Delta Smelt Summer-Fall Habitat Seasonal Report for WY 2023

Central Valley Project and State Water Project

California-Great Basin Region 10

Photo Credit: CDFW

U.S. Department of the Interior and State of California **April 2024**

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.

Delta Smelt Summer-Fall Habitat Seasonal Report for WY 2023

Central Valley Project and State Water Project

California-Great Basin Region 10

prepared by
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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Contents

List of Tables

List of Figures

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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
FNU	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
State Water Board	State Water Resources Control Board
SDM	Structured decision-making
SMSCG	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

Executive Summary

The Delta Smelt Summer Fall Habitat Action (SFHA) includes operational actions aimed to improve habitat and food for the species during the June-October time period when the population generally experiences low survival. Water year (WY) 2023 was classified as Wet, and the summer-fall Suisun Marsh Salinity Control Gates (SMSCG) and Fall X2 actions were implemented. While SMSCG operations are not required in a Wet year, they were used to implement the additional 100-thousand-acre feet (TAF) action as described in the State Water Project (SWP) Incidental Take Permit (ITP). This followed the no-action years of WY 2020, 2021 and 2022.

The primary hypotheses tested in this report are 1) decreasing X2 will maximize Delta Smelt growth and survival through increased habitat quality and increased copepod biomass in Suisun Bay, 2) operating the SMSCG will maximize Delta Smelt growth and survival through increased habitat quality and increased copepod biomass in Suisun Marsh, and 3) operation of the SMSCG will increase Delta Smelt habitat in Grizzly Bay. Habitat quality includes abiotic factors (salinity, turbidity, and temperature) and biotic factors (food availability) and habitat quantity includes the acreage of suitable low salinity habitat.

The SMSCG were operated from August 15 to October 17, 2023, during which 100 TAF of water were used to prevent salinity intrusion while the gates were being operated. Habitat conditions were measured in three key regions: Suisun Marsh, Suisun Bay, and the lower Sacramento River for the relevant abiotic and biotic factors. Suitable Delta Smelt thresholds for the abiotic factors are temperature equal to or less than 22 °C (considered optimal for smelt growth, although smelt can survive at higher temperatures and optimal temperatures may not be available at all times), salinity below 6 PSU, and turbidity equal to or greater than 12 FNU. Biotic conditions related to food availability have been preliminarily assessed for chlorophyll-α, while the zooplankton and phytoplankton data are currently pending.

After analyzing empirical data on habitat conditions, Delta Smelt survey detections, and an *in situ* enclosure experiment, we were able to support some of the SFHA hypotheses:

1. **Decreasing X2 will maximize the area of Delta Smelt habitat in Suisun Bay with appropriate temperatures, turbidity, salinity, and increased calanoid copepod biomass which will result in higher Delta Smelt growth and survival** – *Partially supported*.
    a. We found that the number of days with salinity less than 6 PSU in Suisun Bay in 2023 with an 80 km X2 action was similar to years with a 74 km X2 action (2017, 2019), though high temperatures limited total number of suitable habitat days. Area of LSZ in 2023 was similar to or lower than 2017. We did not have any non-X2 years with high flows for comparison, and cannot conclusively tie this to the action.
    b. Previous years with a 74 km X2 action (2017, 2019) had higher calanoid copepod biomass in the Marsh and Bay than drier years. In 2023 there was higher calanoid copepod biomass in the Marsh, but we did not see a similar increase in the Bay.
    c. We did not have enough Delta Smelt catch data to assess the impact of the action habitat on Delta Smelt growth and survival.

2. **Operating the SMSCG during the summer and fall will maximize the duration and area of Delta Smelt habitat in Suisun Marsh with appropriate temperatures, turbidity, salinity, and increased calanoid copepod biomass that can be accomplished with 100 TAF of water, which will result in higher Delta Smelt growth and survival** – *Partially supported.*
    a. We found that the number of days with salinities below 6 PSU in Suisun Marsh was similar to other high-flow years (2017, 2019) and the 35-day SMSCG action in 2018, though high temperatures limited total number of suitable habitat days. Area of LSZ habitat was higher than 2017. Temperatures were higher in Suisun Marsh than Rio Vista in 2023, contrary to our prediction based on temperature patterns in 2020-2022.
    b. Modeling suggests that the SMSCGs decreased salinity in the Marsh more than the X2 action would have alone.
    c. We did not have enough Delta Smelt catch data to assess the impact of better habitat on wild Delta Smelt growth and survival. Delta Smelt in enclosures had lower growth and survival at Belden's Landing than Rio Vista, contrary to our hypothesis.
    d. The biomass of calanoid copepods did not increase during the 35-day 2018 action. There was an increase in biomass during the 2023 action, which may have been due to the wet conditions and fall X2 action as well as the SMSCG action, but it is unclear.

3. **Operating the SMSCG will increase the area of appropriate Delta Smelt habitat in Grizzly Bay –** *Supported.*
    a. Modeling data suggesting a decrease in salinity of 1-2 PSU in Grizzly Bay, increasing the low salinity zone in this region.

Some of the data within this report is still being analyzed and may not yet be available for this draft of the report. However, the operation of the SMSCG and Fall X2 requirements had a meaningful impact on salinity in the Suisun Marsh and Suisun Bay. We saw an increase of several hundred acres of LSZ habitat in Suisun Bay and Marsh, and, if salinity limited access to the places that were coolest and most turbid (such as Suisun Bay), there still was an increase in the amount of suitable Delta Smelt habitat this water year associated with the SFHA operations.

Purpose

The following 2023 Seasonal Report for the Delta Smelt SFHA describes the operations of the Central Valley Project (CVP) and State Water Project (SWP) and Delta Smelt habitat conditions in water year (WY) 2023. This report may support adjustments, if necessary, to the Delta Smelt SFHA Guidance Document (Guidance Document) for WY 2024, and future operations, including Delta Smelt SFHA plans, by documenting the ecological responses that occurred during habitat actions or in some cases the absence of an action (e.g., food actions), and comparisons to previous years were appropriate. The structure of the following Seasonal Report for the Delta Smelt SFHA has been modified for WY 2023 and was approved by the Delta Coordination Group (DCG).

This document fulfills commitments under the 2020 Record of Decision (ROD) signed by the U.S. 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) 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 2023. Finally, this document may 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 2023 with inclusion of previous non-action years for comparison, when applicable.

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. Some habitat information deemed important characterizing the food web in the summer and fall (e.g., zooplankton, etc.) of 2023 will be captured throughout subsequent versions of this report until the final completion in May 2024. In addition, the majority of 2023 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.

Background

Delta Smelt Summer-Fall Habitat

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 SMSCG in the summer or fall 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 Managed Wetland Food Subsidies Study.

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 zooplankton 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 SFHA will investigate summer-fall habitat to better quantify and integrate information on how food, turbidity, salinity, water velocity, and water temperature interact to contribute to improved overall recruitment (Pg. 1, Guidance Document). Overall, the 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 hypothesis that led to the inclusion of the summer-fall habitat action in the Proposed Action, 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 PSU or less, turbidity higher than 12 FNU, and water temperatures below 22°C based on new temperature thresholds (see DCG Temperature Constructs 2023Sep28 Draft.pdf).

> *Salinity*: Delta Smelt has been described as a semi-anadromous species. The species spawns in freshwater and most individuals migrate into the low-salinity zone (0.5-6 PSU 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 indicators of Delta Smelt habitat suitability.

Temperature: 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 °C, indicating that warmer temperatures are increasingly stressful (Nobriga et al. 2008, Sommer and Mejia 2013, Komoroske et al. 2014). In this report, we use 22°C as a threshold below which Delta Smelt typically experience positive growth. Above 22°C, growth may be limited or less positive (Lewis et al. 2021) due to sublethal stress responses (Komoroske et al. 2015, Jeffries et al. 2018), behavioral changes (Davis et al. 2019), and foraging and consumption constraints (Smith and Nobriga, 2023).

Turbidity: Water clarity 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, Bever et al 2016), because it improves feeding and reduces predation (Hasenbein et al. 2016, Ferrari et al. 2014).

Biotic habitat attributes such as 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 2023). Food may contain toxins due to 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).

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

Actions taken this year:

1. Fall X2
2. 100 TAF for SMSCG operation

Actions that may be taken in future years, science/monitoring is included in this report:

1. NDFS
2. SDWSC
3. Managed Wetlands

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 2023 was a Wet year, Reclamation and DWR through the Delta Coordination Group (DCG) developed an SFHA Action Plan for the WY 2023 (Appendix C - 2023 SFHA Action Plan - Final.pdf).

As described in the 2023 Action Plan addendum, the final 2023 Sacramento Valley WY designation was Wet, and CDFW decided to implement the 100 TAF action through daily operations of the Suisun Marsh Salinity Control Gates starting August 15th or when the 3-day average salinity at Belden's Landing is 4 PSU, whichever is first, and continuing until the 100 TAF was exhausted or October 22nd, whichever came first. The three-day average salinity at Belden's Landing remained below 4 PSU until August 15th (at which point it was 3.73 PSU), so gate operations started on August 15th. DWR conducted weekly analysis of flow required to offset gate operations (see 'Implementation' section below) and concluded that 100 TAF had been exhausted on October 17th, at which point gates were held in the 'open' position until a planned maintenance closure occurred on November 7th. Tidal Operations resumed per D-1641 and the Suisun Marsh Preservation Agreement on November 27th, once the maintenance was complete.

In addition to SMSCG operations, the Wet water year designation required DWR and Reclamation to maintain X2 at 80 km for the months of September and October. This condition was not met in October of 2023 (average X2 at 80.6 km).

Objectives and Hypotheses

Hypotheses:

1. Decreasing X2 will maximize the area of Delta Smelt habitat in Suisun Bay with appropriate temperatures, turbidity, and salinity, which will result in higher Delta Smelt growth and survival.
2. Decreasing X2 will increase biomass of calanoid copepods in the low salinity zone through increased transport of freshwater species from upstream, which will result in higher Delta Smelt growth and survival.
3. Operating the SMSCG during the summer and fall will maximize the duration and area of Delta Smelt habitat in Suisun Marsh with appropriate temperatures, turbidity, and salinity that can be accomplished with 100 TAF of water, which will result in higher Delta Smelt growth and survival.
4. Operating the SMSCG during the summer and fall will increase biomass of calanoid copepods in Suisun Marsh through increased transport of freshwater species from upstream, which will result in higher Delta Smelt growth and survival.
5. Operating the SMSCG will increase the area of appropriate Delta Smelt habitat in Grizzly Bay.

To address each of these hypotheses, we will rely on three primary comparisons:

1. Inter-annual comparisons – We will compare constituents during 2023 to conditions in previous wet years with X2 actions (2017, 2019), previous years with SMSCG actions (2018) and dry years with no action (2020-2022). The actions were not implemented in the same way in each year (Table 1), and other differences between water years make these comparisons difficult, but historical years still provide useful context for this year's observations.
2. Regional comparisons – We expect X2 actions to improve conditions in Suisun Bay. We expect SMSCG actions to improve conditions in Suisun Marsh. Neither action will change conditions in the River, and the River will always be hotter and clearer (less ideal).

TABLE 1. HISTORICAL YEARS USED FOR COMPARISON TO 2023, WITH ACTIONS TAKEN IN EACH YEAR.

Year	Water Year Type	X2 Action	SMSCG Action
2017	Wet	X2 at or below 74 km for September and October	None
2018	Below Normal	None	35-day gate operation, Aug 2 – Sep 7
2019	Wet	X2 at or below 74 km for September and October	None
2020	Dry	None	SMSCG operation starting Sept. 1*
2021	Critical	None	SMSCG operation starting Sept. 1*
2022	Critical	None	SMSCG operation starting Sept. 1*
2023	Wet	X2 at or below 80 km for September and October	SMSCG operating Aug 15-Oct 17

*The Suisun Marsh Preservation Agreement requires SMSCG operation starting in September when the seven-day running average mean daily high tide salinity at any compliance station is 17.0 mS/cm or greater.

Delta Coordination Group

WY 2023 was the first year the SFHA could be implemented since the action was instated in the 2019 Biological Opinions, because the previous drought (2020-2022) precluded actions. The DCG completed several activities in 2023 including updating the Monitoring and Science Plan, a second iteration of the structured decision-making (SDM) model, and providing recommendations for the Action Plan (Appendix C). Within the Action Plan, the DCG collaboratively developed more detailed hypotheses and uncertainties for each habitat and food action. The second iteration of SDM for NDFS was focused on a Below Normal year with the following updates and improvements: 1) repeating the contaminants expert elicitation with modified performance metrics and a larger solicitation group, 2) determining how to operationalize learning as an objective in the SDM model, and 3) integration of weighting to include DCG member interests in a standardized and transparent method. Lastly, the DCG participated in a SFHA Review Workshop held by the ITP Adaptive Management Team to develop a shared vision and scope of the 4-year independent review focused on reviewing the current monitoring and science in place and providing guidance on a path the DCG may take for improvements to decision making, monitoring, and adaptive management of the SFHA.

Action Implementation

SMSCG and X2 Implementation

The SMSCG were not operated from January 5, 2023, through August 14, 2023; two out of the three gates were held open, and one was removed with a stoplog in its place for refurbishment (note that this configuration is hydraulically equivalent to having two gates operational and one closed). SMSCG operations began on August 15th to comply with the 2023 Delta Outflow Operations Plan as required under the State Water Project's Incidental Take Permit, see Table 2 below. Operations continued until modeling suggested approximately 100 TAF had been used to offset gate operations (details below), which occurred on October 17, 2022. Two out of the three gates were then held open until a planned maintenance closure occurred November 6th -21st. This operational schedule maintained the daily-average salinity at Belden's Landing below 3 PSU for the second half of August and the entirety of September, October and November, lower than previous wet years and much lower than previous dry and critically dry years (Figure 2).

To provide a visual comparison of flow conditions in 2023 versus previous years, we have graphed daily Delta Outflow and X2 positions from DWR's Dayflow model for 2017-September 30th of 2023. Dayflow is not available for water year 2024 (including October of 2023), so we instead used daily estimates of X2 and Delta Outflow from CDEC. The CDEC estimates of X2 are made by interpolating between the salinity at several discrete monitoring stations in the system, with the furthest upstream station at 81km. Therefore, this method does not provide estimates of X2 when it is greater than 81 km (Figure 1). The daily estimates from CDEC are provided here as an indicator of habitat conditions, but are not used for compliance, which is calculated on a monthly basis.

X2 in 2023 differed from the previous wet years of 2017 and 2019 as calculated by the Dayflow model (Figure 1, Figure 3). This difference is consistent with the change in the Fall X2 requirement from 74 km to 80 km with the new 2019 Biological Opinions. Published models of low salinity zone habitat area versus X2 suggest that habitat area is lower with an X2 above 81 km than below 80 (Kimmerer et al. 2013), so Figure 1 indicates lower habitat area in 2023 than 2017 and 2019, with higher habitat area in September of 2023 than October of 2023 (see Extent of Appropriate Delta Smelt habitat below, for details).

Method of Calculating X2 for Compliance Purposes

The X2 position is estimated by the Projects in the lower Sacramento River when the daily average EC is below 2.64 mS/cm at Collinsville and above 2.64 mS/cm at Martinez. The three stations identified in the State Water Resources Control Board's 2000 Revised Water Rights Decision 1641 (Collinsville, Chipps Island, and Port Chicago) as well as the station at Martinez are used to estimate the X2 location. Those stations are located at 81 km, 74 km, 64 km, and 56 km east of the Golden Gate Bridge, respectively. To calculate the X2 location, the Projects interpolate between the two stations where EC at the downstream location is above 2.64 mS/cm and EC at the upstream location is below 2.64 mS/cm. To calculate the monthly average X2 location, the Projects conduct the same interpolation on the monthly average EC for the stations that bound 2.64 mS/cm.

Note that the Projects do not need a method to calculate the daily X2 position for official compliance purposes when the daily EC at Collinsville (X2 position at 81 km) is greater than

2.64 mS/cm as long as the monthly average EC at that station is below 2.64 mS/cm. The daily estimates of X2 presented in Figure 1 are for use as a habitat indicator only and are not used for compliance.

Fall X2 operational constraints

On August 23rd, the total Feather River release was increased from 4,500 to 6,000 cfs to help support Delta water quality in preparation of operating to Fall X2 for September and October. The releases were held at 6,000 cfs until September 14, when releases were increased mid-September to 7,000 cfs and subsequently to 7,500 cfs on September 21. Beginning on September 30, release reductions were initiated for storage conservation and to meet the CDFW minimum instream flow release to be no greater than 2,500 cfs by October 15. After October 15 of each year, releases are required to remain below 2,500 cfs per the CDFW 1983 agreement. By November 1, the Feather River release was at its minimum instream flow requirement. While there were Feather River release limitations to accommodate the River Valve Outlet System rehabilitation project during the Fall X2 September-October period, this release limitation did not impact the SWP's ability to meet Fall X2 prior to reducing to meet DFW's October 15 instream flow requirement. When increased outflow was needed, the SWP reduced exports to increase outflow as described below.

During the month of August Sacramento River releases were decreased from 10,750 cfs at the beginning of the month to 8,550 by September 1 in order to start the reduction to lower flows to reduce the potential amount of fall-run Chinook salmon redd dewatering while, at the same time, minimizing winter-run Chinook salmon redd dewatering. Five different alternatives were considered with the objective of getting to base winter flows faster with less impact to both winter-run and fall-run Chinook salmon. Releases continued to decrease throughout October and reached a base flow of 5000 cfs by November 6.

Beginning September 1 releases to the American River began to decrease from the summer flow of 4,000 cfs to 3,000 cfs by the end of the month. Further decreases took place in October to get down to the base fall flow of 2,000 cfs by October 31 to avoid impacts to fall-run Chinook salmon through redd dewatering. The decreases also helped with river temperature management because power bypasses are more effective with a lower release. On October 30, a power bypass of 500 cfs began at Folsom Dam.

Project exports varied in September and October when the Biological Opinion/ITP's requirement of X2 controlled to produce an outflow that would be responsive to the changing EC conditions at Collinsville. The Projects estimated that a monthly average EC at Collinsville of around 2.3 mS/cm would result in an X2 location near 80 km. At the start of September, the Projects were in the process of increasing outflow to decrease the EC from 3.76 mS/cm. These actions were successful and by mid-month the running average EC was below the 2.3 mS/cm goal, resulting in the Projects being able to increase exports. The monthly average X2 for September was 78 km. At the start of October, the EC gradually increased, and the Projects once again decreased exports, allowing outflow to increase. In October, tidal anomalies resulted in tides being higher than predicted, causing difficulties in meeting X2. Prior to the tidal anomaly around October 8, the EC at Collinsville was approaching 2.2 mS/cm. However, over the following two days, daily EC jumped to 3.99 mS/cm. The Projects continued to decrease exports, but the EC remained persistently high (in the range of 2.8 mS/cm). The Projects planned for the last week of the month to have very high outflows which would have likely reduced the EC, however, another unexpected tidal anomaly occurred around October 20, increasing the EC to 3.94 mS/cm in a single day and changing the trajectory of the monthly average EC. October's average X2 location came in at 80.6 km.

TABLE 2. 2023 SUISUN MARSH SALINITY CONTROLS GATE OPERATIONS. FLASHBOARD STATUS INDICATES IF THEY ARE INSTALLED OR REMOVED. BOAT LOCK STATUS INDICATES IF IT IS CLOSED OR IN OPERATION.

Date	Gate Status	Flashboard Status	Boat Lock Status	Notes
1/5/23 – 6/10/23	2 Open 1 Closed*	Installed	Operational	Gates opened to reduce stage to combat overtopping RRDS levees at the intakes
6/11/23 – 8/13/23	2 Open 1 Closed*	Removed	Closed	Flashboards removed for end of control season
8/14/23	2 Open 1 Closed*	Installed	Operational	Flashboards installed early to meet ITP requirement of using 100 TAF of water
8/15/23 – 10/17/23	2 Operational 1 Closed*	Installed	Operational	Operations started to meet ITP requirement of using 100 TAF of water
10/18/23 – 10/31/23	2 Open 1 Closed*	Installed	Operational	Operations suspended when 100 TAF of water was exhausted

*One gate removed with a stoplog in its place, hydraulicly equivalent to one gate closed

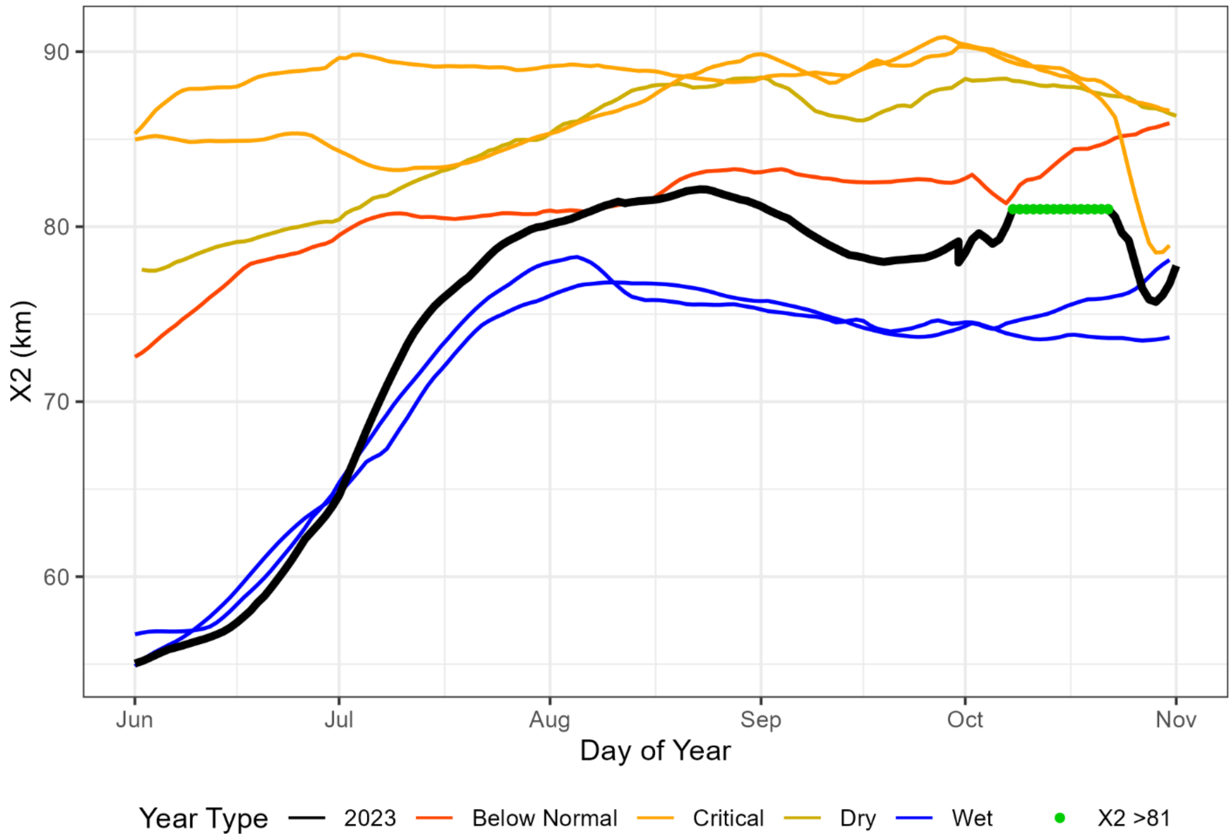

FIGURE 1. LOCATION OF X2 FOR JUNE-OCTOBER OF 2023 (BLACK LINE) AS CALCULATED BY DAYFLOW (JUNE-SEPTEMBER) AND CDEC STATION CX2 (OCTOBER), WITH PREVIOUS DATA FOR 2017-2022 FROM DAYFLOW SHOWN FOR COMPARISON. REAL-TIME CALCULATIONS FOR X2 FROM CDEC ARE NOT AVAILABLE.

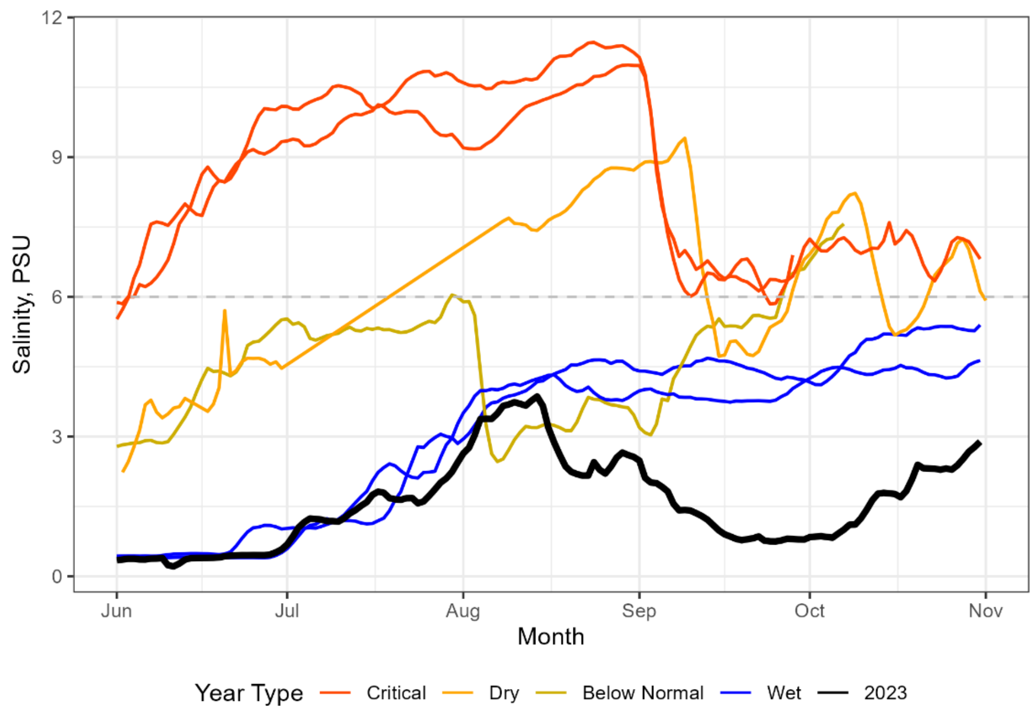

FIGURE 2. SALINITY AT BELDEN'S LANDING IN 2023 (BLACK LINE) IN COMPARISON TO PREVIOUS CRITICAL YEARS (2021, 2022), DRY YEARS (2020), BELOW NORMAL YEARS (2018) AND WET YEARS (2017, 2019). GREY DOTTED LINE SHOWS THE SIX PSU THRESHOLD FOR GOOD DELTA SMELT HABITAT.

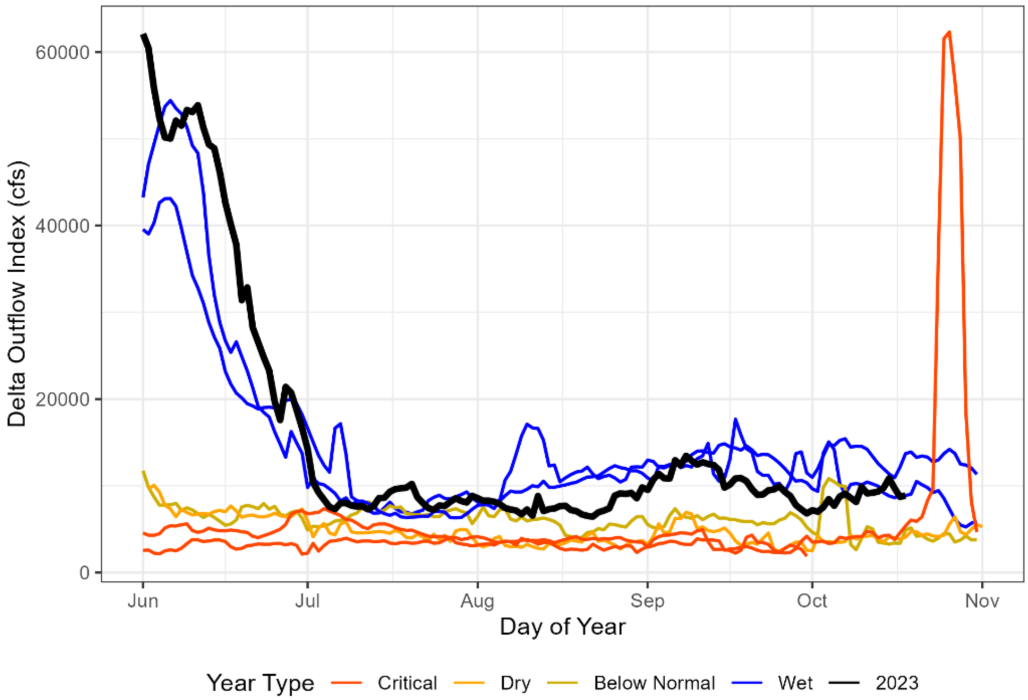

FIGURE 3. DAILY NET DELTA OUTFLOW INDEX FOR THE SUMMER-FALL PERIOD FOR 2023 (BLACK LINE) IN COMPARISON TO PREVIOUS CRITICAL YEARS (2021, 2022), DRY YEARS (2020), BELOW NORMAL YEARS (2018) AND WET YEARS (2017, 2019).

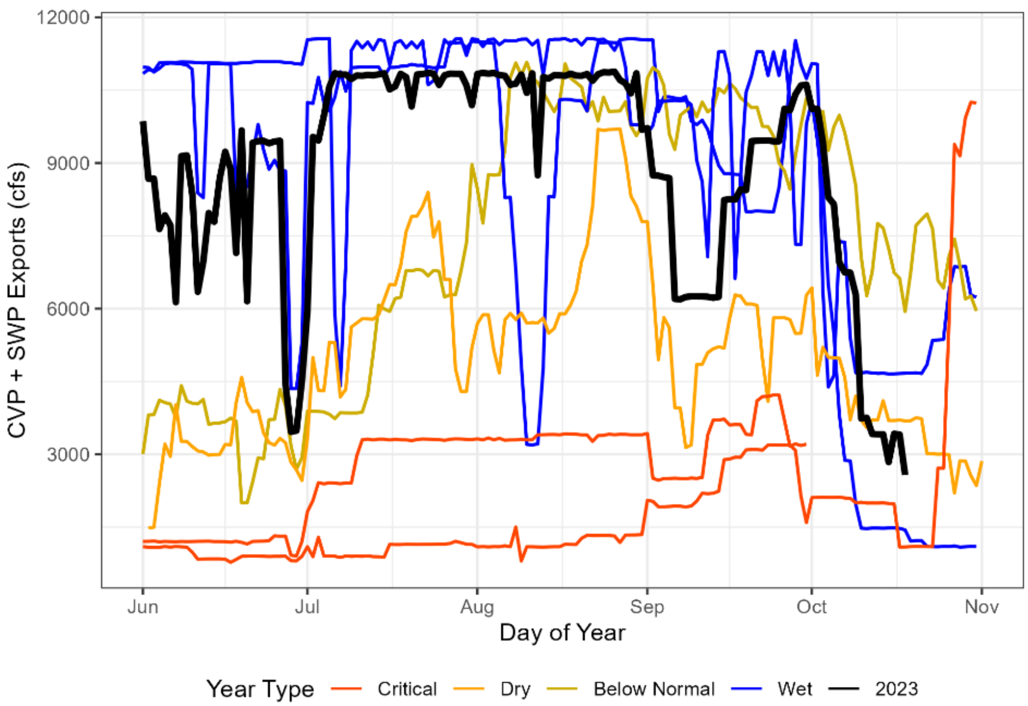

FIGURE 4. DAILY COMBINED EXPORTS FROM THE CENTRAL VALLEY PROJECT (CVP) AND STATE WATER PROJECT (SWP) FOR THE SUMMER-FALL PERIOD FOR 2023 (BLACK LINE) IN COMPARISON TO PREVIOUS CRITICAL YEARS (2021, 2022), DRY YEARS (2020), BELOW NORMAL YEARS (2018) AND WET YEARS (2017, 2019).

DSM2 Modeling of SMSCG water cost

DWR staff used the Delta Simulation Model (DSM2) to determine the condition for which there would be no net difference in salinity between the with- and without-SMSCG operation.

DSM2 was run with the SMSCG operating tidally beginning August 15th as a baseline scenario, then run iteratively, without the SMSCG operation, but with decreased outflow (500 cfs, 1,000 cfs, and 1,500 cfs less than in the baseline scenario). Figure 5 is a plot of the outflow assumptions for the final accounting.

The salinity results at Collinsville under the base case and the three alternatives are compared in Figure 6.

