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IEP Newsletter

Interagency Ecological Program for the San Francisco Estuary

IN THIS ISSUE

IEP Newsletter

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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 Articles in the newsletter are intended for rapid communication and are not peer reviewed.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 *Fish and Wildlife Scientific Aid Luke Olson from the California Department of Water Resources Division of Integrated Science and Engineering Yolo Bypass Fish Monitoring Program measures water turbidity in the Toe Drain in the Yolo Bypass in Yolo County, California.* Photo taken June 10, 2024. Andrew Nixon/California Department of Water Resources. Public domain.

ABOVE *Boats from the California Department of Water Resources, California Department of Fish and Wildlife and contractor Cramer Fish Sciences operate in the Sacramento-San Joaquin Delta to conduct pilot studies to determine if and how eDNA can be utilized to estimate relative larval smelt entrainment near water export facilities.* Photo taken April 9, 2025. Xavier Mascareñas/California Department of Water Resources. Public domain.

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

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Of Interest to Managers

Fish Salvage at the State Water Project and Central Valley Project's Fish Facilities during the 2023 Water Year

Geir Aasen and Walter Griffiths from the California Department of Fish and Wildlife summarized results from water year (WY) 2023 for fish salvage associated with water exports by the federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP's Tracy Fish Collection Facility (TFCF) and the SWP's Skinner Delta Fish Protective Facility (SDFPF) remove fish from water exported from the southern end of the Sacramento–San Joaquin Delta located in Byron, California and the fish are released back to the Delta (a process called "salvage"). In general, total fish salvage has been influenced by exports in recent years (i.e., lower salvage with decreased exports) which generally corresponds to a decrease in abundance over time for many fish species due to drought conditions and lower exports. In WY 2023, large increases in salvage of species including Chinook Salmon, Steelhead, Striped Bass, cultured Delta Smelt, and Sacramento Splittail were recorded, likely attributable to increased rainfall and outflow which increased juvenile populations and flushing of fish downstream within the reach of the facilities pumps. Salvage of Green Sturgeon remained equal or within the low range of salvage from WYs 2017–2022, most likely due to low population size. But noteworthy was the WY 2023 Longfin Smelt salvage which was a large decrease from WYs 2020–2022, most likely because high outflows flushed the Longfin Smelt downstream and outside the influence of the facilities pumps and water exports.

2022 San Joaquin River White Sturgeon Telemetry Study

The 2022 San Joaquin River White Sturgeon Telemetry Study data report was prepared by Kristie Braken-Guelke, Austin Demarest, and Heather Swinney (U.S. Fish and Wildlife Service). This study first began in 2012 to track the migration and habitat use of White Sturgeon in the San Joaquin River basin. We maintain an existing array of VR2W–69 kHz stationary receivers and, as feasible, new receivers are installed to expand the potential area in which acoustically tagged White Sturgeon are monitored. In 2022, three new receivers were installed expanding receiver coverage into the Eastside Bypass. Based on our efforts, it is estimated that a maximum of 73 tagged White Sturgeon remain in the river system with active tags. Our efforts to detect previously tagged individuals have been successful; in fact, a female White Sturgeon tagged in 2015 was detected for 4 minutes on January 14, 2023, near Valley Grassland State Park at one of the new receiver locations. The telemetry results from this study can be used to document baseline passage conditions in the Eastside Bypass and be a useful monitoring tool for assessing sturgeon passage at future remedied barriers. Although we focused on tagging and tracking the movement of adult and sub-adult White Sturgeon in the San Joaquin River, we believe this effort should be expanded to collect data for all life stages of both Green Sturgeon and White Sturgeon in the Sacramento and San Joaquin rivers.

2023 Delta Juvenile Fish Monitoring Program—Salmonid Annual Report

The purpose of this report is to summarize juvenile salmonid surface trawl and beach seine sample data obtained during the 2023 (August 2022 to July 2023) Delta Juvenile Fish Monitoring Program monitoring year. Authors Erika Holcombe, Eric Huber, and Adam Nanninga (U.S. Fish and Wildlife Service) present status and trend information about salmonid immigration into the Delta from the Sacramento and San Joaquin rivers, salmonid occupancy within the Delta, and salmonid emigration from the Delta into the San Francisco Bay. Relevant results include: more salmonids entered the Delta from the San Joaquin River in monitoring year 2023 than in monitoring year 2022; no winter-run Chinook Salmon or Steelhead were sampled in either the Central Delta or South Delta regions; and for the first time in 4 years, salmonids were sampled by beach seine in the San Francisco Bay. The results presented here provide insight into population-level responses of multiple races of Central Valley Chinook Salmon and winter Steelhead to a critically dry water year in 2022 and a wet water year in 2023.

Delta Juvenile Fish Monitoring Program Electrofishing 2023 Report

This report was written by Jacob Stagg (U.S. Fish and Wildlife Service) and provides a summary of the 2023 field year (August 1, 2022–July 31, 2023) for the Delta Juvenile Fish Monitoring Program Electrofishing Survey as well as spatiotemporal distribution information on four native fish species (Chinook Salmon, Sacramento Splittail, Sacramento Pikeminnow, and Hitch). This survey provides fisheries monitoring survey data throughout the freshwater zones of the Delta, including understudied habitats such as vegetated areas and the Central and South Delta regions. Accordingly, Delta Juvenile Fish Monitoring Program's electrofishing survey offers fisheries management the ability to expand the scope of information on spatiotemporal occupancy patterns and population status for littoral fish species associated with nearshore habitats within the San Francisco Estuary, particularly for species that are structure-oriented and, hence, unable to be sampled with trawl nets or seines. This report will help the Interagency Ecological Program research and management community fill information gaps about the Delta's ecology.

2023 Delta Juvenile Fish Monitoring Program—Nearshore Fishes Annual Report

This report of nearshore, non-salmonid fish assemblages in the Bay and Delta is written by Jennifer Whitt, Eric Huber, Christian Gredzens and Adam Nanninga of the U.S. Fish and Wildlife Service. The authors describe the abundance trends from 1995 to 2023 for five Centrarchid species commonly occurring in the Delta (Largemouth Bass, Bluegill, Redear Sunfish, Green Sunfish, and Warmouth) and two additional species commonly occurring in the San Francisco Bay (Topsmelt and Bay Pipefish). Potential biological (e.g., fish life histories, habitat preferences) and physico-chemical (e.g., habitat conditions, climatic events) drivers for the observed trends are presented.

Behavior of Cultured Delta Smelt in Field Enclosures: Does Ancestry Matter?

Scott Meyer and colleagues from the Department of Water Resources investigated potential behavioral impacts of hatchery propagated Delta Smelt in the wild. Using a field enclosure design in 2021, they conducted a pilot study evaluating the swimming behavior of Delta Smelt from varied hatchery and wild-lineages (i.e., more or less domesticated). Behavior of domesticated groups were similar; however, the authors discuss challenges of behavior evaluations in the field and analysis, and suggest the study should be repeated and domestication monitored as the hatchery program grows to support supplementation of the species.

Investigating the Consequences of a Hypoxia Event in Fall 2021

Luke Olson (Department of Water Resources) and Mitch Olinger (Department of Water Resources) describe a large atmospheric river event in fall 2021 that led to a notable drop in dissolved oxygen in the Sacramento–San Joaquin Delta, including within the Yolo Bypass Toe Drain channel. The low dissolved oxygen levels observed were unprecedented in relation to historical recorded values in the Yolo Bypass and appear to have triggered a shift in fish community, mainly driven by the decrease in White Catfish catch. This event highlights the importance of long-term monitoring data as a valuable baseline for comparing change over time, especially when these discrete and significant events occur.

DATA REPORT

Fish Salvage at the State Water Project and Central Valley Project's Fish Facilities during the 2023 Water Year

Geir Aasen (California Department of Fish and Wildlife [CDFW]), Walter Kyle Griffiths (CDFW)*

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Introduction

Two fish protective facilities reduce fish losses associated with water exports by the federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP Tracy Fish-Collection Facility (TFCF) and the SWP Skinner Delta Fish Protective Facility (SDFPF) salvage fish (fish are removed from exported water and released back to the Delta) from water exported from the southern end of the Sacramento–San Joaquin Delta located in Byron, California (Aasen 2013). Salvage reporting is required by contract with the California Department of Water Resources and the United States Bureau of Reclamation to provide information for stakeholders such as the Smelt Monitoring Team and the Salmon Monitoring Team for near real time management of listed species. Both facilities use louver-bypass systems to divert fish from the exported water (Aasen 2023). The salvaged fish are periodically loaded into tanker trucks and transported to fixed release sites in the western Delta. Export and salvage operations began in 1957 at the TFCF and in 1968 at the SDFPF.

This report summarizes salvage information from the 2023 water year (WY) for both the TFCF and the SDFPF while examining data from WY's 1981 to 2023 for salvage trends over time, emphasizing recent years. The following species were given individual consideration, including listed species, Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead (*O. mykiss*), Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), and Green Sturgeon (*Acipenser medirostris*). Striped Bass (*Morone saxatilis*) was included as an apex predator, Sacramento Splittail (*Pogonichthys macrolepidotus*) was included as a species of special concern, and Threadfin Shad (*Dorosoma petenense*) as an important forage fish.

Methods

Systematic sampling was used to estimate the numbers and species of fish salvaged at both facilities and data reported by CVP and SWP. Bypass flows into the fish-collection buildings were generally sub-sampled once every 1 or 2 hours for 5 to 30 minutes at the SDFPF and once every 2 hours for 30 minutes at the TFCF. Fish with a fork length (FL) of 20 mm or larger were identified, counted, and measured. These fish counts were expanded to estimate the total number of fish salvaged in each 1 to 2 hour period of water export. For example, a subsample duration of 30 minutes over an export period of 120 minutes gives an expansion factor of 4, which is then multiplied by the number of fish per species collected during the fish count. These incremental salvage estimates were then summed across time to develop monthly and annual species-salvage totals for each facility.

The loss of Chinook Salmon is estimated from the number of juvenile Chinook Salmon entrained by the facility less the number of Chinook Salmon that survive salvage operations (Fish Salvage Monitoring c2013). Salmon salvage and loss were summarized by origin (i.e., hatchery fish defined as adipose fin clipped or wild fish defined as non-adipose fin clipped) and run (fall, late-fall, winter, or spring). Runs of Chinook Salmon were initially determined by the Delta length criteria based on length at date of salvage (Fish Salvage Monitoring c2014). Run identification was updated when information from coded wire tags (CWT) from hatchery Chinook or DNA samples from wild Chinook Salmon became available. The Delta length-at-date criteria is a modified version of the Fisher Model with expanded boundaries for winter-run Chinook Salmon. This is necessary because juvenile FL ranges from runs were not segregated and empirical fork lengths trends for all runs did not exhibit the constant apparent growth rates used to generate length-at-date size criteria (Harvey and Stroble 2013). Consequently, apparent growth rates and size ranges vary among runs leading to potential misclassification with the Delta length-at-date criteria (Harvey and Stroble 2013). Hence, changes were made to update run identification based upon CWT-determined runs in WY 2017 and DNA-determined runs in 2018.

Larval fish were collected and examined for the presence of Delta Smelt and Longfin Smelt less than 20 mm FL. Smelt less than 20 mm FL are reported as detections rather than numbers to avoid any confusion with salvage since fish less than 20 mm FL are not included in salvage. Larval sampling in WY 2023 ran from March 1 through June 6 at both the SDFPF and the TFCF. These dates were based on optimum water temperature for spawning early in the year and lack of detection of larvae at the end of the season. Larval samples were collected once for every 1–6 hours of water export. The TFCF sampled every 6 hours while the sampling interval at SDFPF varied due to facility shutdown from low water exports. The duration of larval sampling was 30 minutes. To retain these smaller fish, the screen used in the routine counts was lined with a 0.5 mm Nitex mesh. Larval fish from the TFCF were identified to the species level by TFCF personnel, while only non-Centrarchidae larval fish from the SDFPF were identified to species.

Results

Water Exports

The SWP in WY 2023 (a wet year) exported 3.66 billion m^3 of water. This was a large increase from WY 2022 (0.79 billion m^3), the record low export in WY 2021 (0.71 billion m^3), and at the upper range of WYs 2015–2020 (1.38–4.44 billion m^3; **Figure 1**). The CVP in WY 2023 exported 2.74 billion m^3 of water. This was a large increase from WY 2022 (1.74 billion m^3), WY 2021 (1.14 billion m^3), and WY 2015 (0.86 billion m^3, a record low) but within range of WYs 2017–2020 (2.43–3.31 billion m^3). It should be noted that WYs 2020–2022 were drought year types with 2 years of extreme droughts in WYs 2021–2022 (**Table 1**). Total export in WY 2023 at SWP was an increase from WYs 1981–2022 average (2.94 billion m^3) and nearly equal to the average at CVP (2.73 billion m^3).

Exports at the SWP peaked in January, March, July–August 2023 (**Figure 2**). During this period, the SWP exported 1.93 billion m^3, which represented 52.7 % of the total annual export. In contrast, exports at the CVP peaked consistently during January-September 2023 (with a small decrease in April). The cumulative water export for those months was 2.46 billion m^3, which represented 89.8 % of the annual export. SWP monthly exports ranged from 35.97 to 504.62 million m^3. CVP monthly exports ranged from 78.12 to 315.54 million m^3. The pattern of monthly export at both facilities generally follows the same trend year to year with lower exports occurring in spring due to salvage of listed species including Chinook Salmon, Steelhead, Longfin Smelt, and Delta Smelt and their respective Biological Opinion triggers which lowers exports.

Total Salvage and Prevalent Species

Total fish salvage (all fish species combined) at the SDFPF in WY 2023 was 1,437,583 (**Figure 3**). This was a large increase from WY 2022 (440,412), the record low in WY 2021 (164,423), WY 2020 (435,541), but within the range of WYs 2017–2019 (660,001–2,104,742). Total fish salvage at the TFCF in WY 2023 was 13,382,124. This was a large increase from WY 2022 (1,631,861), WY 2021 (381,373), WYs 2016–2020 (1,432,489–2,061,113), and the record low in WY 2014 (160,681).

Threadfin Shad was the most-salvaged species at both the SDFPF and TFCF (**Table 2**). Sacramento Splittail and Striped Bass were the second and third most-salvaged fish at SDFPF, respectively. Common Carp and Sacramento Splittail were the second and third most-salvaged fish at TFCF, respectively. Native species comprised 18.7% of total fish salvage at SDFPF and 16.7% of total fish salvage at TFCF. This was a large increase from WY 2022 at the SDFPF (2.9%) and TFCF (0.9%). Large increases in native species are mainly due to large increases in Sacramento Splittail salvage since this species have boom populations in high outflow years which generally have increased exports (Wang and Reyes 2007). These boom populations also influences higher

Figure 1. Annual water exports in billions of cubic meters for the State Water Project and the Central Valley Project, Water Years 1981 to 2023.

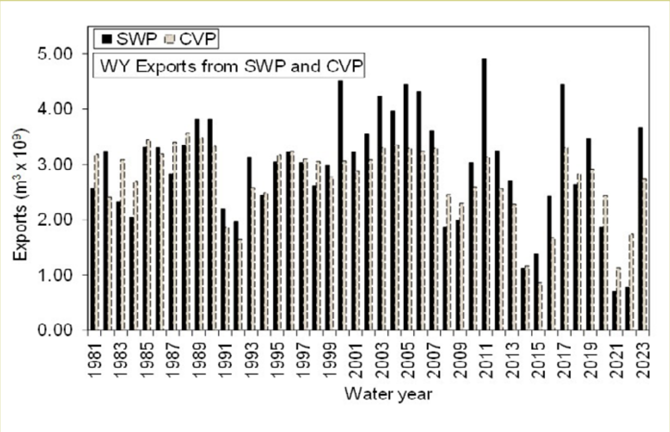


Figure 2. Monthly water exports in millions of cubic meters for the State Water Project and the Central Valley Project, Water Year 2023.

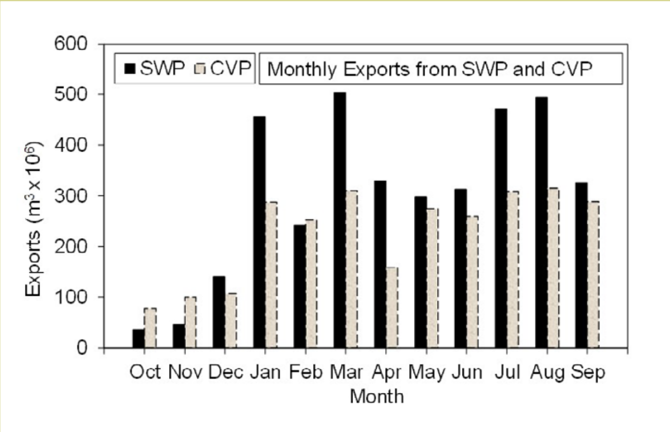


Table 1. Water year type for Sacramento Valley during 1981–2023.

Year	Water year type	Location
1981	Dry	Sacramento Valley
1982	Wet	Sacramento Valley
1983	Wet	Sacramento Valley
1984	Wet	Sacramento Valley
1985	Dry	Sacramento Valley
1986	Wet	Sacramento Valley
1987	Dry	Sacramento Valley
1988	Critical Dry	Sacramento Valley
1989	Dry	Sacramento Valley
1990	Critical Dry	Sacramento Valley
1991	Critical Dry	Sacramento Valley
1992	Critical Dry	Sacramento Valley
1993	Above Normal	Sacramento Valley
1994	Critical Dry	Sacramento Valley
1995	Wet	Sacramento Valley
1996	Wet	Sacramento Valley
1997	Wet	Sacramento Valley
1998	Wet	Sacramento Valley
1999	Wet	Sacramento Valley
2000	Above Normal	Sacramento Valley
2001	Dry	Sacramento Valley
2002	Dry	Sacramento Valley
2003	Above Normal	Sacramento Valley
2004	Below Normal	Sacramento Valley
2005	Above Normal	Sacramento Valley
2006	Wet	Sacramento Valley
2007	Dry	Sacramento Valley
2008	Critical Dry	Sacramento Valley
2009	Dry	Sacramento Valley
2010	Below Normal	Sacramento Valley
2011	Wet	Sacramento Valley
2012	Below Normal	Sacramento Valley
2013	Dry	Sacramento Valley
2014	Critical Dry	Sacramento Valley
2015	Critical Dry	Sacramento Valley
2016	Below Normal	Sacramento Valley
2017	Wet	Sacramento Valley
2018	Below Normal	Sacramento Valley
2019	Wet	Sacramento Valley
2020	Dry	Sacramento Valley
2021	Critical Dry	Sacramento Valley
2022	Critical Dry	Sacramento Valley
2023	Wet	Sacramento Valley

total fish salvage at higher exports. Relatively few listed species including Chinook Salmon, Steelhead, Delta Smelt, and Longfin Smelt were salvaged at the SDFPF (0.4 % combined, of total fish salvage). This was a large decrease from WY 2022 when listed species comprised 1.1 % of salvage. Relatively few listed species including Chinook Salmon, Steelhead, Delta Smelt, and Longfin Smelt were salvaged at the TFCF (0.2 % combined of total fish salvage). This was a small decrease from WY 2022 when these species comprised 0.3 % of salvage.

Chinook Salmon

Annual salvage estimates of Chinook Salmon (all runs and origins combined) at both facilities in WY 2023 were a large increase compared to the trend seen during drought years WY 2020–2022, but well below pre-2000 levels (**Figure 4**). Salvage of juvenile (34–227 mm FL) Chinook Salmon (4,195) at SDFPF in WY 2023 was well below WY 2017 (23,118), but a large increase from WYs 2020–2022 (302–1,187). The record low occurred in WY 2014 (64). Mean salvage for Chinook Salmon in WYs 2001–2022 at SDFPF was only 7.5 % of the mean salvage in WYs 1981–2000. The same trend was seen for salvage of juvenile Chinook Salmon (30–245 mm FL) at the TFCF in WY 2023 (21,057) which was slightly less than in WY 2017 (23,633), but a large increase from WYs 2020–2022 (892–3,690). The record low occurred in WY 2015 (187). Mean salvage for WYs 2001–2022 was only 10.0 % of the mean salvage for WYs 1981–2000.

Wild Chinook Salmon salvaged at the SDFPF were primarily wild fall-run fish, which comprised 96.7 % of wild fish, followed by wild spring-run fish (**Table 3**). Salvaged wild Chinook Salmon at the TFCF were also primarily wild fall-run fish, which comprised 97.9 % of wild fish caught, followed by wild spring-run fish. At the SDFPF, the majority of wild fall-run fish were salvaged in May (1,082) and wild fall-run fish were also most frequently salvaged in May (8,139) at the TFCF.

Annual loss of Chinook Salmon (all origins and runs) was higher at the SDFPF (18,438) than at the TFCF (14,426), despite salvaging less fish (**Table 3**). Greater entrainment loss at the SDFPF than at the TFCF was attributable to greater prescreen loss occurring in Clifton Court Forebay (Fish Salvage Monitoring c2013).

Steelhead

Salvage of Steelhead (both wild and hatchery-raised) continued the pattern of low salvage observed since WY 2005 (**Figure 5**). SDFPF salvage of Steelhead (1,052)(124–476 mm FL) in WY 2023 was a large increase from the record low in WY 2021 (69) and within the range of WYs 2018–2020, 2022 (141–1,562). The salvage composition for juvenile Steelhead was 748 hatchery and 304 wild fish with most wild Steelhead salvaged in March (178).

At the TFCF in WY 2023, salvage of Steelhead (768) (179–444 mm FL) was an increase from WY 2022 (394) and a small increase from WYs 2018–2022 (488–740), but a large increase from the

Figure 3. Annual salvage of all fish taxa combined at the State Water Project and the Central Valley Project, Water Years 1981 to 2023.

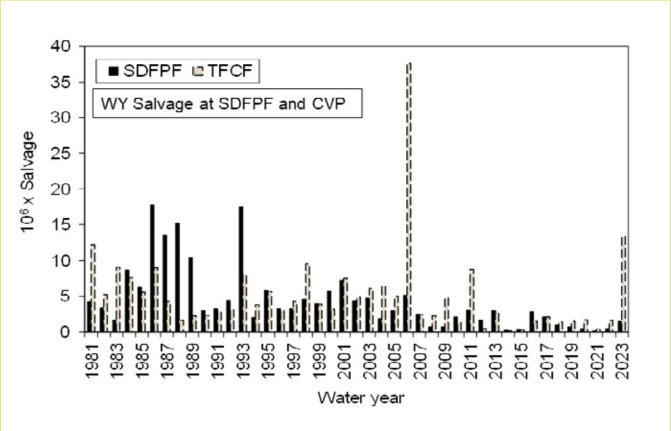


Figure 4. Annual salvage of Chinook Salmon (all races and wild and hatchery origins combined) at the State Water Project and the Central Valley Project, Water Years 1981 to 2023.

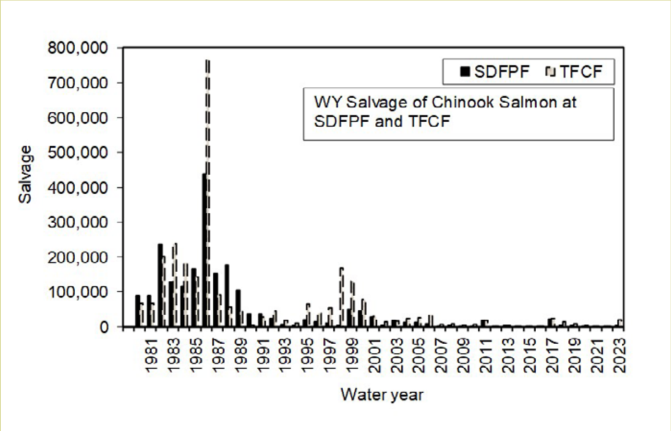


Figure 5. Annual salvage of Steelhead (wild and hatchery origins combined) at the State Water Project and the Central Valley Project, Water Years 1981 to 2023.

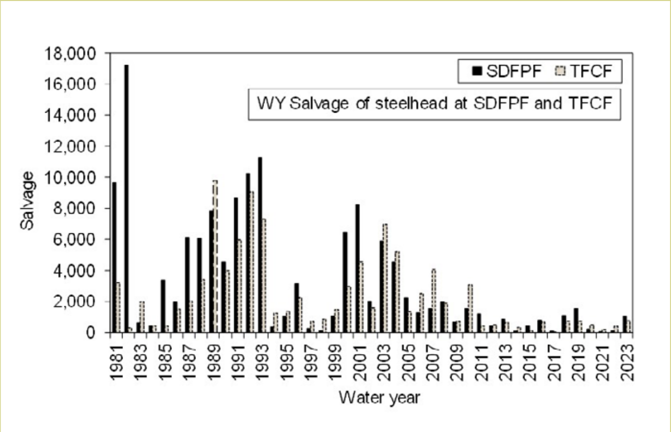
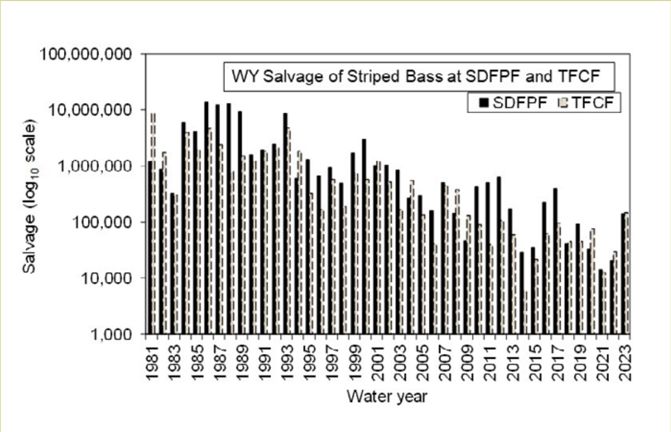


Figure 6. Annual salvage of Striped Bass at the State Water Project and the Central Valley Project, Water Years 1981 to 2023. The logarithmic scale is log10.



record low in WY 2017 (30). Most wild Steelhead were salvaged in March (63) and the salvage composition was 612 hatchery and 156 wild fish.

Striped Bass

Salvage in WY 2023 of Striped Bass (20–611 mm FL) at the SDFPF (141,913) was a large increase from WY 2022 (20,522), the record low in WY 2021 (13,939), and WYs 2015–2020 (32,508–396,161). Salvage in WY 2023 of Striped Bass (20–565 mm FL) at the TFCF (148,037) was a large increase from WY 2022 (29,706), WY 2021 (12,567), and WYs 2015–2020 (21,398–74,759). The record low salvage of Striped Bass at TFCF occurred in WY 2014 (5,933). Salvage at the SDFPF and the TFCF continued a declining trend observed since the late 1980s (Loboschefsky et al. 2012) (**Figure 6**). Prior to WY 1990, annual Striped Bass salvage estimates were generally above 1,000,000 fish.

Most Striped Bass salvage at the SDFPF occurred with peaks in November-April which accounted for 84.8 % of total WY salvage. At the TFCF, in contrast to the highest winter salvage at SDFPF, summer salvage in June and July accounted for 77.9 % of total WY salvage. Striped Bass were salvaged every month at both the SDFPF and the TFCF, with the lowest monthly salvages occurring in October at the SDFPF and in May at the TFCF.

Delta Smelt

Salvage of Delta Smelt continued the pattern of mostly low salvage observed since WY 2005 (**Figure 7**). Salvage of Delta Smelt (59–76 mm FL) at the TFCF in WY 2023 was low (36). The salvaged Delta Smelt were of hatchery origin from releases in winter 2023 with the exception of one unmarked Delta Smelt at TFCF. The last known incidence of Delta Smelt salvage (wild) at TFCF was in WY 2019 (8). Salvage of Delta Smelt (64–73 mm

Table 2. Annual fish salvage and percentage of annual fish salvage (%) collected from the State Water Project and the Central Valley Project, Water Year 2023.

Common Name	Scientific Name	SDFPF Salvage	SDFPF Percent	TFCF Salvage	TFCF Percent
Threadfin Shad	*Dorosoma petenense*	758,061	52.7	5,395,049	40.3
Splittail	*Pogonichthys macrolepidotus*	260,053	18.1	2,063,115	15.4
Striped Bass	*Morone saxatilis*	141,913	9.9	148,037	1.1
Bluegill	*Lepomis macrochirus*	97,712	6.8	265,242	2.0
Common carp	*Cyprinus carpio*	51,197	3.6	4,355,824	32.5
Inland Silverside	*Menidia beryllina*	42,090	2.9	33,065	0.2
American Shad	*Alosa sapidissima*	33,324	2.3	62,657	0.5
Largemouth Bass	*Micropterus salmoides*	21,936	1.5	353,832	2.6
White Catfish	*Ameiurus catus*	8,267	0.6	263,668	2.0
Black Crappie	*Pomoxis nigromaculatus*	4,463	0.3	110,568	0.8
Chinook Salmon	*Oncorhynchus tshawytscha*	4,195	0.3	21,057	0.2
Yellowfin Goby	*Acanthogobius flavimanus*	3,374	0.2	7,788	0.1
Channel Catfish	*Ictalurus punctatus*	2,571	0.2	76,952	0.6
Lamprey Unknown	*Lampetra*	2,091	0.1	79,604	0.6
Shimofuri Goby	*Tridentiger bifasciatus*	2,081	0.1	14,344	0.1
Golden Shiner	*Notemigonus crysoleucas*	1,139	0.1	13,288	0.1
Prickly Sculpin	*Cottus asper*	1,129	0.1	10,175	0.1
steelhead	*Oncorhynchus mykiss*	1,052	0.1	768	0.0
Redear Sunfish	*Lepomis microlophus*	355	<0.1	26,158	0.2
Bigscale Logperch	*Percina macrolepida*	263	<0.1	792	<0.1
Warmouth	*Lepomis gulosus*	76	<0.1	1,560	<0.1
Western Mosquitofish	*Gambusia affinis*	58	<0.1	5,569	<0.1
Rainwater killifish	*Lucania parva*	34	<0.1	9,366	0.1
Sacramento pikeminnow	*Ptychochelius grandis*	30	<0.1	235	0.0
Brown bullhead	*Ameiurus nebulosus*	27	<0.1	355	0.0
Tule perch	*Hysterocarpus traskii*	20	<0.1	654	0.0
Delta Smelt	*Hypomesus transpacificus*	16	<0.1	36	0.0
Black Bullhead	*Ameiurus melas*	12	<0.1	919	0.0
Starry flounder	*Platichthys stellatus*	11	<0.1	80	0.0
Threespine stickleback	*Gasterosteus aculeatus*	8	<0.1	2,907	0.0
Hardhead	*Mylopharodon conocephalus*	6	<0.1	0	0.0
Longfin Smelt	*Spirinchus thaleichthys*	6	<0.1	20	0.0
Pumpkinseed	*Lepomis gibbosus*	5	<0.1	0	0.0
Goldfish	*Carassius auratus*	4	<0.1	437	<0.1
White sturgeon	*Acipenser transmontanus*	2	<0.1	945	<0.1
Pond Loach	*Misgurnus anguillicaudatus*	2	<0.1	20	<0.1
Sacramento Sucker	*Catostomus occidentalis*	0	0	55,020	0.4
Red Shiner	*Cyprinella lutrensis*	0	0	1,755	<0.1
Pacific Lamprey	*Entosphenus tridentatus*	0	0	116	<0.1
Green Sunfish	*Lepomis cyanellus*	0	0	61	<0.1
Large-scale Loach	*Paramisgurnus dabryanus*	0	0	16	<0.1
Sacramento Blackfish	*Orthodon microlepidotus*	0	0	16	<0.1
Fathead Minnow	*Pimephales promelas*	0	0	8	<0.1
Loach (all spp.)	*Cobitoidea*	0	0	8	<0.1
River Lamprey	*Lampetra ayresi*	0	0	8	<0.1
Shokihaze Goby	*Tridentiger barbatus*	0	0	8	<0.1
Wakasagi	*Hypomesus nipponensis*	0	0	8	<0.1
Blue Catfish	*Ictalurus furcatus*	0	0	5	<0.1
Pacific Staghorn Sculpin	*Leptocottus armatus*	0	0	4	<0.1
White Crappie	*Pomoxis annularis*	0	0	4	<0.1
Hitch	*Lavinia exilicauda*	0	0	1	<0.1

Table 3. Chinook Salmon annual salvage, percentage of annual salvage, race and origin (wild or hatchery), and loss at the State Water Project and the Central Valley Project, Water Year 2023.

Facility	Origin	Race	Salvage	Percentage	Loss
SDFPF	Wild	Fall	1,762	96.7	7,878
SDFPF	Wild	Late-fall	8	0.4	35
SDFPF	Wild	Spring	52	2.9	230
SDFPF	Wild	Winter	0	0	0
Total Wild	—	—	*1,822*	—	*8,143*
SDFPF	Hatchery	Fall	5	0.2	21
SDFPF	Hatchery	Late-fall	456	19.2	1,977
SDFPF	Hatchery	Spring	1,884	79.4	8,174
SDFPF	Hatchery	Winter	28	1.2	123
Total Hatchery	—	—	*2,373*	—	*10,295*
Grand Total	—	—	***4,195***	—	***18,438***
TFCF	Wild	Fall	17,484	97.9	11,612
TFCF	Wild	Late-fall	28	0.1	20
TFCF	Wild	Spring	344	1.9	259
TFCF	Wild	Winter	4	<0.1	3
Total Wild	—	—	*17,860*	—	*11,894*
TFCF	Hatchery	Fall	40	1.2	33
TFCF	Hatchery	Late-fall	372	11.6	275
TFCF	Hatchery	Spring	2,797	87.1	2,221
TFCF	Hatchery	Winter	4	0.1	3
Total Hatchery	—	—	*3,213*	—	*2,532*
Grand Total	—	—	***21,057***	—	***14,426***

Figure 7. Annual salvage of Delta Smelt at the State Water Project and the Central Valley Project, Water Years 1981 to 2023. The logarithmic scale is log10.

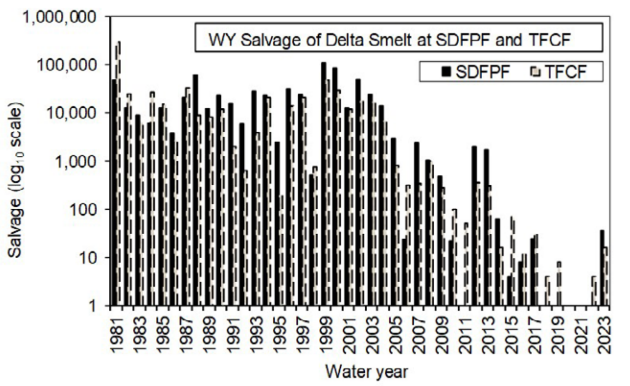


Figure 8. Annual salvage of Longfin Smelt at the State Water Project and the Central Valley Project, Water Years 1981 to 2023. The logarithmic scale is log10.

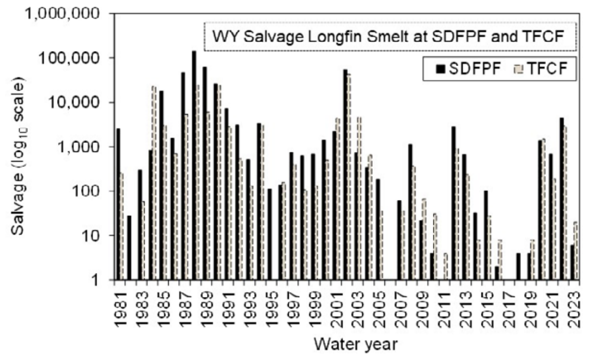
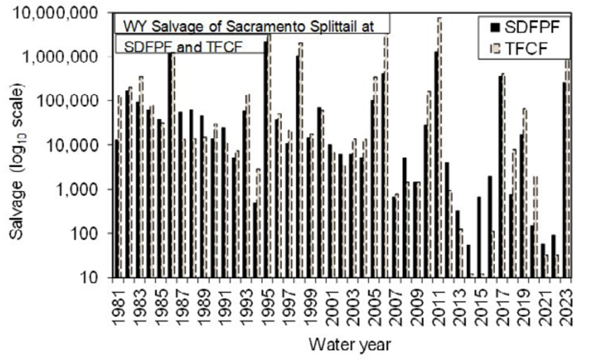


Figure 9. Annual salvage of Sacramento Splittail at the State Water Project and the Central Valley Project, Water Years 1981 to 2023. The logarithmic scale is log10.



FL) at the SDFPF in WY 2023 was also low (16) and were also of hatchery origin from releases in winter 2023. The last incidence of Delta Smelt salvage (wild) at SDFPF was in 2017 (25). The absence of Delta Smelt at the SDFPF is particularly notable as 1,701 fish were salvaged from this facility as recently as WY 2013. This follows general population decreases as observed in recent survey data (Tempel et al. 2021).

No Delta Smelt less than 20 mm FL were detected at the TFCF in WYs 2016–2019 or 2021–2023, and only one individual was sampled in WY 2020. No Delta Smelt less than 20 mm FL have been detected at the SDFPF since 2016.

