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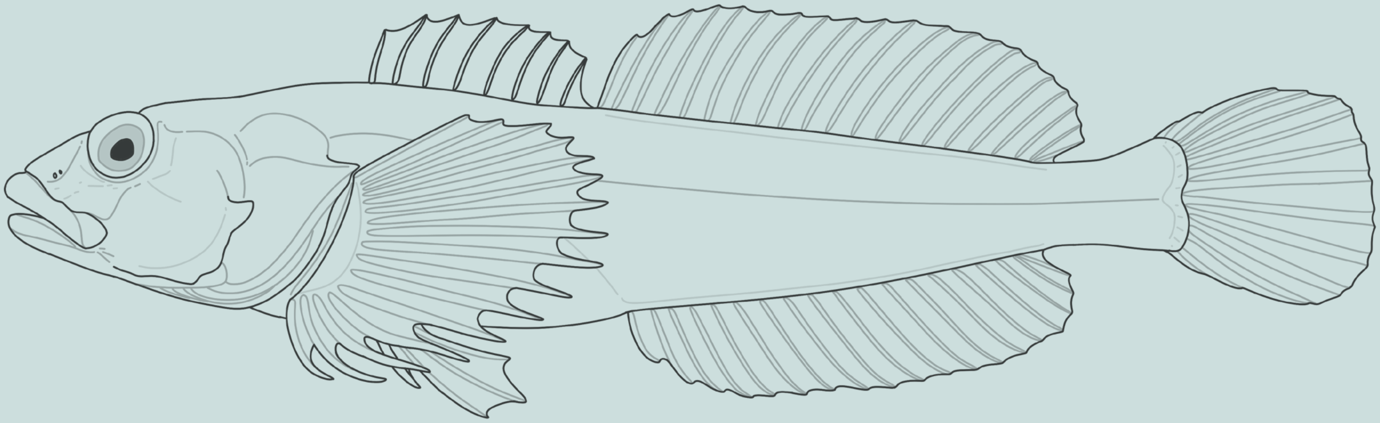
IEP Newsletter

Interagency Ecological Program for the San Francisco Estuary



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IEP Newsletter

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DYLAN STOMPE / CDFW

About this Newsletter

The IEP Newsletter is a triannual product of the Interagency Ecological Program (IEP) that publishes perspectives on our Program and community, reviews, data reports, research articles, and research notes. The newsletter is a forum for resource managers, scientists, and the public to learn about recent important programmatic and scientific topics from across the San Francisco Estuary. Articles in the newsletter are intended for rapid communication and are not peer reviewed. Primary research results reported in the newsletter should therefore be considered preliminary and interpreted with caution. Any permissions for use of copywritten or otherwise previously published materials, figures, data, etc., is the responsibility of the submitting author and should be obtained prior to submission to the IEP Newsletter editors.

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Article Submission Deadlines for this Calendar Year

Issue	*Submission Deadline*
1 (Winter)	February 15
2 (Spring)	June 15
3 (Summer/Fall)	October 1

Newsletter Sections

ON THE COVER Prickly sculpin, by Sky Jung. **ABOVE** CDFW Senior Environmental Scientist (Specialist) Dylan Stompe holding a Sacramento pikeminnow captured as part of the IEP Enhanced Large Fish Study, June 2023.

The Interagency Ecological Program (IEP) is a consortium of three State and six federal agencies conducting monitoring and special studies within the Bay-Delta.

https://iep.ca.gov

Of Interest to Managers

2021–2022 Yolo Bypass Fisheries Monitoring Status and Trends Report

The 2022 water year Yolo Bypass fish community, dominated by Killifish and Mississippi Silverside, is described in a data report by Alexandria Evans (California Department of Water Resources) and colleagues. They describe fish community patterns in the community across the water year in the context of environmental conditions, including hydrology and water quality, with an emphasis on impacts of drought on fish communities.

2020–2022 Yolo Bypass Fish Monitoring Program: Lower Trophic Data Status and Trends Report

Mackenzie Miner, Luke Olson, and Mitchell Olinger (California Department of Water Resources) describe seasonal and interannual trends in water quality and the lower trophic community at two stations in the Yolo Bypass and compare them with trends in the lower Sacramento River for water years 2020–2022. This reporting period captures the sampling response to the COVID-19 pandemic and highlights information gaps present as the result of suspended sampling. Dry conditions persisted across all 3 years of the reporting period. Generally, there was greater plankton and invertebrate abundance in the Yolo Bypass compared with the Sacramento River. Greater prey abundance in the Yolo Bypass may lead to faster growth or increased survival in the Yolo Bypass for native species such as Chinook Salmon and Sacramento Splittail. Understanding the lower trophic conditions associated with drought is important for understanding native species and the estuary, and it provides valuable baseline information, especially with regard to restoration projects in the Delta intended to enhance habitat and prey resources for native fishes.

2023 Status and Trends Report for Pelagic Fishes in the Upper San Francisco Estuary

The authors present the 2023 Status and Trends Report for Pelagic Fishes in the Upper San Francisco Estuary. This report provides the annual contractual obligation summarizing indices reported by California Department of Fish and Wildlife studies including: the Smelt Larva Survey, the 20-mm Survey, the Summer Townet Survey, the Fall Midwater Trawl Survey, and the San Francisco Bay Study. The 2023 Indices for Delta Smelt, Longfin Smelt, Splittail, American Shad, Threadfin Shad, and Striped Bass are collated in this report. This edition will also include design-based abundance indices for Delta Smelt and Longfin Smelt, caught by the Smelt Larva Survey, as previously reported in 2022. Trends of the included species saw notable increases this year compared to 2022. However, some species like Delta Smelt continue to show very low abundance and detection across multiple surveys.

Representation of Fish Species by Life Stage Amongst IEP Surveys

The authors investigate the representation of different San Francsico Estuary (SFE) fish species by life stage in 15 major fish monitoring surveys. They do this by identifying and applying length cutoffs from juvenile to adult, defined as the average of maximum and minimum reported lengths at sexual maturity, for 36 SFE fish species. Once split by life stage, the analysis developed by Stompe et al. (2020) was applied to assign a score of representation within a given survey. This article serves as a useful tool for identifying surveys relevant to a given species and/or life stage, especially when selecting surveys for further abundance, distribution, or trend analysis. Because the authors also compiled information on the reported sizes at sexual maturity for 36 SFE fish species, it may also serve as a useful reference of life history information.

DATA REPORT

2021–2022 Yolo Bypass Fisheries Monitoring Status and Trends Report

Alexandria Evans* (California Department of Water Resources [CDWR]), James (JT) Casby (CDWR)

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Introduction

Largely supported by the Interagency Ecological Program (IEP), the California Department of Water Resources (CDWR) has operated the Yolo Bypass Fish Monitoring Program (YBFMP) since 1998. The program collects baseline data on hydrology, water quality, lower trophic community (phytoplankton, zooplankton, and aquatic and terrestrial insects), and juvenile and adult fishes in the Yolo Bypass. The YBFMP, mandated in CDWR's 2020 Incidental Take Permit (Section 3.13.1, CDFW 2020), has provided critical information regarding the significance of seasonal floodplain habitat to native fishes (Sommer et al. 2004a). As the largest remnant floodplain of the Sacramento River, the Yolo Bypass is identified as a high restoration priority by the National Marine Fisheries Service's Biological Opinion (NMFS 2019), California EcoRestore (CDWR 2024b), and the California Natural Resources Agency Delta Smelt (CNRA 2016) and salmon resiliency strategies (CNRA 2017). As such, the data provided by the YBFMP are critical for evaluating the success of current and future restoration projects. Moreover, data acquired from this monitoring effort over the last 2 decades has increased our understanding of the crucial role that the Yolo Bypass plays in the San Francisco Estuary ecosystem (e.g., Sommer et al. 1997; Sommer et al. 2001a; Feyrer et al. 2006a; Lehman et al. 2007; Frantzich et al. 2018; Goertler et al. 2018; Mahardja et al. 2019). This data report describes the fisheries sampling effort for water year (WY) 2022 (October 1, 2021, through September 30, 2022), including a summary of water quality metrics and fish catch by species and gear type.

Methods

Study Site

The 24,000 ha Yolo Bypass was engineered for flood management of the Sacramento River and is the largest floodplain in the Sacramento–San Joaquin Delta (Schemel et al. 2004). Sampling occurred in the Toe Drain, a perennial riparian channel on the eastern edge of the Yolo Bypass (Figure 1). The 2022 water year was characterized as "critical" according to the California Data Exchange Center's Water Supply Index (CDWR 2024a).

Larval Fishes

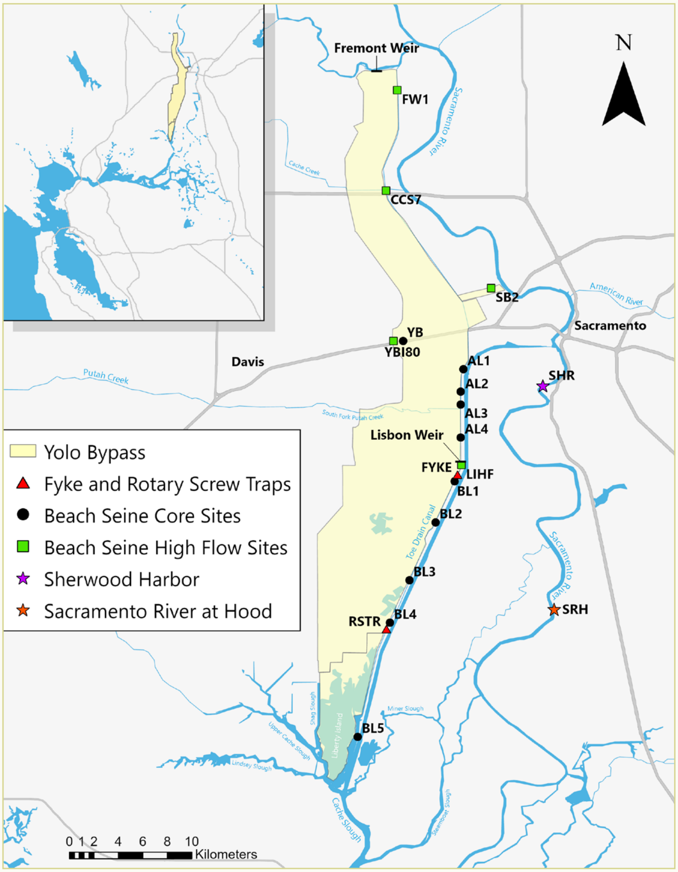
A survey for the general composition and timing of larval fishes in the Toe Drain has been conducted since 1999. Sampling is conducted by towing a 2 m long, 500 µm mesh net with a 0.65 m diameter opening for 10 minutes during ebb tide. A single sub-surface tow is taken every other week between January and June at the rotary screw trap location (Figure 1).

Juvenile and Adult Fishes

Since 1998, small adult (e.g., Delta Smelt) and juvenile fish have been sampled with a 2.44 m diameter rotary screw trap located in the Toe Drain of the Yolo Bypass approximately 14.5 km south of the Lisbon Weir (Figure 1). The rotary screw trap generally operates 5 days per week from January through June (Figure 2). Since outflow in tidal systems can sometimes be net negative due to tidal flow, the volume of water is unknown and highly variable in the Yolo Bypass. Due to the difficulty of calculating flow of tidal systems like the Toe Drain, sampling time (total hours based on set, check, and pull times) is used to calculate "catch per hour" rather than catch per unit effort. Circumstances that prevent fishing the trap a full 5 days per week include obstruction by large debris or strategic avoidance of high debris flow periods (e.g., the start of inundation periods or heavy wind/rainstorms).

Every other week throughout the year, we supplement the collection of small adult and juvenile fish in the Yolo Bypass by conducting beach seine surveys at various locations along the Toe Drain (Figure 1, Figure 2) using a 7.6 m wide and 1.2 m tall seine net with 0.32 cm mesh. The spread of Water Hyacinth (*Eichhornia crassipes*), Brazilian Waterweed (*Egeria densa*), and Water-primrose (*Ludwigia peploides*) in the Toe Drain

Figure 1. Map of Yolo Bypass showing the various sampling locations of the YBFMP.



occasionally precluded beach seine surveys at the farthest downstream location, station BL5. During periods of inundation, we sample five additional sites that are only accessible during flooding (Figure 1).

Since 1999, the YBFMP has seasonally deployed a 3.15 m diameter steel-framed fyke trap to monitor upstream migrations of large adult fish in the Toe Drain. The trap is located 1.2 km below Lisbon Weir and 21 km north of the terminus of the Toe Drain (Figure 1). The fyke trap is operated 5 days per week between October and June (Figure 2) and is checked once every 24 hours. In WY 2022, YBFMP suspended fyke trap monitoring on April 7, 2022, due to sea lion bycatch. Sampling was resumed on May 24, 2022, after modifications were completed to prevent future bycatch (Figure 2).

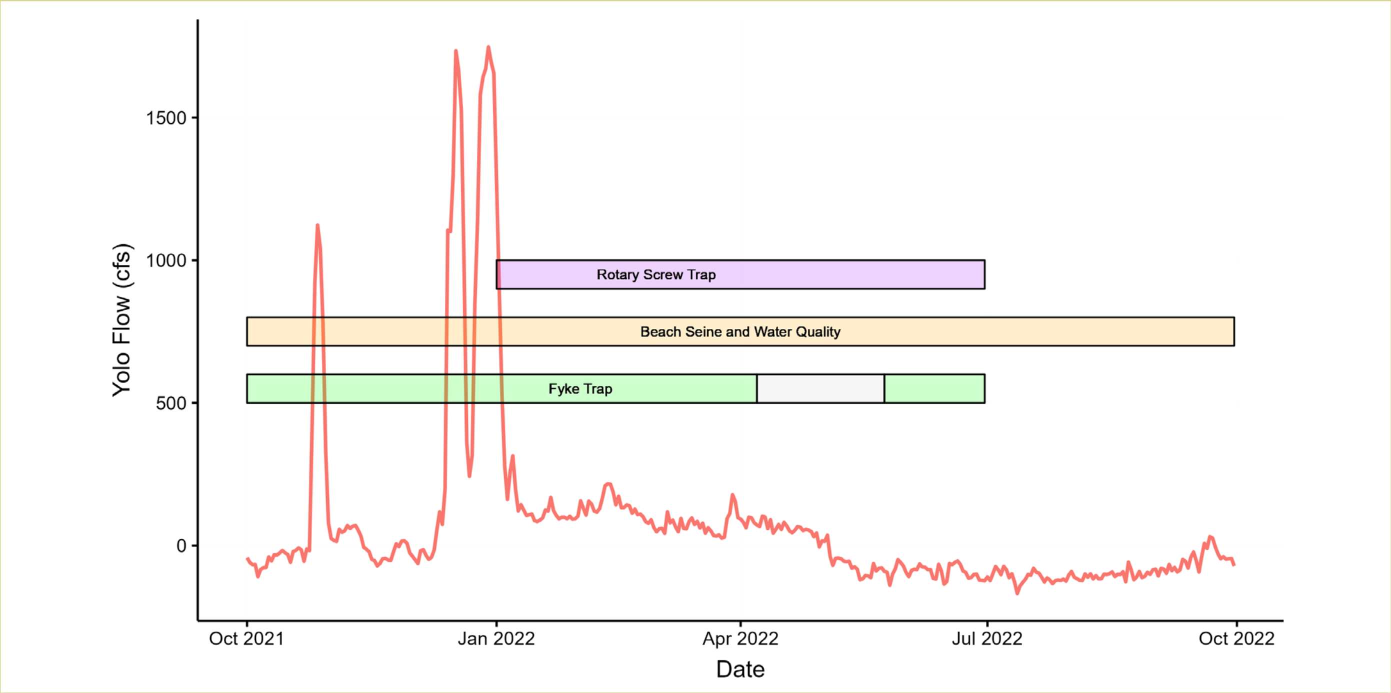
Data for all fish catch, along with associated water quality data, can be accessed online as part of the Environmental Data Initiative (IEP 2023). For all methods, proportion of catch was calculated using the following equation:

$$x = \left(\frac{total\ \ count\ \ of\ \ specific\ \ species\ \ by\ \ gear\ \ type}{total\ \ count\ \ of\ \ all\ \ species\ \ by\ \ gear\ \ type}\right) \times 100$$

Water Quality

Concurrent with fish sampling, field crews collected several discrete water quality parameters using a YSI Pro DSS handheld instrument and Secchi disc during each fish sampling event. These parameters included water temperature (°C), specific conductivity (µS/cm), dissolved oxygen (DO; mg/L), pH, turbidity (FNU), and Secchi depth (m). Additionally, a multi-parameter YSI 6600

Figure 2. Fishing effort by gear type summarized against average daily flow for WY 2022 at Lisbon Weir (CDWR 2023). Gray sections represent when sampling usually occurs but did not due to sea lion bycatch.



Sonde (Yellow Springs Instruments) located at Lisbon Weir and a YSI EXO2 Sonde at Hood on the Sacramento River collected DO, turbidity, conductivity, pH, temperature, and chlorophyll-a (µg/L) at 15-minute intervals year-round. For this report, water quality results reflect data from the continuous stations due to their increased temporal coverage.

Results and Discussion

Hydrology

In WY 2022, the Sacramento River watershed experienced a "critical" water year type with below-average precipitation (CDWR 2024a). The Yolo Bypass had an average daily flow of 75.2 cfs (SD = 331.2 cfs), with a peak flow of 1920 cfs on December 29, 2021 (Figure 2, CDWR 2023). Historically, the Yolo Bypass floods 2 out of 3 years (Schemel et al. 2004). The last flooding event occurred in WY 2019, when the floodplain was inundated for 73 days between February and April of 2019 (Kwan et al. 2021). Flooding events occur when water levels at Fremont Weir and Lisbon Weir exceed their monitoring stage heights of 32 and 13 feet, respectively (Figure 3), causing water to spill into the Yolo Bypass. In WY 2022, the maximum stage heights recorded at Fremont Weir and Lisbon Weir were 25.7 feet and 7.4 feet, respectively, resulting in 0 days of bypass inundation since neither weir overtopped (Figure 3). Inundation events are important to the aquatic habitats and resident fish populations of the Yolo Bypass as those events drive food web production and provide spawning and rearing habitat for native fish species such as Chinook Salmon (*Oncorphynchus tshawytscha*), Sacramento Splittail (*Pogonichthys macrolepidotus*), Sacramento Blackfish (*Orthodon microlepidotus*), and Delta Smelt (*Hypomesus transpacificus*) (Harrell and Sommer 2003; Takata et al. 2017; Kwan et al. 2019).

Water Quality

During WY 2022, the two continuous monitoring stations used in this report experienced several probe outages, scheduled maintenance, and unforeseen issues, resulting in data gaps (Figure 4). The summaries presented here are based on the best available data.

In WY 2022, conductivity in the Yolo Bypass (190.4–947.8 µS/cm) was far more variable than the Sacramento River at Hood (henceforth Sacramento River; Figure 1) (105.6–224.7 µS/cm; Figure 4A). The increased variability in the bypass can be attributed to its unique hydrologic complexity, as conductivity is a key indicator of significant changes in water source input and water chemistry (Schemel et al. 2004). This complexity is affected by tidal flow, residence time, salinity, and sediment transportation/deposition (Frantzich et al. 2018). The Yolo Bypass is hydrologically complex as it receives water from several sources including adjacent tributaries, agricultural drainage, seasonal flooding, and tidal flows, which also contribute to conductivity fluctuations (Sommer et al. 2004b). The highest conductivity measurements were observed during the early spring, in which there was a decrease in water entering the system from upstream sources and water temperatures began increasing.

Figure 3. Stage heights of Lisbon and Fremont Weir and corresponding inundation thresholds.

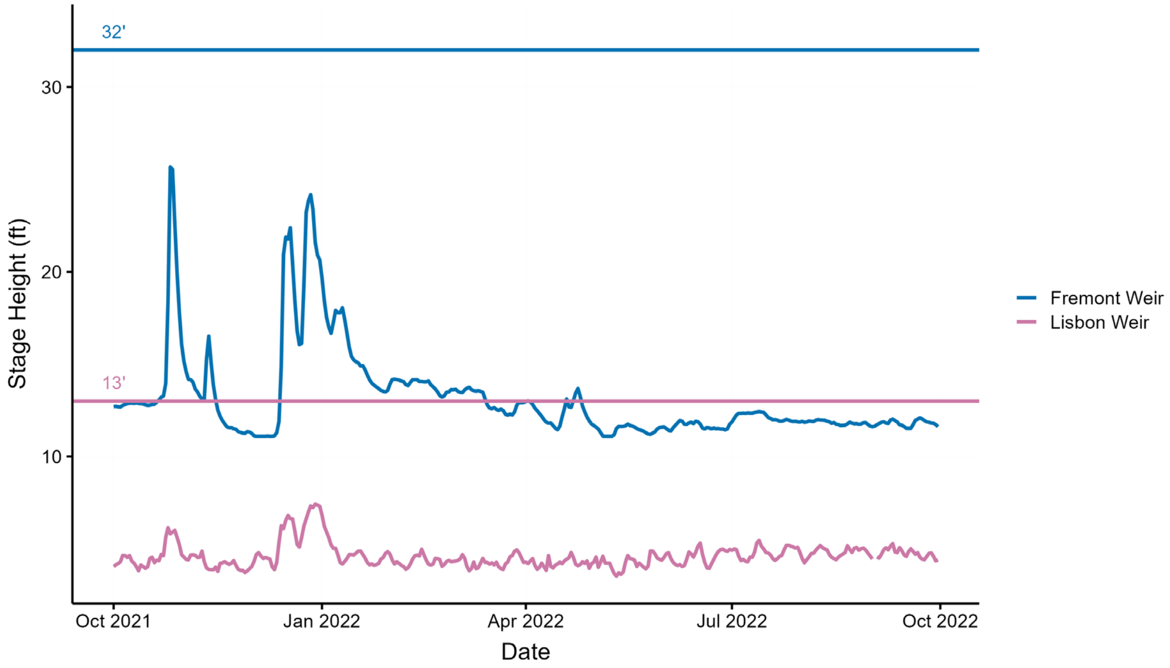
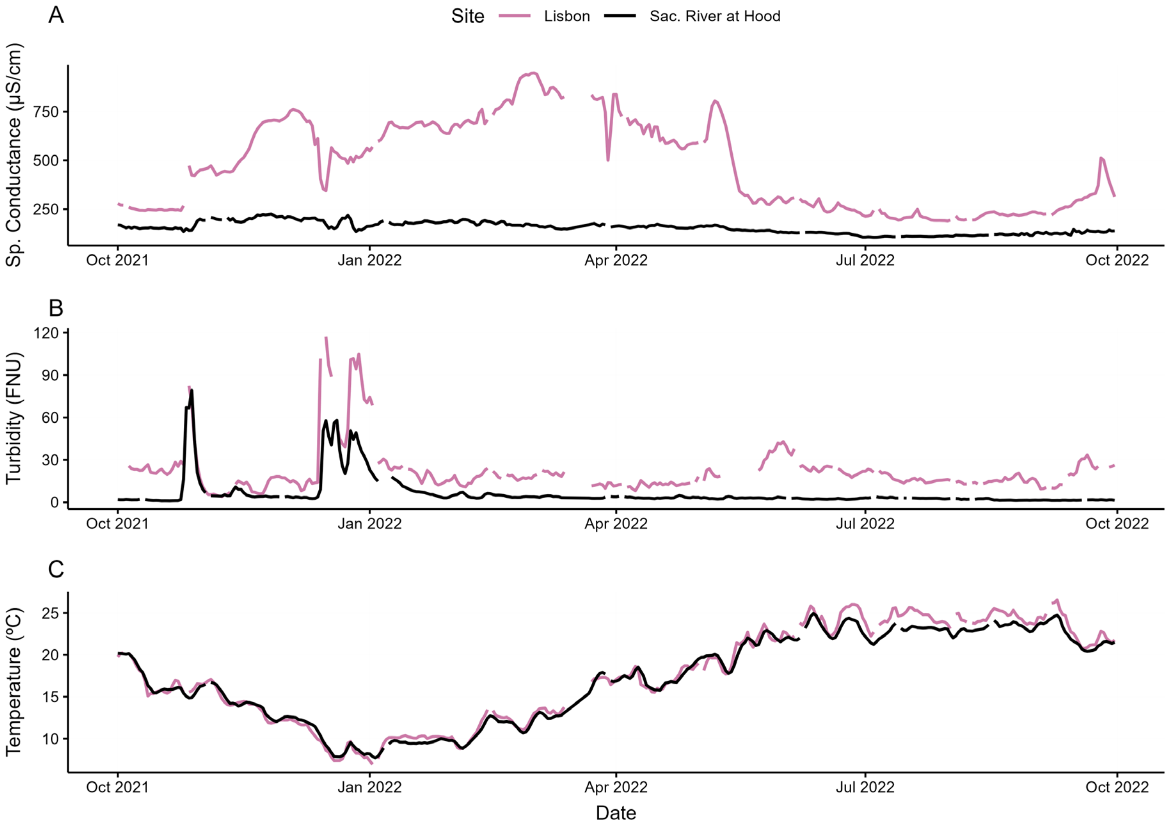


Figure 4. Time-series plots for specific conductivity (a), turbidity (b), and water temperature (c) at Lisbon Weir in the Yolo Bypass and Hood Station in the Sacramento River. The two continuous monitoring stations used in this report experienced several probe outages, scheduled maintenance, and unforeseen issues, resulting in data gaps.