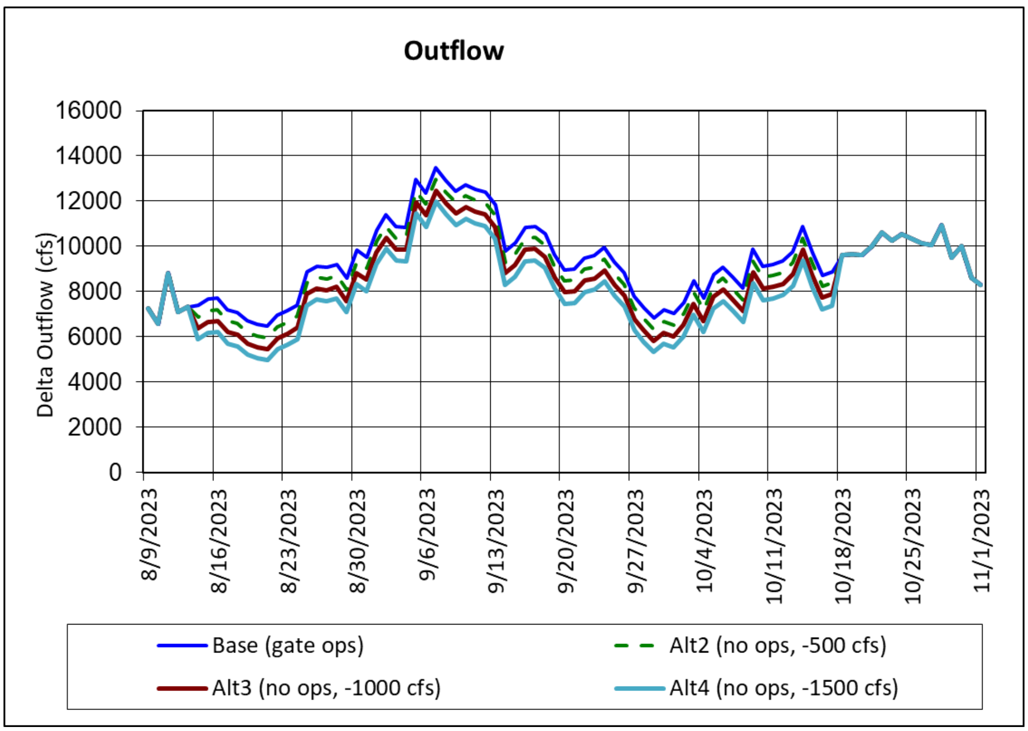

FIGURE 5. DELTA OUTFLOW IN 2023 UNDER SEVERAL SCENARIOS USED TO CALCULATE OUTFLOW NEEDED TO OFFSET THE SMSCG OPERATIONS.

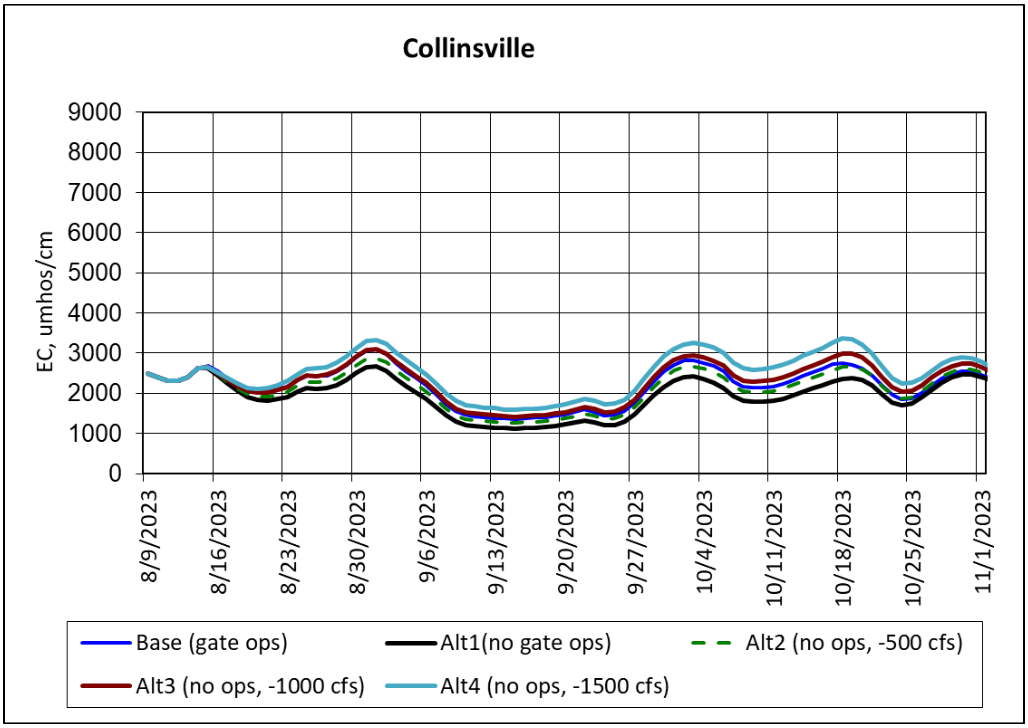

FIGURE 6. SPECIFIC CONDUCTANCE AT COLLINSVILLE UNDER SEVERAL OPERATIONAL SCENARIOS, USED TO CALCULATE OUTFLOW NEED TO OFFSET THE SMSCG ACTION.

A sum of the EC differences between the base case and each of the alternative scenarios is calculated and plotted, and a linear regression of the Sum of EC differences and outflow decreases is solved for zero to get a case with no net change in salinity. For the complete operation, spanning from August 15th through October 18th, the amount of outflow required to offset the SMSCG operation averaged approximately 794 cfs, for a total volume of approximately 100.8 TAF.

SMSCG and X2

Monitoring – Methods

Water Quality

Water quality monitoring relies on the network of continuous sondes distributed throughout the region (Figure 7). In 2021, three new sondes were placed in Grizzly Bay, as per the requirements in the 2020 ITP, one at the mouth of Montezuma Slough, one in the eastern region of Grizzly Bay, and one at the Tule Red restoration site. Sondes are calibrated and exchanged per their organization's Quality Assurance Project Plans\s.

Water temperature, specific conductance, and turbidity data was compiled from various continuous water quality stations in and around Suisun Marsh, Grizzly and Suisun Bays, and in the lower Sacramento River. Specific conductance values were converted to salinity using the wql R package (Jassby et al. 2017) and daily averages were calculated for water temperature, turbidity, and salinity. We then compared the number of days each region had salinities below 6 PSU, turbidities above 12 FNU, and temperatures below 22 °C from June-October of each year.

Increased duration of suitable temperature, turbidity, and salinity in Suisun Marsh would support the hypothesis that the 100 TAF action or SMSCG action increased Delta Smelt habitat. Increased duration and/or area of suitable temperature, turbidity, and salinity in Suisun Bay would support the hypothesis that the X2 action increased Delta Smelt habitat.

We also graphed salinities at stations in Grizzly Bay versus SMSCG operations to see whether gate operations cause a decrease in salinity at these stations. If salinities at these stations drop when the Gates are operated, it will support our hypothesis that gate operations can improve Delta Smelt habitat in Grizzly Bay.

Delta Smelt habitat hindcast models

We modeled the area of habitat with appropriate salinity, 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). The SCHISM hydrodynamic algorithm is based on mixed triangular-quadrangular unstructured grids in the horizontal plane and a flexible coordinate system in the vertical plane (Zhang et al. 2015). The DWR application of SCHISM to the Bay-Delta as well as a regional description of performance is described in Ateljevich et al. (2014, 2015). We used the SCHISM model to produce the area below 6 PSU that also has a turbidity of 12 FNU or higher, and water temperature of 22°C or lower, similar to the metric used in the DCG decision-making process. Temperature and turbidity may be interpolated from discrete water quality monitoring stations and/or data collected from continuous sondes.

We compared the hind-cast habitat area (in acres) calculated after the 2023 action to the predicted habitat area modeled during the spring 2023 decision making process. In brief, DWR used the same SCHISM methods described above with hydrologic conditions from representative years with different water year types to model of the potential effect of operating the SMSCG in different operational scenarios (see Summer-Fall Habitat Action Plan for details on modeling). 2017 was used as an example of a Wet year (similar to 2023), 2010 was used as an example of an Above Normal year, 2016 was used as an example of a Below Normal year, and 2020 was used as an example of a Dry year. In 2023, we operated the SMSCG for 63 days (August 15- October 17), similar to the 60-day continuous gate operations used in the modeling.

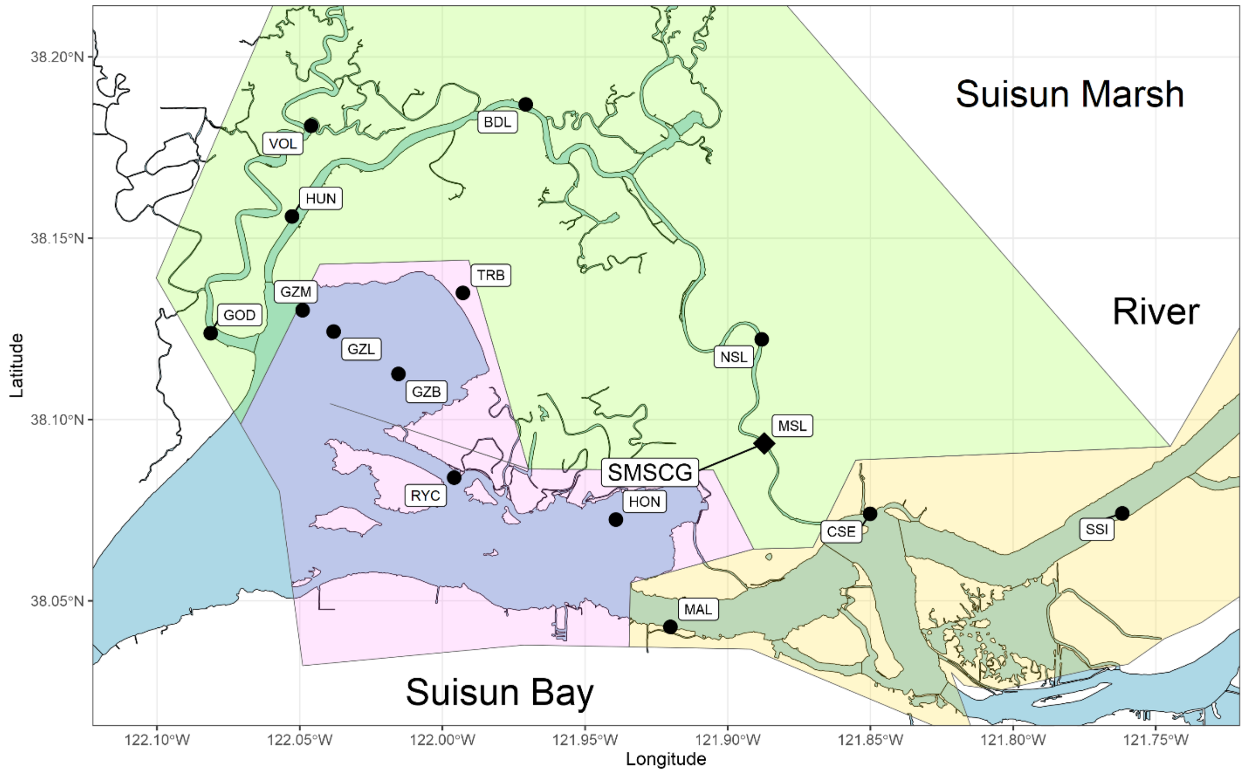

FIGURE 7. MAP OF WATER QUALITY SONDES USED FOR ANALYSIS OF DELTA SMELT HABITAT. NOTE THAT STATIONS HUN (HUNTER CUT) AND VOL (VOLANTI) WERE OUT OF SERVICE DURING THE FALL OF 2023 FOR NEEDED MAINTENANCE.

Phytoplankton

Phytoplankton serves as food for many of the zooplankton that Delta Smelt eat. Phytoplankton levels may limit zooplankton if concentrations of chlorophyll-*a* are less than 10 ug/L (Müller-Solger et al. 2002). Management actions, such as the SMSCG operations, can alter phytoplankton abundance and composition by altering water residence time and salinity. Phytoplankton community composition sampling was initiated in 2020 and currently includes 13 sampling sites, which are a subset of zooplankton stations (Figure 8). There are six fixed sites within Suisun Marsh and three in the River region, as well as one fixed site within each Grizzly Bay and Honker Bay and the existing "floating" stations at 2 PSU and 6 PSU. Samples were collected as 60-mL surface water samples preserved with Lugol's iodine solution. These samples augment existing IEP phytoplankton community composition data that is collected monthly by EMP at all their fixed stations. Taxonomic analysis was conducted by BSA Environmental Services, Inc. (Beachwood, OH), following the same methods and procedures as the EMP phytoplankton samples.

Zooplankton

Zooplankton were monitored primarily using four existing IEP surveys, including the CDFW Summer Townet (STN) and Fall Midwater Trawl (FMWT), as well as the DWR/CDFW Environmental Monitoring Program (EMP)(Kayfetz et al. 2020) (Figure 8). Previous reports also included the USBR Directed Outflow Project (DOP), but this survey is not being conducted in

2023. However, for this report we still include DOP data which has now been integrated with the other monitoring surveys. Additional sampling is conducted specifically for this management action to increase the spatial and temporal resolution of data in the area of interest (see SMSCG monitoring plan for details). EMP data for 2023 was not available in time for this report.

We compared calanoid copepods, a common Delta Smelt prey item, biomass per unit effort (BPUE), in the Low Salinity Zone in 2023 versus previous years with different salinity conditions in Suisun Marsh and Suisun Bay using linear mixed effect models with a random effect of month (logBPUE~ Region*Year + (1|Month)). We also compared biomass of Delta Smelt prey in upstream areas versus the Low Salinity Zone. Increased zooplankton biomass in Suisun Marsh during 2023 and other years with low salinity supports the hypothesis that operating the SMSCGs increases food availability for Delta Smelt. Increased zooplankton biomass in Suisun Bay and Grizzly Bay during 2023 and other years with low salinity supports the hypothesis that having lower X2 increases food availability for Delta Smelt in Suisun Bay.

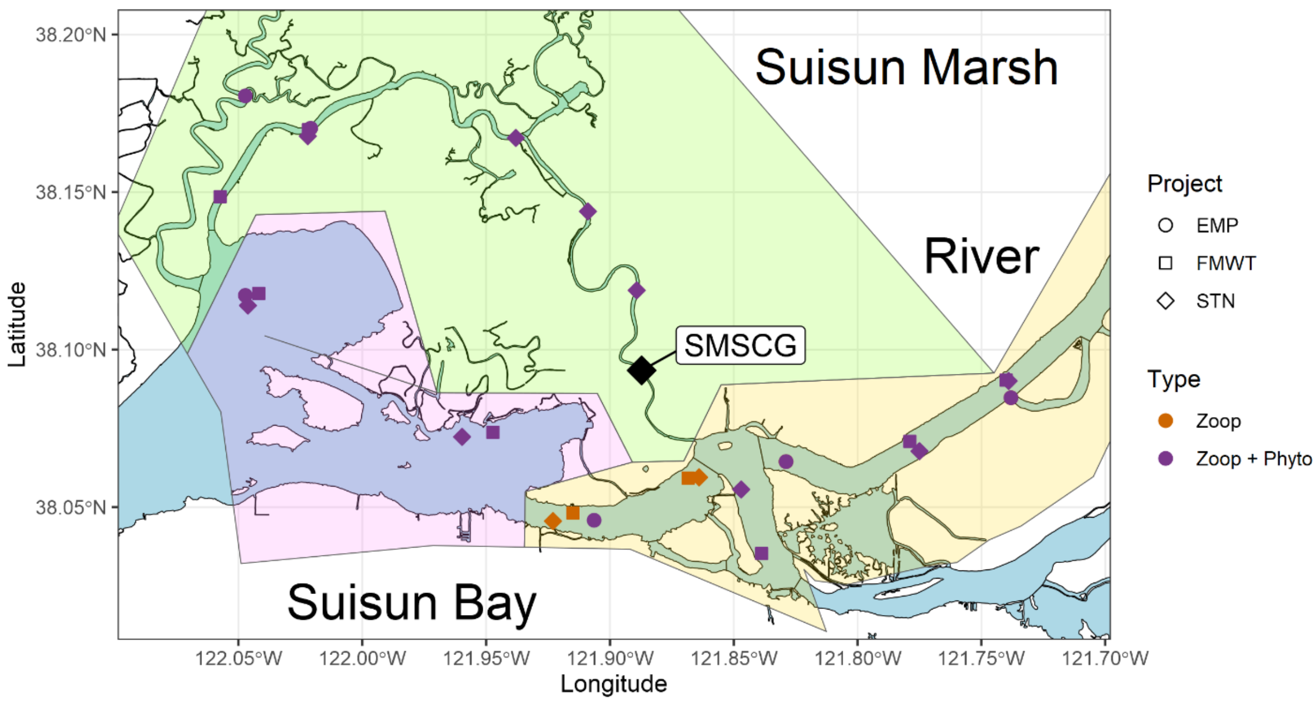

FIGURE 8. MAP OF FIXED STATIONS WHERE PHYTOPLANKTON (PHYTO) AND ZOOPLANKTON (ZOOP) SAMPLES ARE COLLECTED. DOP STATIONS ARE RANDOMLY SELECTED SO ARE NOT SHOWN.

Delta Smelt Abundance and Distribution

Fish monitoring relied entirely on existing surveys such as the USFWS Enhanced Delta Smelt Monitoring Program (EDSM) and Delta Juvenile Fish Monitoring Program (DJFMP), the UC Davis Suisun Marsh Survey, and California Department of Fish and Wildlife's (CDFW) Summer Townet Survey (STN), San Francisco Bay Study, and Fall Midwater Trawl Survey (FMWT). We did not have high enough Delta Smelt catch to statistically analyze any changes in Delta Smelt abundance or distribution as a result of the actions in 2023. However, we graphically present data on Delta Smelt catch by region to see whether they are using habitat in Grizzly Bay, Suisun Bay, and Suisun Marsh which has been made available by the X2 and SMSCG actions.

Experimental Releases

Between the start of experimental releases in 2021 and the beginning of the 2023 Summer-Fall Habitat Action, nearly 100,000 cultured Delta Smelt were released into the Delta. 55,733 cultured Delta Smelt were released in WY 2022 and 43,725 in November to January of WY 2023 at Rio Vista and the Sacramento Deepwater Ship Channel in the northern Delta. As of October 2023, 92 Delta Smelt have been recaptured throughout the Delta for WY2023, as compared to 114 in WY 2022 following the start of experimental releases. Planned releases for WY 2024 include a target of 75,000 released fish at Rio Vista with four paired hard and soft releases, and piloting large-scale transport methods between November 2023 and January 2024. Experimental Release Technical Planning and Reports are available upon request to USFWS.

Delta Smelt Enclosures

To test whether Delta Smelt have higher growth and survival in Suisun Marsh or Rio Vista, we used experimental enclosures. Previous attempts to use these enclosures in the summer and fall months found that high levels of biofouling (algae and invertebrates) grow on the enclosures during the summer, providing an unrealistic representation of habitat conditions. Therefore, the primary goal of our study in 2023 was to test methods of reducing biofouling. The greater similarity in salinity in Suisun Marsh and Rio Vista than occurs during drier years made it unlikely that we would see major differences in smelt growth and survival between the two sites.

Study Questions

1. Can biofouling of cages be mitigated during a six-week summer deployment?
2. How does biofouling impact the smelt's zooplankton community within the cages?
3. How does biofouling impact Delta Smelt within the cages?
4. How do different locations impact biofouling and other Delta Smelt habitat parameters?

Enclosure Methods

Four enclosures, holding 70 Delta Smelt each, were placed in two locations, Suisun Marsh near Belden's Landing, and Sacramento River next to the City of Rio Vista. The enclosures were 1.22m tall and 0.95m in diameter, made of a 14-gauge perforated aluminum sheet with 4.76 mm holes on 6.35 mm centers, providing for 51% open area. These were the same enclosures used in previous field experiments and described in Baerwald et al. (2023).

Smelt came from the Fish Conservation and Culture Facility (FCCL) in Byron, CA, and approximately 200 days post hatch. They were transferred to the enclosures on August 30th and 31st. Enclosures were checked immediately after smelt were deployed in the cages and weekly thereafter. Two of the cages at each site were scrubbed from the outside with plastic-bristled brushes once per week to remove algae. The other two cages were replaced every two weeks with a clean cage. At the end of six weeks (October 10th and 11th), all cages were removed.

To test whether biofouling impacted smelt prey abundance inside the cages, we collected zooplankton samples inside and outside the cages every two weeks. To quantify biofouling levels at the end of the deployment, we measured the density of algae and amphipods on the inside surface of the cage using fouling plates. We also scraped amphipods and algae off a 0.25 m^2 section of the inside of the cage.

To assess whether there were differences in smelt survival and condition between biofouling treatments or sites, we counted recovered smelt from the cages, measured smelt length, weight, condition factor, hepatosomatic index, and liver glycogen at the end of the deployment. We also assessed the critical thermal maximum for six fish from each cage and analyzed the diet from 10 fish from each cage.

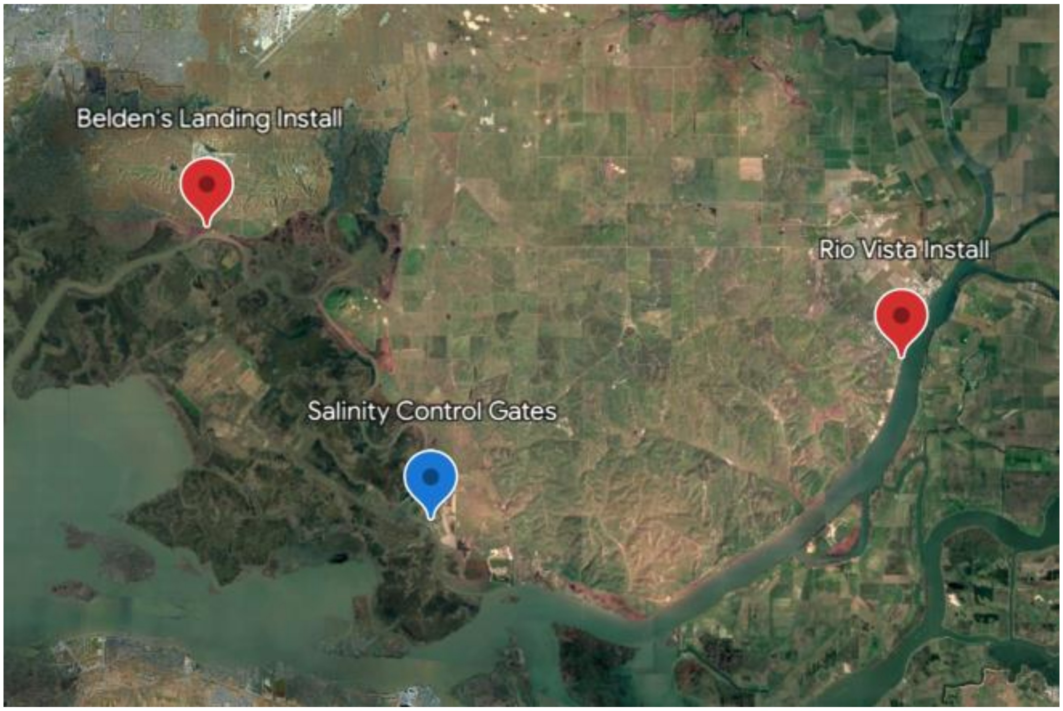

FIGURE 9. ENCLOSURE DEPLOYMENT STUDY SITE LOCATIONS FOR THE BIOFOULING STUDY

SMSCG and X2 Results

Extent of Appropriate Delta Smelt Habitat

Observed Water Quality

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. Conditions in Suisun Bay and Suisun Marsh are suitable for Delta Smelt when salinity is 6 PSU or less, which generally occurs when X2 is less than about 75 km (FLOAT-MAST 2021).

During 2023, most stations in Suisun Bay had average daily temperatures below 22 °C (Figure 10), indicating potential for positive smelt growth for much of the summer. There was, however, an extended warm period in August with temperatures above 22°C where less positive growth or no growth could occur. Salinities rose to above 6 PSU in August except at station HON (Honker Bay), but dropped back below 6 PSU in September, when both the SMSCG action and Fall X2 actions occurred coinciding with a neap tide. Salinities increased slightly in October during the spring tide. Turbidity remained well above 12 FNU during the entire period, and Chlorophyll was high, surpassing 10 mg/L at several points throughout the summer, particularly in Grizzly Bay.

Most stations in Suisun Marsh had average daily temperatures below 22 °C until late July where temperatures rose slightly more than in Suisun Bay (Figure 10). Water temperatures dropped back below 22 °C in September and October. Most stations had salinity below 6 PSU, except for some higher salinities in the western marsh (such as station GOD, see Figure 10). Salinities decreased in late August after the beginning of the SMSCG action on August 15th but rose again in October. Turbidity remained above 12 FNU throughout the region, except at NSL (National Steel) where it occasionally dropped below 12. Chlorophyll was higher than the Sacramento River, but slightly lower than Suisun Bay.

In the Sacramento River region, water temperatures were slightly cooler than in Suisun Marsh, particularly at station MAL (Figure 10). All stations had salinity well below 6 PSU, but also had low turbidity, frequently below 12 FNU and low chlorophyll.

When comparing conditions in 2023 to previous years, salinity in the Bay Region was similar to wet years with X2 at 74 km (2019 and 2019), and a majority of the days were suitable for Delta Smelt (<6 PSU, Figure 11, supplemental Figure 43), though temperatures in July and August limited total number of good habitat days (Figure 12, Table 3, supplemental Figure 42). It is important to remember that the position of X2 during the 2023 action was 6 km higher than in 2017 or 2019, however we found the change in X2 standard did not result in a reduction in days with appropriate salinity in 2023. This result may have been due to the operation of the SMSCG which may have offset the change in the X2 standard.

In Suisun Marsh, salinity was similar to conditions in 2017 (74 km X2 action), 2018 (35-day SMSCG action) and 2019 (74 km X2 action). However, temperatures in the Marsh were higher than in 2018 (Figure 12, supplemental figure 35), limiting the effectiveness of the SMSCG action in providing Delta Smelt habitat (Figure 12). The 2018 SMSCG action was of shorter duration (35 days versus 63 days), however days with appropriate salinity were the same in both years in Suisun Marsh. Both the Marsh and Bay had high turbidity in all years (Figure 12, Table 3 supplemental Figure 44). In the River Region, we did not expect an effect of either action on Delta Smelt habitat, and we found that either water temperature or turbidity were most often limiting Delta Smelt habitat availability (Figure 12). Neither water temperature nor turbidity is directly affected by the SMSCG action or X2 action.

FIGURE 10. PLOT OF DAILY AVERAGE CHLOROPHYLL, SALINITY, TEMPERATURE AND TURBIDITY AT CONTINUOUS MONITORING STATIONS THROUGHOUT THE AREA. BLACK DOTTED LINES INDICATE DELTA SMELT HABITAT THRESHOLDS, AND THE GRAY LINE IS A COMMONLY USED REFERENCE POINT FOR HIGH PLANKTON GROWTH. RED VERTICAL LINES INDICATE THE START AND END DATE OF THE SMSCG ACTION.

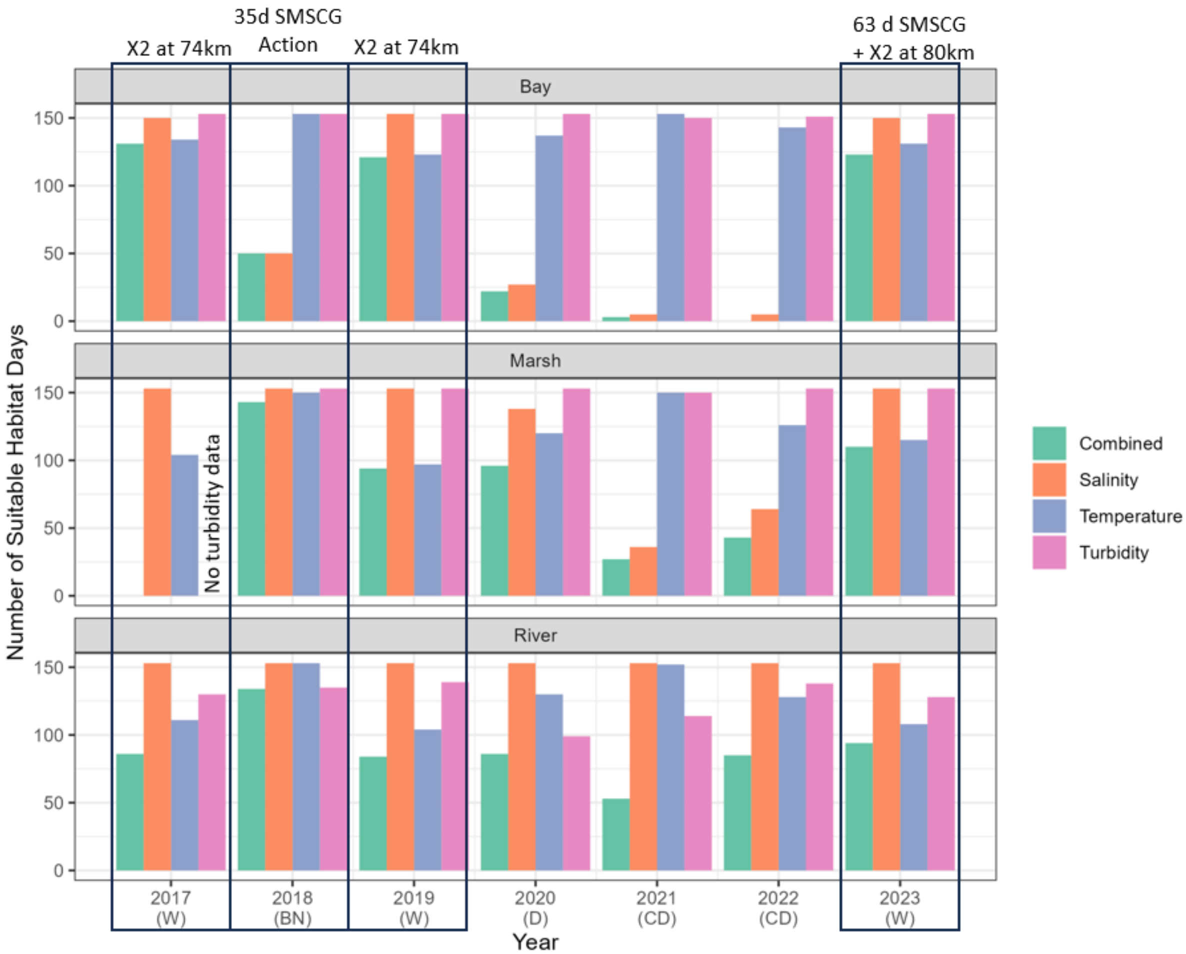

FIGURE 11. NUMBER OF DAYS WATER QUALITY CONDITIONS IN THE BAY, MARSH, AND RIVER MET THE SUITABLE SMELT HABITAT CRITERIA (E.G., < 6 PSU SALINITY, < 22°C TEMPERATURE, > 12 FNU TURBIDITY) FOR 2017-2023. BOXES AROUND YEARS DESIGNATE TYPES OF HABITAT ACTIONS, AND WATER YEAR TYPE IS INDICATED BELOW THE YEAR.

TABLE 3. NUMBER OF DAYS WITH APPROPRIATE DELTA SMELT HABITAT CONDITIONS IN EACH REGION AND YEAR DURING THE SUMMER-FALL TIME PERIOD (OUT OF A TOTAL POSSIBLE OF 153).

Year	Region	Combined good smelt habitat days	Days >12 FNU	Days < 22 °C	Days < 6 PSU
2017	Bay	131	153	134	150
2017	Marsh	0	0	104	153
2017	River	86	130	111	153
2018	Bay	50	153	153	50
2018	Marsh	143	153	149	153
2018	River	134	135	153	153
2019	Bay	121	153	123	153
2019	Marsh	94	153	97	153
2019	River	84	139	104	153
2020	Bay	22	153	137	27
2020	Marsh	96	153	120	138
2020	River	86	99	130	153
2021	Bay	3	150	153	5
2021	Marsh	26	150	150	35
2021	River	53	114	152	153
2022	Bay	0	151	143	5
2022	Marsh	43	153	126	64
2022	River	85	138	128	153
2023	Bay	123	153	131	150
2023	Marsh	110	153	115	153
2023	River	94	128	108	153

Hindcast Modeling

The chart below shows the modeled quantity of Low Salinity Zone (LSZ) acreage in the Suisun Marsh over time (Figure 12), with and without the SMSCG operation. Note that the quantity of LSZ acreage increased in the without-SMSCG operation case during September. This is likely attributable to the Projects’ increasing Delta outflow in order to meet the September Fall X2 requirement. The increase in LSZ acreage dropped again once Delta outflow decreased at the end of September.