Longfin Smelt

Salvage of Longfin Smelt (86–101 mm FL) at the SDFPF in WY 2023 (6) was a large decrease from WYs 2020–2022 (677–4,494) but similar to WYs 2017–2019 (0–4). Longfin Smelt (74–110 mm FL) salvage at the TFCF in WY 2023 (20) was also a large decrease from WYs 2020–2022 (188–2,954) but similar to WYs 2017–2019 (0–8; **Figure 8**). Low annual salvage of Longfin Smelt has generally been observed since 1995 and generally coincides with the declining annual populations of Longfin Smelt (Tempel et al. 2021). After 1995, the only exception occurred in WY 2002, when Longfin Smelt salvage was 43,056 at TFCF and 54,594 at SDFPF. It is uncertain why Longfin Smelt salvage continued to increase during WYs 2020–2022 but may be related to the recent increase in the population seen in the South Bay and the Delta (Gross et al. 2022; Tempel et al. 2021). Increases in Longfin Smelt salvage could also be an observed distributional shift as the Estuary gets saltier during dry years pulling Longfin Smelt upstream and closer to the facilities (Dege and Brown 2004). In contrast, high outflows in WY 2023 may have flushed Longfin Smelt downstream and outside the influence of the facilities pumps and water exports.

Salvage of adult Longfin Smelt at the SDFPF occurred equally in January and March. Salvage of adult Longfin Smelt at the TFCF occurred in January and February with peak salvage in January (16). No juvenile Longfin Smelt were salvaged at either facility which differed substantially from WYs 2020–2022 when all salvaged Longfin Smelt were juveniles.

No Longfin Smelt less than 20 mm FL were detected in qualitative larval sampling at the SDFPF, which was a decrease from WY 2022 (detected on 9 days) and WYs 2018 and 2021 (2 days), while none were detected in WYs 2017 and 2019. No Longfin Smelt less than 20 mm FL were detected at the TFCF, which was a decrease from WY 2022 (31), WY 2021 (13), and WY 2020 (18), while none were detected in WYs 2019–2017 (0).

Sacramento Splittail

Salvage of Sacramento Splittail (20–585 mm FL) in WY 2023 at the SDFPF (260,053) was within the upper range of WYs 2012–2022 (55–355,538; **Figure 9**). The largest salvage on record was WY 1995 (2,190,435), which was another high outflow year.

Figure 10. Annual salvage of Threadfin Shad at the State Water Project and the Central Valley Project, Water Years 1981 to 2023.

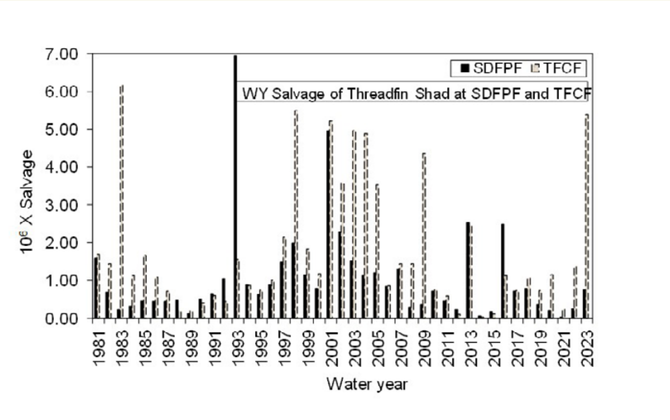
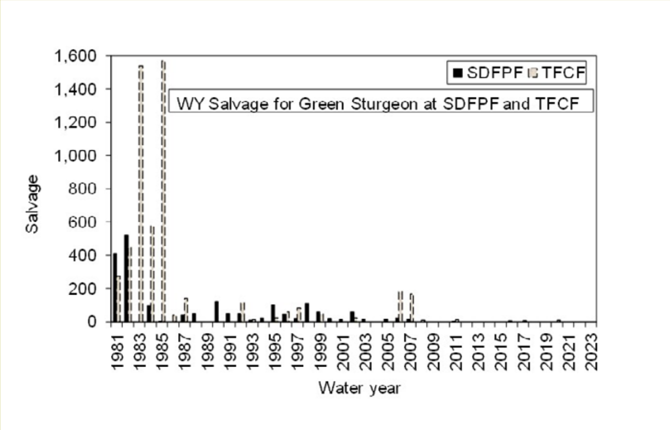


Figure 11. Annual salvage of Green Sturgeon at the State Water Project and the Central Valley Project, Water Years 1981 to 2023.



Salvage at the TFCF (20–527 mm FL) in WY 2023 (2,063,115) was a large increase from WYs 2012–2022 (12–415,517). The largest salvage on record was WY 2011 (7,660,024). Record low salvages occurred at SDFPF in 2014 (55) and in WYs 2014–2015 (12) at TFCF. Sacramento Splittail salvage estimates have followed a boom-or-bust pattern, often varying year to year by several orders of magnitude. High Sacramento Splittail salvage is generally associated with high outflow years and high young-of-the-year recruitment (Wang and Reyes 2007).

Threadfin Shad

Annual salvage in WY 2023 of Threadfin Shad (20–338 mm FL) was much lower at the SDFPF (758,061) than at the TFCF (5,395,049; **Figure 10**). Salvage at the TFCF in WY 2023 was substantially higher than in WY 2022 (1,358,630) and substantially higher than WYs 2017–2021 (731,760–1,358,630). Salvage at the SDFPF in WY 2023 was substantially higher than in WY 2022 (259,991) and similar to WYs 2017–2021 (213,244–799,776). Similar to Sacramento Splittail, annual salvage estimates of Threadfin Shad are highly variable between WYs.

Green Sturgeon

No Green Sturgeon were salvaged at the SDFPF in WY 2023 as in WY's 2017–2022. The last Green Sturgeon salvage occurred in WY 2016 (4). No Green Sturgeon were salvaged at the TFCF in WY 2023, which was a decrease from WY 2020 (8), and equal to WYs 2018–2019 and WYs 2021–2022 (0) (**Figure 11**). Low annual salvages (<200 individuals) have generally been observed since 1983 at SDFPF and since 1986 at TFCF. A second distinct decline in salvage is seen since WY 2008 for both facilities.

Summary

Salvage has a complex relationship between many parameters including export rate, outflow, climate, droughts, timing of winter storms, population size, biological opinions for listed species, and regulatory compliance among other factors. In contrast to WY 2022, large increases in WY 2023 salvage of species including Chinook Salmon, Steelhead, Striped Bass, cultured Delta Smelt, and Sacramento Splittail were recorded, likely attributable to increased rainfall and outflow which increased juvenile populations and flushing of fish downstream within the reach of the facilities pumps which also increased exports in WY 2023. Salvage of Green Sturgeon remained equal or within the low range of salvage from WYs 2017–2022, most likely due to low population size. But noteworthy was the WY 2023 Longfin Smelt salvage which was a large decrease from WYs 2020–2022, most likely because high outflows flushed the Longfin Smelt downstream and outside the influence of the facilities pumps and water exports (Gross et al. 2022).

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Remembering Geir Aasen

In November 2025, we lost a friend and colleague, Geir Aasen. Geir, a CDFW environmental scientist, was the lead salvage database scientist, responsible for one of California's longest running fish monitoring datasets. Geir had a plethora of salvage database knowledge and expertise, and he regularly applied his depth of experience to complex issues in the Delta ecosystem.

Geir was known across multiple wildlife agencies, working in collaboration with both state and federal groups to monitor and protect fish and other wildlife in the Delta.

Outside of his work, Geir was an avid outdoorsman and loved to spend his weekends hunting or fly fishing for trout, both here in California as well as in Norway where he was raised. While many scientists may hope during their terms to make a difference in environmental science and conservation, Geir's work established real protocols and monitoring practices to help protect California's natural resources. Geir is remembered by many for his wry sense of humor, his entertaining stories, his practical advice, and his patient teaching ability.

Beyond his professional contributions, Geir left a lasting mark on the people fortunate enough to work alongside him. His willingness to share knowledge, lend a hand, and approach challenges with patience and humility made him not only a respected scientist but a trusted colleague.

DATA REPORT

San Joaquin River White Sturgeon (*Acipenser transmontanus*) Telemetry Study

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Introduction

Little is known about the migratory habits of San Francisco Estuary White Sturgeon (*Acipenser transmontanus*) and their use of the San Joaquin River, California. In 2007, California Department of Fish and Wildlife (CDFW) implemented Sturgeon Report Cards to monitor and evaluate sturgeon populations. This program requires all individuals participating in the White Sturgeon Recreational Fishery to purchase a Sturgeon Report Card (SRC). The adoption of a SRC program has helped the CDFW document sturgeon captured or recreationally harvested each year. These SRCs are either returned to CDFW when a White Sturgeon is harvested within the slot limit of 40 to 60 in or at the end of the year to provide additional data and help with setting recreational harvest limits. The CDFW SRC data has shown that White Sturgeon are captured throughout the San Joaquin River.

The U.S. Fish and Wildlife Service's (USFWS) Anadromous Fish Restoration Program (AFRP) first surveyed and successfully detected White Sturgeon eggs in the San Joaquin River in 2011, approximately 40 river kilometers (rkm) downstream from the San Joaquin River Restoration Program (SJRRP) Restoration Area (RA) (Jackson et al. 2016) near the town of Patterson. Discovery of eggs led the USFWS to initiate an acoustic tagging and telemetry program for White Sturgeon in Spring 2012 to better understand the spawning migration, periodicity, and reproductive success of this species within the San Joaquin River below the confluence with the Merced River. These studies suggested a spring migration and spawning window for White Sturgeon from February through May (Heironimus et al. 2015) and the potential for successful spawning in the San Joaquin River even during dry water years (e.g., 2012 and 2016). Furthermore, the migratory path of this species includes the river's confluence with the Merced River near Hills Ferry. From 2016 to 2018, Lodi Fish and Wildlife Office (LFWO) fish biologists successfully detected twelve tagged White Sturgeon at Hills Ferry, the furthest downstream entrance to the RA. Acoustic detections of each individual fish provide invaluable data supporting spatial and temporal trends of White Sturgeon migration and habitat use within the San Joaquin River and RA.

The capture of two White Sturgeon and the first documented capture of a Green Sturgeon (*A. medirostris*) in the RA occurred during SJRRP salmonid monitoring efforts at Hills Ferry in March and April 2019, further supporting that sturgeon use the RA. To expand White Sturgeon monitoring in the San Joaquin, three receivers were deployed upstream of Hills Ferry near the Fremont Ford Bridge, Van Clief Road, and below the Sack Dam in 2019, but were removed shortly thereafter due to issues with routine accessibility. Limited receiver deployments due to funding, accessibility, and routine maintenance issues are emblematic of constraints to LWFO's effort to track White Sturgeon and have prevented a full exploration of migratory corridors, distribution, and potential barriers that require remediation to facilitate upstream migration and habitat use.

This study tracked the migration and habitat use of White Sturgeon that have been acoustically tagged as early as 2012 (**Figure 1**), as well as additional sturgeon that have been tagged annually below major migratory barriers in the RA. An array of 24 acoustic receivers previously existed in the main stem of the San Joaquin River and its tributaries (Merced, Stanislaus, and Tuolumne rivers), stretching from directly upstream of the confluence of the San Joaquin and Merced rivers downstream to directly upstream of Mossdale. In 2022, LFWO extended this array by installing three additional acoustic receivers further upstream into the RA (indicated with an asterisk in **Table 1** and visually represented in the **Figure 2** inset). New receiver site locations, include: (1) Valley Grasslands State Park on the San Joaquin River (labeled SJR LVG); (2) near Van Clief Road in the San Joaquin River directly downstream of the Eastside Bypass (labeled SJR VC); and (3) at a site directly downstream of the Van Clief Diversion Fish Passage Project in the Eastside Bypass (labeled EB DS KRW; **Table 1**; **Figure 2**).

Figure 1. USFWS measuring and inserting an acoustic tag in a White Sturgeon captured at Sturgeon Bend in the San Joaquin River downstream of the Restoration Area.

Methods

From 2012 through 2018, we tagged 91 White Sturgeon with 69 kHz Vemco© acoustic transmitters and Passive Integrated Transponder (PIT) tags. In 2022, acoustic tagging occurred from February through May. We captured adult White Sturgeon using gill and trammel nets used in the previous White Sturgeon studies conducted by the LFWO (**Figure 3**). From February 28 through May 3, 2022, we sampled with gill and trammel nets for 16 of the days. We captured and tagged sturgeon following standard operating procedures that were previously established by the LFWO. LFWO installed three new acoustic receivers (VR2W–69 kHz stationary receivers, Vemco©, Bedford, Nova Scotia) in the RA on February 23 and 25, 2022. We maintained the remaining 24 receivers within the array by offloading data every four months, installing new batteries every twelve months, and updating each device to the latest firmware when necessary. General River flow and water temperature data acquired from U.S. Geological Survey gage stations located near these receivers can provide further insight into potential drivers for White Sturgeon migratory behavior and habitat use. Data offloads from the three new receivers occurred on May 17 and 19, 2022. Additional data offloading for two of three receivers occurred on February 15 and 17, 2023; however, we were unable to offload the most upstream receiver due to high flows that overtopped the stream bank preventing access to the receiver. A partnership was developed between LFWO and CDFW to replace receiver batteries, update firmware, and offload and share data for the other 24 receivers within LFWO's acoustic receiver array. Partnering with CDFW in 2022 has helped improve efficiency for acoustic receiver array maintenance.

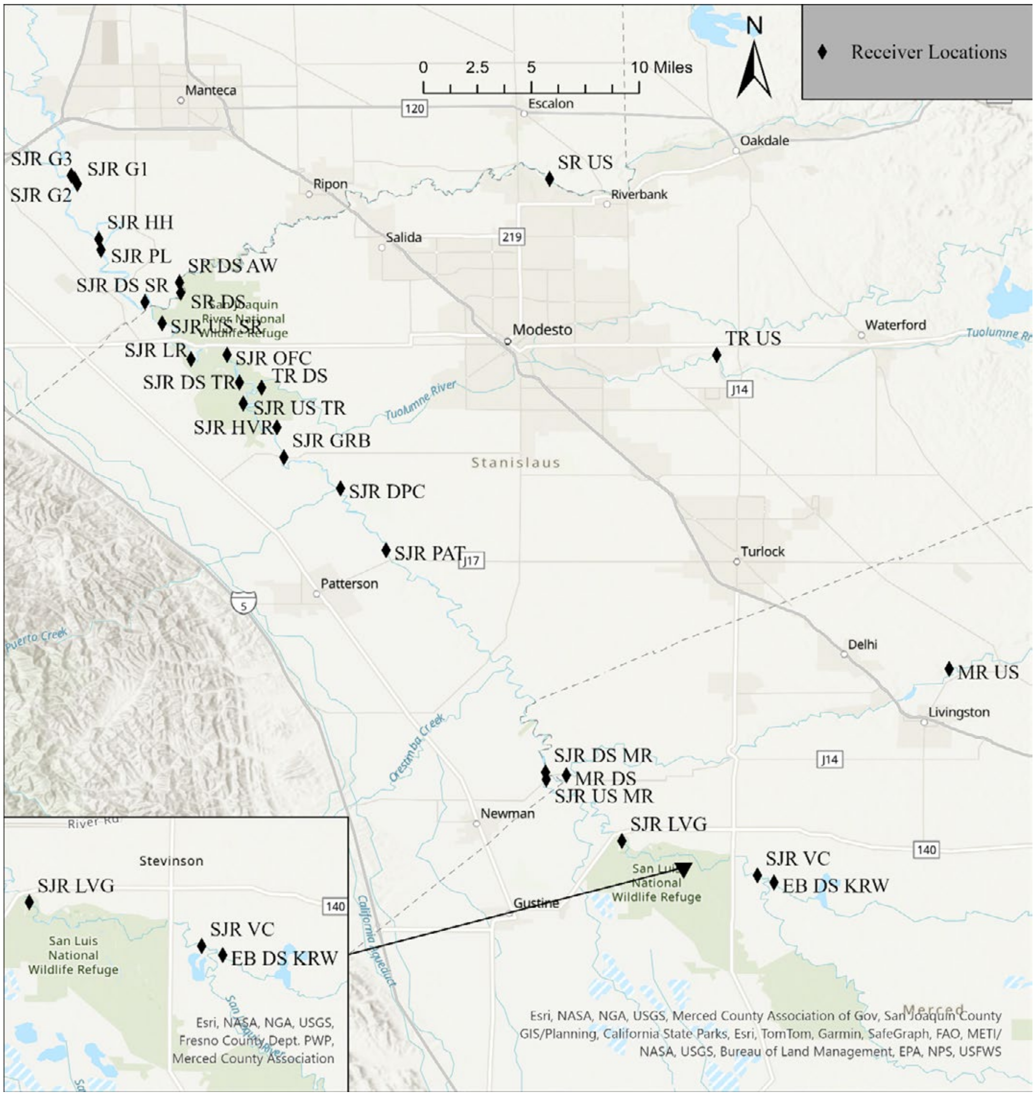
Table 1. Spatial geographic coordinates of the VR2W-69 kHz acoustic receiver sites in the San Joaquin River watershed in 2022. Coordinates are listed in order of downstream to upstream placement. The three new receivers (also the furthest upstream receiver sites) in the Restoration Area are displayed with an asterisk.

Receiver ID	Latitude (North)	Longitude (West)
SJR G1	37.74603102	-121.2906512
SJR G2	37.74959	-121.29254
SJR G3	37.75198	-121.29489
SJR HH	37.70935	-121.27642
SJR PL	37.70205	-121.27496
SJR DS SR	37.66708332	-121.2454881
SJR US SR	37.65287	-121.23399
SJR OFC	37.63171	-121.19047
SJR DS TR	37.61316	-121.1822167
SJR US TR	37.59907	-121.17965
SJR HVR	37.58312	-121.1571
SJR GRB	37.56294	-121.15241
SJR DPC	37.54216	-121.14447
SJR DS MR	37.35784291	-120.9776185
SJR US MR	37.34689254	-120.9766461
SR US	37.74968	-120.9744
SR DS	37.67329	-121.22156
SR DS AW	37.68023	-121.22237
TR US	37.6316	-120.86243
TR DS	37.60968	-121.16737
MR US	37.42092	-120.70667
MR DS	37.349648	-120.9631431
SJR LR	37.6287483	-121.2146464
EB L MR	37.17749751	-120.6519769
EB DS KRW*	37.27774152	-120.8240527
SJR VC*	37.28251662	-120.8351561
SJR LVG*	37.30559158	-120.925963

Results

During our first year of monitoring with the three new receivers (February 2022 through January 2023), they stayed active, collecting data in the RA. In fact, a female White Sturgeon was detected for 4 minutes on January 14, 2023, near Valley Grassland State Park (site code SJR LVG). This fish had previously been tagged in the San Joaquin River by the LFWO on April 1, 2015, where it was immediately released back into the San Joaquin River. The individual was 154-cm long (fork length) with a 66-cm girth at its original tagging. These acoustic detections at the Valley Grasslands State Park receiver indicate that this fish migrated at least 12.1 rkm upstream from the downstream entrance

Figure 2. VR2W-69 kHz acoustic receiver sites in the San Joaquin River watershed in 2022, with emphasis on the three new receivers furthest upstream in the Restoration Area (see figure inset).



of the RA. With the furthest upstream acoustic receiver in the Eastside Bypass being inaccessible due to high flows in February 2023, we do not currently know if this tagged White Sturgeon migrated further up the river corridor until this receiver gets rechecked at later date. These data may provide further insight about this individual's migration path and habitat use within the RA after being detected at Valley Grasslands State Park.

We had captured a total of 16 White Sturgeon, 19 Common Carp (*Cyprinus carpio*), and one Striped Bass (*Morone saxatilis*) from March 23 through May 3, 2022. The geographic coordinates of the captured White Sturgeon are reported in **Table 3** along with the spatial extent depicted in **Figure 4**. These captures included 14 White Sturgeon that had not been previously captured or tagged by LFWO or other Central Valley monitoring projects. The remaining two captures were recaptured individuals (**Table 2**). LFWO captured one White Sturgeon that had been originally captured and tagged with a PIT tag previously on March 20, 2012, at a measured fork length of 125 cm. When it was recaptured on March 23, 2022, it had a measured fork length of 143 cm with a 55 cm girth which equates to a growth rate of 1.8 cm of length per year since 2012. The other recaptured White Sturgeon had been originally captured, tagged, and released at Sturgeon Bend on March 24, 2022, and then recaptured at Sturgeon Bend again on March 28, 2022. When this

Table 2. White Sturgeon captures from gill and trammel net surveys in the San Joaquin River from March 1 through May 3, 2022. For fish that were not recaptured, tag IDs indicate the tags implanted at capture.

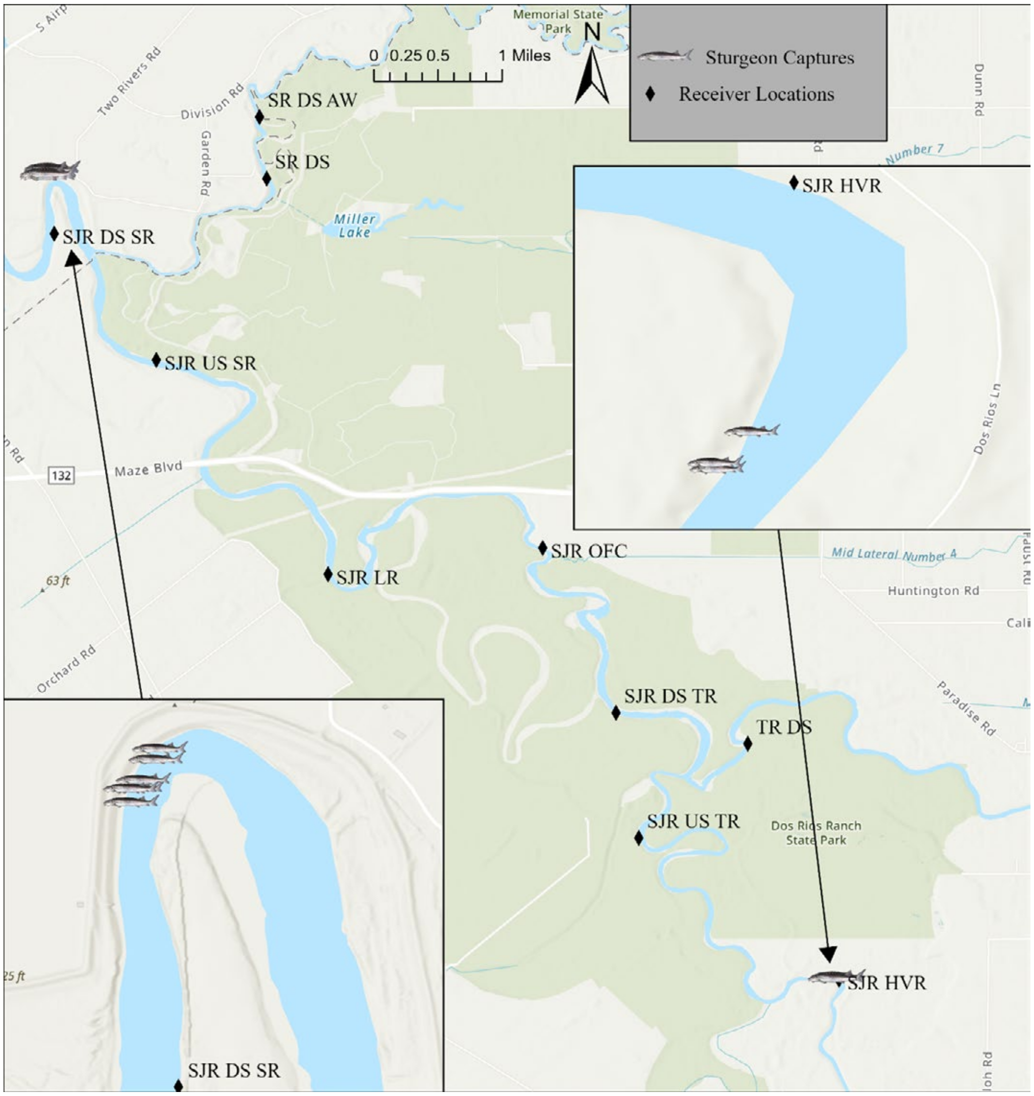
Date	Length (cm)	Girth (cm)	Recapture	Pit Tag ID	Acoustic Tag ID
03/23/22	145	74.5	No	900226000765244	19529
03/23/22	-	-	No	-	-
03/23/22	184	68	No	900226000765288	19532
03/23/22	-	-	No	-	-
03/23/22	143	55	Yes	985121021183148	63053
03/23/22	104	-	No	-	-
03/23/22	174	62	No	900226000765276	19531
03/24/22	152	61	No	900226000765278	19536
03/28/22	-	-	Yes	900226000765278	19536
03/28/22	162	65	No	900226000765286	19530
03/31/22	155	61	No	900226000765213	19533
03/31/22	121	44	No	900226000765249	19527
04/05/22	130	51	No	900226000765256	19528
04/55/22	153	65	No	900226000765279	19539
04/28/22	154	62	No	900226000765238	19534
05/03/22	114	47	No	900226000765205	19537

Table 3. Spatial geographic coordinates of the captured White Sturgeon from March 1 through May 3, 2022, that received an acoustic tag, noting that some individuals were recaptures of previous tagging events.

Acoustic Tag ID	Latitude (North)	Longitude (West)
19529	37.672528	-121.245827
19532	37.671851	-121.246229
19531	37.671615	-121.246314
63053	37.671615	-121.246314
19531	37.671615	-121.246314
19536	37.672000	-121.246105
19536	37.671851	-121.24632
19530	37.671851	-121.24632
19533	37.581271	-121.157573
19527	37.581496	-121.157364
19528	37.581307	-121.157586
19539	37.581307	-121.157586
19534	37.671641	-121.246171
19537	37.671772	-121.24632

Figure 3. USFWS field crew setting a trammel net in the San Joaquin River to capture adult White Sturgeon for biological data collection and acoustic tag insertion.

Figure 4. White Sturgeon capture locations in the San Joaquin River watershed in 2022. Nearby VR2W-69 kHz acoustic receiver sites were displayed for spatial reference.



fish was recaptured on March 28, 2022, the suture condition and overall biological condition was visually assessed. The sutures were still intact, and the incision showed no signs separation or secondary infection prior to its immediate release back into the San Joaquin River. On March 23, 2022, we captured seven White Sturgeon in the first 30 minutes of sampling. To minimize stress and risk of mortality, three of the White Sturgeon were released without being tagged, and only one of the three had been measured prior to being released. We measured the remaining four, tagged them with PIT and acoustic tags, and released them after recovering from surgery. The remaining eight White Sturgeon captures included seven individuals that had been measured, tagged, and released. The 2022 tagging season was successful and allowed the LFWO to implant PIT and acoustic tags into 11 new White Sturgeon. This effort also provided growth information from a White Sturgeon that received a tag by the LFWO a decade ago.

Discussion

The 11 White Sturgeon tagged in 2022 increased the total number of LFWO-tagged White Sturgeon to 102 individuals. Although 102 individuals have been tagged since 2012, the battery life for V16-4x acoustic tags is approximately 10 years. Therefore, we can safely assume that the 10 acoustic tags implanted in 2012 stopped transmitting acoustic signals by May 2022, and the 18 acoustic tags implanted in 2013 stopped transmitting acoustic signals by May 2023. These losses in ability to detect sturgeon tagged in 2012 and 2013 does not account for losses of individuals due to recreational harvest, predation, or other causes of mortality. The CDFW also reported that one of the PIT and acoustic tagged White Sturgeon tagged by LFWO in 2014 was harvested in the California White Sturgeon recreational fishery in 2022. Based on this information, the maximum number of White Sturgeon tagged by LFWO and transmitting acoustic signals for the acoustic telemetry project in the San Joaquin River consists of only 73 individuals today. However, the CDFW has also tagged White Sturgeon and even one Green Sturgeon and installed acoustic receivers at alternate locations within the San Joaquin Basin. The combination of these two receiver arrays allowed both the LFWO and the CDFW receivers to detect the holding and outmigration of the tagged Green Sturgeon in 2022 through 2023. Although this effort to tag sturgeon in the San Joaquin River has continued, the total number of sturgeon available to provide data for understanding migratory corridors, distribution, and potential barriers that require remediation is a moving target because each year the total number of acoustically tagged sturgeon in the San Joaquin River will decrease as batteries expire. It is essential that LFWO continues this baseline effort of maintaining the acoustic array and capturing and tagging additional White Sturgeon in the San Joaquin River to better understand how they are using the RA and to identify if future fish passage projects successfully allow sturgeon passage.

Although LFWO has been focused on tagging and tracking the movement of adult and sub-adult White Sturgeon in the San Joaquin River, expanding this effort to collect data for all life stages of both Green Sturgeon and White Sturgeon should be prioritized for the San Joaquin and Sacramento rivers, as well as other tributaries in the Central Valley of California. The AFRP developed a charter in 2023 specifying Green Sturgeon and White Sturgeon information needs for the Central Valley Project Improvement Act (CVPIA) to guide activities to inform the Near-Term Restoration Strategy (NTRS) and further the development of the sturgeon decision support model. This charter specifies metrics for both Green Sturgeon and White Sturgeon: 1) identifying habitat suitability criteria for juveniles and adults based on field validation; 2) estimating habitat availability in acres at various flows; 3) estimating juvenile abundance; 4) estimating adult abundance; and 5) developing a 2-D hydrodynamic model based on the availability of existing models. The tasks outlined within the NTRS included five information priorities for the sturgeon. These five priorities included: 1) early juvenile survival and growth of wild fish (larvae to age-1 [first ocean migration]); 2) adult and sub-adult survival and movement (system wide); 3) spawner abundance monitoring; 4) estimate juvenile rearing and adult spawning habitat availability (system wide); and 5) White Sturgeon spawning distribution. Although these tasks have been identified as information priorities, only a few ongoing efforts are collecting data that could be used to inform the sturgeon decision support models, which in turn, will support the development of future recommendations for restoration emphasis to the implementing agencies.

The LFWO is currently collecting data that could be used to help inform priority 2. However, this effort is only focused on White Sturgeon and is constrained to rkm 62 to 135 in the San Joaquin River with the first 0.5 rkm in the Eastside Bypass, first 32 rkm in the Stanislaus, and first 23 rkm in both the Tuolumne and Merced rivers. From 2011 through 2018, LFWO conducted White Sturgeon spawning surveys to confirm and identify where spawning occurred in the San Joaquin River. However, spawning surveys were discontinued due funding constraints. If additional funding was secured, it could be used to identify suitable habitat and flows for spawning in the San Joaquin River (priority 4). In addition, these surveys could provide invaluable information to initiate studies focused on capturing, tagging, and tracking the movement of young-of-year White Sturgeon to address information about early juvenile survival, growth, and habitat availability (priorities 1 and 4). While these efforts would not fill all the data gaps that have been prioritized, it would increase White Sturgeon monitoring activities in the San Joaquin River and its tributaries and could collect initial data on Green Sturgeon to inform the CVPIA NTRS and further the development of a decision support model.

Acknowledgements

LFWO would like to acknowledge the SJRRP, including U.S. Bureau of Reclamation, for land access permission at several locations to deploy the receivers in the SJRRP RA. Previous acoustic tagging and receiver efforts were funded by USFWS, and U.S. Bureau of Reclamation under the CVPIA AFRP. Various contributors and partners, including universities and the CDFW, are involved in maintaining and deploying new acoustic tag receiver arrays downstream that contribute to the network of shared data in the sturgeon monitoring community. Special thanks to the California Fish Passage Forum for funding and supporting the new receiver installation, existing receiver maintenance, sturgeon tagging, and reporting activities planned for 2024. Data will be made available upon contacting the Corresponding Author directly. Any use of trade, product, website, or firm names in the publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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DATA REPORT

2023 Delta Juvenile Fish Monitoring Program Salmonid Annual Report

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Introduction

Intraspecific diversification of Pacific Salmon (*Oncorhynchus* spp.) has occurred for the past six million years (Waples et al. 2008). At or near the southern end of their global distribution, California Central Valley salmonids have evolved complex life histories in response to the highly dynamic and variable environmental conditions in the Sacramento–San Joaquin Delta (Delta) watershed, including a fall-, late fall-, winter- and spring-run of Chinook Salmon (*O. tshawytscha*) (Yoshiyama et al. 1998) and summer and winter Steelhead runs (*O. mykiss*) (McEwan 2001). Due to a combination of habitat loss and degradation (especially blockage of historically available habitat, water diversions, and altered flow and water temperature regimes), harvest pressures, and introduced competitors, predators, and diseases since Euro-American colonization, only small fractions of historical population numbers currently remain of these iconic species (NMFS 2014). The summer Steelhead run has been extirpated, the Chinook Salmon winter-run Distinct Population Segment (DPS) is listed as endangered, and both the spring-run Chinook Salmon DPS and spring-run Steelhead DPS are listed as threatened under the federal Endangered Species Act. The Central Valley fall-run/late fall-run Chinook Salmon DPS dominates the population complex, is currently unlisted, and supported heavily by hatchery supplementation (Huber and Carlson 2015; Sturrock et al. 2019). The commercial salmon fishery was closed in 2008–2009 and 2023–2024 due to low population numbers.

California Central Valley Chinook Salmon and Steelhead use the Delta for rearing and migration. Juvenile salmonids must travel from upstream natal tributaries through the Delta before exiting the San Francisco Estuary (Estuary) and entering the Pacific Ocean through the Golden Gate. Approximately 27% of water flowing through the Delta is allocated to the Central Valley Project (CVP) and State Water Project (SWP) to supply water to over 29.5 million Californians and 3.75 million acres of farmland (LAO 2008). These and other water diversions throughout the Delta have the potential to negatively affect salmonid rearing, survival, and migration pathways (Kimmerer 2008; NMFS 2009, 2019). The impacts of these hydrological alterations depend on the timing and distribution of salmonids in the system, which vary interannually (Munsch et al. 2019). Since 1976, the U.S. Fish and Wildlife Service's Delta Juvenile Fish Monitoring Program (DJFMP) has monitored the annual timing, distribution, relative abundance, and survival of juvenile salmonids and other fishes throughout the Delta to improve our understanding of salmonid ecology and mitigate the impacts of the CVP and SWP water export operations on their populations.

The purpose of this report is to summarize juvenile salmonid surface trawl and beach seine sample data obtained during the 2023 (Aug 2022 to Jul 2023) DJFMP monitoring year (MY). Note that information for our non-salmonid catch trends can be found in the DJFMP Nearshore Fishes Annual Report also presented in this newsletter. We present status and trend information about 1) immigration into the Delta from the Sacramento and San Joaquin Rivers, 2) residency within the Delta, and 3) emigration from the Delta into the San Francisco Bay. We also present data about environmental conditions. The complete DJFMP dataset, including 1) a complete description of sampling procedures, 2) non-salmonid catch data, and 3) environmental data not included in this report, is available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2023).

Methods

Over the years as adaptive management information needs evolve, the DJFMP has used various gear types and sample frequencies throughout the year to examine the temporal and spatial distribution of fishes in lower river mainstem in-channel habitats and Delta and San Francisco Bay littoral zones. A complete description of the historical and current methods is available at the DJFMP Environmental Data Initiative Data Portal (IEP et al. 2023). The technical report produced by Dekar et al. (2013) contains detailed descriptions of the sampling equipment used.

Data Collection

During the 2023 MY, the DJFMP used a combination of surface trawl (mid-water [MWT] and Kodiak [KDT]) and beach seine sampling methods to monitor the distribution of juvenile salmonids (**Table 1**, **Table 2**). The DJFMP sampled 56 beach seine sites and three trawl sites throughout the Delta and Estuary (**Figure 1**). Trawl sites were located at the entry (Sherwood Harbor on the Sacramento River and Mossdale on the San Joaquin River) and exit (Chipps Island) points of the Delta (**Table 1**, **Figure 1**). We stratified the beach seine sites into seven geographic regions, including the (1) Lower Sacramento Seine, (2) North Delta Seine, (3) Central Delta Seine, (4) South Delta Seine, (5) Lower San Joaquin Seine (Delta Entrance Seine from San Joaquin River), (6) Bay Seine (San Francisco and San Pablo Bays), and the (7) Sacramento Seine (Delta Entrance Seine from Sacramento River) (**Table 2**, **Figure 1**). All monitoring was conducted year-round during daylight hours (between 06:00 and 18:00 PST).

The DJFMP exclusively used a MWT at the Chipps Island Trawl site and a KDT at the Mossdale Trawl site (**Figure 1**). The Sacramento River Trawl site used a KDT from October to March and a MWT for the remainder of the year (**Table 1**). The KDT was used in place of the MWT at the Sacramento site during winter and spring to maximize the capture of larger and less abundant runs of Chinook Salmon (Brandes et al. 2000). We sampled the Chipps Island and Sacramento River sites three times per week throughout the MY except between February and March or April, when sampling was increased to five times per week (**Table 1**). The reason for increased effort during winter and spring was to target salmon tagged and released in the Sacramento River as part of a study using coded wire and acoustic tags for survival, genetic monitoring, and trawl efficiency analyses.

The U.S. Fish and Wildlife Service (USFWS) conducts trawl sampling at the Mossdale site in collaboration with the California Department of Fish and Wildlife (CDFW) from July through September and again from January through March (three times per week). This cooperative effort involves an integrated sampling plan using a mix of crews and gear. The USFWS samples from October through December (three times per week), and CDFW samples from April through June (five to seven times per week) (**Table 1**, **Figure 1**). The increased sampling effort is required to adequately monitor juvenile salmon outmigration. Mossdale data collected from both DJFMP and CDFW monitoring programs are included in this report.

