Long-Term Operation

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

Central Valley Project, California

Interior Region 10 – California-Great Basin

U.S. Department of the Interior November 2023

Mission Statements

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

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

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1. Introduction

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

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

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2. Initial Alternatives Report

2.1 Management Questions

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

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

2.2 Initial Analyses

Reclamation solicited input for the knowledge base paper, *Delta Spring Outflow Management Smelt Growth and Survival Knowledge Base Document*.

Reclamation completed a literature review.

Reclamation reviewed physical and biological modeling developed by the Upper Sacramento Scheduling Team during the real-time pulse flow planning process in 2020–2023.

2.3 Initial Findings

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

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

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

2.4 Subsequent Considerations

Reclamation solicited input for the knowledge base paper, *Delta Spring Outflow Management-Smelt Growth and Survival.*

Reclamation completed a literature review.

Reclamation reviewed physical and biological modeling developed as part of Upper Sacramento Scheduling Team process for spring pulse flows in 2020–2023.

3. Public Draft EIS Scenarios

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

3.1 Run of River

[Placeholder]

3.2 No Action

[Placeholder]

3.3 Alternative 1 – Water Quality Control Plans

[Placeholder]

3.4 Alternative 2 – Multi-Agency Consensus

[Placeholder]

3.5 Alternative 3 – Modified Natural Flow Hydrograph

[Placeholder]

3.6 Alternative 4 – Reservoir Flexibility

[Placeholder]

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4. Performance Metrics

4.1 Biological

Biological metrics consider direct observations and environmental surrogates as follows.

Smelt metrics (Delta and longfin):

- Survival and
- Physical habitat quality and quantity

Food web metrics:

- Zooplankton (prey availability)

Salmon metrics:

- Juvenile salmonid survival and travel time in Sacramento River
- Juvenile survival probability to Chipps Island
- Juvenile physical habitat quality and quantity

4.2 Water Supply

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

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

4.3 National Environmental Policy Act Resource Areas

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

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5. Methods Selection

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

5.1 Literature

5.1.1 History of Spring Outflow Effects by Regulatory Regime

5.1.1.1 1950s – early 1970s: Onset of Central Valley Project Operations

The C.W. "Bill" Jones Pumping Plant was constructed from 1947 to 1951. During this era, there were no Water Right Decisions that provided recommendations or regulatory requirements for Delta outflow.

D-1275: Water Right Decision D-1275 was adopted in May of 1967. At this point, this Water Right Decision did not provide recommendations or requirements for Delta outflow. Presented in D-1275 is DWR's plan of Delta outflow at 1,800 cfs and Bureau of Reclamation's plan of Delta outflow at 1,500 cfs.

5.1.1.2 1978: Water Right Decision D-1485

Unlike the 1960s, during the 1970s exports began to occur year-round and were increasing in volume. Water Right Decision D-1485 marked the beginning of environmental protections and management to outflow requiring standards for the protection of fish and wildlife.

D-1485 was adopted in 1978 to establish water quality standards, including flows to be maintained for the protection of fish and wildlife, imposed as a condition to all of the CVP and SWP permits. The two documents adopted by the Water Board (a water quality control plan and a water right decision) represent a unified effort by the Board to develop and implement under its full authority a single comprehensive set of water quality standards to protect beneficial uses of Delta water supplies (D-1485, page 6). D-1485 was the first Water Right Decision to consider monthly Delta outflow, pumping, and protections for listed fish. D-1485 additionally calls for research studies to determine "outflow needs in San Francisco Bay, including ecological benefits of unregulated outflows and salinity gradients established by them." This Water Right Decision outlined Delta outflow and net stream flow values for striped bass and salmonid protection by month for varying water year types.

5.1.1.3 1990s & Early 2000s: CVPIA, D-1641, CALFED

By the early 1990s, agreements were in place allowing the California Department of Fish and Wildlife (CDFW) to monitor salvage operations providing further benefits to protected fish.

During this era there were requirements set in place to address standards for fish and wildlife protection with written intent to restore the Bay-Delta ecosystem and improve water management. Among these requirements was consideration of the export rate restriction standard (E/I ratio). The Central Valley Project Improvement Act (hereafter CVPIA) passed mandating changes in CVP management specifically for "protection, restoration, and enhancement of fish and wildlife" (Section (b) (4) of CVPIA). There was organization of federal and state agencies through CALFED. Water Board Decision D-1641 outlined a long-term plan to limit pumping to protect juvenile Chinook salmonids.

CALFED: CALFED was organized in 1994, a partnership between federal and state agencies with management and regulatory responsibilities in the Delta. The lead CALFED agencies released a Final Programmatic Environmental Impact Statement/Environmental Impact Report and the Preferred Alternative on July 21, 2000. This was followed by the signing of the ROD on August 28, 2000, which formally approved a long-term plan to restore the Bay-Delta ecosystem and improve water management.

D-1641: In 2000, through adoption of D-1641, the SWP and CVP were mandated to comply with the objectives in the 1995 Bay-Delta Plan. The requirements in D-1641 address standards for fish and wildlife protection, municipal and industrial water quality, agricultural water quality, and Suisun Marsh salinity. D-1641 also authorizes SWP and CVP to jointly use each other's points of diversion in the southern Delta, with conditional limitations and required response coordination plans. Objectives include outflow requirements and specific spring export restraints. Important Bay-Delta Standards in D-1641 include habitat protection outflow and salinity starting conditions (hereafter "Spring X2"), export/inflow (E/I) ratio, minimum Delta outflow, Sacramento River Rio Vita flow standards.

D-1641 additionally established a systematic approach for operations' effects on the geographical position of X2. The compliance location and number of X2 days a month between February and June is defined by regulatory standard tables. Additionally, there is a salinity starting gate requirement condition that must be met in all by very dry January conditions.

5.1.1.4 Late 2000s & 2010s: 2008/2009 Reasonable and Prudent Alternative

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

2008 Biological Opinion: The 2008 USFWS Biological Opinion suggests a reasonable and prudent alternative (RPA) to minimize the impact of the amount of extent of incidental take on listed species. This RPA consists of five components suggested to protect all life stages of Delta Smelt, habitat restoration including improving habitat for Delta Smelt rearing and growth, and monitoring. None of these five components explicitly call for spring Delta outflow.

2009 Biological Opinion: There are no reasonable and prudent measures (RPMs) in the 2009 NMFS Biological Opinion for spring outflow actions. 2009 NMFS Biological Opinion recommends Action I.2.2. November through February Keswick Release Schedule (Fall Actions). If operations to meet Delta outflow conditions occur, Action I.2.2. (Action I.2.2.C. Implementation and Exception Procedures for EOS Storage of 1.9 MAF or below) recommends

CVP/SWP Delta combined exports decrease to 2,000 cfs or more restrictive to meet legal requirements while maintaining a 3,250 cfs Keswick release (p. 596).

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

Currently there are measures in place to provide continued protections for listed fish within Reclamation's 2020 Proposed Action (PA) via the 2020 Record of Decision (ROD) and DWR's 2020 Incidental Take Permit (ITP).

2019 Biological Opinion: The 2019 NMFS Biological Opinion does not have any RPMs or RPAs associated with spring Delta outflow.

2020 ROD/PA and 2020 ITP: 3.17.1 Spring Outflow Action (2020 ITP, page 42) may include export reductions to maintain CVP and SWP's contribution towards spring Delta outflow. 4.10.1.2 Spring Pulse Flows (2020 PA, page 4-28) allow for the implementation of a spring pulse action from Shasta Reservoir if specific environmental conditions are met.

5.1.2 Effects on Listed Native Fish Species

CVP and SWP operations can potentially influence the growth and survival of foraging and migrating smelts and salmonids in Delta habitats by modifying hydrology and diversions. Conceptual models for salmonids (Windell et al. 2017) and smelts (IEP MAST 2015, Rosenfield 2010) describe some of the effects that flow and related parameters can have on these species.

Juvenile Winter-Run Chinook salmon are generally rearing and outmigrating through the Bay-Delta between November and April (Appendix C, *Species Spatial-Temporal Domains*). Habitat quality plays an important role in migration, growth, and survival of juvenile Chinook salmon outmigrants (Windell et al. 2017). Studies have shown that juvenile outmigrants from the Sacramento River experience higher survival when riverine inflows are higher (Kjelson et al. 1982, Buchanan et al. 2021, 2017). Pulse flows can increase instream flow, creating outmigration cues and affecting numerous habitat attributes, which can result in changes in juvenile salmonid survival (Windell et al. 2017). Higher flows can also inundate floodplains and increase connectivity, allowing juvenile salmonids access to refuge habitat and higher quality food habitat (Windell et al. 2017, Sommer et al. 2001).

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

Longfin smelt are a small, euryhaline, anadromous, pelagic fish species that typically reach maturity at the end of their second year (Dryfoos 1965; Merz et al. 2013). Spawning can occur between January and May, and larvae are typically detected between February and May (Merz et al. 2013). Longfin smelt larvae are most frequently detected from the confluence west to San Pablo Bay, with distribution extending upstream of the Confluence through the northern and eastern part of the Delta earlier in their development (Merz et al. 2013). Several studies have found a positive relationship between freshwater flow and Longfin smelt abundance (Jassby et al. 1995, Kimmerer 2002, Rosenfield and Baxter 2007). The mechanism is not well understood, but may be related to increased spawning habitat, decreased predation, and increased food resources, leading to faster growth (Rosenfield 2010).

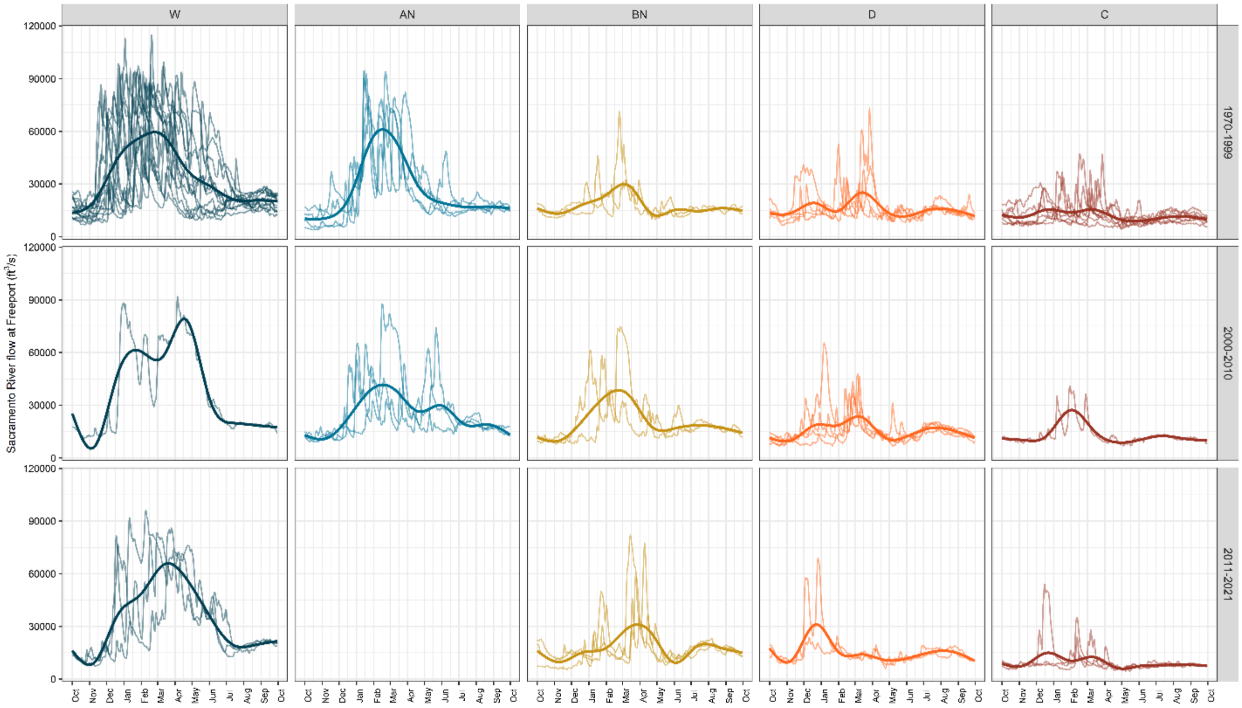
5.2 Datasets

The impacts of spring pulses on the Sacramento River and Delta outflow on federally listed native fish species are influenced by multiple factors including hydrology, water quality, and fish population abundance and distribution. Monitoring of hydrodynamics, water quality, and fish populations has been ongoing for over forty years, for some datasets, and covers the full spatial extent of the upper Sacramento River and Bay-Delta. These data and the following plots serve as the foundation and to illustrate patterns of interannual variability in historical hydrology and trends in water quality. They also provide data and visualizations of trends in federally listed native fish population abundances and distribution through the Sacramento River and Bay-Delta.

Presented in this section are three themes of empirical data: hydrodynamics, water quality parameters, and biological datasets. Hydrodynamics datasets (Section 5.2.1, *Hydrodynamics*) include five decades of flows on the Sacramento and San Joaquin rivers, X2 location, Delta inflow, and State Water Project and Central Valley Project exports, 1970 – 2021. Water quality parameters (Section 5.2.2, *Water Quality Parameters*) include turbidity, salinity, temperature, and chlorophyll a. Fish and other biological datasets (Section 5.2.2) include Chinook salmon catch per unit effort, zooplankton abundance, benthos abundance by taxonomic group, and invasive clam abundance.

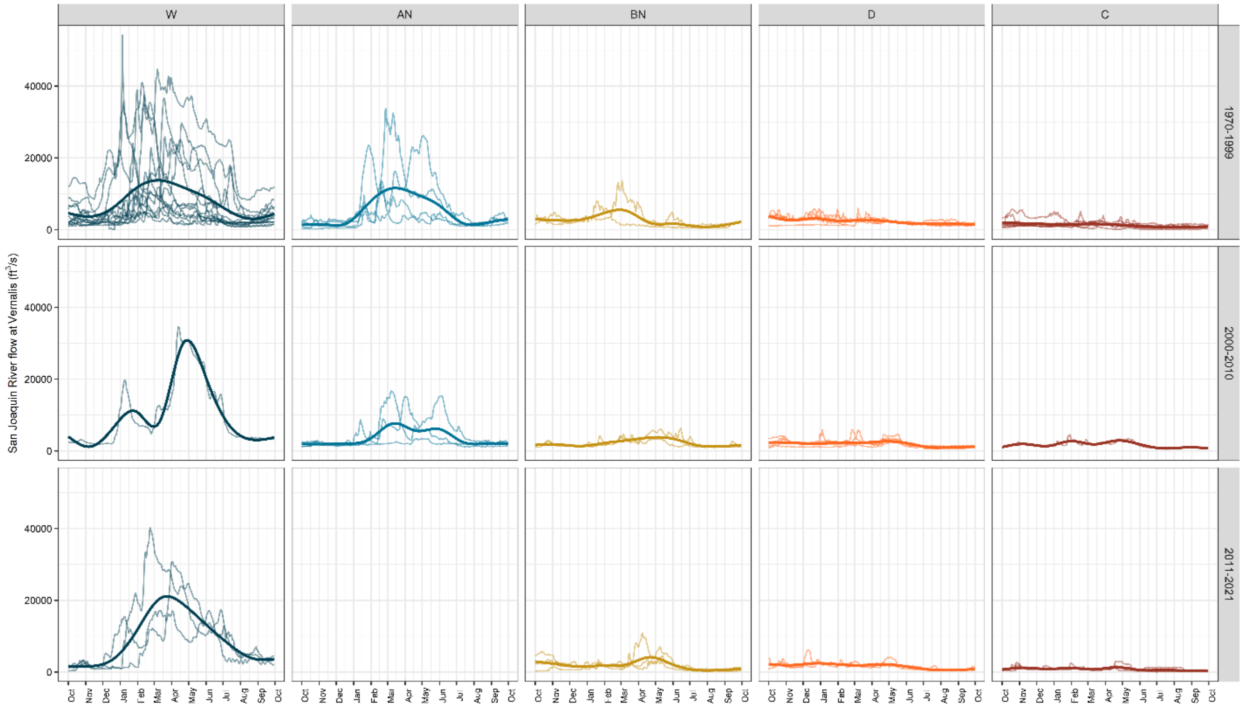
While some datasets include data gaps or shorter sampling efforts than others, overall, a large body of historic monitoring data within the Sacramento River and Bay-Delta is available. These data sets, in conjunction with modeled data (i.e., CalSim 3, Delta Simulation Model II [DSM2], USRDOM), serve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

5.2.1 Hydrodynamics



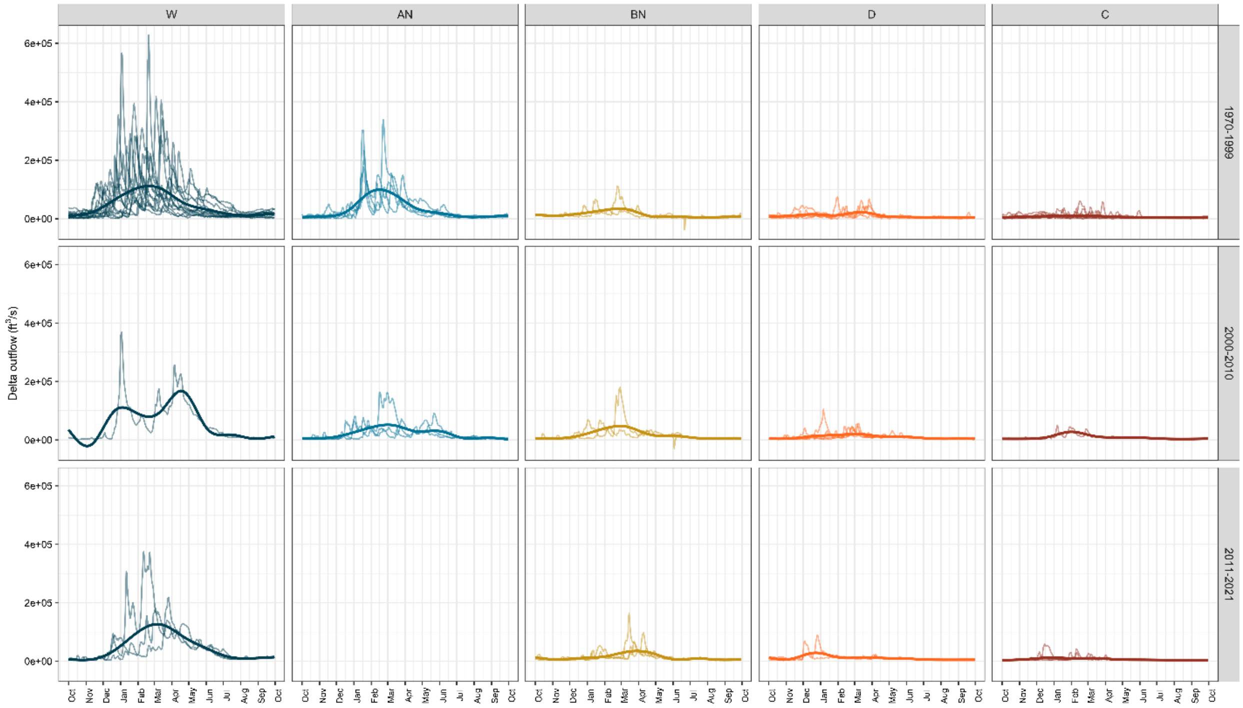
Source: DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow).
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

Figure 1. Estimated Sacramento River flow at Freeport data from 1970 to 2021 by water-year type and time periods (1970-1999: pre-D-1641 and CALFED era, 2000-2010: D-1641 and CALFED era, 2011-2021: post-2008/2009 Biological Opinions).