Turbidity can be an essential indicator of an estuarine habitat, because it determines the depth of the euphotic zone, an area where light penetration is sufficient to allow primary production and develops valuable pelagic fish habitat (Morgan-King and Schoellhamer 2013; Frantzich et al. 2018). Turbidity in the Yolo Bypass is typically higher and more variable than in the Sacramento River. Similar to previous years, this trend continued with higher levels of turbidity in the Yolo Bypass during WY 2022 (Figure 4B). The first major increase in turbidity is usually a product of sediments dislodged and/or mobilized following winter rainstorms, while subsequent increases are often associated with heavy rainstorms later in the year that transport large pulses of sediment through the watershed (Morgan-King and Schoellhamer 2013). The highest turbidity recorded in the Yolo Bypass during WY 2022 was 117.5 FNU, compared to 79.2 FNU in the Sacramento River.

Water temperatures in the Yolo Bypass are generally higher but more variable than in the Sacramento River (Goertler et al. 2018), although both locations follow typical seasonal trends with peak temperatures in the summer and coolest temperatures in the winter. When inundated, the shallow and broad topography of the Yolo Bypass floodplain results in more extreme hydrologic variability throughout the year, however, during non-inundated years the Yolo Bypass can have similar water temperature trends to that of the Sacramento River (Sommer et al. 2004a; Figure 4C). In WY 2022, the highest water temperature in the Yolo Bypass at Lisbon Weir occurred on September 9, 2022, at 26.6 °C, while the Sacramento River peaked at 24.9 °C on June 12, 2022 (Figure 4C). The lowest water temperature recorded in the bypass was 6.9 °C, and in the Sacramento River it was 7.7 °C. Water temperature plays a significant role not only for lower trophic food production (Lehman et al. 2007) but also for the timing of outmigration from the floodplain (Takata et al. 2017) and increased size diversity of juvenile Chinook Salmon (Goertler et al. 2018).

Fishes

In WY 2022, three fish species were caught in larval fish surveys (Table 1). Prickly Sculpin (*Cottus asper*) and Mississippi Silverside (*Menidia audens*) were the most frequently caught species (n=741; n=116). In comparison, during WY 2021, six species of larval fish were caught. Mississippi Silverside was the most abundantly caught species (n=68), and Threadfin Shad (*Dorosoma petenense*) was the second most abundant species by count (n=38).

A total of 35 fish species were collected in the WY 2022 sampling period; of which only 9 are native to the Sacramento–San Joaquin Delta (Table 2). Mississippi Silverside was the most frequent species sampled in beach seine surveys (53.6%). Killifish (Lucania spp.) was the most abundant species sampled in the rotary screw trap sampling method (85.2%), and Black Crappie (*Pomoxis nigromaculatus*) was the most numerous species sampled using the fyke trap sampling method (35.7%). Mississippi Silverside and Killifish are non-native species in the Sacramento River watershed, yet these species represented 38.0% and 42.0%, respectively, of the total fish catch in WY 2022. In WY 2021, YBFMP staff identified a newly introduced killifish species, the Bluefin Killifish (*Lucania goodei*) (Mahardja et al. 2020; Robinson et al. 2023). Due to potential hybridization complicating morphological identification, the program began recording all individuals as "Killifish" and sub-sampling for genetic verification. In comparison to WY 2019 (n=10), WY 2021 and WY 2022 had elevated killifish counts (n=2,260; n=5,846) after the identification of the Bluefin Killifish in the system.

In WY 2021, White Catfish (*Ameiurus catus*) made up 30.1% of the total fish catch (n=326; Robinson et al. 2024). Interestingly, in WY 2022 these non-native catfish only made up 1.6% (n=216) of the total fish catch. We hypothesize that an unprecedented hypoxia event that followed a seasonably early atmospheric river event on October 24, 2021, may have caused this shift. There were 18 days between October 30, 2021, and December 1, 2021, in which DO levels in the Toe Drain measured below 2 mg/L (Olson and Olinger 2024). Field surveys observed a fish kill after the atmospheric river event, suggesting a negative effect on the local fish community. It is presumed that the abnormally large amount of rainfall following 2 consecutive years of severe drought (WY 2020 and WY 2021) was a significant driver of this hypoxia event (Robinson et al. 2022; Olson and Olinger 2024). The Yolo Bypass is used predominantly for cattle grazing and seasonal crops (Sommer et al. 2001b), and the rainfall created runoff that may have transported high amounts of organic material, pesticides, and fertilizers into the Toe Drain, ultimately causing temporary eutrophication of the system that stimulated aerobic decomposition and rapidly depleted the DO. Following this event, we observed an unusually abrupt change in the species composition of the local fish community, with the percent catch of Centrarchidae (sunfishes) increasing and Ictaluridae (catfishes) decreasing. Olson and Olinger (2024) further details the impact of this low DO event on fish species in the Yolo Bypass.

The most abundant native fish species sampled in WY 2022 were Prickly Sculpin (*Cottus asper*) in beach seine surveys (2.2%) and rotary screw trap (0.2%) and Hitch (*Lavinia exilicauda*) in the fyke trap (7.0%), beach surveys (1.2%), and rotary screw trap (0.1%). In WY 2022, native Splittail (*Pogonichthys macrolepidotus*) was the third most abundant native species caught, whereas in years with floodplain inundation, such as WY 2019, Splittail dominated native species catch. In WY 2019, Splittail made up 79.13% of the total rotary screw trap catch (Kwan et al. 2021). WY 2021 and WY 2022 were deemed "critical" water years with no

Table 1. Larval fish species catch data from larval tows conducted at the rotary screw trap for WY 2022.

Date	Mississippi Silverside *Menidia audens*	Prickly Sculpin *Cottus asper*	Threadfin Shad *Dorosoma petenense*
10-Jan	0	0	0
24-Jan	0	1	0
7-Feb	1	5	0
22-Feb	0	28	0
14-Mar	0	19	0
28-Mar	0	665	0
11-Apr	0	6	0
25-Apr	0	15	0
9-May	26	2	0
23-May	47	0	0
7-Jun	30	0	13
21-Jun	12	0	1
Total	**116**	**741**	**14**

Table 2. Fish species catch data and percent (species catch/overall catch) summarized by gear type for WY 2022, sorted in descending order of total abundance.

Scientific Name	Common Name	Beach Seine Catch	Beach Seine %	Fyke Trap Catch	Fyke Trap %	Screw Trap Catch	Screw Trap %	Total
Lucania spp.	Killifish	2,425	27.1%	0	0.0%	3,421	85.2%	5,846
Menidia audens	Mississippi Silverside	4,792	53.6%	0	0.0%	495	12.3%	5,287
Pomoxis nigromaculatus	Black Crappie	12	0.1%	348	35.7%	2	0.0%	362
Gambusia affinis	Western Mosquitofish	198	2.2%	0	0.0%	42	1.0%	240
Acanthogobius flavimanus	Yellowfin Goby	219	2.5%	0	0.0%	2	0.0%	221
Ameiurus catus	White Catfish	0	0.0%	212	21.7%	4	0.1%	216
Percina macrolepida	Bigscale Logperch	210	2.4%	0	0.0%	0	0.0%	210
Cottus asper	Prickly Sculpin	195	2.2%	0	0.0%	7	0.2%	202
Micropterus salmoides	Largemouth Bass	180	2.0%	12	1.2%	0	0.0%	192
Lavinia exilicauda	Hitch	105	1.2%	68	7.0%	4	0.1%	177
Lepomis macrochirus	Bluegill	134	1.5%	21	2.2%	1	0.0%	156
Pogonichthys macrolepidotus	Splittail	15	0.2%	100	10.2%	2	0.0%	117
Catostomus occidentalis	Sacramento Sucker	73	0.8%	18	1.8%	1	0.0%	92
Tridentiger bifasciatus	Shimofuri Goby	84	0.9%	0	0.0%	8	0.2%	92
Cyprinus carpio	Common Carp	4	0.0%	82	8.4%	2	0.0%	88
Morone saxatilis	Striped Bass	41	0.5%	44	4.5%	1	0.0%	86
Dorosoma petenense	Threadfin Shad	54	0.6%	18	1.8%	2	0.0%	74
Lepomis microlophus	Redear Sunfish	55	0.6%	3	0.3%	0	0.0%	58
Alosa sapidissima	American Shad	49	0.5%	3	0.3%	0	0.0%	52
Notemigonus crysoleucas	Golden Shiner	34	0.4%	1	0.1%	11	0.3%	46
Micropterus punctulatus	Spotted Bass	27	0.3%	0	0.0%	0	0.0%	27
Ictalurus punctatus	Channel Catfish	3	0.0%	12	1.2%	0	0.0%	15
Hypomesus nipponensis	Wakasagi	9	0.1%	0	0.0%	0	0.0%	9
Pomoxis annularis	White Crappie	0	0.0%	9	0.9%	0	0.0%	9
Ptychocheilus grandis	Sacramento Pikeminnow	0	0.0%	9	0.9%	0	0.0%	9
Lepomis gulosus	Warmouth	7	0.1%	1	0.1%	0	0.0%	8
Oncorhynchus tshawytscha	Chinook Salmon	1	0.0%	6	0.6%	0	0.0%	7
Ameiurus nebulosus	Brown Bullhead	0	0.0%	6	0.6%	0	0.0%	6
Gasterosteus aculeatus	Threespine Stickleback	0	0.0%	0	0.0%	6	0.1%	6
Hysterocarpus traskii	Tule Perch	4	0.0%	0	0.0%	1	0.0%	5
Ameiurus melas	Black Bullhead	1	0.0%	2	0.2%	0	0.0%	3
Micropterus dolomieu	Smallmouth Bass	1	0.0%	1	0.1%	0	0.0%	2
Pimephales promelas	Fathead Minnow	1	0.0%	0	0.0%	1	0.0%	2
Lepomis cyanellus	Green Sunfish	1	0.0%	0	0.0%	0	0.0%	1
Oncorhynchus mykiss	Rainbow/Steelhead Trout	1	0.0%	0	0.0%	0	0.0%	1

floodplain inundation events. In WY 2021 and WY 2022, Splittail contributed 4.2% and 0.0% (2 individuals caught), respectively, to the total rotary screw trap catch (Robinson et al. 2023). Splittail are floodplain spawners (Moyle et al. 2004), indicating that the absence of floodplain inundation of the Yolo Bypass decreased the potential for local Splittail recruitment during WY 2022 (Feyrer et al. 2006b).

Conclusions

WY 2022 was the second consecutive "critical" water year. Peak turbidity and specific electrical conductance were higher in the Yolo Bypass than in the Sacramento River reference site, while peak water temperature was similar for both sites. Larval tows caught more Prickly Sculpin than any other species. Mississippi Silverside made up the greatest proportion of catch in beach seine surveys, Killifish composed the greatest proportion of catch in the rotary screw trap, and Black Crappie composed the greatest proportion of catch with the fyke trap. In both the beach seine surveys and rotary screw trap, Prickly Sculpin was the most abundantly caught native species, whereas Splittail were the most abundant native species caught in the fyke trap. Presumably due to the extended drought conditions followed by a large atmospheric river, the Toe Drain experienced a hypoxia event that may have altered the fish community. Prolonged drought conditions also reduced available spawning habitat for native Splittail, with a decrease in WY 2022's overall catch in comparison to previous water years (i.e., 2019).

Acknowledgements

The YBFMP would not be possible without the support from IEP. We thank the following WY 2022 YBFMP field staff: Naoaki Ikemiyagi, Nicole Kwan, Mackenzie Miner, Luke Olson, Lisa Vance, Jesse Adams, Mitch Olinger, Emily Hubbard, Mallory Bedwell, Catarina Pien, Allison Brady, and Parisa Hurley, as well as our volunteers. We also acknowledge Dr. Ted Sommer for pioneering scientific research in the Yolo Bypass.

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DATA REPORT

2020–2022 Yolo Bypass Fish Monitoring Program: Lower Trophic Data Status and Trends Report

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Introduction

The Yolo Bypass, a 24,000 ha engineered flood control structure, is the largest floodplain in the Sacramento–San Joaquin Delta (Schemel et al. 2004). During wet periods, floodwaters from the Sacramento River may be redirected through the Fremont and Sacramento Weirs into the Yolo Bypass, resulting in floodplain inundation (Sommer et al. 2001a; Schemel et al. 2004; Sommer et al. 2004). However, during dry periods, the lower regions of the Yolo Bypass function as a tidal slough complex within a perennial channel (Mahardja et al. 2019).

Flow inputs to the complex include rice crop inundation, local irrigation, municipal wastewater effluents (Frantzich et al. 2018), and four western tributaries: Ridge Cut Slough, Cache Creek, Willow Bypass Slough, and Putah Creek, all of which contribute inputs variably by season and water year type. These tributaries and the floodplain drain into a perennial channel, the Toe Drain, flowing along the eastern edge of the Yolo Bypass, which remains wetted year-round, providing connectivity to the greater estuary through the Cache Slough Complex and North Delta.

Supported by the Interagency Ecological Program (IEP), the California Department of Water Resources (CDWR) has collected lower trophic data as a component of the Yolo Bypass Fish Monitoring Program (YBFMP) since 1998. The lower trophic component of the program collects baseline data on phytoplankton, zooplankton, water quality, and hydrology for evaluating differences between and identifying trends within the Yolo Bypass and the adjacent Sacramento River. Sampling is performed at three stations: Screw Trap in the Toe Drain (STTD), Lisbon Weir in the Toe Drain (LIS), and Sherwood Harbor (SHR) in the Sacramento River (Figure 1). Discrete measurements of chlorophyll *a* (Chl *a*), phytoplankton, and water quality are collected at all three locations; zooplankton and drift invertebrates are sampled at STTD and SHR.

Having both floodplain and tidal wetland habitats, the Yolo Bypass has been identified as a region of high restoration priority by the National Marine Fisheries Service's Biological Opinion on Long-term Operation of the Central Valley Project and the State Water Project (NMFS 2019), California EcoRestore (CDWR 2021), and the California Natural Resources Agency's Delta Smelt (CNRA 2016) and salmon resiliency strategies (CNRA 2017). Accordingly, monitoring the lower trophic food web is crucial for contextualizing the success of ongoing and future restoration projects. This report summarizes the spatiotemporal patterns of YBFMP's lower trophic data for water years (WYs) 2020, 2021, and 2022 (October 1, 2019 through September 30, 2022) and includes abiotic data to frame the variability in physical conditions within and across water years and how those conditions may affect lower trophic communities. In response to the Covid-19 pandemic, the YBFMP lower trophic sampling was suspended for much of WY 2020 and sporadically in WY 2021 in compliance with the California State of Emergency stay-at-home order issued by the governor. Due to this suspension, data summaries presented in this report are limited to October to mid-March in WY 2020 and from October to April in WY 2021 (Figure 2).

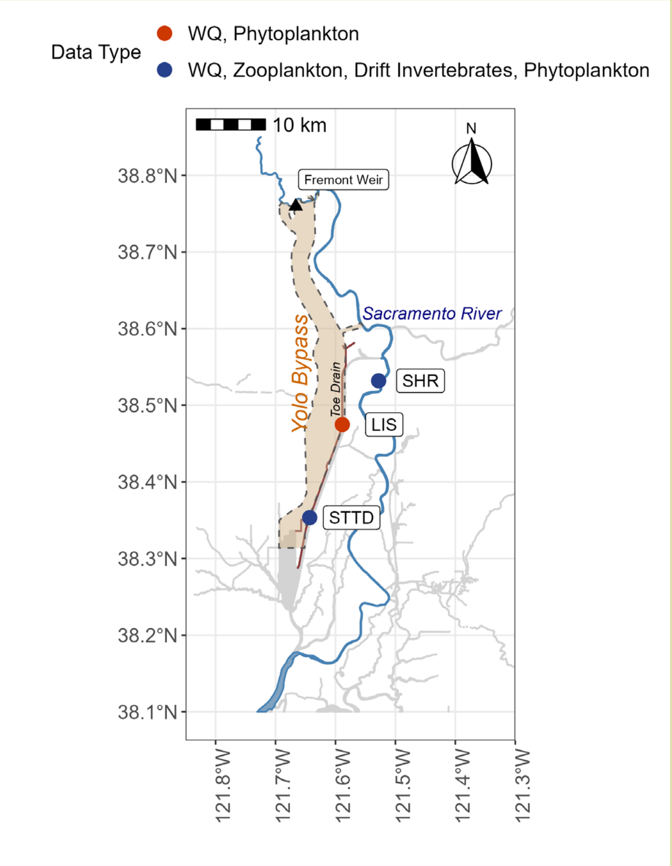
Methods

Sample Collection

Year-round, every 2 weeks, concurrent with lower trophic sampling at all stations, we collected water quality data using a YSI ProDSS handheld meter to measure surface water (≤1 m depth) temperature (degrees Celsius, °C), specific conductance (µS/cm), pH, dissolved oxygen (mg/L), and turbidity (FNU). Additionally, at two sites (STTD and SHR), we used a light meter (LI-COR LI-250A) to collect light attenuation (subsurface irradiance; mol $\cdot$ m^{-2} $\cdot$day^{-1}) at 75%, 50%, 25%, and 1% of the surface reference value in the water, though only data collected to 75% of the surface reference value and corresponding depth data are reported. Measurements beyond 75% of the surface reference value are often at a depth beyond what our sampling equipment can reach.

We sampled lower trophic communities (phytoplankton, zooplankton, and drift invertebrates) in the Yolo Bypass at the

Figure 1. Map of Lower Trophic Stations. Station colors indicate data types collected at each station. Orange polygon indicates the area of the Yolo Bypass. The Toe Drain, where LIS and STTD are located, and the Sacramento River, where SHR is located, are highlighted in brown and blue, respectively. The Fremont Weir, labeled towards the top of the Yolo Bypass with a triangle, is one of the locations where water from the Sacramento River enters during periods of flooding.



base of the Toe Drain (STTD), just upstream of the stair-steps at Liberty Island, and in the Sacramento River at Sherwood Harbor (SHR) during an ebb tide, when possible, to permit sampling from a stationary platform (Figure 1). During periods of high flows, nets were deployed from a stationary platform to sample zooplankton communities (i.e., dock or rotary screw trap), and when flows were insufficient to sample from a stationary location (fewer than 100 revolutions/ minute), tows were conducted off a motorized boat at a low speed, 0.45-1.34m/s. Zooplankton samples were collected using surface tows of two plankton nets 0.50 m in diameter and 2 m in length with 150 μm and 50 μm mesh and cod ends towed for 5 minutes and 2 minutes, respectively. We sampled drift invertebrates using a partially submerged 500 μm rectangular net (0.46 m x 0.3 m; 0.91 m long) towed for 10 minutes.

We deployed all nets fitted with a General Oceanic's Model 2030R flowmeter for calculating the volume of water sampled and to estimate catch per unit effort (CPUE). When necessary, given flow and turbidity conditions, tow durations were shortened to avoid net clogging and/or backflow. Samples were preserved in 10% buffered formalin with Rose Bengal dye and sent to taxonomists (zooplankton to BSA Environmental Services, Inc.; drift invertebrates to Eco Analysts, Inc.) for identification and enumeration. Zooplankton and invertebrates were identified to the lowest taxonomic level possible (usually to order). Further details regarding methodology can be found in our metadata (EDI Data Portal).

At all three stations, we collected surface water samples (at 1 m depth) to obtain Chl α, phytoplankton, and nutrient concentrations. Chl α samples were filtered using 47 mm diameter, 1 μm pore glass fiber filters and preserved with supersaturated magnesium carbonate. Nutrient samples were filtered using 47 mm diameter, 0.45 μm mixed cellulose ester disc filters. CDWR's Bryte Chemical Laboratory analyzed environmental water samples for the following dissolved analytes: ammonia (mg/L as N, EPA 351.2, and 350.1, 1993), nitrate and nitrite (mg/L as N, SM 4500 NO3-F, 2012, 017), ortho-phosphate (mg/L as P, EPA 365.1, 1993), and silica (SiO2, mg/L, EPA 200.7, 1994). Chl α concentrations were determined using SM 10200H.

We preserved phytoplankton samples in 60 mL amber glass vials with Lugol's Iodine solution and shipped to taxonomists (BSA Environmental Services, Inc.) for identification and enumeration. Taxonomists identified phytoplankton to the lowest taxonomic level possible (usually species or genus) using the Utermöhl technique (Utermöhl 1958), with at least 400 algal units counted in total and at least 100 units of the dominant taxa. Taxonomists also recorded length measurements on the first 25 units of major phytoplankton taxa and the first 5 units of minor taxa to calculate biovolume ($\mu m^3 L^{-1}$) from formulas given for different algal shapes by Keller et al. (1982).

Data Preparation

We reviewed and processed sample data for quality control and uploaded data, where complete and available, to CDWR databases and public repositories (i.e., Environmental Data Initiative [EDI]). Discharge data, measurements of water volume, were downloaded from the California Data Exchange Center (CDEC) from the Lisbon Weir station using the CDECRetrieve package in R (Rodriquez and Cain 2024). Nutrient concentration data were downloaded from the Water Data Library (WDL) after being entered by the CDWR Bryte Chemical Laboratory (CDWR 2023a). For data types that had not yet been uploaded to public repositories at the time of this writing (zooplankton, phytoplankton, drift invertebrate data), data were acquired using internal YBFMP databases.

We plotted data to visualize spatiotemporal trends over time, seasons, and location, and to visually inspect for outliers. We removed outliers with presumed incorrect values based on comparison with other sensors and the rest of the dataset. We checked zooplankton and drift invertebrate data for missing flowmeter, subsample volume, and count values where appropriate. We calculated CPUE as the number of taxa per cubic meter. For any invertebrate order that made up less than 8% and for any zooplankton order that made up less than 3% of the given season and water year grouping, another category was created and named “Other” to simplify community visualizations. Further details on CPUE calculations and QA/QC methods can be found in IEP (2021a; drift invertebrates) and IEP (2021b; zooplankton). We defined seasons as follows: fall = October–December; winter = January–March; spring = April–June; and summer = July–September.

