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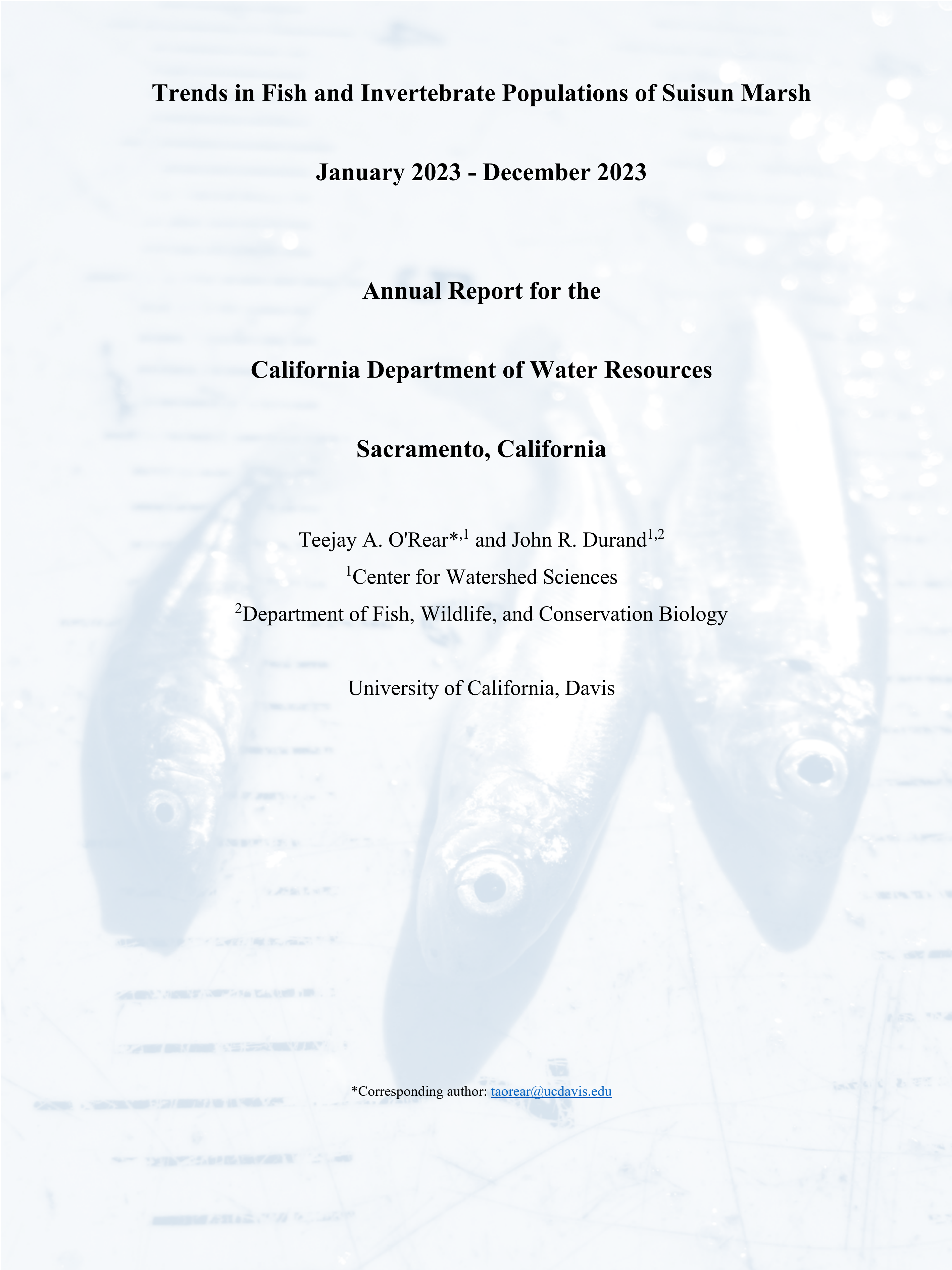

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2023 - December 2023

Annual Report for the

California Department of Water Resources

Sacramento, California

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SUMMARY

Suisun Marsh, at the geographic center of the northern San Francisco Estuary, provides important habitat for native and non-native fishes, as well as many valued and endangered plants, reptiles, mammals, and birds. The University of California, Davis, Suisun Marsh Fish Study, in partnership with the California Department of Water Resources (DWR), has systematically monitored the marsh's fish populations since January 1980. The study's main purpose has been to determine natural and human-caused factors affecting fish and invertebrate distribution and abundance.