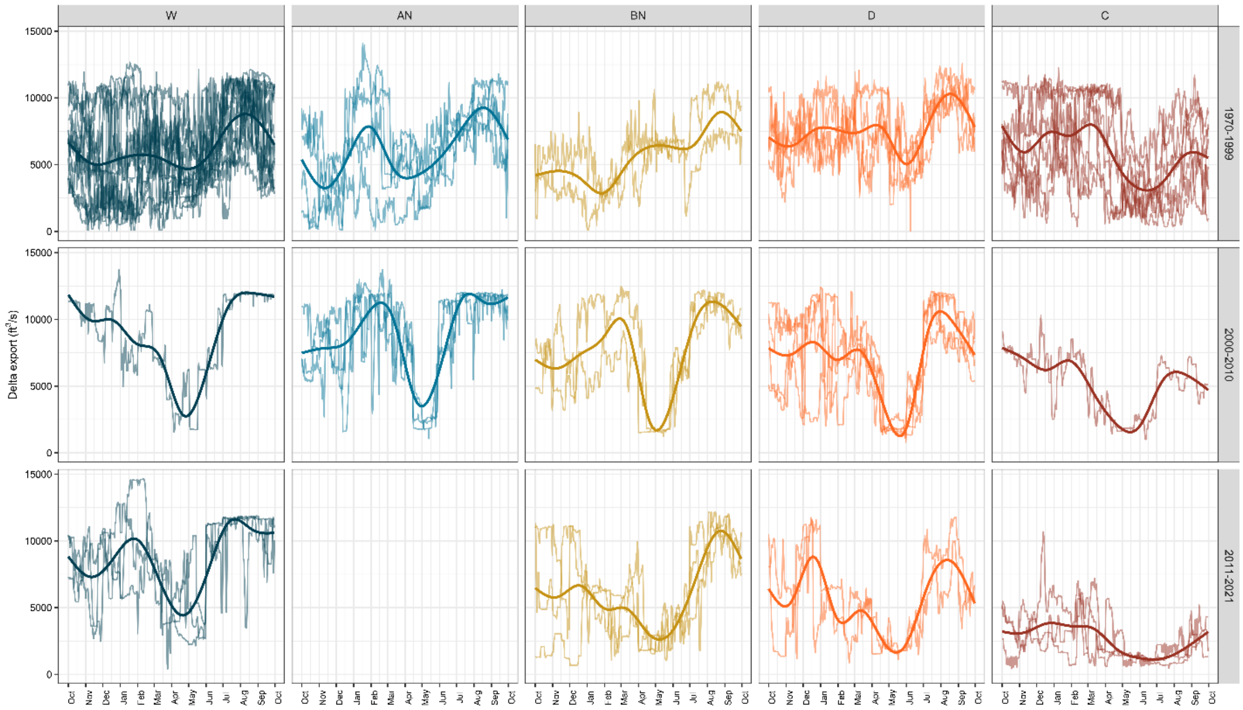
Source: DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow).
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

Figure 2. Estimated San Joaquin River flow at Vernalis data from 1970 to 2021 by water-year type and time periods (1970-1999: pre-D-1641 and CALFED era, 2000-2010: D-1641 and CALFED era, 2011-2021: post-2008/2009 Biological Opinions).



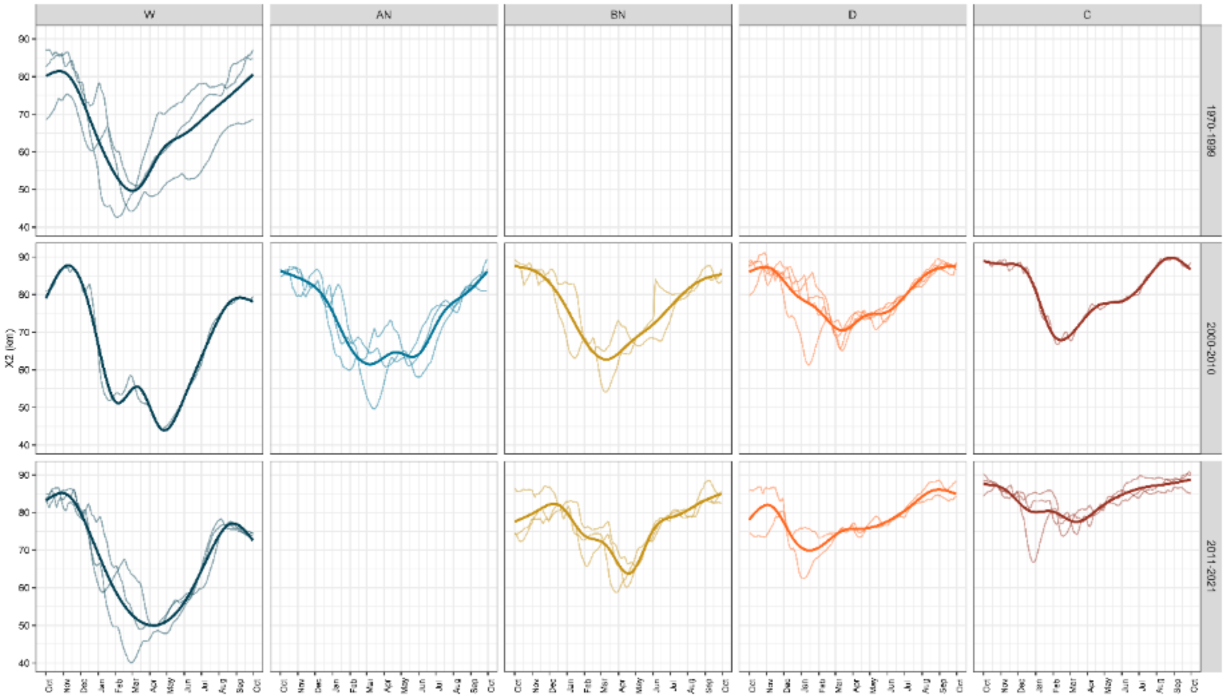
Source: DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow).
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

Figure 3. Delta Outflow data from 1970 to 2021 by water-year type and time periods (1970-1999: pre-D-1641 and CALFED era, 2000-2010: D-1641 and CALFED era, 2011-2021: post-2008/2009 Biological Opinions).



Source: DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow).
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

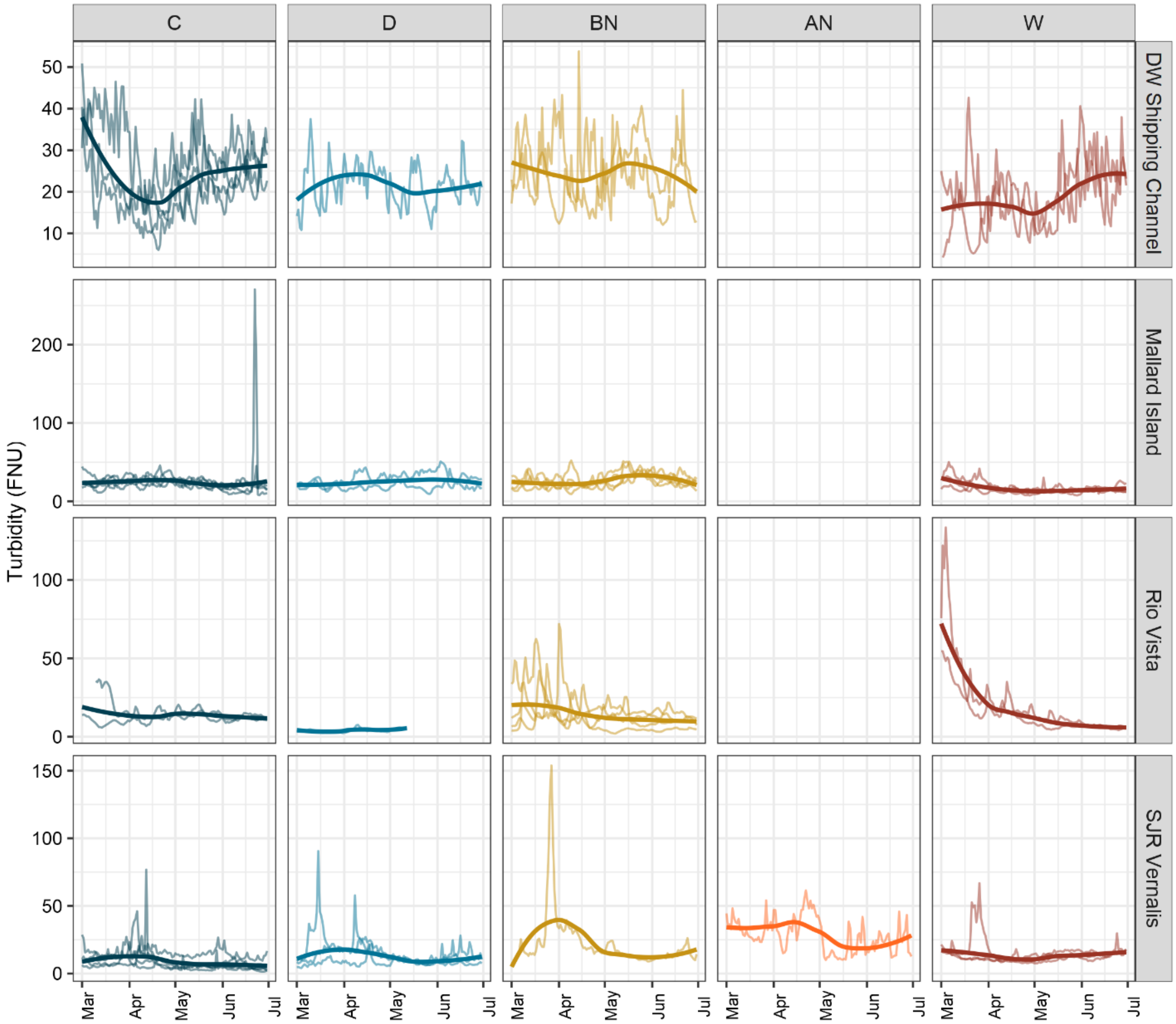
Figure 4. Combined Delta exports data from 1970 to 2021 by water-year type and time periods (1970-1999: pre-D-1641 and CALFED era, 2000-2010: D-1641 and CALFED era, 2011-2021: post-2008/2009 Biological Opinions).



Source: DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow).
Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

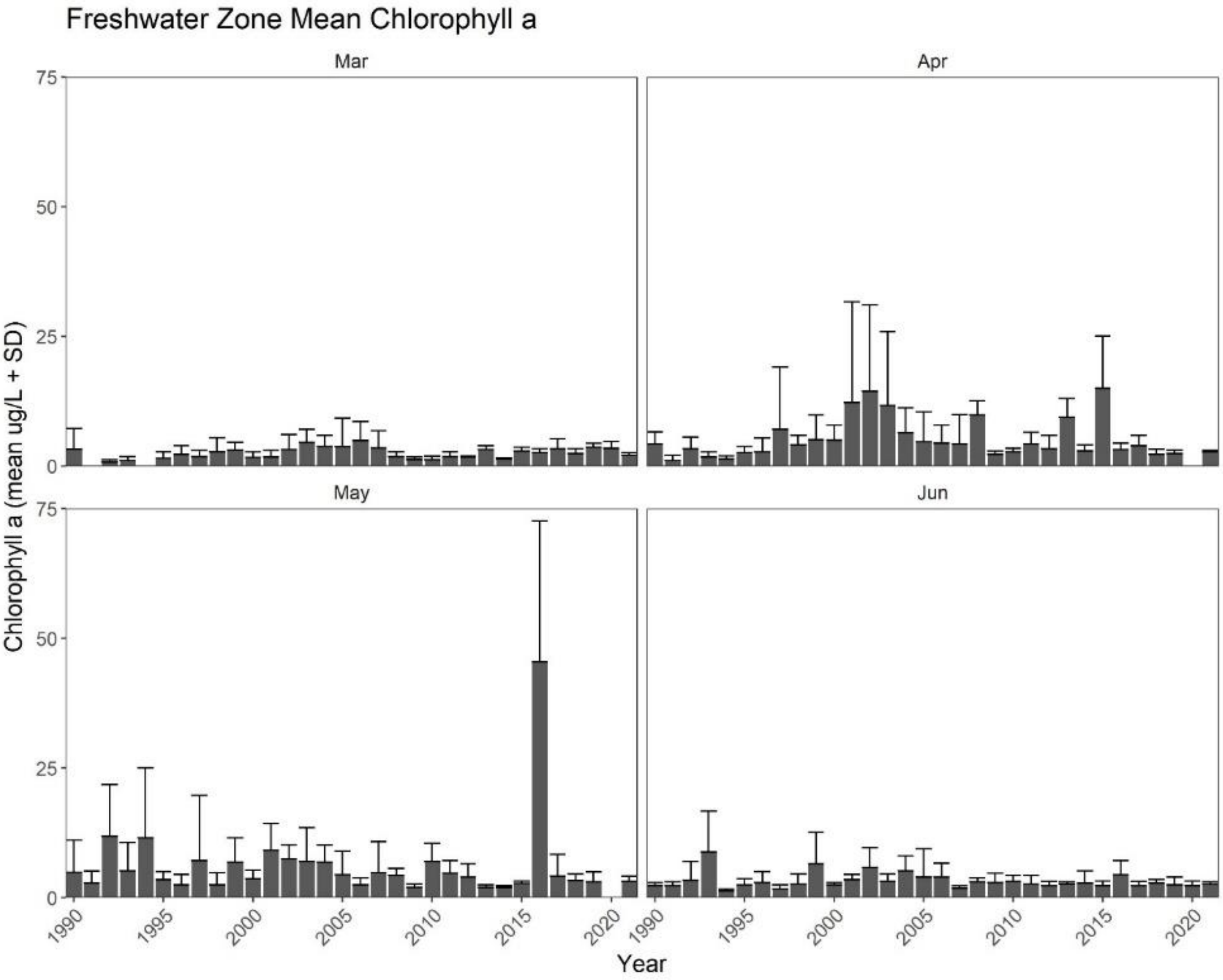
Figure 5. X2 data from 1997 to 2021 by water-year type and time periods (1970-1999: pre-D-1641 and CALFED era, 2000-2010: D-1641 and CALFED era, 2011-2021: post-2008/2009 Biological Opinions).

5.2.2 Water Quality Parameters



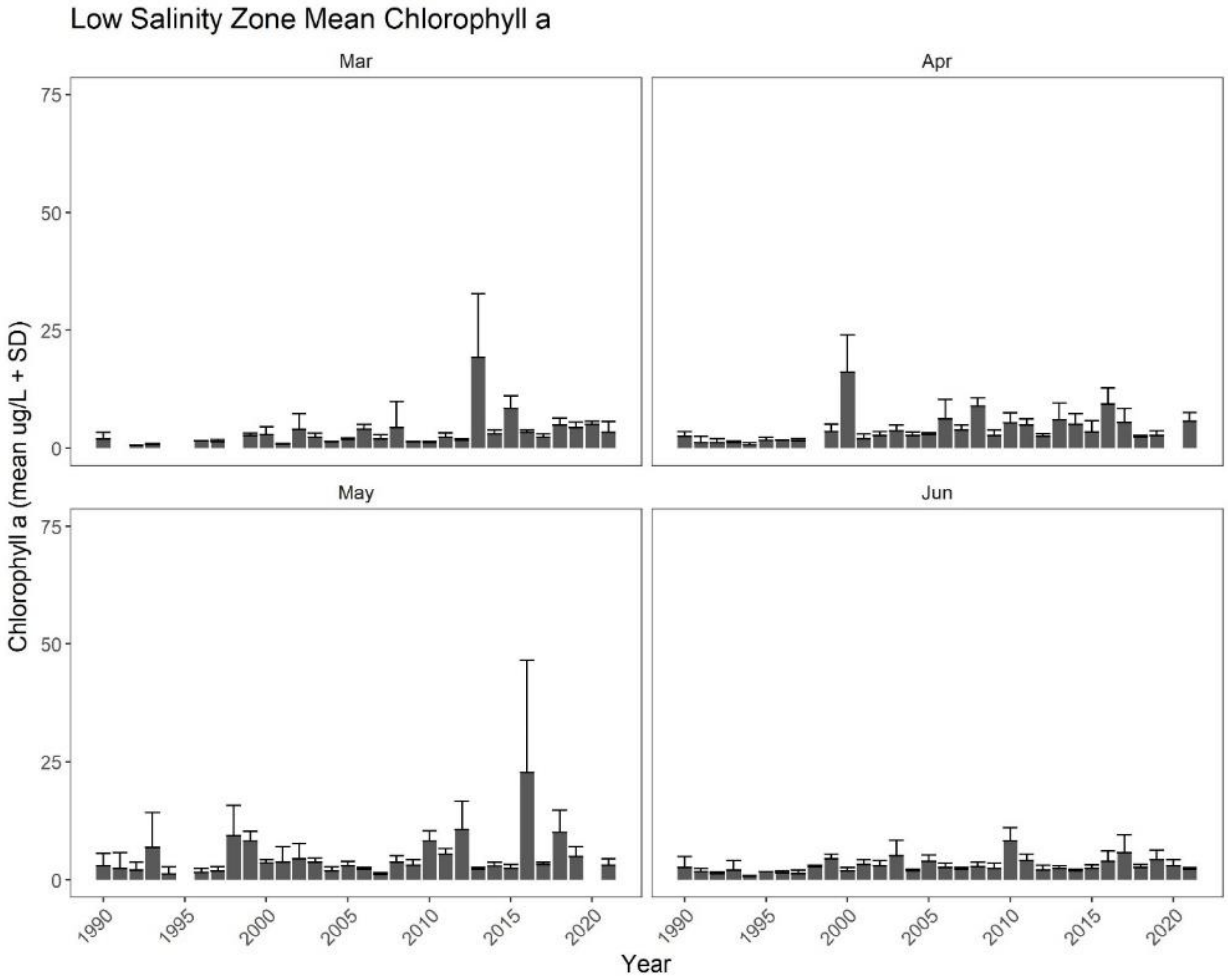
Source; CDEC (MAL and SJR; https://cdec.water.ca.gov/) and NWIS (DWC and SRV; https://waterdata.usgs.gov/nwis?).
Event data were downloaded from CDEC and NWIS. Raw data were filtered to values greater than 0, and dates with less than 20 hours out of 24 hours per day were removed. Mean turbidity values that appeared to deviate drastically from the surrounding values were plotted against flow as a check, and removed if deemed to be erroneous. Data were then averaged on a daily timestep. Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category’s dataset (which may include multiple water years). Note scales on the y-axis differ for each station. Start date differs for each station based on data availability: SRV, SJR and MAL (2010), DWC (2014).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

Figure 6. Daily average turbidity through water year 2022 by water-year type.