We conducted all data manipulations and visualizations in R version 4.3.1 (R Core Team 2023), using the R packages dplyr (Wickham et al. 2022), tidyr (Wickham and Girlich 2022), ggplot2, and ggpubr (Wickham 2016, Kassambara 2020).

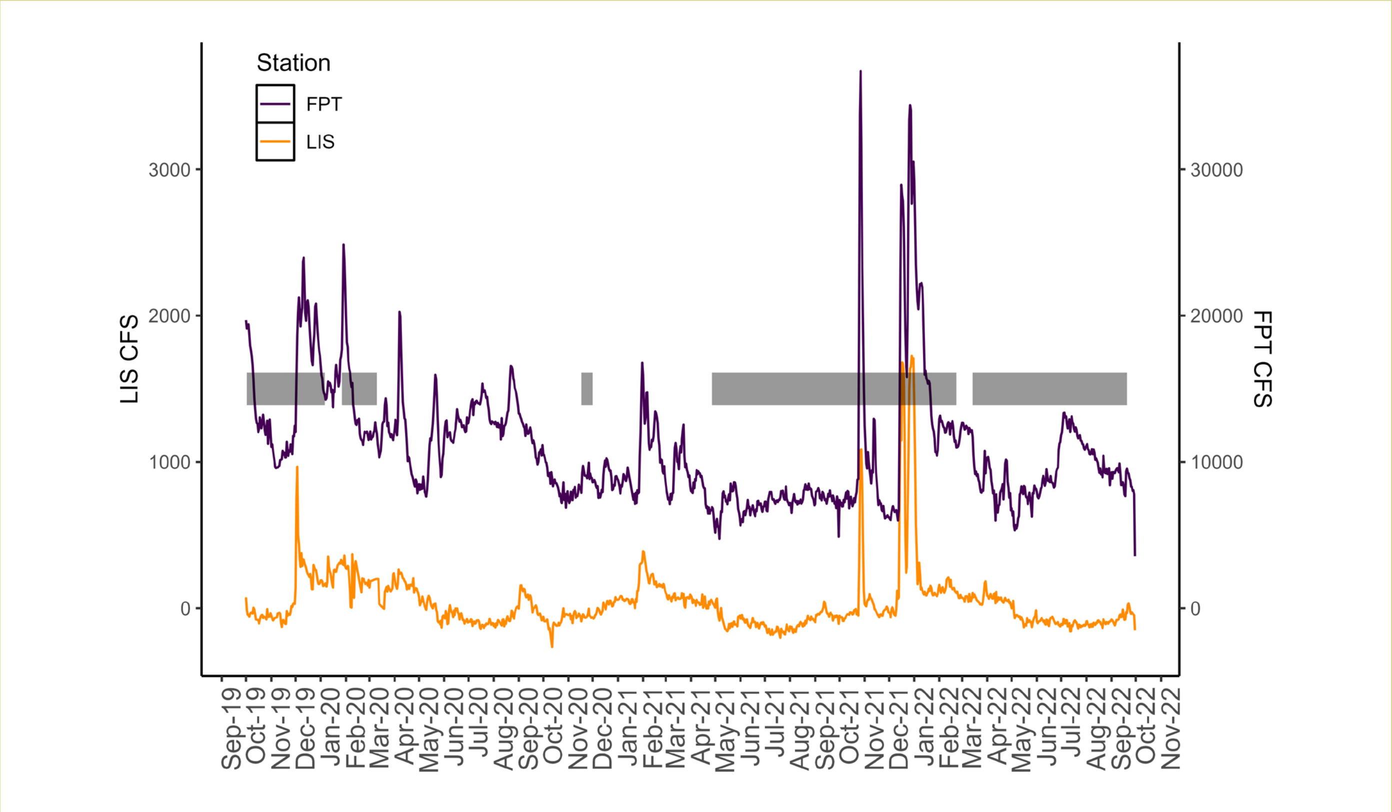
Results & Discussion

Physical Conditions (Flow and Water Quality)

Overall, the water years included in this report were characterized by drought conditions with limited positive outflow in the Yolo Bypass and Cache Slough Complex, particularly in summer months (CDWR 2023b). Seasonal patterns of discharge measured at Lisbon Weir were consistent across sampling locations, with fall or winter representing periods of highest daily average discharge and spring or summer having the lowest. Daily average discharge ranged from -265 cubic feet per second (cfs) to 1,725 cfs in the Toe Drain and 3,566 cfs to 36,721 cfs in the Sacramento River (Figure 2). Mean daily discharge during the reporting period for each year was 54 ± 224 cfs, -18 ± 194 cfs, and 75 ± 362 cfs in WY 2020, 2021, and 2022, respectively, measured in the Yolo Bypass at Lisbon Weir and 13,365 ± 4,513, 8,351 ± 4,813, and 11,099 ± 6,980 cfs in WY 2020, 2021, and 2022, respectively, in the Sacramento River at Freeport (FPT) (Figure 2). Though conditions were dry across all 3 years, there was a large increase in discharge measured during the fall and winter of WY 2022 directly following an atmospheric river event. The event accounted for 6 inches of rainfall in the region. Despite this short, saturated period, a historically low proportion of rice field acreage was planted in the Colusa Basin and resulted in reduced agricultural return flow in the Yolo Bypass during summer months. As such, in the summer of WY 2022 net outflow was reduced compared to previous years and resulted in very few days of positive outflow.

Water temperatures in the Yolo Bypass (LIS and STTD) and the Sacramento River (SHR) followed typical seasonal trends and ranged from 8.0 to 25.9°C in the Yolo Bypass and from 8.5 to

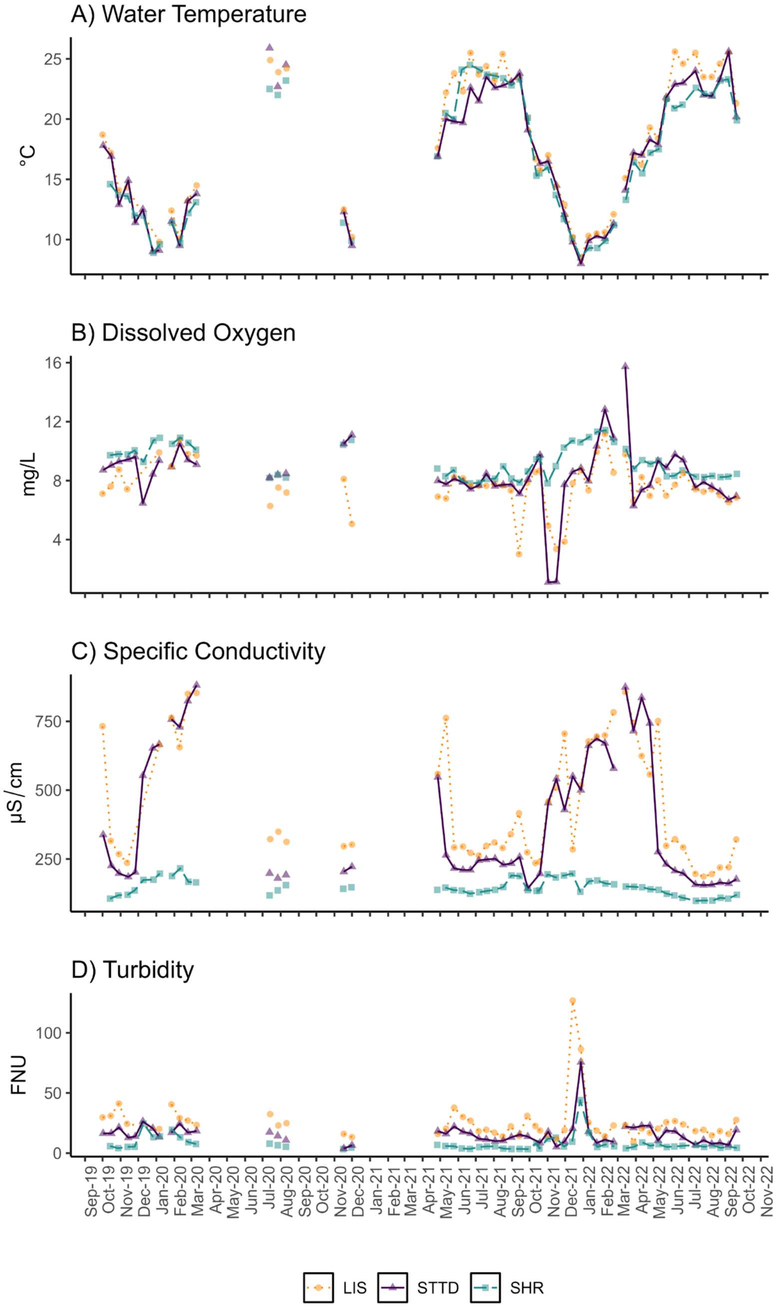
Figure 2. Daily mean discharge measured at the Lisbon Weir (LIS) in the Toe Drain and Freeport (FPT) in the Sacramento River in cubic feet per second (CFS). Periods for which sampling occurred are highlighted in grey rectangles.



24.5°C in the Sacramento River; the highest water temperature recorded was in the Yolo Bypass at STTD in July 2022 (Figure 3A). Dissolved oxygen (DO) measurements followed a similar seasonal pattern and were generally elevated at SHR relative to sites in the Yolo Bypass (LIS and STTD, Figure 3B); however, following suspected high organic matter input (USGS 2018), during the atmospheric river event in WY 2022, we observed exceptionally low concentrations of DO at both sites in the Yolo Bypass (e.g., 3.01 mg/L at LIS, 1.11 mg/L at STTD; Figure 3B).

Additionally, the Yolo Bypass sites had consistently higher average values of specific conductivity (449 ± 217 µS/cm at LIS; 388 ± 239 µS/cm at STTD) and turbidity (26 ± 18 FNU at LIS; 16 ± 10

Figure 3. Discrete water quality, (A) Water Temperature (˚C), (B) dissolved oxygen (mg/L), (C) specific conductance (µS/cm), and (D) turbidity (FNU), from two locations in the Yolo Bypass, in the Toe Drian (LIS and STTD), and the Lower Sacramento River (SHR). Data collected by YBFMP using a calibrated YSI ProDSS multiparameter digital water quality meter. Gaps in sampling due to the Covid-19 pandemic result in data points that are disconnected visually and temporally from other data points.



FNU at STTD) compared to measurements in the Sacramento River (146 ± 29 µS/cm ; 8 ± 7 FNU) across the 3 years, although there was high variability amongst these metrics (Figure 3C and 3D). Again, because of increased runoff following precipitation in the region, we observed abnormally high specific conductance values in fall 2022 (421±176 µS/cm at LIS; 445 ± 130 µS/cm at STTD) relative to the values observed in 2020 (388 ± 232 µS/cm at LIS; 336 ± 191 µS/cm at STTD) and 2021 (299 ± 4 µS/cm at LIS; 213 ± 12.7 µS/cm at STTD).

Irradiance data, which vary depending on the amount of ambient light, turbidity, suspended solids, and abundance of phytoplankton, follow the above regional turbidity patterns (Figure 4). Measured at depths corresponding to the 75% surface reference value, the measurable euphotic zone is often greater at SHR (0.73 ± 0.35 m) than at STTD (0.46 ± 0.22 m).

Nutrients

CDWR's Bryte Laboratory reporting limit for dissolved ammonia increased from 0.01 mg/L of nitrogen to 0.05 mg/L of nitrogen in 2018. This, in combination with low levels of these analytes in the study sites as well as upgrades to regional wastewater treatment facilities (including an upgrade in April 2021 [Sacramento County Regional Sanitation District 2021]) led concentrations of ammonia, nitrate-nitrite, and ortho-phosphate to regularly fall below reporting limits during this reporting period. Nutrient concentrations, except for dissolved silica, were higher on average in the Yolo Bypass compared to the Sacramento River. Dissolved ammonia, when above the reporting limit, ranged from <0.05 to 0.13 mg/L; nitrate and nitrite ranged from <0.05 to 1.08 mg/L; and measurements of dissolved ortho-phosphate ranged from <0.05 to 0.55 mg/L (Figure 5). Concentrations of these analytes were generally elevated in the fall and winter months, and lowest in the summer. Our highest observation of dissolved ammonia did correspond in time to the atmospheric river event in the fall of WY 2022 at LIS. Conversely, average dissolved silica concentrations were notably higher in the Sacramento River (SHR) compared to the Yolo Bypass (at LIS and at STTD) for all years and all seasons. Inputs from weathered rock, reduced residency times, and nutrient limitation resulting in less uptake of dissolved silica by diatoms (e.g., Turner et al. 2003) likely contributed to elevated concentrations of silica in the Sacramento River.

Figure 4. Discrete measurements of light attenuation (µmol s-1 m^{-2}) data collected at STTD and SHR between water years 2020 and 2022.

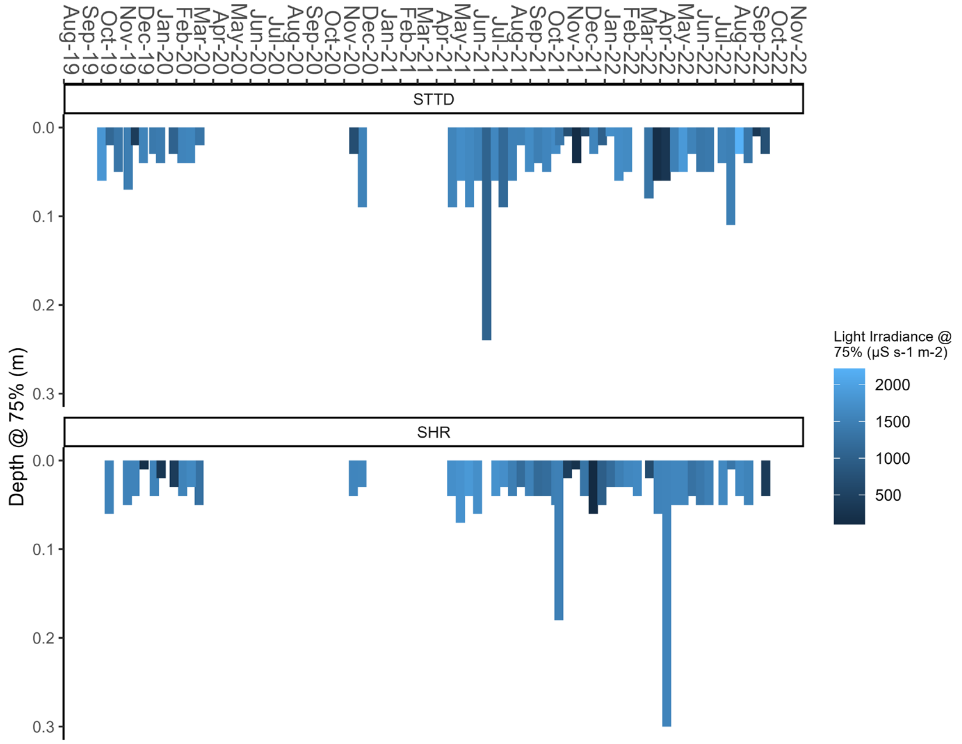
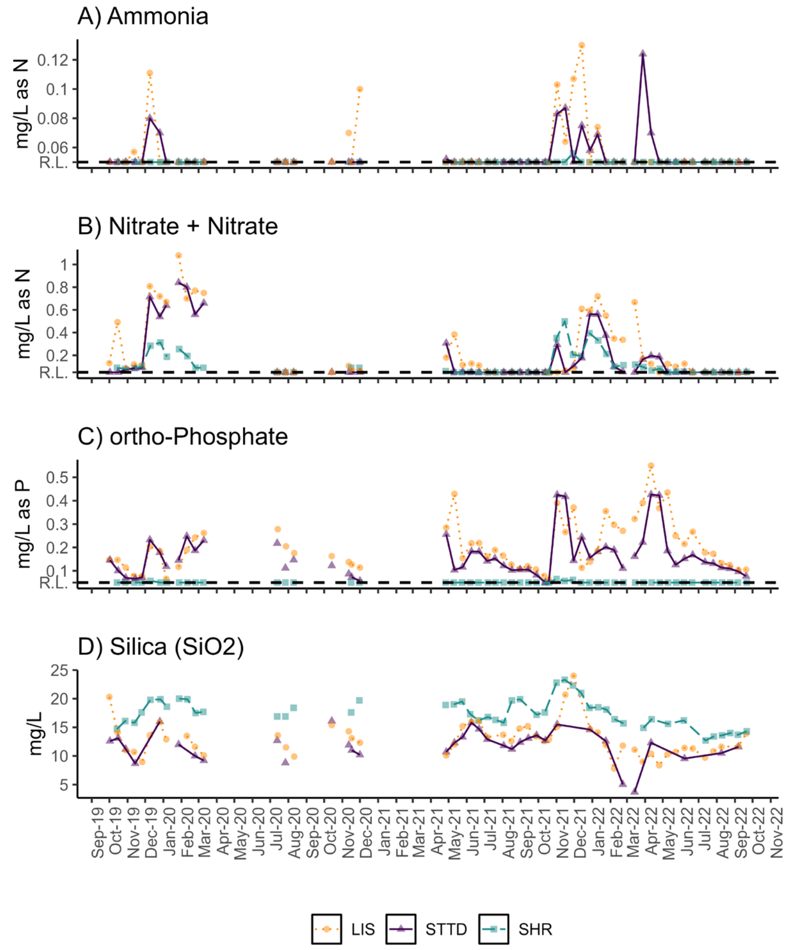


Figure 5. Nutrient concentrations during water years 2020-2022 for dissolved ammonia, dissolved nitrate-nitrite, dissolved ortho-phosphate, and dissolved silica. Nutrients are measured at two sites in the Toe Drain (LIS and STTD) and an adjacent site in the Sacramento River (SHR). Dashed black lines represent the reporting limit for specified analytes (Ammonia R.L.: 0.05 mg/L of N; Nitrate Nitrite R.L.: 0.05 mg/L of N; ortho-Phosphate R.L.: 0.05 mg/L of P), analytical values below the reporting limit are considered non-detects.



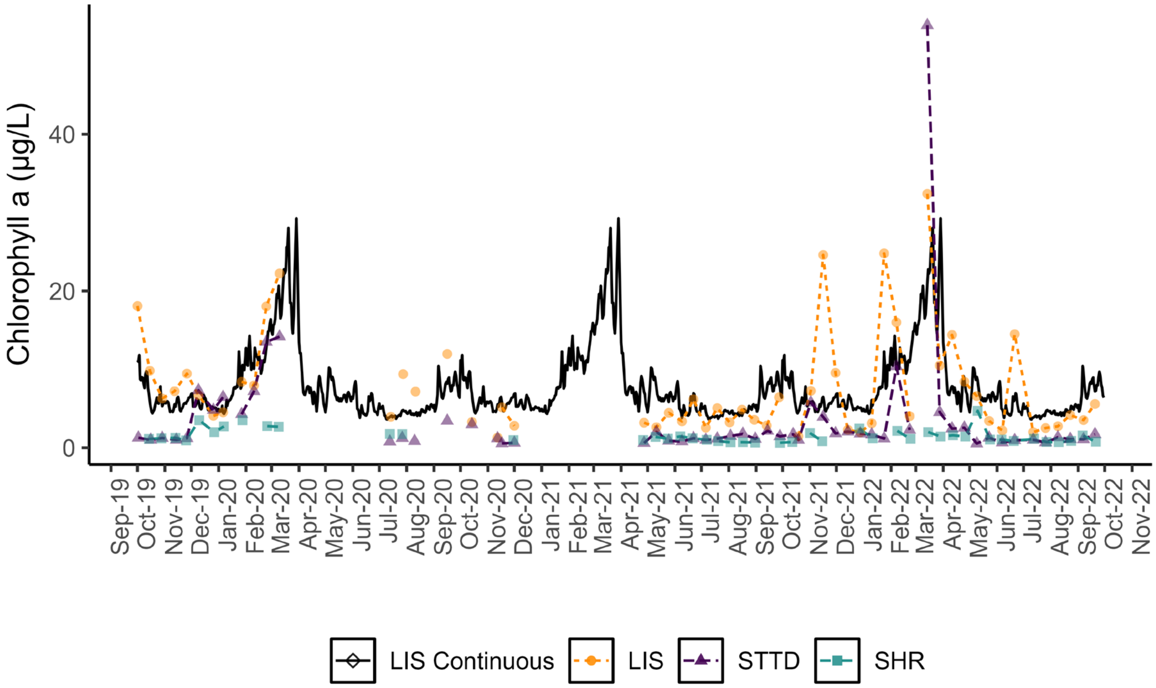
Biotic Conditions

Chlorophyll α and Phytoplankton

Discrete measurements of Chl α concentrations ranged from 0.54 to 53.90 µg/L and were generally higher in the Yolo Bypass (LIS and STTD) compared to the Sacramento River (SHR) over all 3 water years, consistent with the inverse relationship of Chl α and flow previously observed by Sommer et al. (2004) and water year classifications of dry and critical for this reporting period. Additionally, Chl α concentrations observed within the Yolo Bypass varied spatially and temporally, with higher spikes at LIS compared to STTD (Figure 6). Seasonally, Chl α was highest in all winter seasons compared to spring, summer, and fall (Figure 6). Using continuous measurements of Chl α collected by a sonde at the same location as discrete sampling at the Lisbon Weir, the impact of suspended sampling was observable as discrete samples captured only some of the trends in Chl α over time (Figure 6). It is possible these differences are due to minor variances in sampling depth, as well as differences in methodology as continuous measurements are made with Total Algae sensors and discrete measurements are processed in a lab.

Measurements of phytoplankton biovolume fluctuated over the reporting period and across seasons (Figure 7A). In the Yolo Bypass at LIS and STTD, biovolume density was generally greatest in the winter months of 2020 and 2022, where comparisons were possible. Measurements of biovolume in the Sacramento River (SHR) were greatest in the summer. Pennate diatoms were

Figure 6. Time series plot of (A) chlorophyll α, (B) phytoplankton biovolume density, (C) Zooplankton CPUE, and (D) Drift Invertebrate CPUE in the Yolo Bypass (LIS and STTD) and Sacramento River (SHR) between water years 2020 and 2022. Although varying by season and with occasional exceptions, Chlorophyll α concentration, phytoplankton biovolume, zooplankton and drift invertebrate CPUE was generally greater in the Yolo Bypass (LIS and STTD) than in the Sacramento River. Gaps in sampling are clear throughout parts of 2020 and 2021 due to the Covid-19 Pandemic.



very abundant at all three locations, making up between 54%, 77%, and 26% of the biovolume in WY 2020, 2021, and 2022, respectively. In WY 2022, centric diatoms were the most common algal group, representing 72% of the overall biovolume sampled (Figure 8A). Nitzschia spp. and Cyclotella spp. were the most numerous genera among pennate and centric diatoms, respectively.