The three-year drought ended in calendar year 2023, when heavy rain and snow returned to the San Francisco Estuary Watershed. Delta outflow was higher than average through most of the year, with substantial flooding also occurring - similar to 2011. Consequently, salinities were lower than average for nearly the entire year, bolstered by operation of the Suisun Marsh Salinity Control Gates in late summer and early autumn to enhance conditions for Delta smelt (*Hypomesus transpacificus*). Water temperatures through the first half of the year were abnormally low, another similarity to 2011, although they again were warmer than usual in much of the year's latter half. Despite the high outflows, the water was often clearer than in the past during spring and summer, though still muddy and much more turbid relative to most of the Delta. Dissolved-oxygen concentrations were sufficient for all marsh fishes except in upper Boynton Slough in October, when it fell below 1 mg/L.

The low temperatures, and high flows and low salinities enhanced by the additional operations of the Suisun Marsh Salinity Control Gates, shifted the invertebrate and fish assemblages substantially. Large non-native, plankton-eating invertebrates requiring moderately salty water for part of their life cycle [*e.g.*, overbite clam (*Potamocorbula amurensis*), Black Sea jellyfish (*Maeotias marginata*)] fell to low abundance levels, while Siberian prawn (*Palaemon modestus*), a salt-tolerant freshwater non-native shrimp, remained abundant. As for fishes, many notable ones present during the drought declined to low levels or vanished. Gone were pelagic and benthic marine fishes caught in 2021 and 2022 [*e.g.*, arrow goby (*Clevelandia ios*), jacksmelt (*Atherinops californiensis*), northern anchovy (*Engraulis mordax*)], replaced in part by freshwater fishes, with substantial increases in Sacramento pikeminnow (*Ptychocheilus grandis*) and several non-natives: threadfin shad (*Dorosoma petenense*), common carp (*Cyprinus carpio*), and black crappie (*Pomoxis nigromaculatus*). Notably, however, Mississippi silverside (*Menidia audens*) were at their lowest abundance since 2011, due to delayed reproduction and recruitment. In contrast, the cool temperatures through spring allowed Chinook salmon (*Oncorhynchus tshawytscha*) smolts to persist much longer than usual. For the non-native anadromous striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*), numbers were improved relative to the drought years, due to higher, favorable flows spanning their spawning periods, but, like for Mississippi silverside, the cool temperatures appeared to delay reproduction. Longfin smelt (*Spirinchus thaleichthys*), however, were much lower in the wet year relative to the drought years, though mostly due to the high flows shifting their spawning habitat downstream of Suisun Marsh. Sacramento splittail, the most-abundant native fish in Suisun Marsh, again posted very high numbers in 2023, but the age composition shifted, being strongly dominated by age-0 fish. They continue to flourish in Suisun Marsh. In contrast, for the eighth consecutive year, no Delta smelt were captured by the Suisun Marsh Fish Study despite both current actions to enhance the species through hatchery releases and favorable habitat conditions (*e.g.,* cool water, high

outflows). In sum, 2023 was somewhat like a return to historic cool, wet years, with higher numbers of anadromous fishes, strong numbers of Sacramento splittail, and fewer overbite clam and Black Sea jellyfish; but given a warming climate and population trends, such a recurrence will be increasingly rare.