When spatially mapping the salinity in Suisun Bay and Suisun Marsh (Figure 13) the distribution of the impact of the action becomes clear. The greatest increase in the LSZ occurred in the western side of Suisun Marsh and the northwest side of Grizzly Bay in the Suisun Bay region.

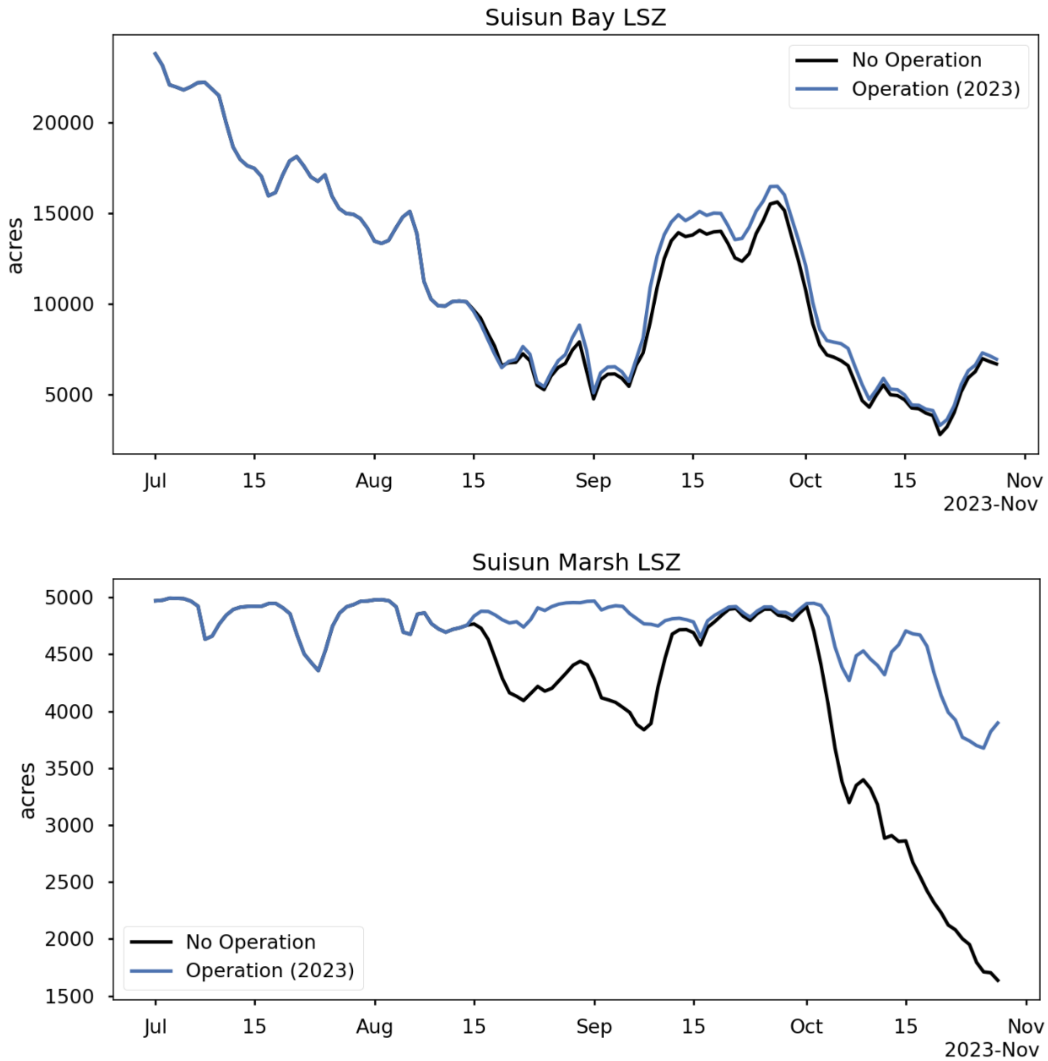

FIGURE 12. AREA OF THE LOW SALINITY ZONE (<6 PSU) IN SUISUN BAY (TOP) AND SUISUN MARSH (BOTTOM) FOR THE SUMMER-FALL HABITAT ACTION (JULY-OCTOBER). BLUE LINE SHOWS OBSERVED LSZ AREA, BLACK LINE SHOWS THE MODELED AREA OF LSZ THAT WOULD HAVE OCCURRED IF THE GATES HAD NOT BEEN HELD IN THE OPEN POSITION.

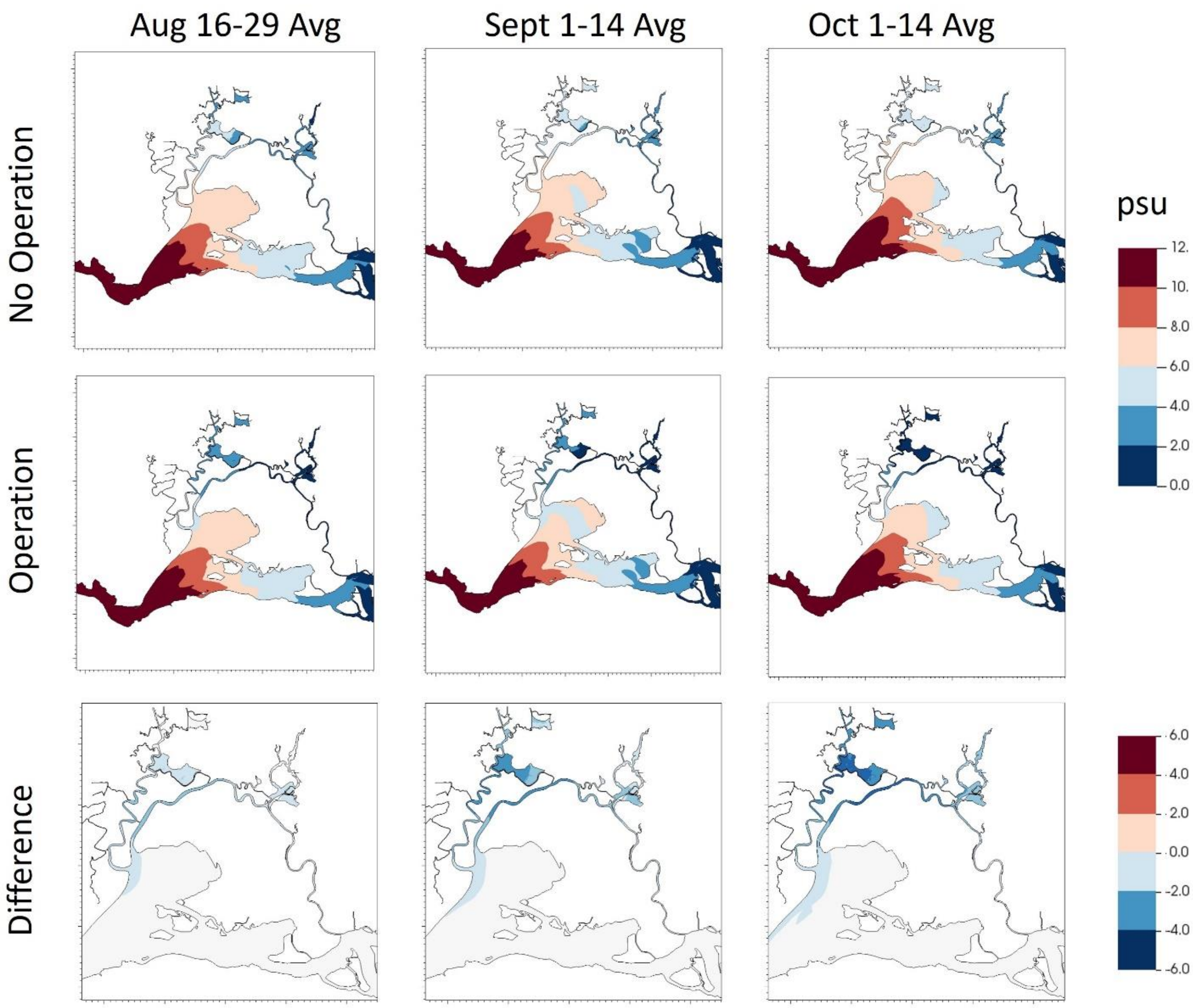

FIGURE 13. MAP OF MODELED LOW SALINITY ZONE HABITAT (LESS THAN 6 PSU) IN THE NO-OPERATION VERSUS OPERATIONAL SCENARIO AND DIFFERENCE BETWEEN SCENARIOS.

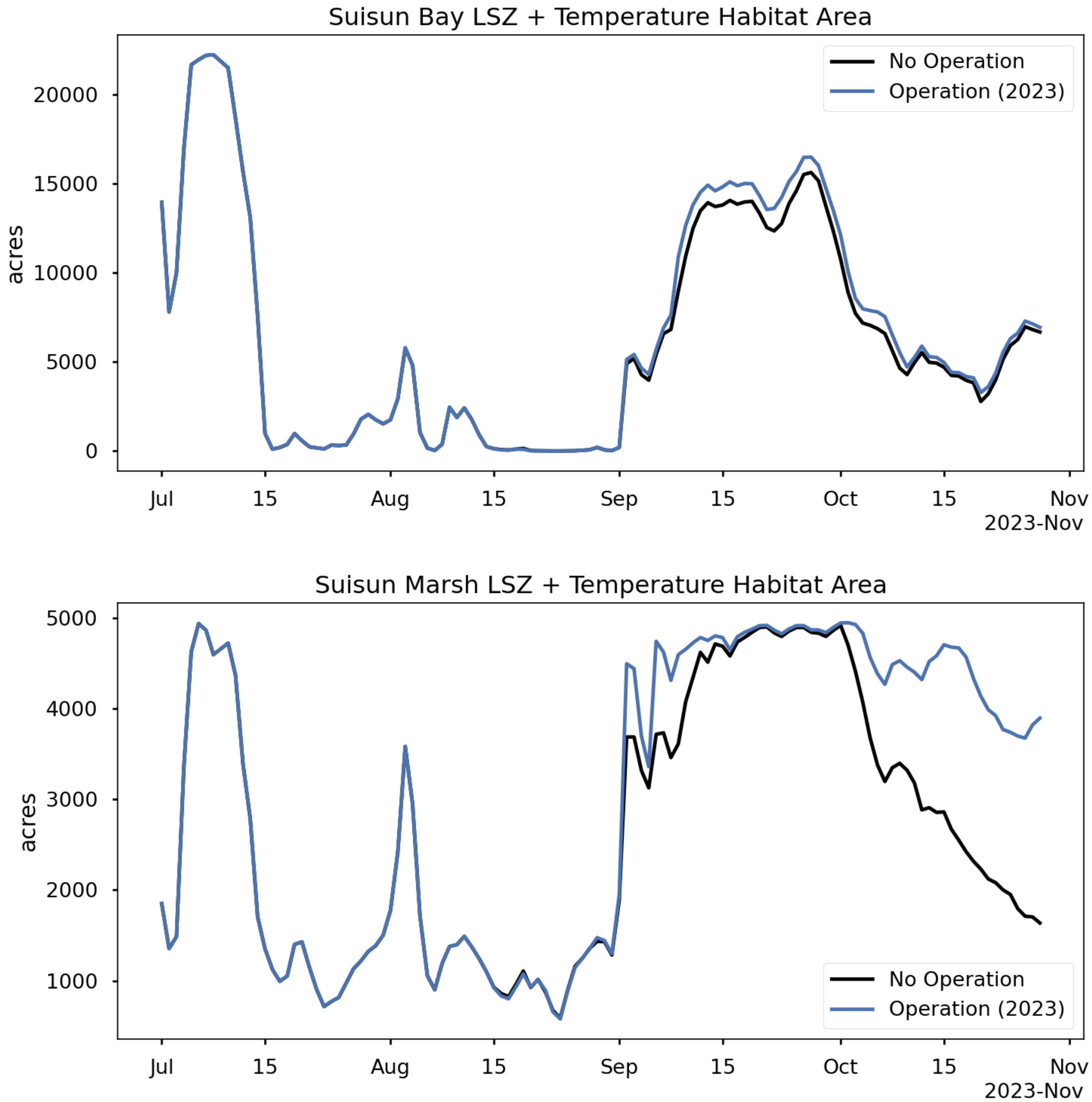

Figure 14. Area appropriate smelt habitat that is both less than 6 PSU and less than 22 C in Suisun Bay (top) and Suisun Marsh (bottom) for the summer-fall habitat action (July-October). Blue line shows observed habitat area, black line shows the modeled area of habitat that would have occurred if the gates had not been held in the open position.

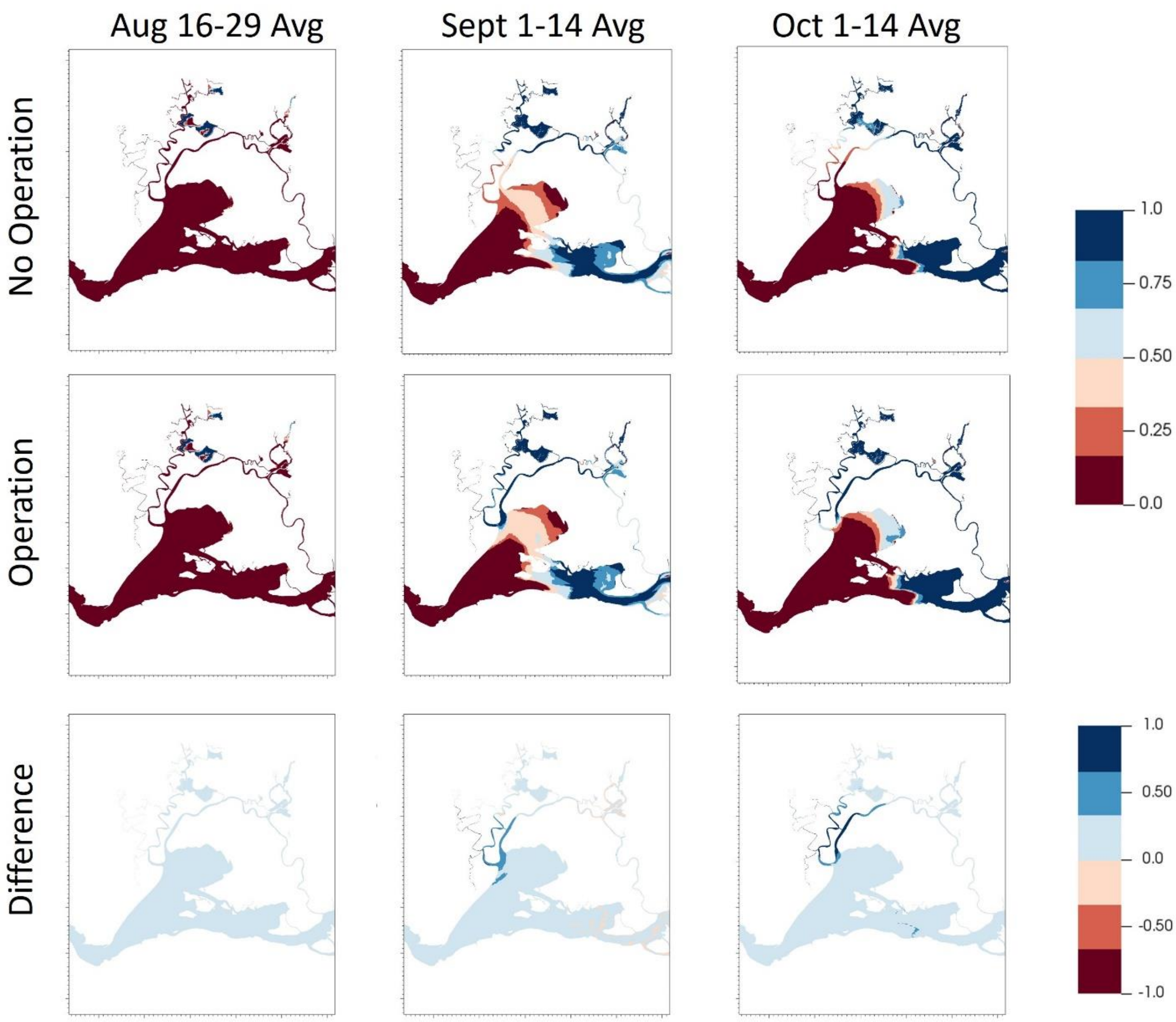

FIGURE 15. MAP OF APPROPRIATE DELTA SMELT HABITAT (LESS THAN 6 PSU AND LESS THAN 22 C) IN THE NO-OPERATION VERSUS OPERATIONAL SCENARIO AND DIFFERENCE BETWEEN SCENARIOS. COLORS INDICATE PROPORTION OF THE 14-DAY TIME PERIOD THAT BOTH PARAMETERS WERE SUITABLE, WITH 1 BEING 14 DAYS AND 0 BEING 0 DAYS.

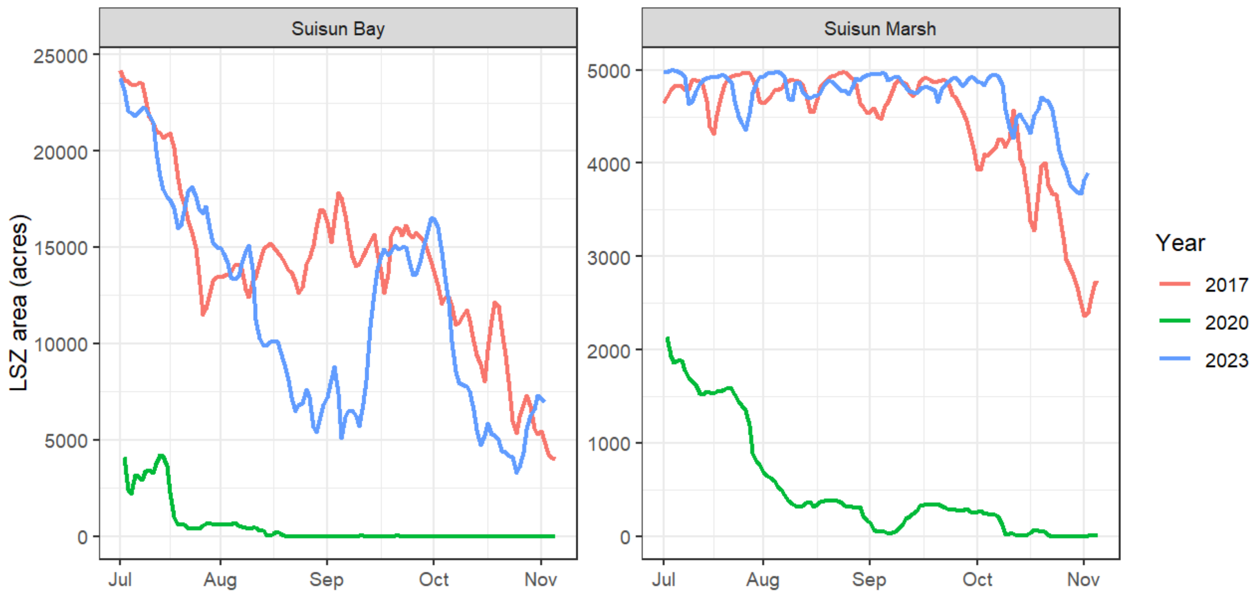

FIGURE 16. AREA OF LOW SALINITY ZONE HABITAT IN SUISUN MARSH AND SUISUN BAY (ACRES) IN 2023 VERSUS 2017, WHICH HAD AN X2 ACTION AT 74 KM, AND 2020, WHICH HAD NO ACTIONS.

While the area of the LSZ was over 4,000 acres in Suisun Marsh during most of the summer, when looking at the area of the LSZ that also had water temperatures below 22 °C, much of the Marsh and Bay was not considered suitable habitat for Delta Smelt during much of the summer, including the beginning of the gate operation period at the end of August (Figure 14). Thus, the difference in habitat for both temperature and salinity combined was chiefly in the western end of Montezuma Slough and Suisun Slough (Figure 15).

We do not have models of LSZ area for all previous years used for comparisons, but we have areas of LSZ for 2017 (a wet year with an X2 action at 74 km), and 2020 (a dry year with no actions). In Suisun Bay, LSZ area in 2023 was similar to or lower than area in 2017, and much higher than 2020. In Suisun Marsh, LSZ area was similar to or higher than 2017, and much higher than 2020 (Figure 16).

When comparing the predicted LSZ area benefit modeled during the decision making process in the spring of 2023 to the hindcast models performed after the action, the 2023 gate operation achieved greater habitat acreage in Suisun Marsh than the model of 2017 conditions (very wet year), and similar to the predicted benefits for 2010 (Above Normal year), both in terms of absolute acreage increase and as a percentage of the baseline habitat (Figure 17). The gain in LSZ in 2023 was appreciably lower (498 acres and 11% increase in LSZ) than would have been expected in the Below Normal (1489 acres and 100% LSZ) or Dry year models (1621 acres and 310% increase LSZ) in Suisun Marsh. In Suisun Bay, the 2023 action resulted in slightly less (390 acres, 3.4% increase) habitat than the model predicted for the Wet year scenario (2017, 540 acres and 3.9% increase in LSZ), Above Normal (2010, 592 acres and 9% increase) or Below Normal (2016, 489 acres, 15% increase) modeled scenarios, but much more than was predicted in the Dry year scenario (2020, decreased habitat). These models only evaluate the area of the LSZ; temperature, turbidity, or food supply also limit Delta Smelt habitat availability beyond the limitations of the LSZ.

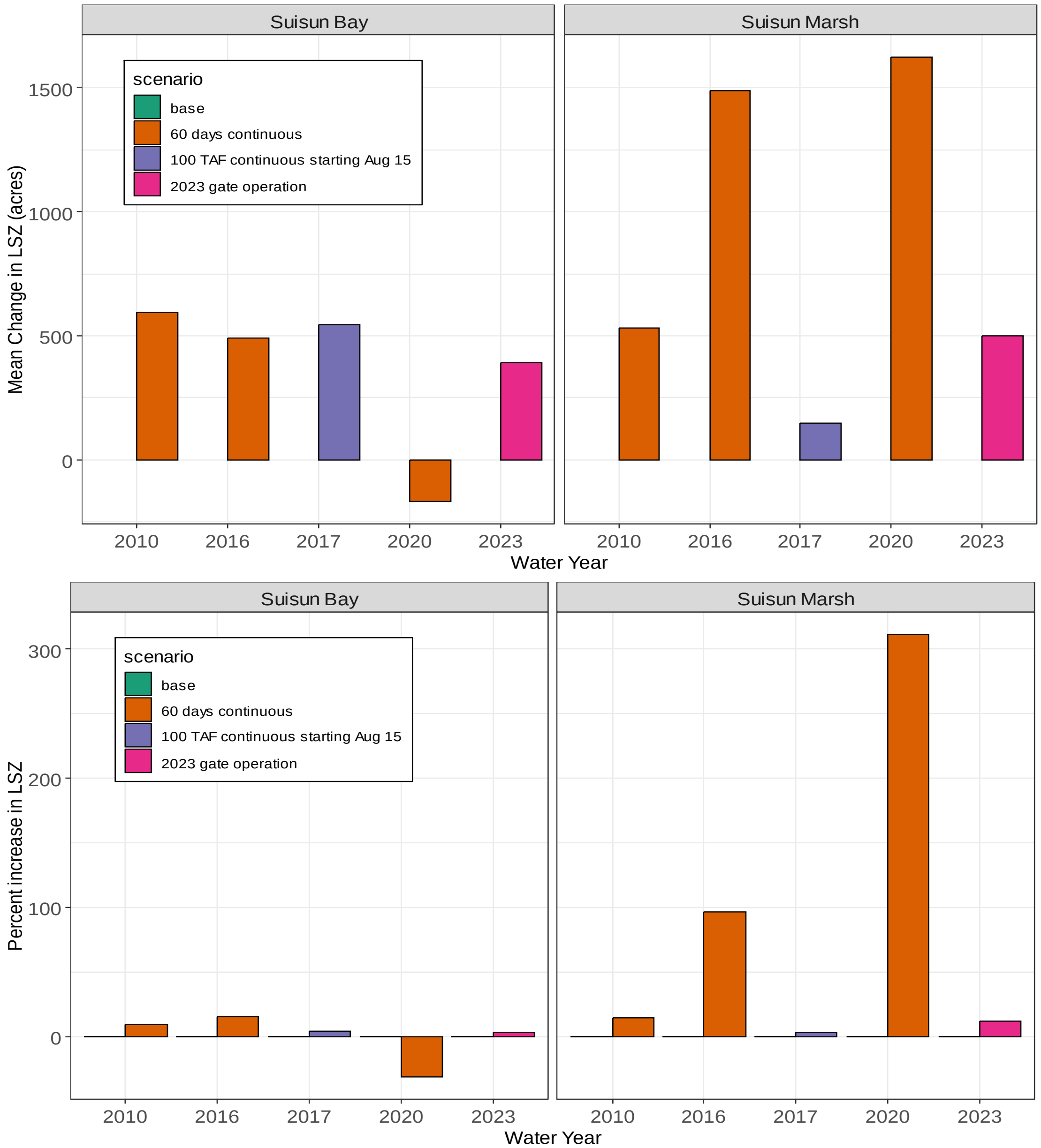

FIGURE 17. DAILY MEAN CHANGE IN LOW SALINITY ZONE (LSZ) HABITAT ACREAGE (TOP PLOT) AND PERCENT INCREASE IN LSZ HABITAT (BOTTOM PLOT) VERSUS BASE-CASE SCENARIO (NO SMSCG OPERATION), FOR JULY-OCTOBER IN VARIOUS WATER YEARS. MODELED RESULTS FROM 2010 (ABOVE NORMAL), 2016 (BELOW NORMAL), 2017 (WET), AND 2020 (DRY), WERE DEVELOPED DURING SPRING OF 2023 AND USED TO GUIDE DECISION MAKING. RESULTS FROM 2023 REFLECT SCHISM MODELING OF THE 2023 ACTION SHOWN IN FIGURE 12 AND FIGURE 13.

Phytoplankton

Together, DWR and DFW collected 103 phytoplankton samples in the SMSCG footprint in 2023. This expanded phytoplankton survey started in 2020, and therefore, 2023 is the first year with X2 and/or SMSCG actions. We used an ANOVA to determine whether there were significant effects of month, year, region, or the interactions among them on phytoplankton biovolume. For region, we only compared Suisun Marsh and the Lower Sacramento River because sample sizes in Suisun Bay were relatively low and variable. There were no significant interaction terms, and there were no differences in biovolume among months ($p = 0.79$) or regions ($p = 0.42$). However, there were differences among years ($p < 0.0001$, Figure 18). Specifically, biovolume in 2020 was 2.0 times, 2.1 times, and 2.2 times higher than in 2021, 2022, and 2023, respectively ($p < 0.001$ for all pairwise comparisons). No other pairwise comparisons among years were significantly different. Though Suisun Bay was not included in the statistical analysis, it is worth noting that biovolume was very high in July 2022 due to a diatom bloom.

In addition to biovolume, estimated biomass and estimated mass of essential long chain fatty acids were analyzed because these metrics are potentially more directly relevant to understanding the abundance and forage quality of phytoplankton for zooplankton. Both metrics were highly correlated with biovolume (corr > 0.94 for both comparisons), thus only biovolume is shown.

Phytoplankton taxa vary in quality as forage for zooplankton. For example, diatoms are considered high quality forage while cyanobacteria are considered low quality. Diatoms comprised the highest proportion of the biovolume across nearly all years, months, and regions, with centric diatoms generally replacing pennate diatoms in increasingly saline regions (Figure 18). Cryptophytes and cyanobacteria typically comprised the next highest proportion of the biovolume, particularly in the Lower Sacramento River. A PERMANOVA conducted on genus-level data indicated that community composition differed significantly between regions (Suisun Marsh vs. Lower Sacramento River) and among years ($p < 0.001$ for both predictors).

See Appendix A: Abiotic and Biotic Habitat Figures and Tables for additional plots and analysis of primary producer abundance and composition.

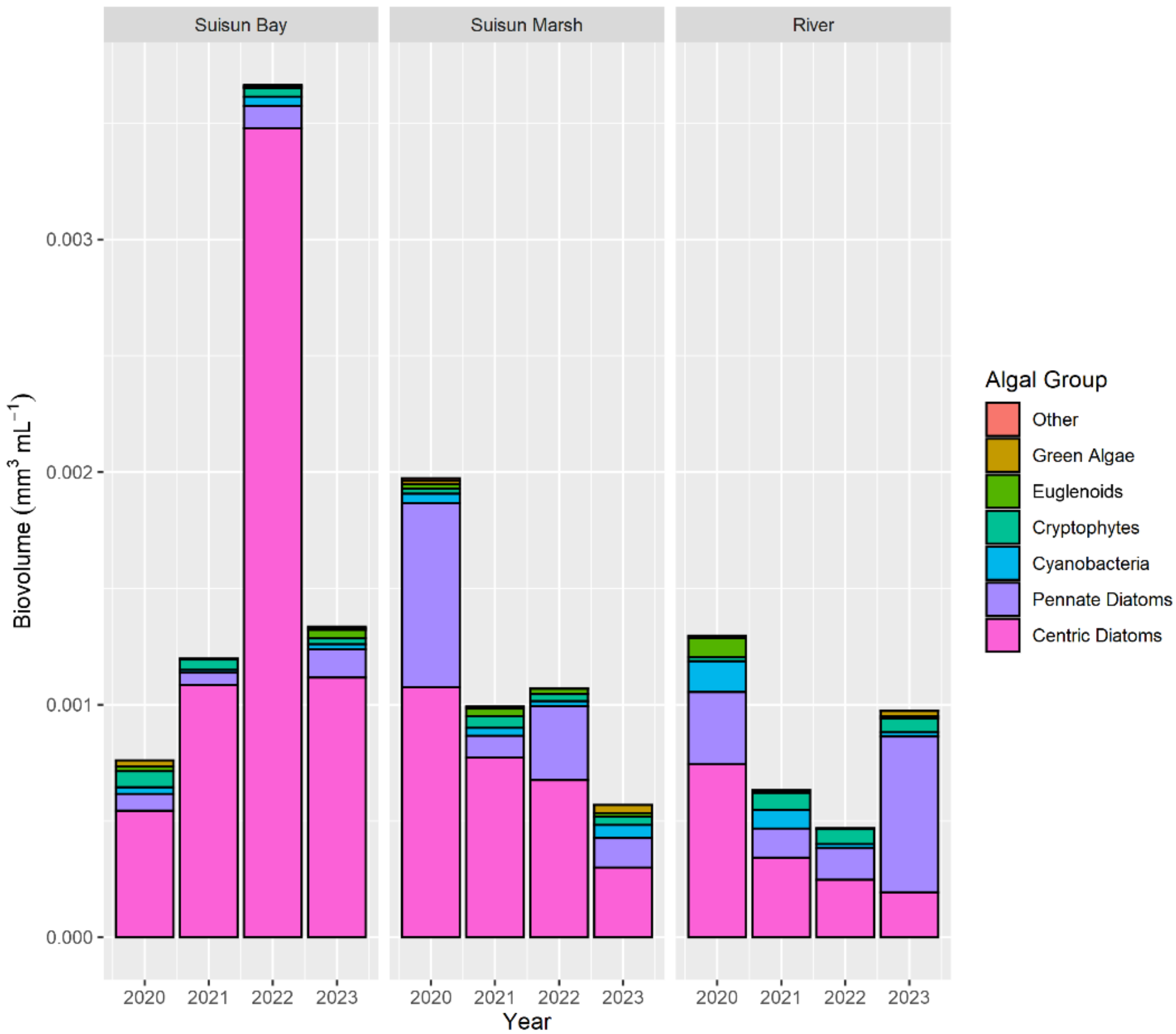

FIGURE 18. PHYTOPLANKTON BIOVOLUME IN SUISUN BAY, SUISUN MARSH, AND THE RIVER FROM 2020 TO 2023.

Zooplankton

STN and FMWT collected 100 mesozooplankton samples in the SMSCG footprint in 2023. DOP did not sample in 2023, and 2023 data from EMP was unavailable at the time of this report.

Statistical model outputs and post-hoc contrasts of calanoid copepod biomass are summarized in Appendix A, Tables Table **7**- Table 10. Across all years, mean calanoid BPUE was second highest in 2023, with 2017 having the highest, though this difference was not statistically significant (Table 8). Mean BPUE was highest in 2023 in the River region with *Pseudodiaptomus* making up most of the biomass, followed by Suisun Marsh and then Suisun Bay. However, none of the 2023 regional differences were significant. (Figure 19, Table 9), Overall, the lower Sacramento River region had consistently higher BPUE of calanoid copepods in most years, with the species varying depending on salinity. Higher salinity species (e.g., *Tortanus*) have higher BPUE and move further upstream in drier years. Freshwater species (e.g., *Pseudodiaptomus* and *Acartiella*), move further downstream and into the marsh during wetter years.