Zooplankton

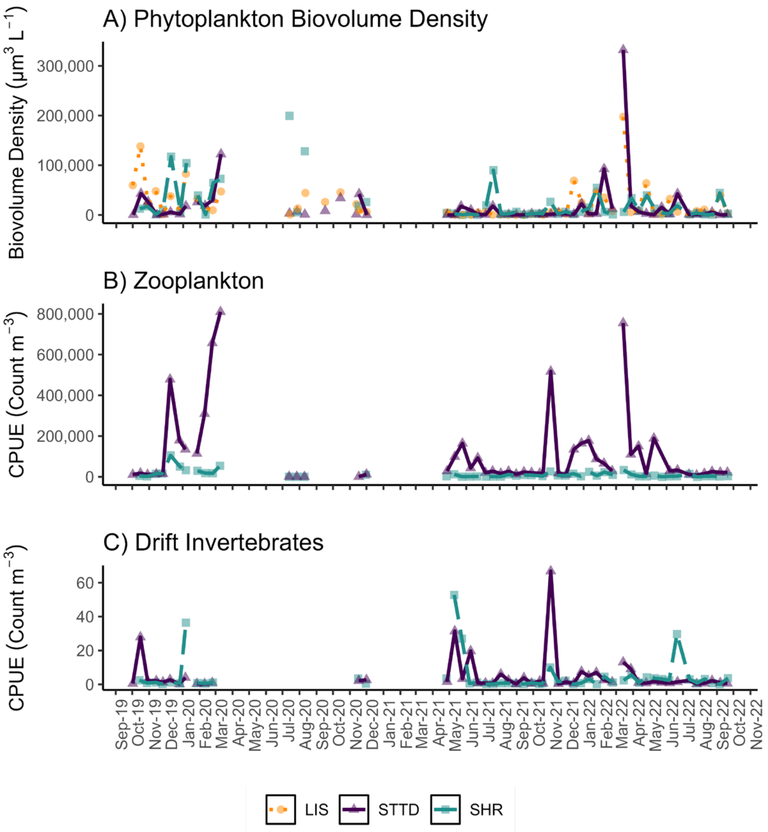
Mean zooplankton CPUE was much higher in the Yolo Bypass (510.6 count/m^{-3} ± 7,233.4), measured only at STTD, compared to measurements of CPUE in the Sacramento River (57.0 count/m^{-3} ± 623.9) (Figure 7B), and it was greatest during the fall and winter, again, when comparisons were possible. Consistent with previous reporting periods, similar species compositions were observed across sampling locations. Microzooplankton were predominant among sampling efforts and were composed primarily of rotifers (Figure 8B). Calanoid copepod abundance increased in the spring and/or summer in the Yolo Bypass in all sampling years but remained a smaller proportion of the overall catch at SHR, where rotifers or Cladocera more often dominated. Calanoid copepods are abundant within the Cache Slough Complex (Kimmerer et al. 2018, Frantzich et al. 2021) and may have been more predominant within the Toe Drain during the reporting period as the result of advection and net negative outflow during dry conditions.

Drift Invertebrates

Daily CPUE for drift invertebrates was highly variable between region, season, and water year, ranging from 4.8 to 79.3 organisms per cubic meter (count/m^3) in the Yolo Bypass and 3.5 to 84.9 organisms (count/m^3) in the Sacramento River (Figure 7C). Though drift invertebrate communities were distinct between the Sacramento River and Yolo Bypass, Diptera and Hemiptera were commonly represented at both locations (Figure 8C). When compared across seasons and water years, the STTD demonstrated a greater number of unique orders in spring 2021 and fall 2022 (S = 19) relative to SHR in spring 2021(S = 22). CPUE was greatest at STTD in fall 2022 (79.341 count/m^{-3}) and at SHR in spring 2021 (84.915 count/m^{-3})

Diptera were the most observed taxa at SHR (105.01 count/m^3) with the greatest proportional catch (89.68%) and CPUE (34.89 count/m^3) in winter of WY 2020 (Figure 8C). Amphipoda

Figure 7. Continuous chlorophyll α measured in the Yolo Bypass at Lisbon Weir and discrete chlorophyll α measurements collected at LIS, STTD in the Yolo Bypass and at SHR in the Sacramento River between water years 2020 and 2022. Continuous data is recorded every 15 minutes and downloaded from http://wdl.water.ca.gov/waterdatalibrary/.



were the most observed taxa at STTD (104.58 count/m³) with the greatest proportional catch (70.84%) and CPUE (79.34 count/m³) being in fall of 2022 (Figure 8C). These results are consistent with past analyses where it was found that increased flow and Diptera abundance were positively correlated in the Yolo Bypass (Sommer et al. 2004). As such, reduced abundance of Diptera, relative to previous reporting periods, may have been the result of drier conditions.

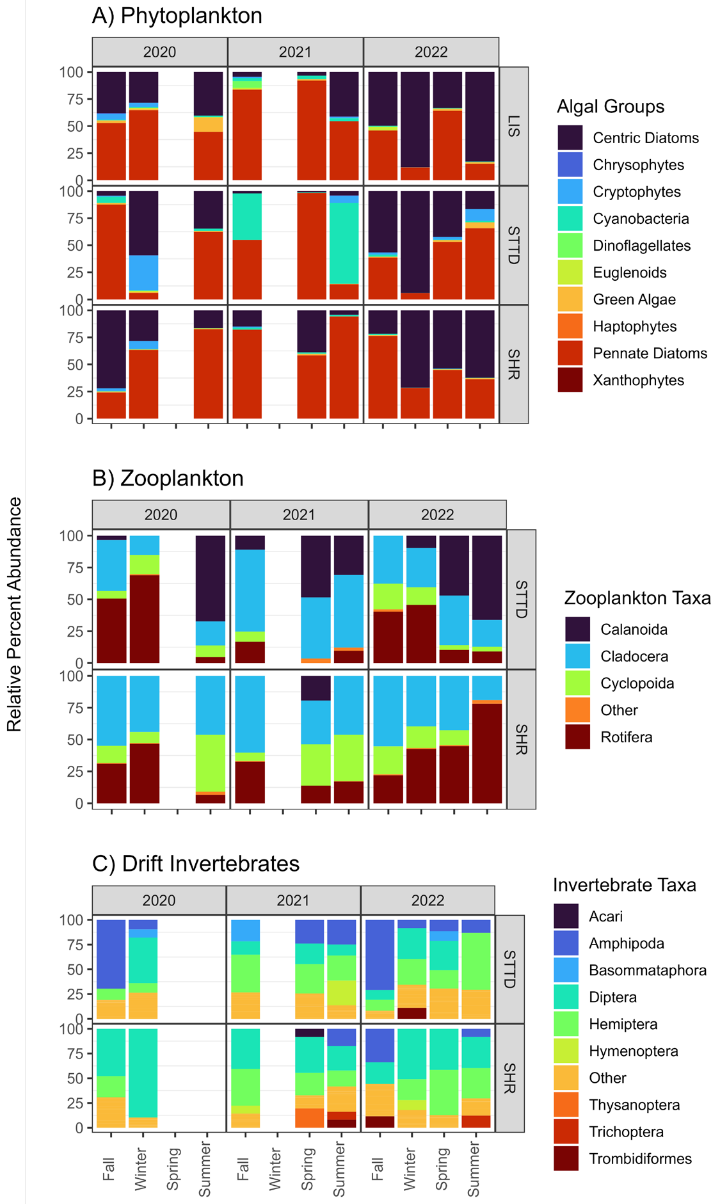
Conclusions

This report describes the biological and environmental data at two sites in the Yolo Bypass (LIS and STTD) and one comparison site in the middle Sacramento River (SHR) over a three-year period. While annual Chl *a* values were greatest at sites in the Yolo Bypass (particularly at LIS) compared to the Sacramento River and followed consistent seasonal patterns, phytoplankton density varied between regions and seasons. Overall, we observed higher temperatures, turbidity, specific conductivity, nutrient concentrations, as well as higher zooplankton and drift invertebrate CPUE in the Yolo Bypass compared to the Sacramento River. Conversely, the Sacramento River tended to have higher concentrations of dissolved oxygen and silica. Differences observed in abiotic characteristics and biological CPUE between the Sacramento River and Yolo Bypass are likely the result of increased water residency times, shallower bathymetry, and source water inputs in the Yolo Bypass (i.e., municipal wastewater inputs, among others) (Sommer et al. 2004; Frantzich et al. 2018).

Broad regional patterns notwithstanding, inferences and comparisons of these data should be viewed with some uncertainty given sampling gaps in WY 2020 and 2021 from the Covid-19 pandemic. These gaps in data limit our ability to perform interannual, seasonal, and water year comparisons. In conjunction with continuous measurements of Chl *a* at Lisbon Weir, our discrete Chl *a* data, which captured some but not all the variation in productivity across the reporting period, illustrates the importance of consistent data collection and the consequences of suspended sampling, like the Covid-19 pandemic, on long term monitoring programs like the YBFMP (Figure 6).

Water years 2020–2022 established the driest 3-year period on record in California (CDWR 2022), yet we also detected the

Figure 8. Relative Percent Abundance of (A) Phytoplankton classified by Algal Groups sampled at LIS, STTD and SHR, (B) Zooplankton caught in 150um and 50um nets sampled at STTD and SHR, and (C) Drift Invertebrates, classified by order, in 500 um drift nets sampled at STTD and SHR. For drift invertebrates, organisms which represented less than 8% of the total CPUE within a given season were collectively summed into the "Other" category.



impact of an atmospheric river event on abiotic metrics and analytes across and within regions. Swings such as these in climate extremes are projected to increase in frequency and intensity with climate change (Swain et al. 2018); therefore, continuing to contextualize lower trophic resources during these periods of extreme hydrologic change may help inform water management decisions in the Yolo Bypass and food web processes in the future.

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DATA REPORT

2023 Status and Trends Report for Pelagic Fishes in the Upper San Francisco Estuary

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Abstract

This 2023 Status and Trends Report aims to provide a more complete overview of annual recruitment success with relative abundance and distribution patterns for certain pelagic fishes in the San Francisco Estuary (Estuary), with a focus on the estuary upstream of San Pablo Bay. Specifically, this report summarizes annual abundance indices from six of the Interagency Ecological Program's (IEP) long-term fish monitoring surveys: 1) Smelt Larva Survey (SLS), 2) Spring Kodiak Trawl (SKT), 3) 20-mm Survey, 4) Summer Townet Survey (STN), 5) Fall Midwater Trawl Survey (FMWT), and 6) San Francisco Bay Study (SFBS) midwater trawl (MWT) and otter trawl (OT). Some of the California Department of Fish and Wildlife (CDFW) long term monitoring surveys annually publish memos reporting abundance indices and distribution patterns for certain species of interest. These species include Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), Splittail (*Pogonichthys macrolepidotus*), American Shad (*Alosa sapidissima*), Threadfin Shad (*Dorosoma petenense*), and Striped Bass (*Morone saxatilis*). A summary and analysis of these memos, as well as data that is not traditionally reported, is presented here in order to better understand trends across multiple surveys and gear types.

Above average precipitation in 2023 marked the end of a multiyear drought cycle (California Department of Water Resources [DWR] Northern Sierra Precipitation: 8-Station Index). Most of the focal species' annual abundance indices saw notable improvements relative to previous years. Delta Smelt indices continued to decline across all surveys with the exception of SLS. The Longfin Smelt all-ages index for FMWT increased. The SFBS MWT age-2+ Longfin Smelt increased while the age-0 and age-1 indices decreased. In contrast, the SFBS OT Longfin Smelt age-0 and age-2+ increased, while the age-1 index decreased. The FMWT Splittail index maintained a declining trend, while both SFBS indices increased. American Shad, Threadfin Shad, and age-0 Striped Bass all had increased indices across surveys.

Introduction

The San Francisco Estuary (Estuary) is an intricate and diverse ecosystem that is at the center of California's water conveyance system. It is the largest estuary in western North America, and it is also one of the most imperiled. Since the inception of the Federal and State water projects, the Estuary has experienced multiple ecosystem shifts. Several of these shifts have been detected through the collective monitoring efforts of multiple surveys over the last 67 years (Tempel et al. 2021). Individually, each survey gear provides a relative abundance index to determine annual recruitment success over time ("status and trends") for certain fish species. Together, these surveys provide a more complete spatial and temporal analysis of fish abundance and distribution throughout the estuary (Figures 1 to 3). Additionally, these IEP surveys consist of multiple gear types that target different early-life stages of fishes. Annual and real-time survey memos are published for each study (except the San Francisco Bay Study) to report on the relative abundance and distribution of select species of interest.

This report provides brief summaries of each survey gear as well as the 2023 species indices for Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), Splittail (*Pogonichthys macrolepidotus*), American Shad (*Alosa sapidissima*), Threadfin Shad (*Dorosoma petenense*), and Striped Bass (*Morone saxatilis*). We use data from the California Department of Fish and Wildlife's (CDFW): 1) Smelt Larva Survey (SLS), 2) Spring Kodiak Trawl (SKT), 3) 20-mm Survey, 4) Summer Townet Survey (STN), 5) Fall Midwater Trawl Survey (FMWT), and 6) San Francisco Bay Study (SFBS) midwater trawl (MWT) and otter trawl (OT). Note, 2023 was the final year of sampling for SKT. This report aims to provide better perspective by reporting combined survey data within a single document to more clearly present pelagic fish abundance in the upper Estuary.

Figure 1: Station distribution for the San Francisco Bay Study (SFBS), which samples year-round.

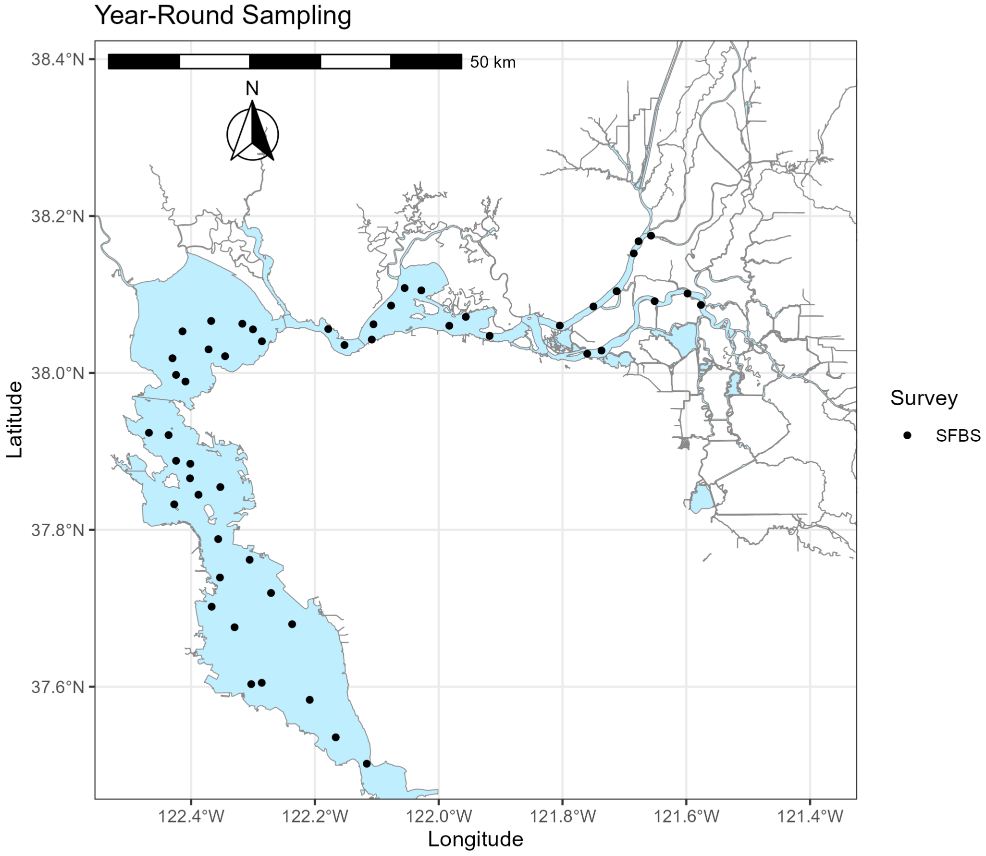


Figure 2: Station distribution for the IEP surveys that sample Winter-Spring. Surveys include Smelt Larva Survey (SLS), 20-mm Survey (20mm), and Spring Kodiak Trawl (SKT).

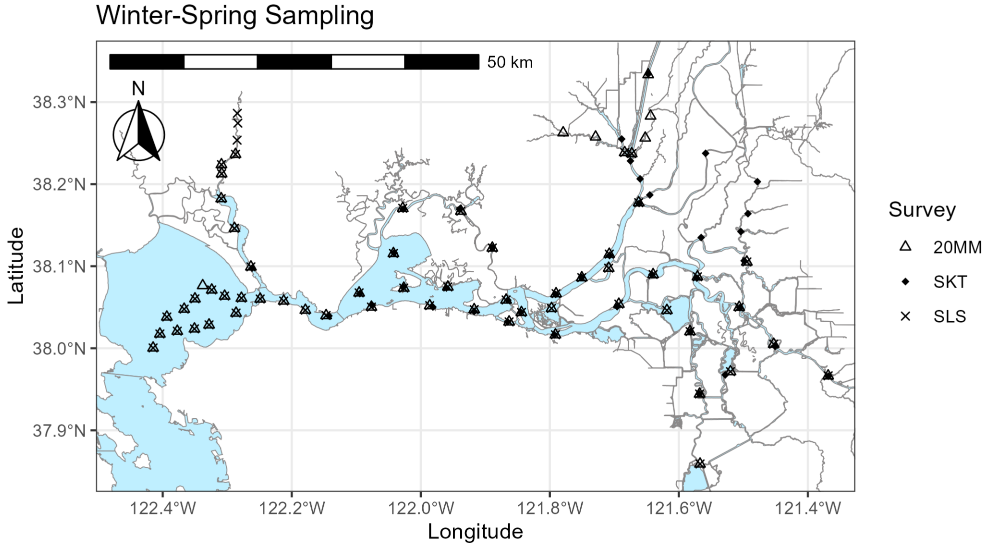
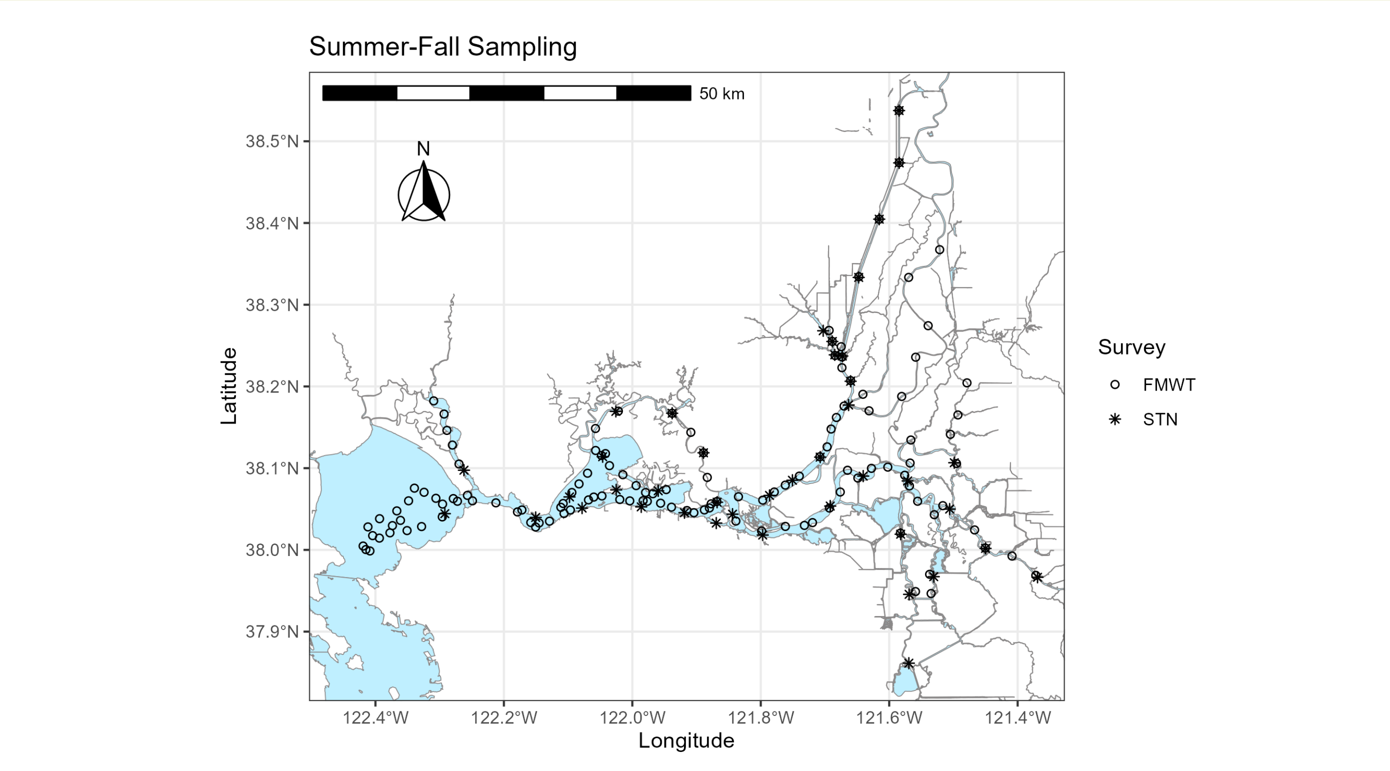


Figure 3: Station distribution for the IEP surveys that sample Summer-Fall. Surveys include Summer Townet (STN), and Fall Midwater Trawl (FMWT).



Methods

2023 Survey-Gear Background

The following is a brief description of methods for the individual survey gears. Indices calculated by each survey gear are listed within their respective methods and index calculations are described in Table 1. More information is available online at Bay-Delta Studies and Surveys.

Smelt Larva Survey

The SLS was initiated in January 2009 to provide near real-time distribution and abundance of larval Longfin Smelt and to monitor their vulnerability of entrainment into the water export facilities. In 2023, SLS sampled 59 fixed stations every other week from December to March, totaling eight sampling weeks (Figure 2). The 12 South and Central Delta stations are prioritized and processed within 72 hours of sample collection to inform water operations managers of Longfin Smelt's proximity to the water export pumps. The SLS sampling season initially sampled every other week at 35 fixed stations, conducting six sampling weeks between January and March in the Upper San Francisco Bay Estuary. Nine Napa River stations were added in 2014, totaling 44 fixed stations in the estuary (2014–2018, 2021–present). In the 2021 sampling season, the SLS extended the sampling season to start in early December 2020 to target earlier Longfin Smelt spawning events, thus increasing the season to eight sampling weeks. In the 2023 sampling season, the SLS expanded into San Pablo Bay to improve spatial balance among the regions of the estuary and to further capture Longfin Smelt distribution in wetter years. The SLS gear is a cone shaped 500-µm mesh net (505-µm pre-2014) net, 3.35-m long, lashed to a metal D-frame on skis with a mouth area of 0.37 m^2. Samples are preserved in 10% buffered formalin for later identification and enumeration of larval fishes.

The 2023 SLS sampling season began on December 5, 2022 and collected 461 fish samples by March 17, 2023. The SLS occasionally cannot sample all stations in a survey due to barriers such as aquatic vegetation, vessel mechanical challenges, staffing shortages during COVID, bridge accessibility, and weather. In survey 1 (sampling week 3), all Napa River stations were dropped due to severe weather conditions and one South Delta station was not sampled due to inaccessibility past the non-operational Highway 4 Old River Bridge.

This report will use the new design-based abundance indices for the SLS. Historically, this survey gear has been used to track the presence and location of larval osmerids. The new design-based abundance indices are set within 9–10 regions spaced throughout the Upper Estuary. Larval fish catch per unit effort is expanded by sub-regional volumetric expansions and summed across all sub-regions. The variance of the index is based upon 9–10 regions (dependent on years and stations sampled). Additional information on variance calculations can be found in Polansky et al. (2019). Abundance values reported in this status and trends report will be higher than previously reported. This is due to an enhancement of the variance calculation. Specifically, regional data that was previously excluded is now included.

Spring Kodiak Trawl

The SKT was initiated in 2002 to determine the timing, distribution, and abundance of spawning Delta Smelt. The survey concluded in 2023. The SKT provided state and federal managers with near real-time maturity and egg-stage data for adult Delta Smelt to assess their risk of larval entrainment into the water export facilities. Initially, 39 stations throughout the upper San Francisco Estuary were sampled monthly from January to May, sometimes December. Station 719 in the Sacramento Deep Water Shipping Channel was added in 2005, totaling 40 stations. The Kodiak trawl net had mouth dimensions of 25 feet wide by 6 feet high when stretched taught. Net mesh sizes graduate in five sections from 2-inch stretch-mesh at the mouth to 0.25-inch stretch-mesh at the cod-end. A 10-minute surface tow was conducted at each station with two boats that spread the net mouth fully open. All fish, shrimp, and jellyfish collected in the tows were identified and enumerated in the field.