We aimed to conduct ten 20-minute tows at each trawl site per sample day. Occasionally hazardous environmental conditions or vessel or sampling gear failures reduced the total number of daily tows. The distance traveled during each tow was recorded using a mechanical flow meter (General Oceanics, model 2030R). All tows were performed facing upstream in the middle of the channel at the Sacramento and Mossdale Trawl

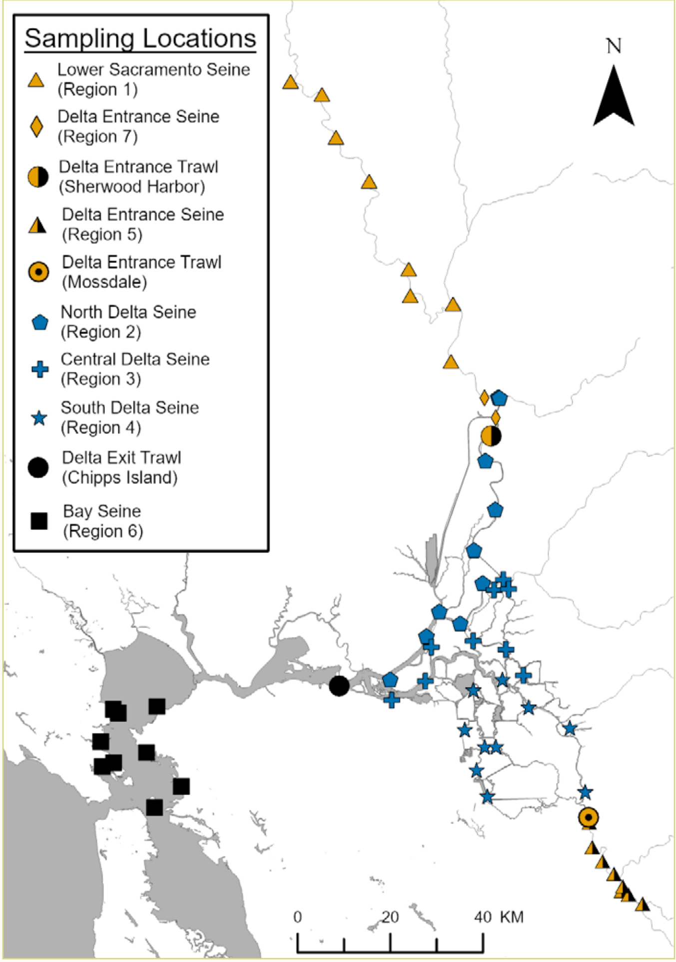
Table 1. Scheduled monthly sampling matrix indicating number of sampling days per week for trawls. Sampling methods include mid-water trawl (MWT) and Kodiak trawl (KDT) in the Sacramento River (Sac R), San Joaquin R (SJR), and at Chipps Island (Delta) which is located downstream of the confluence of the Sacramento and San Joaquin Rivers.

Trawl Region/Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sac R/Sherwood MWT	0	0	0	3	3	3	3	3	3	0	0	0
Sac R/Sherwood KDT	3	5	5	0	0	0	0	0	0	3	3	3
Delta/Chipps Island MWT	3	5	5	5	3	3	3	3	3	3	3	3
SJR/Mossdale KDT	3	3	3	5-7	5-7	5-7	3	3	3	3	3	3

Table 2. Scheduled monthly sampling matrix indicating number of sampling days per week for beach seines (a value of 0.5 indicates one sample every two weeks). Beach seine hauls were conducted in the Lower Sacramento River (SR1), North Delta (SR2), Central Delta (SR3), South Delta (SR4), San Joaquin River (SR5), San Francisco Bay (SR6) and Sacramento Region (SR7).

Seine Region/Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SR 1/Lower Sac R Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 2/North Delta Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 3/Central Delta Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 4 /South Delta Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 5 /SJR Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 6 /Bay Seine	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SR 7/Sac Seine	1	0	0	0	0	0	0	0	0	3	3	3

Figure 1. Map of the United States Fish and Wildlife Service Delta Juvenile Fish Monitoring Program surface trawl and beach seine sampling sites and regions in the Sacramento–San Joaquin Delta and San Francisco Bay.



sites, which have reach lengths of approximately 6.5 km and 3 km, respectively. In contrast, we conducted Chipps Island tows (~4 km reach length) facing both upstream and downstream in the channel's north, south, and middle lanes regardless of tidal stage. All channel lanes at Chipps Island are scheduled to be sampled each day, but the order and number of tows per lane are randomly selected (two lanes receive three tows each and one lane receives four tows per day).

We delineated seine regions by proximity to canals or water bypasses where fish may be diverted from historical migration routes. We used a 15.2 m x 1.3 m beach seine net with a 3 mm delta square mesh, a 1.2 m bag in the center of the net, and a float line and lead line attached to 1.8 m tall wooden poles on each side. Crew members generally deployed beach seines from the shoreline within unobstructed habitats including boat ramps, mud banks, and sandy beaches.

We scheduled all seine sites to be sampled once per week throughout the MY except for (1) San Francisco and San Pablo Bay Seine sites (scheduled once every two weeks) and (2) Sacramento Seine sites (scheduled three times per week from October through December and once per week in January; **Table 2**, **Figure 1**). Increased effort in the Sacramento region during fall and winter was done to strategically target federal Endangered Species Act endangered winter-run Chinook Salmon and inform Delta Cross Channel operations.

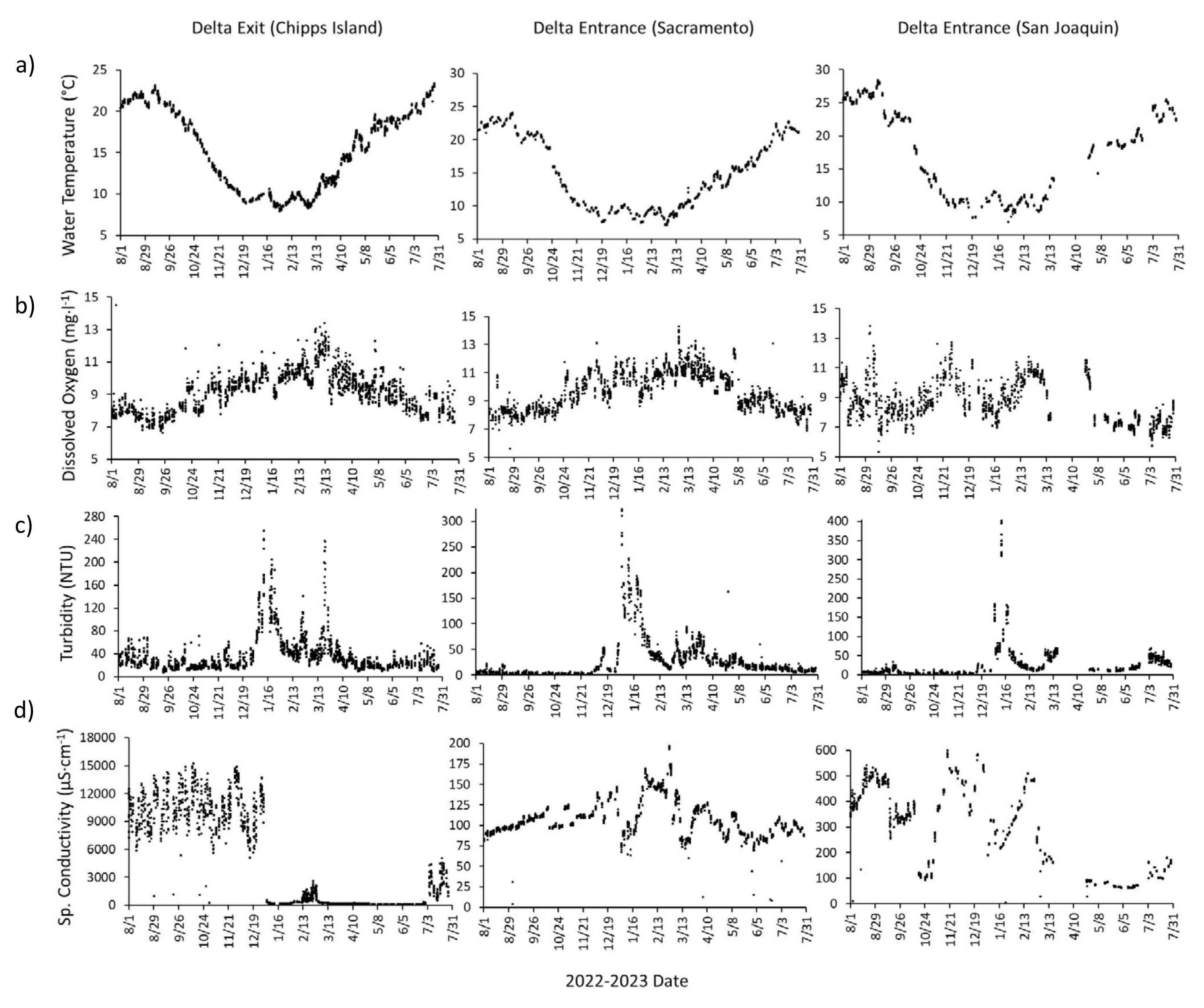
We measured sampled salmonids greater than or equal to 25 mm fork length (FL) to the nearest millimeter. We determined the race of all juvenile Chinook Salmon using the river Length-at-Date Criteria (LDC) developed by Fisher (1992) and modified by Greene (1992), except for individuals captured in the San Joaquin River Basin (i.e., Mossdale Trawl and Lower San Joaquin River Seine; **Figure 1**). Individuals sampled in the San Joaquin basin were classified as non-winter-run regardless of LDC since winter-run Chinook Salmon are not known to occur in the San Joaquin River watershed currently (Yoshiyama et al. 1998). A subsample of unmarked Chinook Salmon collected at each site was sampled for genetic information using caudal fin clips to verify race designation. If more than 50 individuals of a Chinook Salmon race were captured, we randomly selected a subsample of 50 individuals and measured for FL. The remaining fish were enumerated but not measured for size. We recorded all juvenile salmonids with adipose fin clips, pelvic fin clips (used to mark a specific brood stock of winter-run hatchery fish), and other forms of marks or tags (e.g., stain dye, disc tags, acoustic tags) as marked along with their respective marking and(or) tag type. All juvenile Chinook Salmon with adipose fin clips and intact pelvic fins were considered hatchery-origin and transported to the Lodi Fish and Wildlife Office for coded wire tag extraction and race and hatchery-origin determination (by cross-referencing data with the Regional Mark Information System database [RMIS 2023]). We recorded juvenile Chinook Salmon with adipose and pelvic fin clips as hatchery-reared winter-run and adipose fin-clipped juvenile Steelhead as hatchery-origin. We released all individuals soon after capture.

We measured water quality variables (water temperature, conductivity, dissolved oxygen, and turbidity) for each tow (**Figure 2**) or seine haul (**Figure 3**). Also, while not presented here, we measured Secchi depths for each tow, as well as substrate compositions and flow velocities for each seine haul. We obtained hydrological data from the California Department of Water Resource's DAYFLOW program.

Data Analysis

To compare the timing, distribution, and relative abundance of juvenile salmonids, we calculated mean monthly and annual catch-per-unit-effort (CPUE; catch per water volume sampled by seine haul or trawl tow) values for each seine region and trawl site. Before estimating CPUE, we excluded fish count data that were obtained during incomplete sampling procedures or technical difficulties like net twists or major cod-end blockages

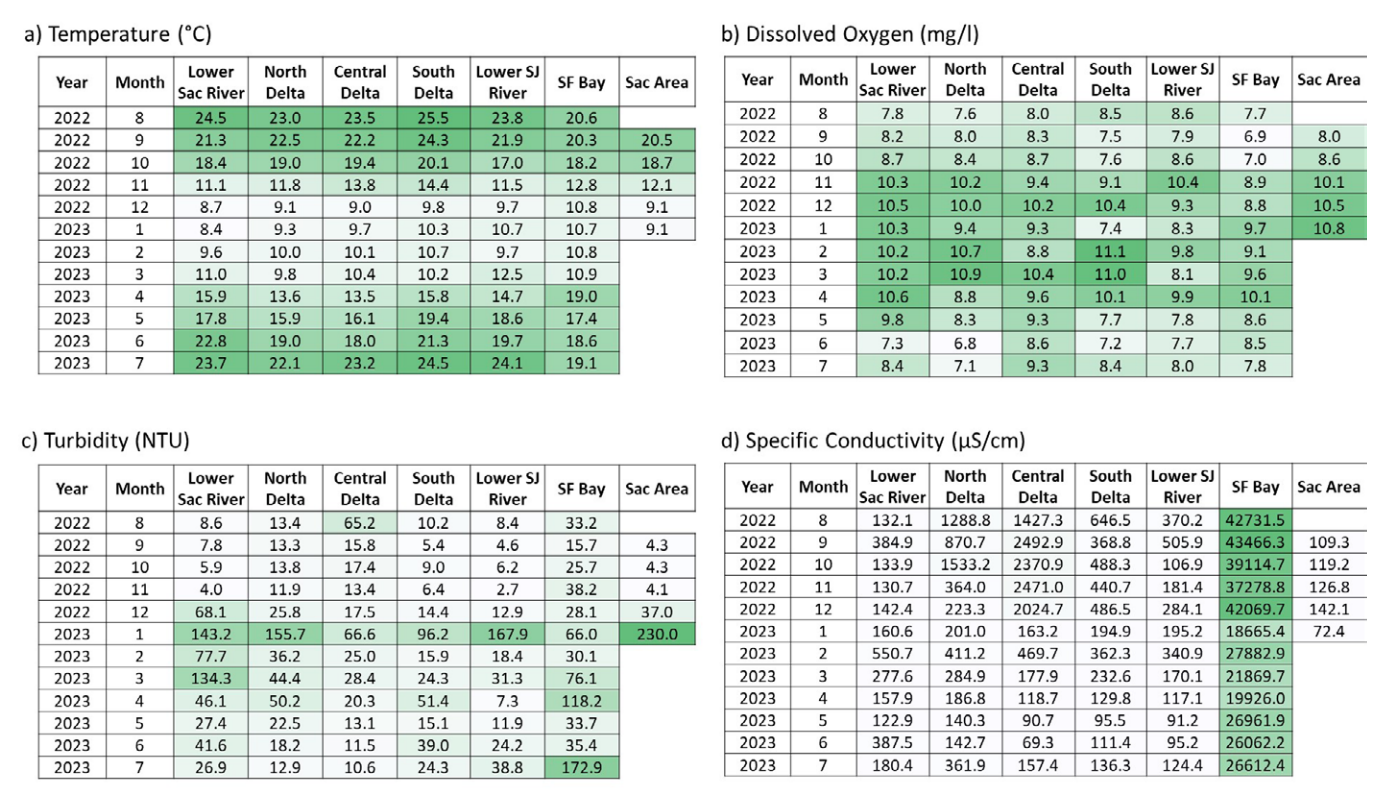
Figure 2. Water quality data for the three DJFMP trawl sites in the Sacramento–San Joaquin Delta during the 2023 monitoring year (August 2022 to July 2023). Water quality variables include (a) water temperature, (b) dissolved oxygen, (c) turbidity, and (d) specific conductivity.



(i.e., gear condition code >2 in the DJFMP dataset [IEP et al. 2023]) or flow meter technical difficulties. For seine surveys, we removed samples with missing volume estimates and volume outliers identified by the exceedance of the standard minimum and maximum seine net dimensions set by the DJFMP standard operating procedure for seine surveys. For trawls, volume outliers were identified as values outside the normal volume range of DJFMP trawls (1,000–50,000 m^3). We treat all adipose fin-clipped juvenile salmonids as marked hatchery fish in our dataset. Salmonids with other marks or tags (e.g., stain dye, disc tags, acoustic tags) used for special studies were excluded from our analyses (n=1 fish, MY 2023). Since 1998 (brood year 1997), all juvenile winter-run Chinook Salmon and Steelhead from Central Valley hatcheries have been adipose fin-clipped, so all unmarked individuals from these taxa were classified as natural-origin (USFWS 2011; NMFS 2014). For juvenile Chinook Salmon identified as non-winter-run, we estimated the number of hatchery- and natural-origin juveniles using the methods detailed in Graham et al. (2018) since hatchery-origin individuals are not all marked.

Calculations of mean monthly and annual CPUE values were performed in a manner to avoid overweighting sampling sites due to differences in sampling frequencies. Detailed descriptions of calculation methods are available in Nanninga and Huber (2022).

Figure 3. Monthly averages for water quality data for the seven DJFMP seine regions in the Sacramento–San Joaquin Delta during the 2023 monitoring year (August 2022 to July 2023). Water quality variables include (a) water temperature, (b) dissolved oxygen, (c) turbidity, and (d) specific conductivity. Conditional formatting applied with darker green representing highest average values.



a) Temperature (°C)

Year	Month	Lower Sac River	North Delta	Central Delta	South Delta	Lower SJ River	SF Bay	Sac Area
2022	8	24.5	23.0	23.5	25.5	23.8	20.6	
2022	9	21.3	22.5	22.2	24.3	21.9	20.3	20.5
2022	10	18.4	19.0	19.4	20.1	17.0	18.2	18.7
2022	11	11.1	11.8	13.8	14.4	11.5	12.8	12.1
2022	12	8.7	9.1	9.0	9.8	9.7	10.8	9.1
2023	1	8.4	9.3	9.7	10.3	10.7	10.7	9.1
2023	2	9.6	10.0	10.1	10.7	9.7	10.8	
2023	3	11.0	9.8	10.4	10.2	12.5	10.9	
2023	4	15.9	13.6	13.5	15.8	14.7	19.0	
2023	5	17.8	15.9	16.1	19.4	18.6	17.4	
2023	6	22.8	19.0	18.0	21.3	19.7	18.6	
2023	7	23.7	22.1	23.2	24.5	24.1	19.1	

b) Dissolved Oxygen (mg/l)

Year	Month	Lower Sac River	North Delta	Central Delta	South Delta	Lower SJ River	SF Bay	Sac Area
2022	8	7.8	7.6	8.0	8.5	8.6	7.7	
2022	9	8.2	8.0	8.3	7.5	7.9	6.9	8.0
2022	10	8.7	8.4	8.7	7.6	8.6	7.0	8.6
2022	11	10.3	10.2	9.4	9.1	10.4	8.9	10.1
2022	12	10.5	10.0	10.2	10.4	9.3	8.8	10.5
2023	1	10.3	9.4	9.3	7.4	8.3	9.7	10.8
2023	2	10.2	10.7	8.8	11.1	9.8	9.1	
2023	3	10.2	10.9	10.4	11.0	8.1	9.6	
2023	4	10.6	8.8	9.6	10.1	9.9	10.1	
2023	5	9.8	8.3	9.3	7.7	7.8	8.6	
2023	6	7.3	6.8	8.6	7.2	7.7	8.5	
2023	7	8.4	7.1	9.3	8.4	8.0	7.8	

c) Turbidity (NTU)

Year	Month	Lower Sac River	North Delta	Central Delta	South Delta	Lower SJ River	SF Bay	Sac Area
2022	8	8.6	13.4	65.2	10.2	8.4	33.2	
2022	9	7.8	13.3	15.8	5.4	4.6	15.7	4.3
2022	10	5.9	13.8	17.4	9.0	6.2	25.7	4.3
2022	11	4.0	11.9	13.4	6.4	2.7	38.2	4.1
2022	12	68.1	25.8	17.5	14.4	12.9	28.1	37.0
2023	1	143.2	155.7	66.6	96.2	167.9	66.0	230.0
2023	2	77.7	36.2	25.0	15.9	18.4	30.1	
2023	3	134.3	44.4	28.4	24.3	31.3	76.1	
2023	4	46.1	50.2	20.3	51.4	7.3	118.2	
2023	5	27.4	22.5	13.1	15.1	11.9	33.7	
2023	6	41.6	18.2	11.5	39.0	24.2	35.4	
2023	7	26.9	12.9	10.6	24.3	38.8	172.9	

d) Specific Conductivity (µS/cm)

Year	Month	Lower Sac River	North Delta	Central Delta	South Delta	Lower SJ River	SF Bay	Sac Area
2022	8	132.1	1288.8	1427.3	646.5	370.2	42731.5	
2022	9	384.9	870.7	2492.9	368.8	505.9	43466.3	109.3
2022	10	133.9	1533.2	2370.9	488.3	106.9	39114.7	119.2
2022	11	130.7	364.0	2471.0	440.7	181.4	37278.8	126.8
2022	12	142.4	223.3	2024.7	486.5	284.1	42069.7	142.1
2023	1	160.6	201.0	163.2	194.9	195.2	18665.4	72.4
2023	2	550.7	411.2	469.7	362.3	340.9	27882.9	
2023	3	277.6	284.9	177.9	232.6	170.1	21869.7	
2023	4	157.9	186.8	118.7	129.8	117.1	19926.0	
2023	5	122.9	140.3	90.7	95.5	91.2	26961.9	
2023	6	387.5	142.7	69.3	111.4	95.2	26062.2	
2023	7	180.4	361.9	157.4	136.3	124.4	26612.4	

Summary

Water Quality (Trawl Surveys)

During MY 2023 water temperatures ranged from 7.0 to 28.4°C, with both low and high extremes observed on the San Joaquin River (**Figure 2a**). Dissolved oxygen content reached the highest level of 25.7 mg·l-1 at the Delta Exit (Chipps Island) and the lowest level of 1.1 mg·l-1 on the Sacramento River (**Figure 2b**). Turbidity levels ranged from 7.4 to 255.0 NTU at the Delta Exit (Chipps Island) and from 1.4 to 402.0 NTU at the Delta Entrances (**Figure 2c**). Specific conductivity values had the widest range at the Delta Exit (Chipps Island) from 48.8 to 15,231.0 µS, with a significant decrease in January due to increased storm activity (**Figure 2d**).

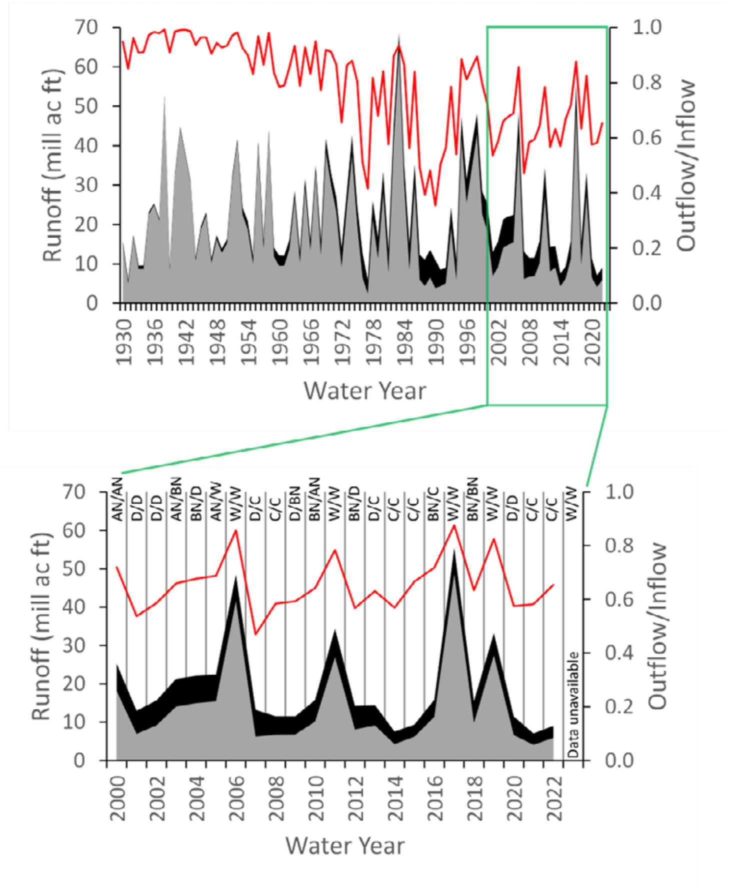
Water Quality (Seine Surveys)

During MY 2023, water temperatures were coolest in the North Delta and warmest in the South Delta, however overall averages between the regions differed by less than two degrees (**Figure 3a**). Dissolved oxygen content ranged from an overall average of 9.4 mg·l-1 in the Lower Sacramento River to 8.6 mg·l-1 in San Francisco Bay (**Figure 3b**). Turbidity levels were greatest in the San Francisco Bay with an overall mean of 56.1 NTU, and all regions saw a marked increase in turbidity during January due to increased storm activity (**Figure 3c**). As expected, specific conductivity average values were greatest in the San Francisco Bay and lowest in the Lower San Joaquin River (**Figure 3d**).

Historical Delta Hydrology

The highest Delta inflows occurred in water year 1983 (68.7·106 ac ft) followed by 2017 (55.5·106 ac ft), 1938 (52.7·106 ac ft), 2006 (48.5·106 ac ft), and 1998 (48.0·106 ac ft) (**Figure 4**). The lowest Delta inflows occurred in water year 1977 (6.0·106 ac ft) followed by 1931 (6.0·106 ac ft·106 ac ft), 2021 (7.1·106 ac ft), 2014 (7.5·106 ac ft), and 1991 (8.5·106 ac ft) (**Figure 4**). The water year with the lowest outflow to inflow ratio occurred in 1990 (0.35) followed by 1988 (0.39), 1977 (0.42), 2007 (0.47), and 1989 (0.48) (**Figure 4**). According to the California Department of Water Resources' water year hydrologic classification types, 'Critically Dry' water years in both the Sacramento and San Joaquin Valleys occurred in 2008, 2015, 2021, and 2022 (**Figure 4**). 'Wet' water years in both valleys occurred in 2006, 2011, 2017, 2019, and 2023 (**Figure 4**).

Figure 4. Timeseries of Total Delta inflow (QTOT; black shading, primary y-axis) and outflow (QOUT; gray shading, primary y-axis) from the California Department of Water Resource's (CDWR) DAYFLOW program. Also shown is the ratio of outflow to inflow (QOUT/QTOT; red line, secondary y-axis). We present the total timeseries (top) and the years considered in this report (bottom). Also shown in the bottom panel are CDWR's water year hydrologic classification types for the Sacramento (before "/") and San Joaquin Valleys (after "/") ('W': Wet year type; 'AN': Above normal year type; 'BN': Below normal year type; 'D': Dry year type; 'C': Critical year type).



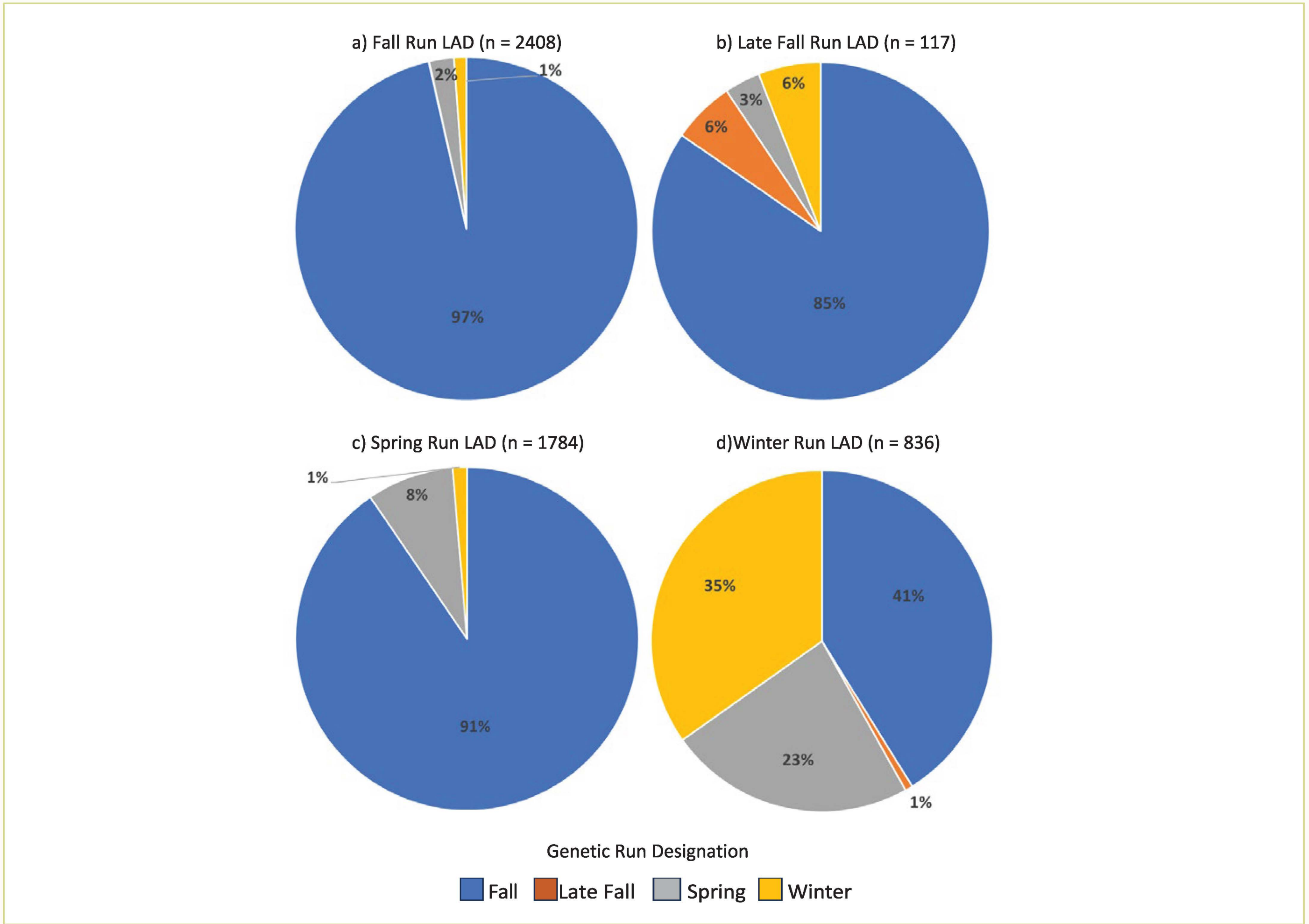
Chinook Salmon Race Assignments

As mentioned previously, we determined race assignments of unmarked juvenile salmonids in the field and present results here for each group based on LDC. These criteria use spawning times specific for each run and expected juvenile growth rates to estimate length ranges for each run type over a calendar year (Fisher 1992; Greene 1992). However, these assignments may be inaccurate if there is extensive overlap in the timing or size of individuals sampled from different runs (Brandes et al. 2021). In addition, changes in hatchery practices and sizes-at-release for fall-run Chinook Salmon documented in the Central Valley (Huber and Carlson 2015) could affect assumptions made when using LDC. Indeed, results from genetic analyses performed on 5,145 juvenile Chinook Salmon collected between 2017 and 2022 by the DJFMP show that designations based on LDC tend to underestimate fall-run Chinook. All other runs are overestimated, with only 6% of late fall, 8% of spring, and 35% of winter-run length-at-date designations being consistent with genetic analyses (**Figure 5**).

Delta Immigration from the Sacramento River Basin

During the 2023 MY, we documented winter-run juvenile Chinook Salmon entering the Delta from the Sacramento River from 7 Dec to 14 Apr (**Figure 6**). The onset of detection was approximately two months later in the season compared to MY 2022. This delay is inconsistent with the strong association that exists between the onset of significant juvenile winter-run-sized Chinook Salmon outmigration and the first day of 400 m^3s-1 measured at Wilkins Slough (rkm 190) (del Rosario et al. 2013); this threshold value was surpassed before the start of the 2023 MY (flow on 1 Aug measured at 966 m^3s-1). However, given the

Figure 5. Results of genetic analyses for run designation of Chinook Salmon for fish designated by Length-at-Date Criteria as (a) Fall, (b)Late fall, (c)Spring, and (d)Winter during monitoring years 2017–2022. All fish were unmarked and sampled by trawl at the Delta entrance from the Sacramento River at Sherwood Harbor (n=1754) or Delta Exit at Chipps Island (n=3391).



thermal migration barriers in the Delta during the summer for juvenile salmonids (Mahardja et al. 2022), it is not surprising that winter-run migration was not documented as early as expected based on flow alone.

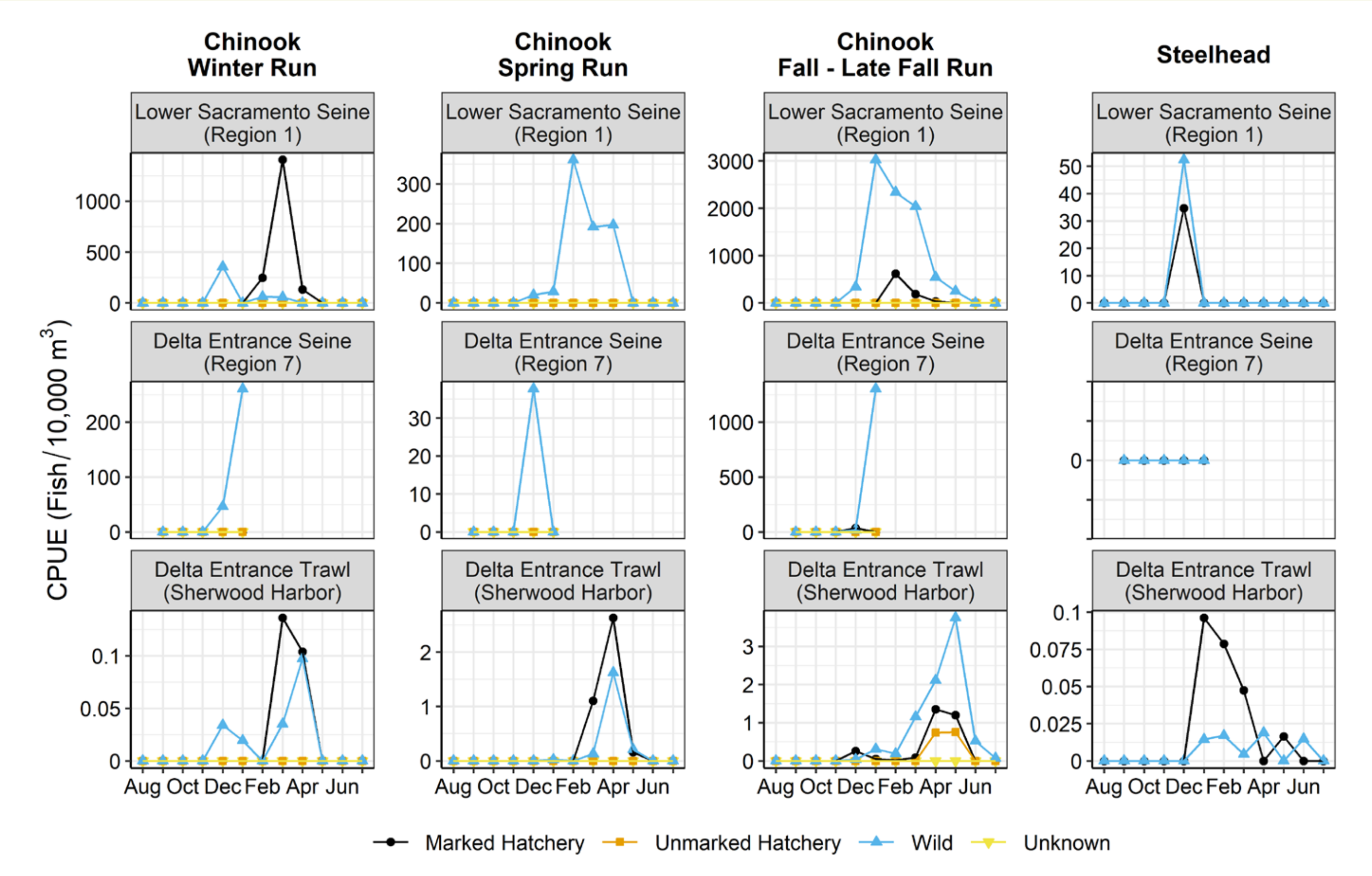
Winter-run Chinook Salmon hatchery releases occurred between February and April for MY 2023 (RMIS 2023) and hatchery-origin individuals were only sampled in the Delta during those same months (**Figure 6**). Unlike previous years, we did not observe a higher proportion of hatchery fish caught by trawl compared to seines (**Figure 6**). This observation may be due to a low overall catch of winter-run juveniles, particularly at the Sacramento Trawl site (**Figure 6**). This trend has been observed previously across multiple years in this region and may result from body size and habitat use differences between natural- and hatchery-origin fish (Huber and Carlson 2015; Roegner et al. 2016).

Spring-run Chinook Salmon were detected from 29 Dec to 17 May during the 2023 MY (**Figure 6**). At the Sacramento Trawl site, peak relative abundance was observed in April. Peak abundance of spring-run Chinook Salmon sampled by seine occurred between December and February (**Figure 6**). Hatchery releases of spring-run fish occurred in March and April of 2023 (RMIS 2023), and detections of hatchery-origin fish occurred between March and May (**Figure 6**).

Fall- and late fall-run juvenile Chinook Salmon were detected from 7 Dec to 12 July during the 2023 MY (**Figure 6**). At seine sites (**Figure 1**), peak relative abundance was observed in January (**Figure 6**). Trawl relative abundance peaked in May (**Figure 6**). The occurrence of hatchery-origin fish in trawl catches (**Figure 6**) coincided with the timing of hatchery releases, which mostly occurred from December through May (RMIS 2023).