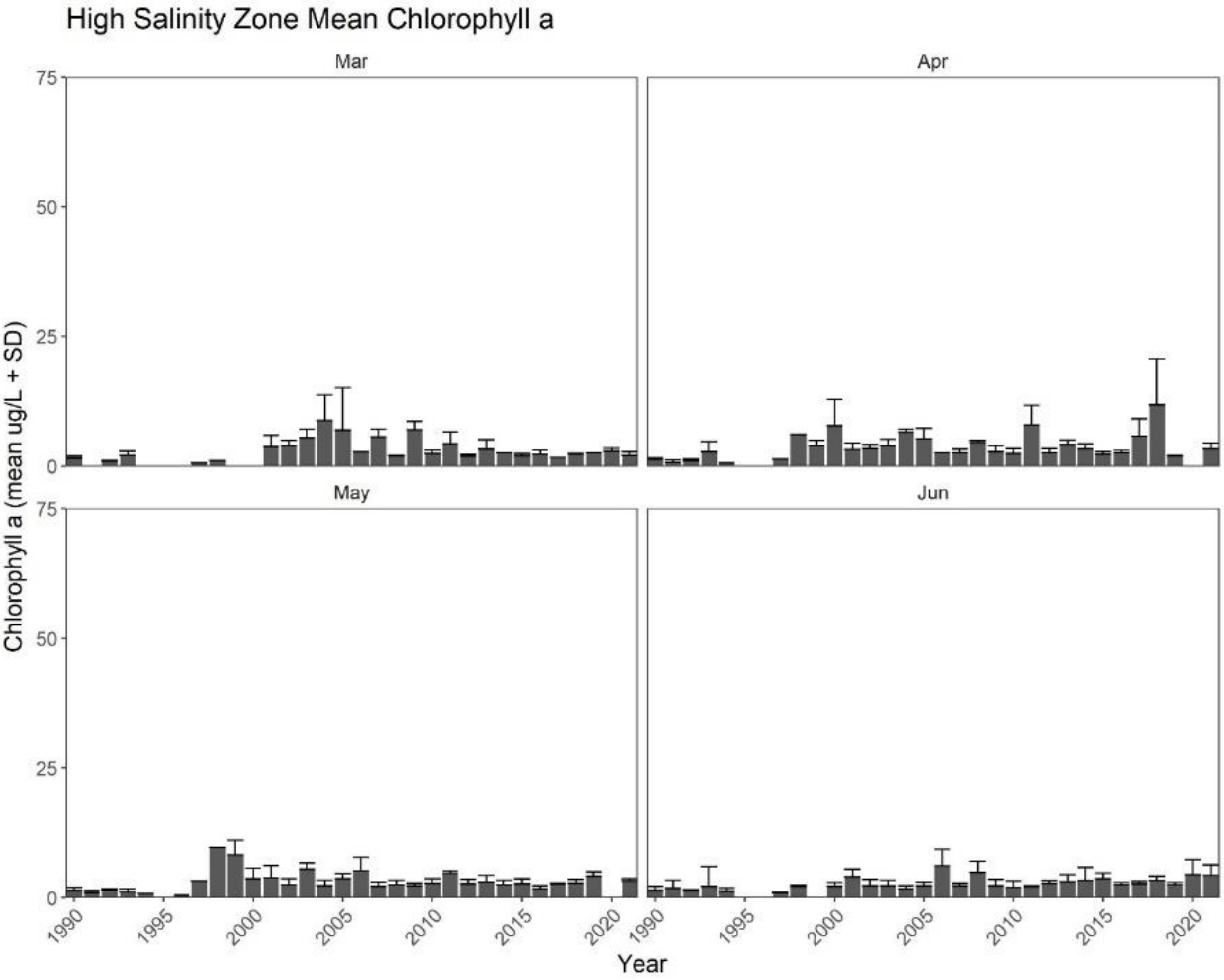
Source: Data downloaded and plotted using Zooper package in R).
Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 7. Chlorophyll a mean monthly concentration measured by the Environmental Monitoring Program from March through June of each year, 1990-2021.



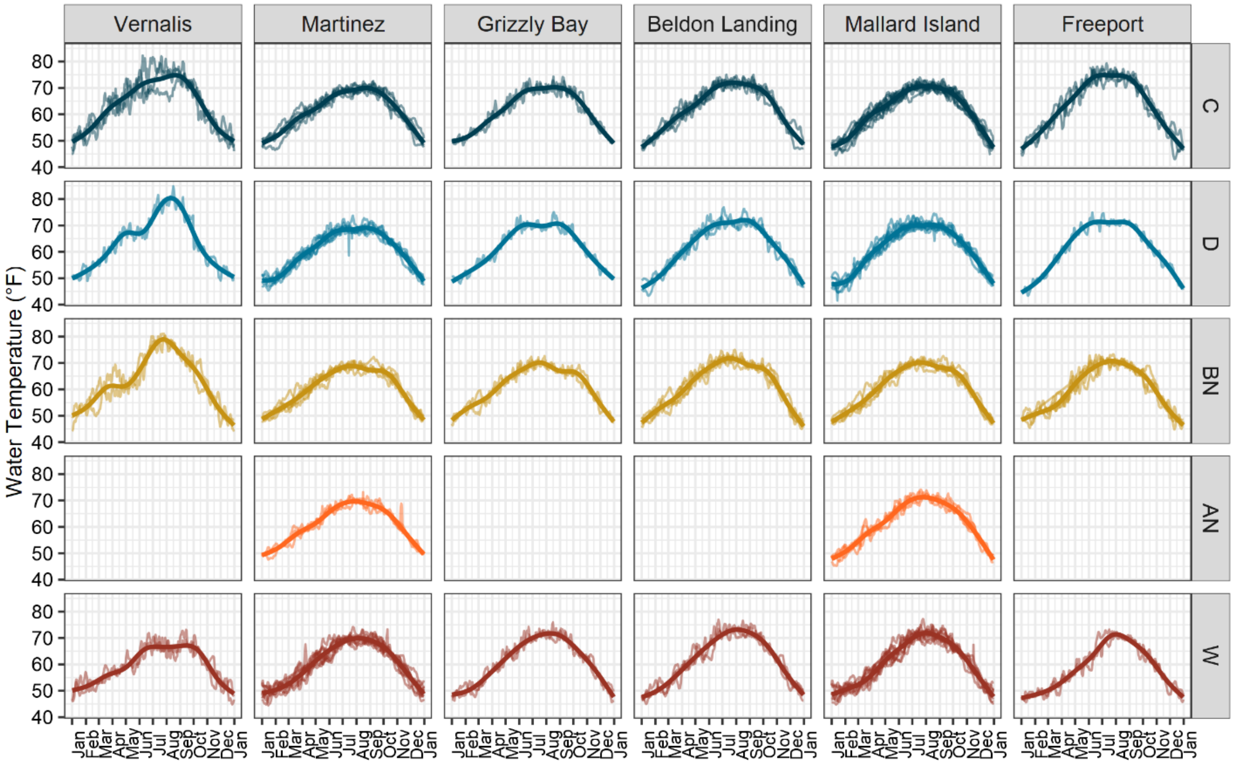
Source: Data downloaded and plotted using Zooper package in R).
Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 8. Chlorophyll a mean monthly concentration measured by the Environmental Monitoring Program from March through June of each year, 1990-2021.



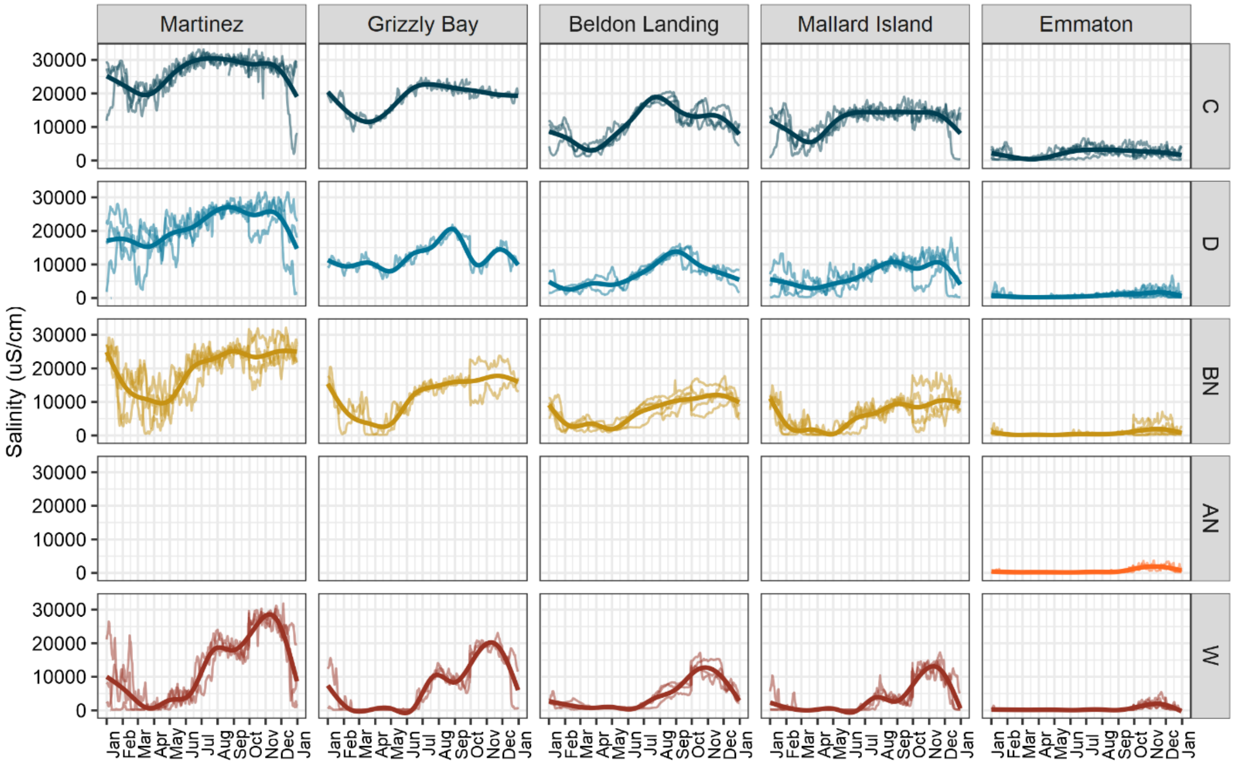
Source: Data downloaded and plotted using Zooper package in R).
Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 9. Chlorophyll a mean monthly concentration measured by the Environmental Monitoring Program from March through June of each year, 1990-2021.



Source:; CDEC (https://cdec.water.ca.gov/).
Event data downloaded from CDEC, converted to hourly data, and averaged on a daily time step. QA/QC were applied to data prior to averaging (see https://portal.edirepository.org/nis/mapbrowse?packageid=edi.591.2 for description of QA/QC methods). Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years). Start date differs for each station based on data availability: VNS (2014), MRZ (1994), MAL (1987), GZL (2015); BDL (2008), FPT (2009).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

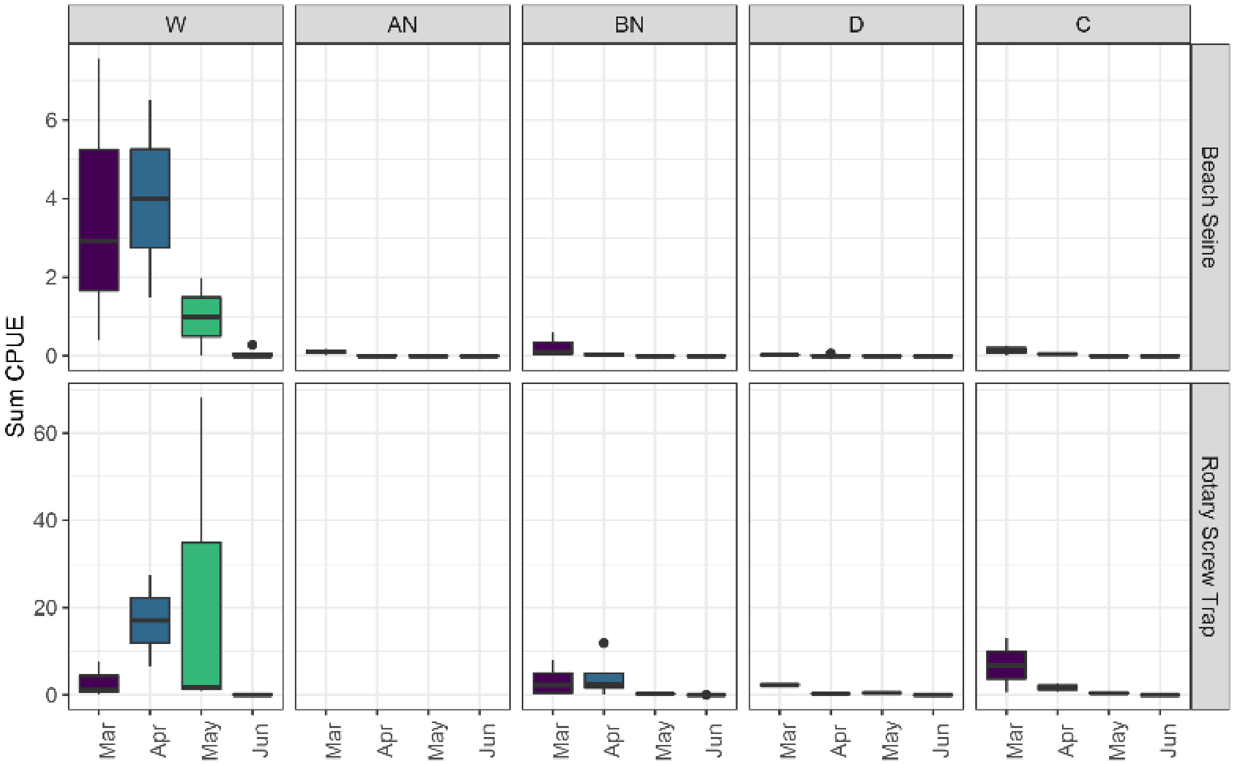
Figure 10. Daily average water temperature through water year 2022 by water-year type.



Source: CDEC (https://cdec.water.ca.gov/).
Event data downloaded from CDEC then averaged. Minor QA/QC applied (Filtered between 0 and 50,000 µS/cm; minor outlier removal). Each thin line represents a water year within a category and bolded line represents the LOESS smoothed trend line in each category's dataset (which may include multiple water years). Start data differs for each station: MRZ and MAL (2002), EMM (2000); GZL (2015); BDL (2009).
W: Wet, AN: Above Normal, BN: Below Normal, D: Dry, C: Critical.

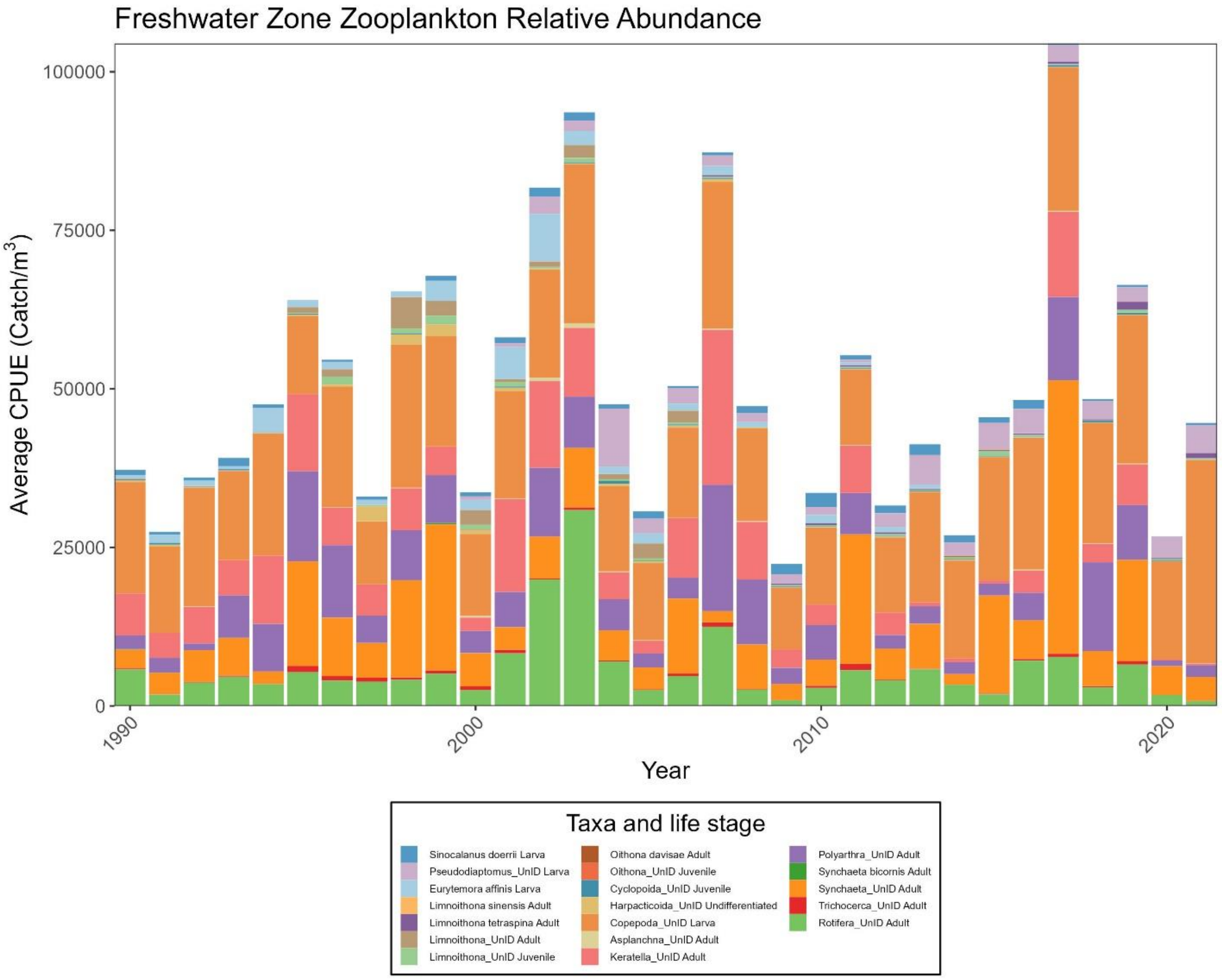
Figure 11. Daily average salinity (uS/cm)) through water year 2022 by water-year type.