The 2023 Spring Kodiak Trawl sampling season began on January 9, 2023 and collected 200 fish samples by May 4, 2023. All stations were sampled for a total of 5 sampling weeks.

20-mm Survey

The 20-mm Survey was initiated in 1995 in response to the listing of Delta Smelt as threatened under the Federal Endangered Species Act and the California Endangered Species Act in 1993. This survey monitors the distribution and abundance of post-larval and juvenile Delta Smelt. The survey name refers to the size (fork length) of Delta Smelt that the survey gear targets, which further corresponds to the size at which Delta Smelt are identified and counted at the State Water Project and Central Valley Project fish salvage facilities. Although designed for Delta Smelt, the 20-mm Survey is effective at sampling the pelagic post-larval and juvenile fish community present in the spring and early summer. Historically, the 20-mm Survey has sampled 47 fixed stations every other week between April and August, completing eight sampling weeks. In 2005, a ninth sampling week was added, and the survey has been consistently sampling March through July. In 2023, the 20-mm Survey expanded into San Pablo Bay to improve spatial balance among the regions of the estuary as defined by the 6-Agency Survey Redesign Team. Currently, the 20-mm Survey samples every other week at 61 fixed stations with a total of nine sampling weeks between March and July each year (Figure 2). Three tows are conducted at each station using a fixed-mouth, 1,600 µm mesh net (Dege and Brown 2004). Samples are preserved in 10% buffered formalin for later identification and enumeration of larval fishes. The 12 South and Central Delta stations are prioritized and processed within 72 hours of sample collection to inform water operations managers of Delta Smelt's proximity to the water export pumps.

The 2023 20-mm Survey sampling season began on March 13, 2023 and collected 1,562 fish samples by July 7, 2023. The 20-mm Survey occasionally cannot sample all stations in a survey due to barriers such as aquatic vegetation, vessel mechanical challenges, bridge access, and weather. In the 2023 season, 85 samples were not collected due to these various reasons.

Summer Townet Survey

The STN survey began in 1959 to index age-0 Striped Bass abundance, which it has done for all years except 1966, 1983, 1995, and 2002. Delta Smelt indices were also calculated for the period of record, except for 1966 through 1968. Historically, STN conducted two to five surveys annually, but in 2003 CDFW standardized sampling to six surveys per year, beginning in early June and continuing every other week into August. STN samples 40 stations, nine of which are considered non-index stations. More detailed descriptions of pelagic fish and zooplankton catch along with field procedures can be found on the CDFW Summer Townet Survey web page.

The 2023 STN season began on June 7 and ended on August 19, 2023. All stations were sampled during the 2023 season.

Fall Midwater Trawl

The FMWT survey was established in 1967 to examine the relative abundance and distribution of age-0 Striped Bass. It has been conducted in all years except 1974 and 1979 (for additional information see the CDFW FMWT web page). Over time, the FMWT survey has also been used to track other common pelagic fish species in the upper estuary (Stevens 1977), including Delta Smelt, Longfin Smelt, Splittail, American Shad, and Threadfin Shad. The FMWT survey currently conducts a single tow at 130 stations monthly from September through December (Figure 3). The annual abundance index calculation uses catch per tow data from the historic 100 index stations (Stevens 1977). The remaining 30 stations were added in 1990, 1991, 2009, 2021, and 2023 to improve understanding of pelagic fish distribution and habitat use into upstream areas; largest expansion was in 2009 for increased Delta Smelt habitat monitoring in the north Delta. The 100 index stations were grouped into 14 regions to calculate monthly and annual abundance indices (see Table 1). The catch from the 30 non-index stations can be substantial, as areas like the Sacramento Deep Water Shipping Channel and Cache Slough appear to be refuge habitat for many pelagic species as conditions deteriorate in other areas of the estuary. Since these new stations were added, a large portion of the total American Shad and Threadfin Shad catch has been from this area. In 2023, eight new stations were added to further expand sampling in upstream areas of the Napa River, Suisun Marsh, and Cache Slough complex to improve spatial balance among the regions

Table 1. Detailed descriptions of each index presented in this report and its corresponding survey gear including the years conducted, gear type, index calculation, index species, seasonal sampling period, and targeted life stages.

Survey	Years Active	Gear Type	Index Description	Index Species	Index time period	Sampling time period	Targeted Life Stage
Spring Kodiak Trawl	2002–2023	Trawl-net, 7.6m x 1.8m mouth size with graduated changes in mesh size beginning at 5cm stretch-mesh to 0.64cm stretch Mesh at the cod-end; surface tow.	To calculate the index, stations are grouped into 3 spatial regions and a mean catch per 10,000 cubic meters of water (i.e., CPUE) is calculated. The regional means are then summed to create an index for each survey, and survey indices are summed to calculate the SKT index.	Delta Smelt	4 Sampling Surveys	January-April	Adult
Smelt Larva Survey	2009–present	Fixed-mouth, 500-µm mesh net; oblique tow	Design Based Abundance Indices (Polansky et al 2019, Melwani et al. 2022).	Delta Smelt, Longfin Smelt	All SLS Surveys	December-March	Larval
20 mm	1995–present	Fixed-mouth, 1,600 µm mesh net	Catch data averaged by survey (for fish <60mm FL) for all stations to determine when mean FL reaches or surpasses 20 mm. The 2 surveys before and after when this target is reached are used to calculate the annual abundance index. From this subset of surveys, DS CPUE is calculated for each of the 41 index stations. CPUE for each tow is calculated by dividing catch by the volume of water filtered during the sample and multiplied by 10000 to obtain a whole number. CPUE is then averaged across tows for each index stations. The resulting mean station CPUE values are log (log10(x+1)) transformed. These values are averaged within each survey and then the mean values are back transformed to return to original scale. One is subtracted from each survey value and these values are summed across the 4 surveys to obtain the annual abundance index.	Delta Smelt	4 sampling surveys bracketing when fish reach 20 mm fork length.	March-July	Larval-Juvenile
Summer Townet	1959–present	Fixed-mouth; 1.27 cm stretched mesh tapering down to bobbinet codend with 8 holes per 2.54 cm; oblique tow	Catch per tow data from the 31 index stations are used for index calculations. For each survey, the total species catch by each station is multiplied by a water volume weighing factor. These products are then summed across all index stations within a survey, then divided by 1000 to produce the survey abundance index. The annual abundance index for age-0 Striped Bass is interpolated using index values from the two surveys that bound the date when mean FL reached 38.1 mm. For Delta Smelt, the annual index is the average of the first two survey indices of each year.	Age-0 Striped Bass, Delta Smelt	2 sampling surveys bracketing when age-0 Striped Bass reach 38.1 mm fork length; Delta Smelt index is calculated only for surveys 1 and 2	June-August	Larval-Juvenile
Fall Midwater Trawl	1967–present	Midwater trawl using 17.7m long net tapering down to 1.27cm mesh	100 index stations are grouped into 14 regions. Monthly indices are calculated by averaging catch per tow in each region, multiplying these means by their water volume weighting factors, and summing these products. Annual abundance indices are the sum of the 4 monthly indices.	Delta Smelt, Longfin Smelt, Age-0 Striped Bass, Threadfin Shad, American Shad	4 sampling surveys	September-December	Juvenile-Sub-adult
San Francisco Bay Study	1980–present	Midwater trawl using 17.7m long net tapering down to 1.2cm codend mesh; otter trawl with a 0.55cm codend mesh.	Annual abundance indices are calculated as the average of monthly indices over the period for which the age class was most abundant. The 35 index stations are assigned to 5 regions. The region's water volume weighting factor (for the MWT) or the area weighting factor (for the OT) is multiplied by the mean regional CPUE and these products are summed across all 5 regions for the monthly indices.	Age-0 Delta Smelt, Striped Bass, American Age-0 Delta Smelt, Striped Bass, American Shad, Splittail, Age-0, Age-1, and Age-2+ Longfin Smelt	June-October Age-0 Delta Smelt, Striped Bass); July-October (age-0 American Shad); May-October (age-0 Longfin Smelt, Splittail); 4 sampling surveys, February-May (Age-1 and Age-2+ Longfin Smelt)	Monthly year round	Juvenile-Sub-adult

Table 2. Number of days per year that water temperatures were >22.0°C among Antioch (ANH), Mossdale (MSD), and Rio Vista (RVB) DWR CDEC stations during years 2020–2023.

Year	ANH	MSD	RVB	Total
2020	56	108	88	252
2021	32	69	86	187
2022	66	122	91	279
2023	57	51	49	157

of the estuary as defined by the 6-Agency Survey Redesign Team. The 2023 FMWT season began on September 4 and was completed on December 20, 2023. All stations were sampled for each survey month.

San Francisco Bay Study

The SFBS began in 1980 to determine the effects of freshwater outflow on the abundance and distribution of fishes, shrimp, and crabs throughout the San Francisco Estuary (Figure 1). Each month the SFBS samples 52 stations, which have been consistently sampled since 1980 and used to calculate the annual abundance indices (see Table 1, Orsi 1999). Every station is sampled with an otter trawl to sample the demersal fishes, shrimp, and crabs, and a midwater trawl to sample pelagic fishes and gelatinous zooplankton (see the CDFW San Francisco Bay Study web page for additional information).

All SFBS surveys were completed in 2023. Four non-index stations for a total of eight tows were not sampled in 2023 due to a bridge closure and "geotechnical drill testing." A total of 640 OT and 640 MWT tows were conducted in 2023. This article will report Delta Smelt, Longfin Smelt, Striped Bass, American Shad, and Splittail detection through 2023. Additional information about study methods, including index calculation, can be found in IEP Technical Report 63 (Orsi 1999). See Hieb et al. (2019) for fish abundance and distribution trend information for other species through 2016.

Results and Discussion; 2023 Water Year and Fish Catch

2023 Water Year

Daily freshwater outflow (cfs) at Chipps Island and X2 location (km) estimates were obtained from the DWR DAYFLOW website (Dayflow - Datasets - California Natural Resources Agency Open Data). Data was available through water year 2023 (October–September) and net outflow per day was plotted to present the 2023 water year relative to the highly variable conditions since water year 2011 (Figure 4). X2 is the estimated distance in kilometers from the Golden Gate Bridge to location of 2 ppt salinity near bottom of the water column. Water year type classifications were provided by DWR (WSIHIST [ca.gov]).

Daily Delta water temperatures (°C) were queried from the DWR California Data Exchange Center (CDEC) website (CDEC Station Locator; Table 2). DWR CDEC stations for Antioch (ANH), Rio Vista Bridge (RVB), and Mossdale (MSD) were selected as historically used to inform Delta temperatures relative to Delta Smelt spawning conditions. The wet year of 2023 had fewer days above 22.0 C than the dry and critically dry period of 2020–2022.

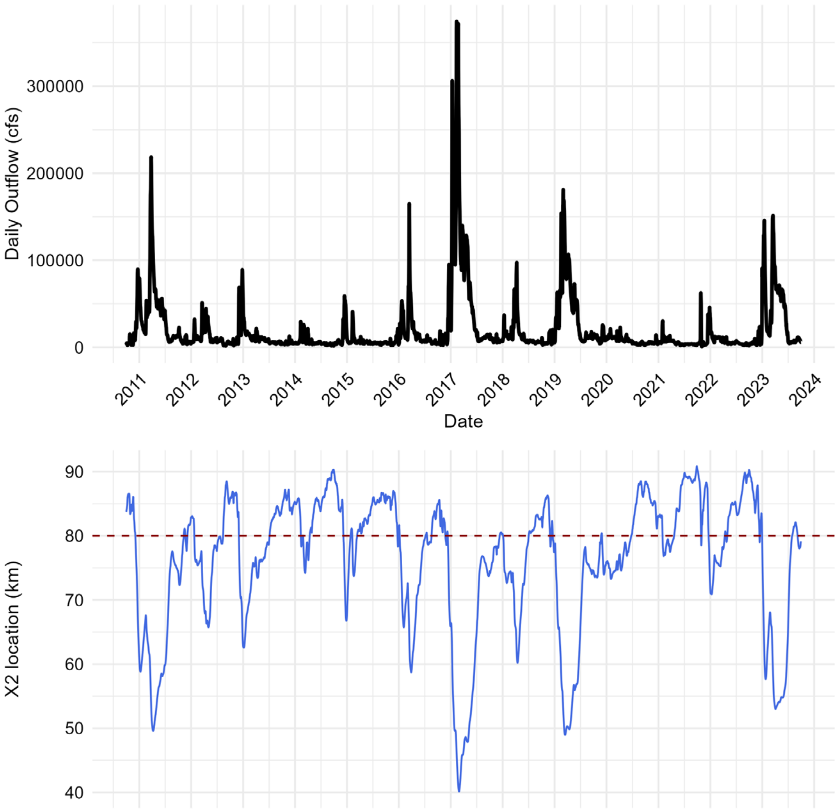
The 2023 water year brought much needed relief to the state of California with improved storage and flows in rivers. There was record snowpack, that in turn maintained consistent flows throughout summer months. The majority of the state's watersheds drain via the Sacramento and San Joaquin rivers into the upper Estuary. Increased Delta freshwater outflow aided in moving the Lower Salinity Zone into Suisun Bay, increasing spawning and rearing habitat for estuarine species. Also, this amount of water temporally and spatially expanded the inundation of riparian and wetland habitats for native species like Splittail, which use floodplains for spawning. Decreased water flow into the estuary can have complex impacts on fishes. In general, decreased flow can result in poor habitat conditions (e.g., increased temperatures, increase in harmful algal blooms, decreased habitat volumes, a more upstream location of the low salinity zone, lower primary and secondary productivity, etc.), which can negatively impact production and survival of young fish.

Delta Smelt

The state and federally listed (USFWS 1993; Tempel et al. 2021) Delta Smelt was collected by the SKT (n=4), SLS (n=4), 20-mm Survey (n=19), and STN (n=1) in 2023 among the CDFW surveys. The detection of this species was likely aided by the 3 years of multi-agency experimental hatchery releases of fish produced by the UC Davis Fish Conservation and Culture Laboratory. This year more than 90,000 hatchery origin fish were introduced into the system through multiple rounds of releases. The FMWT continued to observe no Delta Smelt, which were last captured by this survey in 2017. While SFBS has recaptured hatchery origin fish, this occurred outside of the index period.

Despite increased detection in 2023, a continued trend of severe population decline has been observed among several IEP monitoring programs. In 2023, only SKT produced a historical index value that was not 0. Abundance indices across the various long-term monitoring programs (Figures 5 and 6) show the continued reduced state of Delta Smelt abundance throughout the estuary. Delta Smelt are native osmerids and considered environmentally sensitive due to an annual life cycle, dependence on a spatially-limited oligohaline to freshwater habitat, and low fecundity (1,200 to 2,600 eggs per female on average; Moyle et al 1991). Adults migrate upstream into freshwater in the winter, and spawn in early spring. After hatching, larvae migrate downstream. Juveniles rear in low salinity habitat through the summer and fall. This low salinity rearing habitat is crucial to the species' success and the size and suitability of this environment is dependent on freshwater outflow. 2023 marked the first above average water year since 2019 (Figure 4). The previous three years experienced low freshwater outflow (Figure 4) and a greater frequency of days in the Delta with high-water temperatures (>22°C; Table 2) which are stressful conditions for the Delta Smelt population (Swanson et al. 2000). The increased freshwater outflow this year provided positive effects on multiple habitat metrics like temperature and salinity and served to reduce environmental stress on this struggling species.

Figure 4. Daily freshwater outflow estimates (cfs) at Chipps Island for water years 2011-2023, with associated mean daily X2 (km upstream of the Golden Gate Bridge) location plotted below. The horizontal red dashed line indicates the X2 location relevant to the Summer–Fall Habitat Action Plan (SFHA). In accordance with the 2020 DWR Incidental Take Permit and USFWS 2019 Biological Opinion for Delta Smelt, a required 30-day average of X2 to be less than or equal to 80 km for the months of September and October. Outflow and X2 data were provided by the Dayflow program (DWR 2024).



Longfin Smelt

Longfin Smelt in the Estuary are considered a distinct population segment and bolster the southernmost population of this species. Resident populations of this native anadromous osmerid have been declining in the estuary for decades. Fish typically migrate upstream to spawn in lower salinity habitat from November through May. Newly hatched larvae use the upper estuary for rearing and begin migrating downstream to more marine environments in the summer as inland temperatures increase. Fish will continue to rear in San Francisco Bay, as well as migrate into the Pacific Ocean. Adults are semelparous and in some cases can live longer than two years.

The 2023 FMWT Longfin Smelt (all ages) annual index was 464. This was an increase from the 2022 value, and the highest index value since 2011 (Figure 7). The majority (92%) of Longfin Smelt caught by FMWT in 2023 were age-0 fish. A similar trend occurred for SLS, where the 2023 design based abundance estimate increased from the 2022 value (Figure 8). This continues the slow increasing trend of FMWT and SLS Longfin Smelt indices since 2015 (Figures 7 and 8). However, abundance indices continue to be significantly lower than historic values.

The 2023 SFBS MWT age-0 Longfin Smelt index was 7,608, which was a decrease from 2022 (Figure 7). Although the SFBS MWT age-0 Longfin Smelt indices increased in recent years, values were still much lower than historic highs from the 1980s and early 1990s. The 2023 SFBS MWT age-1) index was 2,344, a decrease from 2022 (Figure 9), while the age-2+ index was 177 a significant increase from 2021 and 2022 (Figure 10). The 2023 SFBS OT age-0 Longfin Smelt index was 46,093, over four times the 2022 index (Figure 7). The 2023 OT age-1 index was 8,352, a decrease from the 2022 index (Figure 9) while the age-2+ index was 137, a slight decrease from 2022 (Figure 10). Overall, SFBS and FMWT Longfin Smelt indices continued a positive trend. The population was most likely bolstered by the above average water year, as well as the enhanced abiotic and biotic factors that are associated with increased outflow. However, indices continue to be much lower than historic survey highs (Figures 7 to 10).

Figure 5. Delta Smelt annual abundance indices from: 20-mm (1995–2023), Spring Kodiak Trawl (2002–2023), Summer Townet Survey (1959–2023), Fall Midwater Trawl (1967–2023), and San Francisco Bay Study Midwater Trawl (1980–2023). Note differences in the y-axis scales for each IEP survey.

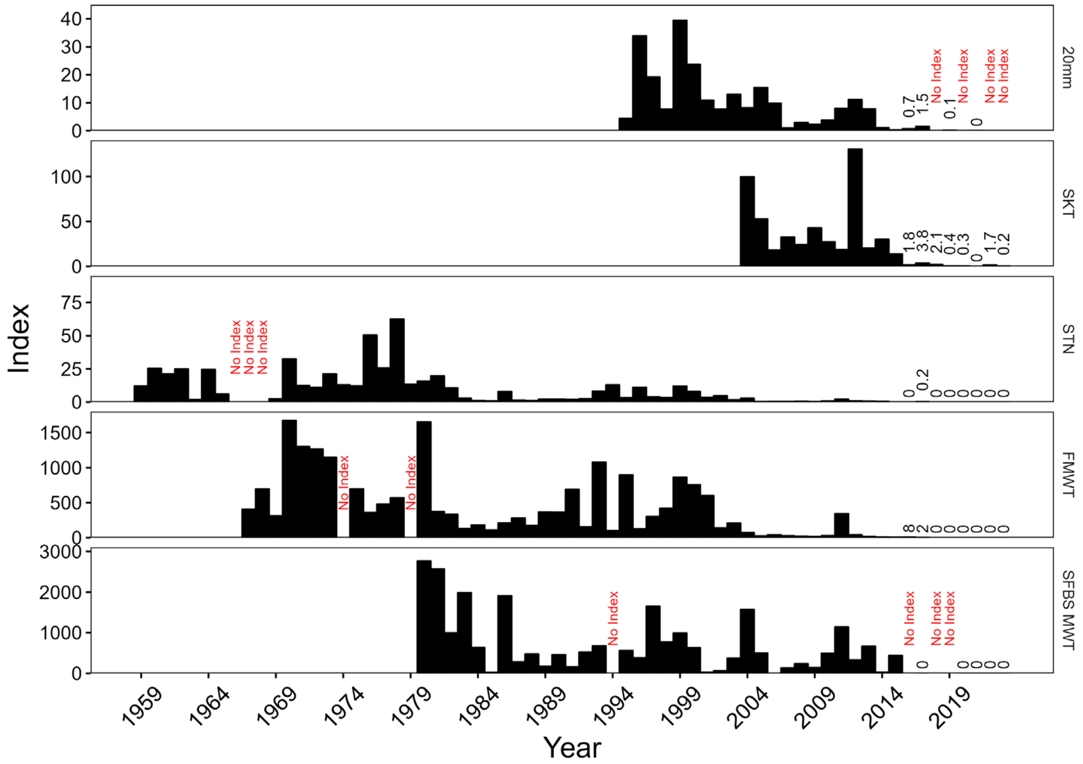


Figure 6. Smelt Larva Survey Delta Smelt design-based abundance indices. Delta wide abundance is plotted for survey years 2009–2023. Red points denote the abundance value for a given year, the grey ribbon indicates upper and lower confidence intervals.

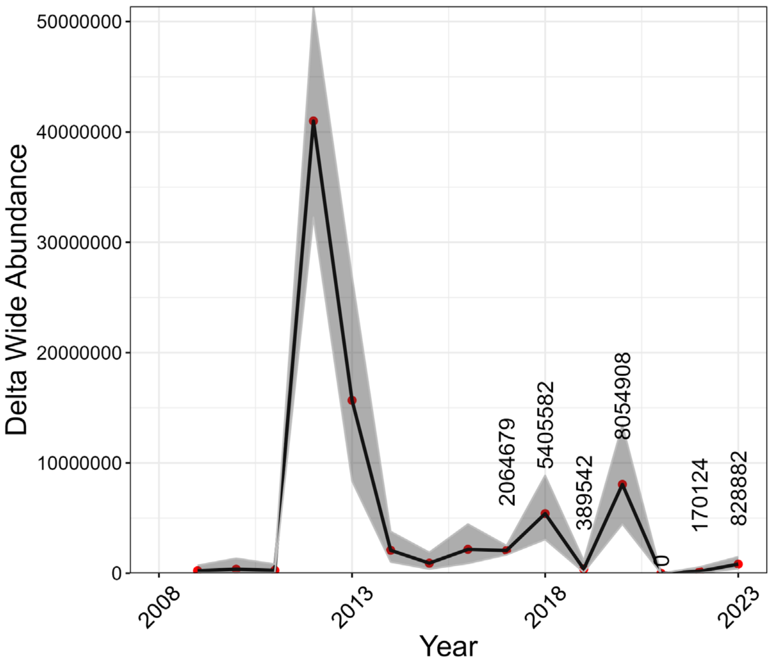


Figure 7. Longfin Smelt annual abundance indices from: Fall Midwater Trawl Survey (all ages,1967–2023), San Francisco Bay Study Otter Trawl (age-0, 1980–2023), San Francisco Bay Study Midwater Trawl (age-0, 1980–2023). Note differences in the y-axis scales for each IEP survey.