The DJFMP detected juvenile Steelhead from 12 Dec to 1 Jun during MY 2023. At the Lower Sacramento Seine sites detections occurred only in December and, unexpectedly, a higher proportion of natural-origin Steelhead were observed compared to hatchery-origin (**Figure 6**); however overall abundances appear

Figure 6. Monthly catch-per-unit-effort for hatchery- and natural-origin juvenile salmonids entering the Sacramento–San Joaquin Delta from the Sacramento River basin during the 2023 monitoring year (August 2022 to July 2023).



to be relatively low (**Figures 6–11**). At the Delta entrance trawl site from the Sacramento River (Sherwood Harbor, **Figure 1**), relative abundance peaked in January (**Figure 6**). The timing of catches is expected because the vast majority of hatchery-origin Steelhead smolts have been released in January and February since the late 1990s (Huber et al. 2024).

In MY 2023, twelve natural-origin Steelhead were captured out of a total of 46 individuals. In 2021 natural-origin Steelhead accounted for only 6.9% of 86 total Steelhead captured, and in MY 2022 no natural-origin Steelhead were collected. The scarcity of natural-origin Steelhead sampled by the DJFMP from the Sacramento Basin highlights the relatively poor condition of wild Central Valley *O. mykiss* populations (NMFS 2016).

Delta Immigration from the San Joaquin River Basin

During MY 2023, Chinook Salmon were captured by the Mossdale Trawl between 3 Jan and 14 July, and by the San Joaquin Seine between 11 Jan and 7 Apr (**Figure 7**). Trawl sampling was canceled for approximately three weeks (20 Mar to 23 Apr) due to high water levels and unsafe sampling conditions. No Steelhead were captured by the San Joaquin Seine, and only one Steelhead was captured by the Mossdale Trawl (individual captured on 10 Jun; **Figure 7**). The low catch of Steelhead in the San Joaquin River is consistent with previous years; only twelve *O. mykiss* were caught by Mossdale Trawl surveys from 2017–2022.

Delta Occupancy

We observed only six winter-run juvenile Chinook Salmon in the North Delta Region across four days from 27 Dec to 30 Dec in MY 2023 (**Figure 8**). No winter-run individuals were sampled in the Central Delta or South Delta during MY 2023 (**Figure 8**), similar to observations in the last 3 years (**Figure 9**).

Spring-run Chinook Salmon juveniles were observed in the North Delta during the 2023 MY from 9 Dec to 12 Apr, with a peak relative abundance occurring in March (**Figure 8**). Spring-run individuals were also observed in the Central Delta between January and April, but none were detected in the South Delta during MY 2023 (**Figure 8**).

Fall- and late fall-run Chinook Salmon juveniles were observed in the North Delta during the 2023 MY from 14 Dec to 7 Jun, with a peak relative abundance observed in March

Figure 7. Monthly catch-per-unit-effort for hatchery- and natural-origin juvenile salmonids entering the Sacramento–San Joaquin Delta from the San Joaquin River Basin during the 2023 monitoring year (August 2022 to July 2023).

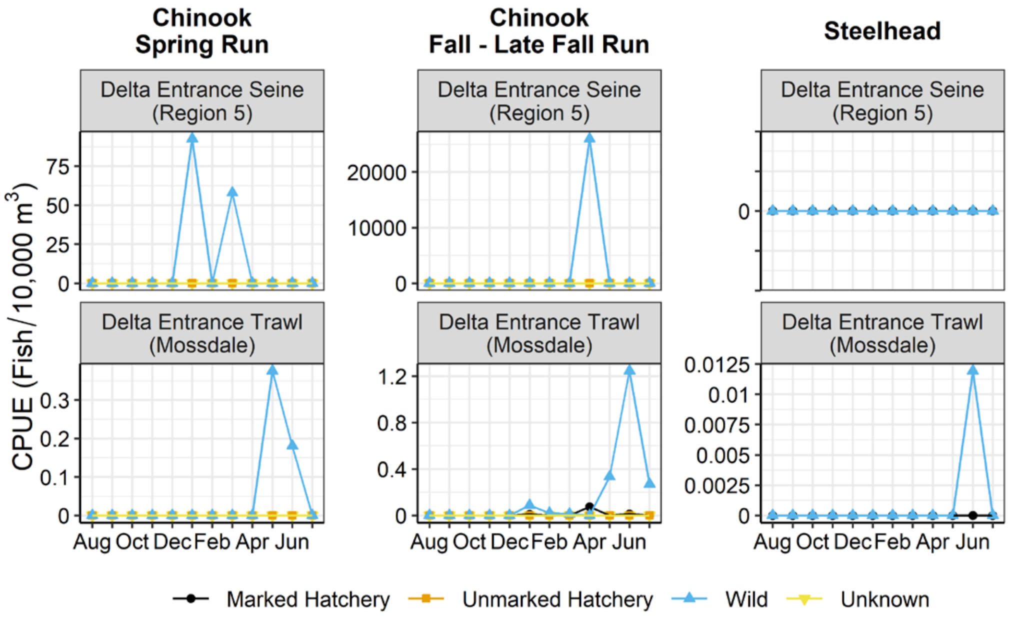


Figure 8. Monthly catch-per-unit-effort for hatchery- and natural-origin juvenile salmonids in Delta littoral zones sampled by beach seines during the 2023 monitoring year (August 2022 to July 2023).

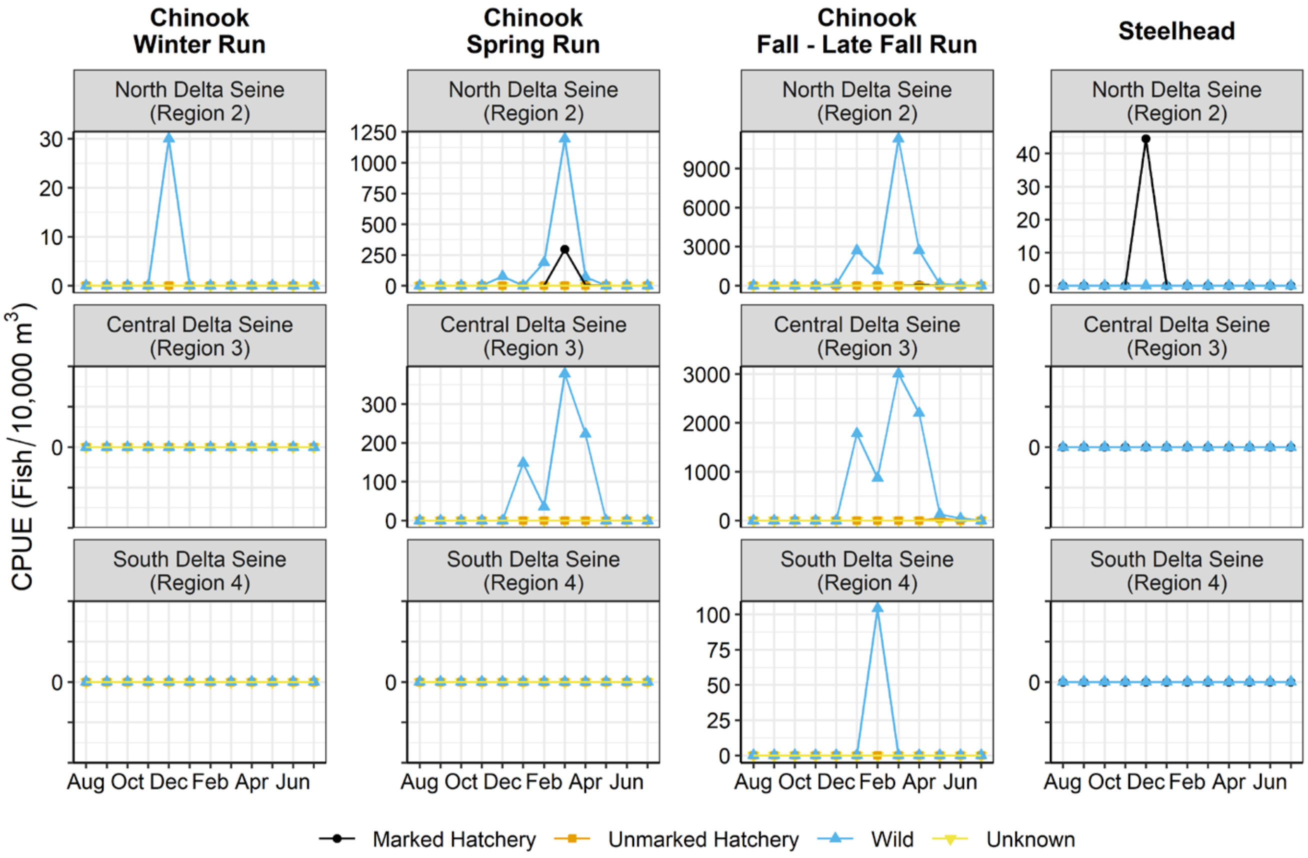


Figure 9. Annual catch-per-unit-effort for hatchery- and natural-origin juvenile salmonids in Delta littoral zones sampled by beach seines for monitoring years 2000 to 2023.

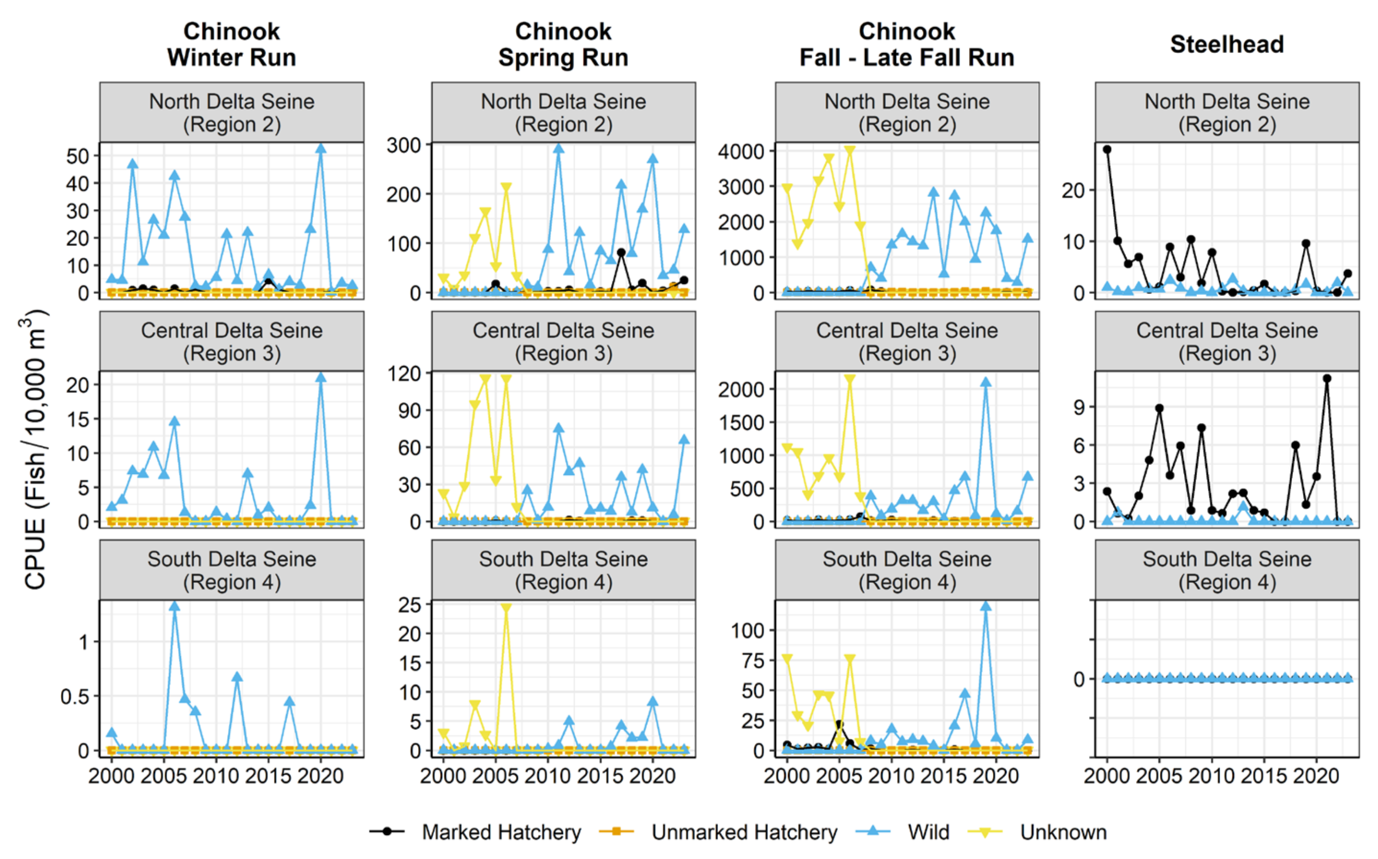
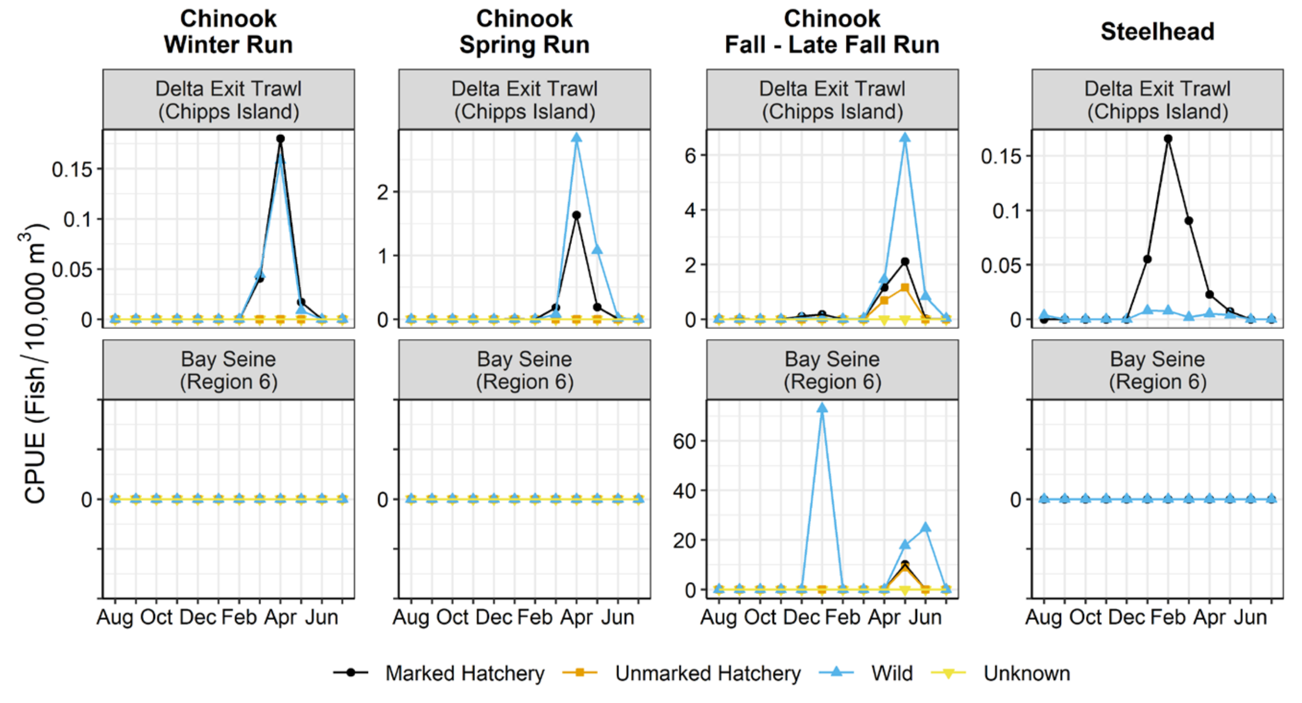


Figure 10. Monthly catch-per-unit-effort for hatchery- and natural-origin juvenile salmonids entering the San Francisco Estuary/Bay from the Sacramento–San Joaquin Delta during the 2023 monitoring year (August 2022 to July 2023).



(**Figure 8**). In the Central Delta, juvenile Chinook Salmon were sampled from 19 Jan to 16 Jun, with a peak in March (**Figure 8**). One fall-run juvenile Chinook Salmon individual was detected in the South Delta on 22 Feb during MY 2023 (**Figure 8**).

Only six juvenile Steelhead (all hatchery-origin) were captured in the North Delta region during the 2023 MY, all collected in a single seine haul on 14 Dec (**Figure 8**). No Steelhead were captured in the Central Delta region or South Delta region (**Figure 8**). Data from MY 2023 for the South Delta region was consistent with data from previous years (**Figure 9**). Standardized Steelhead abundances in the Central Delta during MY 2023 was similar to MY 2022 but inconsistent with years before 2022 (**Figure 9**).

Delta Emigration

Winter-run juvenile Chinook Salmon exited the Delta between 5 Mar and 1 May during MY 2023, with peak emigration observed in April (**Figure 10**). No winter-run were detected in the Bay Seine surveys (**Figure 10**), consistent with data from previous years (**Figure 11**).

During MY 2023, spring-run juvenile Chinook Salmon had peak emigration observed in April, with individuals exiting the Delta between 17 Mar and 9 Jun. No spring-run were detected in the Bay Seine surveys (**Figure 10**), consistent with data since 2020 (**Figure 11**).

Fall- and late fall-run juvenile Chinook Salmon exited the Delta between 13 Dec and 17 July, with peak emigration observed in May (**Figure 10**). Only seven individuals were captured by Bay Seine surveys (**Figure 10**). These observations are similar to data from 2016–2019 but inconsistent with catch data collected since MY 2020 (**Figure 11**).

Juvenile Steelhead exited the Delta during MY 2023 between 3 Aug and 22 May, with peak emigration observed in February (**Figure 10**). Again, this is not surprising because the vast majority of hatchery-origin Steelhead smolts have been released in January and February since the late 1990s (Huber et al. 2024). The total catch was dominated by hatchery-origin fish; natural-origin *O. mykiss* represented only 6.5% of the catch (**Figure 10**). These observations of hatchery dominance of the population complex are consistent with previous years (**Figure 11**). No Steelhead were detected in the Bay Seine samples (**Figure 10**), consistent with data from previous years (**Figure 11**).

Delta Cross Channel Operation

The main purpose of the Delta entry seine survey is to detect winter-run and larger juvenile Chinook Salmon before reaching the Delta Cross Channel. The timing and duration of the Delta Cross Channel gate closures (**Figure 12**) typically correspond to our detection of juvenile salmonids in the South Delta, indicating that efforts to limit entrainment at the CVP (C.W. Bill Jones

Figure 11. Annual catch-per-unit-effort for hatchery- and natural-origin juvenile salmonids entering the San Francisco Estuary/Bay from the Sacramento–San Joaquin Delta for monitoring years 2000 to 2023.

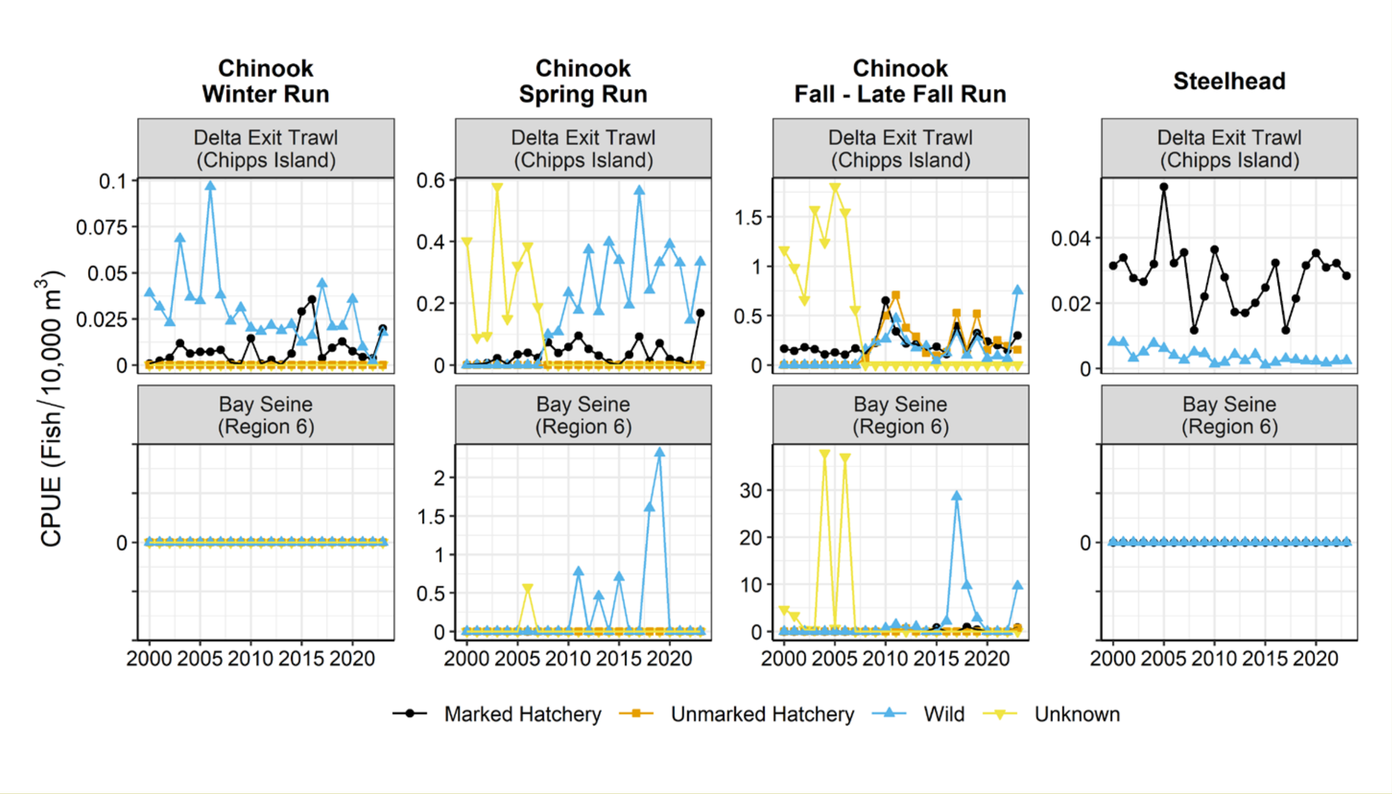
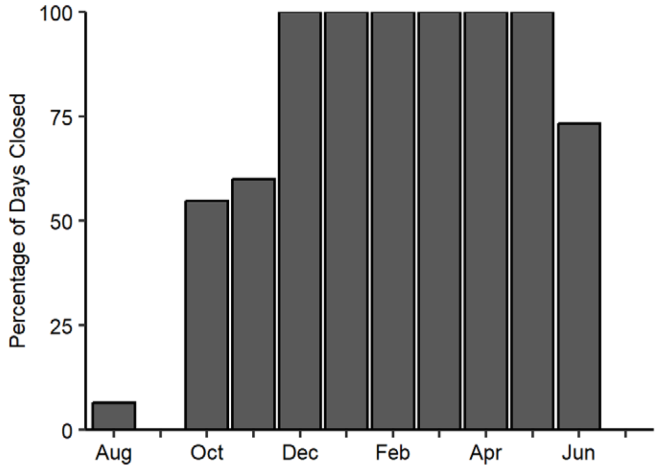


Figure 12. Delta Cross Channel operations as percentage of days closed per month during the 2023 (August 2022 to July 2023) monitoring year.



Pumping Plant) and SWP (Harvey O. Banks Pumping Plant) pumping facilities were likely effective. However, only one juvenile Chinook Salmon was detected in the South Delta during MY 2023 (**Figure 8**).

In summary, since 1976, the USFWS's DJFMP has monitored the annual timing, distribution, and relative abundance of juvenile salmonids throughout the Delta. The rich long-term DJFMP dataset informs hypothesis-driven science and adaptive water and conservation management, including mitigation of CVP and SWP water export operations on salmonid populations.

Here, we document the status and trends of juvenile salmonids migrating and rearing in the Delta and Estuary during a "Wet" water year following two "Critically Dry" (2021 and 2022) water years (**Figure 4**).

Salient findings include:

- More salmonids entered the Delta from the San Joaquin River in MY 2023 than in MY 2022.
- For the first time in four years, salmonids were sampled in the Bay Seine surveys.
- Spring-, fall-, and late fall-run Chinook Salmon were not sampled in the South Delta in MY 2021 or 2022. Only one fall-run individual was detected in MY 2023.
- No winter-run Chinook Salmon or Steelhead were sampled in the Central or South Delta in MYs 2022 and 2023.
- Only 10 Steelhead (natural- and hatchery-origin) were sampled by seine in MY 2023. Four Steelhead (all natural-origin) were sampled by seine in MY 2022.

Data Access

The full DJFMP dataset, including environmental data not included in this report, and a description of sampling procedures are available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2023).

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DATA REPORT

Delta Juvenile Fish Monitoring Program Electrofishing 2023 Report

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Introduction

The US. Fish and Wildlife Service's (USFWS) Delta Juvenile Fish Monitoring Program (DJFMP) initiated its boat electrofishing survey (EFISH) in 2016 in response to an independent review of its overall monitoring goals and design (IEP-SAG 2013). Key recommendations from the review panel stressed the need to develop new methods that would use stratified random sampling of all available habitats to increase the detection probability of rare species and, hopefully, lead to more precise fish population abundance estimates. EFISH aims to describe spatiotemporal occupancy patterns, assess population statuses, and evaluate long-term trends for littoral fish species associated with near-shore habitats of the San Francisco Estuary (hereafter estuary) (Perry et al. 2016).

This report summarizes the catch information from the 2023 EFISH field year (FY) (August 1, 2022, to July 31, 2023) and demonstrates several methods to analyze spatiotemporal information collected over the past two field seasons. Data used in this report are publicly available on the EDI Data Portal (IEP 2023a).

Methods

Data Collection

The EFISH sampling design was developed to be comparable to Brown and Michniuk (2007) to build on their 20-year analysis of fish assemblages in the estuary using electrofishing data. We divided the estuary into six large regions (Cache Slough/Liberty Island Complex, North, Central, West, South-Central, South), each of which consists of three subregions (18 total) to offer a finer resolution in occupancy analysis (**Figure 1**). Each region is sampled at least once per month in random order except for the West Delta Region, which can only be sampled during high outflow periods when water conductivity levels are below the operating threshold of the equipment using our standard settings (~2000 µS).

The EFISH field year extends from the previous August through July to coincide with the juvenile salmon monitoring season outlined by Brandes et al. (2000). At the start of each field year, a list of 30 sample sites is generated within each subregion using a stratified random sampling design (Hines et al. 2010). These sites are sampled in the order in which they are generated or based on their feasibility and accessibility to sampling equipment (e.g., sites that are too far apart to be completed within

Figure 1. Map of the San Francisco Estuary depicting the six regions (colors) and 18 subregions (polygons) used in the boat electrofishing survey.

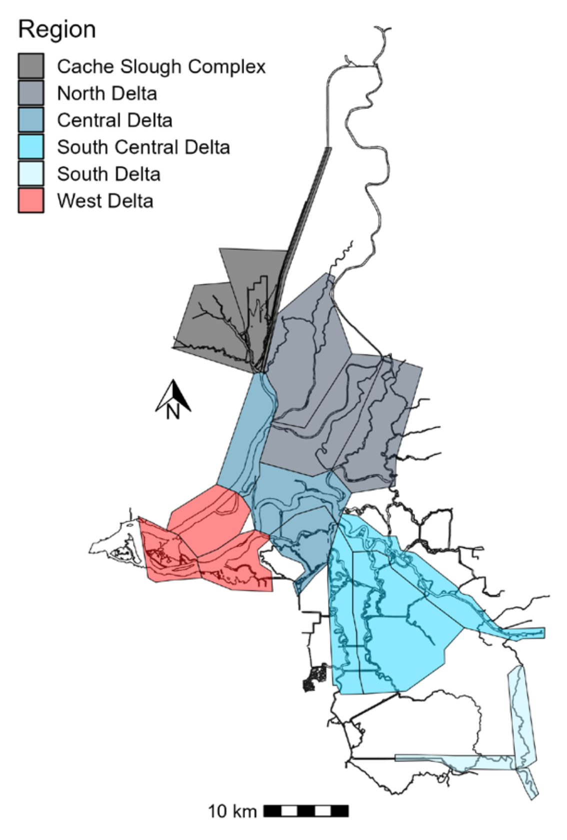
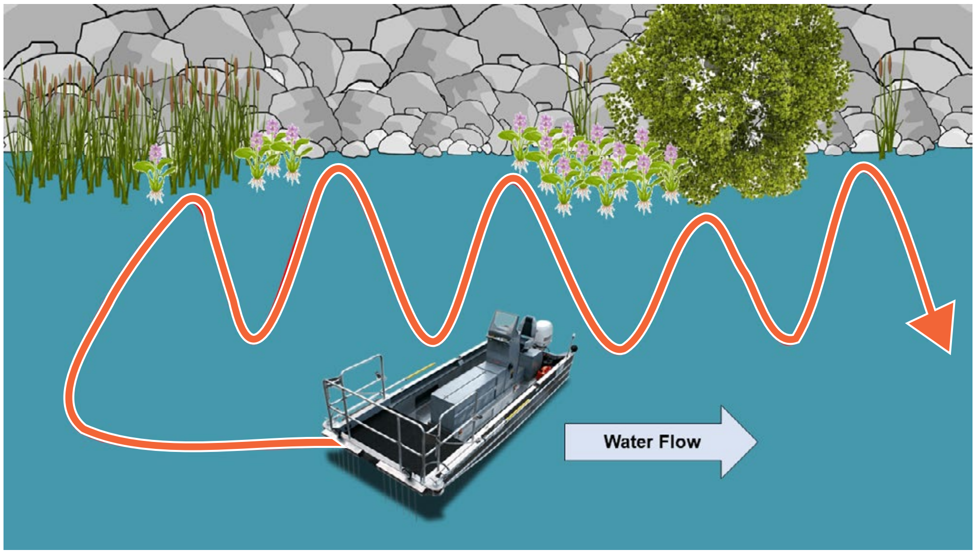


Figure 2. Sampling schematic showing the five short line approaches for each of the six segments that make up a DJFMP boat electrofishing survey transect.



the same day or too close to public/private docks). Each site or transect is sampled using a single-pass design with six replicate segments that allow for spatially dependent occupancy and detection probability estimation. A segment consists of several perpendicular shoreline approaches approximately 6 m out from the shoreline and about 20–30 m in length along the shore, resulting in the shocking time for each approach being approximately 20 sec (**Figure 2**). In FY 2022, segments consisted of three shoreline approaches combined for a 120–180 m long sampling transect or 720–1,080 m^2 and roughly a minute of shocking time per transect. For FY 2023, the number of approaches for each segment was increased from three to five, which extended the distance and time of each transect by two-fifths.

We used an 18-foot Smith-Root Heavy Duty Series Electrofishing Boat equipped with an APEX control unit capable of producing up to 80 peak amps of DC power. The APEX unit is set to 40 Hz with a duty cycle of 15%; this limits potential hyperreflexia and allows for improved recovery while requiring less power to immobilize the fish (Miranda 2005). Voltage selection is based on a vessel-specific Power Goal Table that prescribes the appropriate power goal (watts) based on ambient water conductivity (measured in μS/cm) at the sampling site.

Upon reaching a site, crew members first record environmental information including weather, wind speed (mph), tidal flow, channel type, and water quality (dissolved oxygen [mg/L], temperature [°C], water turbidity [NTU], Secchi depth [m], ambient conductivity [μS/cm], and specific conductivity [μS/cm]). After the transect is completed, the net handlers identify fish to species level (except for Lampetra spp., ammocoetes), enumerate, and measure lengths of up to 15 individuals for each species before releasing them back to the environment. Meanwhile, the data recorder makes a visual habitat assessment of each segment and records the dominant bank type (i.e., riprap, mud bank, sand beach, mudflat, artificial structure) and dominant substrate present (i.e., sand, mud, rock, pavement). The data recorder then estimates the percentage of shoreline covered by large woody debris, emergent vegetation, and floating vegetation on a scale of 0 to 4 (corresponding to 0%, 25%, 50%, 75%, and 100% cover) as well as the presence or absence of submerged aquatic vegetation (SAV). Starting in July 2022, the SAV assessment was revised to a visual estimation of percent coverage that is defined categorically. Observations are made from the boat using a mix of rapid assessments and side-scan sonar. The assessment categories were defined as follows: 0 = no visible rooted SAV; 1 = sparse coverage, ≤25% of transect covered with SAV; 2 = scattered or interrupted coverage, 26–75% of transect covered with SAV; 3 = mostly or fully covered, >75% of transect covered with SAV; and 4 = overgrown, SAV reaches the surface and impedes boat movement.

Analyses

We summarized catch and sampling effort data for FY 2023 for each species caught by calculating catch per unit effort (CPUE) at the segment level, defined as the number of individuals caught divided by shocking time per segment in minutes. We summarized CPUE by calculating the mean and standard deviation across all samples from FY 2023. We also calculated percent catch by dividing the total count of that species by the total count summed over all species and multiplying this proportion by 100.

We created heat maps of juvenile spatiotemporal distribution for four native species: Chinook Salmon (*Oncorhynchus tshawytscha*), Sacramento Splittail (*Pogonichthys macrolepidotus*), Sacramento Pikeminnow (*Ptychocheilus grandis*), and Hitch (*Lavinia exilicauda*). Juvenile fish were defined as fish with fork lengths of 150 mm or less. We calculated CPUE (fish caught per minute) at the segment level for each species and plotted mean CPUE by field year, month, and subregion.

We generated spatial distribution maps for the first two quarters of FY 2022 and 2023 (January through June) for the four native fish species listed previously. This date range was chosen to compare the distribution of each species under different hydrological conditions. The California Department of Water Resources' Sacramento Valley water year (WY) index notes that WY 2022 was classified as a critically dry water year in both the Sacramento and San Joaquin Valleys, and WY 2023 was classified as wet in both valleys. We calculated CPUE (fish caught per minute) at the segment level and subsequently calculated mean CPUE for each combination of subregion, species, and field year.

Summary

Interannual Comparison

During FY 2023, EFISH sampled a total of 44 fish species (**Table 1**). The total was seven more species than were captured in FY 2022 and may have been due, in part, to the increased effort in 2023 compared to 2022 (see Methods) (Stagg et al. in prep). The five most captured species were Bluegill (*Lepomis macrochirus*), Largemouth Bass (*Micropterus salmoides*), Redear Sunfish (*Lepomis microlophus*), Mississippi Silverside (*Menidia audens*), and Golden Shiner (*Notemigonus crysoleucas*), all of which are nonnative and comprised 81% of the total catch (**Table 1**). The previous field year had the same top-five species that comprised a similar percentage of the total catch (Stagg et al. in prep). Native species comprised approximately 9% of total catches in FY 2023, slightly greater than the relative catch of natives in 2022 (7%). The most commonly sampled native fishes in FY 2023 were Hitch (2.25%) and Sacramento Splittail (2.03%).

Overall catch numbers were higher in FY 2023 compared to FY 2022 across most species. For resident native fish Hitch, Tule Perch (*Hysterocarpus traskii*), and Sacramento Sucker (*Catostomus occidentalis*) catches increased by roughly a third or more without a significant change to CPUE, while other natives like the Sacramento Pikeminnow saw a slight increase in CPUE. In contrast, Prickly Sculpin (*Cottus asper*) had a large drop in CPUE from FY 2022 to FY 2023. The diversity of native fish catches increased from FY 2022 to 2023 with Hardhead (*Mylopharodon conocephalus*), Steelhead (*Oncorhynchus mykiss*), and Sacramento Blackfish (*Orthodon microlepidotus*) being observed in the latter year. Most notably, catches of native migratory species like Chinook Salmon and Sacramento Splittail increased a thousand-fold in FY 2023 compared to FY 2022. This is likely due to the widespread flooding observed in 2023, as these species have their greatest recruitment classes during years of high rainfall (Sommer et al.1997; Moyle et al. 2004), which activates vast areas of flood plains for juvenile rearing (Sommer et al. 2001).

Native Juvenile Fish Distribution

The CPUE and catch distribution of juvenile Chinook Salmon, Sacramento Splittail, Sacramento Pikeminnow, and Hitch generally increased between FY 2022 and FY 2023 (**Figure 3**). Starting in FY 2022, juvenile Chinook Salmon were only captured in the lower Sacramento River around Rio Vista and in the vicinity of the confluence of the San Joaquin and Sacramento Rivers (**Figure 3A**). The first and last Chinook Salmon captures occurred in December 2022 and April 2023, respectively. In FY 2022, juvenile salmon catches were low across all Lodi Fish and Wildlife Office programs (Holcombe and Nanninga in prep a). The 2022 values may have been low because hatchery-origin fall run smolts are often released downstream of the confluence during critically dry years (Huber and Carlson 2015; Sturrock et al 2019). The practice of stocking smolts into high-conductivity waters limits EFISH's ability to encounter these fish as the electrical field struggles to pass through a fish whose internal conductivity is lower than that of its environment (Kolz 2006). In FY 2023, EFISH initially collected juvenile salmon in the Sacramento River in December 2022 with CPUE peaking in May 2023 and captures continuing through July 2023. Juvenile salmon were captured in all regions, indicating a strong recruitment year for natural-spawning fish and more hatchery-origin smolts being released upstream.