In Suisun Marsh, 2017 and 2023 mean BPUE of calanoid copepods were statistically higher than 2022 (Table 10), but there were no other significant differences between years in that region, contrary to our hypotheses that X2 action years and SMSCG years would have higher BPUE. In Suisun Bay, there were no differences in mean BPUE between any years (Table 10), though biomass in the X2 action years of 2017 and 2019 appeared higher than other years (Figure 19). In the River, 2017 and 2023 were statistically higher than other years, contrary to our hypothesis that flow would have little effect on total BPUE in this habitat.

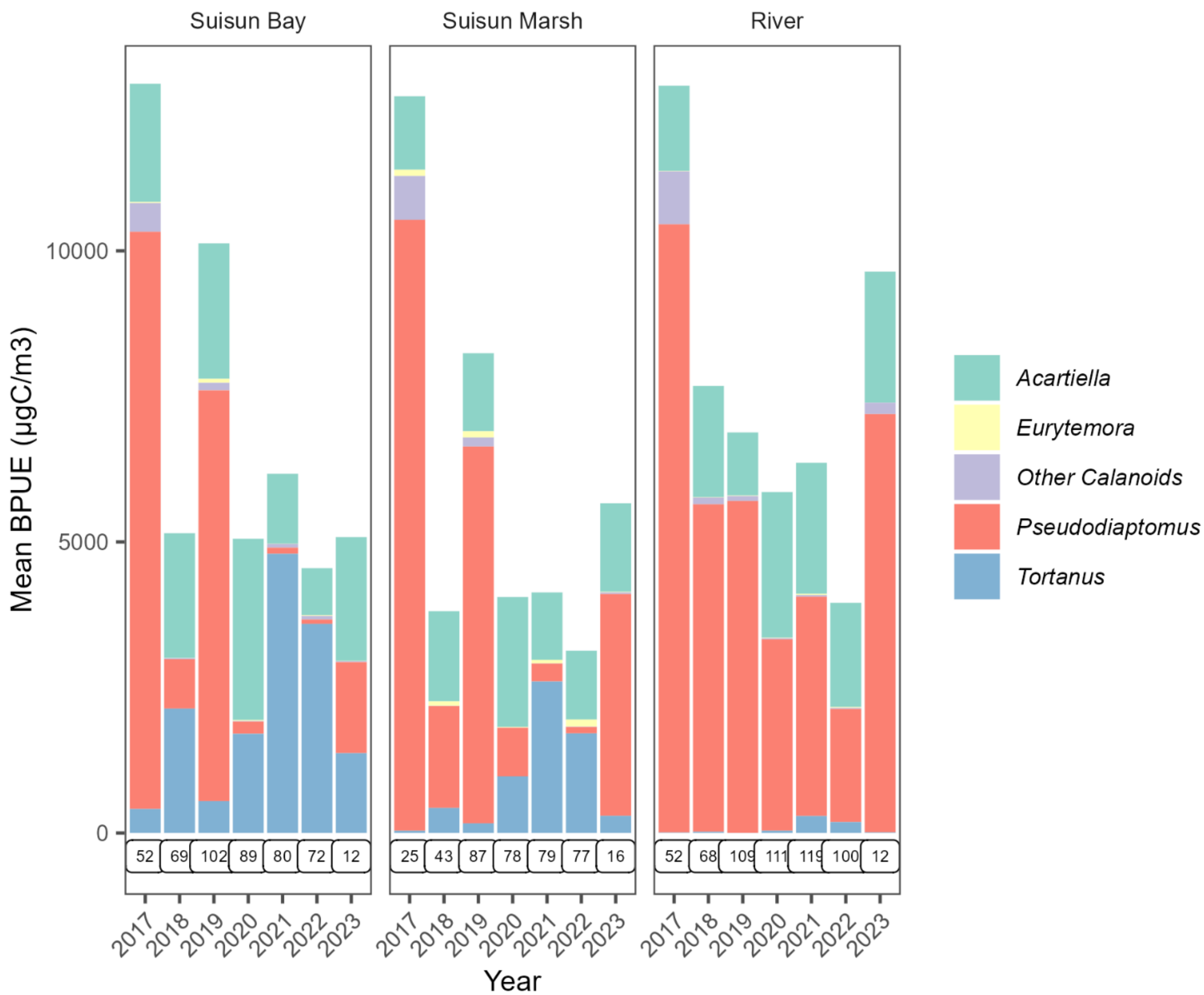

FIGURE 19. BPUE OF CALANOID COPEPODS IN SUISUN BAY, MARSH, AND THE RIVER FROM 2017 TO 2023. NOTE THAT 2023 DOES NOT INCLUDE EMP DATA.

Delta Smelt Status

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 did catch one Delta Smelt in Montezuma Slough in August of 2023, but this occurred after the first two surveys (upon which the index relies), giving the Delta Smelt abundance index of zero for the year (https://apps.wildlife.ca.gov/Townet/Main/DeltaSmeltIndices). The 2023 Fall Midwater Trawl Survey did not capture any Delta Smelt at their fixed index stations so far, making a 0 index for this survey as well. Unlike some recent years, survey efforts in WY2023 were not reduced due to COVID or wildfire smoke.

EDSM Delta Smelt catch and abundance estimates in summer-fall period 2023 was somewhat similar to summer-fall period of 2022 (generally lower than summer-fall catch and abundance estimates from 2017-2019), with several fish caught between June and October (Figure 21, Table 4). Just as the past few years, it is likely that a large portion of the 2023 cohort caught in the summer-fall months was produced by the hatchery-reared Delta Smelt released in the previous winter.

Importantly, one Delta Smelt was caught in Montezuma Slough during the SMSCG action (STN station 609) and three smelt were caught in Grizzly Bay during the Fall X2 and SMSCG action period (Table 4). It is unknown whether the presence of these fish in the region was directly caused by the summer-fall habitat action, but these regions would have likely had a salinity above 6 PSU, where smelt are seldom caught, if the action had not occurred.

TABLE 4. DELTA SMELT CATCH, JUNE 2023-OCTOBER 2023

Date	Number	Fork length (mm)	Survey	Location
6/7/2023	1	16.6	EDSM	Yolo Bypass Toe drain
6/28	1	90	Chipps Island	Chipps Island
7/7	1	41	EDSM	Confluence
7/11	1	37	EDSM	Confluence
8/21	1	50	STN	Montezuma Slough Station 609
9/21	1	54	EDSM	Grizzly Bay
9/25	1	48	EDSM	Grizzly Bay
9/28	1	70	EDSM	Grizzly Bay
10/5	1	60	EDSM	Rio Vista
10/24	1	53	EDSM	Sherman Island

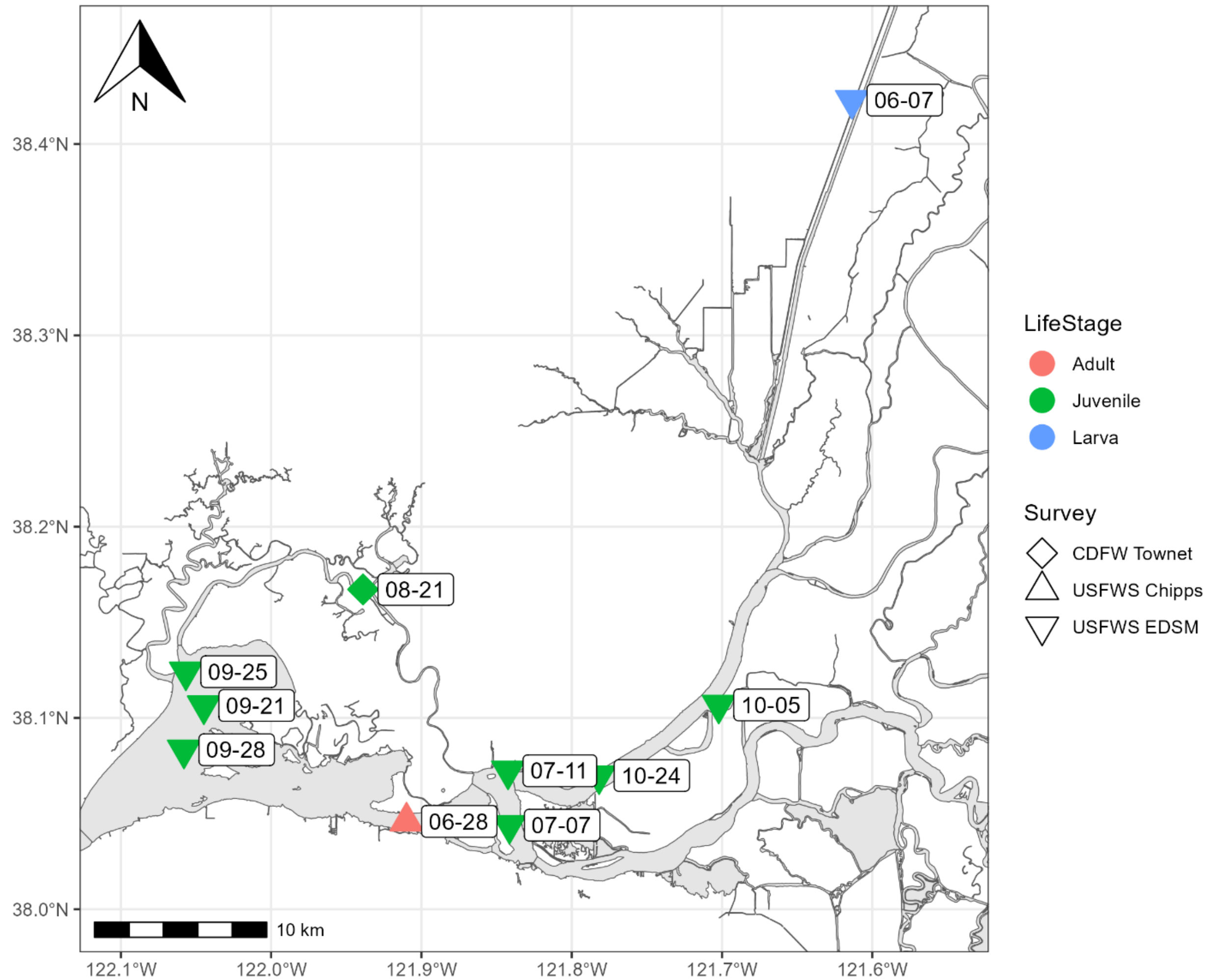

FIGURE 20. MAP OF DELTA SMELT CATCH DURING THE ACTION PERIOD. THE DATE OF EACH CAPTURE IS INDICATED NEXT TO THE POINT.

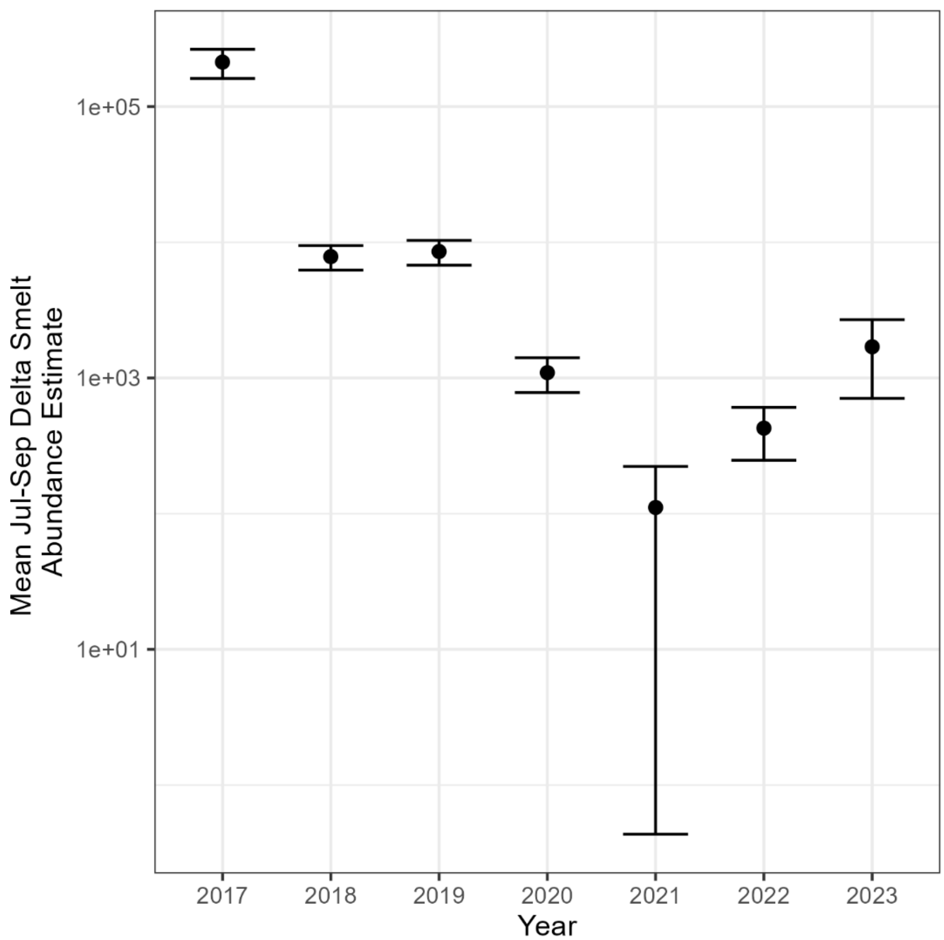

FIGURE 21. AVERAGE DELTA SMELT ABUNDANCE ESTIMATE FOR JULY THROUGH SEPTEMBER. ABUNDANCE ESTIMATES ARE CALCULATED BY EDSM ON A WEEKLY BASIS, THEN SUMMARIZED BY CALCULATING THE AVERAGE AND STANDARD ERROR OVER THE SUMMER-FALL HABITAT SEASON.

Delta Smelt Cage Deployments

The results presented here should be considered preliminary and will be updated in a separate enclosure report after all data are fully analyzed.

Data on density of biofouling communities are not available yet, however visual inspections of the enclosures showed that cages which were exchanged every two weeks had less algae and epibenthic/epiphytic organisms than cages that were scrubbed once per week (Figure 22). The clod cards from the inside of the cages lost significantly less mass than the cards on the outside of the cages, though there was no statistically significant difference between biofouling treatments. This suggests that even the exchanged cages reduce current speeds and water movement on the inside of the cages.

FIGURE 22. CAGES REMOVED FROM THE WATER AFTER THE SIX WEEK DEPLOYMENT. THE CAGE ON THE LEFT WAS EXCHANGED EVERY TWO WEEKS, WHEREAS THE CAGE ON THE RIGHT WAS SCRUBBED ONCE PER WEEK. THE BIOFOULING COMMUNITY IS APPARENTLY MUCH LIGHTER ON THE CAGE THAT WAS EXCHANGED.

Preliminary data on survival and growth demonstrated survival was highly variable, ranging from 88% to 20% of fish remaining after six weeks (Figure 23). An ANOVA testing for significant differences between biofouling treatment (exchanged versus scrubbed) and site (Rio Vista versus Belden's Landing) found no statistically significant differences in survival ($p>0.05$). However, the survival at Rio Vista tended to be higher than Belden's Landing and cages that were exchanged tended to have lower survival than cages that were scrubbed. The condition factor of fish at Rio Vista was significantly higher than condition factor of fish at Belden's Landing ($p <0.001$), but there was no difference in condition factor between biofouling treatments (Figure 24).

Together, these results suggest that exchanging cages did reduce biofouling, however, the reduction in biofouling did not impact smelt growth or survival (diet and condition analysis pending). Contrary to our expectations, smelt deployed at Belden's Landing had lower condition factor and may have had lower survival than Rio Vista. This may indicate that some aspects of the habitat at Rio Vista were better than Belden's Landing, however, full implications of this difference will be clearer once all the data are available, and increased replication may be required to reduce uncertainties.

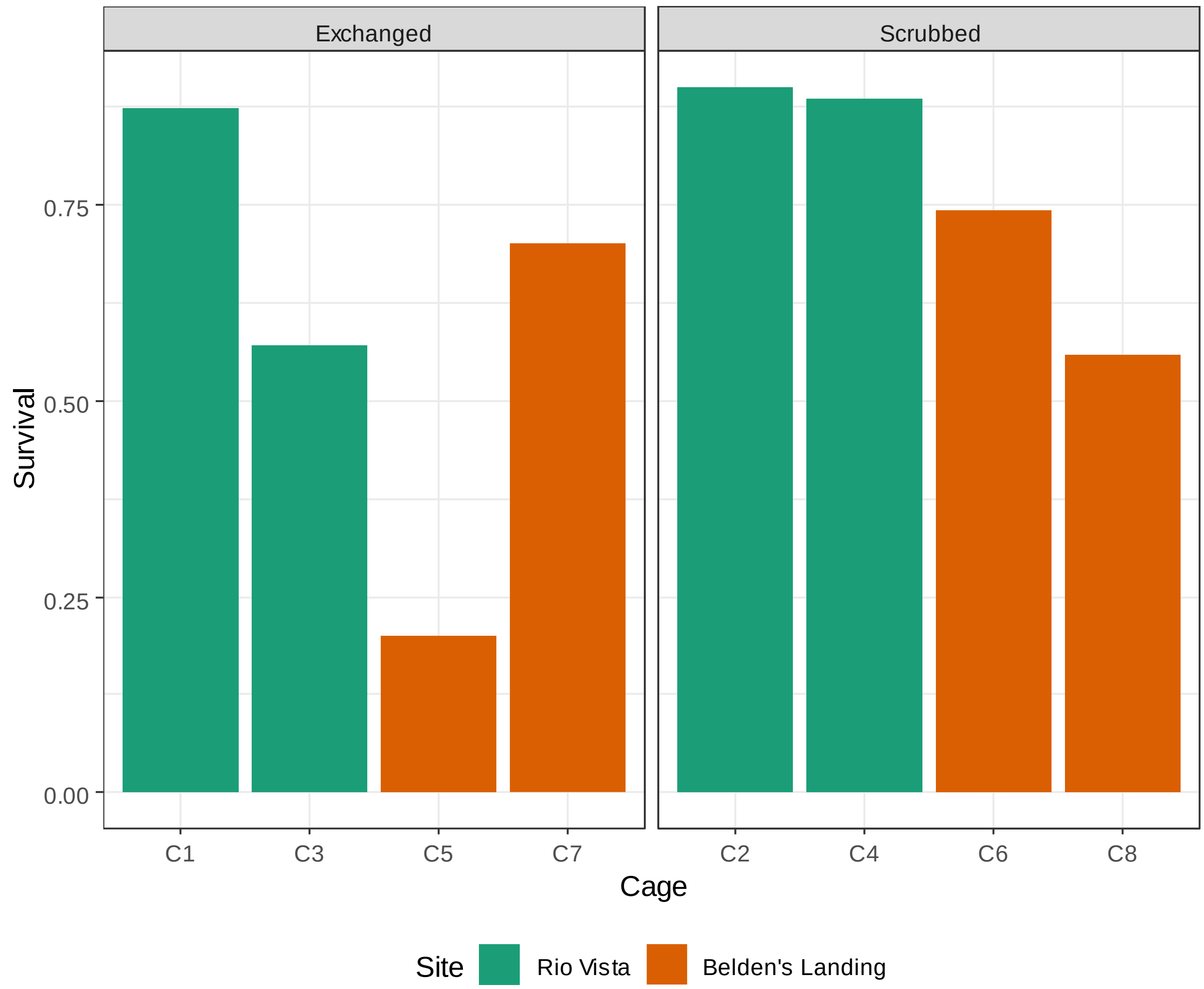

FIGURE 23. SURVIVAL OF DELTA SMELT IN CAGES BY SITE (RIO VISTA OR BELDEN'S LANDING) AND BIOFOULING TREATMENT (SCRUBBED ONCE PER WEEK OR EXCHANGED WITH CLEAN CAGES EVERY TWO WEEKS).

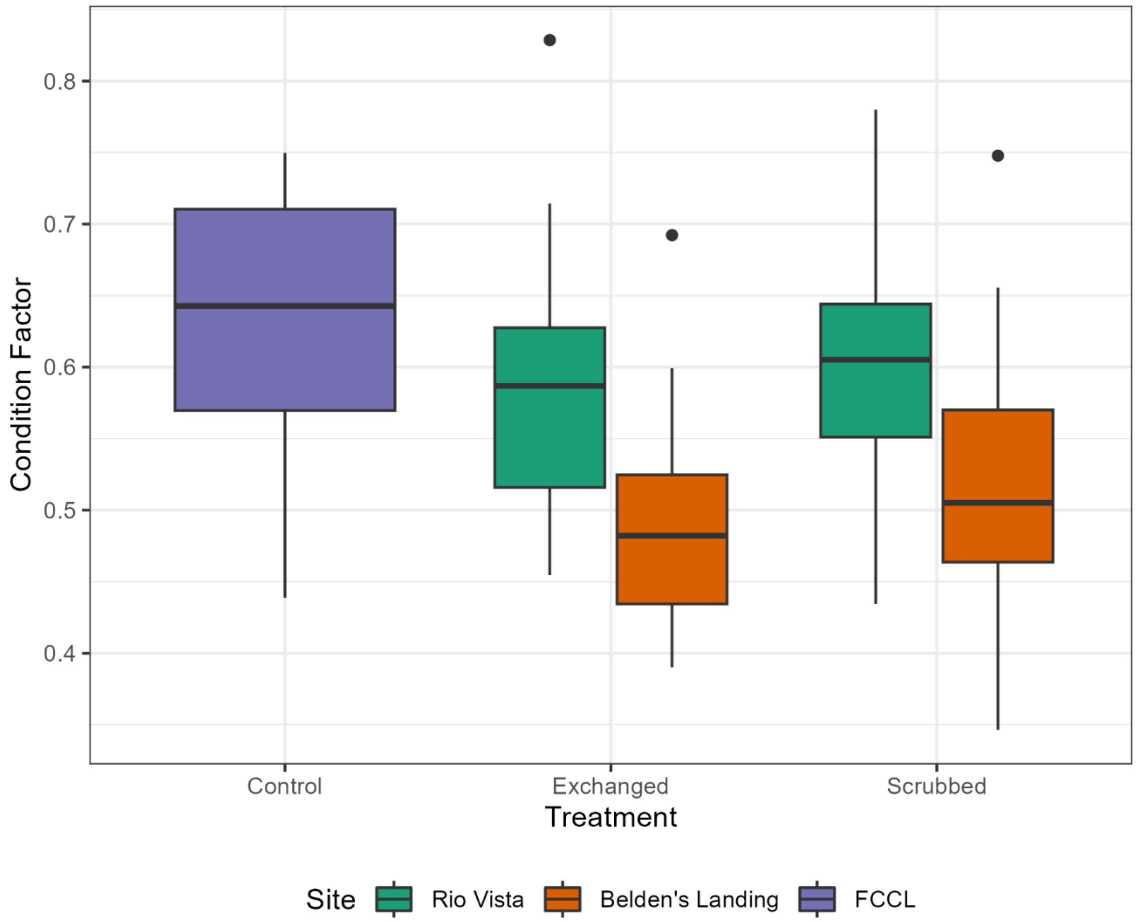

FIGURE 24. BOX PLOTS OF DELTA SMELT CONDITION FACTOR (WIGHT IN MG/FORK LENGTH CUBED * 100). CONDITION FACTOR WAS SIGNIFICANTLY LOWER AT BELDEN'S LANDING THAN RIO VISTA ($P < 0.001$), AND ALL FIELD-DEPLOYED CAGES WERE LOWER THAN THE FCCL CONTROL, BUT NO DIFFERENCE BETWEEN THE EXCHANGED AND SCRUBBED TREATMENTS ($P = 0.3$).

Flow Action Discussion

The 2023 Sacramento Valley Water Year designation was Wet, and the summer-fall SMSCG and Fall X2 actions occurred. In Wet years, Delta Smelt habitat is expected to have higher quality and quantity than in drier years due to the increased Delta outflow. The SMSCG operation (implemented by means of the 100 TAF action) reduced the salinity in the Suisun Marsh and Suisun Bay, and salinity is one of the three abiotic factors that are used to define suitable Delta Smelt habitat. The alteration of the salinity levels shifted that abiotic variable from non-suitable to suitable in part of Suisun Marsh and Suisun Bay during the SMSCG period, creating a continuous corridor of Delta Smelt habitat from upstream to Honker Bay, and through the Marsh to Grizzly Bay (Figure 12). In the attempt to meet the Fall X2 standard, high outflow in September and the beginning October increased habitat area in both the Suisun Bay and Marsh but masked any effect of the SMSCG on salinity at Belden's Landing during this time period. The benefit of the SMSCG in terms of increased habitat acreage in Suisun Marsh was greater than predicted by modeling in the spring of 2023, but lower than would be expected in a drier water year (Figure 17).

Suitable Delta Smelt habitat measured at continuous stations across the monitoring region demonstrated that the number of days with suitable salinity in Suisun Marsh in 2023 were similar to other years with an X2 action (2017 and 2019) or a SMSCG action (2018). The 2017 and 2019 X2 actions had a lower X2 standard (74 versus 80 km), but total number of days with habitat below 6 PSU at continuous monitoring stations in Suisun Bay and Suisun Marsh were the same in all years despite the change, which may have been due to the combined benefit of the SMSCG action and the X2 action. The 2018 SMSCG action was shorter (35 days versus 63 days), but both durations of actions maximized the number of days in Suisun Marsh below 6 PSU.

Spatial modeling of habitat area would predict that the higher X2 in 2023 would result in lower LSZ habitat area (based on analysis by Kimmer et al. 2013). We did not perform hindcast modeling of habitat area in all previous years, but comparisons of habitat area in 2023 versus 2017 and 2020 show that habitat area Suisun Bay in 2023 was similar to 2017 in July and the first part of August, lower in the second part of August and September, and similar in the second half of September, and lower in October. Suisun Marsh had similar habitat area to 2023 in July, August, and September, and more habitat area in October (Figure 16).

Despite the improved salinity, high water temperatures (>22°C) limited the benefits of the actions. There was less overlap of all three key abiotic factors (e.g., salinity, turbidity, and water temperature) than some previous years (Figure 11, Figure 14). An analysis of the fall X2 action of 2017 also concluded that high water temperatures may have limited the effectiveness of that action (FLOAT-MAST 2021; Smith and Nobriga, 2023). Because salinity conditions in the Marsh were similar in 2017, 2018, 2019, and 2023, it is unclear whether the SMSCG action increased habitat above the increase provided by the X2 action. Modeling indicated some increase in the area of the Low Salinity Zone in the western marsh and Grizzly Bay (Figure 12), but during the month of August most of this region had water temperatures above 22°C, where growth is most likely to be low. Because we do not have data from previous wet years without an X2 action (such as 2006 or the late 90s, before the array of water quality sondes were established), we cannot evaluate the effect of the X2 action above the impact of the wet water year itself. Modeling indicated some increase in the area of the Low Salinity Zone in the western marsh and Grizzly Bay (Figure 12), but this area was reduced when water temperature was taken into account. Increase in area with appropriate temperature and salinity was seen only in the western end of Montezuma Slough and Suisun Slough during the action (Figure 15).

The effect of the fall X2 action did not have a clear effect on zooplankton biomass. While the total BPUE of calanoid copepods in Suisun Bay was higher in the X2 action years of 2017 and 2019, it was not particularly high in 2023 (Figure 19). In Suisun Marsh, we expected higher BPUE in years with X2 actions or SMSCG actions, and we did see the highest biomass in the marsh in the X2 action years of 2017, 2019, and 2023, but these differences were not always statistically significant due to the extremely high variability in zooplankton. We only statistically compared total calanoid copepod biomass, however not all copepods are created equal for smelt diets. The freshwater copepod *Pseudodiaptomus forbesi* is considered particularly good prey for Delta Smelt (Slater and Baxter 2014) and showed clear increases in both Suisun Marsh and Suisun Bay in wetter years and years with X2 actions. In drier years, the total biomass was similar, but much of this biomass was made of *Tortanus sp*., a large, predatory copepod not commonly found in smelt diets. Future analyses may want to focus on *Pseudodiaptomus* for evaluating the food benefits of the actions.

We could not attribute changes in the distribution and abundance of Delta Smelt to the SFHA operations due to extremely low catch. However, several Delta Smelt were caught in Grizzly Bay and one smelt was caught in Montezuma Slough during the SMSCG action in regions where salinity had been reduced by the SFHA (Figure 20). This provides evidence that conditions in the region were suitable for Delta Smelt, and operation of the SMSCG or the increase in outflow may have transported them into the area (though this is speculative). Experimental releases of Delta Smelt continued in WY 23 and are anticipated to increase in WY 24, increasing the likelihood of smelt being captured during future actions.

Ongoing attempts to determine whether Delta Smelt have higher growth and survival in Suisun Marsh or Sacramento River (Rio Vista) continued in WY 23. Biofouling of enclosures are thought to distort the actual habitat conditions compared to the site-specific ambient conditions; however, preliminary findings from the 2023 summer-fall enclosure deployments testing biofouling reduction methods provide new perspectives. Visual inspections of enclosures that were either cleaned on a weekly basis or replaced on a biweekly basis with a clean cage at both sites suggest exchanged enclosures had less algal growth than the scrubbed enclosures. No statistically significant changes in survival between the two locations or biofouling treatment types were evident, however, the fish condition factor at the Rio Vista site was significantly better than at the Suisun Marsh site. This finding contradicts the hypothesis that the Suisun Marsh would provide better habitat than Rio Vista. There is still data to be analyzed but this finding could call into question the habitat characteristics that are most important for the growth and survival of Delta Smelt in the wild.

Conclusions

After analyzing all available monitoring data, we can reach the following conclusions in relation to our hypotheses:

1. **Hypothesis: Decreasing X2 will maximize the area of Delta Smelt habitat in Suisun Bay with appropriate water temperatures, turbidity, and salinity, which will result in higher Delta Smelt growth and survival.**
   This hypothesis was partially supported.
    a. We found that the number of days with salinity less than 6 PSU in Suisun Bay in 2023 with an 80 km X2 action was similar to years with a 74 km X2 action (2017, 2019), though high temperatures limited total number of suitable habitat days. Area of LSZ in 2023 was similar to or lower than 2017. We did not have any non-X2 years with high flows for comparison, so cannot conclusively tie this to the action.
    b. We did not have enough Delta Smelt catch data to assess the impact of better habitat on Delta Smelt growth and survival.

2. **Hypothesis: Decreasing X2 will increase biomass of calanoid copepods in the low salinity zone through increased transport of freshwater species from upstream, which will result in higher Delta Smelt growth and survival.**
   This hypothesis was partially supported.

    a. Previous years with a 74 km X2 action (2017, 2019) had higher calanoid copepod biomass in the Marsh and Bay than drier years. In 2023 there was higher calanoid copepod biomass in the Marsh, but we did not see a similar increase in the Bay.
    b. We did not have enough Delta Smelt catch data to assess the impact of better habitat on Delta Smelt growth and survival.

3. **Hypothesis: Operating the SMSCGs during the summer and fall will maximize the duration and area of Delta Smelt habitat in Suisun Marsh with appropriate temperatures, turbidity, and salinity that can be accomplished with 100 TAF of water, which will result in higher Delta Smelt growth and survival.**
   This hypothesis was partially supported.
    a. We found that the number of days with salinities below 6 PSU in Suisun Marsh was similar to other high-flow years (2017, 2019) and the 35-day SMSCG action in 2018, though high temperatures limited total number of suitable habitat days. Area of LSZ habitat was higher than 2017. Temperatures were higher in Suisun Marsh than Rio Vista in 2023, contrary to our prediction based on temperature patterns in 2020-2022.
    b. Modeling suggests that the SMSCGs decreased salinity in the Marsh more than the X2 action would have alone.
    c. We did not have enough Delta Smelt catch data to assess the impact of better habitat on wild Delta Smelt growth and survival. Delta Smelt in enclosures had lower growth and survival at Belden’s Landing than Rio Vista, contrary to our hypothesis.

4. **Hypothesis: Operating the SMSCGs during the summer and fall will increase biomass of calanoid copepods in Suisun Marsh through increased transport of freshwater species from upstream, which will result in higher Delta Smelt growth and survival.**
   This hypothesis was not supported.
    a. The biomass of calanoid copepods did not increase during the 35-day 2018 action. There was an increase in biomass during the 2023 action, which may have been due to the wet conditions and fall X2 action as well as the SMSCG action, but it is unclear.

5. **Hypothesis: Operating the SMSCGs will increase the area of appropriate Delta Smelt habitat in Grizzly Bay.**
   This hypothesis was supported.
    a. Modeling data suggesting a decrease in salinity of 1-2 PSU in Grizzly Bay, increasing the low salinity zone in this region.

Additional Food Web Actions

No food web actions were implemented in 2023, but monitoring and special studies were conducted to help inform their implementation in future years.