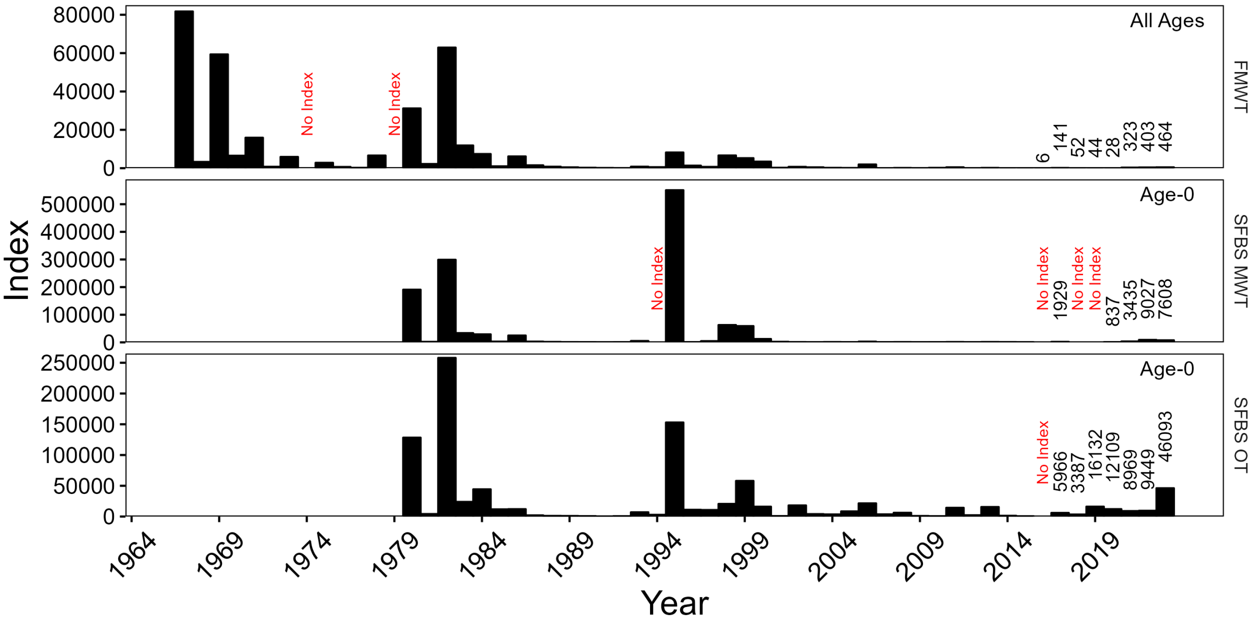


Figure 8. Smelt Larva Survey Longfin Smelt design-based abundance indices. Delta wide abundance is plotted for survey years 2009–2023. Red points denote the abundance value for a given year, the grey ribbon indicates upper and lower confidence intervals.

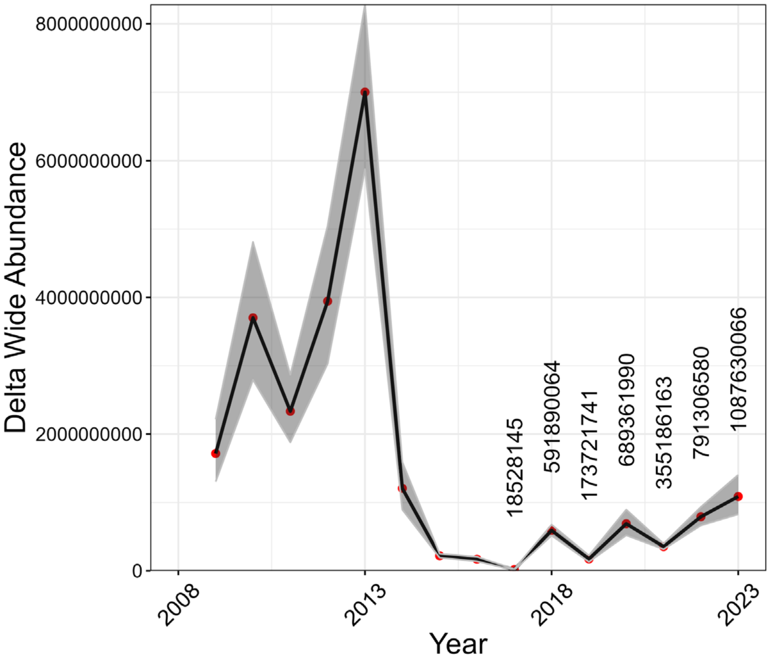


Figure 9. Longfin Smelt age-1 annual abundance indices from: San Francisco Bay Study Otter Trawl (1980–2023), San Francisco Bay Study Midwater Trawl (1980-2023). Note differences in the y-axis scales for each graph.

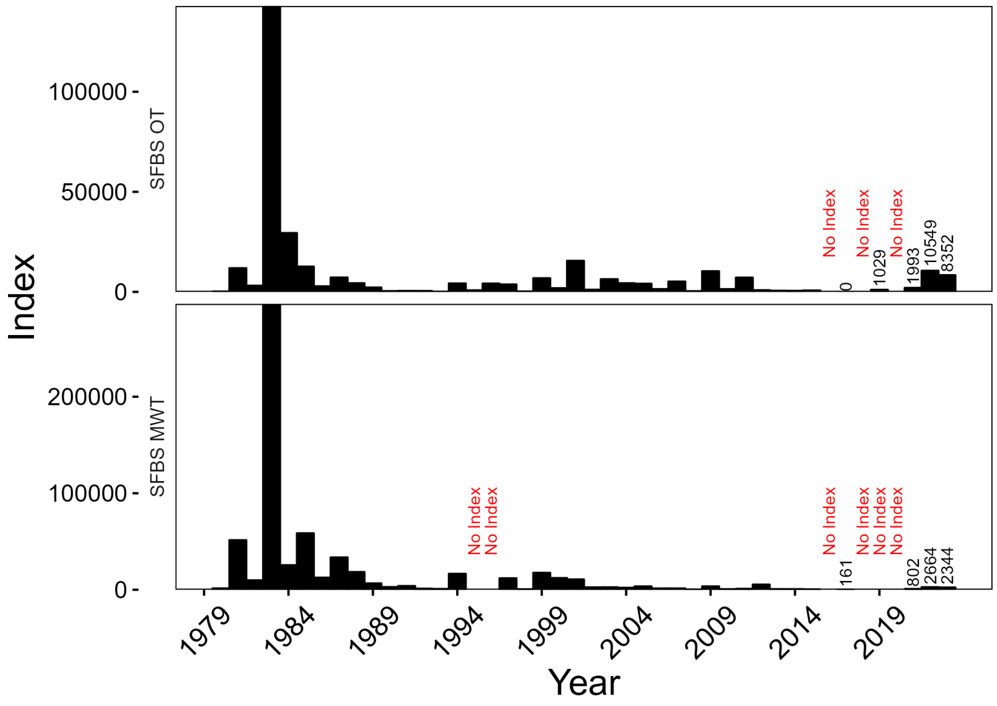
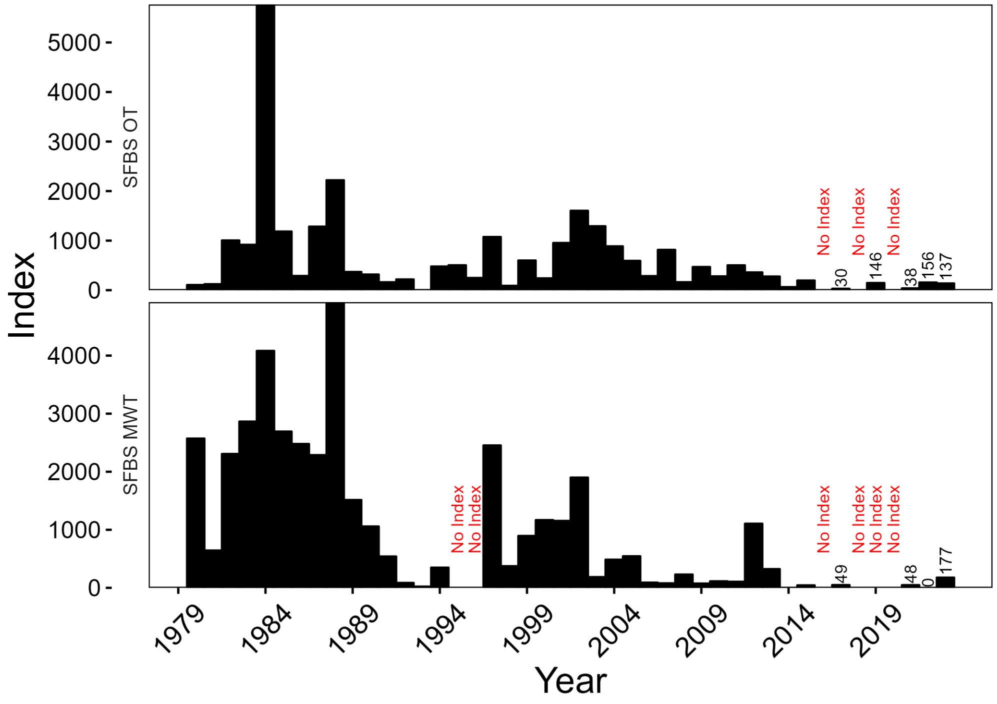


Figure 10. Longfin Smelt age-2 annual abundance indices from: San Francisco Bay Study Otter Trawl (1980–2023), San Francisco Bay Study Midwater Trawl (1980–2023). Note differences in the y-axis scales for each graph.



Splittail

Splittail is a large cyprinid endemic to central California that typically spawns and forages in shallower regions of the estuary, such as inundated floodplains and river margins (Sommer et al. 1997; Moyle et al. 2004). Capture of this species by FMWT and SFBS usually occurs during high water years, when increased precipitation promotes floodplain habitat inundation.

In 2023, FMWT captured a total of four Splittail at Montezuma Slough non-index stations. No Splittail were observed at index stations, leading to a 2023 FMWT index of 0. The 2023 SFBS MWT and OT age-0 Splittail abundance indices were 155 and 299, respectively (Figure 11); both were increases from 2020 to 2022, which had indices of 0.

Splittail spawn in the Sacramento, San Joaquin, Cosumnes, Napa, and Petaluma rivers' floodplains, as well as in Butte Creek and other small tributaries (Moyle et al. 2004; Feyrer et al. 2015) from March through May and the resulting larvae and small juveniles disperse downstream in late spring and summer. The outmigration of Splittail coincides with reduced river flows that decrease available backwater and edge-water habitats. FMWT and SFBS generally detect strong year classes, such as in 1998 and 2011, related to high outflow and long periods of floodplain inundation (Moyle et al. 2004). No Splittail collected by FMWT in 2023 was unexpected, while the SFBS age-0 indices were modest considering the high outflow.

American Shad

American Shad is native to the Atlantic Coast of North America and was introduced to the estuary in the 1800s (Dill and Cordone 1997). American Shad is anadromous, and adults return from the ocean to fresh water, especially the American and Feather rivers in spring to spawn. Juveniles are usually initially detected by surveys in summer and fall as they migrate to the ocean. The FMWT and SFBS MWT American Shad indices represented out-migrating juveniles.

The 2023 all ages FMWT index was 2,421, an over three times increase of the 2022 value, while the 2023 SFBS MWT age-0 index was 48,691, an over tenfold increase from 2022. These were the highest indices for both surveys since 2017 (Figure 12).

Threadfin Shad

Threadfin Shad is native to the Gulf Coast of North America and was introduced to California in the 1950s as food supply for other pelagic species (Dill and Cordone 1997). It spawns in freshwater during late spring and summer. Much like American Shad, Threadfin Shad has a high growth rate and is a prolific spawner.

The 2023 FMWT Threadfin Shad index was 515, double the value of the previous year (Figure 13). The FMWT Threadfin Shad index remained below historical values, similar to other pelagic fishes in the upper estuary.

Age-0 Striped Bass

The STN, FMWT, and SFBS (MWT and OT) age-0 Striped Bass indices saw increases in 2023 but continued a declining trend since the 1970s (Figure 14). The STN age-0 Striped Bass index was 1.4 and Striped Bass reached an average FL of 38.1 mm on August 2, 2023.The 2023 FMWT index increased as well, with a value of 266. FMWT non-index catch was relatively minor, with around 4% of the total catch coming from non-index stations in the Napa River, Sacramento Deep Water Shipping Channel, and Montezuma Slough. The 2023 SFBS MWT age-0 striped bass index increased to 3,550, over four times the 2022 index, while the 2023 SFBS OT index increased to 6,241, over five times the 2022 index.

Although age-0 Striped Bass abundance indices improved in 2023, most paled in comparison to historical values. Stevens et al. (1985) hypothesized that four factors may be responsible for the decreasing abundance of Striped Bass: 1) the adult population was too small to maintain adequate egg production; 2) planktonic food production has decreased to a point that is too low to sustain historic population levels; 3) loss to entrainment in water diversions; and 4) pollution in the form of pesticides, petrochemicals, and other toxic substances. More recently, Sommer et al. (2011) argued that age-0 Striped Bass distribution had shifted to shoal and shoreline areas from channels due to food availability, based on long term FMWT and SFBS catch comparisons between shoal and channel stations. This distributional trend is still supported by more recent data. However, Sommer et al. (2011) cautioned against attributing low values in Striped Bass abundance solely to a change in habitat use.

Conclusions

2023 was the first above-average water year the state had experienced since 2019. Beyond the "wet" water year of 2023, additional "summer-fall habitat" actions were conducted to benefit Delta Smelt habitat and food production, which benefited other pelagic fish rearing in the low salinity zone of the upper Estuary. Actions included Suisun Marsh Salinity Control Gate modified operations Aug 15–Oct 17 and also X2 at or below 80 km for September and October (USBR 2024). Abundant precipitation and by association, increased freshwater outflow served to temporarily revitalize the estuary from its depreciated drought-stricken status. Freshwater outflow is documented to have several effects on native and non-native fishes in the upper estuary, including timing and location of spawning, larval growth and survival, and juvenile residence. The 2023 increased outflow and actions shift X2 downstream in the summer-fall, thus increasing habitat quantity with size of the low salinity zone and increase habitat quality such as increased zooplankton as prey for young fish. Conversely, decreased outflow can lead

Figure 11. Splittail annual abundance indices from: Fall Midwater Trawl Survey (1967–2023), San Francisco Bay Study Otter Trawl (1980–2023), San Francisco Bay Study Midwater Trawl (1980–2023). Note differences in the y-axis scales for each IEP survey.

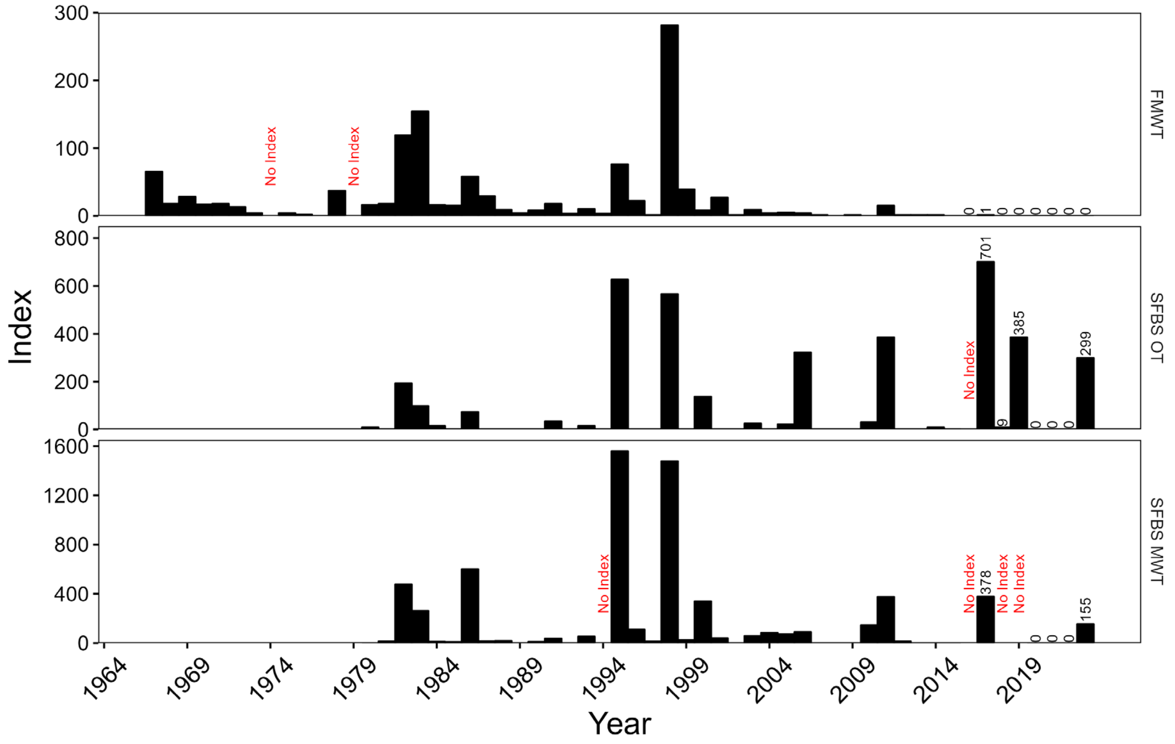


Figure 12. American Shad annual abundance indices from: Fall Midwater Trawl Survey (all ages, 1967–2023), San Francisco Bay Study Midwater Trawl (age-0, 1980–2023). Note differences in the y-axis scales for each IEP survey.

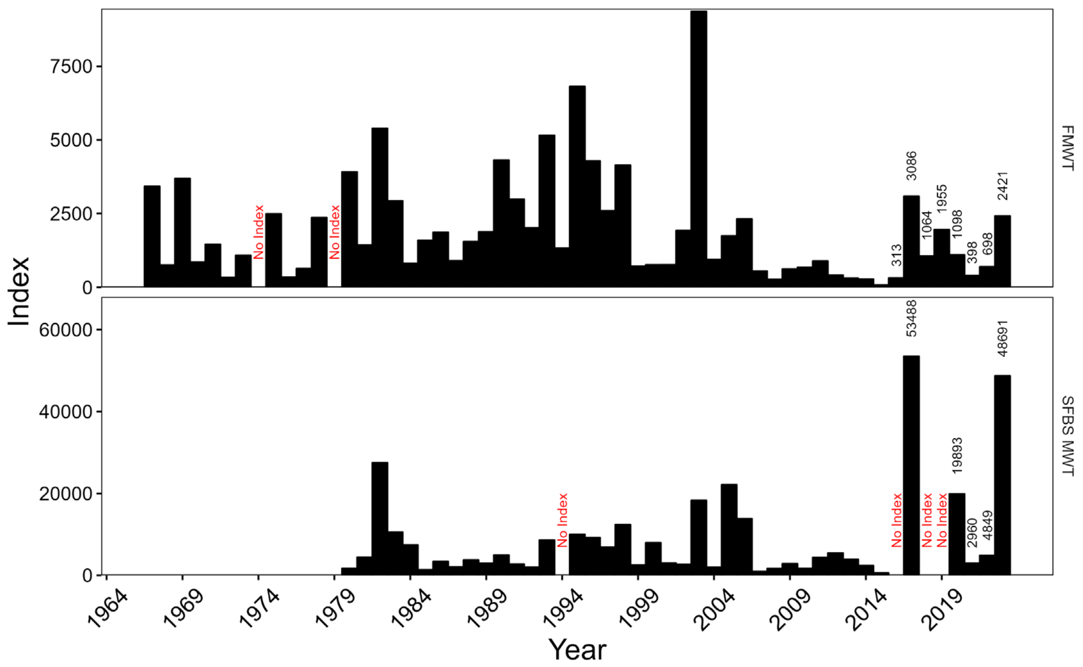


Figure 13. Threadfin Shad annual abundance indices from: Fall Midwater Trawl Survey (all ages, 1967–2023).

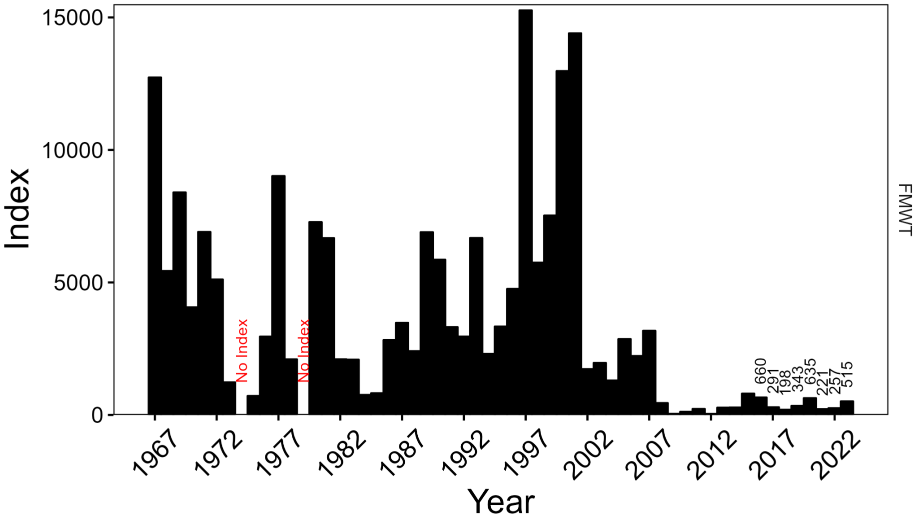
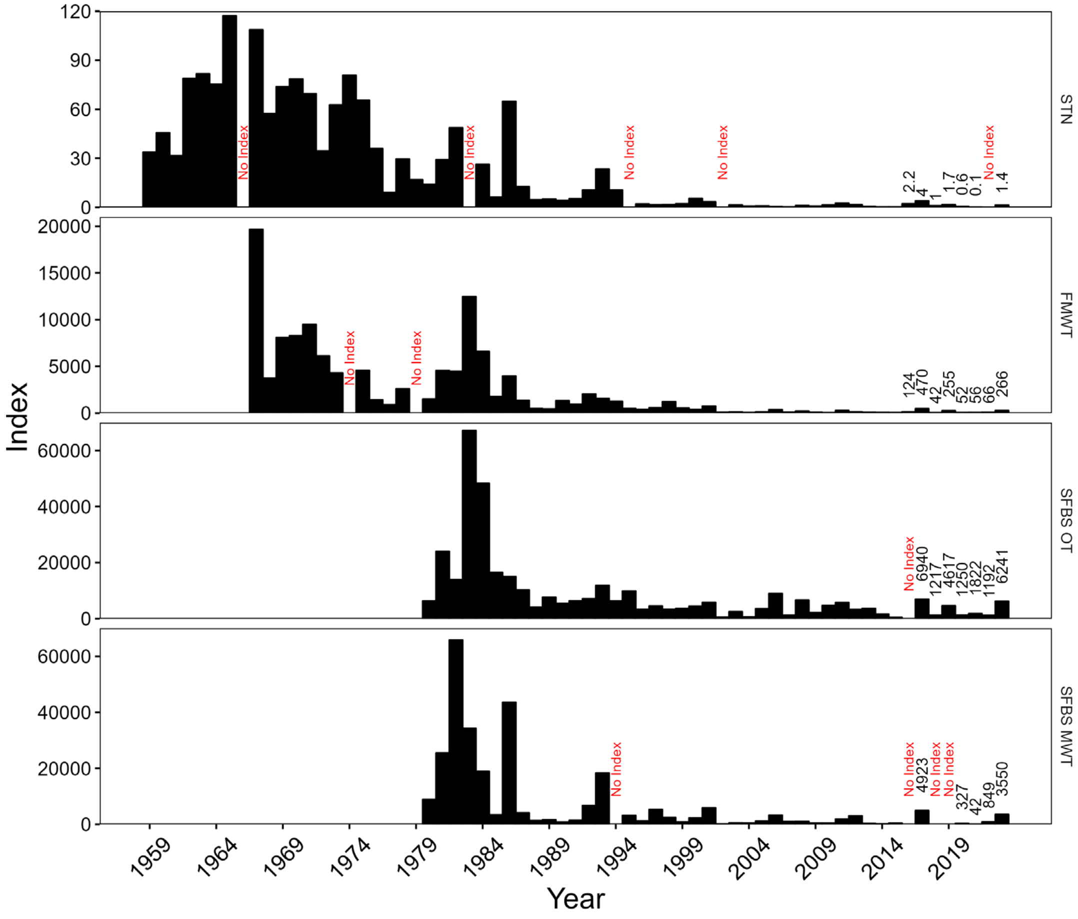


Figure 14. Age-0 Striped Bass annual abundance indices from: Summer Townet Survey (1959–2023), Fall Midwater Trawl Survey (1967–2023), San Francisco Bay Study Otter Trawl (1980–2023), San Francisco Bay Study Midwater Trawl (1980–2023). Note differences in the y-axis scales for each IEP survey



to greater salinity intrusion and shifting preferred brackish and freshwater habitats of fishes relative to fixed stations in the Delta.