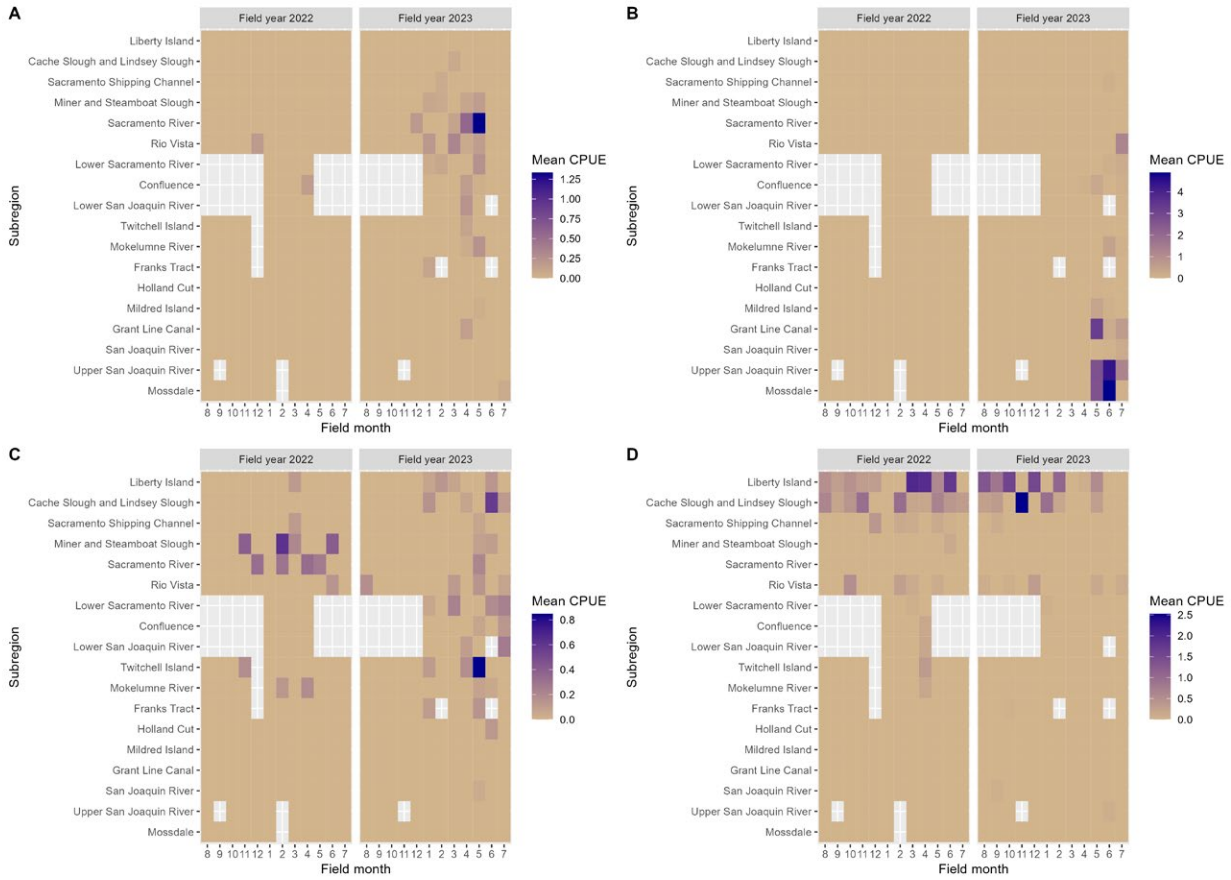
EFISH did not capture juvenile Sacramento Splittail in any region during FY 2022 (**Figure 3B**). Catch data from DJFMP indicated that FY 2022 was a low recruitment year for Splittail, with CPUE over 100 times below average on the Sacramento River and no catches on the San Joaquin River (IEP 2023b). These observations are consistent with a dearth of available floodplain spawning and rearing habitat caused by the drought (DWR 2022). In FY 2023, EFISH caught juvenile Splittail on the San Joaquin River drainage and downstream areas during May, June, and extending into July. Recruitment of juvenile Splittail was likely high on the San Joaquin River, given the abundance of available habitat created by activated floodplains and submerged farmland (DWR 2023). Almost no juvenile Splittail were captured on the Sacramento River drainage upstream of the Rio Vista subregion. The reasons for this are unclear as DJFMP beach seine catches indicate healthy recruitment of Splittail on the Sacramento drainage. One hypothesis is that the steep armored banks throughout the lower Sacramento River caused the juvenile Splittail to migrate along the bottom of the river, putting them out of reach of EFISH's electrical field.

In FY 2022, juvenile Sacramento Pikeminnow appear mostly restricted to the North Delta region and adjacent areas

Table 1. Summary of total catch for the boat electrofishing survey from field year 2023. The table shows the number of each species caught (Total Count), the percentage of total catch that each species represents, the mean catch per unit effort (CPUE) in fish per minute, and the standard deviation of the CPUE.

Common Name	Total Count	Percent Catch	Mean CPUE	SD CPUE
Bluegill	5851	3.61E+01	2.34E+00	7.52E+00
Largemouth bass	3722	2.30E+01	1.42E+00	2.43E+00
Redear Sunfish	2134	1.32E+01	8.38E-01	2.69E+00
Mississippi Silverside	842	5.20E+00	3.27E-01	1.50E+00
Golden Shiner	610	3.76E+00	2.20E-01	7.32E-01
Hitch	364	2.25E+00	1.38E-01	7.17E-01
Splittail	329	2.03E+00	1.65E-01	1.17E+00
Threadfin Shad	309	1.91E+00	1.13E-01	6.82E-01
Tule Perch	236	1.46E+00	9.43E-02	4.41E-01
Striped Bass	235	1.45E+00	8.96E-02	4.16E-01
Common Carp	217	1.34E+00	8.23E-02	7.27E-01
Sacramento Pikeminnow	188	1.16E+00	8.08E-02	3.02E-01
Sacramento Sucker	146	9.01E-01	5.69E-02	2.90E-01
Yellowfin Goby	130	8.02E-01	4.80E-02	3.31E-01
Warmouth	119	7.34E-01	4.52E-02	3.24E-01
Bigscale Logperch	89	5.49E-01	3.08E-02	1.95E-01
Rainwater Killifish	89	5.49E-01	3.08E-02	3.00E-01
Prickly Sculpin	85	5.25E-01	3.65E-02	2.08E-01
Shimofuri Goby	79	4.88E-01	3.21E-02	1.83E-01
White Catfish	79	4.88E-01	2.70E-02	1.41E-01
Chinook Salmon	64	3.95E-01	2.56E-02	1.71E-01
Bluefin Killifish	62	3.83E-01	2.04E-02	1.87E-01
Smallmouth Bass	54	3.33E-01	2.95E-02	2.65E-01
Black Crappie	39	2.41E-01	1.34E-02	1.00E-01
Spotted Bass	30	1.85E-01	1.04E-02	8.13E-02
Black Bullhead	19	1.17E-01	6.54E-03	5.89E-02
American Shad	17	1.05E-01	6.50E-03	7.06E-02
Western Mosquitofish	15	9.26E-02	5.71E-03	9.41E-02
Green Sunfish	9	5.55E-02	3.36E-03	4.27E-02
Lamprey Ammocete	6	3.70E-02	2.32E-03	3.69E-02
Steelhead	5	3.09E-02	2.08E-03	3.44E-02
Channel Catfish	4	2.47E-02	1.60E-03	2.97E-02
Red Shiner	4	2.47E-02	1.78E-03	4.10E-02
Sacramento Blackfish	4	2.47E-02	1.27E-03	2.76E-02
Goldfish	3	1.85E-02	9.52E-04	2.05E-02
Pacific Staghorn Sculpin	3	1.85E-02	1.10E-03	2.45E-02
Brown Bullhead	2	1.23E-02	7.04E-04	1.82E-02
Hardhead	2	1.23E-02	8.24E-04	2.18E-02
Longfin Smelt	2	1.23E-02	6.58E-04	1.73E-02
Unidentified Fish	2	1.23E-02	5.80E-04	1.50E-02
Wakasagi	2	1.23E-02	6.57E-04	1.70E-02
Fathead Minnow	1	6.17E-03	2.67E-04	9.76E-03
Redeye Bass	1	6.17E-03	6.41E-04	2.34E-02
White Crappie	1	6.17E-03	3.23E-04	1.18E-02

Figure 3. Spatiotemporal distribution heat maps of juvenile native fish species ≤ 150 millimeters: *A. Oncorhynchus tshawytscha, B. Pogonichthys macrolepidotus, C. Ptychocheilus grandis,* and *D. Lavinia exilicauda*. Heat map fill is mean CPUE in fish per minute, per month (x-axis) of field years 2022 and 2023 for each subregion (y-axis) of the DJFMP boat electrofishing survey.



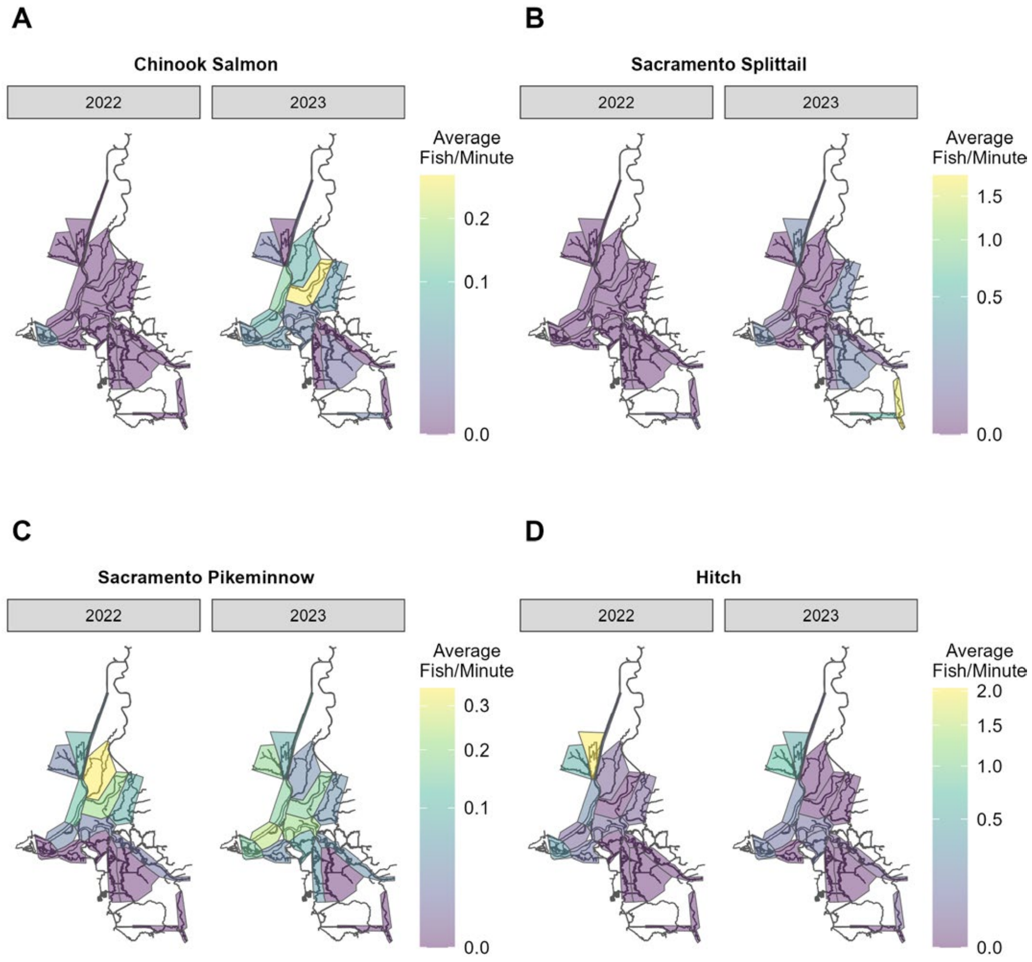
(**Figure 3C**). The distribution changed in FY 2023 as EFISH encountered juvenile Pikeminnow throughout much of the northern half of the Delta and a few places in the South-Central Region. Adult Pikeminnow are thought to spawn in the upper tributaries in spring (Grant and Maslin 1999), and the young are flushed back down into the Delta to rear (Moyle 2002). Low Delta outflow in spring 2022 likely limited the spread of juvenile Pikeminnow throughout the Delta, whereas the high flows in 2023 seem to have dispersed the juveniles over a wider area. Juvenile Pikeminnow CPUE was low or non-existent in the South and South-Central Regions of the Delta in both years (**Figure 3C**). High flows on the San Joaquin River and its tributaries in 2023 should have pushed young Pikeminnow down into the South Delta Region, but this was not observed in the catch.

For both field years, juvenile Hitch catch was concentrated within the Cache Slough Complex Region, predominately Liberty Island and surrounding waterways (**Figure 3D**). The year-round presence of Hitch less than 150 mm in this region likely represents multiple year classes. The prevalence of juvenile Hitch within the Cache Slough Complex Region suggests that the area might be a nursery for Hitch (Macfarlane 2022); indeed, they are abundant in shallow backwaters thick with aquatic vegetation (Durand et al.2019). Juvenile Hitch were also captured at low levels downstream of the Cache Slough Complex Region, mostly in the Rio Vista subregion and some in the Western Delta. Some juvenile Hitch were captured on the San Joaquin River during FY 2023, suggesting another population might be present farther south.

Distribution of Native Fish Under Different Hydrological Conditions

The catch distributions of Chinook Salmon, Sacramento Splittail, Sacramento Pikeminnow, and Hitch from January through June varied between dry FY 2022 and wet FY 2023 (**Figure 4**). No adult encounters were included in this dataset for Chinook Salmon, the maps presented here reflect only juvenile salmon. During the critically dry spring of 2022 juvenile Chinook Salmon catches were nearly non-existent, with only

Figure 4. Spatial distribution maps for *A. Oncorhynchus tshawytscha, B. Pogonichthys macrolepidotus, C. Ptychocheilus grandis,* and *D. Lavinia exilicauda*. CPUE in fish per minute by subregion for the first two quarters (January-June) in field years 2022 and 2023.



a single capture in the Confluence subregion in the far west of the survey area (**Figure 4A**). This observation indicates the poor recruitment of naturally spawned salmon documented in the DJFMP 2022 Salmon report (Holcombe and Nanninga in prep b) and the practice of stocking hatchery west of the confluence (Huber and Carlson 2015), especially during drought (Sturrock et al. 2019). During widespread flooding of FY 2023, Chinook Salmon exhibited a broader distribution in the Delta with most captures extending from the Sacramento River down to the confluence with the San Joaquin River. Chinook Salmon captures in the South and South-Central Delta Regions also indicate strong recruitment for the San Joaquin tributaries. The DJFMP has previously documented the decline of salmon catch through drought periods and their subsequent rebound during wetter years (McKenzie 2021; Holcombe and Nanning in prep a,b , Stagg et al. in prep).

For the critically dry water year of 2022, only two Sacramento Splittail individuals (both adults) were captured in the South Delta Region (**Figure 4B**). Splittail catches in FY 2023 were dominated by young-of-year fish, with the highest CPUE seen in the South Delta Region on the San Joaquin River. Juvenile Splittail were also captured on the Mokelumne River and around the West Delta Region. Adult Splittail were captured in the Cache Slough Complex Region in January and February of FY 2023. These adults might have been captured in the area during their spawning migration as Splittail are known to make spawning runs up into the Yolo Bypass during wet water years (Sommer et al.1997; Moyle et al. 2004).

During the drought in FY 2022, Pikeminnow catches were concentrated on the Sacramento River and surrounding waterways (**Figure 4C**). Two Pikeminnow were also captured on the San Joaquin River near its connection to the Mokelumne River. Most catches were juveniles: only nine adult Pikeminnow (>250mm) were captured during this period. These adults were distributed across a wide range from the Liberty Island subregion in the north to the San Joaquin River subregion in the south. Low catches of adult Pikeminnow during the spawning season might suggest that they had returned to the headwaters to spawn (Grant and Maslin 1999). However, adult catches outside this time window were even lower as only two individuals were caught. Catches of Pikeminnow increased during the high flows that characterized FY 2023. EFISH encountered them over an expanded distribution, particularly in the lower regions of the Central and Western Delta. Sixteen adult Pikeminnow were captured during this time window over a similar range in the previous year. The lack of catches in the South Delta Region under either water year type could suggest little to no Pikeminnow recruitment in the San Joaquin River. Contributing factors to the lack of Pikeminnow on the San Joaquin River may be poor connectivity during periods of low outflow. Also, dense aquatic vegetation, especially Hyacinth (*Eichhornia crassipes*) and Brazilian Waterweed (*Egeria densa*) has clogged up much of the waterways in recent years and may prevent access to the South Delta (Madsen et al. 2021). Furthermore, competition with non-native predators like Largemouth Bass or poor water quality conditions might limit Pikeminnow presence in the South Delta. Future studies may help clarify why Pikeminnow presence appears to be relatively low in the upper San Joaquin River.

The distribution of Hitch was relatively consistent between the two water year types. CPUE decreased slightly in the Cache Slough Complex, North, and West Delta Regions in FY 2023 compared to the previous year (**Figure 4D**). EFISH catches of Hitch were mainly restricted to the North Delta Arc, an area defined by the contour of the Sacramento River as it stretches from the Cache Slough Complex Region out to Suisun Marsh (Macfarlane 2022). Hitch habitat likely extends further west of the Confluence subregion because the fish can tolerate salinity concentrations up to 9 ppt (Smith 1977). However, EFISH cannot access these higher conductivity waters as noted previously. The similar CPUE for Hitch within the North Delta Arc might indicate that this area can support a stable population of the species. Outside the regions already mentioned, two juvenile Hitch were captured on the San Joaquin River upstream of the Central Delta region during the flooding of 2023. It is unclear if these fish are colonizers from a known population of Hitch in the northern Delta or isolated populations farther south.

Management Implications

The EFISH sampling design is designed to avoid biases associated with a non-random sampling scheme, expand DJFMP's ability to sample a wider variety of habitats and increase the detection capability of structure-oriented species. This information offers unique insights into near-shore fish communities not captured by other long-term monitoring programs (McKenzie and Mahardja 2021). This survey aims to generate information on spatiotemporal occupancy patterns of littoral fish and species-specific density data as well as long-term trends in habitat associations over a broad area. USFWS's partners at the United States Geological Survey are currently working on models to predict occupancy patterns and estimate the overall abundance of fishes within the estuary using data collected by EFISH. When coupled with other IEP surveys, EFISH can offer management a greater understanding of the Delta ecosystem and enable water and conservation managers to make more informed decisions about California's precious water resources.

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DATA REPORT

2023 Delta Juvenile Fish Monitoring Program Nearshore Fishes Annual Report

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Introduction

The Delta Juvenile Fish Monitoring Program (DJFMP) of the United States Fish and Wildlife Service (USFWS) has monitored fishes within the Sacramento–San Joaquin Delta (Delta) and San Francisco Bay (Bay) since 1976. Over time, the monitoring program has evolved in response to emerging water management needs and threatened and endangered species listings under the federal Endangered Species Act (ESA). Initially, the objectives were to (1) monitor juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) abundance in the system, (2) evaluate the importance of the Bay as a nursery habitat for juvenile salmon, and (3) determine the effect of altered river flows from the proposed Peripheral Canal on juvenile salmon rearing and migration (Brandes and Mclain 2000). Following the rejection of California Proposition 9 (Water Facilities Including a Peripheral Canal. California Proposition 9) in 1982, the DJFMP's focus shifted to evaluating the effects of through-Delta water conveyance on the relative abundance, distribution, and survival of juvenile Chinook Salmon in the Delta and Bay. The program expanded geographically and temporally in the 1990s in response to ESA (United States 1983) listings of Sacramento River Winter-run Chinook Salmon (59 Federal Register 440) and California Central Valley Steelhead (*O. mykiss*) (50 Code of Federal Regulations Parts 223 and 224; NMFS 2006). With the growing recognition of the importance of other members of the fish community in shaping ecosystem health and resilience, the objectives of DJFMP were expanded to include documenting the abundance and distribution of non-salmonid species in the Delta and San Francisco Bay.

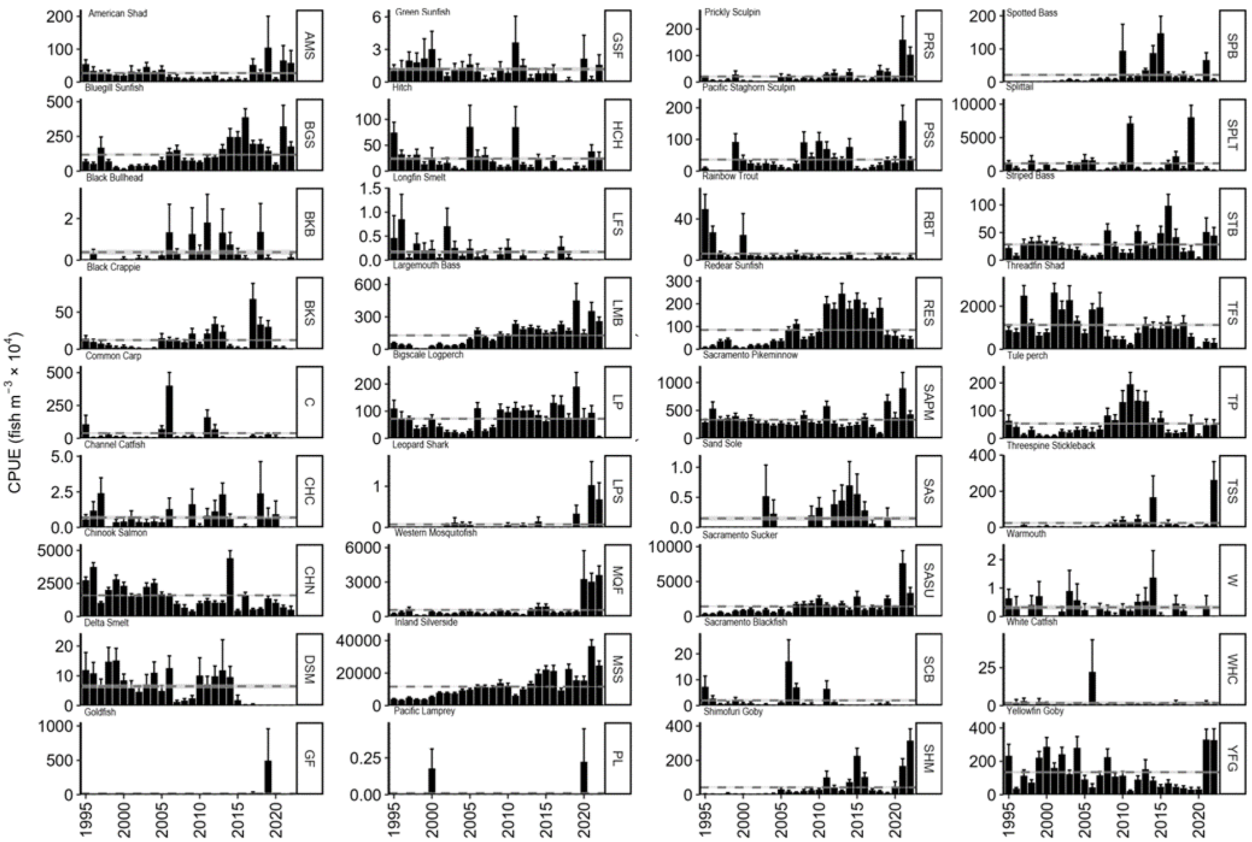
This report describes inter-annual abundance trends and distributional patterns of select nearshore resident fishes and their association with submerged aquatic vegetation (SAV) within the Delta and lower mainstem Central Valley rivers from 1995 to 2023 and San Francisco Bay from 1997 to 2023 (information for our salmonid catch trends can be found in the DJFMP Salmonid Annual Report also published in this newsletter). According to Stompe et al. (2020, *Table 3*), the USFWS's Beach Seine Survey ranks third best out of 14 long-term monitoring surveys in the San Francisco Estuary for determining SAV-associated fish species assemblages.

All years are presented as monitoring years, which run from August of the previous year stated to July of the stated year. We selected these years because the DJFMP began sampling the Delta and rivers year-round in 1995 (i.e., August 1994 to July 1995) and resumed Bay sampling in 1997. Before 1995, sampling in the Delta and rivers did not occur in late spring and summer; these are seasons when juvenile nearshore fishes typically recruit into the beach seine sampling gear. The DJFMP sampled the Bay in 1981 and 1982, and the California Department of Fish and Game (now California Department of Fish and Wildlife, CDFW) sampled from 1983–1986.

Currently, the DJFMP is one of the few long-term monitoring programs that broadly surveys littoral habitats throughout the Delta and Bay, which (1) permits a holistic understanding of fish community changes (Nobriga et al. 2005) and (2) documents the invasions and expansion of non-native fishes in nearshore habitats (Moyle and Bennett 2008; Mahardja et al. 2020). From 1995 to 2023, the DJFMP tracked 36 commonly occurring species caught in the San Francisco Estuary, Lower Sacramento, and San Joaquin Rivers (**Figure 1**). In this report we focus our analyses on a subset of commonly encountered non-native fishes in the Centrarchidae family: (1) Largemouth Bass, Micropterus salmoides; (2) Bluegill, Lepomis macrochirus; (3) Redear Sunfish, Lepomis microlophus; (4) Green Sunfish, Lepomis cyanellus; and (5) Warmouth, Lepomis gulosus. Additionally, we report abundance trends for two native species primarily sampled in the Bay: (1) Topsmelt, Atherinops affinis (family Atherinopsidae); and (2) Bay Pipefish, Syngnathus leptorhynchus (family Syngnathidae).

The complete DJFMP dataset, including 1) a complete description of sampling procedures, 2) non-salmonid catch data, and 3) environmental data, is available at the Environmental Data Initiative Data Portal (IEP et al. 2023).

Figure 1. Mean annual standardized catch values from 2004 to 2023 for 36 species commonly occurring in the San Francisco Estuary and Lower Sacramento and San Joaquin Rivers.



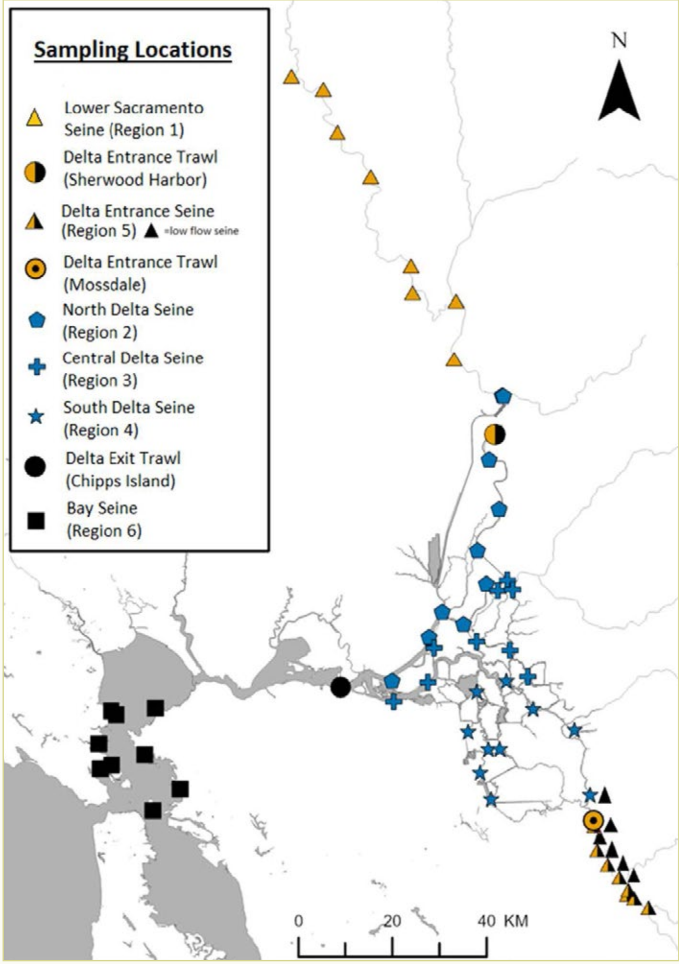
Methods

The DJFMP implemented beach seine surveys (hereafter "seines") to sample fishes at 56 sites throughout the Bay, Delta, and lower Sacramento and San Joaquin Rivers (**Figure 2**). In this report we use relative site names in place of our traditional seine region numbers to aid in the spatial orientation of readers, thus: Seine Region 1 = Lower Sacramento River (8 sites); Seine Region 2 = North Delta (9 sites); Seine Region 3 = Central Delta (9 sites); Seine Region 4 = South Delta (10 sites); Seine Region 5 = Lower San Joaquin River (9 sites); Region 6 = Bay Seine (9 sites; **Figure 2**).

A complete description of the historical and current methods is available at the Environmental Data Initiative Data Portal (IEP et al. 2023). Briefly, the DJFMP seined at fixed sites within regions during daylight hours (between 06:00 and 18:00 PST) using a 15.2 x 1.3 m seine net with 3 mm delta square mesh and a 1.2 m bag in the center of the net. A float line and lead line were attached to 1.8 m tall wooden poles on each side. Beach seines were pulled toward the shoreline by two crew members in unobstructed habitats, including boat ramps, mud banks, and sandy beaches.

All sites were surveyed once per week throughout the year except for the Bay Seine region, which was sampled once every two weeks. Water quality variables (water temperature, conductivity, dissolved oxygen, and turbidity), substrate compositions, and flow velocities were measured for each seine haul (for environmental data see **Figure 3** in the 2024 IEP Salmonid report). A few North Delta and Lower Sacramento River seine sites were sampled three times per week from 1-Oct through the last week of January to intensely monitor for juvenile Winter-run Chinook Salmon abundance and migration timing. If more than 30 individuals of a species were captured, a subsample of 30 individuals was randomly selected and measured for fork length (FL; for fishes with a forked or heart shaped caudal fin) or total length (TL; for fishes with a squared or rounded caudal fin). Captured fish in excess of 30 individuals per species were

Figure 2. Map of the United States Fish and Wildlife Service (USFWS) Delta Juvenile Fish Monitoring Program (DJFMP) beach seine sampling sites and regions in the Sacramento–San Joaquin Delta and San Francisco Bay. Data from Liberty Island seine sites (red and green dots in inset) are in the North Delta region and included in this report for monitoring years 2002–2005 and 2009–2019.



enumerated but not measured (referred to as a "plus count"). Size frequency histograms were plotted for each species (**Figure 3**), and the percentage of juveniles captured and measured was calculated using published data for FL or TL-at-maturity values for Largemouth Bass (Moyle 2002), Bluegill, Redear Sunfish, Green Sunfish, and Warmouth (Moyle 2002). No size-at-maturity value could be found in the literature for Topsmelt or Bay Pipefish. Middaugh et al. (1992) successfully spawned Topsmelt as small as 114 mm standard length, so that value was used after converting it to FL (119 mm FL) according to Froese and Pauly (2023). Ripley and Foran (2006) determined the size-at-maturity for S. fuscus and S. floridae (surrogates for Bay Pipefish) to be 125 mm and 103 mm TL, respectively. An average of these values (114 mm TL) was used for length at maturity for Bay Pipefish.

Before estimating catch-per-unit-effort (CPUE, fish·m-3), we filtered the DJFMP dataset (IEP et al. 2023) by excluding samples collected during poor sampling conditions, such as net twists or snags (i.e., gear condition codes >2 in the dataset) and flow-meter and(or) data recording errors identified by sampling volume outliers. To compare the CPUE of species across space and time, we calculated mean annual CPUE values for each of the eight seine regions. To limit the overweighting of sampling sites due to differences in sampling frequency, months and sites were equally weighted in the calculation of annual regional CPUE values were calculated following methods similar to those used in the 2020 Delta juvenilr fish montioring program Bearshire fishes annual report (McKenzie 2019).

Results and Discussion

Largemouth Bass (*Micropterus salmoides*)

Largemouth Bass is a common species in the sloughs of the Delta and are one of the system's top predators (Ferrari et al. 2014). Unlike other species in the sunfish family that tend to be flat, the Largemouth Bass is streamlined in a fusiform shape. Their facilitated shape and emarginated tail make the Largemouth Bass more agile and quick in open waters than other sunfish (Weinersmith et al. 2019). As juveniles, they feed primarily on aquatic insects, and as adults, they feed mainly on crayfish and other fish, especially other Centrarchids (ibid).

This novel species, introduced to the area a century prior, has shown a positive facilitative interaction with the invasive macrophyte, Egeria densa (Brazilian Waterweed) (Moyle 2002; Conrad et al. 2016). The positive correlation between vegetation and Largemouth Bass population recruitment is documented in several regions (Durocher et al. 1984; Orth 1990; Willis and Guy 1991). Locally, Brazillian waterweed has become the dominant SAV species, increasing the recruitment of juvenile Largemouth Bass (Conrad et al. 2016).

Our beach seine catch shows a similar increasing trend for nearly all regions we sample (**Figure 4**). The CPUE of Largemouth Bass in the lower Sacramento and San Joaquin Rivers and South and Central Delta regions generally increased over the last 20 years, with some years increasing substantially (**Figure 4**). What is surprising is the relatively stable catch of Largemouth Bass (average 57.7 CPUE) in the North Delta Region, which warrants future investigation (**Figure 4**).

Bluegill (*Lepomis macrochirus*)

Bluegill Sunfish is a common North American fish that is native to the regions of the United States that lie east of the Rocky Mountains from Texas up to western New York. Bluegill's morphological adaptations allow them to respond rapidly with phenotypic plasticity that helps them survive changes in the ecosystem (Gaston and Lauer 2015).

Figure 3. Size distribution of measured fish from 1995–2023 DJFMP beach seine surveys in the Sacramento–San Joaquin Delta and San Francisco Bay/Estuary. Median fork lengths are indicated with a vertical orange line.

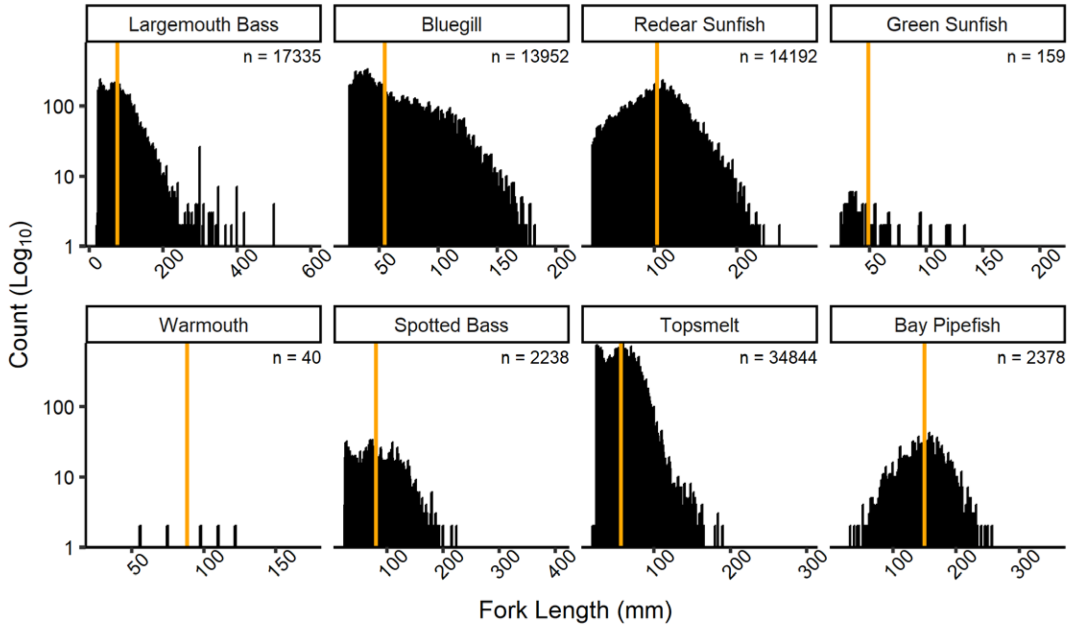
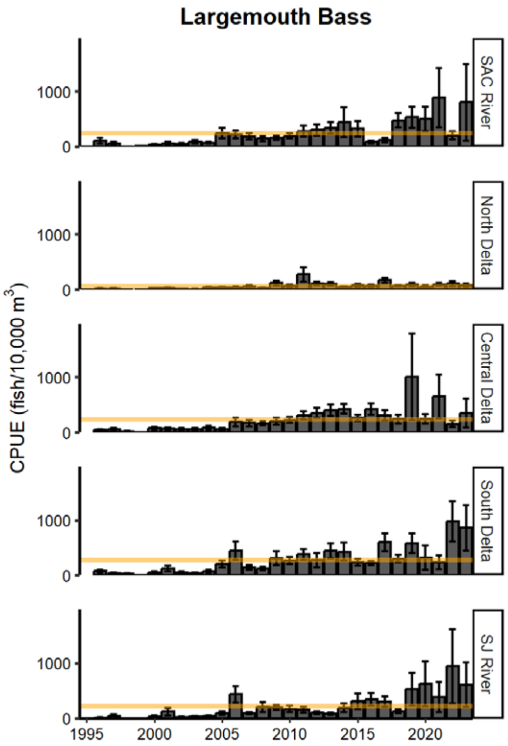


Figure 4. Annual catch-per-unit-effort (CPUE) of Largemouth Bass (*Micropterus salmoides*) in beach seine regions from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.