5.2.3 Biological Observations



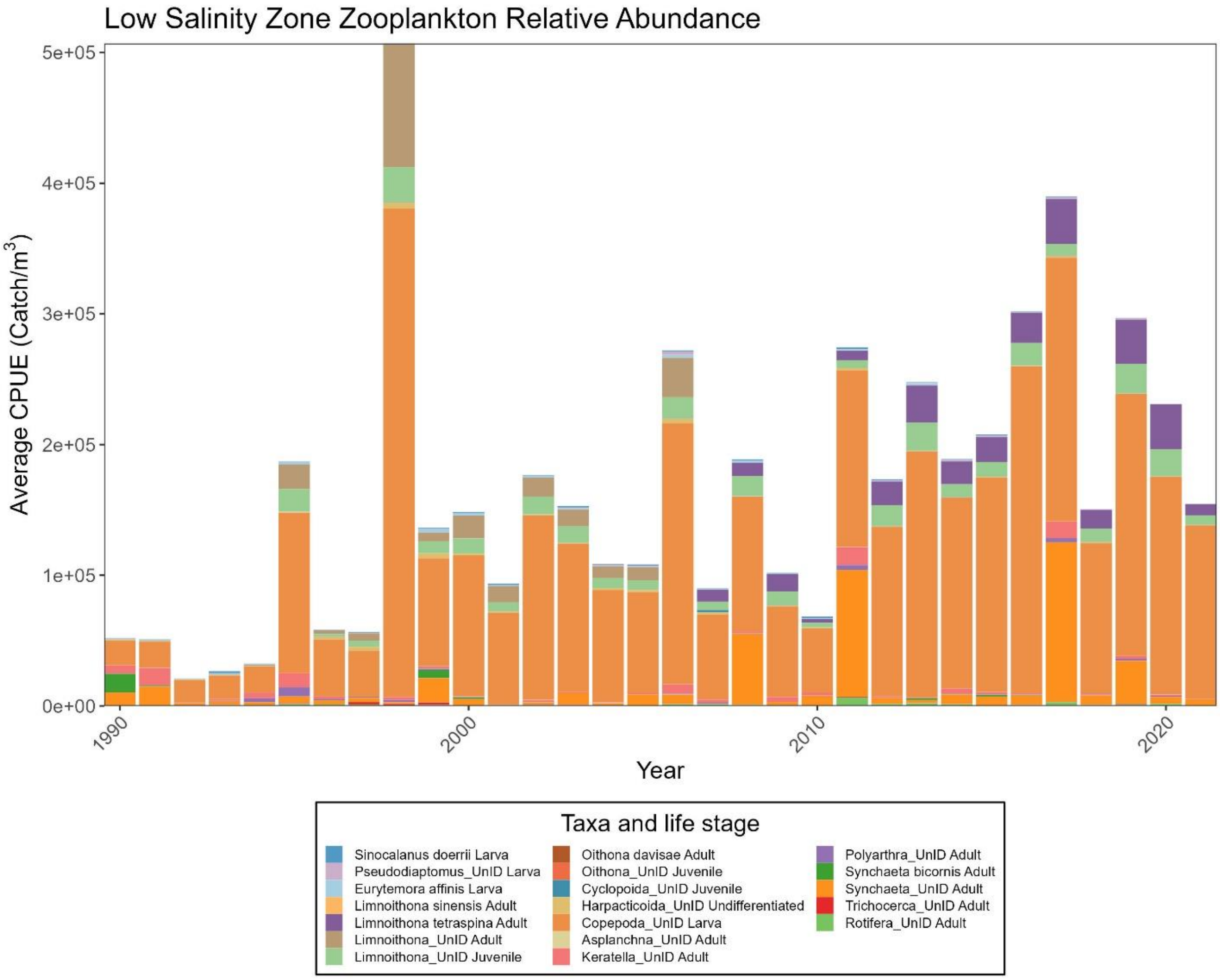
Source: Yolo data are from IEP et al. 2022. Water year classifications from https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST.
Beach seine data are between water years 2000-2019, Rotary screw trap data are between WY 2010-2019 due to lack of accurate effort data prior to 2010 for rotary screw trap. Beach seine CPUE is calculated by volume (count/m^3) while rotary screw trap data CPUE is calculated by hours (count/hours of effort). CPUE values are summed by month and method and boxplots represent CPUE over different water years.

Figure 12. Juvenile Chinook Salmon CPUE in Yolo Bypass.



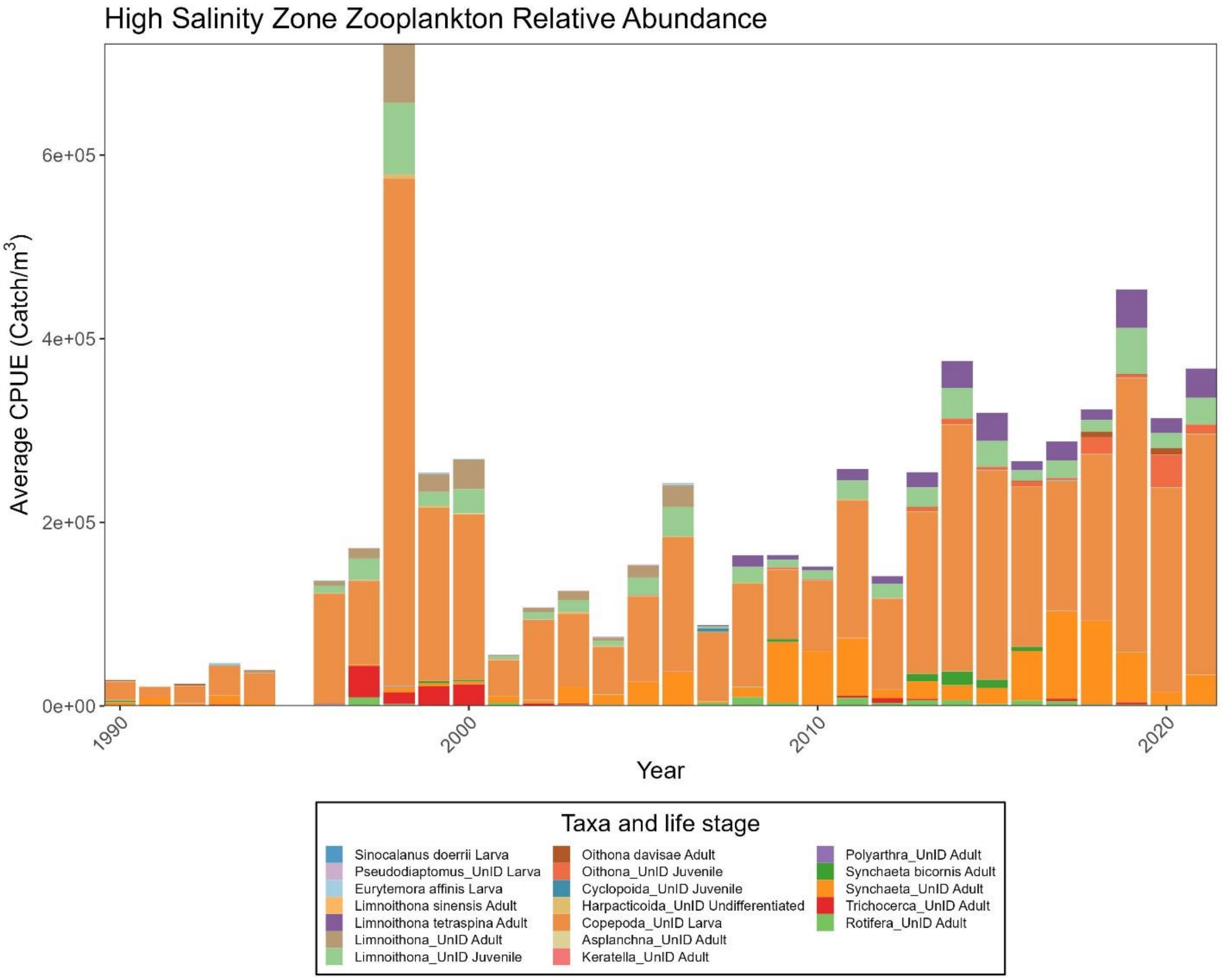
Source: Data downloaded and plotted using Zooper package in R.
Mean catch per unit effort [CPUE] calculated as number of individuals per cubic meter. Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 13. Freshwater zone micro-zooplankton mean annual relative abundance collected by the Environmental Monitoring Program from March through June of each year, 1990 – 2021.



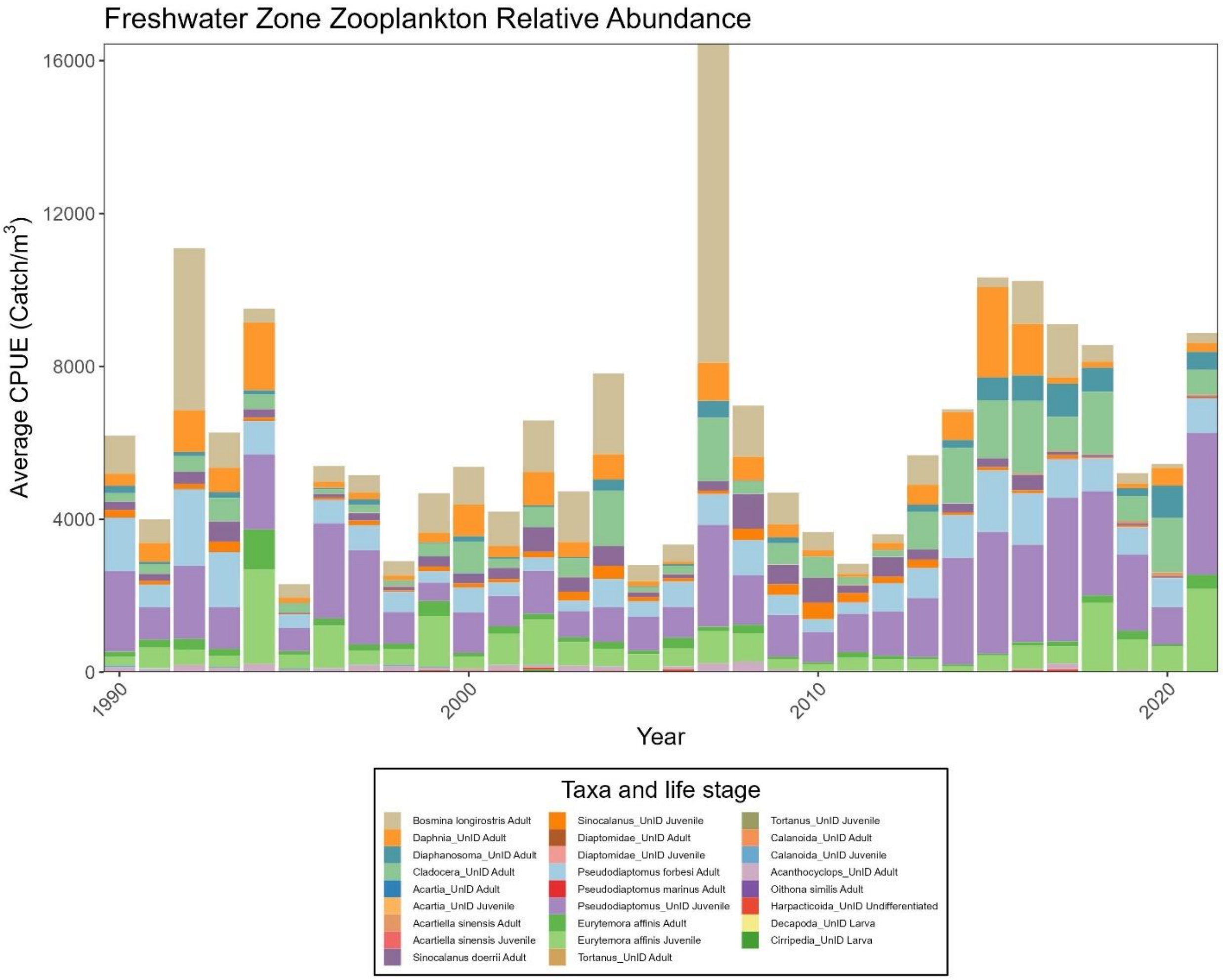
Source: Data downloaded and plotted using Zooper package in R.
Mean catch per unit effort [CPUE] calculated as number of individuals per cubic meter. Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 14. Low salinity zone micro-zooplankton mean annual relative abundance collected by the Environmental Monitoring Program from March through June of each year, 1990 – 2021.



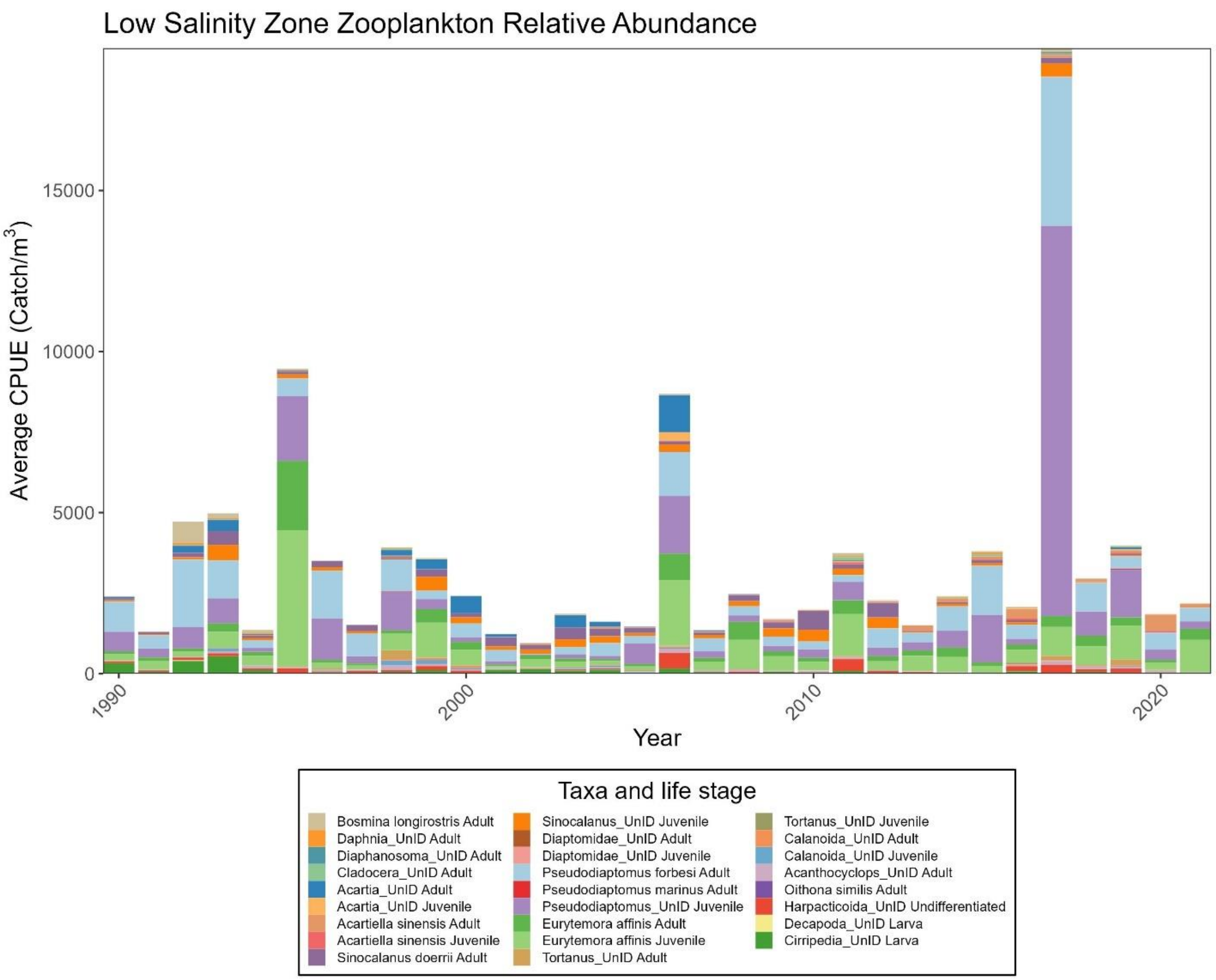
Source: Data downloaded and plotted using Zooper package in R.
Mean catch per unit effort [CPUE] calculated as number of individuals per cubic meter. Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 15. High salinity zone micro-zooplankton mean annual relative abundance collected by the Environmental Monitoring Program from March through June of each year, 1990 – 2021.