North Delta Food Subsidy

Background

The North Delta Food Subsidies (NDFS) managed flow action redirects agricultural drainage 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. These actions are intended to transport nutrients and upstream produced phytoplankton and zooplankton (food) to increase the quality of habitat for Delta Smelt into the North Delta, including Cache Slough Complex (CSC) and potentially the lower Sacramento River. Previous flow actions have been accomplished by generating a larger than normal flow pulse of approximately 15-30 thousand acre-feet in the Yolo Bypass Toe Drain during the summer or fall period for a period of 4-6 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), though results have been variable across years (Davis et al. 2022).

Two types of flow actions (i.e., managed flow pulse) have been conducted to date: a Sacramento River action and an agricultural drainage action. The Sacramento River flow action involves rerouting of Sacramento River water through the Colusa Basin to the Yolo Bypass Toe Drain (Frantzich et al. 2021). The agricultural drainage action involves redirecting agricultural drainage water from the Colusa Basin (primarily rice agriculture) through the Yolo Bypass (Davis et al. 2022). During flow actions, DWR alters the operation of the Knights Landing Outfall Gates (KLOG) and Wallace Weir (near Knights Landing, CA) to direct the pulse into the Yolo Bypass Toe Drain 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 Reclamation and the irrigation 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 (Figure 25). 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.

Introduction

There was no managed flow action in 2023 because of ongoing consultation on the Endangered Species Act with respect to how the NDFS project is affecting threatened and endangered species in the region. Despite no managed action, standard NDFS monitoring proceeded, beginning in June and continuing through October, to improve understanding of the baseline ecological conditions in a non-managed context. Water year 2023 was classified as a wet year and followed a severe drought which provides increased context for understanding the effects of past seasons with similar antecedent conditions. Wetter water years tend to have substantial Fremont weir overtopping events which provides a food subsidy through spring as compared to drought years which do not receive off-channel subsidies and generally revert to a distributary (upstream flow) pattern in the Yolo Bypass Toe Drain by early spring. Additionally, regional patterns in agriculture (e.g., crop types and degree of fallowing) and summer/fall flows in the adjacent Sacramento River can affect water operations in the Yolo Bypass. While water allocations rebounded in 2023 and allowed planting of nearly all available rice agriculture fields in the Colusa Basin, the Yolo Bypass was not completely planted due to residual saturated soils from winter/spring flooding. Another driver of food-web conditions in the region is the Sacramento Regional Sanitation facility which discharges municipal wastewater in the Sacramento River near Freeport, CA. A decade long upgrade to tertiary wastewater treatment was finished in 2021 and is hypothesized to reduce a major source of nitrogen in the North Delta. This hydrologic and regional context has important implications for how to interpret results from the current monitoring season as well as understanding the effects of past flow actions since other environmental drivers in the region act independently of the managed flow actions. Baseline monitoring permits the observation and contextualization of other regional and temporally variable drivers and aids in the determination of whether observed ecological shifts were due to cause-and-effect relationships attributable to flow actions.

Methods

Sampling Locations

Eleven sites were reoccupied in 2023 to match previous years of NDFS sampling (Table 5). The longitudinal axis of the Yolo Bypass and North Delta was sampled from the northern input at the divergence of the Knights Landing Ridgecut from the Colusa Basin Drain, through the Toe Drain, Cache Slough Complex, to the Lower Sacramento River at Rio Vista Bridge (Figure 25). Two municipal wastewater effluent sites (WWT and DWT) were sampled upstream of their respective confluences with the Toe Drain. A control site in the adjacent Sacramento River at Sherwood Harbor (SHR) was also concurrently sampled.

TABLE 5. ASSOCIATED METADATA PERTAINING TO THE SAMPLING SITES. DISTANCE FROM IS DEFINED AS THE RIVER DISTANCE UPSTREAM FROM RIO VISTA. *SHR DISTANCE IS AN ARBITRARY VALUE FOR PLOTTING THIS CONTROL SITE WHICH INFLUENCES RIO VISTA ECOLOGICAL CONDITIONS THROUGH AN ALTERNATE PATHWAY. **DWT AND WWT DISTANCES ARE SET AT THEIR RESPECTIVE CONFLUENCES WITH THE YOLO BYPASS TOE DRAIN.

SITE	NAME	LATITUDE	LONGITUDE	DISTANCE (KM)
SHR	Sac. River at Sherwood Harbor	38.5322	-121.528	-10*
RVB	Rio Vista Bridge	38.1581	-121.683	0
RYI	Cache slough at Ryer Island	38.2143	-121.668	7.2
LIB	Liberty Island at south breach	38.2404	-121.686	10.7
PRS	Prospect slough	38.2558	-121.671	13.0
BL5	Prospect slough - Below Lisbon 5	38.2746	-121.665	15.2
STTD	Toe Drain terminus	38.3534	-121.643	24.2
LIS	Toe Drain at Lisbon Weir	38.4759	-121.589	38.7
I80	Toe Drain at Interstate 80	38.5747	-121.583	49.8
DWT	Davis wastewater treatment	38.5675	-121.638	52.0**
RD22	Toe Drain at Road 22	38.6775	-121.644	62.6
WWT	Woodland wastewater treatment	38.6816	-121.646	64.0**
RCS	Colusa Drain at Ridge-cut Slough	38.7932	-121.726	78.7

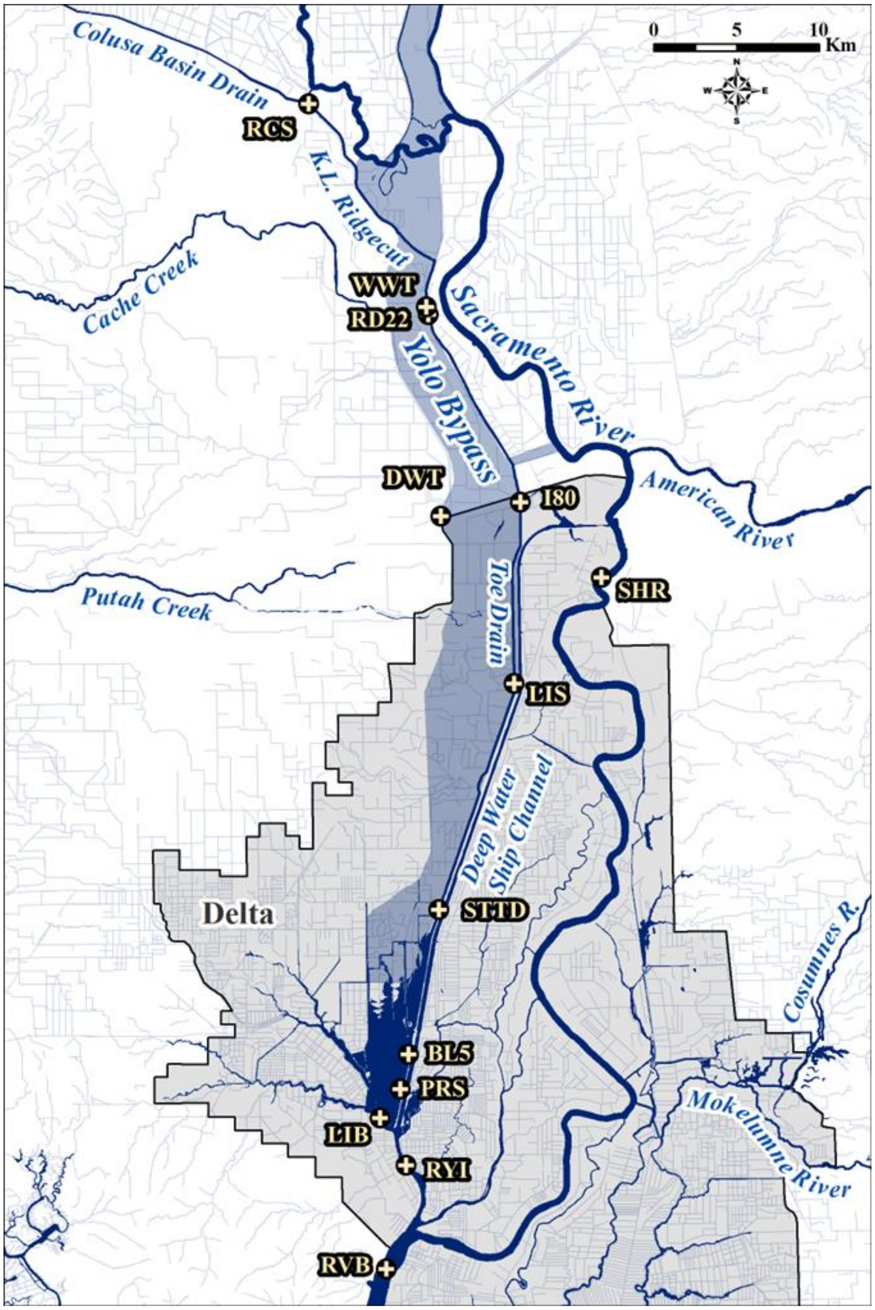

FIGURE 25. MAP OF SAMPLING LOCATIONS FOR THE 2023 NORTH DELTA FOOD SUBSIDIES PROJECT.

Results

Hydrology

The 2023 water year was categorized as a wet water year, (https://cdec.water.ca.gov) with extensive winter and spring flooding across the Central Valley. Similar to past wet years, this led to a delayed reversal of flow in the Yolo Bypass Toe Drain at Lisbon Weir. As flow receded and agricultural diversions increased in mid-May, the net discharge from the Toe Drain resumed its standard summer distribution mode (Figure 26). Despite the wet water year classification, the non-managed flow pulse which occurred between late-August through September was detectable but was not of sufficient magnitude to achieve net positive (downstream) flow through the Toe Drain into the CSC.

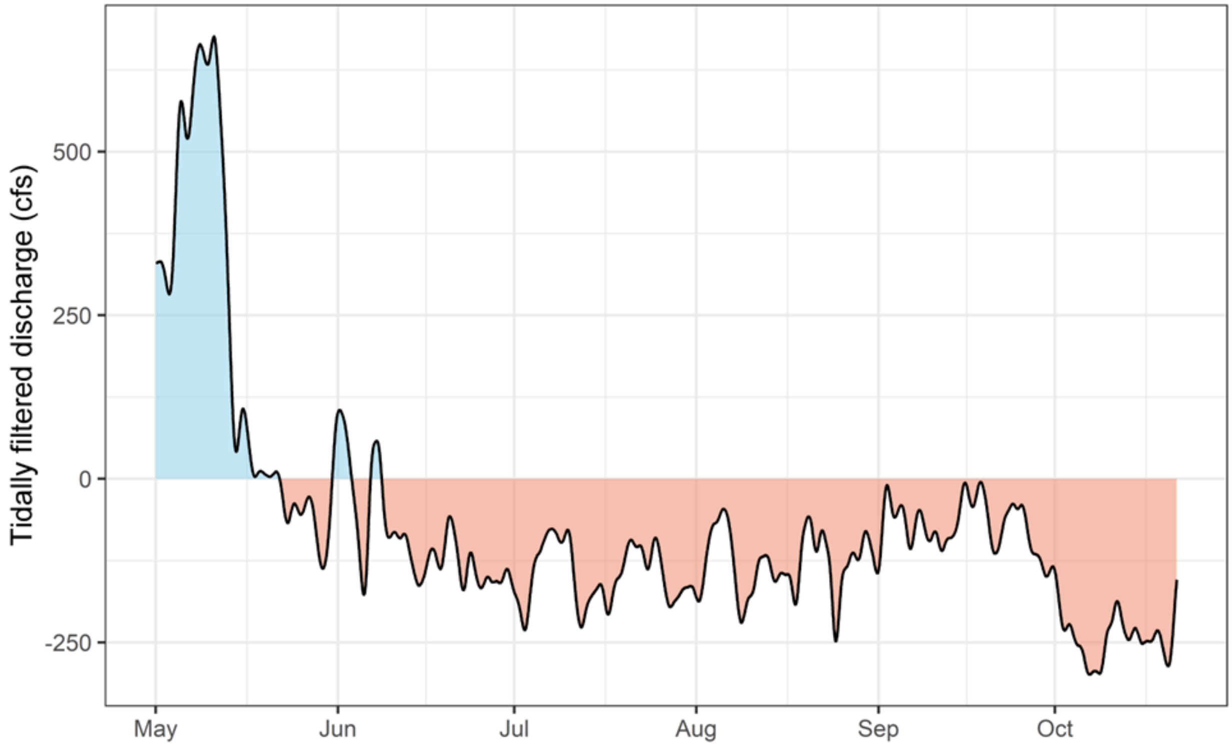

FIGURE 26. TIDALLY FILTERED DISCHARGE IN CUBIC FEET PER SECOND FROM THE LOWER TOE DRAIN AT USGS STATION: 11455140 (APPROXIMATELY 0.4KM DOWNSTREAM OF STTD).

Discrete field water quality measurements

Regional and temporal trends were apparent in the discrete water quality parameters. Regionally, the northern sites showed a distinct pattern of higher conductivity (SPC) and lower water clarity (lower secchi and higher turbidity) compared to southern sites in the CSC and lower Sacramento River (Figure 27). The transition zone was located at LIS during the summer months, but when water conditions were positive or near positive, the transition zone shifted closer to STTD at the terminus of the Toe Drain. The transition zone was especially apparent in the specific conductivity (SPC) parameter and signifies the influence of Sacramento River water entering the lower Toe Drain from the southern end of the CSC. From a temporal perspective there was a gradual trend of increasing water clarity in the CSC.

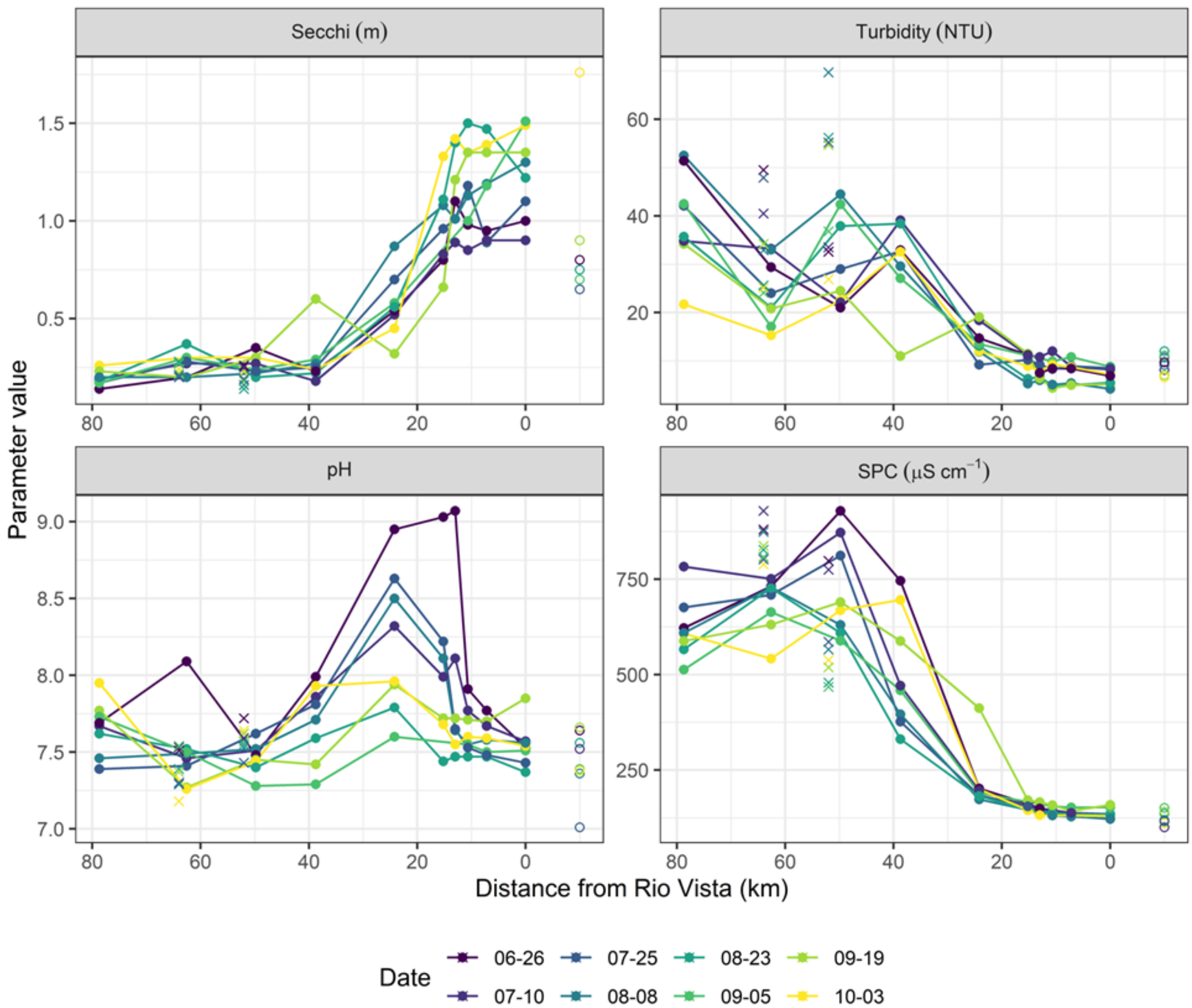

FIGURE 27. DISCRETE WATER QUALITY PARAMETERS (SECCHI DISTANCE, TURBIDITY, PH, AND SPECIFIC CONDUCTIVITY) PLOTTED BY RIVER DISTANCE ON THE X-AXIS AND PARAMETER VALUE ON THE Y AXIS. POINTS ARE CONNECTED BY LINES AND REPRESENTED BY COLORS CORRESPONDING TO EACH SURVEY TRANSECT DATE. NOTE: SHR (OPEN CIRCLE) IS ASSIGNED AN ARBITRARY DISTANCE FROM RIO VISTA OF -10 SO THAT IT APPEARS AS AN ALTERNATE PATHWAY TO THE YOLO BYPASS/CSC LONGITUDINAL AXIS. WASTEWATER TREATMENT INPUTS (DWT AND WWT; X SYMBOLS) ARE POSITIONED AT THEIR CONFLUENCE WITH THE TOE DRAIN BUT NOT CONNECTED BY LINES SINCE THE LOCATIONS ARE OFF CHANNEL.

Discrete nutrients and primary production

Nutrient and chlorophyll-α levels displayed similar regional patterns to the physical water quality parameters. The upstream sites tended to have higher concentrations of chlorophyll-α and pheophytin, higher dissolved organic carbon, higher nutrients (NH4, NO2-No3, PO4), as well as higher concentrations of dissolved minerals (silicate, calcium, and chloride) compared to downstream locations (Figure 28).

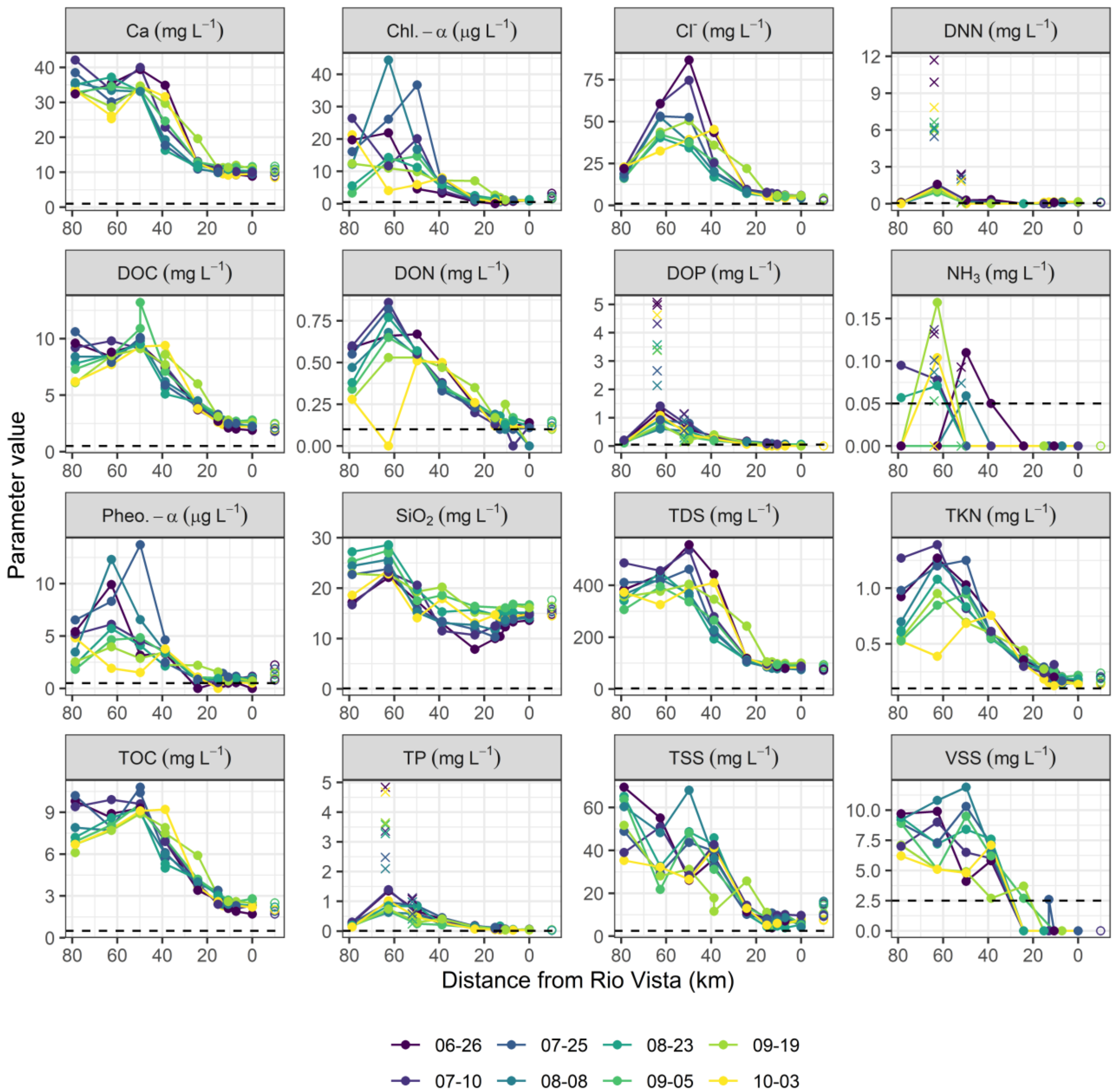

FIGURE 28. NUTRIENT AND PRIMARY PRODUCTION PARAMETERS FROM WATER GRAB SAMPLES PROCESSED AT THE BRYTE LABORATORY. VALUES BELOW REPORTING LIMITS (DASHED LINES) WERE ASSIGNED A VALUE OF ZERO.

Continuous water quality

Distinct regional and temporal patterns in continuous water quality parameters were evident. In general, the upstream region was characterized by higher concentrations of chlorophyll-α, elevated turbidity, elevated specific conductance, and reduced dissolved oxygen (Figure 29). As in the discrete water quality data, the transition zone was located approximately at the LIS site but shifted depending upon variable flow conditions in the Toe Drain. For example, when flow was positive in the Toe Drain in the early season and near positive in September, the specific conductivity at LIS were similar to upstream sites (Figure 30). Conversely, when flow was negative in the Toe Drain during the summer months and October, specific conductivity at LIS and STTD converged with values at downstream sites (Figure 30).

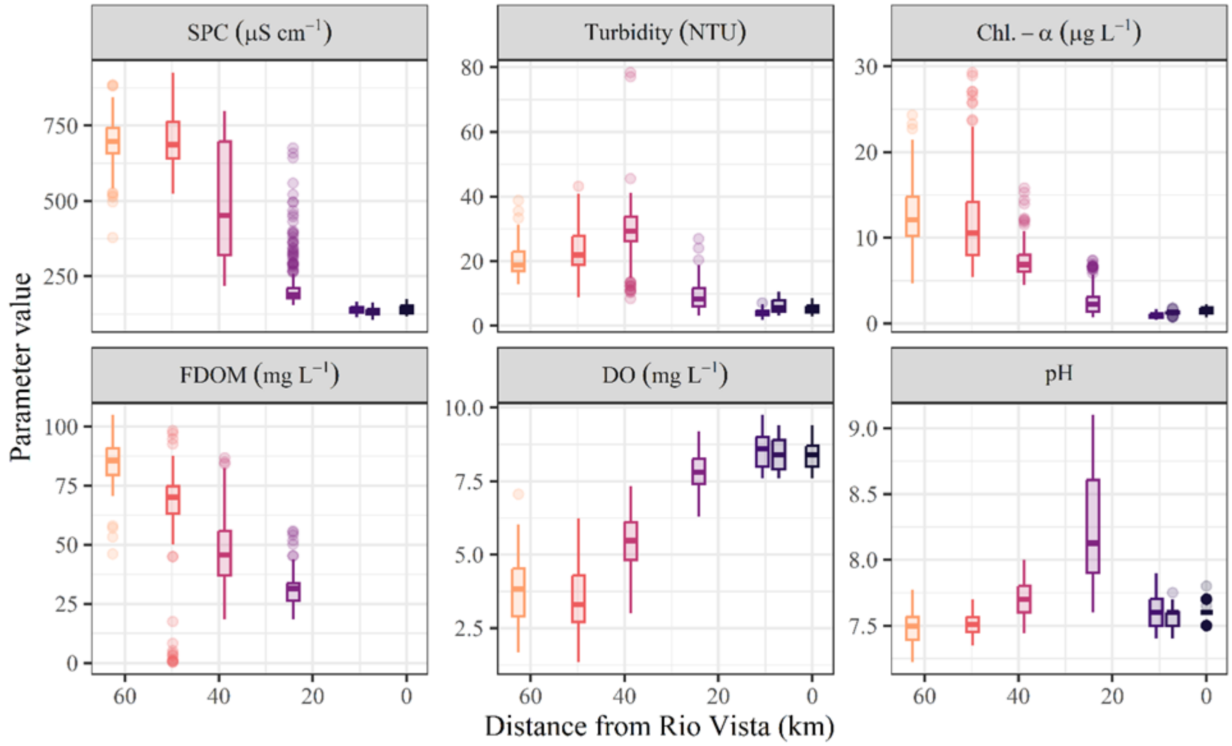

FIGURE 29. BOXPLOTS OF DAILY MEDIAN VALUES FOR CONTINUOUSLY MEASURED WATER QUALITY PARAMETERS GROUPED BY PARAMETER AND SITE DISTANCE UPSTREAM OF RIO VISTA.

Water temperatures were generally higher in the northern region with daily max water temperatures often exceeding 24 Celsius. Dissolved oxygen levels were depressed in the northern sites with values at or below 6mg/L for a majority of the study period. The depressed dissolved oxygen is likely a result of the decreased light penetration due to increased turbidity. There was also increased heterotrophic and autotrophic respiration likely occurring in the stagnant water and higher residence time conditions.

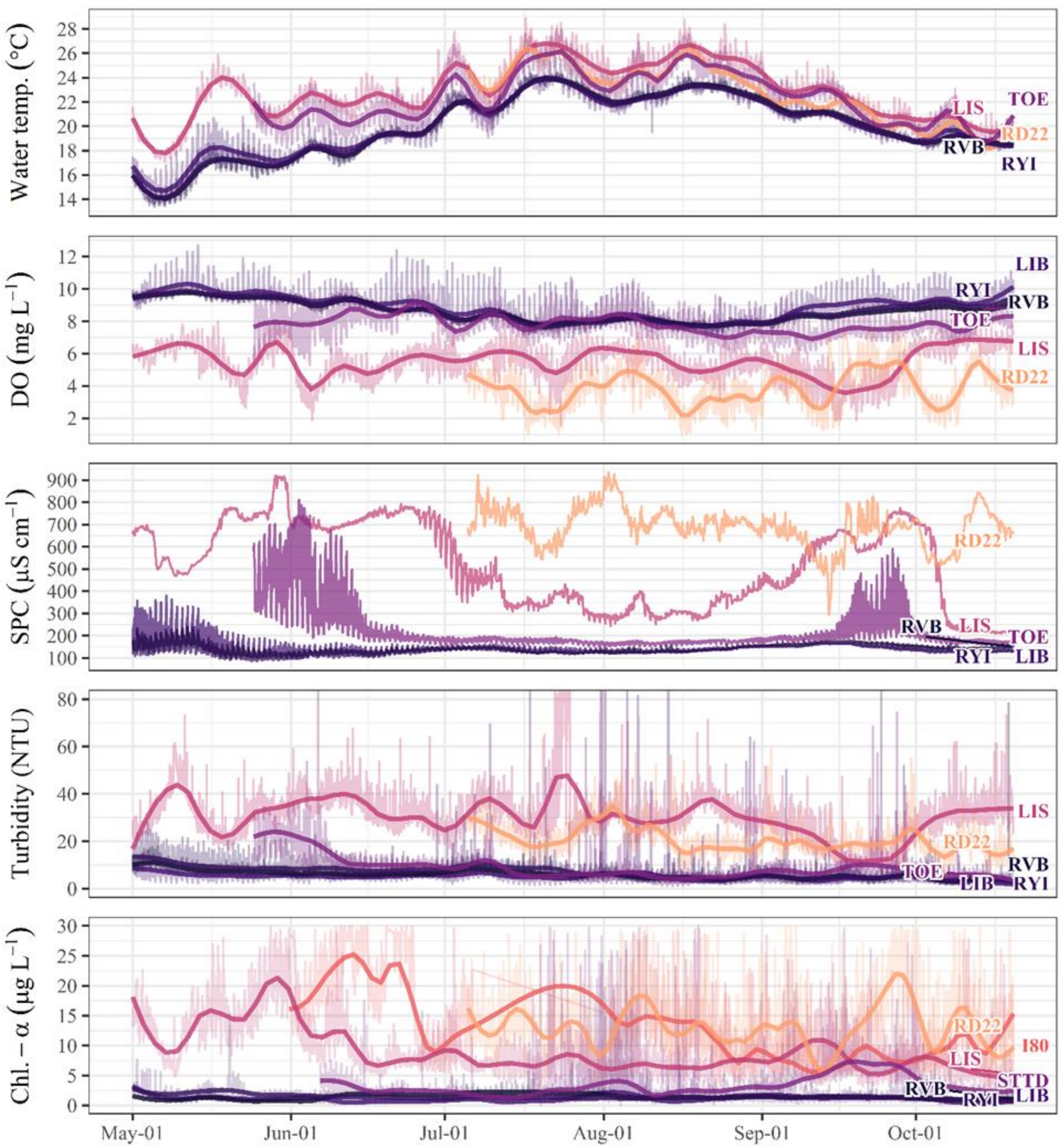

FIGURE 30. TIME SERIES PLOTS OF CONTINUOUSLY RECORDED WATER QUALITY VARIABLES. NOTE: NOT ALL CONTINUOUS DATA HAS BEEN COLLECTED AND PROCESSED.

Phytoplankton

Data forthcoming. Species identification and density estimation is in process by a contractor.

Zooplankton

Seasonal patterns in the zooplankton data included a general trend of reduced abundance as the sampling season progressed. A linear mixed effects model with natural log transformed total zooplankton density (ind/m^3) as the response variable and with day of year as a fixed effect and random effect of station (ln(total density) ~ day + (1|station)), supported the visual assessment with a significant negative slope (slope = -0.01 days, t-value = -4.06, df = 73.2, $p < 0.001$). However, not all sites displayed the decreasing pattern, so to investigate heterogenous responses across sites, a more complex model with variable slopes in addition to intercepts (ln(total density) ~ 1 + (date|station)), was also run. The variable slopes model had a lower AIC value (AIC = 259.7) than the variable intercept only model (AIC = 263.8) indicating a better representation of the data. The variable slopes model indicated that the positive relationship between zooplankton density and day of year was only observed at STTD and SHR. The exact mechanism for why these sites behaved differently from other sites is unclear but may indicate some local hydrodynamics and/or off-channel input effects from nearby restored wetlands (i.e. Flyway Farms).

The zooplankton community showed a strong regional pattern which consisted of a preponderance of Calanoid copepod taxa in downstream locations in the CSC (BL5, PRS, LIB, RYI) and lower Sacramento River (RVB) (Figure 31). This contrasted with the zooplankton community of upstream locations in the Yolo Bypass Toe Drain (RCS, RD22, and I80) dominated by Cladocera and Cyclopoid taxa. While the density of zooplankton was highest in the upstream Toe Drain sites (Figure 31B), the dominant taxa were smaller bodied taxa (Bosmina: max = 79,176 ind/m^3) and life stages (cycolopoid copepedites: max 36972 ind/m^3). A transition zone between the upstream and downstream regions was apparent in the lower Toe Drain encompassing the LIS and STTD sites and displayed the highest variability in community composition as shown by the highest variance along the NMDS1 axis (Figure 32). The control site on Sacramento River (SHR) showed low zooplankton levels and proportionally higher macrozooplankton taxa dominated by bivalvia veliger and insect larvae.