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INTRODUCTION

Suisun Marsh is a predominantly brackish-water region in the San Francisco Estuary surrounded by Suisun, Grizzly, and Honker bays to the south; the Montezuma Hills and higher-elevation prairie to the east; rolling hills traced by I-680 to the west; and Suisun City and Fairfield to the north (Figure 1). It is the largest uninterrupted estuarine marsh remaining on the western coast of the contiguous United States (Moyle *et al.* 1986, Moyle *et al.* 2014). The marsh's size and central location in the northern San Francisco Estuary provides an important nursery and highway for estuarine and migratory fishes, such as Chinook salmon (Vincik 2002) and striped bass. Suisun Marsh also contains vital habitats for many other animals, including waterfowl (Casazza *et al.* 2021), the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*; Smith *et al.* 2020), and the declining western pond turtle (*Actinemys marmorata*; Agha *et al*. 2020).

In January 1980, DWR contracted with UC Davis with the goal of monitoring fishes in Suisun Marsh. Since then, monitoring has remained continuous and in compliance with regulatory requirements of (1) the San Francisco Bay Conservation and Development Commission 4-84 (M) Special Condition B, (2) the US Army Corps of Engineers 16223E58B Special Condition 1, (3) the State Water Resources Control Board Decision 1485 (as amended by Decision 1641), (4) the Suisun Marsh Preservation Agreement 2015 (Agreement Number 4600000633), and (5) the Suisun Marsh Habitat Management, Preservation, and Protection Plan (Suisun Marsh Plan). The study has consistently used two methods for sampling fishes: beach seines and otter trawls. Juveniles and adults of all species have been surveyed systematically since 1980; between 1994 and 1999, larval fishes were also surveyed (Meng and Matern 2001). Primary objectives have included these tasks:

1. Evaluating effects of the Suisun Marsh Salinity Control Gates on fishes and invertebrates (Matern *et al*. 2002, Beakes *et al.* 2020);
2. Examining long-term changes in the Suisun Marsh ecosystem in relation to other changes in the San Francisco Estuary (*e.g.,* Rosenfield and Baxter 2007, Moyle *et al.* 2014, Colombano *et al.* 2020*a*, Bashevkin *et al.* 2022, Stompe *et al.* 2023);
3. Evaluating restoration (*e.g.*, Williamshen *et al.* 2021);
4. Enhancing understanding of important species in the marsh (*e.g.*, Brown and Hieb 2014, Colombano *et al.* 2020*b*).

Secondary objectives have included the following:

1. Supporting research by other investigators (*e.g.,* Liu *et al.* 2012);
2. Providing background information for in-depth studies of other aspects of the Suisun Marsh aquatic ecosystem (*e.g.*, studies of jellyfish biology; Wintzer *et al.* 2011*a*, *b*, *c;* Meek *et al.* 2012);
3. Documenting invasions of new species [*e.g.*, alligatorweed (*Alternanthera philoxeroides*); Walden *et al.* 2019)];
4. Contributing to the general understanding of estuaries through publication of peer-reviewed papers (*e.g.,* Schroeter *et al.* 2015);
5. Training students in fieldwork;