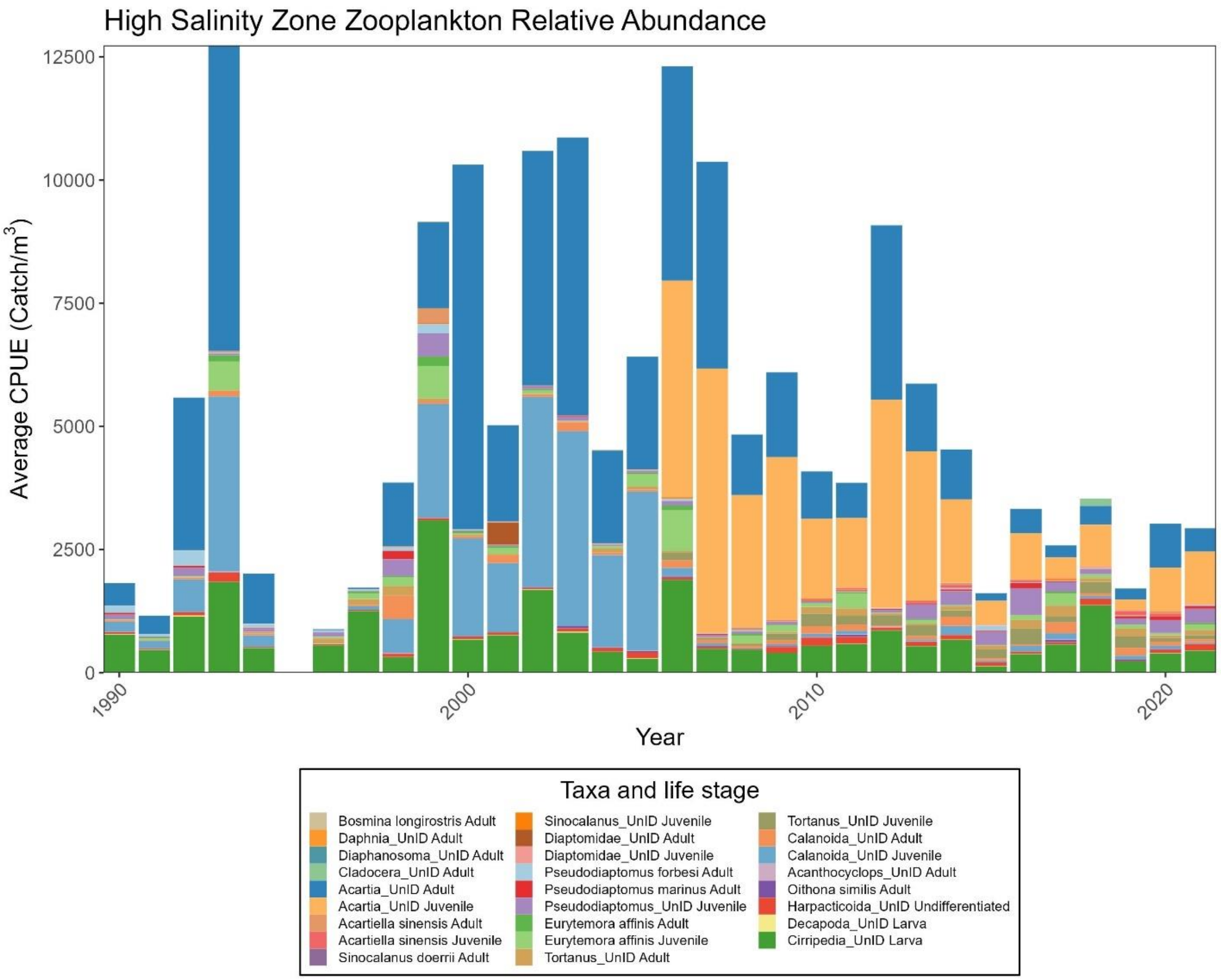
Source: Data downloaded and plotted using Zooper package in R.
Mean catch per unit effort [CPUE] calculated as number of individuals per cubic meter. Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 16. Freshwater zone meso-zooplankton mean annual relative abundance collected by the Environmental Monitoring Program from March through June of each year, 1990 – 2021.



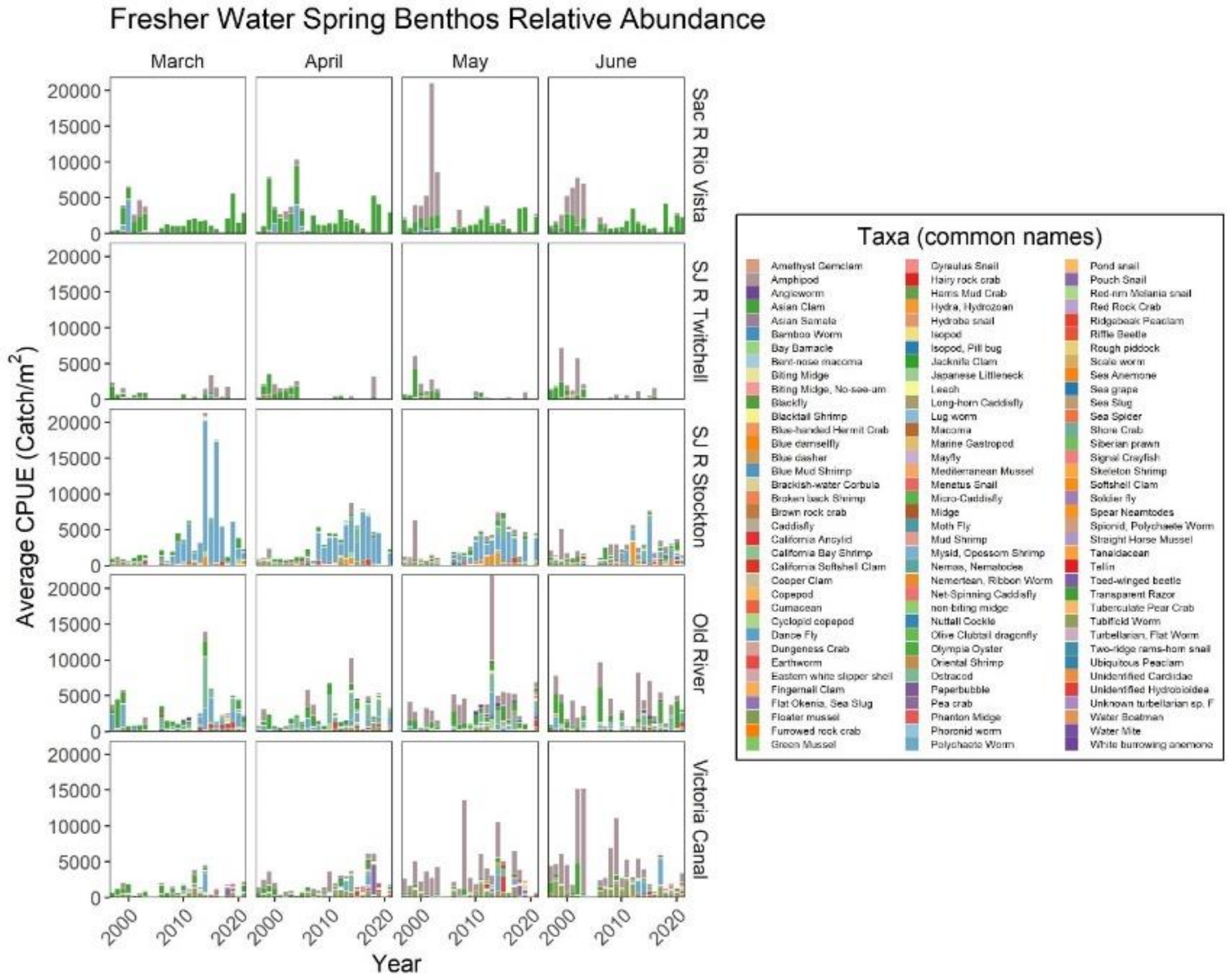
Source: Data downloaded and plotted using Zooper package in R.
Mean catch per unit effort [CPUE] calculated as number of individuals per cubic meter. Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 17. Low salinity zone meso-zooplankton mean annual relative abundance collected by the Environmental Monitoring Program from March through June of each year, 1990 – 2021.



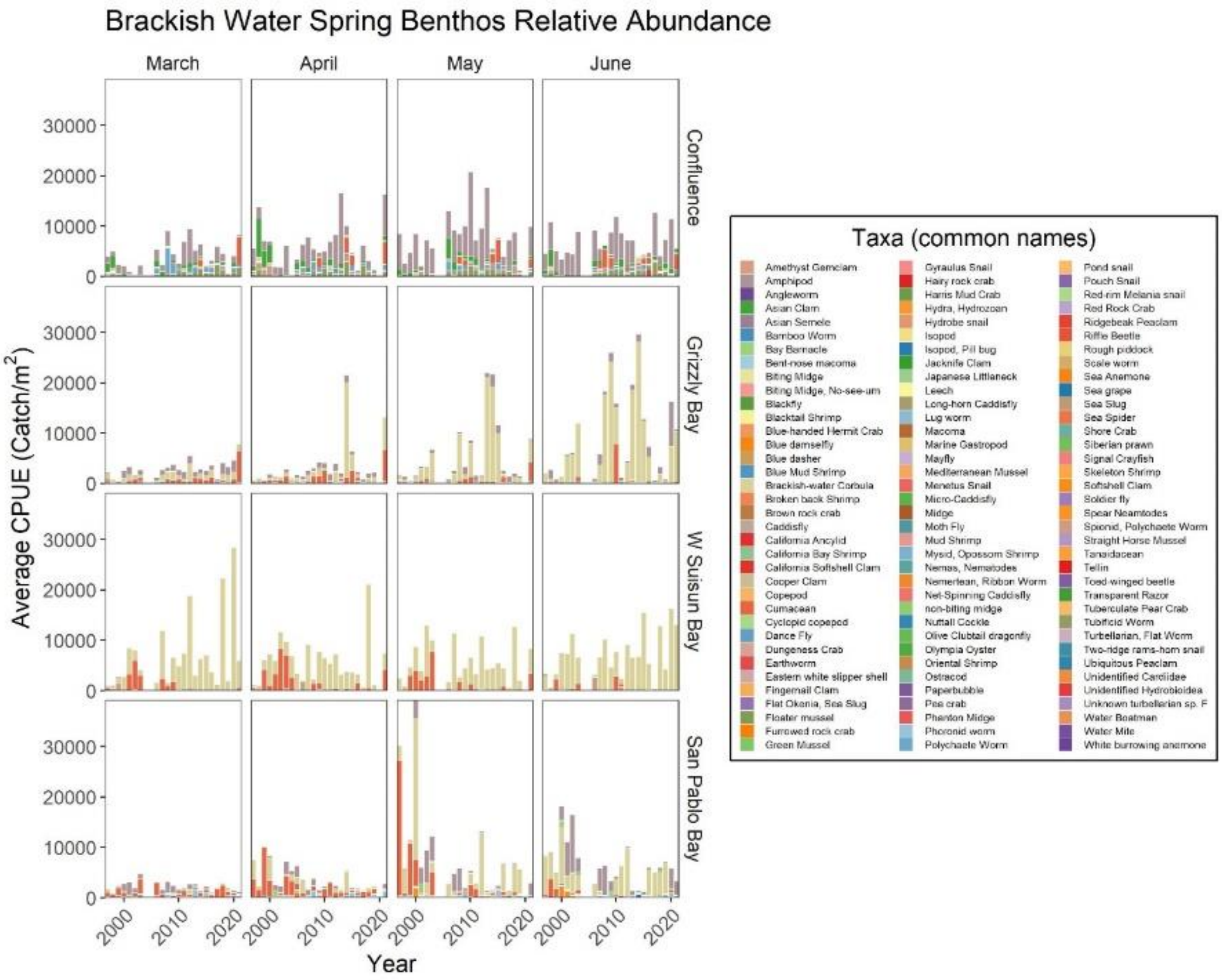
Source: Data downloaded and plotted using Zooper package in R.
Mean catch per unit effort [CPUE] calculated as number of individuals per cubic meter. Salinity zones are defined as follows, based on surface salinity as follows: < 0.5 practical salinity units (PSU), freshwater; 0.5-6.0 PSU, low salinity zone; > 6.0 PSU, high salinity zone.

Figure 18. High salinity zone meso-zooplankton mean annual relative abundance collected by the Environmental Monitoring Program from March through June of each year, 1990 – 2021.



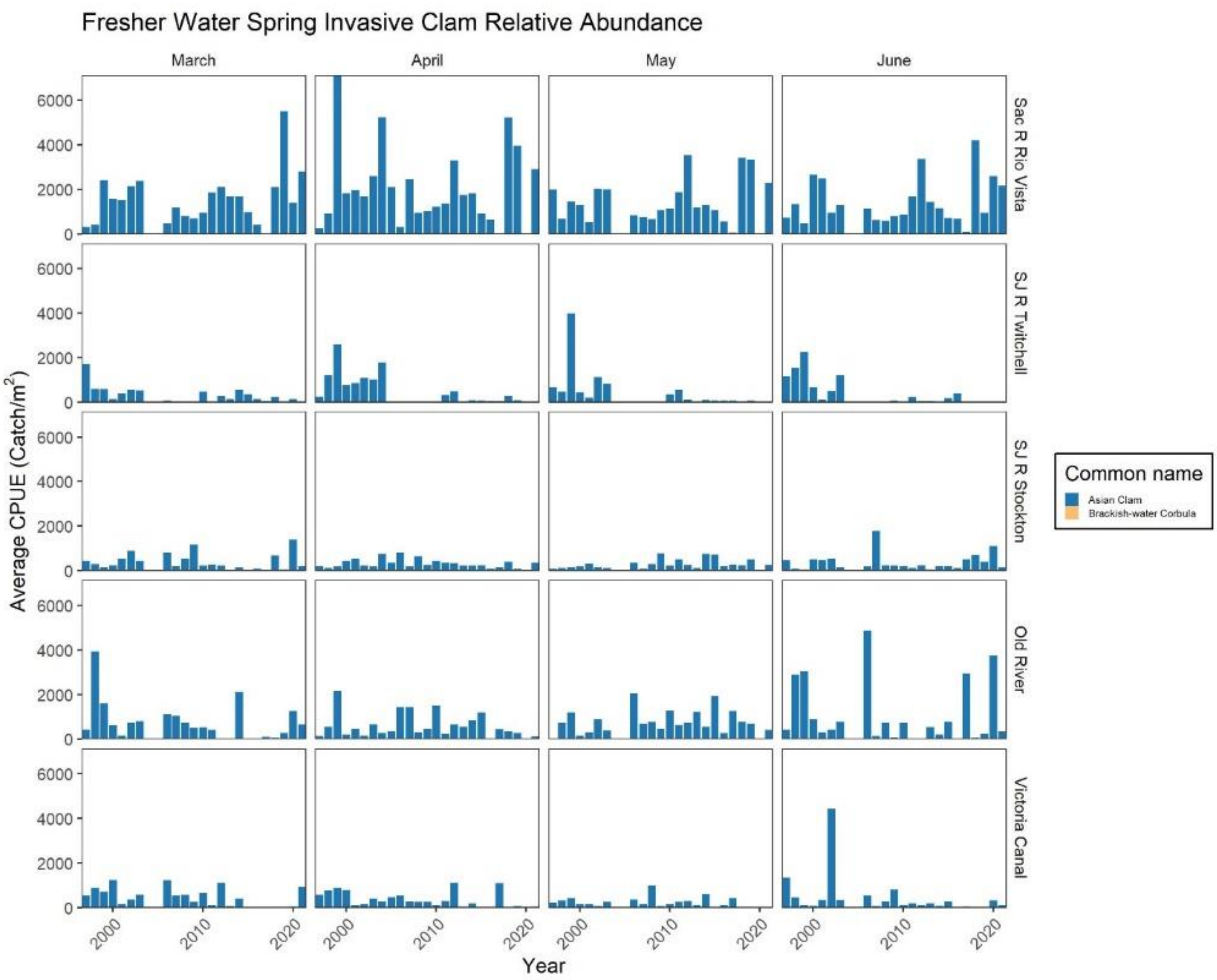
Source: Data downloaded from EDI 12/23/2022.
Mean catch per unit effort [CPUE] calculated as number of individuals per square meter. Samples were collected by the Environmental Monitoring Program from March through June of each year, 1996 – 2021. Taxonomic groups provided as common names. Note the y-axis scales differ between the plot for the fresher regions and the brackish regions.

Figure 19. Benthos mean monthly relative abundance by Enhanced Delta Smelt Monitoring Program (EDSM) region: fresher regions.



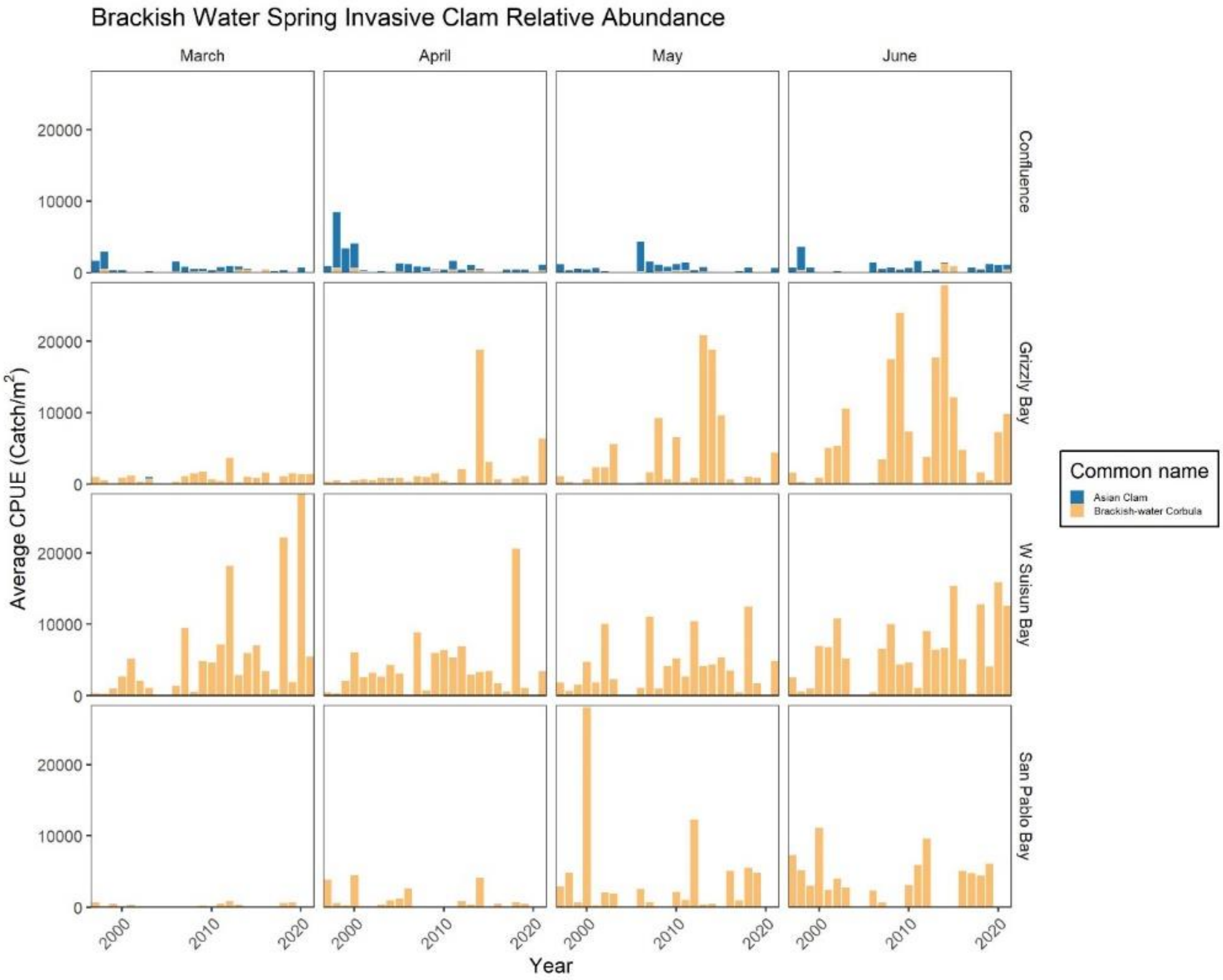
Source: Data downloaded from EDI 12/23/2022.
Mean catch per unit effort [CPUE] calculated as number of individuals per square meter. Samples were collected by the Environmental Monitoring Program from March through June of each year, 1996 – 2021. Taxonomic groups provided as common names. Note the y-axis scales differ between the plot for the fresher regions and the brackish regions.