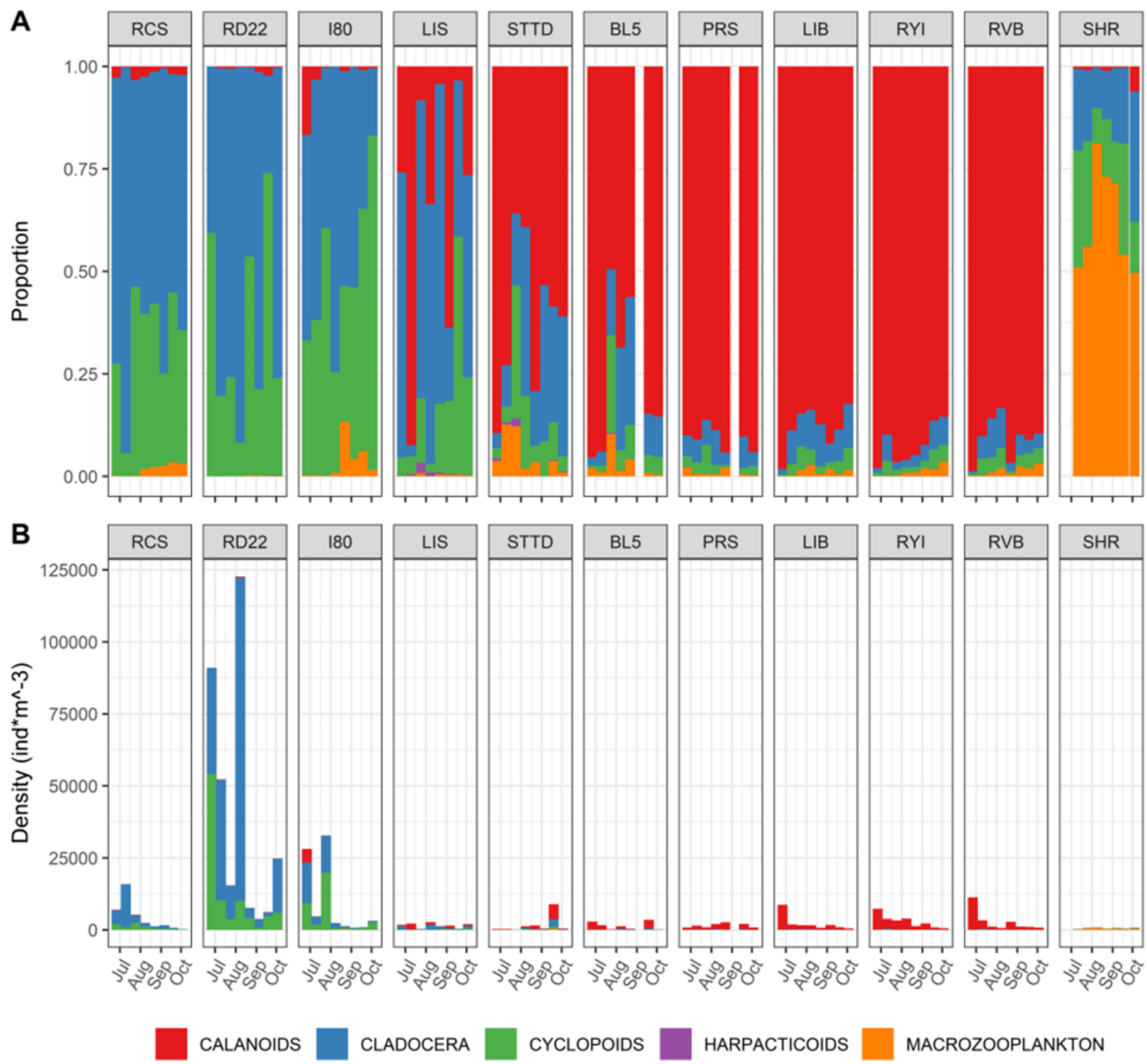

Figure **31**

Seasonal patterns in the zooplankton data included a general trend of reduced abundance as the sampling season progressed. A linear mixed effects model with natural log transformed total zooplankton density (ind/m^3) as the response variable and with day of year as a fixed effect and random effect of station (ln(total density) ~ day + (1|station)), supported the visual assessment with a significant negative slope (slope = -0.01 days, t-value = -4.06, df = 73.2, $p < 0.001$). However, not all sites displayed the decreasing pattern, so to investigate heterogenous responses across sites, a more complex model with variable slopes in addition to intercepts (ln(total density) ~ 1 + (date|station)), was also run. The variable slopes model had a lower AIC value (AIC = 259.7) than the variable intercept only model (AIC = 263.8) indicating a better representation of the data. The variable slopes model indicated that the positive relationship between zooplankton density and day of year was only observed at STTD and SHR. The exact mechanism for why these sites behaved differently from other sites is unclear but may indicate some local hydrodynamics and/or off-channel input effects from nearby restored wetlands (i.e. Flyway Farms).

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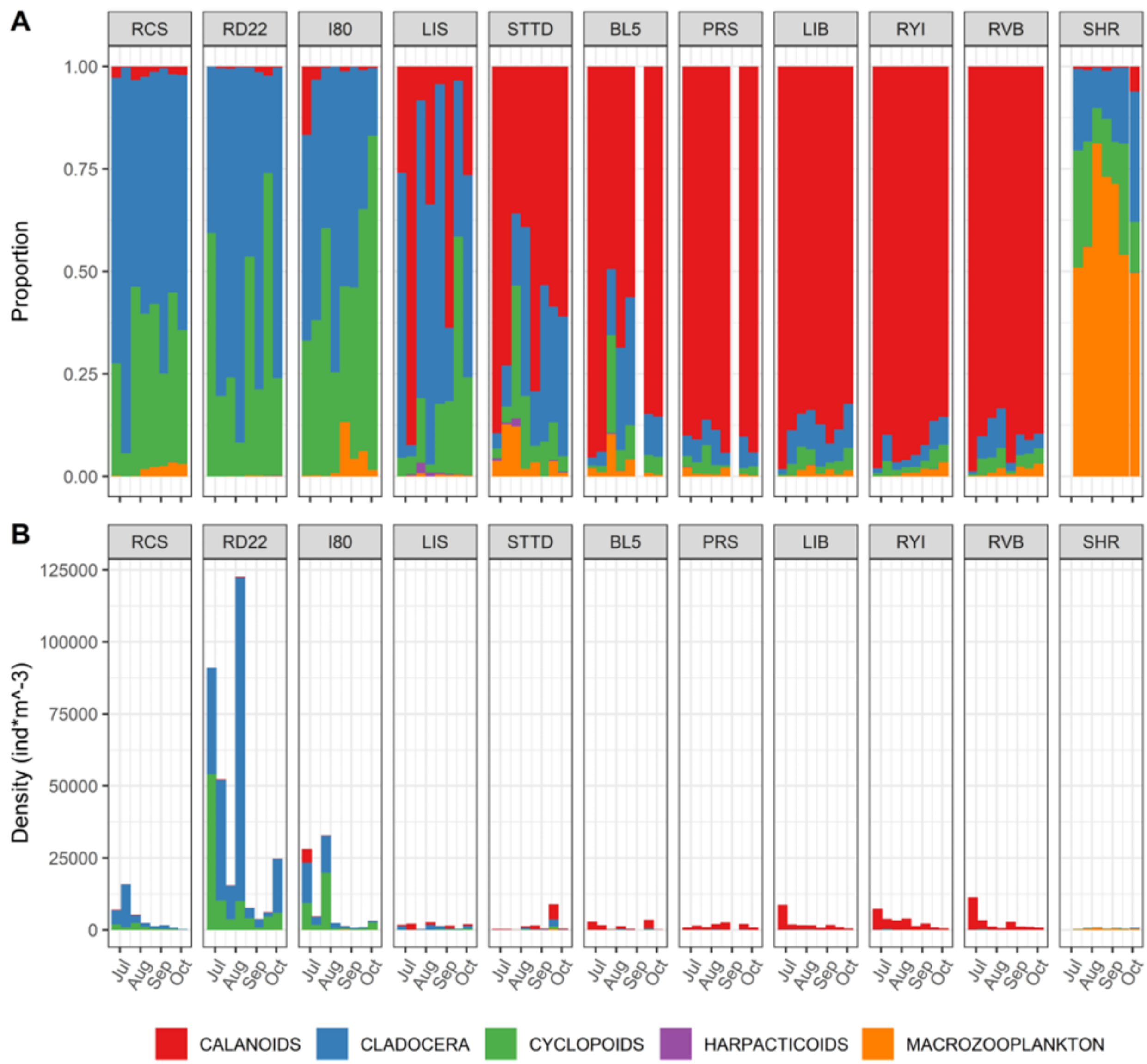

FIGURE 31. A) PROPORTION OF ZOOPLANKTON FOR EACH STATION AND DATE COMBINATION COLORED BY ZOOPLANKTON CLASSIFICATION. B) TOTAL ZOOPLANKTON ABUNDANCE FOR EACH STATION AND DATE COMBINATION COLORED BY ZOOPLANKTON CLASSIFICATION.

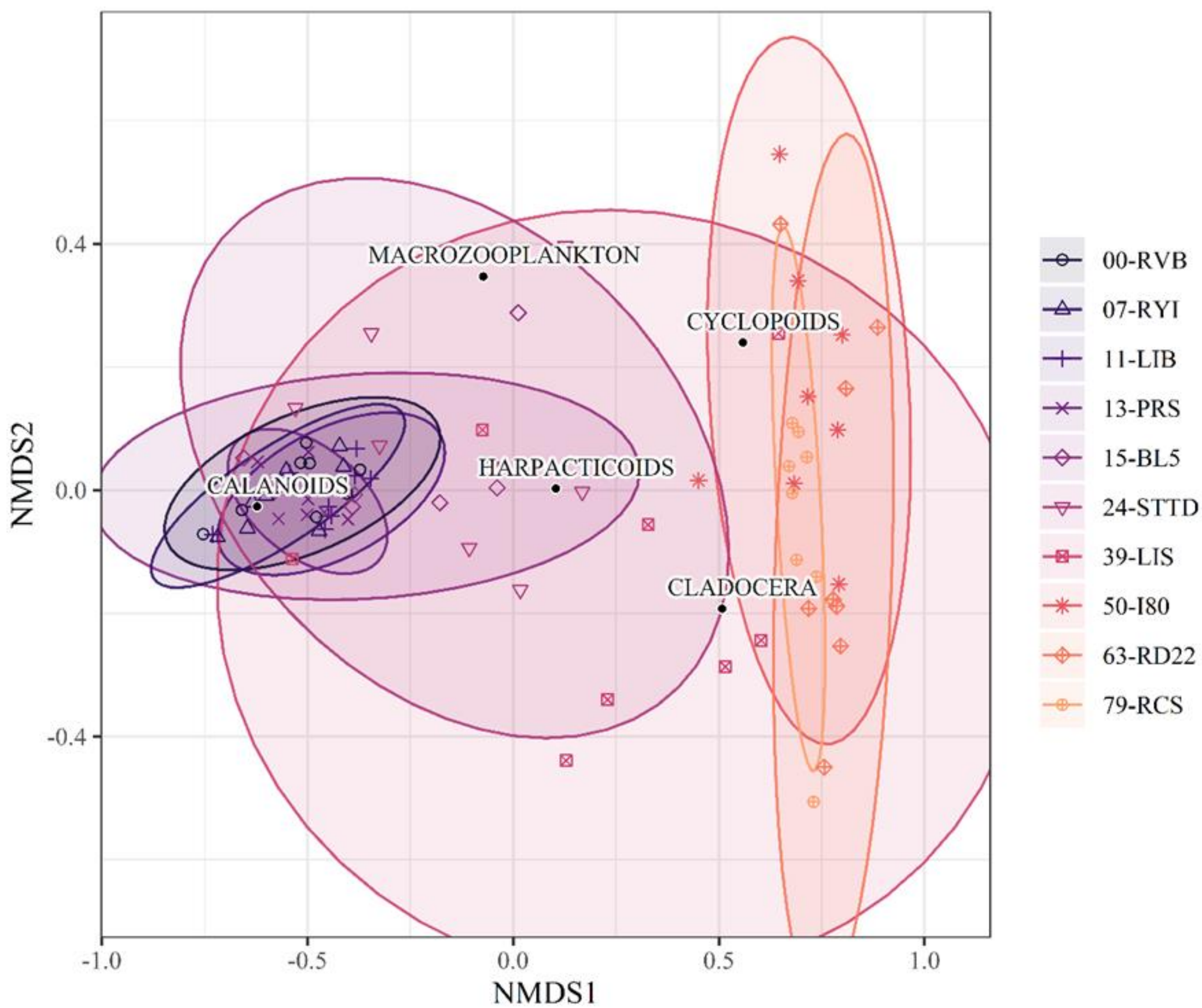

FIGURE 32. NON-METRIC MULTIDIMENSIONAL SCALING PLOT SHOWING THE REGIONAL PATTERNS IN ZOOPLANKTON COMMUNITY. SITE LEGEND INCLUDES STATION NAMES APPENDED WITH TRANSECT DISTANCES IN KM UPSTREAM FROM THE DOWNSTREAM-MOST SITE IN THE SACRAMENTO RIVER AT RIO VISTA (RVB).

Contaminants

Ambient water contaminants

Contaminant concentrations varied both regionally and seasonally across the study (Figure 33 and Figure 34). Notable regional patterns included: 1) the highest number of contaminant compound detections (n = 45) were observed at RD22, 2) the lowest number of detected contaminant compounds (n = 12) occurred at SHR, 3) the three highest contaminant compound concentrations were observed at RCS including 3,4-DCA (4537.8 ng/L), propanil (2478.2 ng/L) and azoxystrobin (1552.7 ng/L), 3) the synergist, piperonil butoxide, was only observed in the northernmost sites (RCS, RD22), 4) deltamethrin, a pyrethroid insecticide, was detected in samples at northern sites (RCS, RD22, and STTD) at levels which exceeded EPA acute invertebrate toxicity benchmarks (United States Environmental Protection Agency, 2023), 5) the aquatic herbicide, fluridone, was observed in the highest concentrations at STTD and LIS but was also present at lower concentrations at RCS, BL5, and RYI.

Notable seasonal patterns included: 1) the primary agricultural fungicide, azoxystrobin, was most prevalent in the Colusa Drain at RCS during the onset of the rice drainage season, early- to mid-August, 2) the synergist, piperonil butoxide, was only observed between Late June and early August, 3) insecticides were consistently found in higher concentrations in the northern sites (RCS, RD22, LIS) compared to sites in the CSC and lower Sacramento River, 4) insecticides, in particular methoxyfenocide, were observed in the highest concentrations at LIS in September and early October.

Suspended particle contaminants

Patterns in suspended particle contaminant detections across sites were generally similar to ambient water contaminants (Figure 35 and Figure 36). However, the SHR site had relatively more contaminant detections in the suspended particles versus the ambient water samples compared to the other sites. Overall, there were fewer contaminant compounds observed across all sites (n = 25) compared to ambient water samples (n = 53).

Notable regional patterns included: 1) the highest number of contaminant compound detections (n = 20) were observed at RCS, 2) the lowest number of detected contaminant compounds (n = 8) occurred at STTD, 3) a high concentration (1107.34 ng/g) of the aquatic herbicide compound, fluridone, was observed at STTD on 9/19/2023, and 4) the legacy organochlorine contaminant, Dichlorodiphenyltrichloroethane (DDT), was observed at SHR as was an organochlorine degradate, DDE, at all sites except STTD.

Notable temporal patterns included: 1) high concentrations of the fungicide compound azoxystrobin were observed during the agricultural drainage period (August-September), 2) insecticides were elevated at upstream sites during the agricultural drainage period, and 3) insectides were prevalent through much of the sampling season in the river (SHR) and sites in the Cache Slough Complex (BL5 and RYI).

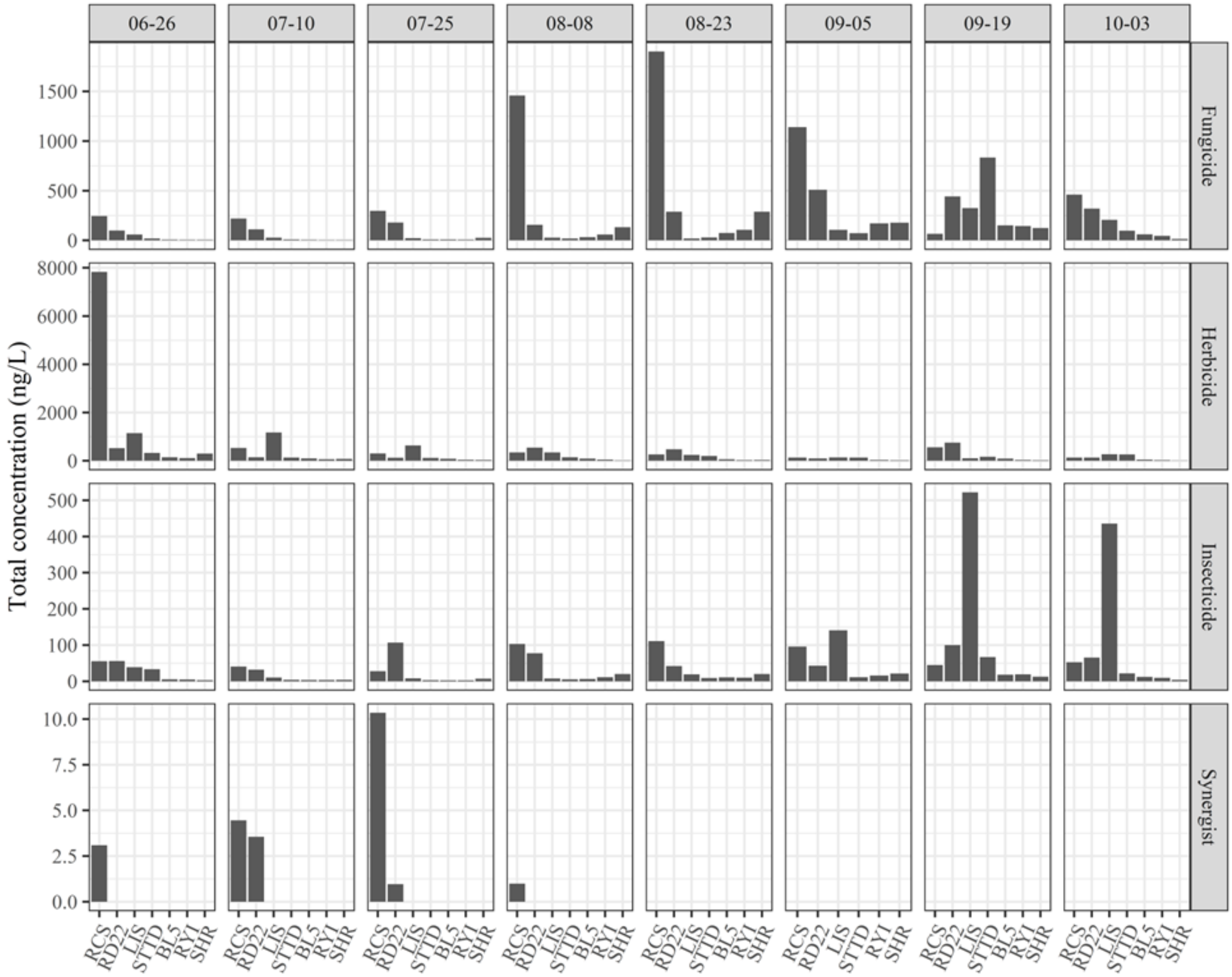

FIGURE 33. CONTAMINANT CONCENTRATIONS FROM AMBIENT WATER SAMPLES IN NANOGRAMS/LITER SUMMED BY SAMPLING TRANSECT START DATE (HORIZONTAL FACET) AND CONTAMINANT CLASSIFICATIONS (VERTICAL FACET).

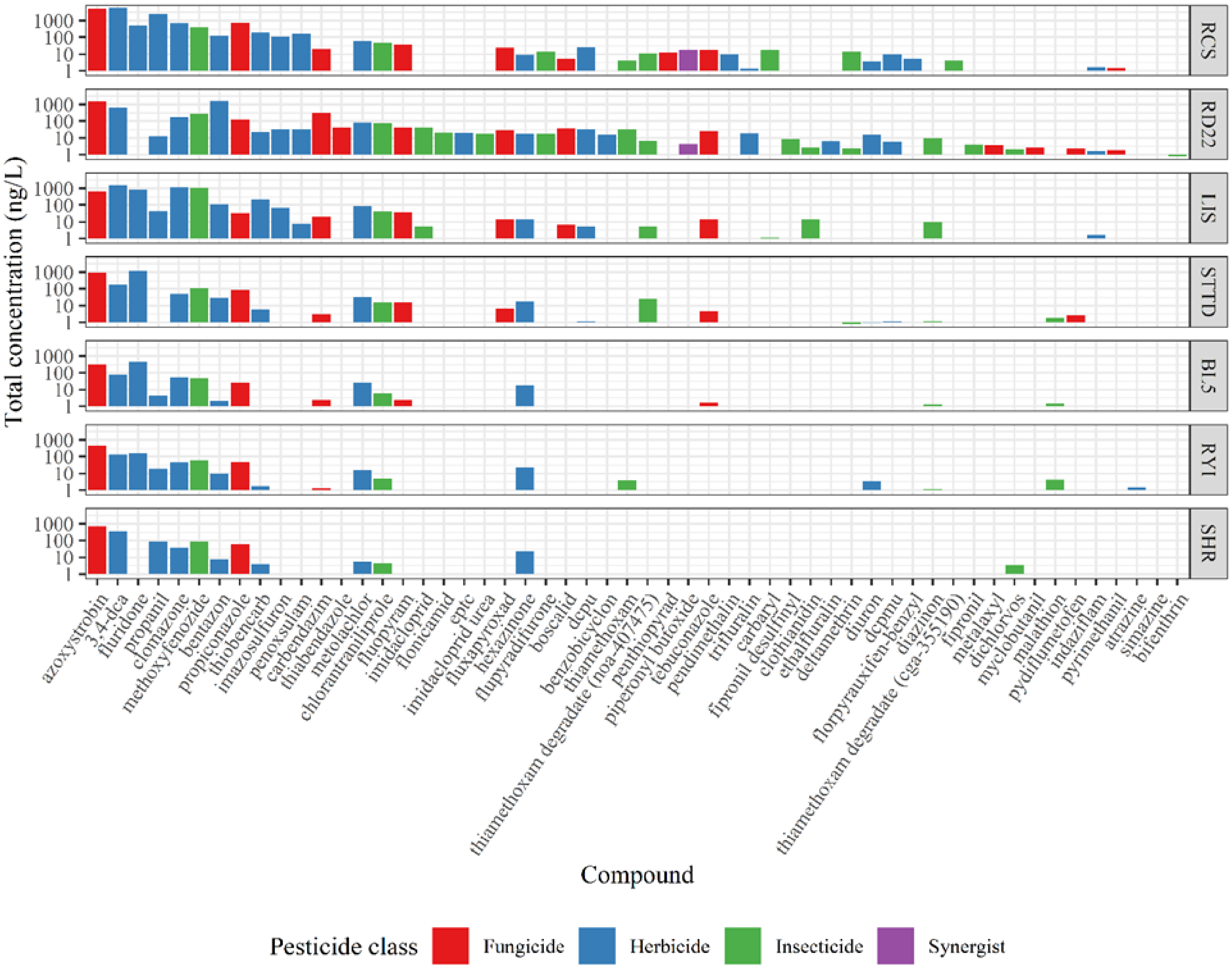

FIGURE 34. TOTAL CONCENTRATION (NG/L) OF INDIVIDUAL CONTAMINANT COMPOUNDS OBSERVED IN AMBIENT WATER SAMPLES SUMMED AT EACH SITE ACROSS ALL SAMPLING TRANSECTS. BAR COLORS REPRESENT THE BROAD CONTAMINANT CLASSES (FUNGICIDES, HERBICIDES, INSECTICIDES, AND SYNERGISTS).

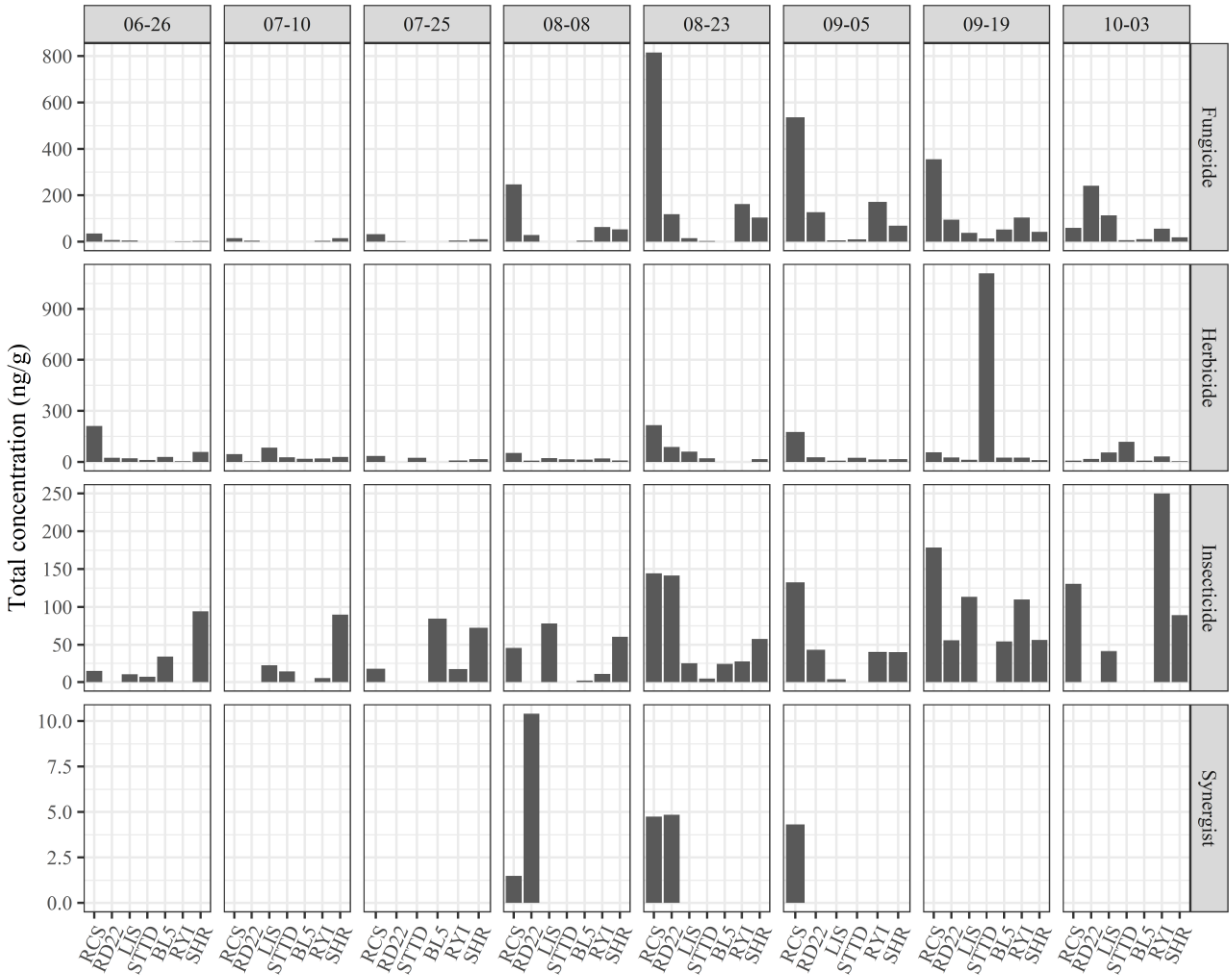

FIGURE 35. CONTAMINANT CONCENTRATIONS IN SUSPENDED PARTICLE SAMPLES IN NANOGRAMS/GRAM SUMMED BY SAMPLING TRANSECT START DATE (HORIZONTAL FACET) AND CONTAMINANT CLASSIFICATIONS (VERTICAL FACET).

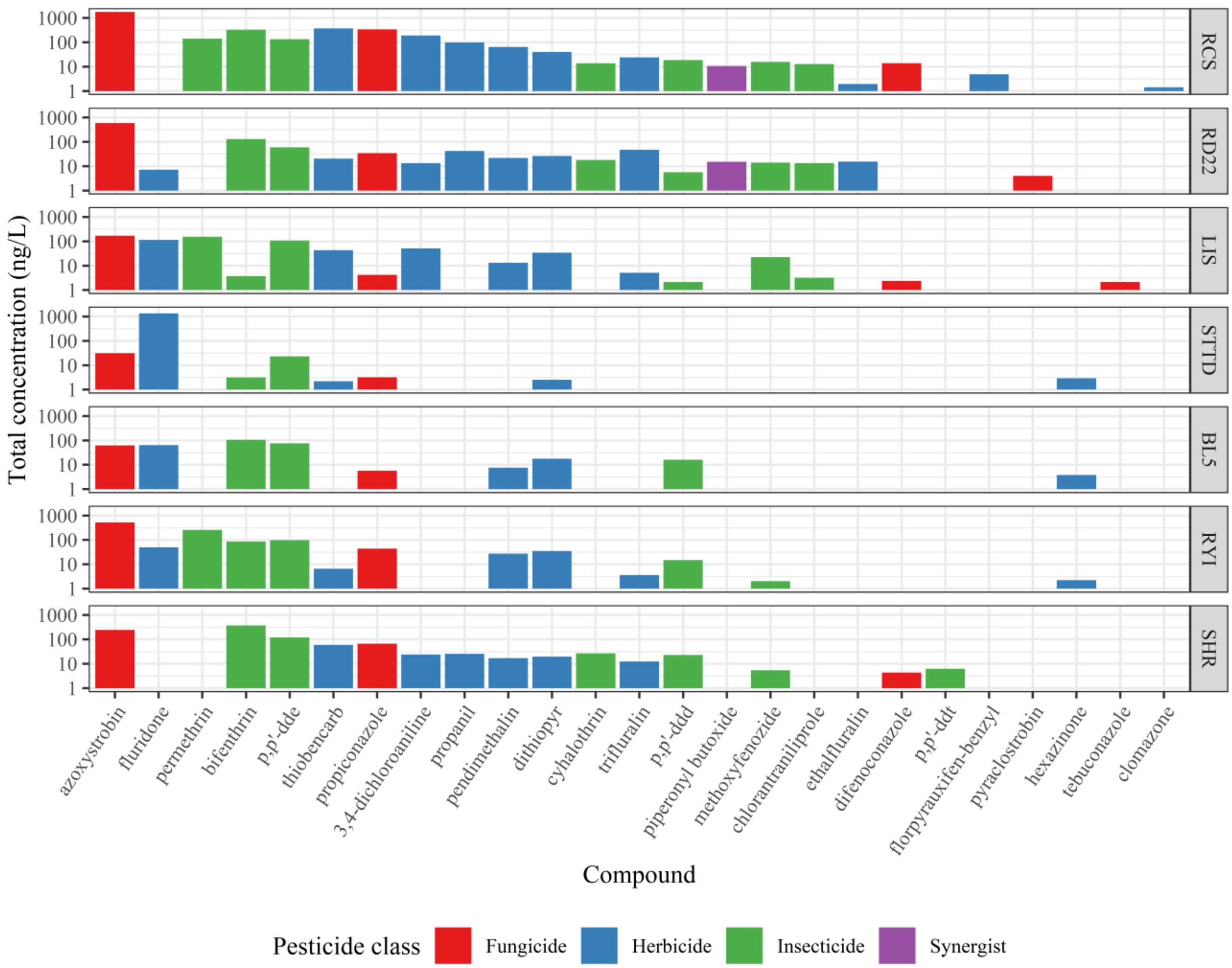

FIGURE 36. TOTAL CONCENTRATION (NG/G) OF INDIVIDUAL CONTAMINANT COMPOUNDS FROM SUSPENDED PARTICLE SAMPLES SUMMED AT EACH SITE ACROSS ALL SAMPLING TRANSECTS. BAR COLORS REPRESENT THE BROAD CONTAMINANT CLASSES (FUNGICIDES, HERBICIDES, INSECTICIDES, AND SYNERGISTS).