In 2023 there were notable abundance index increases for several pelagic species across multiple gear types, however there were still some declines despite the above average water year. Delta Smelt indices continued a negative trend across all surveys. SKT generated an index for Delta Smelt, but it was still a decrease from the 2022 value. SLS saw a marginal increase in its Delta Smelt design-based abundance index. Longfin Smelt indices increased for FMWT (all ages), SFBS MWT (age-2+), SFBS OT (age-0), and SLS (age-0. Longfin Smelt indices decreased for SFBS MWT (age-0, age-1) and SFBS OT (age-1, age-2+). Splittail indices decreased across FMWT but increased for both SFBS MWT and SFBS OT. American Shad indices increased for FMWT and SFBS MWT. Likewise, Threadfin Shad indices also increased for FMWT. Age-0 Striped Bass indices also increased for STN, FMWT, SFBS MWT and SFBS OT.

There was generally an increase of abundance across species and surveys in 2023. The main exception was Delta Smelt, which continued to have very low abundance, despite experimental supplementation. For more information on CDFW surveys, including indices, catch values, length frequency and access to the various datasets discussed above visit: CDFW Bay-Delta Surveys. In addition, you may contact Taylor.Rohlin@wildlife.ca.gov for more information.

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DATA REPORT

Representation of Fish Species by Life Stage Amongst IEP Surveys

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Introduction

The San Francisco Estuary (Estuary) is a highly altered ecosystem consisting of two main freshwater inputs (Sacramento and San Joaquin rivers), a channelized Delta of sloughs and flooded islands, a highly productive transitional marsh and bay (Suisun), and several partially or fully marine bays terminating at the Golden Gate. Multiple large facilities export a percentage of freshwater inflow from the southern portion of the Delta for agricultural and municipal use. To measure the ecological effects of these exports and other water management actions, fish monitoring programs were established by natural resource agencies and university groups, the oldest of which has existed since 1959. Since 1970, these programs have operated under the umbrella of the Interagency Ecological Program (IEP), a consortium of signatory agencies with the goal of providing scientific information to the scientific community, water managers, and the public.

In general, the gear and seasonality of IEP fish surveys were selected to target specific species and life stages of fish, with two notable exceptions (San Francisco Bay Study, Suisun Marsh Fish Study). Despite the targeted nature of most of these surveys, they all recorded catch of all fish species and all or a subset of fish have been measured for at least a portion of each survey's lifespan. As such, non-target species and the greater assemblage of fishes can be tracked using data from IEP surveys, albeit at some unknown level of capture efficiency.

The utility of analyzing trends of non-target species in IEP fish surveys was investigated and visualized in Stompe et al. (2020), where they developed a scoring system for determining the relative ability of each IEP fish survey to represent trends in individual species abundance. This method has proven useful as a means for quickly assessing surveys when determining which monitoring programs should be included when analyzing trends for a given species, especially when that species is not the primary subject of monitoring. However, Stompe et al. (2020) did not include information on life stage, complicating the interpretation of scores where survey gear preferentially captures a given life stage. In this paper, we expand on the work of Stompe et al. (2020) by generating scoring for both juvenile and adult life stages of 36 prominent Delta fish species, as well as adding the new US Fish and Wildlife Service Delta Boat Electrofishing Survey.

The goal of this paper is to provide life stage-specific catch information about species for the 14 long-term surveys investigated in Stompe et al. (2020). We also broaden the analyses to include the USFWS Electrofishing Survey. To accomplish this goal, our specific objectives are to: (1) review the literature to determine juvenile-to-adult transitions according to body length, (2) compile conversion formulas to estimate different body length measurements (i.e., total length [TL], standard length [SL], fork length [FL]), (3) compute species survey ratings for juvenile and adult fishes, and (4) compute mean species survey ratings according to survey type (i.e., midwater or Kodiak trawl, otter trawl, beach seine, electrofishing) and habitat association (i.e., benthic, fringe, pelagic, and submersed aquatic vegetation [SAV]).

Methods

Length cutoffs between juvenile and adult size classes for the 36 Delta fish species included in Stompe et al. (2020) were sourced primarily from Moyle (2002), but also from Froese et al. (2024; Common Carp, Threespine Stickleback, American Shad, Delta Smelt, Longfin Smelt) and from Johnson (1971; Threadfin Shad; see Appendix, Table A1). Transition from juvenile to adult was defined as the length at which a given species became sexually mature, and typically included a minimum and maximum value. For the purpose of this paper, we chose to use the midpoint between the reported minimum and maximum length at maturity values as the cutoff between juveniles and adults (Appendix Table A1).

Length at maturity values were frequently reported using different measuring methods, namely TL, FL, and SL. To ease downstream analysis, all length at maturity cutoffs were converted to FL for fishes with forked, heart-shaped, or heterocercal caudal fins or TL for fishes with square or rounded caudal fins. Length conversions between TL, FL, and SL were sourced from Froese et al. (2024) and Gaeta (2023) for all species except for Bigscale Logperch, for which we generated a length conversion using morphometric analysis of an image of a single individual captured on the Stanislaus River in 2008 (Appendix Figure A1). The length conversions are presented in the Appendix (Appendix Tables A2, A3).

Survey data were sourced from the DeltaFish integrated dataset (Clark and Bashevkin 2022) and from the US Fish and Wildlife Service (USFWS) Delta Boat Electrofishing Survey (IEP et al. 2024). The 'DeltaFish' dataset includes data from the California Department of Fish and Wildlife (CDFW) Summer Townet Survey, the CDFW Fall Midwater Trawl, the CDFW San Francisco Bay Study (Otter and Midwater Trawl), the CDFW 20mm Trawl, the CDFW Spring Kodiak Trawl, the CDFW Smelt Larval Survey, the USFWS Mossdale Trawl, the USFWS Sacramento Trawl (Midwater and Kodiak Trawl), the USFWS Chipps Island Trawl, the USFWS Beach Seine Survey, the USFWS Enhanced Delta Smelt Monitoring Program, and the UC Davis Suisun Marsh Fish Study. Data from the Delta Boat Electrofishing Survey were included through 2023 and data from 'DeltaFish' were included through 2021 as these were the most updated versions of each data source at the time of analysis. The CDFW Fall Midwater Trawl and Summer Townet surveys were filtered to the years 1976–2021 and 1974–2021, respectively, as fish lengths were not recorded for most species caught in these surveys prior to these years. All other sampling events, including samples collected at both core (index) and non-core survey stations, and during normal and supplemental survey periods, were included to maximize comparability with Stompe et al. (2020). In addition, the inclusion of all sampled stations also better conveys information on species detections, providing a resource for researchers and managers interested in species distribution, including across seasons. However, considering the substantial differences in sampling gear among surveys, the duration of the sampling programs, the variety and number of sampling locations, and the timing of the surveys each year, this analysis may have certain limitations.

The methods used in our analysis closely followed those outlined in Stompe et al. (2020). We applied a species-survey rating score to each combination of survey, species, and life stage using the equation:

$$R^2 = \frac{f_{sp,a}}{n} \sqrt[3]{\frac{T_c}{M_c}}$$

Where R represents the species-survey rating, f_(sp,a) is the number of years in which a given species age class was caught in the survey, n is the total number of years in which a survey has operated, T_c is the total catch of a given species age class over the life of the survey, and M_c is the total catch of the most caught species age class over the life of the survey. In this equation, the most frequently contacted species age class receives a score of 1, species age classes never contacted by the survey receive a score of 0, and all other species age classes are assigned a score between 0 and 1 based on the annual frequency and total catch for a given survey. Scores were tabulated and conditionally formatted so that scores of 1 are assigned a green color and scores of 0 are white, with decreasing opacity as a score increases. We summarize species survey ratings by presenting (1) the overall mean R value for each survey and (2) the overall mean R values for each survey-life history stage-habitat association combination.

Results and Discussion

Our findings are consistent with expectations based on gear selectivity and other constraints: (1) juvenile fishes are generally better represented than adults in the 14 long-term monitoring programs investigated by Stompe et al. (2020) (Figure 1), (2) juvenile and adult fishes are represented approximately equally in the USFWS electrofishing program (Figure 1), and (3) electrofishing appears to be better suited for sampling SAV-associated fishes than either trawl- or seine-based surveys (Table 3).

In the context of species detection, there were considerably more instances of zero catch over the life of a survey (R = 0) for adults (161; Table 1) than for juveniles (73; Table 2). Likewise, mean R values were almost universally higher for juveniles than for adults (Figure 1). These results are likely driven by the gear specific selectivity, relative densities, and behavior of adult fishes in relation to juveniles. For example, adults are more likely to avoid trawl or seine gear, are inherently less abundant than juveniles of the same species and may move into other environments not sampled by IEP surveys (e.g., Chinook Salmon in the Pacific Ocean).

Unlike the other surveys, juveniles and adults are represented approximately equally in the USFWS Delta Boat Electrofishing survey (Figures 1, 2). As with the trawl- and seine-based surveys, this is likely driven by differences in the selectivity of this gear type. Large-bodied fishes are generally more susceptible to electric currents (McKenzie and Mahardja 2021) and are easier for field staff visually identify and net, lending to their better representation in these data. Despite the inherently higher densities of juvenile fishes in the Delta, the increased efficiency of this survey likely explains the nearly equal representation of life stages.

When Species Survey Ratings are averaged according to survey type, habitat associations, and life history stage, the USFWS Electrofishing Program ranks highest for juvenile and adult SAV-associated fishes, adult benthic-associated fishes, and adult fringe-associated fishes (Table 3). The CDFW SF Bay Study Otter Trawl ranks highest for juvenile benthic-associated fishes and the USFWS Beach Seine Survey ranks highest for juvenile fringe-associated fishes. The CDFW SF Bay Study Midwater Trawl and USFWS Chipps Island Midwater Trawl ranks highest for juvenile and adult pelagic-associated fishes, respectively (Table 3). These results are unsurprising given the design and original intention of these surveys; however, they may be useful for managers and researchers hoping to investigate assemblages or individual species but who are unfamiliar with the intricacies of IEP surveys. They also demonstrate the generally poor representation or lower abundance of adult fishes available to the benthic, pelagic, and fringe sampling gear of the current IEP monitoring.

This analysis contributes another tool for distinguishing between the numerous surveys of the IEP, streamlining survey selection, and increasing the utility of surveys for scientists and managers. We hope that the evaluations presented here, in addition to the length conversion formulas and juvenile-to-adult life history transition information (see Appendix), will benefit future research and help inform management decisions.

Acknowledgements

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Figure 1. Mean species-survey ratings ('R'; see text for details) for each of the 15 long-term monitoring surveys, broken down by life history stage. Mean R values for juveniles (solid bars) and adults (open bars) are to the right and left of the zero-axis point, respectively.

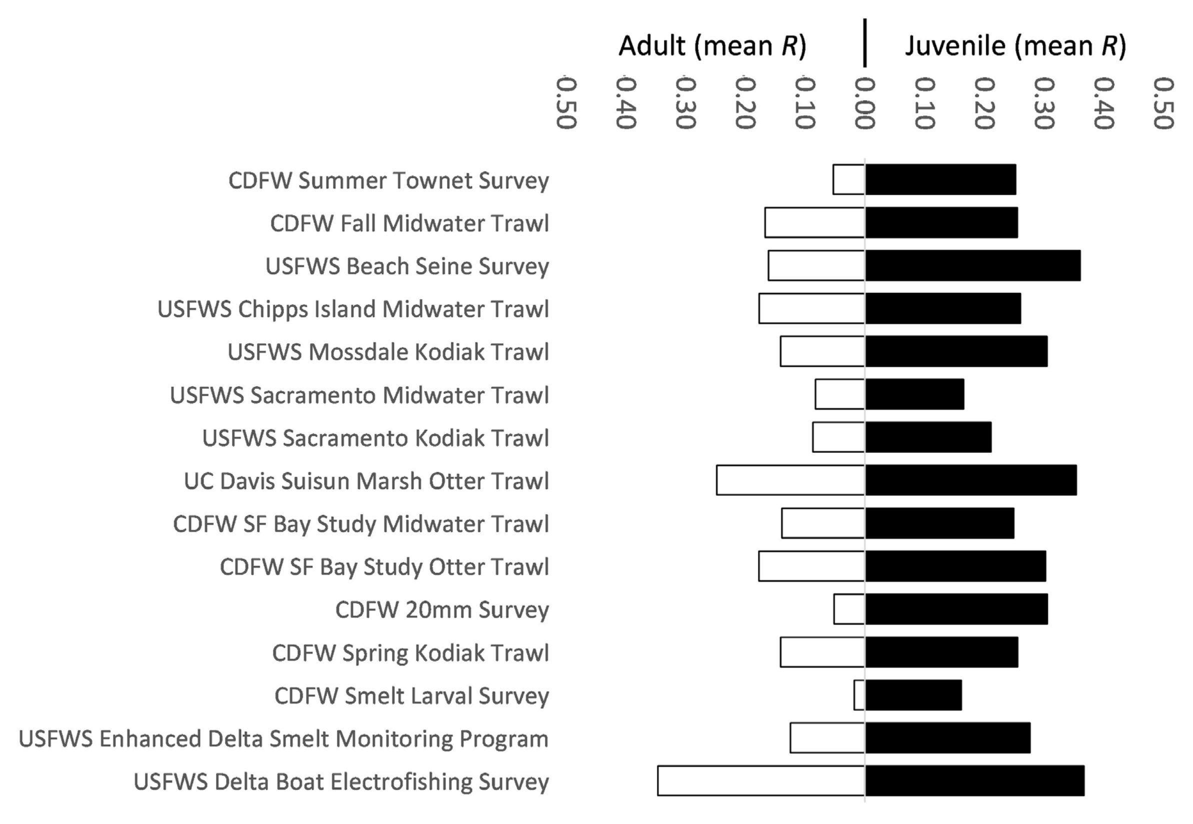

Figure 2. Mean species-survey ratings ('R'; see text for details) for 14 long-term monitoring surveys investigated by Stompe et al. (2020) plus the USFWS electrofishing survey, broken down by habitat association and life history stage.

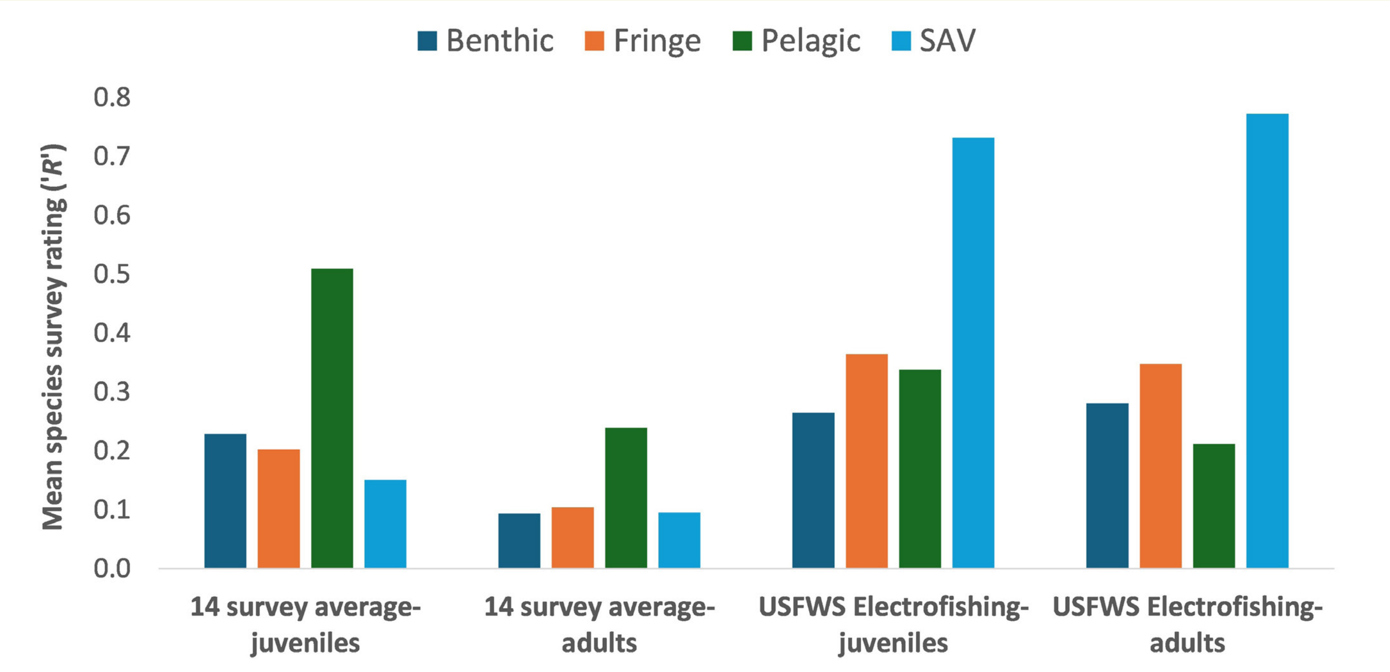

Table 1. Calculated species-survey ratings ('R'; see text for details) for the juvenile life history stage of 36 commonly encountered Delta fish species across 15 long-term surveys. Asterisks and daggers following the common name indicate that the species is listed under the Federal and State Endangered Species Acts, respectively.

Common Name	Habitat association	Native	Anadromous	Salt tolerance	CDFW Summer Townet Survey	CDFW Fall Midwater Trawl	USFWS Beach Seine Survey	USFWS Chipps Island Midwater Trawl	USFWS Mossdale Kodiak Trawl	USFWS Sacramento Midwater Trawl	USFWS Sacramen-to Kodiak Trawl	UC Davis Suisun Marsh Otter Trawl	CDFW SF Bay Study Midwater Trawl	CDFW SF Bay Study Otter Trawl	CDFW 20mm Survey	CDFW Spring Kodiak Trawl	CDFW Smelt Larval Survey	USFWS Enhanced Delta Smelt Monitoring Program	USFWS Delta Boat Electrofishing Survey
Bigscale Logperch	Benthic	N	N	Low	0.09	0.03	0.45	0.02	0.29	0.00	0.04	0.11	0.00	0.39	0.32	0.07	0.30	0.23	0.41
Black Bullhead	Benthic	N	N	Med	0.00	0.00	0.11	0.00	0.07	0.03	0.07	0.33	0.00	0.00	0.03	0.00	0.04	0.05	0.22
Channel Catfish	Benthic	N	N	Med	0.45	0.30	0.17	0.12	0.35	0.22	0.27	0.30	0.23	0.62	0.47	0.06	0.08	0.16	0.19
Green Sturgeon*	Benthic	Y	Y	High	0.02	0.10	0.00	0.07	0.00	0.00	0.00	0.04	0.10	0.28	0.00	0.00	0.00	0.00	0.00
Pacific lamprey	Benthic	Y	Y	High	0.07	0.12	0.08	0.18	0.24	0.22	0.50	0.17	0.10	0.39	0.11	0.24	0.00	0.20	0.09
Pacific Staghorn Sculpin	Benthic	Y	N	High	0.18	0.33	0.41	0.26	0.26	0.00	0.00	0.55	0.47	0.95	0.30	0.16	0.34	0.13	0.11
Prickly Sculpin	Benthic	Y	N	High	0.13	0.03	0.30	0.08	0.24	0.00	0.00	0.69	0.09	0.35	0.59	0.09	1.00	0.28	0.46
Sacramento Sucker	Benthic	Y	N	Med	0.03	0.02	0.74	0.06	0.43	0.14	0.13	0.51	0.00	0.00	0.33	0.00	0.16	0.16	0.38
Shimofuri goby	Benthic	N	N	High	0.38	0.20	0.26	0.11	0.19	0.00	0.00	0.59	0.11	0.45	0.54	0.14	0.07	0.22	0.35
White Catfish	Benthic	N	N	Med	0.64	0.46	0.20	0.17	0.28	0.27	0.20	0.57	0.33	0.67	0.53	0.16	0.26	0.19	0.37
White Sturgeon	Benthic	Y	Y	High	0.06	0.35	0.00	0.27	0.00	0.00	0.00	0.28	0.37	0.48	0.24	0.10	0.08	0.08	0.00
Yellowfin goby	Benthic	N	N	High	0.61	0.49	0.49	0.41	0.35	0.03	0.03	0.76	0.62	0.83	0.82	0.24	0.92	0.34	0.59
Black Crappie	Fringe	N	N	Low	0.12	0.13	0.32	0.13	0.23	0.14	0.28	0.46	0.07	0.04	0.12	0.18	0.00	0.28	0.45
Common Carp	Fringe	N	N	Med	0.18	0.12	0.36	0.17	0.50	0.18	0.27	0.57	0.16	0.14	0.31	0.15	0.05	0.18	0.53
Goldfish	Fringe	N	N	Med	0.13	0.04	0.27	0.09	0.18	0.08	0.26	0.29	0.02	0.04	0.10	0.04	0.00	0.00	0.19
Hitch	Fringe	Y	N	Med	0.02	0.08	0.37	0.06	0.19	0.07	0.12	0.25	0.00	0.03	0.02	0.20	0.00	0.19	0.60
Mississippi Silversides	Fringe	N	N	Med	0.50	0.33	1.00	0.15	0.98	0.23	0.64	0.50	0.14	0.07	0.40	0.75	0.11	0.71	0.82
Sacramento Blackfish	Fringe	Y	N	Med	0.00	0.07	0.20	0.11	0.19	0.05	0.07	0.12	0.02	0.00	0.08	0.06	0.00	0.00	0.11
Sacramento Pikeminnow	Fringe	Y	N	Med	0.02	0.13	0.62	0.24	0.37	0.32	0.47	0.26	0.09	0.12	0.04	0.33	0.00	0.21	0.55
Sacramento Splittail	Fringe	Y	N	Med	0.43	0.39	0.68	0.57	0.75	0.32	0.11	0.81	0.47	0.46	0.38	0.46	0.09	0.34	0.00
Spotted Bass	Fringe	N	N	Low	0.00	0.03	0.26	0.03	0.18	0.07	0.09	0.00	0.00	0.03	0.05	0.07	0.04	0.11	0.43
Threespine Stickleback	Fringe	Y	N	High	0.46	0.26	0.35	0.37	0.24	0.02	0.13	0.73	0.45	0.40	0.47	0.60	0.31	0.38	0.00
Tule Perch	Fringe	Y	N	Med	0.16	0.08	0.39	0.28	0.35	0.19	0.10	0.63	0.12	0.26	0.14	0.15	0.00	0.14	0.40
Warmouth	Fringe	N	N	Low	0.00	0.00	0.11	0.13	0.03	0.04	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.51
Western Mosquitofish	Fringe	N	N	High	0.03	0.00	0.40	0.00	0.36	0.02	0.03	0.00	0.00	0.00	0.14	0.00	0.06	0.12	0.15
American Shad	Pelagic	N	Y	High	0.63	0.96	0.39	1.00	0.38	0.67	0.44	0.52	0.95	0.55	0.49	0.72	0.04	0.84	0.46
Chinook Salmon*†	Pelagic	Y	Y	High	0.23	0.46	0.82	0.93	0.67	1.00	1.00	0.20	0.68	0.34	0.29	0.78	0.15	0.43	0.57
Delta Smelt*†	Pelagic	Y	N	Med	0.74	0.59	0.26	0.56	0.15	0.06	0.03	0.25	0.51	0.40	0.59	0.55	0.36	0.40	0.00
Longfin Smelt†	Pelagic	Y	N	High	0.66	0.89	0.17	0.68	0.05	0.04	0.03	0.68	1.00	1.00	1.00	0.65	0.93	0.42	0.10
steelhead/Rainbow trout*	Pelagic	Y	Y	High	0.02	0.21	0.36	0.44	0.20	0.43	0.52	0.03	0.25	0.03	0.00	0.51	0.00	0.27	0.25
Striped Bass	Pelagic	N	Y	High	1.00	0.89	0.46	0.80	0.48	0.41	0.16	1.00	0.88	1.00	0.89	0.43	0.19	0.63	0.56
Threadfin Shad	Pelagic	N	N	Med	0.78	0.70	0.53	0.33	0.57	0.33	0.39	0.40	0.50	0.24	0.81	0.63	0.05	1.00	0.43
Bluegill	SAV	N	N	Low	0.15	0.21	0.44	0.23	0.45	0.14	0.39	0.09	0.10	0.12	0.16	0.37	0.15	0.45	1.00
Green Sunfish	SAV	N	N	Low	0.02	0.03	0.15	0.07	0.11	0.06	0.18	0.04	0.04	0.00	0.00	0.00	0.00	0.09	0.09
Largemouth Bass	SAV	N	N	Low	0.16	0.09	0.48	0.18	0.36	0.09	0.21	0.00	0.07	0.08	0.20	0.20	0.00	0.30	0.96
Redear Sunfish	SAV	N	N	Low	0.00	0.05	0.41	0.10	0.30	0.05	0.25	0.00	0.02	0.14	0.02	0.12	0.04	0.31	0.88

Table 2. Calculated species-survey ratings ('R'; see text for details) for the adult life history stage of 36 commonly encountered Delta fish species across 15 long-term surveys. Asterisks and daggers following the common name indicate that the species is listed under the Federal and State Endangered Species Acts, respectively.