Although Bluegill can be found in both lentic and lotic environments, they prefer ponds, lakes, reservoirs, and slow-moving streams with little or no water flow (Stuber et al. 1982a). It is well documented that the species prefers areas with abundant SAV (Trebitz et al. 1997; Miller et al. 2018). Unlike other littoral fishes that only feed on aquatic invertebrates seasonally or as juveniles, Bluegill prey on invertebrates associated with SAV throughout all life stages (Christman et al. 2023) and often consume whatever is most abundant (Moyle 2002).

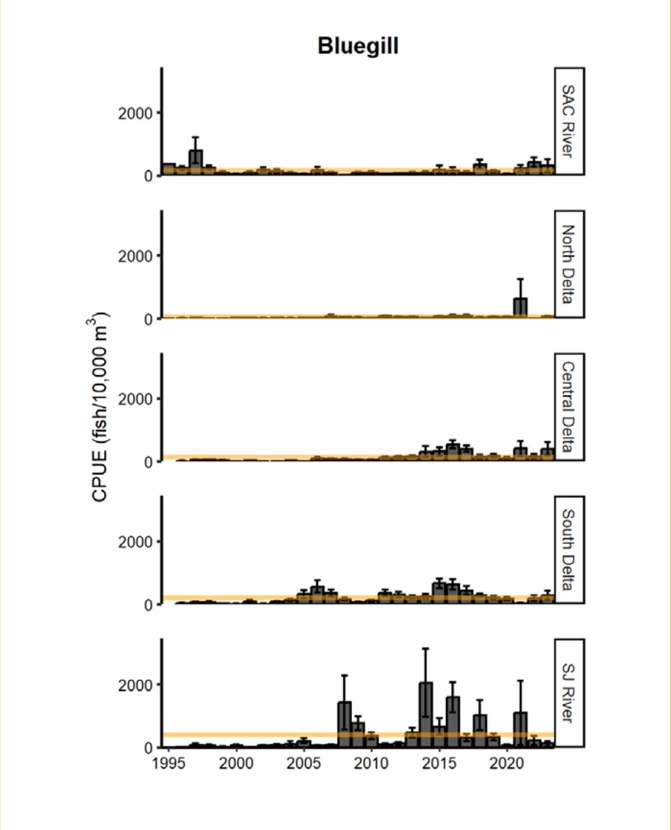
The catch of Bluegill in our DJFMP seines increased around 2014–2017 in the Central Delta, South Delta, and San Joaquin River (peaking in these three years at 536.8, 660.1, 2041.2 CPUE, respectively) (**Figure 5**). Standardized catch at sites along the lower Sacramento River and North Delta showed no trends (**Figure 5**). Both Largemouth Bass and Bluegill showed an increase in standardized catch in many regions around 2015 (**Figures 4 and 5**). However, Largemouth Bass catch continued to increase in subsequent years, while Bluegill catch declined in many regions (**Figures 4 and 5**).

Redear Sunfish (*Lepomis microlophus*)

Native to the southeastern regions of the United States, the Redear Sunfish exhibit an ontogenetic diet shift that switches from smaller benthic invertebrates to larger ones as they grow (Whitney et al. 2021).

Redear Sunfish are associated with vegetated shallow, warm water lakes, bayous, marshes, and reservoirs (Twomey 1984). They prefer habitats with large areas of aquatic vegetation;

Figure 5. Annual catch-per-unit-effort (CPUE) of Bluegill (*Lepomis macrochirus*) in beach seine regions from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.



indeed, Young et al. (2018) report a positive correlation between Redear Sunfish and submerged and emergent aquatic vegetation in the Delta.

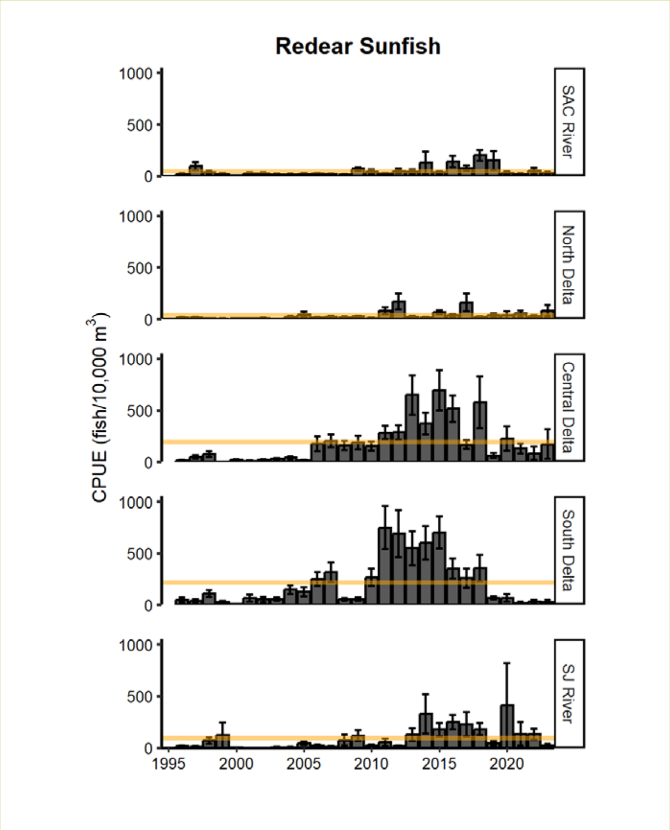
Historically, Redear sunfish are known to be less common in the Delta than Bluegill (Moyle 2002). However, our data indicates that this trend may be changing; Redear Sunfish standardized beach seine catch peaked around 2015–2017 (293.0, 698.6, 327.5 CPUE, respectively), similar to the Bluegill catch (**Figures 5 and 6**). Largemouth Bass populations may be suppressing Lepomis spp. populations through predation (Belk and Hales 1993). It is also possible that gear biases (e.g., Lepomis are more closely associated with vegetation than Micropterus) since seining requires unobstructed habitats; further inquiry is needed.

Green Sunfish (*Lepomis cyanellus*)

Green Sunfish (*Lepomis cyanellus*) is native to the United States Great Lakes as far west as South Dakota, south to Texas, sweeping to the eastern regions from New York to Eastern Florida (Warren 2009).

An ecological generalist, the Green Sunfish prefer streams with aquatic plants, muddy bottoms, and warm, turbid water (Moyle and Nichols 1973). Green Sunfish can often survive in environments many other fish species cannot (Moyle 2002). They prefer 26–30°C water temperatures but can tolerate up to 38°C (Moyle 2002). Green Sunfish can live in low oxygen environments, often lower than 1 ppm (Ribarich 1973), and can survive alkaline waters with a pH as high as 8.5 units (Stuber et al. 1982b).

Figure 6. Annual catch-per-unit-effort (CPUE) of Redear Sunfish (*Lepomis microlophus*) in beach seine regions from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.

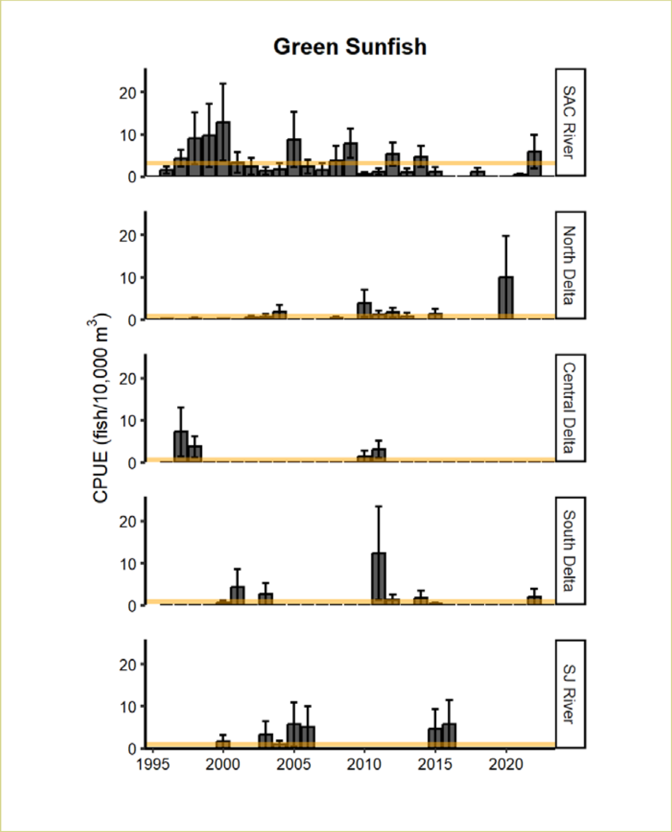


The mean annual standardized beach seine catch for Green Sunfish is variable; no trends in catches since 1995 are apparent (**Figure 7**) (CPUEs fluctuating from 0 to >12). However, the overall catch of Green Sunfish in the lower Sacramento River has decreased over the last twenty years. One possible explanation for the sporadic and infrequent catch of Green Sunfish is the continual increase in Largemouth Bass (**Figure 4**), which can disproportionately prey more on Green Sunfish than other Centrachids (Savitz and Janssen 1982). Another possible explanation for the sporadic Green Sunfish catch is their low salinity tolerance; they avoid water with salinity higher than one to two ppt (Peterson 2011). Since DJFMP seine hauls often occur at tidally-influenced sites (the Bay seines along with Regions 3–5, and 7), salinity is regularly over 2 ppt at those sites (Hutton et al. 2016). The degree to which Green Sunfish populations are subject to biotic and abiotic controls in the Delta merits further study.

Warmouth (*Lepomis gulosus*)

The Warmouth's native distribution is similar to other

Figure 7. Annual catch-per-unit-effort (CPUE) of Green Sunfish (*Lepomis cyanellus*) captured in beach seine regions from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.

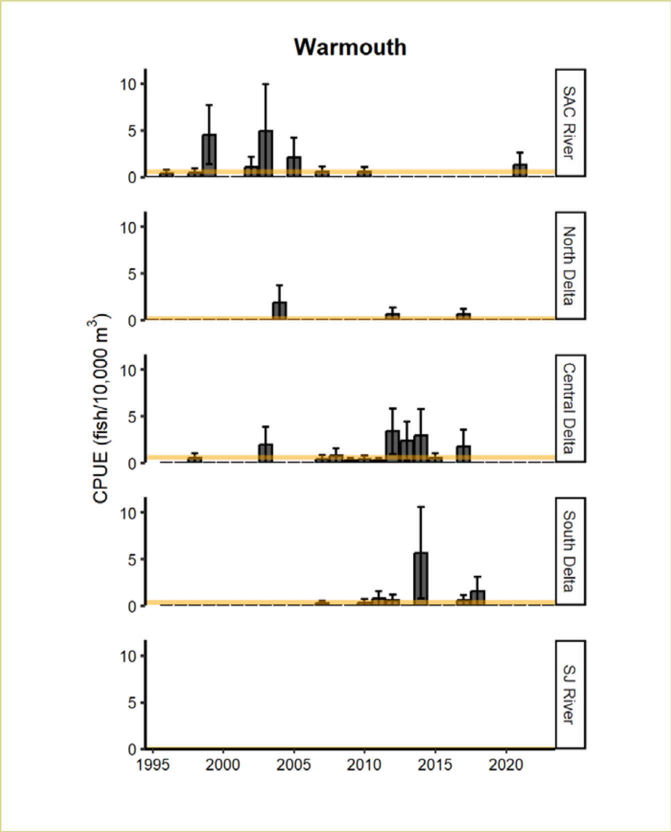


Centrarchidae species in the United States. This area encompasses the Great Lakes and Mississippi drainage basins from Florida to Texas through the Atlantic and Gulf Coast regions.

Warmouth prefer thick weedy areas with muddy bottoms (Larimore 1957). In the Delta, Warmouth are not considered uncommon but are not nearly as common as other Centrarchid species (Moyle 2002). Warmouth prefer more than 1 ppt salinity but tend to avoid high salinity areas greater than 4.1 (McMahon et al. 1984; Moyle 2002). Therefore, it is not surprising that Warmouth are not often found in the tidally-influenced regions of the Delta where the majority of the DJFMP beach seine program samples.

The standardized seine catch of Warmouth has been highly variable interannually since 1995 (**Figure 8**). As with other Centrachid species reported here, Warmouth were captured in slightly greater abundances around 2015 in the Central (max CPUE 3.4) and South Delta (max CPUE 5.7)areas (**Figure 8**). For the last five years, only one Warmouth was captured by DJFMP beach seines, and that fish was captured at the Knight's Landing boat ramp. The reason for the drop in catch across all regions reported is unknown and warrants further investigation.

Figure 8. Annual catch-per-unit-effort (CPUE) of Warmouth (*Lepomis gulosus*) in beach seine regions from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.



Topsmelt (*Atherinops affinis*)

Topsmelt is native to the eastern Pacific Ocean of North America from Canada to both the Baja peninsula of Mexico and the Gulf of California coasts. While not commonly caught in freshwater, Topsmelt are among the most commonly encountered species in the lower reaches of coastal streams (Moyle 2002). In the San Francisco Estuary, they are known to be most abundant in the southern portion of the Bay (Wang 1986). Females can spawn more than once in a season, and the spawning season for Topsmelt is long, typically from April to October (Wang 1986). Larval Topsmelt are more present in the more sluggish waters of the Bay. Wang (1986) notes that Merrit Lake in Oakland is an example of a location where larval Topsmelt were particularly abundant. Juveniles are typically located in the open waters of the Estuary (Wang 1986).

We observe no major long-term trend in Topsmelt catch (**Figure 9**). Catch over the 27-year time series is variable; the highest and lowest mean annual standardized catches occurred in monitoring years 2022 and 2023, respectively (**Figure 9**). From late August to early September of 2022, a bloom of Heterosigma akashiwo (also known as red tide alga) likely caused extreme fish losses in the San Francisco Bay Area, including Lake Merrit in

Figure 9. Annual catch-per-unit-effort (CPUE) of Topsmelt (*Atherinops affinis*) in San Francisco Bay area beach seines from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.

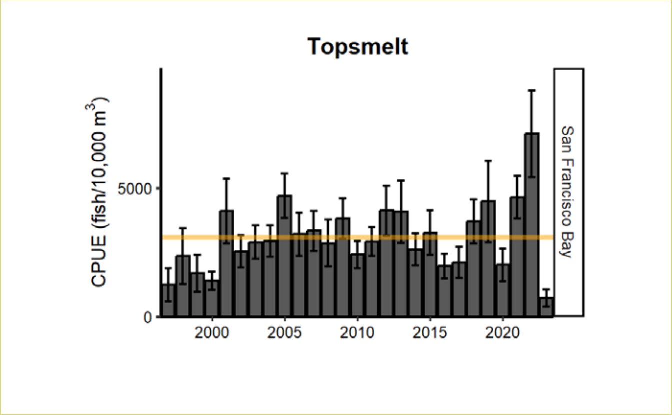
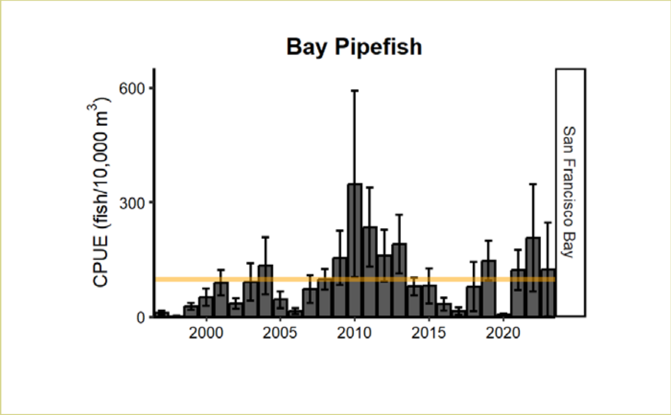


Figure 10: Annual catch-per-unit-effort (CPUE) of Bay Pipefish (*Syngnathus leptorhynchus*) in San Francisco Bay area beach seines from 1995 to 2023. Horizontal orange lines indicate mean annual CPUE.



Oakland (Schreier et al. 2022). This die-off could have significantly reduced recruitment of larval Topsmelt from 2022 into the juvenile population in 2023.

Bay Pipefish (*Syngnathus leptorhynchus*)

The Bay Pipefish is native to bays and estuaries along the western coast of the United States from Alaska to the southern tip of California. Bay Pipefish prefer shallow vegetated areas of the Bay and San Francisco Estuary, particularly areas heavy in eelgrass (Wang 1986). For their entire life cycle, they live in eelgrass, a rarity among Pacific fishes (Louie and Bardeleben 2006). Loss of eelgrass in an estuary has been tied to reductions in Bay Pipefish populations (O'Leary et al. 2021).

Pipefish, like seahorses, are members of the family Syngnathidae (Wang 1986). Males in that family are known to carry the eggs after fertilization in a pouch, and multiple sizes of eggs have been observed in a single male Bay Pipefish, which could indicate deposits from multiple females (Wang 1986).

Annual CPUE of Bay Pipefish in DJFMP seines is sporadic (**Figure 10**). Maximum (348) and minimum (5) mean annual standardized catch occurred in 2010 and 2020, respectively, for unknown reasons. During the last three water years, catch rates appear to be normalizing. However, there are still significant representative variances between the years. These variances fall within the average range between 2008–2013, except 2010, which was an abundant outlier.

Conclusion

Here, we examined the annual abundance patterns of five non-native species and two native bay species captured in the Bay and Delta with beach seines from 1995 to 2023 and described their association with SAV. Observed trends are linked to fish life histories, habitat preferences, regional habitat conditions, and climatic events. Most non-native species in this report rely on SAV in one or more life cycle stages.

SAV has substantially increased in the Delta over the past decades, modifying system dynamics to favor the non-native species introduced to the area (Christman et al. 2023). Khanna et al. (2023) found that over a five-year timespan, ~6–11% of the Delta system was covered in SAV. Habitat complexity has constantly been changing with the alteration in the composition of introduced species with landscape spread. The 2023 water year, preceding two driest years on record, was among the wettest. The changes in the system following may have affected species composition, abundance, and distribution of fish and their associated SAV habitats in the Delta, warranting future investigation.

Since the mid to late 1990s, the DJFMP beach seine fish survey has documented the year-round abundance and distribution of fishes in nearshore habitats of the Delta, lower Sacramento, and San Joaquin Rivers and for the San Francisco Bay. Data interoperability and the free exchange of analyses provided by this, and other Interagency Ecological Program monitoring efforts, help inform insightful and high-quality science needed to reconcile the needs for a reliable and sustainable water supply and a functioning Bay-Delta ecosystem. Indeed, over 30 peer-reviewed scientific journal articles and over 50 gray literature reports have been published using DJFMP data. For example, DJFMP data has enabled scientists to document species declines (Sommer et al. 2007), species introductions (Mahardja et al. 2020), and shifts in species assemblages (Mahardja et al. 2017). Therefore, the DJFMP nearshore fish survey is valuable to scientists studying novel ecosystem ecology and remains a critical component of California water and Bay-Delta adaptive management.

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RESEARCH ARTICLE

Behavior of Cultured Delta Smelt in Field Enclosures: Does Ancestry Matter?

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Abstract

Delta Smelt are an endemic species to the San Francisco Estuary that have experienced a steady population decline leading to their listing as an endangered species. There has been a large multiagency effort to improve the status of Delta Smelt through habitat restoration, maintaining a conservation hatchery and implementation of a supplementation program. Without management intervention, this species would likely face extinction. However, management actions should proceed with caution to avoid unintended negative species impacts. This study describes a pilot investigation of the impacts hatchery domestication may have on certain behavioral attributes of Delta Smelt reared in captivity by observing hatchery and wild-origin Delta Smelt in enclosures in the wild. Using pedigree and genetic analyses, we quantified the genetic domestication index levels of several Delta Smelt families. Families were separated into two groups: high domestication and low domestication. Mixtures of individuals from multiple families were then put in field enclosures to monitor their behaviors over time in a wild setting. We monitored swimming behavior including tailbeats per minute, rheotaxis, and group swim type for four days. We found similar behaviors of the high and low domestication groups; however, certain experimental limitations may have influenced our results. This study did not find evidence to support that behavioral differences exist in the metrics examined during the experimental period between the compared domestication levels. We recommend replicating the study in a more controlled laboratory environment and continuing to evaluate differences between domestication levels as the hatchery program continues and domestication of the hatchery individuals increases.

Introduction

The Delta Smelt (*Hypomesus transpacificus*) is a small pelagic fish endemic to California and has been listed as endangered by the state of California since 2009 and threatened by the federal government since 1993 (Baxter et al. 2010; US Fish and Wildlife Service 2010). Delta Smelt were once an abundant species, with their population spanning across the Sacramento–San Joaquin River Delta and San Francisco Estuary (hereafter called estuary). However, since the 1980s, the Delta Smelt population has been on a steady and precipitous decline to near extinction (Moyle et al. 2016; Hobbs et al. 2018). Loss of habitat (in acreage and suitable quality), increasing pressure from invasive species, water diversions, and severe droughts are some of the main factors attributed to the decreased abundance of Delta Smelt (Mac Nally et al. 2010; Moyle et al. 2016). Delta Smelt are known to be a sensitive species with a rather unique life history. The species exhibits a mostly semelparous life cycle (though some live two years), diadromous strategy (though some estuarine and freshwater residents exist [Hobbs et al. 2019]), and are considered weak swimmers as compared to other species (Swanson et al. 1998; Swanson et al. 2000). These traits may make Delta Smelt less competitive for resources and more susceptible to predation (Davis et al. 2019). As such, Delta Smelt may serve as an indicator species, providing a gauge on the ecological health of the ecosystem. As Delta Smelt populations decline in response to degraded ecosystems, so too may other less sensitive species if the conditions continue or worsen, which can lead to far greater impacts such as ecological collapse (Lakoff 2016).

To address the decline of Delta Smelt and prevent potential extinction (Hobbs et al. 2017; Moyle et al. 2018), large multiagency teams have been established to implement several conservation actions. One such action was the establishment of a hatchery population in 2009 at the Fish Conservation and Culture Laboratory (FCCL) in Byron, CA with a redundant population at the Livingston Stone National Fish Hatchery near Shasta, CA. Additionally, management of natural resources have been implemented (Sommer 2020), such as increasing acreage of restored tidal wetland habitat and improving overlap of key Delta Smelt habitat attributes such as low salinity habitat, increased turbidity, and food availability (Sommer et al. 2020). Furthermore, water operations in winter and spring are actively monitored and managed to reduce entrainment of Smelt in the central and south Delta (Kimmerer 2008). One of the most direct conservation efforts began in 2021, with experimental releases of hatchery Delta Smelt directly into the wild across varied locations in the Delta to subsidize natural populations.

Reinforcing Delta Smelt populations through hatchery supplementation is now considered essential by many to give the species a chance at population stability and avoid extinction in the wild. However, there are important considerations to ensure the success of releases from captivity. For example, use of hatchery fish to augment wild populations may unintentionally reduce genetic diversity through inbreeding, introduce cultured fish with markedly different behaviors wild fish, and hatchery fish can flush-out beneficial genetic adaptations present in wild populations (Naish et al. 2007; Araki and Schmid 2010; Fisch et al. 2013). Supplementation effects have been widely studied in salmonid species, but these impacts are unknown for Delta Smelt. For example, it has been shown in salmonids that hatchery reared fish exhibit deleterious behaviors in the wild (Weber and Fausch 2003), have reduced physiological responses (Webb and Cotel 2011), and are phenotypically smaller and less fit (Metcalfe et al. 2003) than their wild counterparts.

The goal of this study was to investigate if hatchery reared Delta Smelt exhibit altered behaviors (i.e., swimming behaviors) in response to domestication when compared in a field setting. We sought to determine whether the examined traits were associated with generation time in the hatchery (hereafter called Domestication Index [DI]). We evaluated the following questions: 1) Do Delta Smelt with a higher DI exhibit a change in swimming activity as noted by tailbeat frequency, and 2) Is natural swimming behavior such as rheotaxis and swimming type altered by DI? We hypothesized the more domesticated Delta Smelt would exhibit elevated swimming activity and decreased natural behaviors (i.e., directional and type).

Methods

Fish preparation and transport

The UC Davis FCCL reared two different groups of Delta Smelt with varied DI (the level of hatchery ancestry) to test the effect domestication may have on the behavior of sub-adults in the field. We obtained the two different groups of Delta Smelt by identifying spawning pairs of captive and wild-origin males and females based on genetic analysis and pedigree reconstructions (Fisch et al. 2013). We calculated the DI for spawning parents and their progeny (Finger et al. 2018) using pedigree records and PMx software (Lacy et al. 2012). The two DI groups included: 1) Low DI fish from 13 different crosses, 12 of the 13 crosses having one wild parent, with a mean progeny DI = 3.85; 2) High DI fish from 10 different crosses with a mean progeny DI =10.7 (**Table 1**).

Table 1. Description of domestication indices for spawning pairs and progeny used in the current study.

Cross Date	Female DI	Male DI	Progeny DI	DI group
5/20/2020	9.8	9.6	10.7	High
5/20/2020	10.1	10.1	11.1	High
5/20/2020	10.5	9.6	11.1	High
5/22/2020	9.4	10.1	10.8	High
5/22/2020	9.2	9.8	10.5	High
5/22/2020	9.2	10.3	10.8	High
5/22/2020	9.5	9.9	10.7	High
5/22/2020	9.0	9.9	10.5	High
5/22/2020	8.7	9.6	10.2	High
5/22/2020	9.1	9.7	10.4	High
5/20/2020	5.3	0.0	3.7	Low
5/20/2020	5.5	0.0	3.8	Low
5/20/2020	6.3	0.0	4.2	Low
5/20/2020	6.6	0.0	4.3	Low
5/20/2020	6.2	0.0	4.1	Low
5/22/2020	5.7	0.0	3.9	Low
5/22/2020	5.0	0.0	3.5	Low
5/22/2020	4.1	0.0	3.1	Low
5/22/2020	6.5	0.0	4.3	Low
5/22/2020	5.0	0.0	3.5	Low
5/22/2020	5.2	5.2	6.2	Low
5/22/2020	6.5	0.0	4.3	Low
5/22/2020	5.1	0.0	3.6	Low

We transported the progeny once they reached sub-adult stage (average fork length 51 mm and weight 1.05 g, 226 days post hatch) from the FCCL to Rio Vista, CA on the Lower Sacramento River in January 2021. We transported the fish (n=306) via truck in black insulated buckets with screw-top lids (19L). Staff filled each bucket with water from the FCCL that comes from the Sacramento–San Joaquin Delta, which was then salted to 5 ppt, treated with an electrolyte solution, and supersaturated with oxygen to approximately 180%. These steps are taken to reduce stress and minimize mortality, and it is the current standard practice for transporting Delta Smelt from FCCL (Baerwald et al. 2023). Upon arrival at Rio Vista, the buckets were transferred to a boat and then to the enclosures. Each bucket, containing 34 fish, was emptied into its respective enclosure using a water-to-water transfer after allowing for one minute of water exchange between the buckets and the ambient water.

Field deployments

We deployed nine enclosures designed for in situ experiments with Delta Smelt on the Sacramento River near Rio Vista for a planned period of four weeks. Each enclosure was 1.22 m tall and 0.95 m in diameter, constructed of black powder-coated aluminum with 4.76 mm holes on 6.35 mm centers (providing 51% openness), and were floated with buoys to help buffer wake and wind action (Baerwald et al. 2023). The buoyancy from the buoys held the lid of the enclosures roughly 20 cm above the surface of the water. We arranged the enclosures in a parallel line to shore and attached them to each other using 3 m of 6.35 mm stainless steel cable encased in PVC pipe. The PVC pipes add rigidity and help to maintain distance between each enclosure. Enclosures either attached to each other or an anchor buoy secured to a pyramid anchor buried in the substrate (**Figure 1**). The enclosure and buoy system was able to move vertically with the tides while maintaining a standardized distance between enclosures.

We deployed a total of nine enclosures. Three enclosures held Low DI fish (n=34 fish/enclosure; n=102 Low DI fish across replicates), three enclosures held High DI fish (n=34/enclosure; n=102 High DI fish across replicates), and three enclosures held an equal mixture of Low and High DI fish (N=17 Low DI + 17 High DI/enclosure; n=51 Low and 51 High DI fish mixed together in enclosures across replicates).

Video collection methods

To assess Delta Smelt behavior, we attached underwater video cameras (Go Pro Hero 3) to the inside of each Low and High DI enclosure. Video observations were not made for the mixed DI enclosures. The camera was mounted 43 cm from the bottom of each replicate enclosure and angled downward to capture the bottom third of the enclosure and ensure cameras were submerged throughout changes in tidal and wave activity. However, it was possible for fish to swim out of view in this setup, which eliminated our ability to account for all fish at all times during observation. The cameras recorded 10-minute videos twice a day (at 10:00 and 15:00 PST) to attempt to capture differences in behavior throughout a day while ensuring enough daylight is present for visibility (Spencer 1939).

The video recordings used in this study underwent stringent filtering for quality and completeness of footage to standardize and increase certainty of analysis. In total, we collected 258 videos over the course of this study. Of the total 258 videos, 169 recordings were initially removed due to low visibility of fish, 27 were removed because the camera came out of the water, and 14 were removed because of technical problems with file corruption. With the remaining 48 videos of good quality, 10 were removed because the camera either fell out of position or off its mount during the recording, and 28 video recordings were removed because they were less than 10 minutes long (e.g., only a few seconds to minutes recorded) which was essential to obtain replication of those observations. Of the final 10 standardized videos, two were excluded from significance testing because they were the only video analyzed on their respective dates (1/14 and 1/17), meaning no direct comparison of the DI treatment groups could be made on those dates; however those video data are still presented. The videos were analyzed for fish behavior manually using VLC media player and slowed to 50% speed for analysis. The researcher analyzing the videos did not know the DI status of the fish.

Each 10-minute video was broken down into three 1-minute subsamples for analysis, at the 2-, 5-, and 8-minute marks. We assessed average behavior as well as variability in behavior across the 10 minutes, both within and between enclosures. For each 1-minute subsample, individual and group behavior metrics were collected. The metrics assessed were individual swimming activity, mean tailbeat frequency, and group rheotaxis. Individual swimming activity is a qualitative metric of activity type, which includes stroke and glide, continuous, or discontinuous swimming (Swanson et al. 1998). Individual swimming activity was recorded as whichever activity five individual fish, chosen at random, were doing the most during the observation period. Mean tailbeat frequency was calculated as the average tailbeats of 5 distinct fishes over the course of one minute. Group rheotaxis was qualitatively recoded as the activity that the majority (>80%) of the fish in view were doing throughout

Figure 1. Enclosure deployment schematic in Rio Vista January 2021, including three enclosure replicates for each domestication index treatment, Low, High, and mixed. Only the Low and High treatments were evaluated in the current study.

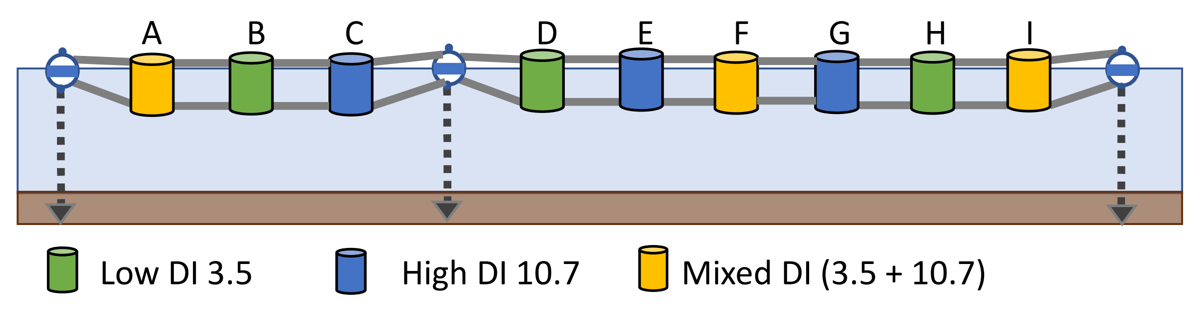


Table 2. Water quality data collected at 10:00 a.m. during video recordings, water quality was only recorded for days and times video analysis was completed.

Date	Temperature (°C)	Turbidity (NTU)	Flow (cfs)	Electrical Conductivity *(us/cm)	Dissolved Oxygen (mg/L)
1/14/2021	10	3.98	69500	211	10.26
1/15/2021	10.1	4.62	79100	215	10.21
1/16/2021	10.1	4.64	76100	225	10.18
1/17/2021	10.2	4.72	58600	288	10.12

the observation period. The rheotaxis activities are described as positive (swimming against flow), negative (swimming with flow), or neutral (listing, no preference) as described in (Coombs et al. 2020).

We obtained water quality data (turbidity, water temperature and flow) from the nearby data collection sites Rio Vista Bridge and Sacramento Rio Vista for periods of time for which observations were taken (CDEC 2023 Nov 21) (**Table 2**).

Statistical Analysis

To evaluate the effect of DI on Delta Smelt behavior, we tested hypotheses for general activity and directional behaviors. Due to a lack of usable observations from both treatment groups, only data from two days of the experiment (1/15 and 1/16) were analyzed. For activity, we analyzed mean tail beats per min (mTBM) with a linear mixed effects model (Bates et al. 2015), using tail beats as the dependent variable and DI as the predictor variable with days post deployment and enclosure as random effects.

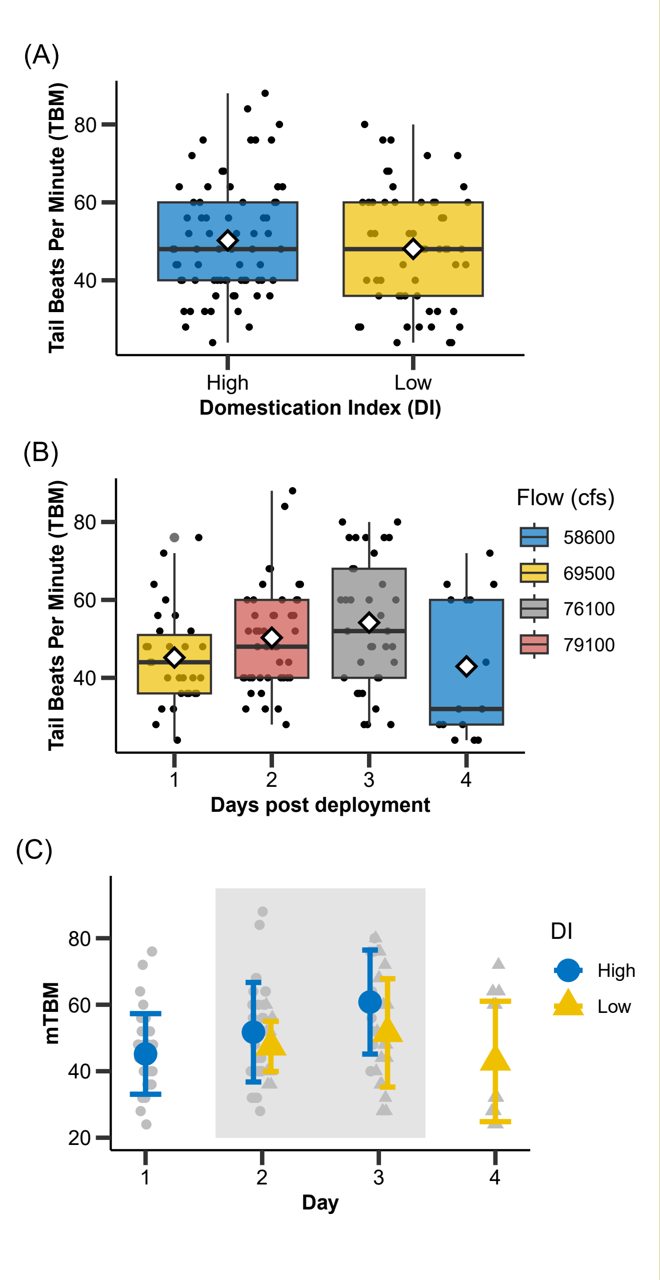
In enclosure C, observations at the two-minute time mark on day two were removed as outliers because they were observed above 1.5*IQR (interquartile range). Flow was tested for inclusion in the model but found to be co-linear with days post deployment, so we only included days post deployment in the final model. Effects were tested using estimated marginal means pairwise comparisons (Searle et al. 1980). Assumptions of the model were evaluated by examining the normality of the residuals. None of the variables required transformation. For directional behaviors, we analyzed group rheotaxis and swim type. To address small sample sizes and non-numerical data, a Fisher's exact test with simulated p-value based on 2,000 replicates was conducted (R Core Team 2023).