6. Providing a venue for managers, biologists, and lay people interested in the marsh to experience it firsthand.

The Suisun Marsh Fish Study has documented many patterns in fish ecology in both space and time. Moyle *et al.* (1986) evaluated the first five years of data collected by the study and found three groups of fishes (a winter group, a spring/summer group, and residents) that differed in timing of abundance peaks, primarily due to life-history differences. The fish assemblage was relatively constant through time; however, total fish abundance declined over the five years because of strong year classes early in the study period followed by both extremely high river flows and drought that resulted in poor recruitment. The authors also found that native fishes were generally more prevalent in small, shallow sloughs, while non-native species were more prominent in large sloughs. Meng *et al.* (1994) incorporated eight more years into their study, which revealed that the fish assemblage was less constant over the longer period than the earlier study indicated. Additionally, non-native fishes had become more common in small, shallow sloughs. Like Moyle *et al.* (1986), Meng *et al.* (1994) found a general decline in total fish abundance through time, partly because of drought and high salinities harming some native fishes. Matern *et al.* (2002), analyzing the 1979 – 1999 period, found results similar to Meng *et al.* (1994): fish diversity was highest in small sloughs, and native fish abundances continued to fall. Since Matern *et al.* (2002), fish abundances have often been at higher levels, particularly in wet years and in smaller sloughs (O'Rear *et al.* 2022, Colombano *et al.* 2020*a*). Notably, warm-water fishes that have become sparse in the estuary's rivers and bays since the early 2000s have either increased in abundance (*e.g.*, Sacramento splittail) or remained abundant (*e.g.*, small striped bass) in Suisun Marsh (O'Rear *et al.* 2021*a*). Finally, fewer native fish captured in the North Delta (Durand *et al.* 2020), the most hospitable freshwater region of the estuary for native fishes (Nobriga *et al.* 2005, Sommer and Mejia 2013), relative to Suisun Marsh has shown that the marsh is precious habitat for native species, especially Sacramento splittail.

Recent studies utilizing or based on data from the Suisun Marsh Fish Study have enhanced understanding of invertebrates, habitats, and water-quality trends in Suisun Marsh. Baumsteiger *et al.* (2017, 2018) showed annual numbers of both Black Sea jellyfish (*Maeotias marginata*) and overbite clam (two non-native species that eat plankton that could have been eaten by pelagic fishes) increased with warmer, saltier water in Suisun Marsh. Many recent studies have found benefits of diked wetlands for valuable fishes. Surveys in and around a restored tidal wetland (Blacklock Island) and a diked wetland (Luco Pond) found higher fish abundances, higher fish diversity, and a higher proportion of native fish in the diked wetland, suggesting diked wetlands can provide benefits to desirable fishes while still supporting waterfowl (Williamshen *et al.* 2021). Tung *et al.* (2021) and Platzer *et al.* (2022) have expanded on Williamshen *et al.* (2021) in consistently finding higher plankton and native fish abundances in diked wetlands relative to tidal wetlands throughout Suisun Marsh. Aha *et al.* (2021) found that Chinook salmon smolts grew better in a diked wetland and in a slough receiving diked-wetland water than in a slough bordered by tidal wetlands. Utilizing water-quality data from the fish study, Bashevkin *et al.* (2022) documented increasing water temperatures in Suisun Marsh. Consequently, the Suisun Marsh Fish Study remains instrumental in enhancing understanding of the estuary, and thus its management, especially within the context of climate change and future restoration (Moyle *et al.* 2014).

The purposes of writing this report were to (1) compare water-quality conditions in 2023 with average conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2023 to annual averages, noting abundance changes between 2022 and 2023; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2023, pointing out unusual occurrences; and (4) describe the geographic distribution of fishes and invertebrates.

METHODS

Study Area

Suisun Marsh is a mosaic of diked wetlands, tidal sloughs, tidal wetlands, and grasslands totaling about 38,000 hectares, with diked wetlands the dominant feature (DWR 2001, O'Rear and Moyle 2015*a*). The marsh is contiguous with the northern boundary of Suisun, Grizzly, and Honker bays and is central to the northern San Francisco Estuary (Figure 1), with San Pablo Bay to the west and the Sacramento-San Joaquin Delta ("Delta") to the east. The two major subtidal channels (referred to as "large sloughs" in this report) in the marsh are Montezuma and Suisun sloughs (Figure 1). Major tributary sloughs (referred to as "small sloughs" in this report) to Montezuma are Denverton and Nurse; Cutoff Slough and Hunter's Cut connect Suisun and Montezuma sloughs (Figure 1). Tributaries to Suisun Slough, from north to south, are Peytonia, Hill, Boynton, Sheldrake, Cutoff, Wells, Cordelia, and Goodyear sloughs (Figure 1). First and Second Mallard sloughs are tributary to Cutoff Slough and are part of Solano Land Trust's Rush Ranch Open Space preserve; Rush Ranch is part of the San Francisco Bay National Estuarine Research Reserve (http://www.sfbaynerr.org).