Sample and data collection

The sampling period began on June 24th and ended on Oct 10th. Sampling transects were conducted once every two weeks with all sites except for SHR collected on one day. The samples collected during each transect included point water quality (with sonde), nutrient and chlorophyll-α grab samples, phytoplankton grab samples, and zooplankton tows (Table 6.). Detailed sampling methods are described in the NDFS Workplan (DWR 2023). Continuous water quality monitoring at a 15-min interval was conducted at a subset of sites and compiled from the DWR Water Data Library (RCS, RD22, I80, LIS, RVB; https://wdl.water.ca.gov/waterdatalibrary) and the USGS National Water Information System (TOE = STTD, LIB, RYI; https://waterdata.usgs.gov/nwis). Point water quality parameters including temperature (°C), dissolved oxygen (mg/L), electrical conductivity (µS/cm), specific conductivity (µS/cm), pH, and turbidity (FNU) were collected at a biweekly interval with a YSI ProDSS handheld sonde. Nutrient and chlorophyll parameters including Chlorophyll a (µg/L), Pheophytin (µg/L), Dissolved Ammonia (mg/L), Dissolved Chloride (mg/L), Dissolved Nitrate Nitrite (mg/L), Dissolved Organic Phosphorous (DOP, mg/L), Dissolved Organic Nitrogen

(DON, mg/L), Dissolved Organic Carbon (DOC, mg/L), Total Organic Carbon (TOC, mg/L), Total Organic Phosphorus (TOP, mg/L), Total Kjeldahl Nitrogen (TKN mg/L), Total Dissolved Solids (TDS mg/L), Total Suspended Solids (TSS mg/L), and Volatile Suspended Solids (VSS, mg/L) were collected at a biweekly interval via grab samples with either a Van Dorn or dip pole method and processed by the Bryte water quality laboratory within 24 hours of field collection. Phytoplankton samples were collected from the water grab samples and preserved on 10% Lugol's solution. Zooplankton samples were collected with a 50 cm diameter and 150 um mesh net towed near the water surface for 5 minutes from either a motorized boat or a pedal powered kayak. Ambient water contaminant samples were collected in 1L brown glass bottles opened and filled underwater at a depth of approximately 0.5m. Suspended particle contaminant samples were collected with a 50cm diameter 150um mesh zooplankton net towed behind a motorized boat or pedal powered kayak for 10 minutes. All contaminant samples were kept refrigerated and assays were conducted at the USGS Sacramento State laboratory within 48 hours of field collections.

TABLE 6. GRID OF DATA AND SAMPLES COLLECTED AT EACH SITE. CELL CODES AND COLORS REPRESENT STATUS OF THE DATA (YY = SAMPLES COLLECTED AND DATA AVAILABLE, YP = SAMPLES COLLECTED AND DATA PARTIALLY AVAILABLE, YN = SAMPLES COLLECTED BUT DATA NOT AVAILABLE, N = NO SAMPLES COLLECTED). DATA ARE PROVISIONAL AND SUBJECT TO CHANGE.

Sample type	RCS	WWT	RD22	DWT	I80	LIS	STTD	BL5	PRS	LIB	RYI	RVB	SHR
Continuous WQ	YY	N	YY	N	YY	YY	YY	N	N	YY	YY	YY	N
Point WQ	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
Nutrients	YP	YP	YP	YP	YP	YP	YP	YP	YP	YP	YP	YP	YP
Phytoplankton	YN	N	YN	N	YN	YN	YN	YN	YN	YN	YN	YN	YN
Zooplankton	YY	N	YY	N	YY	YY	YY	YY	YY	YY	YY	YY	YY
Contaminants WQ	YY	N	YY	N	N	YY	YY	YY	N	N	YY	YY	YY
Contaminants zoop	YY	N	YY	N	N	YY	YY	YY	N	N	YY	YY	YY

Discussion

Similar to past years, strong regional patterns in nutrients, water quality, phytoplankton (chlorophyll-α proxy), and contaminant concentration levels were evident. The regional pattern consisted of high nutrient availability in the middle Yolo Bypass reach of the Toe Drain (near RD22 and I80) where inputs from Woodland and Davis municipal wastewater treatment facilities occur. This area also experiences low to zero discharge for much of the summer and early fall due to a lack of downstream flow through the Knights Landing Ridge Cut and little to no tidal exchange with the downstream reach. The combination of high residence time and high nutrient supply likely contributes to the development of elevated chlorophyll-α levels. This region of the Yolo Bypass Toe Drain is also highly impacted by input of contaminants from agricultural and municipal sources.

Downstream in the CSC and lower Sacramento, the region is characterized by high water clarity and low phytoplankton abundance. Despite the lower phytoplankton densities, the zooplankton densities (based on qualitative zooplankton score) were relatively high. Due to uncertainties in trophic pathways, it is unclear whether the low phytoplankton levels were a result of top-down pressure from grazing zooplankters or bottom-up limitation from low nutrient availability, or a structural control whereby strong tidal pumping and water delivery operations create advective conditions which limit the proliferation of phytoplankton via reduced residence time.

Seasonal progression of ecological conditions was apparent in both the upstream and downstream regions. In the northernmost site, RCS, water quality and lower trophic conditions were dependent primarily on upstream agricultural operations. This resulted in conditions during the growing period (June, July, early August), when low flow conditions were prevalent in the Colusa drain, where zooplankton and phytoplankton levels tended to be higher. During the growing period there was also a tendency for higher agricultural pesticide concentrations. During the agricultural drainage period, a dilution effect was apparent with reduced zooplankton and phytoplankton levels. The agricultural drainage was also associated with an increase in suspended sediments, reduced water clarity and an increase in certain contaminants including the fungicide azoxystrobin increased.

The conditions observed at RCS were disconnected from the nearest site downstream, RD22, for the entirety of the season due to low Sacramento River water stage permitting the Knights Landing Outfall Gates to drain all Colusa Drain waters rather than diverting south through the Knights Landing Ridgecut and ultimately the Yolo Bypass Toe Drain. This meant that the Yolo Bypass Toe Drain conditions were largely dependent upon inputs from wastewater treatment effluent and local agricultural and wetland drainage. The resulting conditions in the center region of the Yolo Bypass Toe Drain were stagnant with little downstream flow observed between RD22 and I80. Due to the high nutrient concentrations in the wastewater effluent, phytoplankton blooms were apparent (chlorophyll-α concentration proxy and visually), but with little to no export of productivity to downstream sites. The exception to this pattern occurred in September when local agricultural drainage resulted in some downstream distribution of upstream derived chlorophyll-α. This can be observed in the data (Figure 30) where water conditions at STTD briefly saw increases in chlorophyll-α and specific conductivity indicating the influence of upstream water sources despite the net flow being negative (i.e., upstream flow). This effect was limited spatially to the terminus of the Toe Drain and the effect was not observed at sites in the CSC (e.g., BL5, PRS, LIB).

In the downstream region including the CSC and lower Sacramento River sites, there was a seasonal pattern with increasing water clarity (evidenced by increased secchi distance and reduced turbidity) throughout the summer and early fall. Despite the apparent lack of phytoplankton in the downstream region, high zooplankton densities were periodically observed (anecdotally for now until zooplankton count data are available). High zooplankton densities observed early in the season may be attributable to the tail end of a prodigious hydrologic year where off-channel inundation of large portions of the Yolo Bypass likely contributed directly to zooplankton levels as well as particulate organic matter which fueled the food web. The lingering effect of off-channel subsidies tapered off through the summer months as the influence of fresher (i.e., lower conductivity), low residence time, Sacramento River water prevailed. This effect was observed in the conductivity data where early season conditions in the downstream region showed higher conductivity levels indicative of Yolo Bypass and Cache Slough water sources, versus later in the season where convergence with Sacramento River conditions was observed.

Despite no managed flow action in 2023, monitoring of conditions in the lower Colusa Drain, Yolo Bypass Toe Drain, and Cache Slough Complex yielded insights into the mechanisms and seasonality which drive ecological conditions in the region. The challenge of determining a cause-and-effect relationship due to managed flow actions is complicated by the fact that each year is unique in its antecedent hydrologic conditions and operation of water infrastructure. Furthermore, the constant efforts against nuisance vegetation and pests results in variable application of pesticides which ultimately affect water bodies in ways that are not fully understood. Non-action years like this are useful in that observed patterns can be used to improve the interpretation of previous action years since there is a paucity of available control data.

Sacramento Deep Water Ship Channel Food Web study

The Sacramento Deepwater Ship Channel (SDWC) is one of the few areas in the Delta in which Delta Smelt are detected fairly consistently. This, despite experiencing temperatures that regularly exceed thresholds for Delta Smelt condition and survival and having less complex habitat than other regions. Understanding why and how this region can support Delta Smelt throughout the year is important for identifying the potential for management actions to further enhance Delta Smelt support. Ongoing research in the Sacramento Deepwater Ship Channel continues to focus on understanding how water exchange and residence time mediate abiotic and biotic drivers of phytoplankton and zooplankton dynamics.

Like other terminal channels and sloughs, the SDWSC has strong, hydrodynamically driven gradients in turbidity, light attenuation, and nutrient availability. The SDWSC can roughly be divided into three hydrodynamic zones: a landward no-exchange zone, a middle low-exchange zone, and a seaward high-exchange zone. Spatio-temporal variation in conditions among zones affects phytoplankton productivity, phytoplankton and zooplankton species composition and biomass distributions, and ultimately food availability for planktivorous fish species. Past and ongoing research continues to disentangle these dynamics.

Smits et al. (2023) assessed: (1) if environmental drivers of phytoplankton and zooplankton vary along a spatial gradient in water exchange and residence time; and (2) if trophic interactions between zooplankton and phytoplankton vary across those gradients. They found that abiotic and biotic (i.e., food web interaction) controls on phytoplankton and zooplankton biomass varied among the three SDWSC exchange zones and differed among taxonomic groups. Trophic interactions were strongest in landward sections where long water residence times were associated with greater zooplankton biomass and stronger top-down (i.e., predation) food web control by zooplankton. They also found that water residence time impacted plankton species composition and the relative strengths of food web interactions. Specifically, different interactions likely arose from differences in species-specific phytoplankton food quality and zooplankton grazing rates. Additionally, spatial differences in predator-prey communities could lead to differences in food web structure and efficiency.

Rates of primary production within the SDWSC vary both spatially and seasonally. Loken et al. (2022) used bottle incubation experiments carried out monthly across all three exchange zones to demonstrate spatio-temporal variation in nutrient limitation resulting from seasonal patterns of uptake and delivery. Limitation developed in the no- and low-exchange zones after spring production reduced N availability and persisted through the summer and autumn. Phytoplankton in the high-exchange zone were rarely nutrient limited. A whole-ecosystem fertilization experiment (Loken et al. 2021, 2022) demonstrated the importance of tidal hydrodynamics on dispersal of nutrients even within the no-exchange zone, highlighting the need to understand the roles of microbes and channel sediments in nutrient cycling. Despite being nutrient limited during summer, especially during periods of diel stratification, the addition of nitrogen fertilizer had little effect on rates of primary production because of dispersive fluxes (Lenoch et al. 2021). Extrapolating these whole-ecosystem experimental results to the SDWSC suggest the system shifts from being primarily light limited to nutrient limited moving landward between the low- and no-exchange zones (Loken et al. 2022). Similar to tidal wetlands, the landward reaches of the SDWSC support higher primary and secondary production, with the potential to subsidize adjacent habitats characterized by lower production and to contribute high quality food sources to the pelagic food web. Current research is exploring how rates of primary production and phytoplankton and zooplankton community structure vary seasonally between the low- and no-exchange zones, and how sediment nutrient fluxes contribute to seasonal nutrient dynamics within the water column.

Suisun Marsh Food Subsidy Studies

Research as of June 30, 2023

Introduction

Studies suggest that managed wetlands–principally operated by duck hunting clubs–enhance plankton productivity in Suisun Marsh within the San Francisco Estuary (SFE). Plankton have declined throughout much of the SFE, largely because of an introduced clam that disrupts the food web, creating food limitation in native planktivorous fish, including Delta smelt. Managed wetland operations may pose a useful tool in subsidizing plankton abundance in adjacent tidal habitats because they are free of clams and allow for exponential growth and concentration of plankton. However, mechanistic understanding of how managed wetlands remains limited, and optimal management regimes for promoting plankton abundances at critical times for pelagic fish are unknown.

We are using an ecosystem-scale Before-After Control-Impact (BACI) study design to understand how managed wetland practices affect phytoplankton and zooplankton production. The two-year study encompasses two complete flood cycles (typically fall through spring) in managed wetlands. We hypothesize that seasonally flooded wetlands will promote high plankton production, perennially flooded wetlands will promote intermediate plankton production, and unrestricted tidal habitats (tidally restored wetlands and reference tidal sloughs) will produce comparably low plankton production likely due to flood-pulse effects and differences in water residence time.

Methods

We collect monthly data on chlorophyll-*a* concentrations, zooplankton densities, and water quality at five seasonally managed wetlands, three tidally restored wetlands, and reference sloughs associated with each wetland distributed throughout Suisun Marsh (Figure 37). Of the managed wetlands, Denverton Duck Club (DDC) has agreed to stay perennially flooded for the duration of our study, while the rest are being flooded seasonally in keeping with typical duck club operations. Whole water grabs are collected for measurements of chlorophyll *a*, nitrate, ammonium, phosphate, dissolved organic carbon, total suspended solids, and volatile suspended solids. Additional water quality data include chlorophyll fluorescence, dissolved oxygen, temperature, conductivity, turbidity, pH, and fluorescent dissolved organic matter (taken with a YSI EXO sonde), Secchi depth measurements, and rapid-assessment zooplankton abundance estimates. Zooplankton tow samples are collected and evaluated for species ID, life stage and egg counts. Quarterly, we conduct *in vitro* incubation trials to estimate phytoplankton and zooplankton growth rates in water collected from different wetlands in controlled temperature and light environments. Field sampling and incubation trials will conclude in spring 2024 after all managed wetlands are drained, followed by sample post-processing and analysis. During data analysis, we will also compare pre- and post-restoration plankton monitoring data from Wings Landing (restored in 2020) to compare before-after effects of tidal restoration on plankton abundances.

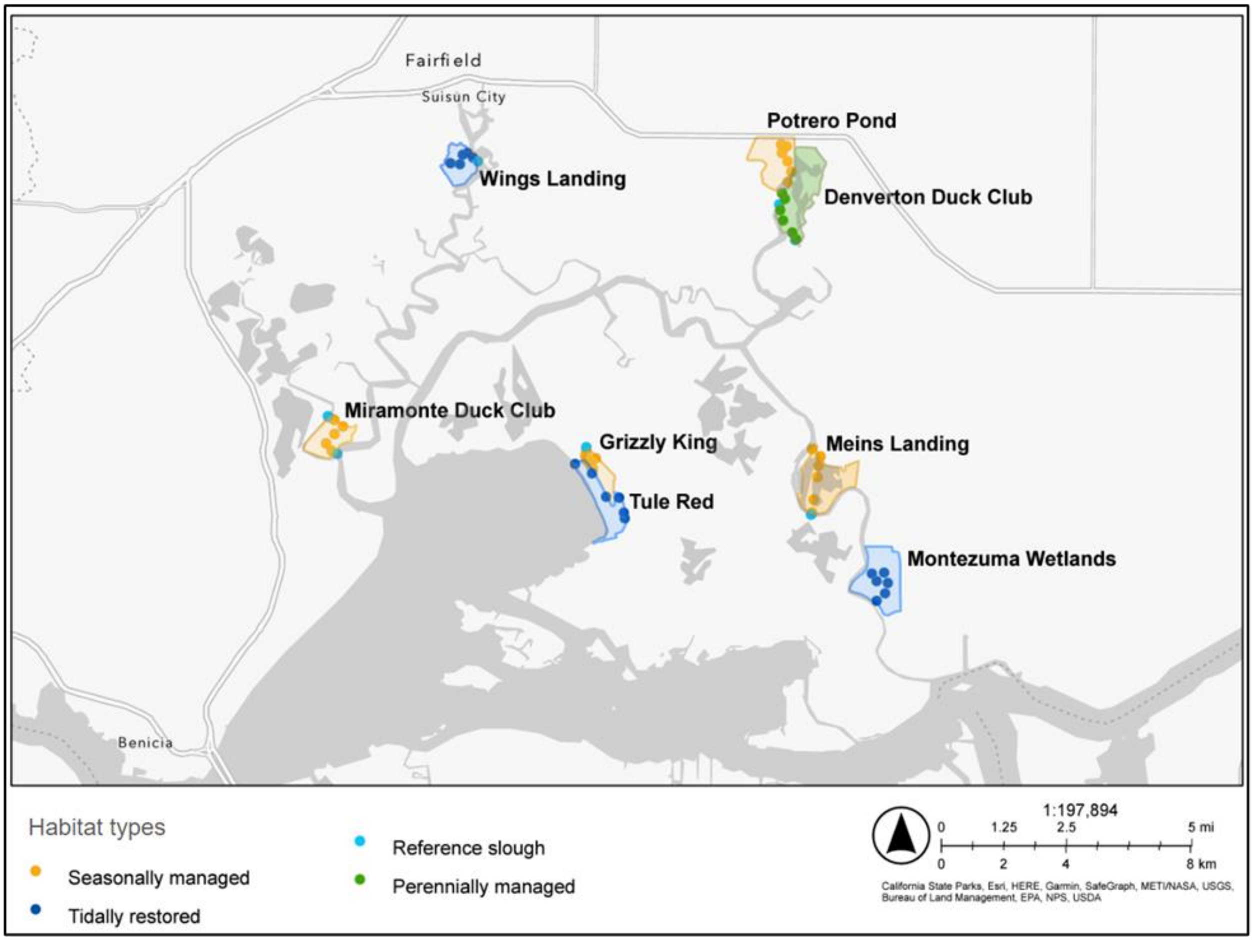

FIGURE 37. MAP OF MONITORING STATIONS FOR A PLANKTON PRODUCTIVITY STUDY IN SUISUN MARSH. STATIONS LOCATED WITHIN SEASONALLY MANAGED WETLANDS (ORANGE), PERENNIALLY MANAGED WETLANDS (GREEN), TIDALLY RESTORED WETLANDS (DARK BLUE) AND ADJACENT REFERENCE SLOUGHS (LIGHT BLUE).

Preliminary Results

We provide a preliminary summary of sonde and rapid-assessment zooplankton data from fall 2022 flood up through October 2023 flood up. Other sample processing and data QA/QC are still in progress. We report on each treatment group (seasonally managed, perennially managed, tidally restored, and reference tidal sloughs).

Daytime dissolved-oxygen trends (DO mg/L) were most variable in seasonally managed wetlands, particularly in the fall flood-up months where DO levels reached hypoxic levels at some stations and supersaturated levels elsewhere (Figure 38). DO levels were relatively stable in all wetland treatment groups during winter, spring, and summer, and rarely decreased to levels <5 mg/L in the tidal environments. Phytoplankton abundance–as measured by chlorophyll-*a* concentration–was highest in seasonally managed wetlands throughout the study period during flooded periods, with peak concentrations occurring in the months following fall flood-up (Figure 39). Zooplankton abundances were patchy and highly variable, although elevated densities were generally restricted to managed wetlands. Copepod abundances were higher in managed wetlands during the flooded months and on two occasions were high in reference sloughs (Figure 40). Cladocerans were restricted to only a few sites, but abundances were higher in managed wetlands during the winter and spring months and were sparse in all wetland treatments during the fall months (Figure 41).

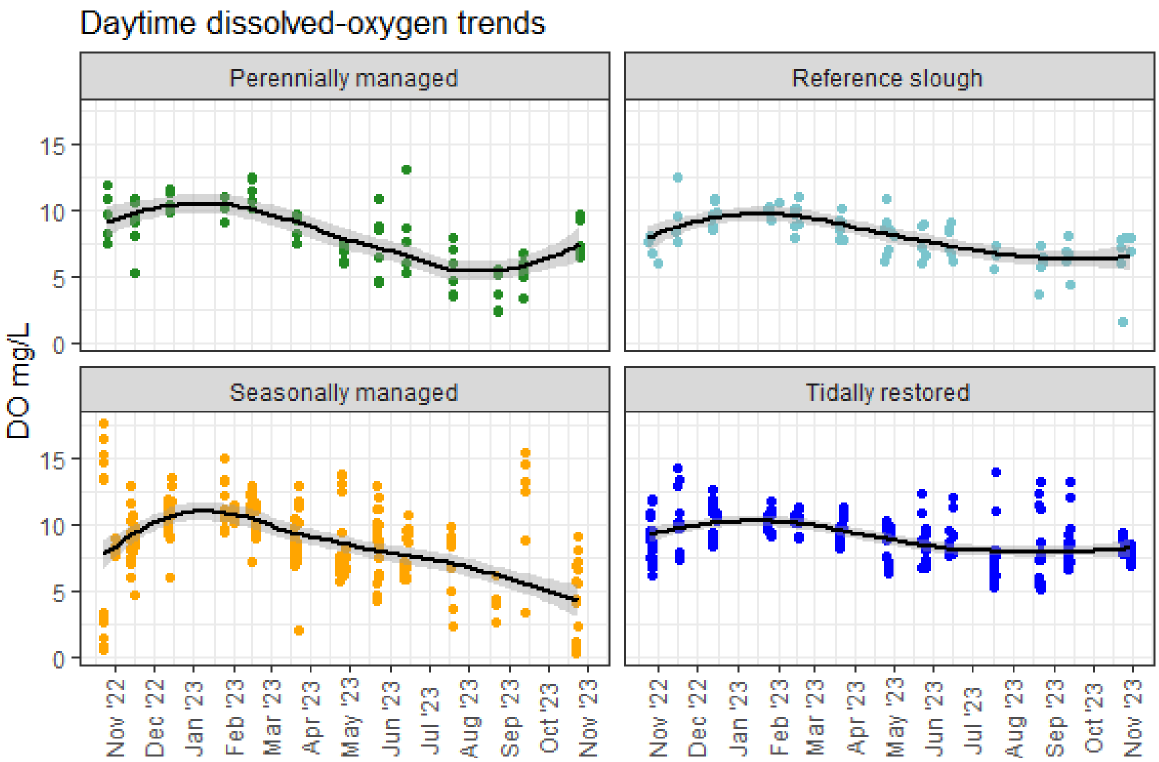

FIGURE 38. POINT AND LOESS REGRESSION PLOTS OF DAYTIME DISSOLVED-OXYGEN TRENDS IN PERENNIALLY MANAGED WETLANDS, SEASONALLY MANAGED WETLANDS, TIDALLY RESTORED WETLANDS, AND ADJACENT REFERENCE SLOUGHS IN SUISUN MARSH.

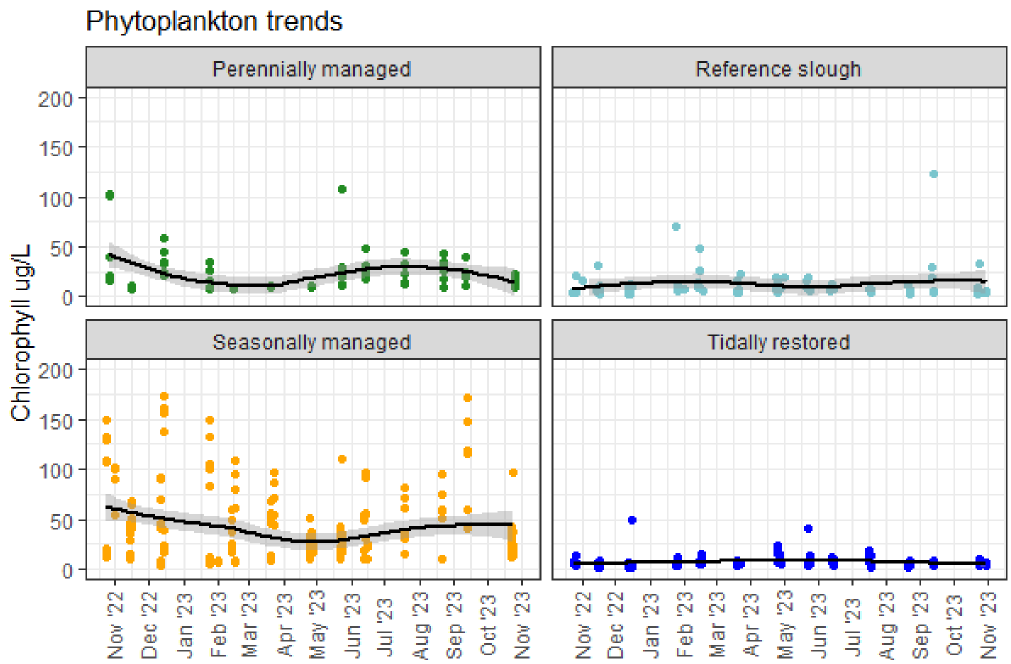

FIGURE 39. POINT AND LOESS REGRESSION PLOTS OF CHLOROPHYLL SONDE MEASUREMENT TRENDS IN PERENNIALLY MANAGED WETLANDS, SEASONALLY MANAGED WETLANDS, TIDALLY RESTORED WETLANDS, AND ADJACENT REFERENCE SLOUGHS IN SUISUN MARSH. OBSERVATIONS ABOVE 200 UG/L NOT SHOWN (N=12 IN SEASONALLY MANAGED WETLANDS) BUT ARE INCLUDED IN LOESS REGRESSION.

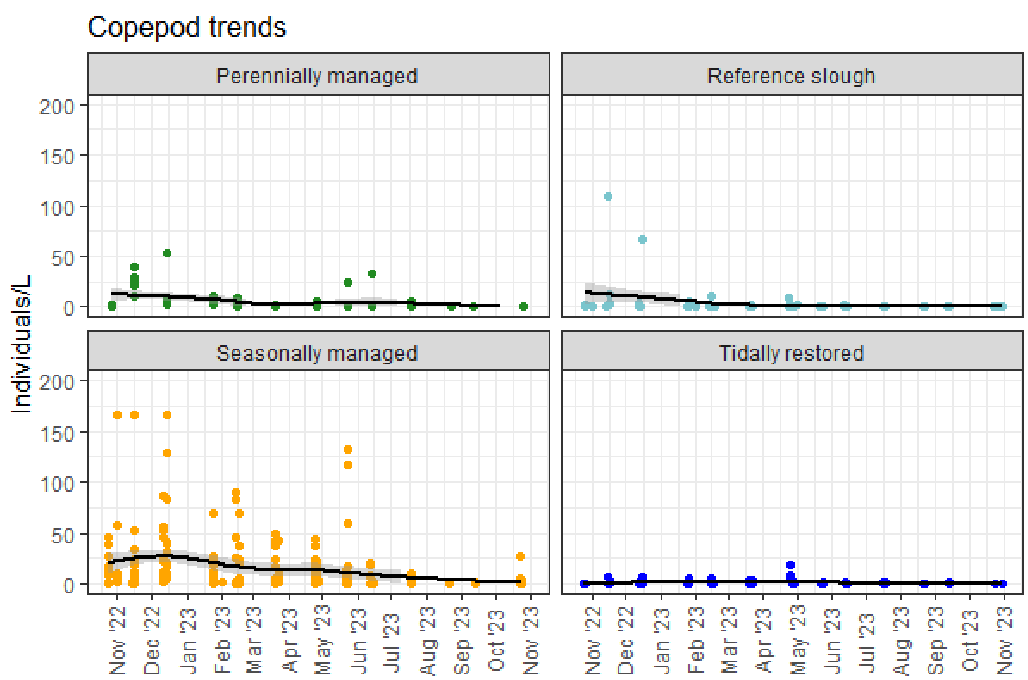

FIGURE 40. POINT AND LOESS REGRESSION PLOTS OF ALL COPEPOD ABUNDANCE TRENDS IN PERENNIALLY MANAGED WETLANDS, SEASONALLY MANAGED WETLANDS, TIDALLY RESTORED WETLANDS, AND ADJACENT REFERENCE SLOUGHS IN SUISUN MARSH. OBSERVATIONS ABOVE 200 COUNTS NOT SHOWN (N=1 IN PERENNIALLY MANAGED; N=3 IN SEASONALLY MANAGED) BUT ARE INCLUDED IN LOESS REGRESSION.

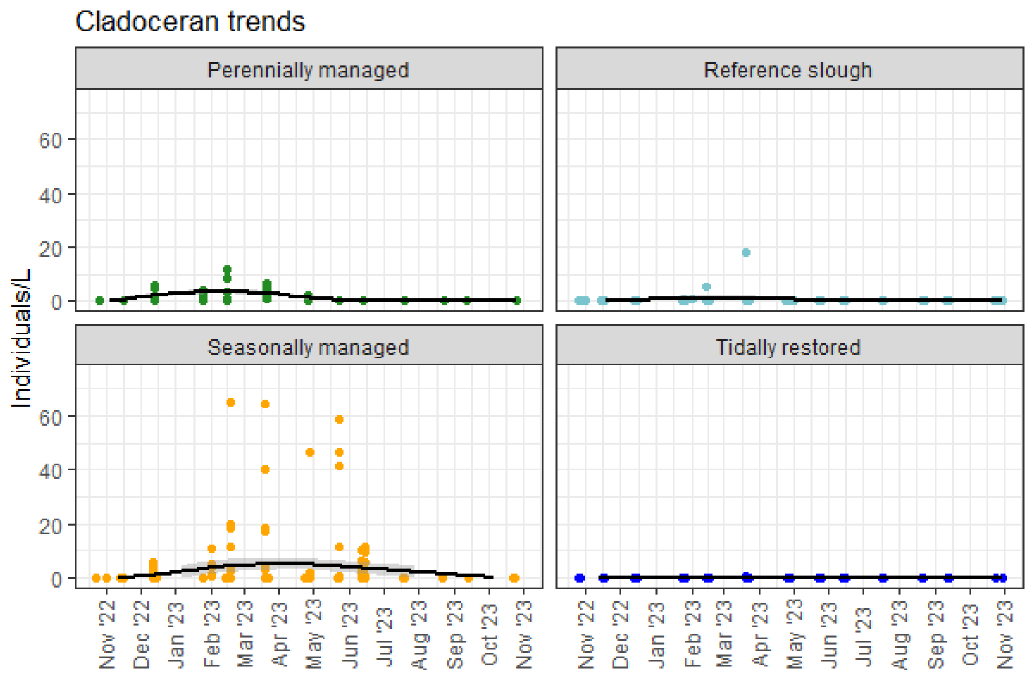

FIGURE 41. POINT AND LOESS REGRESSION PLOTS OF CLADOCERAN ABUNDANCE TRENDS IN PERENNIALLY MANAGED WETLANDS, SEASONALLY MANAGED WETLANDS, TIDALLY RESTORED WETLANDS, AND ADJACENT REFERENCE SLOUGHS IN SUISUN MARSH. OBSERVATIONS ABOVE 75 COUNTS NOT SHOWN (N=1 IN SEASONALLY MANAGED) BUT ARE INCLUDED IN LOESS REGRESSION.

Discussion

To date, our study shows that managed wetlands during flooded periods support higher plankton concentrations than tidal channels and restorations but that water quality trade-offs likely exist. Low chlorophyll concentrations and low daytime DO in some managed wetlands occurred shortly after fall flood-up, while other managed wetlands were associated with high and supersaturated daytime DO. Chlorophyll concentrations and zooplankton abundances responded positively to fall flooding in seasonally managed wetlands and in the first flooded year of the perennially managed wetland, likely due to increased food availability and water residence times expected. Copepods rapidly responded to flooding, often reaching peak abundances within two months, suggesting tight coupling with phytoplankton blooms. Larger-bodied cladocerans were slower to respond to flooding, but tended to dominate the zooplankton biomass once established, possibly because they are efficient grazers and may outcompete copepods. Reference sloughs and tidally restored wetlands supported comparatively low zooplankton abundances, possibly due to lower phytoplankton availability and higher tidal mixing. The occasional high abundances observed in the reference sloughs were likely produced and exported from adjacent seasonally managed wetlands.

Overall, our findings are consistent with our hypotheses, but we observed unexpected trends at our perennially managed wetland, Denverton Duck Club (DCC), and one of the seasonally managed wetlands, Miramonte Duck Club (MDC). We predicted that DCC would respond to the initial fall flood pulse in the first year with high plankton density that diminished thereafter, and that MDC would respond with high plankton densities for both years. However, we suspect that the hydraulic connectivity to the slough channels at DCC and MDC wetlands were higher than the other managed wetlands, resulting in relatively low chlorophyll and zooplankton concentrations and illustrating the important role of water exchange and residence time in regulating plankton abundance and the need to consider managed wetland flushing rates in relation to biomass accumulation. Growth rate data for phytoplankton and zooplankton is pending but may provide more insight on the effects of hydraulic connectivity on plankton production.

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Personal Communications

May 19, 2020 – Microsoft Team's Meeting between USFWS staff Will Smith and Matt Nobriga, and USBR staff Kristin Arend, Brian Mahardja, Josh Israel, and Mike Beakes.