Figure 20. Benthos mean monthly relative abundance by Enhanced Delta Smelt Monitoring Program (EDSM) region: brackish regions.



Source: Data downloaded from EDI 12/23/2022.
Mean catch per unit effort [CPUE] calculated as number of individuals per square meter. Samples collected by the Environmental Monitoring Program from March through June of each year, 1996 – 2021. Taxonomic groups provided as common names.

Figure 21. Invasive clam mean monthly relative abundance by EDSM region: fresher regions.



Source: Data downloaded from EDI 12/23/2022.
Mean catch per unit effort (CPUE) calculated as number of individuals per square meter. Samples collected by the Environmental Monitoring Program from March through June of each year, 1996 – 2021. Taxonomic groups provided as common names.

Figure 22. Invasive clam mean monthly relative abundance by EDSM region: brackish regions.

5.3 Models

5.3.1 Hydrodynamics

5.3.1.1 Particle Tracking Model

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

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

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

5.3.1.2 Bay-Delta SCHISM

The Bay-Delta Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) model is a three-dimensional numerical modeling system for the San Francisco Bay Delta estuary that is based on an unstructured grid numerical model known as SCHISM (Ateljevich et al. 2014; Chao et al. 2017a, 2017b; Zhang et al. 2008, 2016, 2019). The model can predict salinity and temperature in the Bay-Delta. Bay-Delta SCHISM can be used along with Bever et al. (2016) to evaluate physical habitat quality and suitability for Delta and longfin smelt. These quality and suitability criteria are for older life stages, and is not useful for evaluating spring Delta smelt habitats.

5.3.1.3 Water Temperature (HEC-5Q)

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

HEC-5Q can inform juvenile salmonid survival as a function of river temperature. These models are useful for riverine temperature models, but do not apply to the Delta.

5.3.2 Food Web

Several models are available for assessment of food web performance metrics.

5.3.2.1 Effects on Zooplankton: Greenwood (2018)

The density of the key smelt zooplankton prey *Eurytemora affinis* is significantly negatively related to mean March through May X2 and a general linear model to analyze this for different outflow scenarios is available from Greenwood (2018). X2 is the distance, expressed in kilometers from the Golden Gate Bridge, at which channel bottom water salinity (isohaline) is 2 parts per thousand (2 ppt). Greenwood's method (2018) can be used to evaluate potential effects on *E. affinis* and *Crangon* as a result of spring Delta outflow operations. Kimmerer (2002) found statistically significant negative relationships between mean spring (March-May) X2 and the relative abundance (catch per unit effort) of *E. affinis* and *Crangon* (Bay Shrimp); Kimmerer et al. (2009) updated the latter relationship with additional years of data. Application of the Kimmerer et al. (2009) Bay Shrimp X2-abundance relationship can show the relationship between spring X2 and relative abundance of Bay Shrimp. Kimmerer's (2002) method was followed to conduct an analysis for the period from 1980 to 2017 (Greenwood 2018).

5.3.2.2 Effects on Zooplankton: Hennessy and Burris (2017)

Regression equations from Hennessy and Burris (2017) are available that predict *E. affinis* density and mysid shrimp *Neomysis mercedis* density in the low-salinity zone as a function of March through May Delta outflow as well as an equation predicting the density of the smelt zooplankton prey *Pseudodiaptomus forbesi* in Suisun Bay as a function of mean June through September Delta outflow, although this is minimally overlapping the spring Delta outflow period).

The equations outlined in the Hennessy and Burris (2017) memo were examined and it was decided these regressions are too geographically simplistic and temporally broad as currently developed to add value to evaluating effects of operations on the zooplankton community.

5.3.3 Smelt

5.3.3.1 Delta Smelt Individual-Based Model

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

Delta smelt IBM can be used to evaluate the movement and distribution and survival probability performance metrics for Delta smelt. This model can combine Delta Simulation Model II flow data from the Sacramento and San Joaquin Rivers with export level values from the pumping facilities. This model's inputs are different than the numeric modeling developed for the BA, and is not being used.

5.3.3.2 Delta Smelt Life Cycle Model (2021 version)

Polansky et al. (2020) developed a stage-structured state-space life cycle model for Delta Smelt. State-space models are useful as ecological modeling tool because they allow separate descriptions of state and observation processes and because they permit integration of disparate data sets. This Delta Smelt life cycle model was later expanded from four to seven different life stages and to include a component that describes the entrainment process into the Delta export facilities (Smith et al. 2021). This model produces expected values for larval recruitment and survival at the subsequent life stages. The best model in Smith et al. (2021) did not include spring outflow as a variable influencing abundance and survival, so it will not be used to examine spring outflow.

5.3.3.3 Delta Smelt Maunder and Deriso (2011) State-Space Model

Maunder and Deriso (2011) developed a state-space multistage life cycle model for delta smelt that allows for density dependence and environmental factors to impact the different life stages. This model may be applicable to scenario data given assumptions regarding covariates for which the effects of management actions are not predictable.

5.3.3.4 Longfin Smelt Outflow-Abundance Model

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

The potential effect of the alternatives on longfin smelt can be investigated through development of a statistical model relating the longfin smelt fall midwater trawl abundance index to Delta outflow, the fall midwater trawl abundance index 2 years earlier (as a representation of parental stock size), and ecological regime (i.e., 1967–1987, pre-*Potamocorbula amurensis* invasion; 1988–2002, post-*P. amurensis* invasion; and 2003–2020, Pelagic Organism Decline; to represent major ecological changepoints in the Bay-Delta, e.g., Nobriga and Rosenfield 2016). Assess total Delta outflow (summed, thousand acre-feet) for March through May and December through May, similar time periods to previous work by Mount et al. (2013) and Nobriga and Rosenfield (2016).

5.3.4 Chinook Salmon

5.3.4.1 SacPAS Fish Migration Model

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

5.3.4.2 Flow threshold survival model (Michel et al 2021)

The flow threshold survival model (Michel et al. 2021) methods were applied to assess potential effects of spring pulse and Delta outflow effects on juvenile Chinook salmon riverine survival in the Sacramento River as a function of flow. To assess potential effects of Project operations on juvenile Chinook salmon as a result of flow-survival relationships, the flow thresholds and survival estimates from Michel et al. (2021) were applied to Sacramento River at Wilkins Slough flow. The models were fit and validated using acoustic telemetry Chinook salmon smolts released between 2013 and 2019. These flow thresholds and corresponding assumptions are well described and clear from the published paper. This model has recently been used to update survival results for the CVPIA SIT DSMs for Chinook salmon.

5.3.4.3 STARS Models

The STARS model (Survival, Travel time, and Routing Simulation) is an individual-based simulation that predicts fish parameters (survival, travel time, entrainment) of juvenile salmonids migrating through the Delta. The fish parameters are related to movement of individual acoustically tagged late-fall and winter-run Chinook salmon connected to daily data (Delta Cross Channel gate status and Sacramento River flow at Freeport). The implementation of the simulation model currently available for use is calibrated to acoustically tagged late-fall fish released from 2007 to 2011. Data inputs to the model can be obtained by assigning monthly CalSim output to daily values within each month. Results are for individuals in cohorts, or fish who enter the model's "system" daily at Freeport. The use of the STARS model can inform the migrating behavior of juvenile salmonids (i.e., route selection) and total survival in the Delta. It is constructed to understand the space outside the interior Delta, but interpolation could be used to identify possible behavior of fish once they take a specific route away from the Sacramento River (i.e., Delta Cross Channel or Georgiana Slough). STARS provides overall survival and travel time, route-specific survival and travel time, and proportion of fish on a daily timestep that would use individual migration pathways or routes. An application of the STAR models run in real time is available here: https://oceanview.pfeg.noaa.gov/shiny/FED/CalFishTrack/. The code and supporting document are available from USGS (Russ Perry, USGS, Personal Communication). The model structure and assumptions are documented in peer-reviewed literature (Perry et al. 2018). Model development is not currently open and participatory.

The STARS model can be applied to assess the performance metric of routing probability for winter-run Chinook salmon and possibly also spring-run Chinook salmon. The STARS model was applied to the 2019 NMFS Biological Opinion.

5.3.5 Other Species

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

- Striped bass (separate models based on bay otter trawl abundance index, bay midwater trawl abundance index, fall-midwater trawl abundance index, summer townet abundance index, and summer townet survival index).
- American shad (separate models for bay midwater trawl abundance index and fall-midwater trawl abundance index).
- Starry flounder and California bay shrimp (models based on bay otter trawl abundance indices).
- General linear models are also available linking white sturgeon year class strength (based on capture by otter trawls by the San Francisco Bay Study) to March through July and April through May Delta outflow. This can be used as a surrogate for inflow and outflow effects on green sturgeon year class strength.

6. Lines of Evidence

During alternative development, rationales behind different concepts and approaches to species-specific spring outflow management strategies were documented. These concepts are described here as lines of evidence. From the full list of quantitative models outlined above (Section 5.3, *Models*), a subset of tools was selected to evaluate the environmental impacts of the CVP and SWP operations on listed fishes. These tools are included as lines of evidence.

6.1 Effect of Spring Outflow on Water Quality

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

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

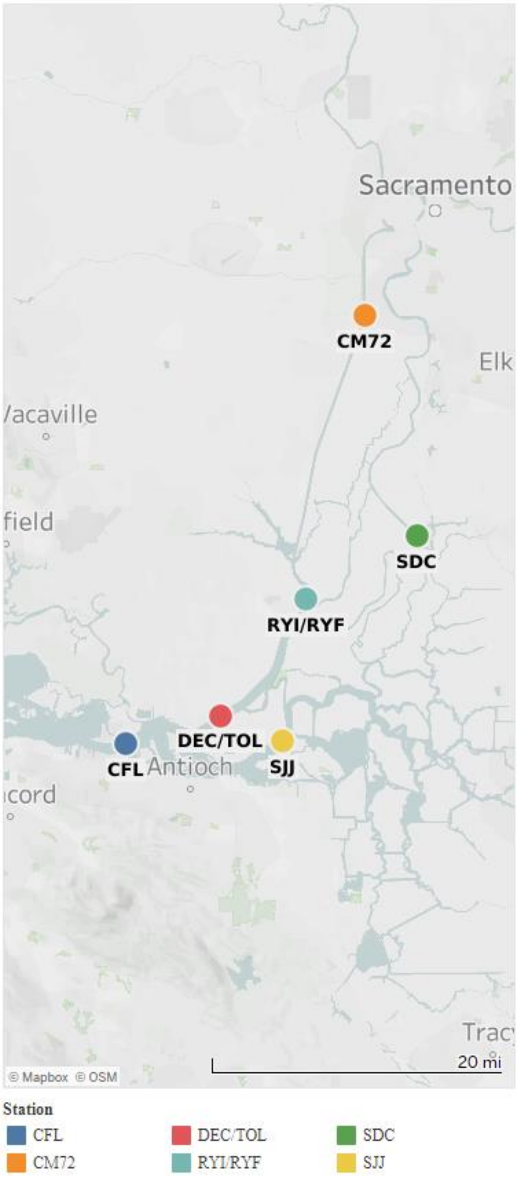
Modeling efforts have observed that X2 responds more rapidly to increases in flow than decreases (Chen et al. 2015), and that the response of X2 is fast when flow is large (MacWilliams et al. 2015), which supports the value of spring outflow pulses for improving Delta habitat as it relates to salinity. However, pulse flows are expected to require a larger total volume of flow to maintain a given X2 than a steady flow corresponding to the same X2 (Monismith 2017).

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

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

6.2 Historical Biogeochemical Fluxes from the USGS Seasonal Analyses, Biomass Flux between Regions

Biogeochemical flux, in the context of the Bay-Delta, is a representation of biomass cycling through lower trophic levels in the riverine and estuarine environment. Trends in water quality parameters (e.g., nitrates, chlorophyll a) have been measured in the Bay-Delta for water years 2014 through the present and are available online at the USGS's webpages (https://tableau.usgs.gov/views/BOR_reporting_test_May-July_2023/Fig_2Totalfluxtidefltrd?%3Aembed=y&%3Aiid=1&%3AisGuestRedirectFromVizportal=y; https://tableau.usgs.gov/views/BOR_reporting_test_v2/Totalfluxandtidefilteredconcentrations?%3Adevice=desktop&%3Aembed=y&%3AisGuestRedirectFromVizportal=y). Interpretations are based on preliminary, curated data summaries provide by USGS. Data have been sampled at six stations (Figure 6.2.1): Confluence (CFL), Decker Island/Toland (DEC/TOL), San Joaquin River at Jersey Point (SJJ), Cache Slough at Ryer Island (RYI/RYF), Sacramento River at Walnut Grove (SDC), and Sacramento Deep Water Ship Channel at channel marker 72 (CM72). Positive flux values and positive slopes of nitrates and chlorophyll a represent seaward transport of the constituent; negative flux values and negative slopes represent landward transport.



Source; Figure and data found online at https://tableau.usgs.gov/views/BOR_reporting_test/Fig_4WYcumulativeflux?%3Aembed=y&%3AisGuestRedirectFromVizportal=y.

Figure 23. Bay-Delta USGS stations sampling biogeochemical variables: nitrate and chlorophyll.

A qualitative comparison of cumulative flux of nitrate (NO_3) across water years (WY) 2019–2022 shows similar trends for dry years (2020–2022) based on the similar slopes (Figure 6.2.2). Exceptions include a relatively large flux at SDC in October and December of WY 2022, due to heavy rain events. Cumulative fluxes were noticeably steeper and positive slopes extended further into the year during WY19, an above normal year type, mostly due to a series of large fall and winter storms. Monthly, seaward nitrate flux was higher in March and April of 2019 compared to 2022, respectively (Figure 6.2.3).

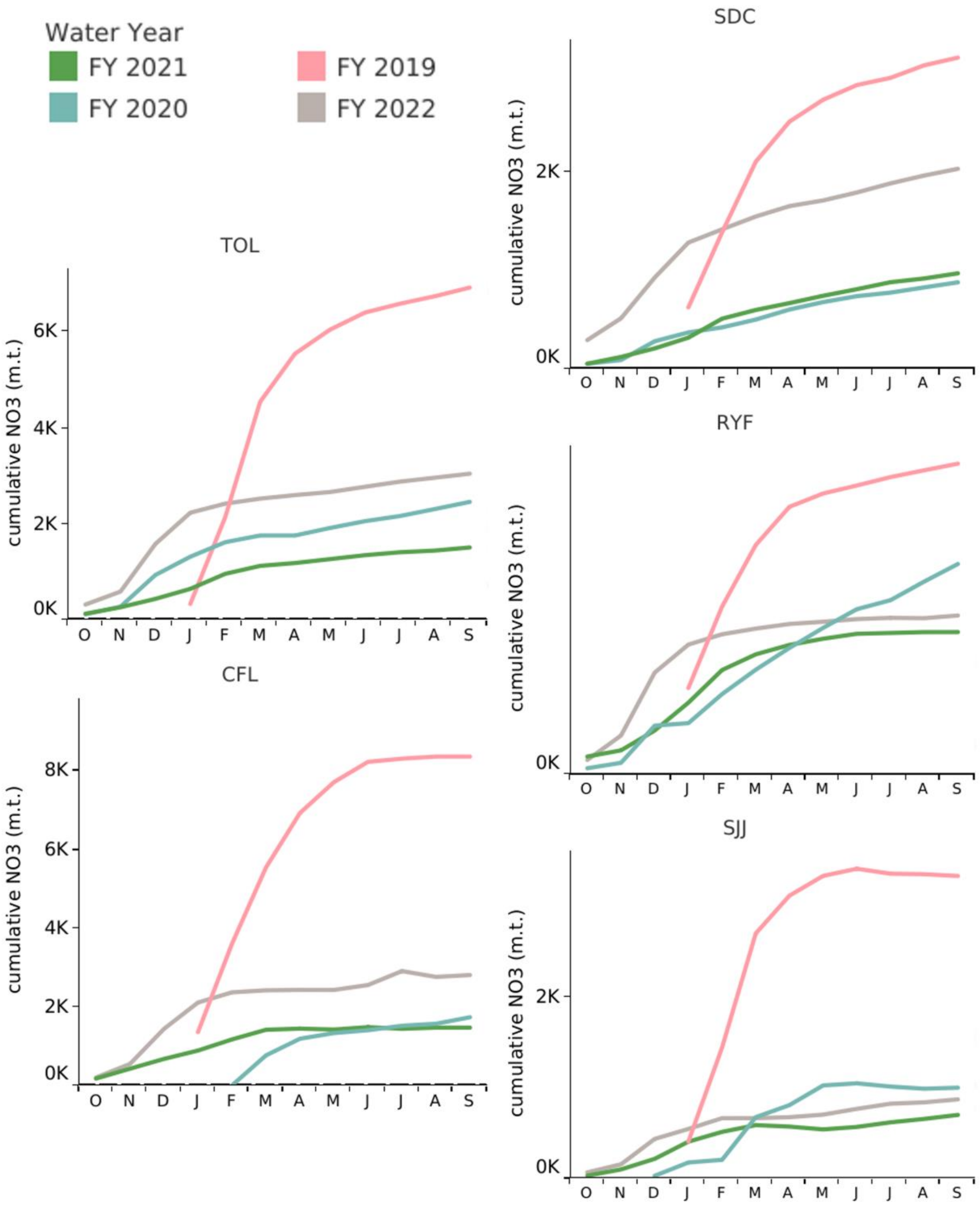


Figure 24. Water year 2019 – 2022 cumulative nitrate (NO_3) flux (metric tons [m.t.]) by site.

