rinde, T.M. Flynn, and S. Lesmeister. 2020a. Interagency Ecological Program: Discrete water quality monitoring in the Sacramento-San Joaquin Bay-Delta, collected by the Environmental Monitoring Program, 1975-2019. ver 3. Environmental Data Initiative. https://doi.org/10.6073/pasta/dc1fd386c098c6b71132150eee7ee86c (Accessed 2020-10-29).

Hobbs, J.A., Lewis, L.S., Willmes, M., Denney, C. and Bush, E., 2019. Complex life histories discovered in a critically endangered fish. Scientific Reports, 9(1), pp.1-12.

Interagency Ecological Program (IEP), R. McKenzie, J. Speegle, A. Nanninga, J.R. Cook, J. Hagen, and B. Mahardja. 2020b. Interagency Ecological Program: Over four decades of juvenile fish monitoring data from the San Francisco Estuary, collected by the Delta Juvenile Fish Monitoring Program, 1976-2019 ver 4. Environmental Data Initiative. https://doi.org/10.6073/pasta/41b9eebed270c0463b41c5795537ca7c (Accessed 2020-11-06).

IEP MAST. 2015. Interagency Ecological Program Management Analysis and Synthesis Team. An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish. Technical Report 90; January 2015. 206pp.

Jungbluth M, Lee C, Patel C, Ignoffo T, Bergamaschi B, Kimmerer W. 2021. Production of the Copepod Pseudodiaptomus forbesi Is Not Enhanced by Ingestion of the Diatom Aulacoseira granulata During a Bloom. Estuaries and Coasts. 44(4):1083–1099. doi:10.1007/s12237-020-00843-9.

Kimmerer, W., 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science, 2(1).

Kimmerer, W. J. and J. K. Thompson 2014. "Phytoplankton Growth Balanced by Clam and Zooplankton Grazing and Net Transport into the Low-Salinity Zone of the San Francisco Estuary." Estuaries and Coasts 37(5): 1202-1218.

Kimmerer WJ, Ignoffo TR, Kayfetz KR, Slaughter AM. 2018. Effects of freshwater flow and phytoplankton biomass on growth, reproduction, and spatial subsidies of the estuarine copepod Pseudodiaptomus forbesi. Hydrobiologia. 807(1):113-130. https://doi.org/10.1007/s10750-017-3385-y.

Komoroske, L.M., R.E. Connon, J. Lindberg, B.S. Cheng, G. Castillo, M. Hasenbein, N.A. Fangue. 2014. Ontogeny influences sensitivity to climate change stressors in an endangered fish. Conservation Physiology 2: doi:10.1093/conphys/cou008.

Komoroske, L. M., Jeffries, K. M., Connon, R. E., Dexter, J., Hasenbein, M., Verhille, C., & Fangue, N. A. (2016). Sublethal salinity stress contributes to habitat limitation in an endangered estuarine fish. Evolutionary Applications, 9(8), 963–981. https://doi.org/10.1111/eva.12385

Kurobe T, Lehman P W, Haque Md E I, Tiziana S, Lesmeister S, Teh S. 2018. Evaluation of water quality during successive severe drought years within Microcystis blooms using fish embryo toxicity tests for the San Francisco Estuary. Science of the Total Environment 610-611: 1029-1037.

Lehman PW, Boyer G, Satchwell M, Waller S. 2008. The influence of environmental conditions on the seasonal variation of Microcystis cell density and microcystins concentration in San Francisco Estuary. Hydrobiologia. 600(1):187-204 doi:10.1007/s10750-007-9231-x.

Lehman, P. W., Kurobe, T., Lesmeister, S., Baxa, D, Tung, A.., Teh, S. J. 2017. Impacts of the 2014 severe drought on the Microcystis bloom in San Francisco Estuary. Harmful Algae 63:94-108.

Lehman P, Teh S, Boyer G, Nobriga M, Bass E, Hogle C. 2010. Initial impacts of Microcystis aeruginosa blooms on the aquatic food web in the San Francisco Estuary. Hydrobiologia. 637(1):229-248.

Lehman, P.W., Kurobe, T., Lesmeister, S., Lam, C., Tung, A., Xiong, M. and Teh, S.J., 2018. Strong differences characterize Microcystis blooms between successive severe drought years in the San Francisco Estuary, California, USA. Aquatic Microbial Ecology, 81(3), pp.293-299.

Lenoch, L. E. K., Stumpner, P. R., Burau, J. R., Loken, L. C., & Sadro, S. 2021. Dispersion and Stratification Dynamics in the Upper Sacramento Deep Water Ship Channel. San Francisco Estuary and Watershed Science.