Attachments

Appendix A: Abiotic and Biotic Habitat Figures and Tables (Included in Report Document)

Appendix B: Summer Fall Habitat Action Monitoring and Science Plan (Separate Document)

Appendix C: 2023 Summer Fall Habitat Action Plan (Separate Document)

Appendix A: Abiotic and Biotic Habitat Figures and Tables

Water quality

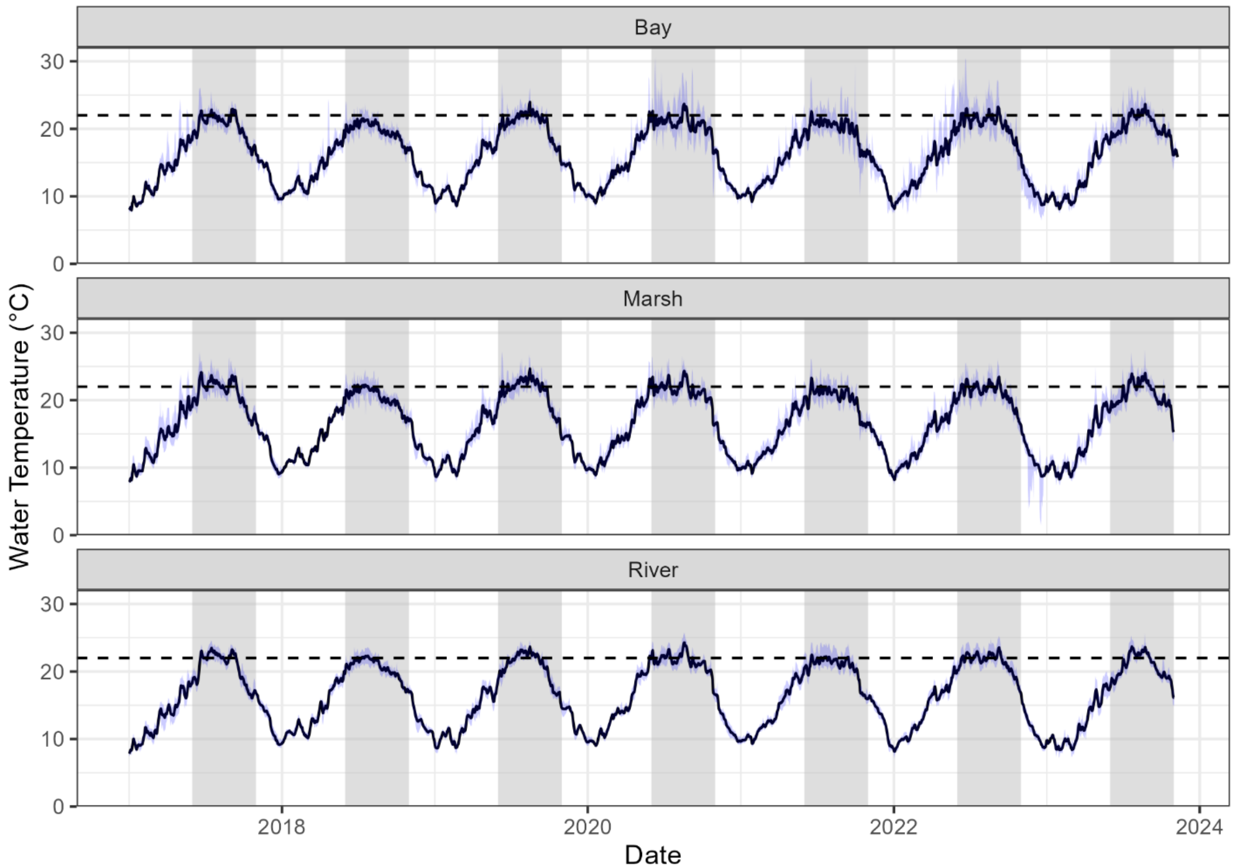

FIGURE 42. DAILY AVERAGE WATER TEMPERATURE FOR CONTINUOUS WATER QUALITY STATIONS IN THE BAY, MARSH, AND RIVER REGIONS FROM 2017-2023. BLACK DOTTED LINES INDICATE DELTA SMELT HABITAT THRESHOLDS AND SHADED AREAS INDICATE SUMMER-FALL MONTHS (JUNE-OCTOBER) EACH YEAR.

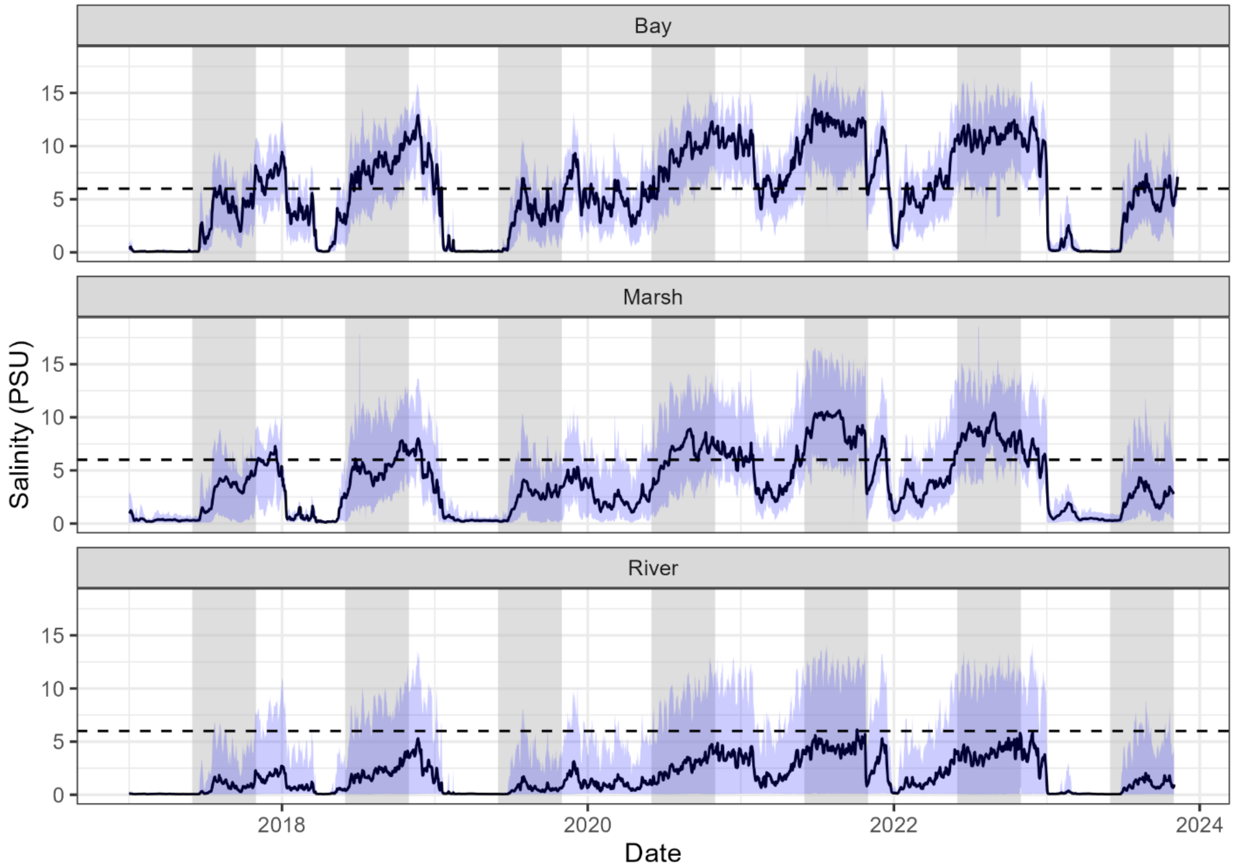

FIGURE 43. DAILY AVERAGE SALINITY FOR CONTINUOUS WATER QUALITY STATIONS IN THE BAY, MARSH, AND RIVER REGIONS FROM 2017-2023. BLACK DOTTED LINES INDICATE DELTA SMELT HABITAT THRESHOLDS AND SHADED AREAS INDICATE SUMMER-FALL MONTHS (JUNE-OCTOBER) EACH YEAR.

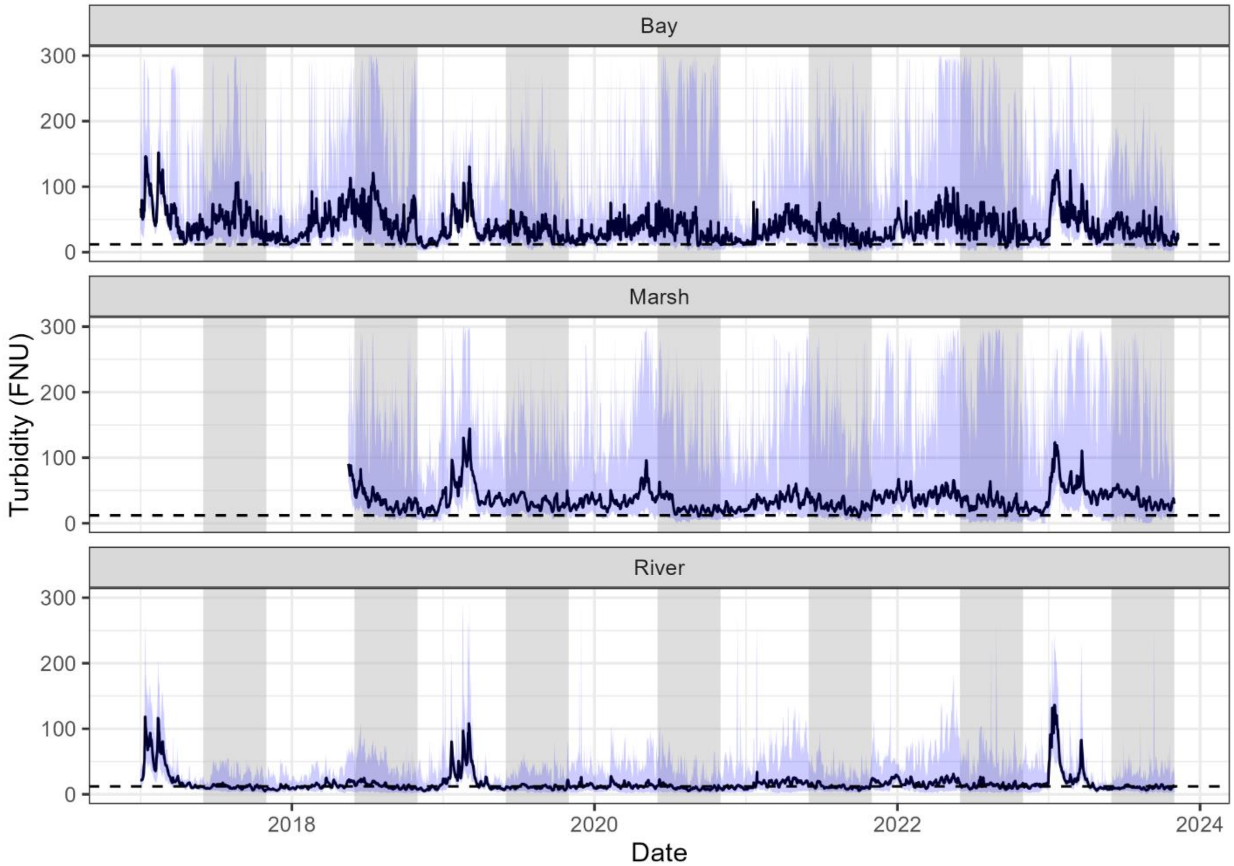

FIGURE 44. DAILY AVERAGE TURBIDITY FOR CONTINUOUS WATER QUALITY STATIONS IN THE BAY, MARSH, AND RIVER REGIONS FROM 2017-2023. BLACK DOTTED LINES INDICATE DELTA SMELT HABITAT THRESHOLDS AND SHADED AREAS INDICATE SUMMER-FALL MONTHS (JUNE-OCTOBER) EACH YEAR.

Phytoplankton

Changes in abundance in 2023 downstream of SMSCGs

In eastern Montezuma Slough, total phytoplankton biovolume was 2.2x higher during the month prior to the start of SMSCG operations on August 15 than during the two months of SMSCG operations (Figure 45). However, this difference was not statistically significant (p = 0.30), likely in part because biovolume was highly variable among samples in the “Before” period. Also, there was only one year of phytoplankton monitoring that occurred during a SMSCG action year, which limited power to detect these differences. The increase in flow and reduction in water residence time produced by operating the SMSCGs could contribute to lower phytoplankton abundance and altered taxonomic composition in Suisun Marsh.

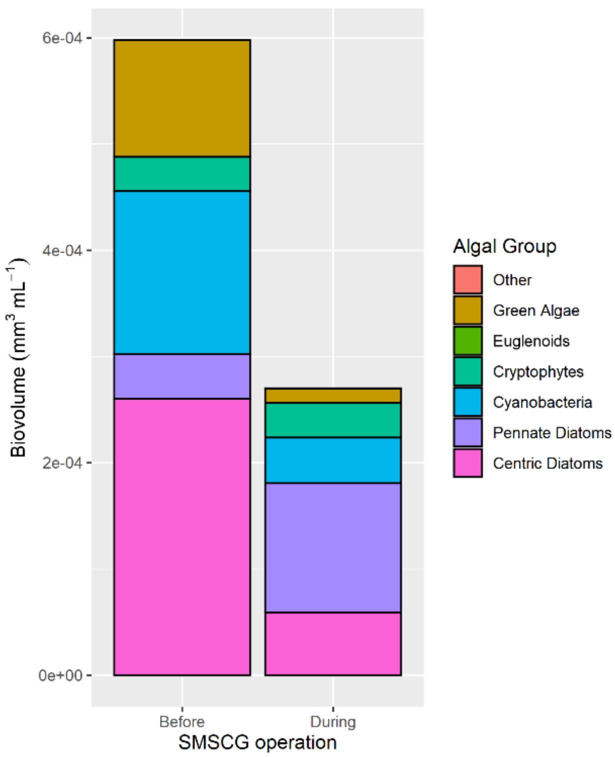

FIGURE 45. PHYTOPLANKTON BIOVOLUME IN EASTERN MONTEZUMA SLOUGH BEFORE AND DURING THE 2023 SMSCG ACTION.

Variation in community composition among regions and years

We made NMDS plots to compare the taxonomic composition of different regions, months, and years. These plots are based on biovolume summarized at the genus level with rare taxa removed (ie, those present in less than 1% of samples). PERMANOVA analysis indicated that composition was significantly different among regions (marsh vs river) and years but not months. Therefore, the plot below shows combinations of regions and years (Figure 46). Despite the significance of these predictors in the PERMANOVA, together they only explain 5.8% of the variation in phytoplankton composition.

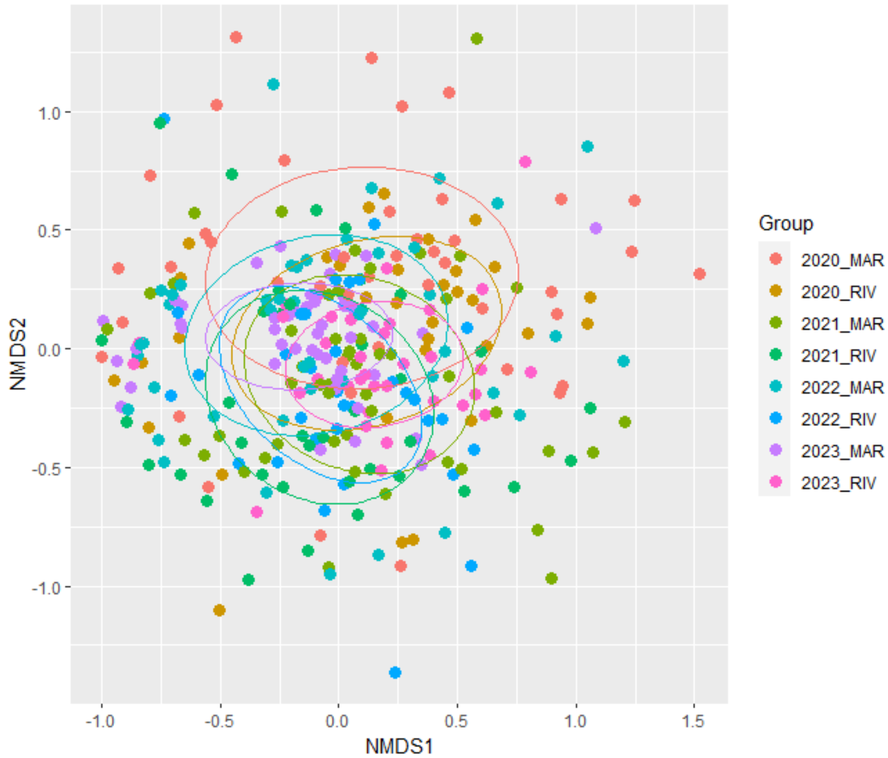

FIGURE 46. NMDS PLOT OF PHYTOPLANKTON COMPOSITION BY REGION AND YEAR.

Comparisons among surveys of primary producer abundance

There are a variety of way in which primary producers are monitored in the Bay-Delta ecosystem. Discrete phytoplankton samples are collected to determine taxonomic composition and estimate biovolume of phytoplankton. Discrete chlorophyll-a samples are collected to estimate concentrations of photosynthetic biomass, including that of phytoplankton. Sondes are often equipped with optical probes to measure fluorescence, which are also used to estimate photosynthetic biomass. Each data type has inherent strengths and weaknesses and measures somewhat different aspects of the primary producer community. Our goal was to compare these different data types using surveys of DWR's Discrete Environmental Program, which has simultaneously collected all three data types at a suite of stations across the Bay-Delta each month for many years. Currently, this report includes the comparison of estimated phytoplankton biovolume and chlorophyll-a samples because these data were readily available in publications on EDI. The analogous fluorescence data was not available in time to be included.

The correlation between chlorophyll-a and phytoplankton biovolume was weak (correlation coefficient = 0.33), which suggests that these two types of data are describing somewhat different aspects of the primary producer community. The relationship appears to be particularly poor at lower values, where the data points create a "scattershot" pattern (Figure 47). However, the relationship looks stronger at higher values, perhaps suggesting that chlorophyll-a and phytoplankton match better when there are algal blooms, which are often comprised of one phytoplankton taxon.

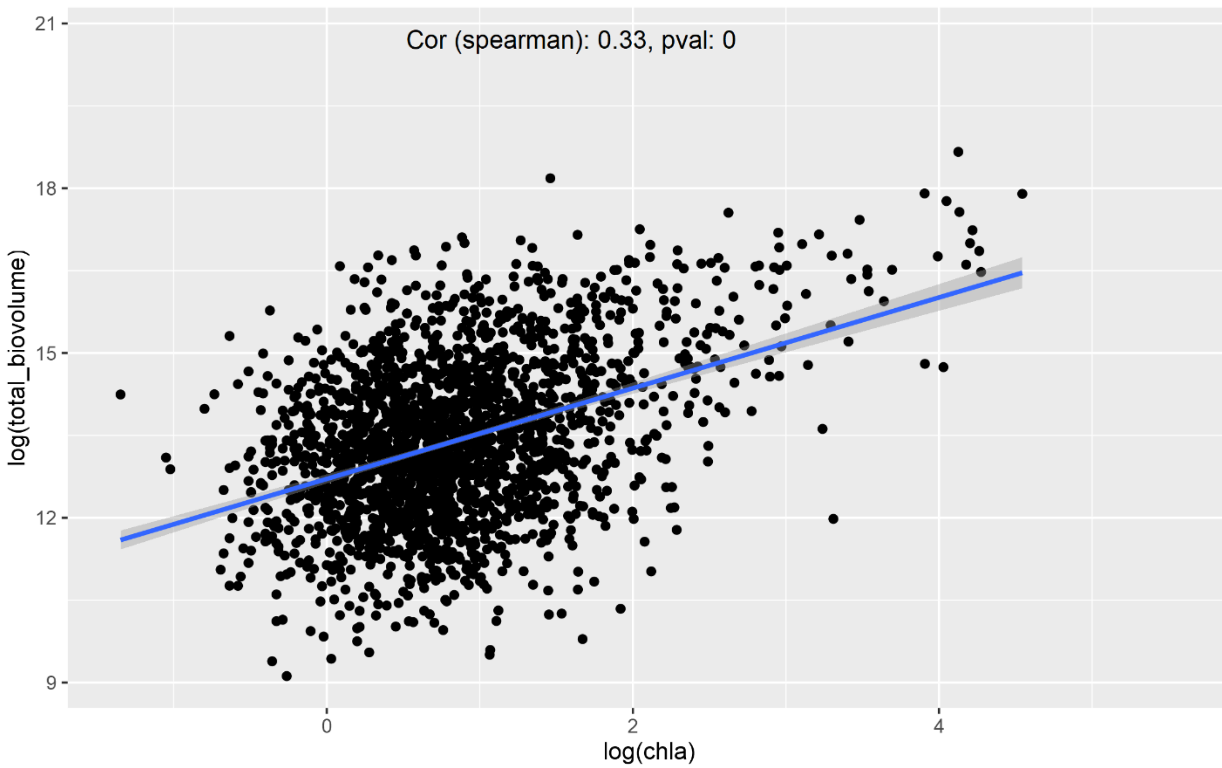

FIGURE 47. CORRELATION BETWEEN CHLOROPHYLL-A SAMPLES AND ESTIMATED TOTAL PHYTOPLANKTON BIOVOLUME. BOTH VARIABLES HAVE BEEN TRANSFORMED USING THE NATURAL LOG.

Zooplankton

TABLE 7. LINEAR MIXED EFFECT MODEL RESULTS OF MEAN CALANOID BIOMASS BY YEAR (2017-2023) AND REGION (SUISUN MARSH, SUISUN BAY, RIVER).

	Estimate	Standard Error	Degrees of Freedom	t-value	p-value
(Intercept)	9.26011	0.20574	11.4827	45.009	2.83E-14
Suisun Bay	-0.697	0.18976	1427.03	-3.6732	0.00025
Suisun Marsh	-0.4802	0.2355	1427.04	-2.039	0.04163
Year2018	-0.4915	0.17837	1427.12	-2.7556	0.00593
Year2019	-0.7728	0.16313	1427.07	-4.7373	2.38E-06
Year2020	-0.8479	0.1627	1427.12	-5.2114	2.15E-07
Year2021	-0.6558	0.16096	1427.13	-4.0742	4.87E-05
Year2022	-1.1959	0.16555	1427.13	-7.224	8.19E-13
Year2023	0.37771	0.31003	1427.11	1.21834	0.2233
Suisun Bay: Year2018	0.48499	0.2517	1427.04	1.92687	0.05419
Suisun Marsh: Year2018	-0.1889	0.30169	1427.05	-0.626	0.53139
Suisun Bay: Year2019	0.79394	0.23186	1427	3.42421	0.00063
Suisun Marsh: Year2019	0.3685	0.27357	1427.06	1.34701	0.17819
Suisun Bay: Year2020	0.81444	0.23442	1427.01	3.4743	0.00053
Suisun Marsh: Year2020	0.33224	0.27548	1427.03	1.20605	0.228
Suisun Bay: Year2021	0.74693	0.23572	1427.01	3.16876	0.00156
Suisun Marsh: Year2021	0.09788	0.2742	1427.05	0.35696	0.72118
Suisun Bay: Year2022	1.01537	0.24162	1427.03	4.2024	2.80E-05
Suisun Marsh: Year2022	0.44488	0.27749	1427.06	1.60322	0.10911
Suisun Bay: Year2023	0.07922	0.43816	1427	0.1808	0.85655
Suisun Marsh: Year2023	-0.2219	0.43816	1427.03	-0.5065	0.61262

TABLE 8. LINEAR MODEL CONTRASTS OF MEAN CALANOID COPEPOD BIOMASS FOR YEARLY COMPARISONS WITH NO SEPARATION OF REGION.

Contrast	Estimate	Standard Error	Degrees of Freedom	t-ratio	p-value
2017 - 2018	0.39	0.12	1427.14	3.36	0.01
2017 - 2019	0.39	0.11	1427.28	3.61	0.01
2017 - 2020	0.47	0.11	1427.34	4.31	< 0.001
2017 - 2021	0.37	0.11	1427.32	3.46	0.01
2017 - 2022	0.71	0.11	1427.37	6.46	<0.001
2017 - 2023	-0.33	0.18	1427.49	-1.84	0.52
2018 - 2019	-0.01	0.09	1427.99	-0.08	1.00
2018 - 2020	0.07	0.10	1428.11	0.77	0.99
2018 - 2021	-0.02	0.10	1428.03	-0.20	1.00
2018 - 2022	0.32	0.10	1428.13	3.25	0.02
2018 - 2023	-0.72	0.17	1427.56	-4.21	<0.001
2019 - 2020	0.08	0.08	1427.17	0.99	0.96
2019 - 2021	-0.01	0.08	1427.04	-0.14	1.00
2019 - 2022	0.32	0.08	1427.06	3.87	<0.001
2019 - 2023	-0.72	0.16	1427.43	-4.34	<0.001
2020 - 2021	-0.09	0.08	1427.06	-1.10	0.93
2020 - 2022	0.24	0.09	1427.07	2.85	0.07
2020 - 2023	-0.80	0.17	1427.66	-4.80	<0.001
2021 - 2022	0.33	0.09	1427.02	3.91	<0.001
2021 - 2023	-0.70	0.17	1427.49	-4.25	<0.001
2022 - 2023	-1.04	0.17	1427.52	-6.23	<0.001

TABLE 9. LINEAR MODEL RESULTS OF MEAN CALANOID COPEPOD BIOMASS FOR COMPARISONS OF REGIONAL DIFFERENCES WITHIN THE SAME YEAR.

Contrast	Year	Estimate	Standard Error	Degrees of Freedom	t-ratio	p-value
River - Suisun Bay	2017	0.70	0.19	1427.03	3.67	<0.001
River - Suisun Marsh	2017	0.48	0.24	1427.04	2.04	0.10
Suisun Bay - Suisun Marsh	2017	-0.22	0.24	1427.08	-0.92	0.63
River - Suisun Bay	2018	0.21	0.17	1427.06	1.28	0.41
River - Suisun Marsh	2018	0.67	0.19	1427.02	3.55	<0.001
Suisun Bay - Suisun Marsh	2018	0.46	0.19	1427.01	2.43	0.04
River - Suisun Bay	2019	-0.10	0.13	1427.05	-0.73	0.75
River - Suisun Marsh	2019	0.11	0.14	1427.08	0.80	0.70
Suisun Bay - Suisun Marsh	2019	0.21	0.14	1427.13	1.48	0.30
River - Suisun Bay	2020	-0.12	0.14	1427.01	-0.85	0.67
River - Suisun Marsh	2020	0.15	0.14	1427.00	1.04	0.55
Suisun Bay - Suisun Marsh	2020	0.27	0.15	1427.02	1.77	0.18
River - Suisun Bay	2021	-0.05	0.14	1427.02	-0.36	0.93

River - Suisun Marsh	2021	0.38	0.14	1427.02	2.72	0.02
Suisun Bay - Suisun Marsh	2021	0.43	0.15	1427.01	2.82	0.01
River - Suisun Bay	2022	-0.32	0.15	1427.03	-2.13	0.08
River - Suisun Marsh	2022	0.04	0.15	1427.06	0.24	0.97
Suisun Bay - Suisun Marsh	2022	0.35	0.16	1427.08	2.23	0.07
River - Suisun Bay	2023	0.62	0.39	1427.00	1.56	0.26
River - Suisun Marsh	2023	0.70	0.37	1427.03	1.90	0.14
Suisun Bay - Suisun Marsh	2023	0.08	0.37	1427.03	0.23	0.97

TABLE 10. LINEAR MODEL RESULTS OF MEAN CALANOID COPEPOD BIOMASS FOR COMPARISONS OF THE YEARLY DIFFERENCES WITHIN THE SAME REGION.

Contrast	Region	Estimate	Standard Error	Degrees of Freedom	t-ratio	P-value
2017 - 2018	Suisun Bay	0.01	0.18	1427.03	0.04	1.00
2017 - 2019	Suisun Bay	-0.02	0.16	1427.09	-0.13	1.00
2017 - 2020	Suisun Bay	0.03	0.17	1427.19	0.20	1.00
2017 - 2021	Suisun Bay	-0.09	0.17	1427.19	-0.53	1.00
2017 - 2022	Suisun Bay	0.18	0.18	1427.35	1.02	0.95
2017 - 2023	Suisun Bay	-0.46	0.31	1427.13	-1.47	0.76
2018 - 2019	Suisun Bay	-0.03	0.15	1427.18	-0.18	1.00
2018 - 2020	Suisun Bay	0.03	0.16	1427.32	0.17	1.00
2018 - 2021	Suisun Bay	-0.10	0.16	1427.31	-0.61	1.00
2018 - 2022	Suisun Bay	0.17	0.16	1427.50	1.06	0.94
2018 - 2023	Suisun Bay	-0.46	0.30	1427.11	-1.53	0.73
2019 - 2020	Suisun Bay	0.05	0.14	1427.05	0.39	1.00
2019 - 2021	Suisun Bay	-0.07	0.14	1427.04	-0.48	1.00
2019 - 2022	Suisun Bay	0.20	0.15	1427.15	1.35	0.83
2019 - 2023	Suisun Bay	-0.44	0.30	1427.13	-1.47	0.76
2020 - 2021	Suisun Bay	-0.12	0.15	1427.00	-0.84	0.98
2020 - 2022	Suisun Bay	0.15	0.15	1427.04	0.96	0.96
2020 - 2023	Suisun Bay	-0.49	0.30	1427.17	-1.65	0.65
2021 - 2022	Suisun Bay	0.27	0.16	1427.04	1.73	0.60
2021 - 2023	Suisun Bay	-0.37	0.30	1427.17	-1.22	0.89
2022 - 2023	Suisun Bay	-0.64	0.30	1427.20	-2.11	0.35
2017 - 2018	Suisun Marsh	0.68	0.24	1427.08	2.79	0.08
2017 - 2019	Suisun Marsh	0.40	0.22	1427.18	1.84	0.52
2017 - 2020	Suisun Marsh	0.52	0.22	1427.11	2.32	0.24
2017 - 2021	Suisun Marsh	0.56	0.22	1427.12	2.51	0.16
2017 - 2022	Suisun Marsh	0.75	0.22	1427.09	3.37	0.01
2017 - 2023	Suisun Marsh	-0.16	0.31	1427.29	-0.50	1.00
2018 - 2019	Suisun Marsh	-0.28	0.18	1427.48	-1.53	0.73
2018 - 2020	Suisun Marsh	-0.16	0.18	1427.39	-0.89	0.97
2018 - 2021	Suisun Marsh	-0.12	0.18	1427.30	-0.67	0.99
2018 - 2022	Suisun Marsh	0.07	0.18	1427.27	0.38	1.00
2018 - 2023	Suisun Marsh	-0.84	0.28	1427.34	-2.94	0.05

2019 - 2020	Suisun Marsh	0.11	0.15	1427.06	0.74	0.99
2019 - 2021	Suisun Marsh	0.15	0.15	1427.03	1.02	0.95
2019 - 2022	Suisun Marsh	0.35	0.15	1427.05	2.29	0.25
2019 - 2023	Suisun Marsh	-0.56	0.26	1427.25	-2.13	0.34
2020 - 2021	Suisun Marsh	0.04	0.15	1427.05	0.27	1.00
2020 - 2022	Suisun Marsh	0.24	0.16	1427.06	1.51	0.74
2020 - 2023	Suisun Marsh	-0.67	0.27	1427.33	-2.52	0.15
2021 - 2022	Suisun Marsh	0.19	0.15	1427.02	1.25	0.88
2021 - 2023	Suisun Marsh	-0.71	0.27	1427.23	-2.69	0.10
2022 - 2023	Suisun Marsh	-0.91	0.27	1427.26	-3.41	0.01
2017 - 2018	River	0.49	0.18	1427.12	2.76	0.09
2017 - 2019	River	0.77	0.16	1427.08	4.74	<0.001
2017 - 2020	River	0.85	0.16	1427.12	5.21	<0.001
2017 - 2021	River	0.66	0.16	1427.13	4.07	<0.001
2017 - 2022	River	1.20	0.17	1427.13	7.22	<0.001
2017 - 2023	River	-0.38	0.31	1427.11	-1.22	0.89
2018 - 2019	River	0.28	0.15	1427.46	1.88	0.50
2018 - 2020	River	0.36	0.15	1427.51	2.38	0.21
2018 - 2021	River	0.16	0.15	1427.59	1.11	0.92
2018 - 2022	River	0.70	0.15	1427.55	4.61	<0.001
2018 - 2023	River	-0.87	0.30	1427.19	-2.87	0.06
2019 - 2020	River	0.08	0.13	1427.15	0.58	1.00
2019 - 2021	River	-0.12	0.13	1427.05	-0.91	0.97
2019 - 2022	River	0.42	0.13	1427.04	3.16	0.03
2019 - 2023	River	-1.15	0.29	1427.11	-3.91	<0.001
2020 - 2021	River	-0.19	0.13	1427.05	-1.50	0.74
2020 - 2022	River	0.35	0.13	1427.08	2.61	0.12
2020 - 2023	River	-1.23	0.29	1427.22	-4.16	<0.001
2021 - 2022	River	0.54	0.13	1427.01	4.12	<0.001
2021 - 2023	River	-1.03	0.29	1427.16	-3.52	0.01
2022 - 2023	River	-1.57	0.30	1427.15	-5.32	<0.001