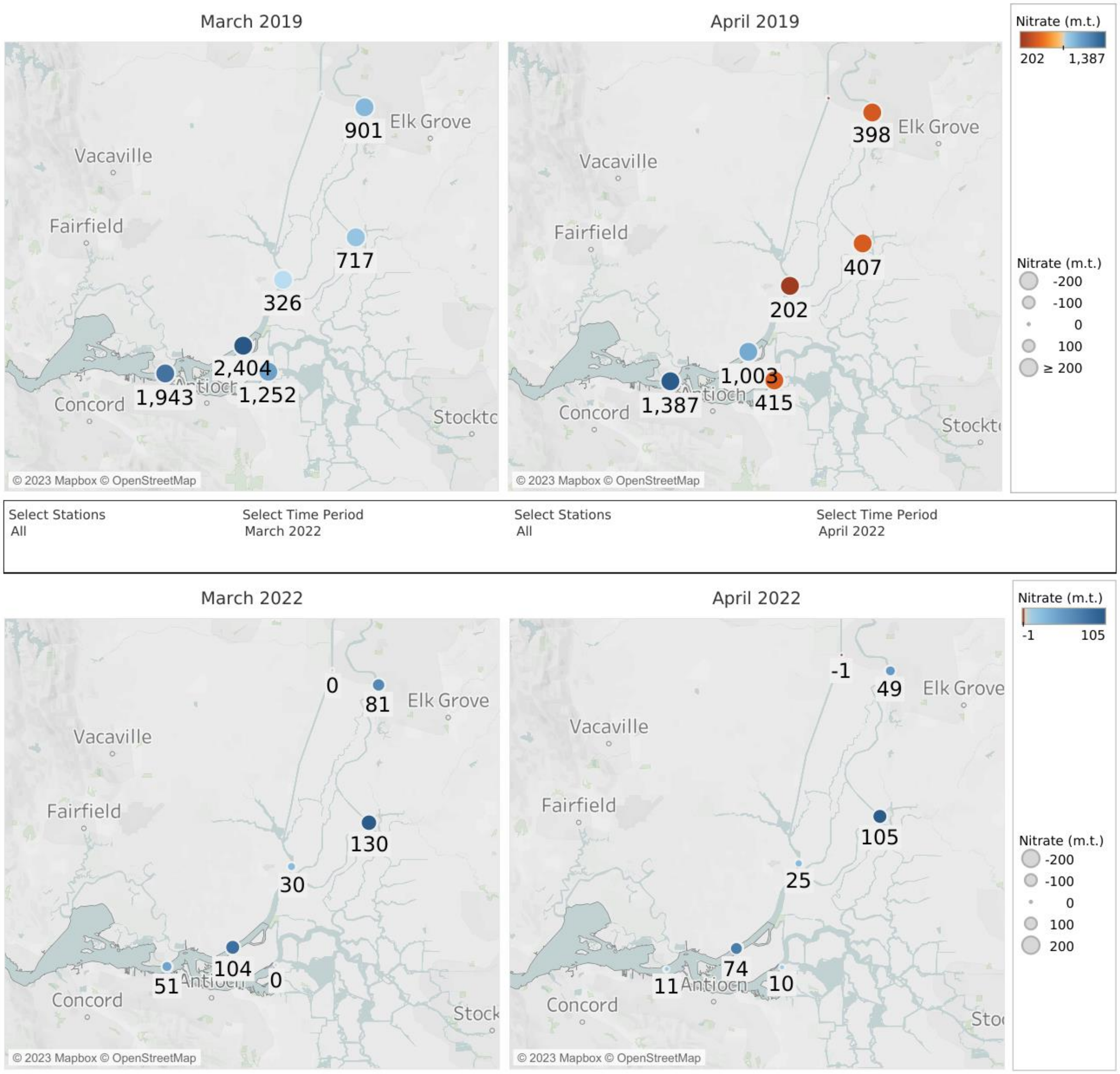


Figure 25. Nitrate flux (megatonnes [m.t.]) in March 2019 (top left), March 2022 (bottom left), April 2019 (top right), and April 2022 (bottom right).

A qualitative comparison of cumulative flux of chlorophyll (Chl a) across water years (WY) 2019–2022 shows similar trends for dry years (2020–2022) based on the similar slopes for each site (Figure 6.2.4). Flux was generally seaward (positive slopes) at SDC, RYF, and TOL throughout the year and at CFL during winter months. A switch to negative (landward) flux after winter is consistent with net cumulative transport of chlorophyll from Suisun Bay into the Confluence region. Consistently negative flux at SJJ is due to net cumulative transport of chlorophyll from the Confluence region into the Central Delta. The positive (seaward) slopes in total cumulative flux at RYF, TOL, and CFL in 2019 were primarily due to series of large fall and winter storms. The steep rises in slopes at these sites in March coincided with the recessional phase of the Yolo Bypass flooding. Monthly, seaward chlorophyll flux in March and April 2019 was higher than in March and April of 2022, respectively (Figure 6.2.5).

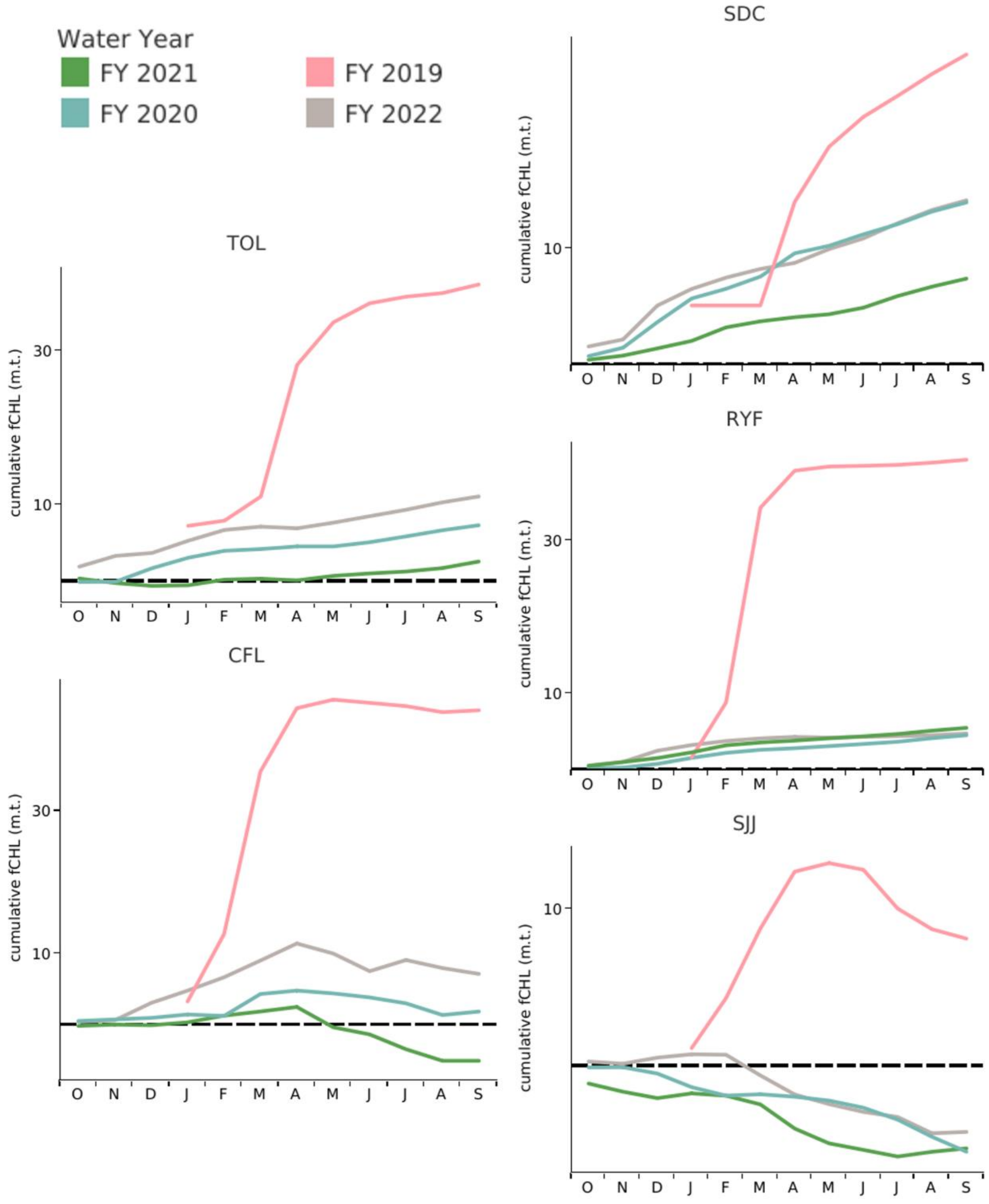


Figure 26. Water year 2019 – 2022 cumulative chlorophyll (Chl a) flux (metric tons [m.t.]) by site.

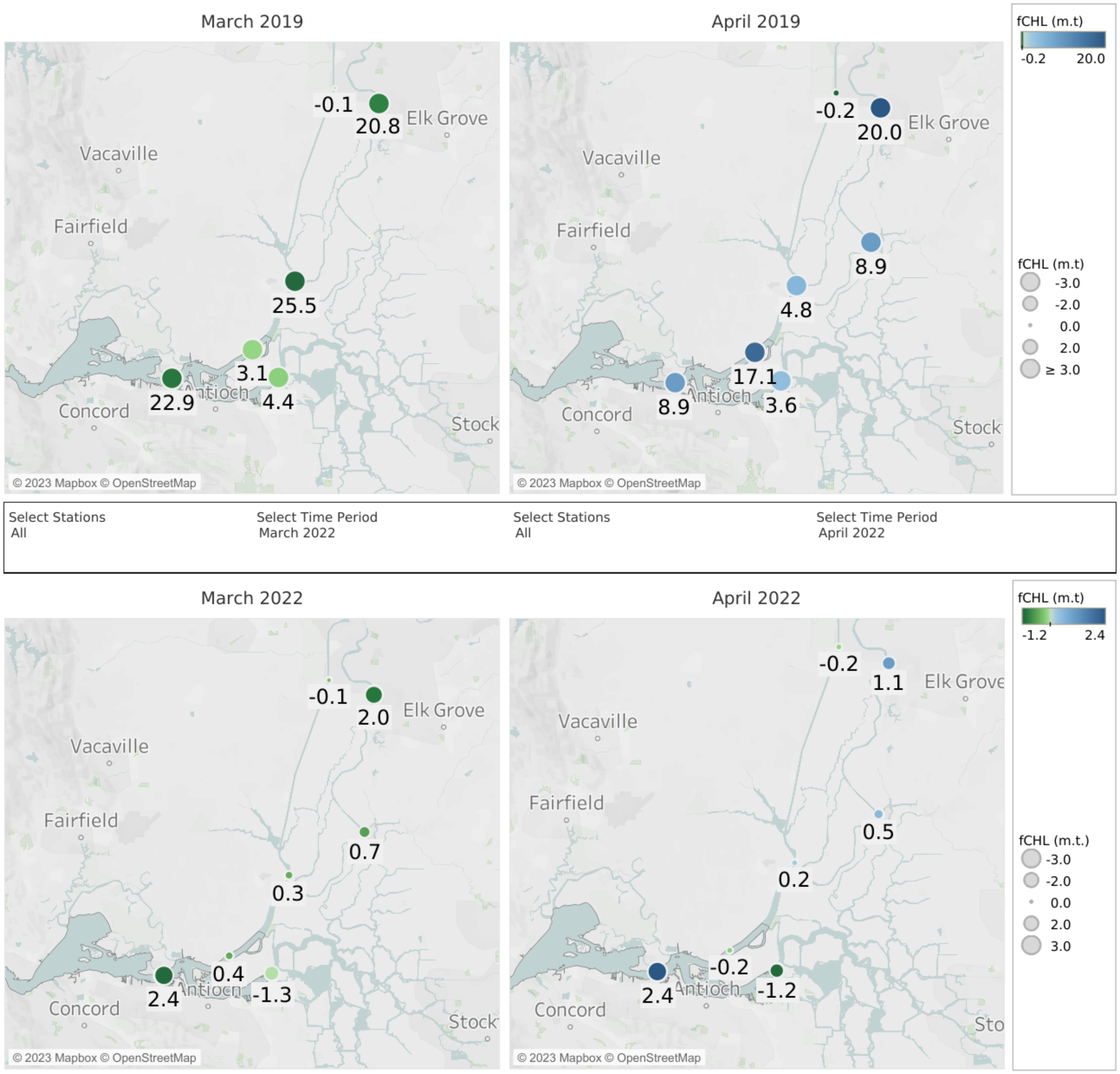
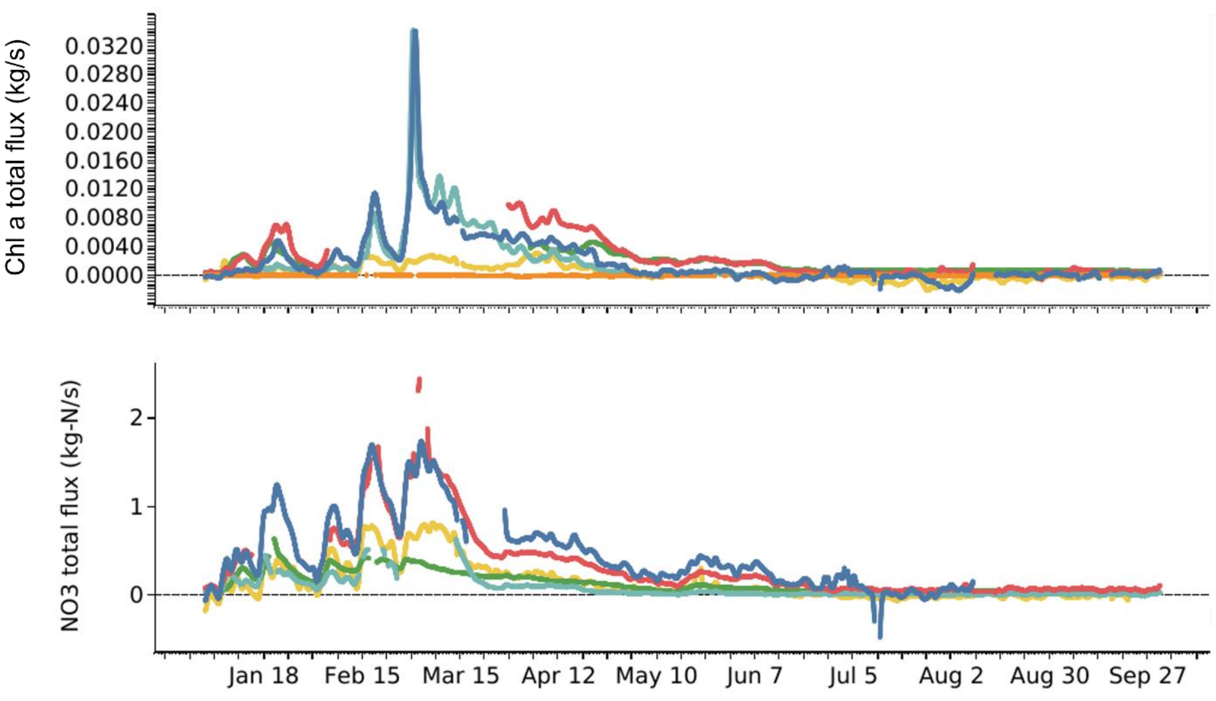


Figure 27. Chlorophyll flux (fCHL, megatonnes [m.t.]) in March 2019 (top left), March 2022 (bottom left), April 2019 (top right), and April 2022 (bottom right).

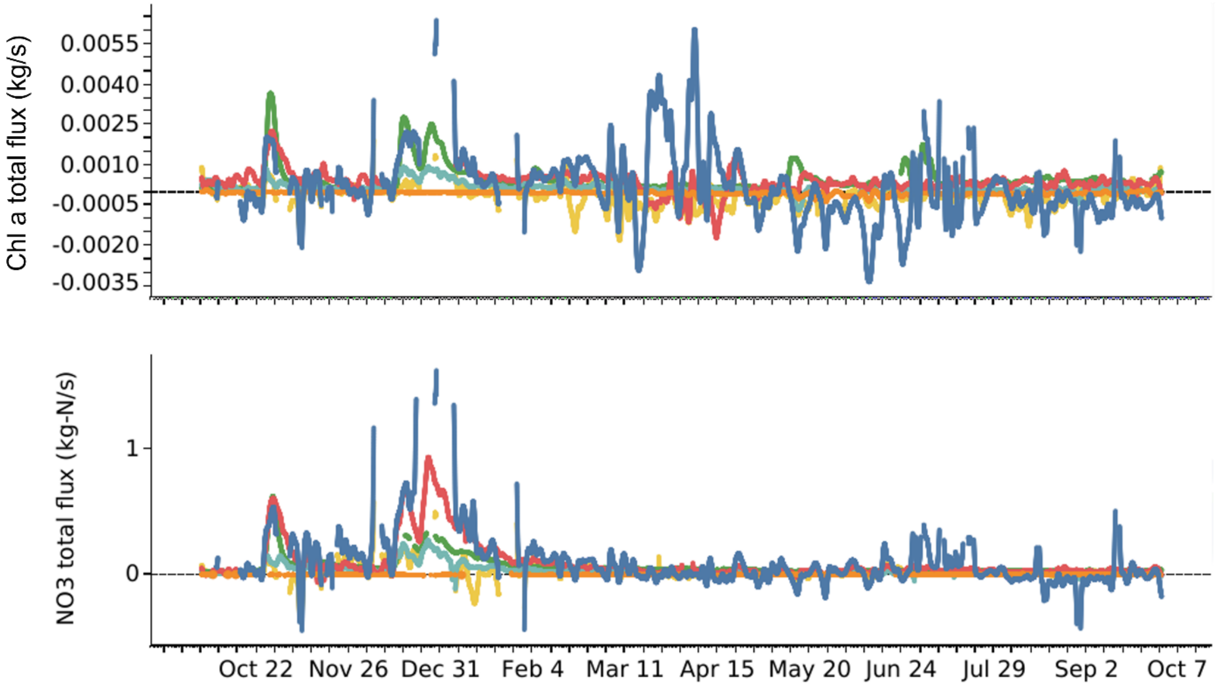
Total flux of both nitrate and chlorophyll a in 2019 and 2022 show similar responses to storm events during late winter and late fall /early winter, respectively (Figures 6.2.6–6.2.7). Estimated fluxes were generally seaward (positive) during these storm events at all sites except SJJ and SDC. In March 2022, a phytoplankton bloom occurred between the confluence and lower Sacramento River. Annual spring blooms in the low salinity zone have been observed consistently and are likely due to light availability and tidal timescale dynamics, in addition to other drivers (Figure 6.2.8).


Water year 2019

Sample stations are: CM72, orange; SDC, green; RYI/RYF, light blue; SJJ, yellow; DEC/TOL, red; and CFL, dark blue.