Suisun and Montezuma sloughs are generally 100-150 meters (m) wide and 3-7 m deep, with banks consisting of a mix of riprap and fringing marsh (Meng *et al.* 1994). Small sloughs are usually 10-20 m wide, 2-4 m deep, and fringed with common reed (*Phragmites australis*) and tules (*Schoenoplectus* spp.). Sloughs are typically bordered by tidal or diked wetlands, with the plant assemblages of both varying widely due to salinity and hydrology (Jones *et al.* 2021). Across waterway types, highest plankton concentrations are often found in diked wetlands (Tung *et al.* 2021, Williamshen *et al.* 2021). Submerged aquatic plants, dominated by sago pondweed (*Stuckenia pectinata*), are found throughout the marsh but are mainly restricted to shallow, subtidal shoals. Sago pondweed has appeared to spread through the 2010s and into the 2020s (O'Rear, personal observation). Substrates in all sloughs are generally fine organics, although a few sloughs also have bottoms partially comprised of coarser materials (*e.g.*, Denverton Slough; Matern *et al.* 2002), and the larger, deeper sloughs (*e.g.*, Montezuma Slough) can have sandy channel beds.

Salinities in Suisun Marsh's waterways are on the fresher side of brackish [annual average whole-marsh salinity equaling about 4 parts per thousand (ppt)] and determined primarily by the volume of inflowing fresh water. Most fresh water enters the marsh from the Delta ("Delta outflow") through Montezuma Slough, although small creeks, particularly on the northwest and west edges of the marsh, also contribute fresh water. As a result, salinities are generally lower in the eastern and northwestern portions of the marsh and higher in the southwestern section by Grizzly Bay. Freshwater inflows are highest in winter and spring due to rainfall and snowmelt runoff, with marsh salinities lowest in these seasons. Salt water enters the marsh mainly through lower Suisun and western Montezuma sloughs from Grizzly Bay via tides, although the effect of the tides is more pronounced on water-surface elevation than on salinity throughout much of the year (Matern *et al.* 2002).