Common Name	Habitat association	Native	Anadromous	Salt tolerance	CDFW Summer Townet Survey	CDFW Fall Midwater Trawl	USFWS Beach Seine Survey	USFWS Chipps Island Midwater Trawl	USFWS Mossdale Kodiak Trawl	USFWS Sacramento Midwater Trawl	USFWS Sacramento Kodiak Trawl	UC Davis Suisun Marsh Otter Trawl	CDFW SF Bay Study Midwater Trawl	CDFW SF Bay Study Otter Trawl	CDFW 20mm Survey	CDFW Spring Kodiak Trawl	CDFW Smelt Larval Survey	USFWS Enhanced Delta Smelt Monitoring Program	USFWS Delta Boat Electrofishing Survey
Bigscale Logperch	Benthic	N	N	Low	0.00	0.02	0.22	0.00	0.13	0.05	0.00	0.00	0.02	0.19	0.02	0.00	0.00	0.00	0.35
Black Bullhead	Benthic	N	N	Med	0.00	0.00	0.02	0.02	0.04	0.00	0.03	0.31	0.02	0.03	0.02	0.00	0.00	0.05	0.40
Channel Catfish	Benthic	N	N	Med	0.00	0.12	0.06	0.07	0.12	0.05	0.03	0.07	0.05	0.17	0.02	0.00	0.00	0.00	0.20
Green Sturgeon*	Benthic	Y	Y	High	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Pacific lamprey	Benthic	Y	Y	High	0.03	0.02	0.00	0.12	0.03	0.05	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.05	0.00
Pacific Staghorn Sculpin	Benthic	Y	N	High	0.00	0.15	0.07	0.04	0.00	0.00	0.00	0.17	0.24	0.63	0.02	0.04	0.00	0.00	0.00
Prickly Sculpin	Benthic	Y	N	High	0.06	0.09	0.23	0.10	0.14	0.00	0.00	0.57	0.02	0.32	0.11	0.08	0.00	0.11	0.57
Sacramento Sucker	Benthic	Y	N	Med	0.00	0.04	0.12	0.08	0.10	0.04	0.00	0.51	0.02	0.04	0.00	0.00	0.00	0.05	0.57
Shimofuri goby	Benthic	N	N	High	0.17	0.24	0.25	0.25	0.22	0.00	0.00	0.51	0.32	0.49	0.28	0.30	0.19	0.26	0.49
White Catfish	Benthic	N	N	Med	0.16	0.42	0.09	0.17	0.21	0.19	0.13	0.50	0.20	0.33	0.21	0.14	0.07	0.13	0.44
White Sturgeon	Benthic	Y	Y	High	0.00	0.04	0.00	0.08	0.00	0.00	0.00	0.08	0.12	0.15	0.00	0.00	0.00	0.00	0.00
Yellowfin goby	Benthic	N	N	High	0.02	0.24	0.14	0.17	0.07	0.02	0.03	0.42	0.29	0.51	0.09	0.08	0.06	0.10	0.35
Black Crappie	Fringe	N	N	Low	0.07	0.08	0.18	0.09	0.15	0.06	0.09	0.35	0.00	0.03	0.08	0.06	0.00	0.15	0.47
Common Carp	Fringe	N	N	Med	0.03	0.21	0.16	0.23	0.20	0.14	0.03	0.55	0.12	0.20	0.00	0.06	0.00	0.06	0.47
Goldfish	Fringe	N	N	Med	0.00	0.00	0.04	0.03	0.10	0.04	0.03	0.26	0.00	0.03	0.00	0.00	0.00	0.00	0.21
Hitch	Fringe	Y	N	Med	0.00	0.07	0.04	0.08	0.04	0.00	0.00	0.07	0.02	0.03	0.00	0.11	0.00	0.17	0.41
Mississippi Silversides	Fringe	N	N	Med	0.09	0.18	0.55	0.12	0.56	0.10	0.39	0.14	0.05	0.00	0.07	0.61	0.00	0.39	0.54
Sacramento Blackfish	Fringe	Y	N	Med	0.00	0.08	0.02	0.09	0.07	0.05	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sacramento Pikeminnow	Fringe	Y	N	Med	0.00	0.07	0.15	0.10	0.07	0.07	0.04	0.21	0.00	0.08	0.00	0.04	0.00	0.00	0.48
Sacramento Splittail	Fringe	Y	N	Med	0.04	0.32	0.08	0.48	0.16	0.23	0.19	0.74	0.38	0.38	0.06	0.41	0.00	0.17	0.00
Spotted Bass	Fringe	N	N	Low	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Threespine Stickleback	Fringe	Y	N	High	0.05	0.03	0.07	0.12	0.00	0.00	0.00	0.45	0.08	0.05	0.00	0.09	0.00	0.05	0.00
Tule Perch	Fringe	Y	N	Med	0.03	0.17	0.30	0.24	0.25	0.13	0.15	0.75	0.09	0.50	0.05	0.00	0.00	0.16	0.60
Warmouth	Fringe	N	N	Low	0.00	0.02	0.09	0.05	0.03	0.02	0.08	0.02	0.00	0.00	0.00	0.00	0.00	0.06	0.61
Western Mosquitofish	Fringe	N	N	High	0.09	0.05	0.56	0.10	0.48	0.04	0.12	0.13	0.00	0.08	0.04	0.14	0.06	0.21	0.40
American Shad	Pelagic	N	Y	High	0.00	0.09	0.00	0.21	0.02	0.18	0.00	0.02	0.04	0.03	0.00	0.00	0.00	0.00	0.00
Chinook Salmon*†	Pelagic	Y	Y	High	0.02	0.23	0.04	0.19	0.03	0.07	0.06	0.00	0.21	0.00	0.02	0.00	0.00	0.05	0.14
Delta Smelt*†	Pelagic	Y	N	Med	0.38	0.61	0.35	0.63	0.16	0.30	0.19	0.34	0.53	0.34	0.23	0.77	0.16	0.29	0.00
Longfin Smelt†	Pelagic	Y	N	High	0.17	0.69	0.05	0.72	0.00	0.03	0.08	0.42	0.70	0.63	0.18	0.42	0.00	0.28	0.09
steelhead/Rainbow trout*	Pelagic	Y	Y	High	0.00	0.08	0.06	0.18	0.02	0.07	0.13	0.08	0.06	0.00	0.00	0.10	0.00	0.00	0.14
Striped Bass	Pelagic	N	Y	High	0.04	0.38	0.06	0.61	0.10	0.20	0.00	0.39	0.48	0.29	0.04	0.18	0.00	0.16	0.42
Threadfin Shad	Pelagic	N	N	Med	0.42	1.00	0.68	0.69	0.69	0.55	0.66	0.60	0.72	0.44	0.21	1.00	0.10	0.84	0.69
Bluegill	SAV	N	N	Low	0.04	0.14	0.32	0.13	0.30	0.11	0.22	0.11	0.04	0.08	0.04	0.21	0.00	0.29	0.97
Green Sunfish	SAV	N	N	Low	0.00	0.04	0.17	0.07	0.10	0.03	0.07	0.04	0.00	0.03	0.00	0.04	0.00	0.00	0.37
Largemouth Bass	SAV	N	N	Low	0.00	0.00	0.24	0.04	0.19	0.02	0.09	0.00	0.02	0.00	0.00	0.04	0.00	0.16	0.89
Redear Sunfish	SAV	N	N	Low	0.00	0.09	0.34	0.08	0.28	0.12	0.25	0.04	0.05	0.25	0.02	0.15	0.00	0.23	0.86

Table 3. Mean species-survey ratings ('R'; see text for details) for each of the 15 long-term monitoring surveys according to habitat association and life history stage. The R values are conditionally formatted from zero to one with zero colored in white and one colored in dark green. The overall mean value across all surveys for each habitat type and life history stage is presented in the far-right column.

Life Stage	Source	CDFW Summer Townet Survey	CDFW Fall Midwater Trawl	USFWS Beach Seine Survey	USFWS Chipps Island Midwater Trawl	USFWS Mossdale Kodiak Trawl	USFWS Sacramento Midwater Trawl	USFWS Sacramento Kodiak Trawl	UC Davis Suisun Marsh Otter Trawl	CDFW SF Bay Study Midwater Trawl	CDFW SF Bay Study Otter Trawl	CDFW 20mm Survey	CDFW Spring Kodiak Trawl	CDFW Smelt Larval Survey	USFWS Enhanced Delta Smelt Monitoring Program	USFWS Delta Boat Electrofishing Survey	Mean R
Adult	Benthic avg	0.04	0.12	0.10	0.09	0.09	0.03	0.02	0.26	0.12	0.24	0.07	0.05	0.03	0.06	0.28	0.11
Juvenile	Benthic avg	0.22	0.20	0.27	0.14	0.23	0.08	0.10	0.41	0.20	0.45	0.36	0.11	0.27	0.17	0.27	0.23
Adult	Fringe avg	0.03	0.10	0.18	0.13	0.16	0.07	0.09	0.29	0.06	0.11	0.02	0.12	0.00	0.11	0.35	0.12
Juvenile	Fringe avg	0.16	0.13	0.41	0.18	0.35	0.13	0.21	0.36	0.12	0.12	0.17	0.23	0.05	0.21	0.36	0.21
Adult	Pelagic avg	0.15	0.44	0.18	0.46	0.15	0.20	0.16	0.26	0.39	0.25	0.10	0.35	0.04	0.23	0.21	0.24
Juvenile	Pelagic avg	0.58	0.67	0.43	0.68	0.36	0.42	0.37	0.44	0.68	0.51	0.58	0.61	0.24	0.57	0.34	0.50
Adult	SAV avg	0.01	0.07	0.27	0.08	0.21	0.07	0.16	0.05	0.03	0.09	0.02	0.11	0.00	0.17	0.77	0.14
Juvenile	SAV avg	0.08	0.10	0.37	0.14	0.30	0.09	0.26	0.03	0.06	0.08	0.10	0.17	0.05	0.29	0.73	0.19

Appendix

Figure A1. Image of Bigscale Logperch (*Percina macrolepida*) used for morphometric analysis. The image was obtained from http://tuolumnerivertac.com/Photos and originally provided by FISHBIO. The specimen was sampled from the Stanislaus River at Oakdale on February 4, 2008. It is measured as having a standard length (SL) of 84 mm and a total length (TL) of 94 mm (SL=0.89*TL). Since it has a square-shaped caudal fin, no fork length conversion is needed.

Table A1. Information about size at juvenile-to-adult life history transitions (‘FL’=fork length, ‘SL’=standard length, ‘TL’=total length; ‘m’=male, ‘f’=female) for 36 commonly sampled Delta fish species.

Common Name	Scientific name	Published Juvenile to Adult size	Published length	Reference	Juvenile to adult size midpoint (cm)	Converted FL (mm) midpoint	Converted SL (mm) midpoint	Converted TL (mm) midpoint
American Shad	*Alosa sapidissima*	37.6 cm (m), 43.4 cm (f)	FL	Froese et al. 2024	40.50	405.00	368.55	456.26
Bigscale Logperch	*Percina macrolepida*	7.5-10.2 cm	SL	Moyle 2002	8.90	99.60	89.00	99.60
Black Bullhead	*Ameiurus melas*	17-23 cm	TL	Moyle 2002	20.00	200.00	173.00	200.00
Black Crappie	*Pomoxis nigromaculatus*	10 -20 cm	TL	Moyle 2002	15.00	143.70	124.80	150.00
Bluegill	*Lepomis macrochirus*	10 cm	FL	Moyle 2002	10.00	100.00	80.80	102.37
Channel Catfish	*Ictalurus punctatus*	30 cm	TL	Moyle 2002	30.00	277.00	239.00	300.00
Chinook Salmon	*Oncorhynchus tshawytscha*	55 cm	FL	Moyle 2002	55.00	550.00	498.85	568.69
Common Carp	*Cyprinus carpio*	25-36 cm	TL	Froese et al. 2024	30.50	278.87	249.49	305.00
Delta Smelt	*Hypomesus transpacificus*	6 cm	FL	Froese et al. 2024	6.00	60.00	56.40	65.48
Goldfish	*Carassius auratus*	11.0-21.5 cm	SL	Moyle 2002	16.25	186.20	162.50	201.34
Green Sturgeon	*Acipenser medirostris*	130-150 cm	TL	Moyle 2002	140.00	1282.00	1116.00	1400.00
Green Sunfish	*Lepomis cyanellus*	5 cm	SL	Moyle 2002	5.00	58.29	50.00	59.00
Hitch	*Lavinia exilicauda*	15-30 cm	FL	Moyle 2002	22.25	253.60	222.50	263.62
Largemouth Bass	*Micropterus salmoides*	18 cm (m), 20 cm (f)	TL	Moyle 2002	19.00	183.58	157.97	190.00
Longfin Smelt	*Spirinchus thaleichthys*	9 cm	TL	Froese et al. 2024	9.00	82.53	76.79	90.00
Mississippi Silversides	*Menidia audens*	8-10 cm	TL	Moyle 2002	9.00	83.97	76.05	90.00
Pacific lamprey	*Lampetra tridentata*	30-76 cm	TL	Moyle 2002	53.00	530.00	530.00	530.00
Pacific Staghorn Sculpin	*Leptocottus armatus*	12-15 cm	SL	Moyle 2002	13.50	158.00	135.00	158.00
Prickly Sculpin	*Cottus asper*	4-7 cm	SL	Moyle 2002	5.50	65.20	55.00	65.20
Redear Sunfish	*Lepomis microlophus*	13 cm	TL	Moyle 2002	13.00	130.00	108.42	130.00
Sacramento Blackfish	*Orthodon microlepidotus*	25-37 cm	FL	Moyle 2002	31.00	310.00	277.48	338.80
Sacramento Pikeminnow	*Ptychocheilus grandis*	22-25 cm	SL	Moyle 2002	23.50	252.90	235.00	277.44
Sacramento Splittail	*Pogonichthys macrolepidotus*	17 cm	SL	Moyle 2002	17.00	191.58	170.00	220.84
Sacramento Sucker	*Catostomus occidentalis*	20-32 cm	FL	Moyle 2002	26.00	260.00	227.70	276.30
Shimofuri goby	*Tridentiger bifasciatus*	3.5-6 cm	TL	Moyle 2002	4.80	48.00	39.20	48.00
Spotted Bass	*Micropterus punctulatus*	15-40.5 cm	TL	Moyle 2002	27.75	266.80	232.70	277.50
steelhead/Rainbow Trout	*Oncorhynchus mykiss*	35 cm	FL	Moyle 2002	35.00	350.00	316.40	351.52
Striped Bass	*Morone saxatilis*	25cm (m), 45cm (f)	FL	Moyle 2002	35.00	350.00	309.75	375.42
Threadfin Shad	*Dorosoma petenense*	4.9 cm	SL	Johnson 1971	4.90	51.96	49.00	59.39
Threespine Stickleback	*Gasterosteus aculeatus*	5.5 cm	TL	Froese et al. 2024	5.50	55.00	47.88	55.00
Tule Perch	*Hysterocarpus traskii*	7-8 cm	SL	Moyle 2002	7.50	82.11	75.00	88.43
Warmouth	*Lepomis gulosus*	7- 10 cm	TL	Moyle 2002	8.50	79.92	67.79	85.00
Western Mosquitofish	*Gambusia affinis*	19-21 mm (M), 24 mm (F)	TL	Moyle 2002	2.15	21.50	18.25	21.50
White Catfish	*Ameiurus catus*	20-21 cm	FL	Moyle 2002	20.50	205.00	186.90	226.00
White Sturgeon	*Acipenser transmontanus*	75-105 cm (m); 95-135 cm (f)	FL	Moyle 2002	105.00	1050.00	970.90	1167.00
Yellowfin goby	*Acanthogobius flavimanus*	9-10 cm (m); 16-18 cm (f)	SL	Moyle 2002	13.50	165.00	135.00	165.00

Table A2. Information about body length conversions (‘FL’=fork length, ‘SL’=standard length, ‘TL’=total length) from Froese et al. (2024) for 28 commonly sampled Delta fish species.

Common Name	Scientific name	slope (FL unk, SL known)	intercept (FL unk, SL known)	slope (FL unk, TL known)	intercept (FL unk, TL known)	slope (SL unk, FL known)	intercept (SL unk, FL known)	slope (SL unk, TL known)	intercept (SL unk, TL known)	slope (TL unk, FL known)	intercept (TL unk, FL known)	slope (TL unk, SL known)	intercept (TL unk, SL known)
American Shad	*Alosa sapidissima*	1.10	0.00	0.89	0.00	0.91	0.00	0.81	0.00	1.13	0.00	1.24	0.00
Black Bullhead	*Ameiurus melas*			1.00	0.00			0.87	0.00	1.00	0.00	1.16	0.00
Black Crappie	*Pomoxis nigromaculatus*	1.22	0.00					0.83	0.00	1.04	0.00	1.20	0.00
Bluegill	*Lepomis macrochirus*	1.26	0.00	0.98	0.00	0.81	0.00	0.79	0.00	1.02	0.00	1.27	0.00
Channel Catfish	*Ictalurus punctatus*	1.14	0.00							1.08	0.00	1.161, 1.360	0.000, 0.000
Chinook Salmon	*Oncorhynchus tshawytscha*	1.10	0.00	0.97	0.00	0.91	0.00	0.88	0.00	1.03	0.00	1.14	0.00
Common Carp	*Cyprinus carpio*							0.82	0.00				
Delta Smelt	*Hypomesus transpacificus*	1.07	0.00	0.92	0.00	0.94	0.00	0.86	0.00	1.09	0.00	1.16	0.00
Goldfish	*Carassius auratus*							0.83	0.00	1.08	0.00	1.24	0.00
Green Sturgeon	*Acipenser medirostris*									1.09	0.00	1.25	0.00
Green Sunfish	*Lepomis cyanellus*	1.17	0.00	0.99	0.00	0.86	0.00	0.85	0.00	1.01	0.00	1.18	0.00
Largemouth Bass	*Micropterus salmoides*	1.13	0.61	0.97	-0.16	0.86	-0.17	0.83	-0.30	1.03	0.16	1.17	0.79
Longfin Smelt	*Spirinchus thaleichthys*	1.08	0.00	0.92	0.00	0.93	0.00	0.95	0.00	1.09	0.00	1.17	0.00
Pacific Staghorn Sculpin	*Leptocottus armatus*			1.00	0.00	0.86	0.00			1.00	0.00	1.17	0.00
Prickly Sculpin	*Cottus asper*			1.00	0.00	0.84	0.00	0.84	0.00	1.00	0.00	1.19	0.00
Redear Sunfish	*Lepomis microlophus*	1.20	0.00	1.00	0.00	0.83	0.00	0.83	0.00	1.00	0.00	1.20	0.00
Sacramento Pikeminnow	*Ptychocheilus grandis*							0.85	0.00				
Spotted Bass	*Micropterus punctulatus*									1.04	0.00	1.203, 1.209	0.000, 0.158
steelhead/Rainbow Trout	*Oncorhynchus mykiss*	0.97	0.00	0.87	0.00	0.90	0.00	0.90	0.00	1.15	0.00	1.11	0.00
Striped Bass	*Morone saxatilis*	1.13	0.00	0.93	0.00	0.89	0.00	0.83	0.00	1.07	0.00	1.21	0.00
Threadfin Shad	*Dorosoma petenense*	1.06	0.00	0.88	0.00	0.95	0.00	0.83	0.00	1.14	0.00	1.21	0.00
Threespine Stickleback	*Gasterosteus aculeatus*									1.00	0.00	1.15	0.00
Tule Perch	*Hysterocarpus traskii*									1.08	0.00	1.18	0.00
Warmouth	*Lepomis gulosus*	1.18	0.00					0.84	0.00	1.00	0.00	1.19	0.00
Western Mosquitofish	*Gambusia affinis*	1.18	0.00	1.00	0.00	0.85	0.00	0.85	0.00	1.00	0.00	1.18	0.00
White Catfish	*Ameiurus catus*			0.91	0.00			0.83	0.00	1.10	0.00	1.21	0.00
White Sturgeon	*Acipenser transmontanus*			0.93	-3.55					1.090, 1.110, 1.114	2.060, 0.000	1.20	0.00
Yellowfin goby	*Acanthogobius flavimanus*			1.00	0.00	0.82	0.00	0.82	0.00				

Table A3. Information about body length conversions (‘FL’=fork length, ‘SL’=standard length, ‘TL’=total length) from Gaeta (*In prep*) for 7 commonly sampled Delta fish species.

Common Name	Scientific name	FL to SL slope	FL to SL intercept	FL to TL slope	FL to TL intercept	SL to TL slope	SL to TL intercept	converted FL (mm)	converted SL (mm)	converted TL (mm)
Channel Catfish	*Ictalurus punctatus*	0.89		1.10		1.24		27.30	24.20	30.00
Mississippi Silversides	*Menidia audens*	0.91	-1.06							
Pacific Staghorn Sculpin	*Leptocottus armatus*	-				1.15			13.50	15.50
Sacramento Splittail	*Pogonichthys macrolepidotus*	0.87	-0.27	1.17	0.69	1.33	2.28		17.00	
White Catfish	*Ameiurus catus*	0.88		1.09		1.24		20.50	18.00	22.30
White Sturgeon	*Acipenser transmontanus*									
Yellowfin goby	*Acanthogobius flavimanus*					1.24	-1.13		13.50	15.60

IEP

Interagency Ecological Program for the San Francisco Estuary

The Interagency Ecological Program for the San Francisco Estuary
is a cooperative effort of the following agencies:

California Department of Fish and Wildlife
California Department of Water Resources
State Water Resources Control Board
National Marine Fisheries Service
US Army Corps of Engineers
US Bureau of Reclamation
US Environmental Protection Agency
US Fish and Wildlife Service
US Geological Survey

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