Results and Discussion

The objective of this study was to determine whether there were detectable behavioral differences between Delta Smelt with high and low domestication levels, based on hatchery ancestry. We observed the behaviors of tail beat frequency, swim type, and rheotaxis and did not detect significant effects of hatchery ancestry on these behaviors. Delta Smelt tail beat frequency (beats per minute, TBM) between High and Low DI groups was similar (Estimated marginal means, estimate=5.18, SE=6.46, df=1.58, t=0.80, p=0.53, n=16). The average TBM was 48 ± 15 and 50 ± 15, for Low and High DI respectively (**Figure 2A**). Flow was excluded for autocorrelation with days post deployment and when plotted there was no clear trend for flow effecting TBM (**Figure 2B**), this was likely due to the differences of flow experienced inside of the enclosures was likely not strong enough to elicit a strong response. We observed a trend of High DI fish increasing their swimming activity over time and Low DI fish decreasing their activity over time (**Figure 2C**), but we were not able to determine this relationship fully because our analyzed data were limited to two days of comparative observations. Directional swimming behavior was also similar between Delta Smelt DI groups. There was no difference in rheotaxis behavior between groups (p=0.462, n=9 for High DI and n=8 for Low DI) or swim type behavior between groups (p=1.00, n=9 for High DI and n=8 for Low DI) (**Figure 3A and 3B**).

In this study, we implemented similar techniques used to study salmonid hatchery impacts and applied them to Delta Smelt while also including a DI to measure how hatchery ancestry may impact their behavior (Huntingford 2004; Armbruster and Reed 2005; Conrad et al. 2013; Foster 2013; Foster and Baker 2019). While we did not find evidence to support detection of differences in swimming behaviors between domestication levels, studies have shown that hatchery salmon exhibit behaviors such as increased predation, decreased foraging efficiency, and decreased aggression (slower to obtain food and fewer dominance displays) (Berejikian et al. 1996; Chittenden et al. 2010; Tang et al. 2017). It is unclear if natural-origin Delta Smelt captured in coming years in the Delta, which may typically be progeny of hatchery released Delta Smelt, could display more wild behaviors and pass those traits on to further progeny. For example, other organisms (threespine stickleback and Pheidole ants) have demonstrated that certain behavioral traits can lie dormant for several generations and then be re-expressed when exposed to the correct stimuli (Foster and Baker 2019). Additional studies to describe how hatchery effects may influence Delta Smelt behavior and how that may be connected to domestication over time will allow us to monitor for differences due to domestication effects and potentially mitigate impacts. Understanding these components of Delta Smelt behavioral biology could lead to improved performance in the wild and increased efficacy of hatchery programs.

Figure 2A. Box and whisker plots for all tailbeat observations across the entire study period binned by High and Low Domestication Index groups. White diamonds represent the mean tail beats per minute of all of the observed fish across the full study period. **Figure 2B.** Average swimming activity as tailbeats per minute (TBM) across days post deployment. Colors indicate flow rate (cfs) at the time of behavior observations.
Figure 2C. Mean (±SE) tail beats per min (mTBM) across days post deployment for High (blue) and Low (yellow) DI fish. Gray points represent individual observations of fish. The gray box highlights the data used in statistical analyses. Only these two days of observations were used because the first and last days of the study do not contain observations from both treatment groups.

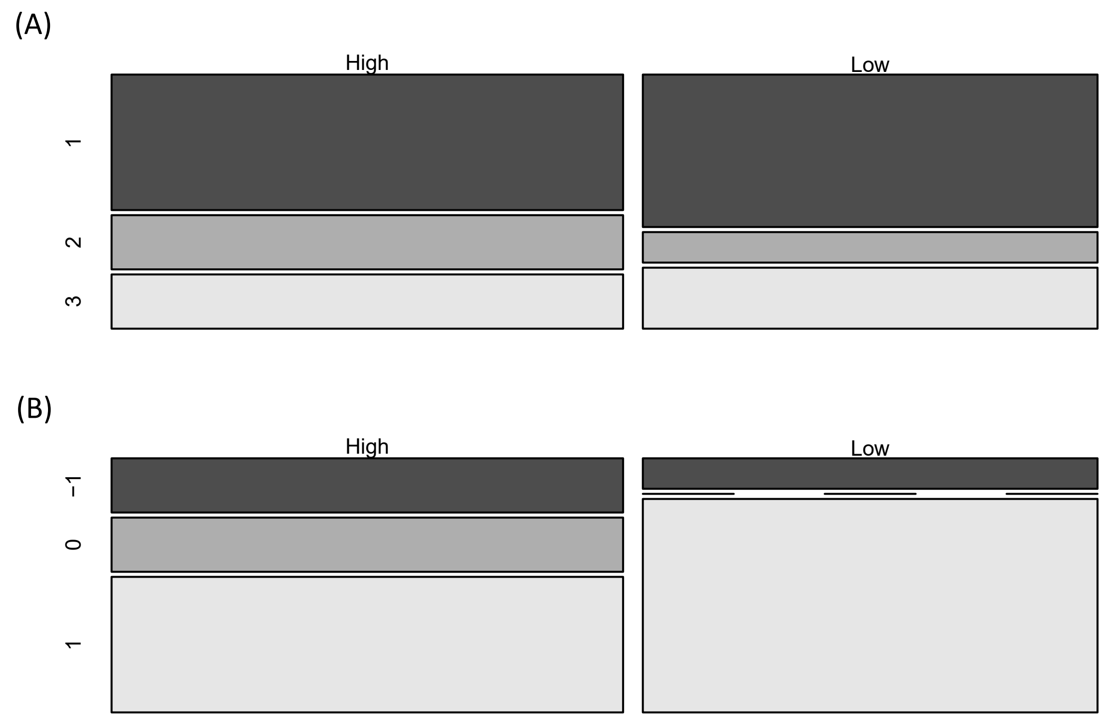


While our study did not contain significant results of domestication effects on swimming behavior, there does remain moderate uncertainty. Our findings were constrained by a number of factors that could have influenced results such as time, turbidity, and sample size, and suggest a laboratory approach for behavior assessments may be a better standardized approach. One of the largest impacts to the study was turbidity and video quality. Ultimately our analyses are based on 10 videos of the total 258 that were collected. We planned to take observations two times each day, one at 10:00 a.m. and another at 3:00 p.m., but turbidity during the afternoon proved too high for reliable observations. The study was also constrained in time because a large storm event occurred in the middle of the planned study period and caused mass mortalities, so observations were discontinued after that point. The constraints of time and data reduced statistical power in our analyses by reducing the number of observation points (Akobeng 2016).

With the limited sample size and high variability of individual behaviors observed, we were not able to make any significant conclusions. However, it is important to consider the trends observed, especially as this study may not be replicable due to the lack of wild-origin Delta Smelt. The tailbeat frequency data exhibited a potential trend where the higher domesticated fish showed higher activity over time than their lower domesticated counterparts (**Figure 2C**), but we lacked data for each DI group on days 1 and 4 that could have strengthened or weakened this trend. A difference in tailbeat frequency can lead to differences in energy efficiency and predator avoidance, which are important factors to success in the wild. There were no observable trends in the rheotaxis or swim type data. This could be due to those behaviors being more nuanced and potentially influenced more directly by the hatchery rearing process (i.e., swimming in circular flow tanks, feeding schedules, and food type) rather than ancestry. These differences in directional activity can be an indication of the fishes ability to adapt to their new environment, which quick adaptation to the local environment is paramount for success. The parameters of this study did not find any significant results, thus we can conclude that the hatchery fish did not exhibit observed behaviors as to be immediately significant and observable relative to their lower domesticated counterparts.

In conclusion, our study did not find evidence of behavioral differences in the behaviors observed between Delta Smelt with relatively low and high domestication. Despite not observing any behavioral differences between the domestication levels of Delta Smelt, it is important to consider evaluating these metrics over time in case behaviors change as hatchery production increases for supplementation purposes. A potential method to monitor these domestication behaviors that requires less effort than field studies and may be more sensitive would be to implement periodic laboratory studies. In the laboratory, other metrics can also be explored that may better handle some of the difficulties we had in this study such as high variability due to

Figure 3A. Swim type mosaic plot, with swim type represented as 1: stroke and glide, 2: continuous swimming, and 3: discontinuous swimming. **Figure 3B.** Group rheotaxis mosaic plot. For Low and High Domestication Index, positive rheotaxis (1) means fish are oriented or swimming against the direction of the flow, negative rheotaxis (-1) are fish swimming with the flow, and neutral (0) are fish swimming with no clear direction or listing.



low sample size and different behaviors. In the interim, some potential behavioral mitigation measures that could be implemented in the hatcheries include varied feeding schedules, use of live feed that mimics what would be consumed in the wild (calanoids), and incorporating actions which illicit anti-predation behaviors. Integrating behavioral studies and mitigation techniques over time as Delta Smelt culture increases can be an important piece in understanding how Delta Smelt culture impacts their behavior and their ability to adapt to the environments they are released into, which can impact their ability to succeed in the wild. Delta Smelt are an integral species to the Delta and it is important that conservation programs are effective in helping the recovery of Delta Smelt and fulfilling the objective of the Interagency Ecological Program to manage the Bay-Delta ecosystem.

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RESEARCH ARTICLE

Investigating the Consequences of a Hypoxia Event in Fall 2021

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Abstract

Periods of low dissolved oxygen (DO), known as hypoxia, appear to be increasing in frequency and intensity in coastal areas around the world. Following a record-setting atmospheric river storm in October 2021, an almost two-month long hypoxia event was observed in the Yolo Bypass of the Sacramento–San Joaquin Delta. Using long-term water quality and fish catch data, this report analyzes the historical context and severity of the hypoxia event and hypothesizes on its mechanisms and impacts to the fish communities within the Yolo Bypass. Continuous water quality data going back to 2013 indicate that this hypoxia event's duration and intensity was unprecedented. Preliminary observations from fish catch data before and after the hypoxia event suggest a decrease in White Catfish (*Ictalurus catus*) catch and an overall community shift toward dominance of Black Crappie (*Pomoxis nigromaculatus*). Additional research and analysis are required to determine the mechanisms that caused this unprecedented hypoxia event and the implications it has on the entire food web. However, this event highlights the importance of long-term monitoring data for comparing change over time, especially in the face of climate change and future uncertainty.

Introduction

Dissolved oxygen (DO) is a vital compound for most organisms in aquatic ecosystems and is necessary for respiration in nearly all eukaryotes, including fish, invertebrates, and plants. DO concentrations in water can be directly affected by both biotic (e.g., photosynthesis and respiration by organisms) and abiotic factors (e.g., temperature, atmospheric pressure, and salinity). Instances of low DO, known as hypoxia, can have natural or anthropogenic origins. Natural hypoxia events in coastal areas can be caused by upwellings where low DO water from the deep ocean comes to the surface (Helly and Levin 2004; Rabalais et al. 2010). Similarly, runoff over wildfire burn scars can cause an influx of debris and organic material into a waterbody, stimulating bacterial decomposition, reducing DO concentrations, and leading to fish kills (Bixby et al. 2015; Dahm et al. 2015; The Associated Press 2022). Anthropogenic impacts can also cause hypoxia when increased nutrient input from agricultural runoff leads to eutrophication and harmful algal blooms, in turn depleting DO concentrations due to high oxygen demand from bacterial decomposition (Wetzel 2001). As such, DO concentrations in any given body of water can fluctuate spatially and temporally as a result of both natural and anthropogenic causes.

Hypoxia frequency and intensity in coastal areas around the world appear to be on an increasing trajectory (Gilbert et al. 2010). A meta-analysis of coastal hypoxia reporting from 1915 to 2006 showed an exponential growth rate of 5.54% ± 0.23% reports per year (Vaquer-Sunyer and Duarte 2008). While part of this growth rate is due to increased observation and documentation, long-term monitoring data supports the trend of increased frequency, severity, and duration of hypoxic events (Vaquer-Sunyer and Duarte 2008; Gilbert et al. 2010). Importantly, future projections of climate change are expected to exacerbate hypoxia in estuaries and coastal areas through a variety of different mechanisms, reinforcing the need for an interdisciplinary approach to understanding and mitigating hypoxia under an uncertain future climate (Altieri and Gedan 2015).

To further examine this trend of increased hypoxia frequency and intensity within the San Francisco Bay-Delta estuary, we investigated the historical context and consequences of an almost two-month hypoxia event during the beginning of Water Year (WY; October 1 through September 30 of the following year) 2022, roughly from late October through mid-December 2021. This hypoxia event occurred in the midst of two consecutive critical WY classifications (2021 and 2022) and during the driest three-year period on record in California (CDWR 2022). Additionally, this event followed an unseasonably large atmospheric river on October 24 and 25, 2021, which dropped approximately 153.93 mm of total rainfall in Sacramento (CDEC; SAE station), over seven times the monthly October precipitation average of 21.59 mm (NOAA n.d.) and setting the record for one-day precipitation in Sacramento (CBS News 2021). As expected, flows increased following the rain event, with discharge at Lisbon Weir (LIS) of the Toe Drain, for example, increasing from -16.23 cubic feet per second (cfs) on 10/24/2021 to a peak of 1,149.84 cfs on 10/27/2021 (CDEC; LIS station). Further, data from continuous sonde measurements in the Cache Slough Complex indicated a drop in DO and corresponding increase in fluorescent dissolved organic matter (fDOM), with the greatest impacts observed within the Toe Drain and Shag Slough (**Figure 1**) possibly due to stormwater runoff of agricultural fields within the Yolo Bypass (L. Stumpner, CDWR/formerly USGS, personal communication). Additionally, field surveys following the atmospheric river observed a fish kill affecting native fish like Chinook salmon (*Oncorhynchus tshawytscha*) during the Fall salmon run in Putah Creek (**Figure 1**), a tributary to the Toe Drain within the Yolo Bypass (Hampton 2021).

To help understand the contributing factors and consequences of this event and potential future events, we used long-term fish data from the Yolo Bypass Fish Monitoring Program (YBFMP; **Figure 1**) and continuous sonde and weather station data from locations in the San Francisco Bay-Delta to investigate the following research questions:

1. How did the duration and intensity of the WY 2022 hypoxia event compare to historical trends?
2. What were the water quality responses following this event?
3. How did the hypoxia event affect the abundance and community composition of resident fishes?

Answering these questions will help further our understanding of hypoxia events in the San Francisco Bay-Delta estuary and help to inform future research opportunities and possible management tools to mitigate these events in the future. With observed increases in hypoxia frequency and intensity in recent years, it is critical to understand the mechanisms and consequences of these events in the face of future uncertainty due to climate change.

Methods

Water quality and precipitation data were obtained online from the California Data Exchange Center (CDEC) and analyzed in RStudio (R Core Team 2022). Specifically, continuous (15-minute interval) DO data were queried from the "LIS - Yolo Bypass at Lisbon" station (LIS; **Figure 1**) for the period of 10/01/2013 – 05/31/2023. The start date of 10/01/2013 was chosen to align with the start of WY 2014 and availability of dissolved oxygen data at LIS. Continuous turbidity, flow, and pH data were queried from the same station for the period of 10/01/2019 – 09/30/2022 to highlight other water quality factors during the hypoxia event and how they may look in other typical dry years. Daily averages were calculated from 15-minute DO, turbidity, flow, and pH intervals for simplification. DO was aligned with daily precipitation data. Daily incremental precipitation data were queried from the "SAE – Sacramento Executive Airport" station (SAE) for the period of 10/01/2013 – 05/31/2023. The start date of 10/01/2013 was chosen to align with the availability of dissolved oxygen data at LIS. The ending date of 05/31/2023 was arbitrarily chosen to capture as much data from WY 2023 as possible while also allowing for data analysis and report writing.

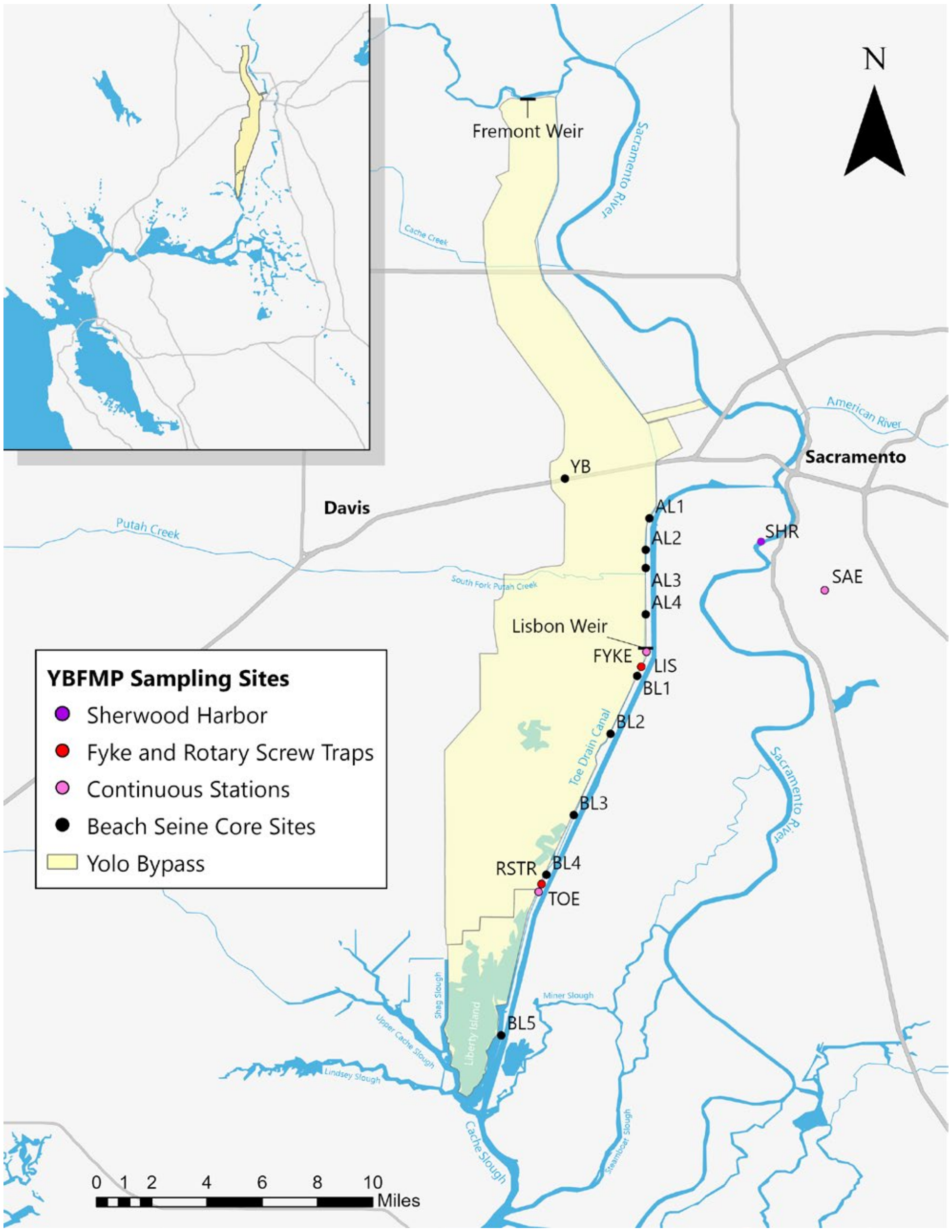
fDOM data were obtained online from the National Water Information System provided by the United States Geological Survey (USGS) and analyzed in RStudio. Specifically, continuous (15-minute interval) fDOM data were retrieved from the "Toe Drain a Liberty Island NR Courtland CA – 11455140" station (TOE; **Figure 1**) for the time period of 10/01/2021 – 09/30/2022 utilizing the "dataRetrieval" R package (DeCicco et al. 2023). The start and end dates of 10/01/2021 – 09/30/2022 were chosen to capture all of WY 2022 during which the low DO event occurred.

Fish catch data were obtained from the EDI Data Portal from the YBFMP, which has sampled fish within the Toe Drain year-round since 1998 (Interagency Ecological Program et al. 2023). The Toe Drain is a perennial channel running along the eastern side of the Yolo Bypass and exiting into the Cache Slough Complex. The bypass serves various purposes for flood control, agriculture, fish habitat, and wildlife habitat (Sommer et al. 2001).

The YBFMP uses a variety of methods to assess fish community within the Toe Drain, including trapping and beach seining. Between the months of October to June, a 3.5 m diameter steel fyke trap is set into the middle of the channel, 1.2 km below Lisbon Weir, and checked daily for larger adult migratory and resident fish species (Kwan et al. 2021; **Figure 1**). Catch per unit effort (CPUE) is calculated by dividing total catch of organisms by hours the trap is fished between checks. Beach seining is conducted every two weeks year-round, to capture smaller adults as well as juvenile fish occupying shallow, littoral habitats. Beach seining sites (**Figure 1**) are split into three sites above the Lisbon Weir (AL 1, 3, and 4) and four sites below the Lisbon Weir (BL 1, 2, 3, and 4). Beach seine site AL 2 is no longer active and BL 5 was excluded from analysis due to being outside the scope of the study area. CPUE for each species was calculated by dividing the number of organisms caught by volume of water sampled by the seine (length*width*depth).

For analysis, sites were consolidated into two separate groups based on their location either above or below Lisbon Weir. This was done as the Lisbon Weir creates a habitat barrier between the "above" and "below" sites (Kwan et al. 2021). Due to overall species richness and the dominance of certain species found in the Toe Drain, analysis occurred on the family taxonomic level

Figure 1. Map of the Yolo Bypass showing data collection sites along Toe Drain. AL = Above Lisbon beach seine sites. BL = Below Lisbon beach seine sites. FYKE = Fyke trap location.



for ease of interpretation. Some analysis was done on the species level for certain species of interest. Fish community data were analyzed between the months of October-December, which were the core months affected by the low dissolved oxygen event, of WY 2014 to 2023 to match WYs with corresponding DO data. WY 2020 was excluded due to a lack of data as field work was suspended by the COVID-19 pandemic. For analysis, each WY encompasses October to September of each year (e.g., WY 2014 spans 10/01/2013 to 9/30/2014). Kruskal-Wallis tests were performed on the CPUE for each species and families of interest during this time to elucidate the relationship between log(CPUE) and each WY. The Kruskal-Wallis test was chosen over a standard analysis of variance due to non-normal distribution within the log(CPUE). Post-hoc Dunn Tests were done after each Kruskal-Wallis test to determine significance of each WY. Fyke trap statistical analysis excludes WYs 2015 and 2017 due to long periods of missed sampling. WY 2022 was excluded from analysis of both fyke and beach seine due to no sampling occurring during the COVID-19 pandemic.

Results

Water Quality

Dissolved Oxygen

Our hypoxia threshold for this analysis is 2 mg/L, consistent with most scientific applications of the term (Diaz and Rosenberg 2008; Shields and Weidman 2008; Vaquer-Sunyer and Duarte 2008; Rabalais et at. 2010). It should be noted that hypoxia definitions vary both spatially and temporally throughout different ecosystems and species, with 2 mg/L being a conservative cutoff capturing most deleterious impacts to aquatic organisms regardless of ecosystem and trophic level, though some organisms experience stress at much higher levels of DO (Shields and Weidman 2008; Vaquer-Sunyer and Duarte 2008). On average, DO levels at LIS between WYs 2014 to 2023 exhibited typical seasonal variation with higher concentrations during the colder months and lower concentrations during warmer months (**Figure 2**). Specifically, the maximum and minimum average daily DO concentrations observed during this period were 11.90 and 0.71 mg/L on 12/23/2017 and 11/19/2021, respectively (**Figure 2**). Excluding WY 2022, in which the hypoxia event occurred, the previous minimum average daily DO concentration was 3.24 mg/L on 11/16/2016, above our hypoxia threshold of 2 mg/L.

During the hypoxia event in WY 2022, daily average DO concentrations dropped at LIS from 7.78 mg/L on 10/24/2021 to below hypoxic levels (2 mg/L) at 1.55 mg/L for the first time in LIS station history on 10/30/2021 (**Figure 2**). DO concentrations continued to decrease to an average daily low of 0.83 mg/L on 11/01/2021 before recovering slightly to 4.27 mg/L on 11/12/2021. A second prolonged decrease in DO concentration was observed on 11/19/2021, reaching a LIS station historic daily average DO low of 0.71 mg/L. DO concentrations returned to roughly pre-atmospheric river conditions of 7.75 mg/L on 12/14/2021 (**Figure 3**). In total, 18 days between 10/30/2021–12/01/2021 were below our 2 mg/L hypoxia threshold. From 10/01/2013 to 05/30/2023, excluding the atmospheric river event of October 2021, there were no instances of the average daily DO concentration falling below our 2 mg/L hypoxia threshold (**Figure 2**).

Dissolved Organic Matter Fluorescence

fDOM exhibited an inverse relationship with DO following the atmospheric river event in late October 2021 (**Figure 4**). Daily average fDOM values at TOE increased from 18.42 quinine sulfate units (QSU) on 10/24/2021 to a maximum value of 100.60 QSU on 10/29/2021 (**Figure 4**). A second spike in fDOM was observed subsequently, peaking at 97.86 QSU on 12/16/2021 before gradually dropping to around 50 QSU in late January 2022. Please note, DO and fDOM data are missing at TOE around the time of the second spike from 12/16/2021 – 12/23/2021 due to unknown reasons.

Other Water Quality Parameters

DO and fDOM were not the only water quality parameters to be affected by this atmospheric river event. Flow, turbidity, and pH also showed changes following the atmospheric river event compared to other WYs. Flow at LIS increased from -16.12 cfs on 10/24/2021 to 427.51 cfs on 10/25/2021 and peaked for the month on 10/27/2021 at 1,149.84 cfs (**Figure 5A**) before returning to more normal rates by the end of the month. Flow increased and

Figure 2. WYs 2014–2023 daily average of dissolved oxygen (top) and precipitation (bottom) data collected Water Data Library Lisbon Weir (LIS). The dashed black line represents the 2 mg/L hypoxia threshold.

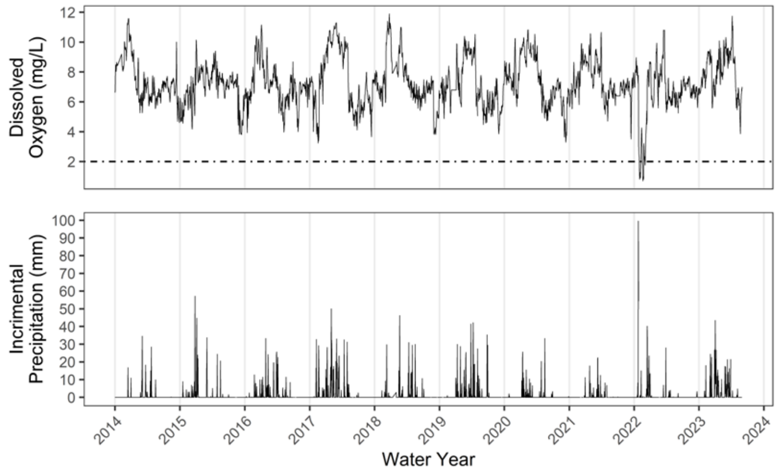


Figure 3. Trends in dissolved oxygen: WY 2022 Lisbon Weir (LIS) daily average dissolved oxygen (red) relative to WY 2014–2021 monthly average (blue) and WY 2022 precipitation (black). The dashed black line represents the 2 mg/L hypoxia threshold.

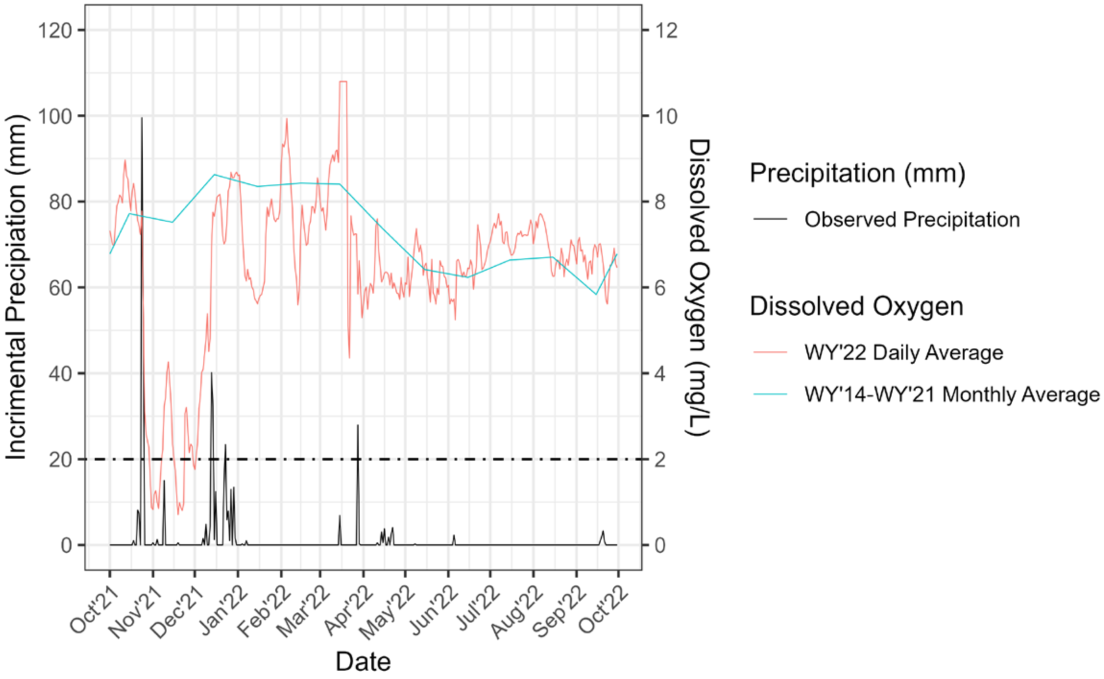


Figure 4. WY 2022 average daily fDOM (top) and dissolved oxygen (bottom). Dashed line represents Lisbon Weir (LIS) station and solid lines represent Toe Drain (TOE) station. fDOM data was only collected at the TOE station.

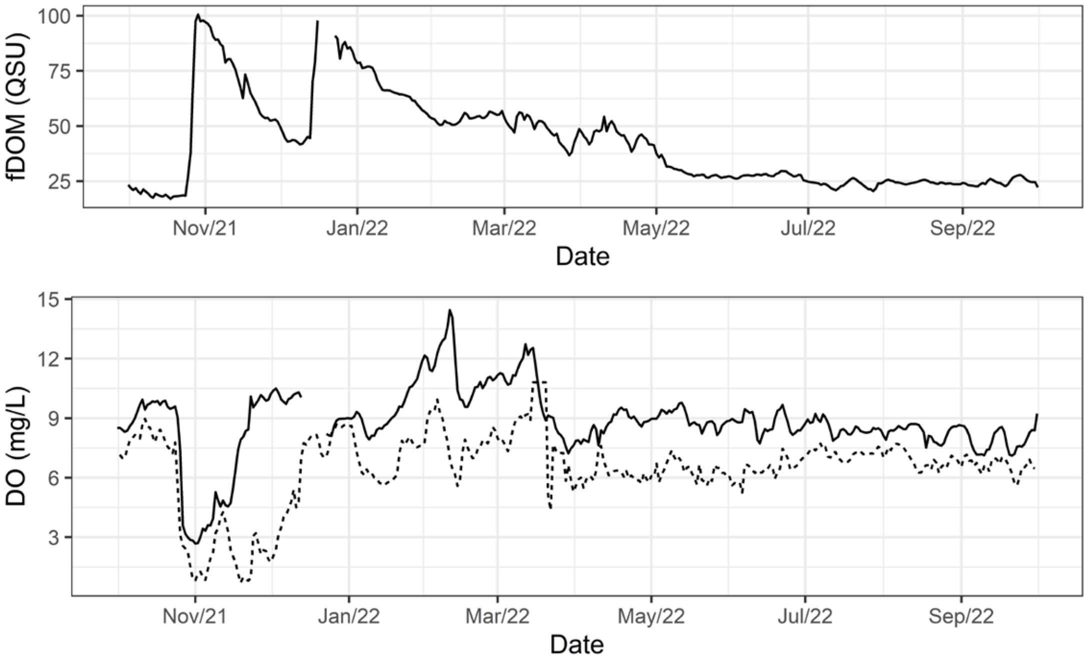
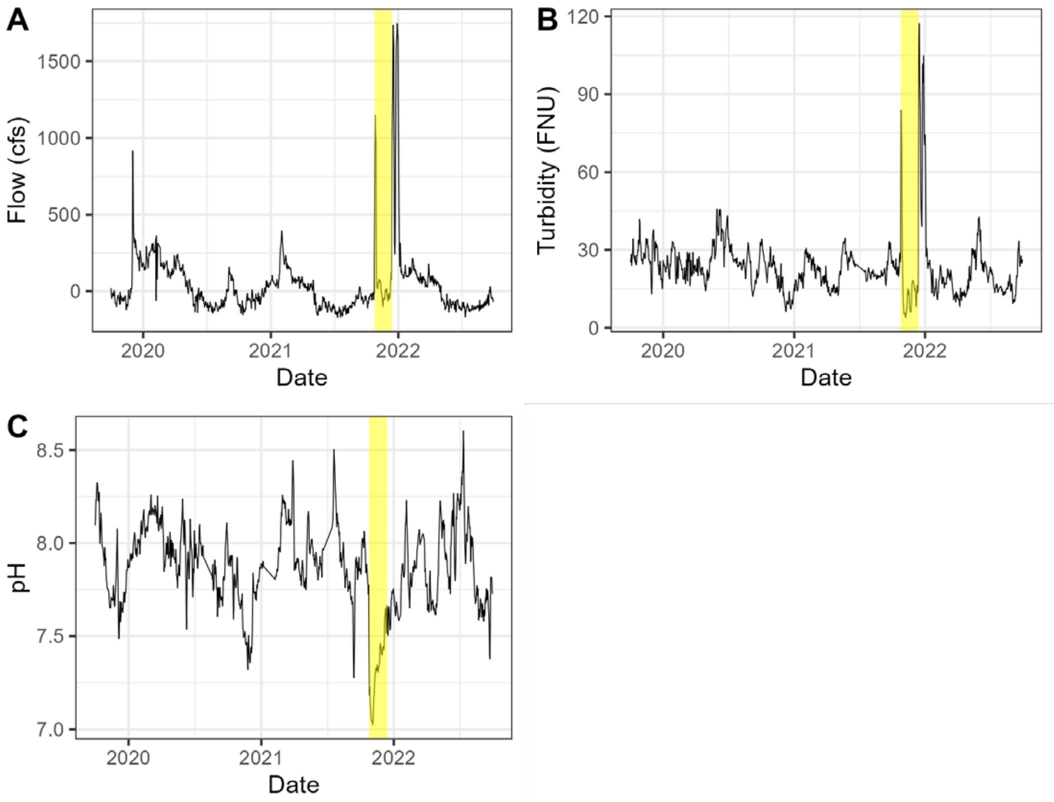


Figure 5. WY 2020–2022 daily average means for Water Data Library Lisbon Weir (LIS) station for flow (A), turbidity (B), and pH (C). Highlighted areas indicate the period of the WY 2022 hypoxia event.



began to fluctuate again between 12/14/2021 and 01/03/2022, peaking at 1,747.62 cfs on 12/29/2021. A 3-day turbidity spike occurred between 10/26/2021–10/28/2021, with a peak of 83.94 FNU on 10/26/2021 (**Figure 5B**). A second, longer duration turbidity spike occurred between 12/14/2021 and 01/03/2022, peaking at 104.81 FNU on 12/28/2021. pH is highly variable in the Yolo Bypass as seen in **Figure 5C**; however, we did see a notable drop in pH following the hypoxia event, with a decrease from 7.77 on 10/24/2021 to a low of 7.02 on 11/04/2021. The pH from 11/04/2021 was one of the lowest recorded pHs in the Yolo Bypass between WYs 2020–2022. Once reaching this recorded low, pH steadily recovered back to its typical range within two weeks.

Fish Community

Fyke Trap

Community composition and catch in the fyke trap shifted during WY 2022 and the year following the hypoxia event (WY 2023; **Figures 6 and 7**). In previous years, starting around WY 2017, Ictaluridae dominated overall composition of catch and total count. The highest catch composition in a single year occurred in WY 2019, where Ictaluridae made up 86.57% of the total fyke trap catch. During the WYs of 2022 and 2023, however, Ictaluridae composition dropped to 20.13% and 2.88%, respectively. During these same two years, the percent contribution of Centrarchidae increased from 9.88% in 2019 to 55.94% in 2022 and 84.84% in 2023. Cyprinidae and Percichthyidae abundance varied slightly throughout the years, though these families were never a main contributor to overall catch composition. However, during the years surrounding the hypoxia event, both families were still present at similar rates as they were before the event.

Some families have a disproportionate composition of species within their respective families, being dominated by only a few or even one species. For this reason, not all species contributed to the changes seen in the fish community before, during, and after this hypoxia event. The species that were found to dominate catch in their respective families were White Catfish (*Ictalurus catus*) making up 95.9% of the total Ictaluridae catch and Black Crappie (*Pomoxis nigromaculatus*) which made up 84.3% of the Centrarchidae catch. Prior to the hypoxia event, White Catfish consistently dominated percent composition of each WY, with the lowest percent composition occurring in WY 2015 at 50.25% and highest in WY 2019 at 86.68% (the highest percent composition across all species and WYs). Once

Figure 6. Percent composition of fish caught in the fyke trap between WYs 2014–2023. "Other" includes all families within a given WY making up <5% composition.