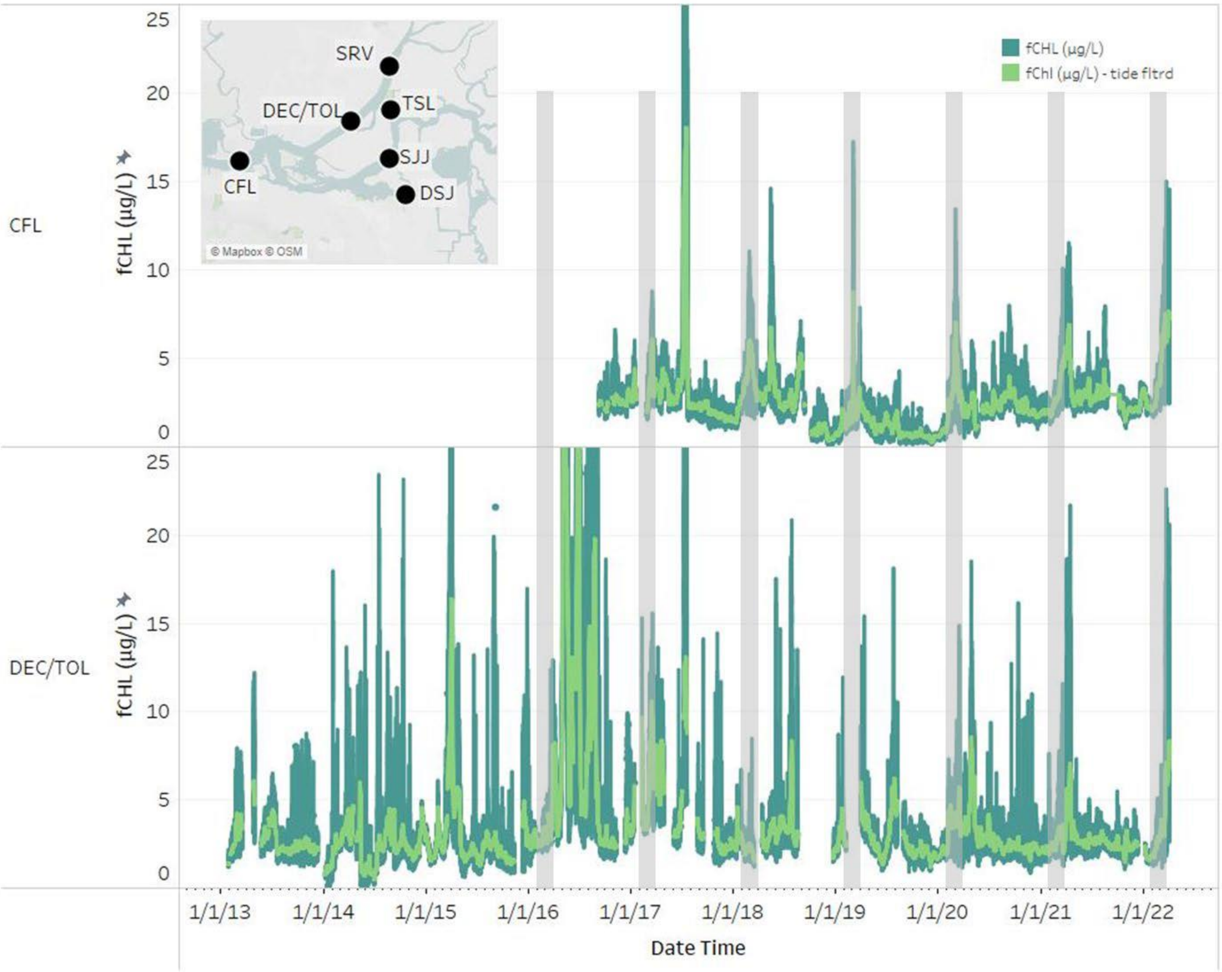
Figure 28. Total flux of chlorophyll a (Chl a; kilograms per second [kg/s]; top panel) and nitrate (NO_3; kilograms of nitrogen per second [kg-N/s]; bottom panel) during water year 2019.

Water year 2022



Sample stations are: CM72, orange; SDC, green; RYI/RYF, light blue; SJJ, yellow; DEC/TOL, red; and CFL, dark blue.

Figure 29. Total flux of chlorophyll a (Chl a; kilograms per second [kg/s]; top panel) and nitrate (NO_3; kilograms of nitrogen per second [kg-N/s]; bottom panel) during water year 2022.



Gray bars indicate February through April for each year.

Figure 30. Chlorophyll fluorescence (fCHL micrograms per liter [µg/L]) at the Confluence (CFL, top panel) and Toland (DEC/TOL, bottom panel) show annual elevations during late winter to early spring.

6.3 Effect of Spring Inflow and Outflow on Ecosystem Productivity

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

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

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

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

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

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

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

6.4 Effects of Spring Outflow on Migratory Conditions and Habitat Use

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

Flow has important effects on salmonid migratory behavior and survival. Downstream migration and arrival of juveniles at Knights Landing in the Sacramento River is correlated with the timing of the first high flows in spring (del Rosario et al. 2013). Migratory travel times of Sacramento River salmon smolts decreases with increasing river discharge (Michel et al. 2013; Steel et al. 2020; Hance et al. 2022). There are positive relationships between river inflow and juvenile Chinook salmon migration survival in the rivers upstream of the Delta (Henderson et al. 2019, Michel et al. 2021, Hassrick et al. 2022) and in the Delta, primarily in the riverine reaches; however, as tidal action becomes the predominant force controlling water velocity and direction of flow (e.g., in the Sacramento River downstream of Georgiana Slough), inflow has less effect on survival (Perry et al. 2018; Hance et al. 2022). The magnitude of river inflow influences predation risk within the Delta and entry into the interior Delta increases with decreasing flow (e.g., at the Sacramento River–Georgiana Slough junction (Perry et al. 2018; Hance et al. 2022). Exports are not identified to influence predation risk within the Delta (Hance et al. 2022), so increased outflow by reducing exports may not affect predation risk. Differences in the survival and migratory success of different life stages of Chinook (e.g., fry, smolt, juvenile) may have different relationships to water year types and managed flow regimes (Sturrock 2015, 2020). Reach-specific pulse flow events also have been observed to increase survival, particularly in low flow years (Henderson et al. 2019; Hassrick et al. 2022). Additional research to quantify how much spring export reductions, tributary releases, and/or both improve migratory conditions will be forthcoming

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

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

6.5 Effect of Spring Inflow and Outflow on Delta Fish Abundance

Various fish-flow relationships have been established in the San Francisco Bay-Delta and have been recently reviewed (Tamburello et al. 2019). However, some questions remain regarding which flow metrics are most correlated with fish abundance metrics/indices. Analysis was conducted for a few fish-flow relationships using more recent data to see if R^2 values of ordinary least squares (OLS) regressions from previous studies are improved or worsened by the use of different flow metrics (Table 1).

Table 1. R^2 value output for each OLS model sorted by flow metric and fish species

Species	X2	Delta Outflow	Delta Inflow	Unimpaired Runoff
Longfin smelt	0.67	0.64	0.64	0.65
Striped bass	0.17	0.11	0.06	0.24
Splittail	0.23	0.28	0.29	0.28

The longfin smelt and splittail relationships are from Kimmerer (2002a). The striped bass relationship is a recreation of Stevens (1977) with the full-time series, using the data from Tamburello et al. (2019) (https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lno.11037). Note that the exact month range that was used in the original analyses cannot be recreated for unimpaired runoff since there is no runoff in the drier months of June and July. Therefore, combined water year runoff value was used.

Longfin smelt abundance is related to all variables. The stronger fit with delta outflow and X2 are likely a consequence of Longfin smelt being distributed downstream of the confluence for most of their life cycle, and indicates that the underlying driver of abundance is related to X2 or outflow instead of unimpaired runoff. Note, however, that other modeling approaches have found unimpaired runoff to have a higher correlation with longfin smelt population dynamics than Delta outflow (Maunder et al. 2015). Indices of parental stock size have also been shown to have strong correlations with Longfin smelt abundance indices, and the intercept of flow-abundance relationships has shifted downward over time (Nobriga and Rosenfield 2016; California Department of Water Resources 2022:Appendix 12B, pp. 12B-99–12B-104).

Splittail exhibited good fit with inflow, which is likely related to their reliance on floodplain habitat (located upstream of the export facilities) for spawning (Kimmerer 2002a). Other species occurring in the Bay-Delta with statistically significant relationships with Delta outflow and X2 include American shad, starry flounder, and California bay shrimp (Kimmerer et al. 2009; Tamburello et al. 2019).

Delta smelt generally have not been shown to have statistically significant relationships with spring Delta outflow using linear models (Kimmerer et al. 2009), although more complex state-space modeling has found evidence for summer Delta outflow being positively related to survival of postlarval Delta smelt (Smith et al. 2021).

6.6 Inflow-Abundance Curves

6.6.1 Background

Various fish-flow relationships have been established in the San Francisco Bay-Delta and have been recently reviewed Tamburello et al. (2019). However, as noted by Tamburello et al. (2019), these relationships can break down over time as ecosystems change. Furthermore, various flow metrics in the system are highly correlated (e.g., X2, Delta inflow, Delta outflow, unimpaired runoff) due to climate and weather being the primary drivers of flow in the system rather than water operations (Kimmerer 2004), but most studies have focused mainly on a single flow metric (e.g., X2) in their analyses. A few flow-species relationships from the scientific literature were selected in the analysis below to evaluate which flow metrics (X2, Delta inflow, Delta outflow, unimpaired runoff) are most correlated with the specific fish abundance metric or index.

6.6.2 Methods

Based on data availability, the X2 relationships with longfin smelt (*Spirinchus thaleichthys*) and splittail (*Pogonichthys macrolepidotus*) from Kimmerer (2002) were selected for analysis. The relationship between Delta outflow and striped bass (*Morone saxatilis*) from Stevens (1977) was also evaluated. For all three species, the analysis was done using updated data from Tamburello et al. (2019). Ordinary least squares (OLS) regressions from the studies were re-created with updated data to see if R^2 value is improved or worsened by the use of different flow metrics: X2, Delta outflow, Delta inflow, unimpaired runoff. X2, Delta inflow, and outflow data were acquired from DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow). Unimpaired runoff estimates were acquired from California Department of Water Resources water year index (https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST). Species-specific range of months used the flow values were as follows: January to June for longfin smelt, February to May for splittail, and June to July for Striped Bass. Note that the exact month range used in the original analyses cannot be recreated for unimpaired runoff since there is no runoff in the drier months of June and July; as such, the total water year sum runoff for both Sacramento and San Joaquin Valley was used for all species. Analysis was conducted in R. Codes to pull datasets, run models, and produce the table output can be found at https://github.com/bmahardja/flow-fish-relationship.

6.6.3 Results

Fit based on adjusted R^2 values was better overall for longfin smelt relative to the other two species (Table 2). The covariate that resulted in the highest R^2 for each species were as follows: X2 for longfin smelt, unimpaired runoff for striped bass, Delta inflow for splittail. The best fit model for striped bass still had relatively poor R^2, consistent with findings of Tamburello et al. (2019) that the relationship has deteriorated over the years.

Table 2. R^2 value output for each OLS model sorted by flow metric and fish species

Species	**X2**	**Delta Outflow**	**Delta Inflow**	**Unimpaired Runoff**
Longfin smelt	0.67	0.64	0.64	0.65
Striped bass	0.17	0.11	0.06	0.24
Splittail	0.23	0.28	0.29	0.28

Results from this analysis are generally aligned with our general understanding of the biology of these species. Striped bass are distributed throughout the Central Valley and spawn in tributaries. Although longfin smelt abundance is highly correlated to all variables, the slightly stronger fit with X2 may be a consequence of longfin smelt being distributed downstream of the confluence for most of their life cycle. Note, however, that other modeling approaches have found unimpaired runoff to have a higher correlation with longfin smelt population dynamics than Delta outflow (Maunder et al. 2015). Indices of parental stock size have also been shown to have strong correlation with longfin smelt abundance indices, and the intercept of flow-abundance relationships has shifted downward over time (Nobriga and Rosenfield 2016). Meanwhile, splittail exhibited good fit with inflow, which is likely related to their reliance on floodplain habitat (located mostly upstream of the export facilities) for spawning (Kimmerer 2002).

6.7 Zooplankton-Delta Outflow Analysis

This section will summarize results from Attachment J, Spring Delta Outflow Zooplankton-Delta Outflow Analysis. This line of evidence was not used in the Initial Alternative Report. Results for the EIS will provide an evaluation of potential changes to food web for the Proposed Action and each of the alternatives binned by water year.

Spring:

During spring months, the following taxon had a significant relationship with Delta outflow: Cladocerans (except *Daphnia*), *Eurytemora affinis* (copepod) adults, Harpacticoid copepods, Other calanoid copepod adults, and Other calanoid copepod copepodites (Table 1).

During wet water years, estimated CPUE for all modelled taxa in all scenarios except for Scenario A3 showed a 1-2% decrease when compared to the No Action Alternative (NAA) scenario. Scenario A3 showed an increase for all taxa ranging from 6% (for other calanoid copepod copepodites) to 10% (for Cladocerans except Daphnia).

During above normal water year types, Scenarios A1, A2A, A2B and A4 showed decreases compared to the NAA scenario. Scenario A1 showed decreases of -6% (Cladocerans except Daphnia) to -4% (other calanoid copepodites and harpacticoids). Scenarios A2A, A2B, and A4 generally had -2 to -3% decreases in mean CPUE compared to NAA. Scenario A2C generally had close to no change from the NAA scenario. A2D had small increases (1% - 2% for all species). Scenario A3 had increases ranging from 8% (harpacticoids and other calanoid copepod copepodites) to 13% (Cladocerans except Daphnia).

During below normal year types, Scenario A1 showed the largest decrease for all species (-7% for Cladocerans except Daphnia to -4% for other calanoid copepod copepodites), while Scenarios A2A, A2B and A4 showed similar decreases for each species. Scenario A2C showed close to no change from the NAA scenario (0 – 1%). A2D showed increases for all species and A3 showed the largest increases for all species.

During dry water year types, Scenario A1 showed the largest decreases compared to the NAA scenario. Scenarios A2A, A2B and A4 show similar decreases. Scenario A2C showed close to no change from the NAA scenario (0 – 1%). Scenario A2D showed increases for all species and Scenario A3 showed the largest increases for all species.

During critical water year types, all alternatives showed increases when compared to the NAA scenario. Scenarios A2B and A4 showed no to very low increases (0 – 1%). Scenarios A1 showed increases ranging from 6 – 9% depending on the species. Scenario A2A and A2C showed similar increases ranging from 8 – 13% depending on the species. Scenario A2D showed the second highest increases ranging from 10 – 17%. Scenario A3 showed the largest increases ranging from 11 – 16%, just slightly higher than Scenario A2D.

In the spring CPUE is less under alternatives compared to NAA for all but critical water years. Higher CPUE in the spring of the taxa mentioned previously provides increased food for delta and longfin smelt and is better for the food web. Thus, alternatives appear to provide benefits over NAA to smelt in the spring of critical water years only.

Summer:

There were no zooplankton taxa that had a statistically significant relationship with outflow in the low salinity zone during the summer (Table 2). While some studies have shown that higher abundances of certain species of zooplankton during summer with higher outflow (Kimmerer et al. 2018) or through managed flow pulses (Frantzich et al. 2021, though this action saw benefits further upstream in freshwater regions), others did not find substantial effects on zooplankton prey from flow pulses (Sommer et al. 2020). Evaluating any possible benefits of increased outflow and flow pulses during summer may be difficult given sampling frequency and the effect size of increases to zooplankton abundances (Brandon et al. 2021).

Fall:

During the fall months, the following taxon had a significant relationship with Delta outflow: *Eurytemora affinis* (copepod) adults and mysids (Table 3). While these relationships were significant the increases and decreases in CPUE across all scenarios are likely negligible.

During wet years scenario, A1 had the largest decrease and Scenario A3 showed the largest increase (Table 15 and Table 17). All other scenarios had no change from the NAA scenario.

For above normal and below normal years, again Scenario A1 had the largest decrease, Scenario A3 had the largest increase and all other scenarios showed moderate increases (around 3 – 4% for both significant species).

For dry years, again A1 and A3 showed the largest decreases and increases respectively but A2D showed a slight increase (3% for *E. affinis* adults and 2% for mysids). All other scenarios were similar and only showed negligible changes when compared to the NAA.

For critical years A1 showed the largest decrease (-24% and -16% for *E. affinis* adults and mysids respectively), while Scenarios A2D and A3 also showed small decreases (between -2 to -4%). Scenario A4 showed no change compared to NAA. Scenarios A2B, and A2C showed small increases (1% for both species) while Scenario A2A showed the highest increase (3% for *E. affinis* adults and 2% for mysids).

6.8 Delta Outflow vs Sturgeon Year Class Index

This section will summarize results from Attachment J.Y *Spring Delta Outflow Sturgeon Year Class Index*. This line of evidence was not used in the Initial Alternative Report. Results will provide estimates of white sturgeon year class index based on its relationship to spring outflow. White sturgeon year class index can be a surrogate for outflow effects on green sturgeon year class strength. These results will be presented for the Proposed Action and each of the alternatives binned by water year.

6.9 Alternative 3 Ecosystem Thresholds

This section will summarize results from Attachment J.Y Alternative 3 Ecosystem thresholds. This line of evidence was not used in the Initial Alternative Report. NEPA alternatives proposed for the long-term operations of the CVP and SWP have different types of ecosystem thresholds for spring Delta outflow. The ecosystem threshold analysis reviews these differing criteria. Results will provide estimates for meeting thresholds for tributary inflows, Delta outflow, and Interior Delta Flows.

These results will be presented for the Proposed Action and each of the alternatives binned by water year.

These results will be presented for the Proposed Action and each of the alternatives.

See attachment XX for detailed analysis and assumptions. The key takeaways include: <insert a few sentences>

6.10 XT Model

This section will summarize results from Attachment J.Y J. SpringDeltaOutflow XT Model. This line of evidence was used in the Initial Alternative Report. Results will provide an evaluation of potential effects of the Proposed Action and alternatives on migrating juvenile salmon in the Sacramento River.

6.11 Flow Threshold Salmon Survival

This section will summarize results from Attachment J. SpringDeltaOutflow Flow Threshold Salmon Survival. This line of evidence was not used in the Initial Alternative Report. To assess potential effects of changes in flow in the Upper Sacramento River on juvenile Chinook salmon as a result of flow-survival relationships, flow thresholds from Michel et al. (2021) were applied to Sacramento River at Wilkins Slough. The model estimates the annual mean probability of juvenile Chinook salmon survival in the Sacramento River between the confluence of Deer Creek and Feather River between March 15 and June 15. Annual mean survival was calculated from daily survival estimates.

6.12 STARS

This section will summarize results from Attachment J, SpringDeltaOutflow STARS. This line of evidence was used in the Initial Alternative Report. To assess potential effects of alternatives to migrating juvenile salmon the STARS model was used to estimate salmonid migration parameters (Travel time, survival, entrainment probabilities).

7.Uncertainty

To inform reliability and value of information regarding spring Delta outflow special studies include the Shasta Spring Pulse Flows studies and Spring Outflow special studies. These are described in the Proposed Action 9.8 Special Studies.

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8.2 Personal Communications

Pasparakis personal communication

Perry personal communication