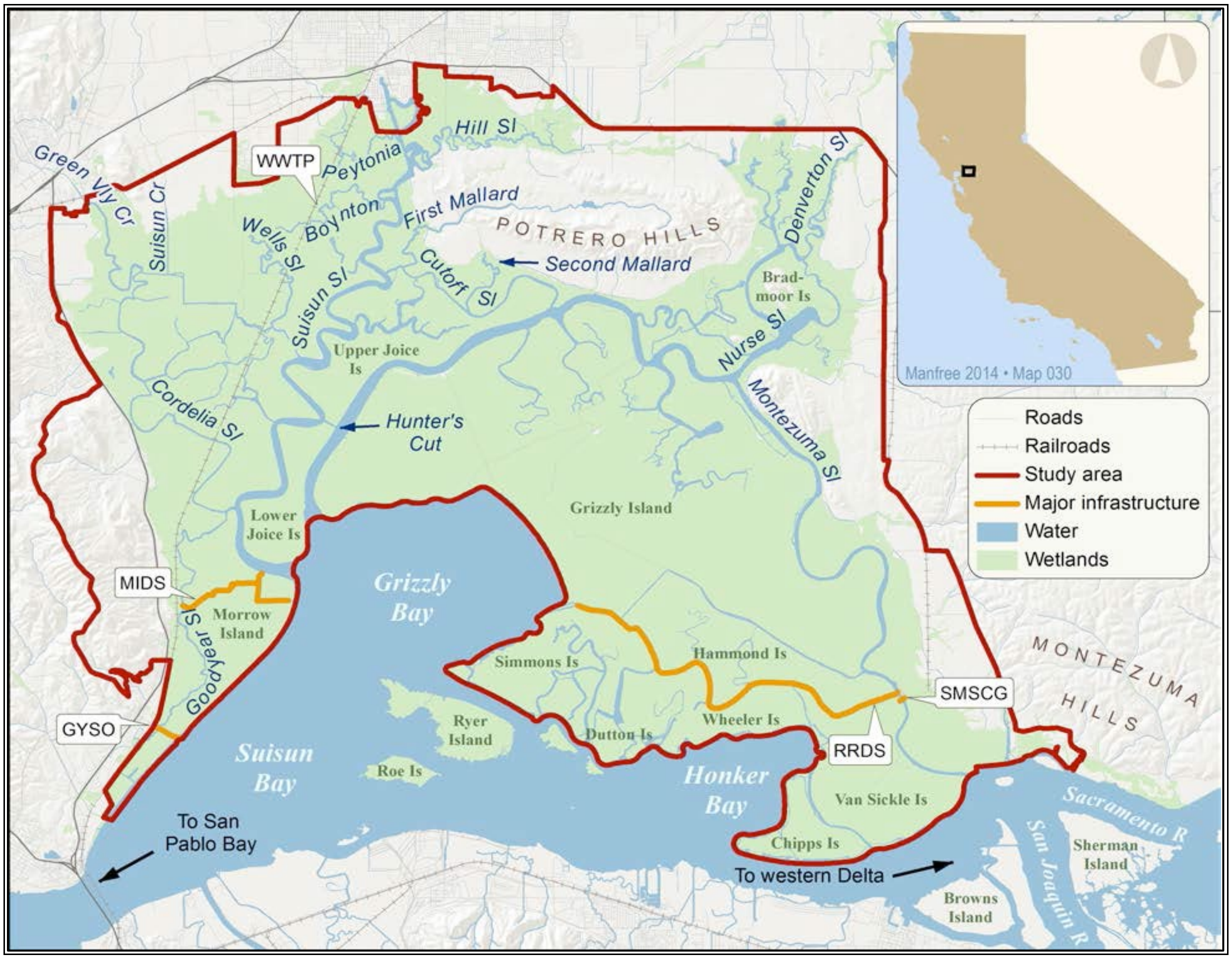

Figure 1. Suisun Marsh study area ["GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point into Boynton Slough; map by Manfree (2017)].

Dissolved-oxygen (DO) concentrations can vary widely in both space and time in Suisun Marsh, and can be affected by decomposition of organic material, temperature, salinity, wind, slough type, and diverting and draining of diked wetlands. High wind speeds and the resultant greater turbulence can increase DO, as has been commonly observed in larger sloughs during summertime concurrent with afternoon westerly coastal winds. Because oxygen solubility decreases with higher salinities and temperatures, DO concentrations are frequently lower in summer and autumn than in winter. Water flowing into sloughs from diked wetlands during autumn can sometimes contain low DO concentrations and may compound regional low DO concentrations, particularly in small dead-end sloughs (Siegel *et al*. 2011) of the western marsh. Likewise, draining wetlands in spring can also depress slough DO levels (Siegel *et al*. 2011), though not as much as in autumn. Consequently, marsh DO is usually high in winter, lower in spring and summer, and lowest in autumn.

Suisun Marsh's sloughs often exhibit low water clarity, especially compared to the Delta (Kimmerer 2004). Water clarity throughout the marsh is generally lower when Delta outflow and sediment loads are both high (*i.e.*, winter, spring, and in wet years; Moyle *et al.* 1986, O'Rear and Moyle 2008, 2014). When outflow is lower in summer or autumn, or during a drought year, clarities are usually higher (O'Rear *et al.* 2020, 2021). During low-outflow periods, lower water clarities typically occur in small sloughs or in large sloughs far from Grizzly Bay and the Delta (Matern *et al.* 2002, O'Rear *et al.* 2020). Since about 2000, clarities during summer and autumn have generally been higher than average, due to sediment-trapping by both dams and invasive aquatic plants in the Delta (Schoellhamer *et al*. 2016).