Mac Nally R, Thomson J, Kimmerer W, Feyrer F, Newman K, Sih A, Bennett W, Brown L, Fleishman E, Culberson S, Castillo G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modelling (MAR). Ecol Appl 20(5):1417–1430. doi: http://dx.doi.org/10.1890/09-1724.1

Mahardja B, Young MJ, Schreier B, Sommer T. 2017a. Understanding imperfect detection in a San Francisco Estuary long-term larval and juvenile fish monitoring program. Fisheries Manag Ecol 24:488–503. https://doi.org/10.1111/fme.12257

Mahardja B, Farruggia MJ, Schreier B, Sommer T. 2017b. Evidence of a shift in the littoral fish community of the Sacramento–San Joaquin Delta. PLoS One; 12(1):e0170683.

https://doi.org/10.1371/journal.pone.0170683

Merz JE, Hamilton S, Bergman PS, Cavallo B. 2011. Spatial perspective for delta smelt: a summary of contemporary survey data. California Fish & Game. 97(4):164-189.

Morgan-King and Schoellhamer 2013. DOI: 10.1007/s12237-012-9574-z

Moyle, P.B., Brown, L.R., Durand, J.R. and Hobbs, J.A., 2016. Delta smelt: life history and decline of a once-abundant species in the San Francisco Estuary. San Francisco Estuary and Watershed Science, 14(2).

Nichols FH, Thompson JK, Schemel LE. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam Potamocorbula amurensis 2. Displacement of a former community. Mar Ecol Prog Ser 66(1–2):95–101. doi: http://dx.doi.org/10.3354/meps066095

Nobriga, M.L., Feyrer, F., Baxter, R.D. and Chotkowski, M., 2005. Fish community ecology in an altered river delta: spatial patterns in species composition, life history strategies, and biomass. Estuaries, 28, pp.776-785.

Nobriga, M.L., Sommer, T.R., Feyrer, Frederick, and Flem-ing, Kevin, 2008, Long-term trends in summertime habitat suitability for delta smelt, Hypomesus transpacificus: San Francisco Estuary and Watershed Science, v. 6, no. 1, http://escholarship.org/uc/item/5xd3q8tx.

Nobriga, M.L. and Smith, W.E., 2020. Did a shifting ecological baseline mask the predatory effect of Striped Bass on Delta Smelt?. San Francisco Estuary and Watershed Science, 18(1).

O'Rear, T. and P. Moyle. 2014. "Suisun Marsh Fish Study: Trends in Fish and Invertebrate Populations of Suisun Marsh January 2012–December 2012." California, California Department of Water Resources.

O'Rear, T. and P. Moyle 2017. Suisun Marsh Fish Study: Trends in Fish and Invertebrate Populations of Suisun Marsh, January 2015-December 2015. Annual Report for the California Department of Water Resources. Sacramento, California, University of California, Davis.

Polansky, L., Newman, K. B., & Mitchell, L. 2021. Improving inference for nonlinear state-space models of animal population dynamics given biased sequential life stage data. Biometrics. https://doi.org/10.1111/biom.13267

Reclamation 2021. Biological Assessment, Sacramento Deepwater Ship Channel Food Web Study Pre-Project Monitoring. 20 pp.

Regional San. 28 June 2021. New Regional San Upgrade Virtually Eliminates Ammonia in Sacramento Region’s Wastewater [Press release]. https://www.regionalsan.com/press-release/new-regional-san-upgrade-virtually-eliminates-ammonia-sacramento-regions-wastewater

Resources Assessment Branch. 2020. Water Quality Evaluation Section (WQES) Field Manual

Resources Management Associates (RMA). 2021a. Numerical Modeling in Support of Reclamation Delta smelt Summer/Fall Habitat Analysis.

Resource Management Associates (RMA). 2021b. Numerical modeling in support of Reclamation Delta smelt summer/fall habitat analysis: Calanoid copepod analysis addendum. Draft Report (May 14 2021).

Rose, K.A., Kimmerer, W.J., Edwards, K.P. and Bennett, W.A., 2013a. Individual-based modeling of Delta smelt population dynamics in the upper San Francisco Estuary: I. Model description and baseline results. Transactions of the American Fisheries Society 142:1238-1259.

Rose, K.A., Kimmerer, W.J., Edwards, K.P. and Bennett, W.A., 2013b. Individual-based modeling of Delta smelt population dynamics in the upper San Francisco Estuary: II. Alternative baselines and good versus bad years. Transactions of the American Fisheries Society 142:1260-1272.

Schoellhamer, D.H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34:885–899.

Schreier BM, Baerwald MR, Conrad JL, Schumer G, May B. 2016. Examination of Predation on Early Life Stage Delta smelt in the San Francisco Estuary Using DNA Diet Analysis. Trans Am Fish Soc. 145(4):723–733. doi:10.1080/00028487.2016.1152299.