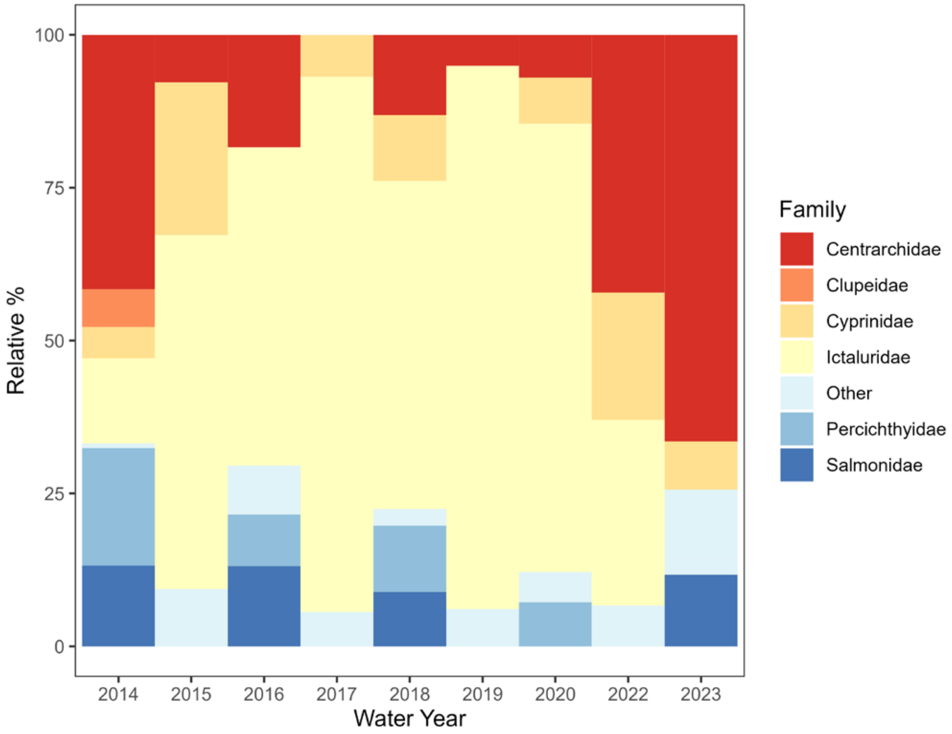
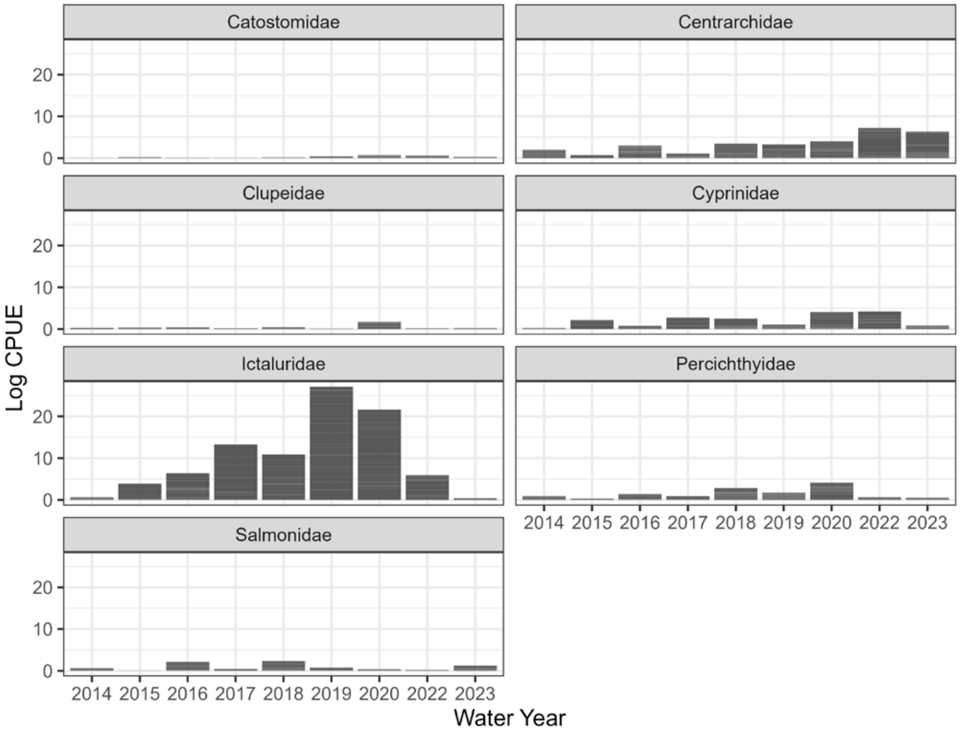


Figure 7. Log(CPUE) of total fish caught in the fyke trap between WYs 2014–2023.



the hypoxia event occurred, during mid-October of WY 2022, Black Crappie began to dominate percent composition of catch in both WYs 2022 and 2023. During this time, the contribution of Black Crappie increased from 5.93% in WY 2020 to 36.65% in WY 2022 and increased again to 60.44% in WY 2023. In contrast, White Catfish decreased from 69.96% in WY 2020 to 27.68% and further to 4.08% the following water years. Observing total catch as well, White Catfish reached its peak in WY 2019 at a CPUE of 62.61, before dropping to 7.17 CPUE in WY 2022 and then to just 0.44 CPUE in WY 2023. Black Crappie show slightly less change in CPUE throughout the hypoxia event, going from 3.11 CPUE in WY 2019 and increasing to 9.49 CPUE in WY 2022. Catch slightly decreased in the year following the hypoxia event, however, to 6.45 CPUE. This shows that while Black Crappie composition in the fyke trap changed, there was little difference in the total catch of the species.

The Kruskal-Wallis test for White Catfish showed significant differences between WYs (df=6, Chi-squared=95.893, $p<0.001$). Following a post-hoc Dunn test, WYs 2022 and 2023 had significant differences ($p <0.05$) between pairwise comparisons of WYs 2020 and 2019 and between each other. This shows that CPUE for White Catfish significantly changed between years before and during the event and continued to significantly decrease in the WY directly after the event. Black Crappie showed significant differences between WYs (df=6, Chi-squared= 32.03, $p<0.001$). However, the post-hoc Dunn test did not show significant difference ($p<0.05$) between pairwise comparisons of the surrounding water years of the hypoxia event, which shows that the CPUE of Black Crappie did not significantly change due to the hypoxia event. One other species that showed some significant difference from a Kruskal-Wallis test between WYs was striped bass (df=6, Chi-Squared=67.812, $p<0.001$). The post-hoc Dunn test shows that WYs 2022 and 2023 had significant difference ($p<0.05$) for pairwise comparisons between WYs 2019 and 2020, but not between each other. These results show that the hypoxia event significantly decreased CPUE for striped bass following the hypoxia event, though they did not continue to decrease the year following the event.

Below Lisbon Beach Seining Sites

Small community shifts were identified around the hypoxia event at beach seining sites below Lisbon Weir (BL). Another major change was a decrease in CPUE during and after the event as seen in **Figure 9**. In the earlier water years, beginning in WY 2016, family Atherinidae, represented by only the Mississippi silverside (*Menidia audens*), increasingly dominated catch composition. Following the hypoxia event in WY 2022, Atherinidae can be seen decreasing between WY 2020 (80.98%) and WY 2022 (58.12%) (**Figures 8 and 9**). This decrease in percent composition during WY 2022 coincides with the increase in another family, Cyprinodontidae. This family is represented by Killifish, the exact species of which cannot be reliably distinguished in the Yolo Bypass. For this reason, YBFMP identifies fish caught by the genus, though two species, Rainwater and Bluefin Killifish, are known to reside in the Toe Drain. The percent composition of Cyprinodontidae increased from 0.09% in WY 2020 to 27.19% in WY 2022. Composition then decreased the following WY to just 2.94% for Cyprinodontidae, with Atherinidae increasing to 82.24%, overwhelming catch composition once again. Despite composition increasing for Atherinidae, the overall number of the fish caught decreased from a CPUE of 2.03 in WY 2022 to 0.59 CPUE in WY 2023 (the lowest CPUE of this family since WY 2015). The CPUE of many other families were observed to decrease between WYs 2020 and 2023, such as Cyprinodontidae decreasing from 0.94 in WY 2022 to 0.02 in WY 2023 and Clupeidae decreasing from 1.05 in WY 2022 to 0.39 in WY 2023.

The Kruskal-Wallis test for the of Atherinidae showed significant difference between WYs (df = 8, Chi-squared = 16.294, p-value = 0.038). Following a post-hoc Dunn test, WY 2022 did not show significant difference ($p < 0.05$) in its pairwise comparisons between WYs 2020 and 2019, the WYs directly before the hypoxia event. WY 2023 showed significant difference between WYs 2020 and 2022, however, suggesting that Atherinidae did not significantly decrease during the event, but showed significant decrease the following year. Cyprinodontidae only had two water years to compare in its Kruskal-Wallis test, WYs 2022 and 2023, which showed no statistical significance (df = 1, Chi-squared = 2.25, p-value = 0.133). Centrarchidae showed significance between WYs (df = 8, Chi-squared = 17.997, p-value = 0.021). The post-hoc Dunn test showed significance (p-value < 0.05) in the pairwise comparisons of WYs 2022 and 2023 between WYs 2020 and 2019, though not between a pairwise comparison of each other. This shows that the decrease in CPUE between the water years before and the water years during and after the hypoxia event were significant, but CPUE did not continue to drop the WY after the event.

Above Lisbon Beach Seining Sites

Similar small changes in community composition were identified for beach seining sites above Lisbon Weir (AL). Overall, Atherinidae's contribution to overall catch steadily increased between WYs 2016 to 2019, seeing its first drop in 4 years in WY 2020, though only slightly (**Figures 10 and 11**). During the hypoxia event, there was little change to CPUE compared to the past couple years, but a drastic drop was observed in WY 2023 following the hypoxia event. Atherinidae's highest percent composition was observed in WY 2022 at 94.73%, an increase from WY 2020 at 60.61%, before decreasing slightly to 82.24% in WY 2023. While many families decreased in catch composition after the hypoxia event, some such as Centrarchidae, Poeciliidae, Gobiidae, and Cyprinodontidae did not. Gobiidae and Centrarchidae both increased in percent composition, going from 0.00% in WY 2022 to 4.36% in WY 2023 and 2.86% in WY 2022 to 7.34% in WY 2023, respectively. The percent

Figure 8. Percent composition of fish caught in all BL beach seining sites between WYs 2014–2023. “Other” includes all families within a given WY making up <5% composition.

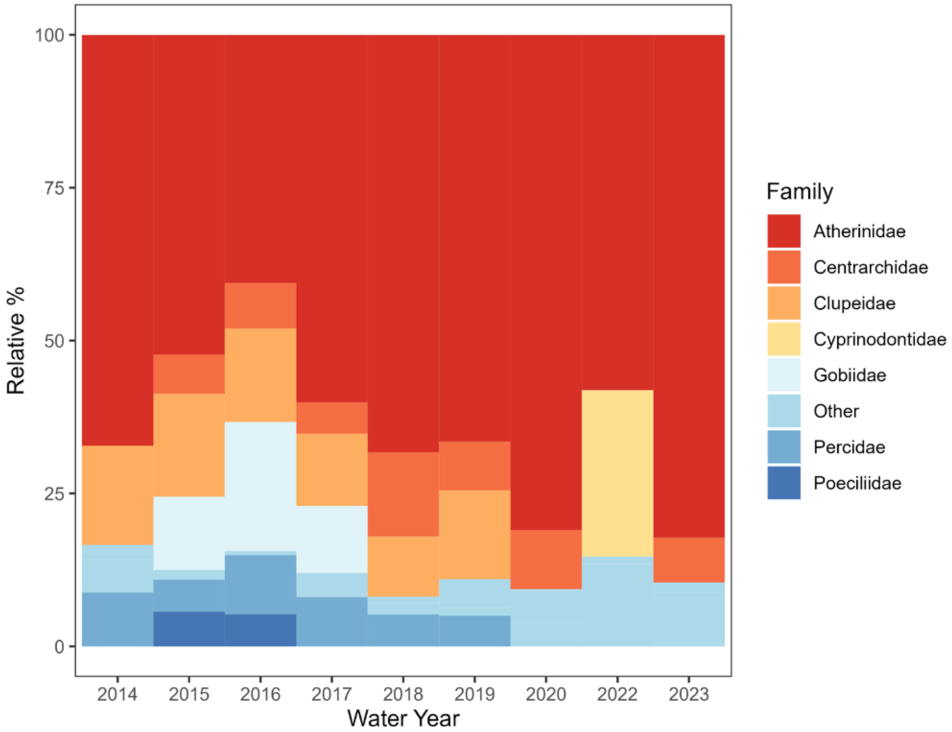


Figure 9. Log(CPUE) of total fish caught in all BL beach seining sites between WYs 2014–2023. “Other” includes all families within a given WY making up a log(CPUE)=0.

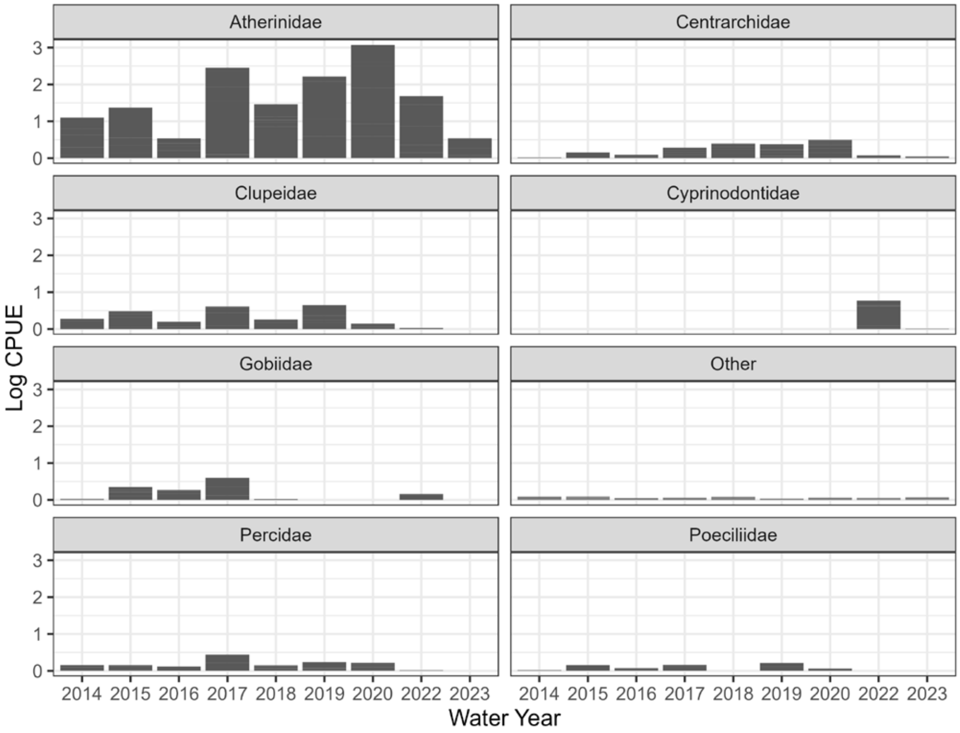


Figure 10. Percent composition of fish caught in all AL beach seining sites between WYs 2014–2023. “Other” includes all families within a given WY making up <5% composition.

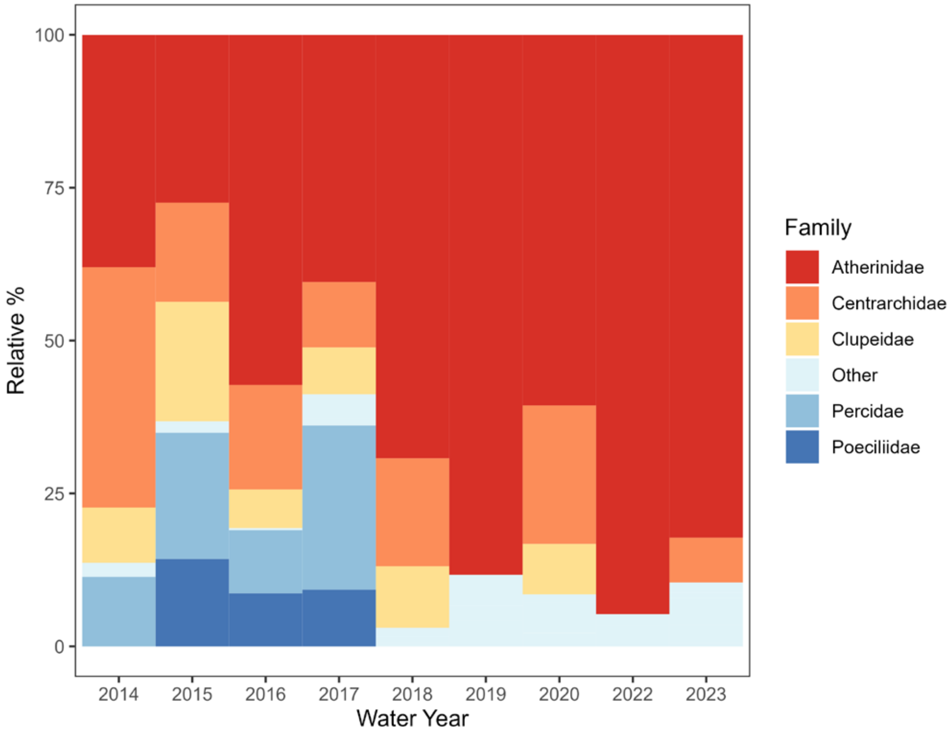
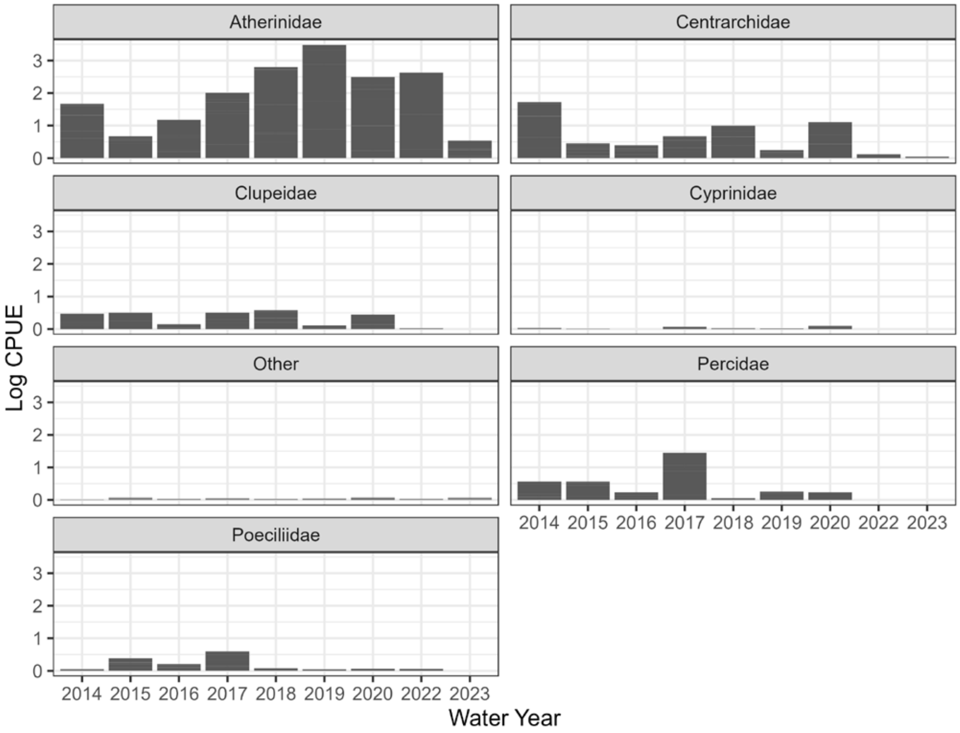


Figure 11. Log(CPUE) of total fish caught in all AL beach seining sites between WYs 2014–2023. “Other” includes all families within a given WY making up a log(CPUE)=0.



contribution of Centrarchidae alternated in an increase/decrease pattern throughout the years. As with the BL beach seine sites, CPUE decreased in WY 2023, with no families having a CPUE greater than 1. The largest decrease in CPUE is seen in Atherinidae, which decreased from 4.31 CPUE in WY 2022 to 0.59 CPUE in WY 2023.

The Kruskal-Wallis test for Atherinidae showed significant differences between WYs (df = 8, Chi-squared = 16.525, p-value = 0.035). From the post-hoc Dunn test, WY 2022 showed no significant difference (p-value < 0.05) between its pairwise comparisons of 2019 and 2020, but WY 2023 showed significant difference between WYs 2019, 2020, and 2022. This shows that the hypoxia event did not cause a significant decrease in CPUE during the event, but CPUE significantly decreased after the event. Centrarchidae did show significant differences between WYs (df = 8, Chi-squared = 16.56, p-value = 0.035). The pairwise comparisons from the post-hoc Dunn test shows that only WY 2023 was significantly different (p < 0.05) than WY 2020, showing a late drop in CPUE following the event.

Discussion

Water Quality

Following the atmospheric river event on 10/24/2021 – 10/25/2021, DO concentrations in the Yolo Bypass Toe Drain dropped expeditiously, falling below our hypoxia threshold of 2 mg/L on 10/30/2021, five days after the atmospheric river. This was the first time since DO measurements have been collected at LIS (starting in 2013) that any daily DO concentration averaged below 2 mg/L. This hypoxia event was also unprecedented in duration, with a total of 18 days spanning a month and a half that averaged below our hypoxia threshold of 2 mg/L at LIS. When looking across WY 2014 through May of WY 2023, this hypoxia event was indeed unprecedented and supports previous research that suggests coastal hypoxia events are increasing in intensity and duration (Vaquer-Sunyer and Duarte 2008; Gilbert et al. 2010). The frequency of these intense and long-duration hypoxia events in the future is uncertain. With climate change projected to intensify hypoxia in estuaries and coastal areas, it is possible that this event, although currently unmatched in magnitude, is a harbinger of future events to come (Altieri and Gedan 2015). Interestingly, the previous historic daily average DO low at LIS prior to the 2021 hypoxia event occurred in the same month (November 2016) and similarly following two consecutive critical WY classifications (2014 and 2015; CDEC). It appears that the transition period between dry and wet seasons during fall may be a vulnerable time for these hypoxia events, especially during prolonged drought periods. Importantly, this potential vulnerability overlaps with the migration of native fishes like Chinook salmon (*Oncorhynchus tshawytscha*), further highlighting the need for an interdisciplinary approach to these events in the future (Altieri and Gedan 2015).

Hypoxia events are complex and affected both directly and indirectly by a multitude of different factors such as temperature, nutrient inputs, and precipitation (Hughes et al. 2015). More research and analysis are needed to fully understand the mechanisms of the hypoxia event in 2021. However, we hypothesize that severe drought conditions coupled with an abnormally large amount of rainfall that occurred early in the WY were significant drivers of the 2021 hypoxia event's intensity and duration. It is probably not a coincidence that this hypoxia event took place in one of the warmest and driest years on record, 2021 (OEHHA 2022), and during the driest three-year period in California's recorded history (CDWR 2022). Consecutive years of drought conditions resulted in reduced flows and higher residence times, likely leading to increased primary productivity and phytoplankton biomass accumulation in the Cache Slough Complex, Yolo Bypass, and other areas of the Delta (Jassby and Cloern 2000; Rabalais et al. 2010). These severe drought conditions and warm temperatures likely created ideal conditions for the growth of phytoplankton and partially contributed to the unprecedented depletion of DO observed in the Yolo Bypass and Cache Slough Complex. Chlorophyll a (*Chl a*) concentrations at LIS before the atmospheric river event increased from around 4 μg/L to 15.15 μg/L on 10/27/2021, before recovering to around 5 μg/L by 10/29/2021 (CDEC). While the spike in Chl a was short-lived, the data supports the notion of temporary eutrophication of the perennial channels of the Yolo Bypass immediately following the atmospheric river.

In addition to the drought and warm temperatures, the record-setting amount of precipitation observed on 10/24/2021 – 10/25/2021 was likely the driving factor of the 2021 hypoxia event. The Yolo Bypass, the largest floodplain of the Sacramento River at 24,000 hectares, drains through the perennial Toe Drain and into the Cache Slough Complex during dry, non-flooded conditions (**Figure 1**). Land use within the Yolo Bypass is dominated by agriculture, primarily consisting of cattle grazing and seasonal crops like rice and tomatoes (Sommer et al. 2001). Runoff from the abnormally large and seasonably early atmospheric river likely activated and transported high amounts of terrestrial organic material (e.g., fDOM), pesticides, fertilizers, and other particles from the agricultural lands within the watershed and concentrated them in perennial channels like Putah Creek and the Toe Drain (**Figure 1**). This pulse of terrestrial organic matter and nutrients from a watershed into a drainage network following a precipitation event is well documented and likely stimulated high rates of detrital aerobic decomposition, resulting in the observed rapid depletion of DO concentrations in the Toe Drain and Cache Slough Complex (Raymond et al. 2016). The fDOM measurements at TOE support this hypothesis, showing an inverse relationship with DO following the atmospheric river (**Figure 4**). While fDOM is a useful parameter for measuring dissolved organic matter in the field, it is important to note that turbidity can influence these in situ measurements (Saraceno et al. 2017). Based on our observations of the 2021 hypoxia event, it appears possible that the first rains of the WY have the greatest capacity to activate terrestrial organic matter and other particles in the watershed and concentrate them in perennial channels, leading to intense hypoxia events.

There was a bimodal drop and corresponding increase in DO and fDOM, respectively, during the month and a half long hypoxia event (**Figure 4**). After the initial DO drop, concentrations recovered slightly before a second drop to hypoxic levels was observed on 11/17/2021 that lasted for about seven days. Similarly, after the initial spike in fDOM immediately following the atmospheric river on 10/29/2021, a second spike in fDOM was observed. It is possible that land management, water management upstream, and/or agricultural practices within the Yolo Bypass or elsewhere in the watershed influenced these observed responses, however more research and analysis is needed to determine the cause.

Fish Community

Changes in the community composition of fish catch in the YBFMP fyke trap indicate that the 2021 hypoxia event affected local fish communities both during and after the event. We noticed that in the year when the hypoxia event occurred, fyke catch composition started to shift relative to previous years. Even two years later, the composition continues to change, despite DO levels having recovered. It is understood that different families of fish can tolerate varied levels of DO concentrations and respond differently to hypoxic areas (Diaz et al. 2008). The two species that contributed most to the difference between the years before, during, and two years after the hypoxia event in the fyke, Black Crappie and White Catfish, both have different habitat and feeding preferences as well as life histories. Mississippi Silversides and Killifish contributed most to changes in the beach seine sites.

Unfortunately, White Catfish physiology has not been well studied by many, though Channel Catfish (*Ictaluridae punctatus*), and Channel x Blue Catfish hybrids are a well-studied species in the Ictaluridae family due to their significance in aquaculture and are a close relative to the White Catfish. Both White Catfish and Channel Catfish can be found within the Yolo Bypass, though White Catfish heavily outweigh catch compared to Channel Catfish. Channel x Blue Catfish do not show stress responses to DO below 2 mg/L over the course of 4 months in continuously monitored aquaculture ponds (Torrans et al. 2015). This study, however, showed that growth and feeding rates can be negatively impacted by prolonged and constant low DO stress. White Catfish diets have been studied in parts of the San Francisco Bay-Delta and San Francisco Estuary, showing that they are benthic generalist carnivores that scavenge on invertebrates and copepods, while adults feed mostly on smaller fish. It has also been observed, in Suisun Marsh, that White Catfish increase their diet of fish in October, when DO levels are generally lower, though not to the extent observed during the 2021 hypoxia event (O'Rear 2012). At levels equivalent to the hypoxia event, below 2 mg/L, Channel x Blue Catfish hybrids showed a decrease in feed intake (Torrans et al. 2015). Hypoxic events caused by eutrophication in the coastal marine ecosystems and estuaries have demonstrated that benthic feeders are negatively impacted as hypoxic events occur closer together in time (Diaz 2001). As such, foraging impacts may be part of the reason why White Catfish responded poorly during this hypoxia event, despite generally being considered hardy fish. In addition, tagging studies done with White Catfish have demonstrated that they move frequently and can travel over 160 km. One tagging study conducted in the Sacramento–San Joaquin Delta showed that most White Catfish moved an average of 16.25 km upstream and 14 km downstream (Pelgen and McCammon 1955). Another study in the St. Johns River in Florida, looking at movement of different Catfish in the system, found that the highest movement detected in all of their tagged fish was a White Catfish that traveled 178.2 km upstream. It was also observed that White Catfish moved much more than the other Catfish, moving 53.9km in 8 days (Hale et al. 1986). With the ability to move large distances and other locations around the Delta and CSC recovering DO levels much faster than seen in the Toe Drain, White Catfish may have moved downstream seeking more favorable conditions. In recent years, both above and below Lisbon Weir beach seine sites had nearly 0 CPUE of White Catfish, suggesting that they spawn and rear elsewhere in the Delta. With a combination of all these factors—poor conditions, high vagility, and separate spawning habitat—White Catfish may have had no incentive to stay during the hypoxia event or return the following year.

DO preference can be seen in Black Crappie. There was a study conducted in the Finger Lakes in Minnesota, a connection of six lakes, to determine responses of Black Crappie to changes in DO and other environmental changes. It was found that Black Crappie will move toward areas with higher DO when it reached below 2 mg/L, though they would stay in areas with DO concentrations as low as 2 mg/L for roughly two weeks. Another significant factor that was found to influence Black Crappie movement was a favoring of lower flows, which can be found in the Toe Drain relative to the rest of the Cache Slough Complex, despite the spike around the time of the atmospheric river event and subsequent flushing of the system a few months after (Knights et al. 1995). The short recovery of DO during the event and lower relative flow compared to the rest of the Cache Slough Complex could have allowed the Black Crappie to have a reset of recovery and endure the final couple of weeks of the hypoxia event once again before potentially being driven out of the system. Low DO is not shown to have effect on Black Crappie spawning, which may have allowed them to maintain levels of recruitment during this event (Siefert and Hermans 1977). By the end of their first year, Black Crappie can reach up to 40–80 mm and 120–210 mm by the end of their second year (Moyle

2002). This size range was detected in fyke trap catch, causing the small drop in CPUE for Centrarchids to not be so drastic for the following WY (2023). Black Crappie diets have mainly been studied in eastern North America, their native range, though some diet studies have been done in the San Joaquin Delta as well. These fish primarily feed on zooplankton and insects in the pelagic zone, though they have been documented to eat fish and crustaceans as well (Moyle 2002). On the US East Coast, the primary insect prey of Black Crappie are Diptera larvae and pupae (Keast 1968). One study on the lower trophic community in the Yolo Bypass showed that Diptera are one of the most common drift invertebrates found in the bypass, especially in years with heavy rain (Sommer et al. 2004; Frantzich et al. 2019), which suggests Black Crappie still had a valuable source of their desired diet. Keast (1968) also found that larger Crappie relied much more heavily on fish rather than smaller insects and crustaceans. Zooplanktivorous fish tend to be less affected by hypoxia events than benthic feeders (Diaz 2001), which may have enhanced survival of younger Black Crappie during the hypoxia event in the Toe Drain. Juvenile Black Crappies are commonly found in the beach seining sites, suggesting that perhaps they spawn and rear their young in the Toe Drain.

Mississippi Silversides have much history within California; originally brought in as a biological control for Clear Lake midges in 1964, their populations exploded by 1968 (Cook and Moore 1970). Due to their high prevalence in the San Francisco Bay-Delta, Mississippi Silversides have been commonly studied within the system. In recent years, their distribution has stretched to most of the Delta. Water quality variables such as specific conductance, turbidity, and DO all can help predict presence of silversides, though DO comparatively does not contribute as heavily to the presence of silversides even at low values (Mahardja et al. 2016). The main diet of Mississippi Silversides includes zooplankton, though they may occasionally feed on copepods and cladocerans. As stated previously, Diaz (2001) found that zooplanktivorous fish may be less affected by hypoxia events. A study conducted in Lake Texoma on the ecology of Mississippi Silversides found that they are found strictly in the littoral zone and anywhere between 0 to 1.5 meters at the surface (Mense 1967). Many aquatic systems exhibit stratification of the water column, with concentrations of DO decreasing with increasing depth. Since Mississippi Silversides live closer to the top column of the water, higher DO levels there may have supported them during this hypoxia event.

Our results highlight that the hypoxia event in fall of 2021 likely impacted fish species in the Toe Drain, though the level of impact was influenced by species-specific tolerance levels, life histories, and ability to move to alternative habitats. While some species, such as White Catfish, displayed a decline in catch, other species, such as native minnows, were less impacted by this event, possibly due to the timing being outside their migratory and spawning window.

Future Opportunities

Though this paper only discussed the consequences to water quality and fish community in the Toe Drain from the hypoxia event, many other parts of the aquatic ecosystem were likely affected. Lower trophic and invertebrate communities have the capacity to be altered by such events as well, and additional research and analysis on these facets of the ecosystem will shed more light on this unprecedented event. The data used from YBFMP, CDEC, and continuous water quality sensors demonstrate just how important long-term monitoring programs are for studying major ecological events. Events such as the 2021 hypoxia event can be unpredictable, and having data over many years to compare can help highlight and understand important ecosystem changes and response. Further, with the potential timing of future hypoxia events overlapping with the migration of native fish species, it is critical that an interagency and interdisciplinary approach is taken to help mitigate these events in the future.

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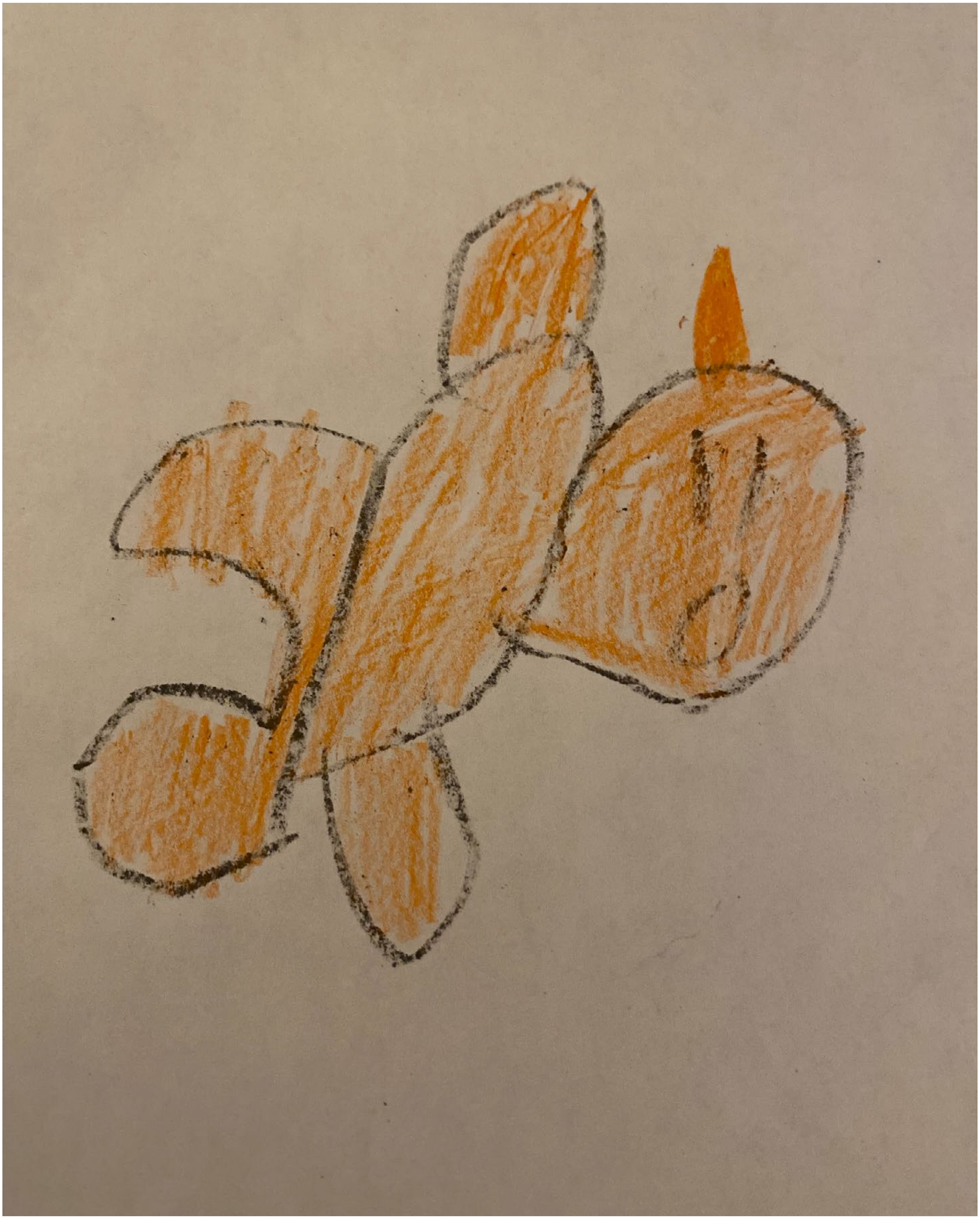
Kid Artwork!

"On the Water" by Brinley Tempel, age 7 (daughter of Trishelle Tempel)



"Bloopy the Fish" by Joaquin Philippart, age 6

"Sturgeon" by Signe Nagarajan, age 15

IEP

Interagency Ecological Program for the San Francisco Estuary

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California Department of Water Resources
State Water Resources Control Board
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