Several water management facilities alter the hydrology and water quality of the marsh. State Water Project and Central Valley Project water-pumping facilities in the southern Delta affect the timing and magnitude of freshwater flow into Suisun Marsh (DWR 1984). The Suisun Marsh Salinity Control Gates, located in eastern Montezuma Slough, provide fresher water for diked wetlands (DWR 2001; Figure 1). The gates, which began operating in 1988, are typically run from autumn through spring when Delta outflow is low and salinity within the marsh is high. They open during ebb tide to allow fresher Delta water into the marsh, then close during flood tide to limit saltier water from intruding into western Montezuma Slough. The gates are also used for fishes, with 2023 being the first year the gates were operated during summer and autumn to meet obligations of DWR's incidental take permit for Delta smelt [California Department of Fish and Wildlife (CDFW) 2020]. Numerous water control structures, most of which are unscreened for fish, are located throughout the marsh; they are opened in early autumn for flooding diked wetlands to attract wintering waterfowl, with water diverted from adjacent subtidal sloughs. Most water control structures remain open to some extent (or are reopened) during winter and spring, mainly to maintain water elevations in the wetlands and to optimize soil conditions for desired waterfowl plants (DWR 1984). Diversions are restricted from some sloughs of the marsh during winter and spring to reduce entrainment of salmonids and smelts. Most wetlands are drained in late spring, with drainage water being discharged directly into sloughs within the marsh, and remain dry throughout summer to promote waterfowl plant growth and seed production. Several canal systems - the Roaring River Distribution System, the Morrow Island Distribution System, and the Goodyear Slough Outfall - redirect water in the marsh, with the goal of providing lower-salinity water for diked wetlands (Figure 1; DWR 2001). The Fairfield-Suisun Sewer District discharges tertiary-treated wastewater into Boynton Slough (Figure 1); the wastewater's salinity is low, and DO concentration is high (*e.g.,* 6 - 7 mg/L; Siegel *et al.* 2011).

Suisun Marsh's macroinvertebrate and fish assemblages are dominated by a mixture of native and non-native species tolerant of (1) fresh to moderately saline water; (2) low water clarity; and (3) warming temperatures (O'Rear *et al.* 2019, Bashevkin *et al.* 2022). Native and non-native shrimps [California bay shrimp and Siberian prawn, respectively] along with non-native clams and Black Sea jellyfish comprise the bulk of the invertebrate catch in most years. These invertebrates are important food-web players, either as competitors [Black Sea jellyfish (Wintzer *et al.* 2011*b*)], fish food [the shrimps (Nobriga and Feyrer 2008)], or both [overbite clam (Feyrer *et al*. 2003, Zeug *et al.* 2014, Colombano *et al.* 2021)]. Native fishes are dominated by four species. Two are benthic (*i.e.*, bottom) fishes - Sacramento splittail and prickly sculpin (*Cottus asper*) - with Sacramento splittail being a Species of Special Concern (Moyle *et al.* 2015). The other two are littoral fishes (*i.e.,* those associated with solid materials in the water column such as aquatic plants) - threespine stickleback (*Gasterosteus aculeatus*) and tule perch

(*Hysterocarpus traski*) - with threespine stickleback often being especially numerous in diked wetlands (Williamshen *et al.* 2021). Anadromous white sturgeon (*Acipenser transmontanus*), both juveniles and adults, can sometimes be abundant in larger sloughs. The most numerous non-native fishes are generally those from Atlantic Ocean watersheds, particularly pelagic (*i.e.*, open-water) anadromous species with juveniles that eat zooplankton (American shad, striped bass), and Japanese estuarine small-bodied gobies. The small benthic fishes (prickly sculpin and the gobies) and threespine stickleback are the fishes most frequently eaten by Suisun Marsh's primary piscivore, adult striped bass (O'Rear and Moyle 2015*b*). Two small-bodied fishes native to the Mississippi River system (threadfin shad and Mississippi silverside) are often the most abundant inshore fish species in Suisun Marsh, along with yellowfin goby (*Acanthogobius flavimanus*), young Sacramento splittail, and young striped bass. Most fishes tend to be more numerous in smaller, dead-end sloughs (Colombano *et al.* 2020) that exhibit higher residence times and greater plankton concentrations (Montgomery *et al*. 2015, Gross *et al.* 2023), especially in wet years (O'Rear *et al.* 2021*a*). The frequently high numbers of American shad, threadfin shad, and striped bass in Suisun Marsh since the early 2000s are notable given that they have co-occurred with estuary-wide declines in plankton and chronically low numbers of pelagic fishes in the estuary's main rivers and bays (the "Pelagic Organism Decline"; Sommer *et al.* 2007).