Schultz, A. A., editor. 2019. Directed Outflow Project: Technical Report 1. U.S. Bureau of Reclamation, Bay-Delta Office, Mid-Pacific Region, Sacramento, CA

Sommer, T., and F. Mejia. 2013. A place to call home: a synthesis of delta smelt habitat in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science 11(2). Available at: http://www.escholarship.org/uc/item/32c8t244.

Sommer, T., R. Hartman, M. Koller, M. Koohafkan, J.L. Conrad, M. MacWilliams, A. Bever, C. Burdi, A. Hennessy, and M. Beakes. 2020. Evaluation of a large-scale flow manipulation to the upper San Francisco Estuary: Response of habitat conditions for an endangered native fish. PLoS ONE 15: e0234673. https://doi.org/10.1371/journal.pone.0234673

Starcevich, L. A., G. DiDonato, T. McDonald, and J. Mitchell. 2016. A GRTS user's manual for the SDrawNPS package: A graphical user interface for generalized random tessellation stratified (GRTS) sampling and estimation. Natural Resource Report NPS/PWRO/NRR—2016/1233. National Park Service, Fort Collins, Colorado.

State Water Resources Control Board. 2000. Revised Water Right Decision 1641

Stevens, D., and A. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99(465):262–278.

Suisun Marsh Preservation Agreement (SMPA). 2015. United States Bureau of Reclamation

Swanson, C., T. Reid, P.S. Young, and J.J. Cech, Jr. 2000. Comparative environmental tolerances of threatened delta smelt (Hypomesus transpacificus) and introduced wakasagi (H. nipponensis) in an altered California estuary. Oecologia 123:384–390.

Thompson, J., J. R. Koseff, S. G. Monismith and L. Lucas. 2008. "Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study." Journal of Marine Systems 74(1-2): 153-166.

Thomson, J. R., Kimmerer, W. J., Brown, L. R., Newman, K. B., Mac Nally, R., Bennett, W. A., Feyrer, F., & Fleishman, E. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications, 20(5), 1431–1448. https://doi.org/10.1890/09-0998.1

Twardochleb L., Maguire A., Dixit L., Bedwell M., Orlando J., MacWilliams M., Bever A., and B. Davis. 2021a. North Delta Food Subsidies Study: Monitoring Food Web Responses to the North Delta Flow Action, 2019 Report. Department of Water Resources, Division of Environmental Services.

Twardochleb L., Martinez, J., Bedwell, M., Frantzich, J., Sommer, T., and B. Davis. 2021b. North Delta Food Subsidies 2021-2023 Operations and Monitoring Plan. Department of Water Resources, Division of Environmental Services.

United States Fish and Wildlife Service (USFWS). 2019. Biological Opinion for the Reinitiation of Consultation of the Coordinated Operations of the Central Valley Project and State Water Project. U.S. Fish and Wildlife Service, Sacramento, California

United States Fish and Wildlife Service, T. Senegal, R. Mckenzie, J. Speegle, B. Perales, D. Bridgman, K. Erly, S. Staiger, A. Arrambide, and M. Gilbert. 2022. Interagency Ecological Program and US Fish and Wildlife Service: San Francisco Estuary Enhanced Delta Smelt Monitoring Program data, 2016-2021 ver 8. Environmental Data Initiative. https://doi.org/10.6073/pasta/e1a540c161b7be56b941df50fd7b44c5 (Accessed 2023-02-06).

United States Fish and Wildlife Service (USFWS), California Department of Water Resources, United State Bureau of Reclamation, California Department of Fish and Wildlife, and University of California Davis. 2020. Delta smelt Supplementation Strategy.

United States Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife, California Department of Water Resources, United State Bureau of Reclamation, United States Geologic Survey and University of California Davis. 2021. Delta smelt Experimental Release Study Plan, Draft 5; Sept 2021.

United States Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife, California Department of Water Resources, United State Bureau of Reclamation, United States Geologic Survey and University of California Davis. 2022. BY 2021 ERTT Summary of Activities, Draft; July 2022.

Wilkerson, F. P., Bay, F., Dugdale, R. C., Hogue, V. E., & Marchi, A. 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts, 29(3), 401–416. http://sfbay.wr.usgs.gov/access/wqdata

Zhang, Y.J., Ye, F., Stanev, E.V. and Grashorn, S., 2016. Seamless cross-scale modeling with SCHISM. Ocean Modelling, 102, pp.64-81.

Attachments

Appendix A- Abiotic and Biotic Habitat Figures

Appendix B- 2022 Summer-Fall Habitat Action Plan