Sampling

Since 1980, juvenile and adult fish have been sampled monthly at standard sites within subtidal sloughs of Suisun Marsh (further information can be found in Appendix A). Originally, 47 trawl sites in 13 sloughs were sampled; several of these sites were sampled only in 1980 and 1981, with 17 sites in seven sloughs being sampled consistently until 1994 (O'Rear and Moyle 2008). From 1994 to the present, 21 sites in nine sloughs have been regularly sampled by otter trawl (Figure 2). Since 2014, two additional trawl sites in Denverton and Nurse sloughs (DV1 and NS1, respectively; Figure 2) and a historic site in Montezuma Slough (MZ6; Figure 2) have been sampled; their data were included in monthly and slough-to-slough calculations in this report, with data from the NS1 and MZ6 sites also included in annual calculations. Beach seines have been conducted at the DV2, MZ6, and SU1 sites, where smooth shores have allowed effective sampling. Both trawling and seining in a newly restored wetland complex (Montezuma Wetlands; Appendix B) by an ancillary project with the same methods as the fish study occurred throughout 2023, with those data included in monthly and slough-to-slough comparisons.

Trawling was conducted using a four-seam otter trawl with a 1.5-m X 4.3-m opening, a length of 5.3 m, and mesh sizes of 35-millimeter (mm) stretch in the body and 6-mm stretch in the cod end. The otter trawl was towed at 4 km/hr for 5 minutes in small sloughs and at the same speed for 10 minutes in large sloughs. Inshore fishes were sampled with a 10-m beach seine having a stretched mesh size of 6 mm. All samples were conducted during daylight hours. For each site, discrete samples of temperature (degrees Celsius, °C), salinity (parts per thousand, ppt), and specific conductance (microSiemens, µS) were recorded with a Yellow Springs Instruments PRO2030 meter deployed about 0.5 m below the water surface. Dissolved-oxygen parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also measured with the PRO2030. Water transparency (Secchi depth, cm), tidal stage (ebb, flood, high, low), and water depths (m) were also recorded.

Contents of each trawl or seine were placed into large containers of water. Fishes were identified and measured to the nearest mm standard length (mm SL) and then released. Sensitive native species were processed first. Numbers of Black Sea jellyfish medusae, Siberian prawn, oriental shrimp (*Palaemon macrodactylus*), California bay shrimp, Harris mud crab (*Rhithropanopeus harrisii*), overbite clam, Asian clam (*Corbicula fluminea*), and other large invertebrate species were also recorded. Siberian prawn were first positively identified in February 2002, although they likely comprised a large percentage of the 2001 and early 2002 shrimp catch that was recorded as oriental shrimp. Abundances of Siberian prawn for this report were only considered from 2002 onward. Records for Asian clam did not begin until 2006. Opossum shrimp (Mysida) were pooled into one category, "mysids," and given an abundance ranking: 1 = 1-3 mysids, 2 = 4-50 mysids, 3 = 51-100 mysids, 4 = 101-500 mysids, and 5 = >500 mysids. No distinction was made between native and non-native opossum shrimps, both of which likely contributed to the catch (*e.g.*, *Hyperacanthomysis longirostris*, *Neomysis mercedis*; Carlson and Matern 2000, Schroeter 2008). Organic material was classified (emergent/terrestrial-plant detritus, mud, wood, and submersed aquatic plants/algae, with submersed plants identified to species) and then estimated for volume.

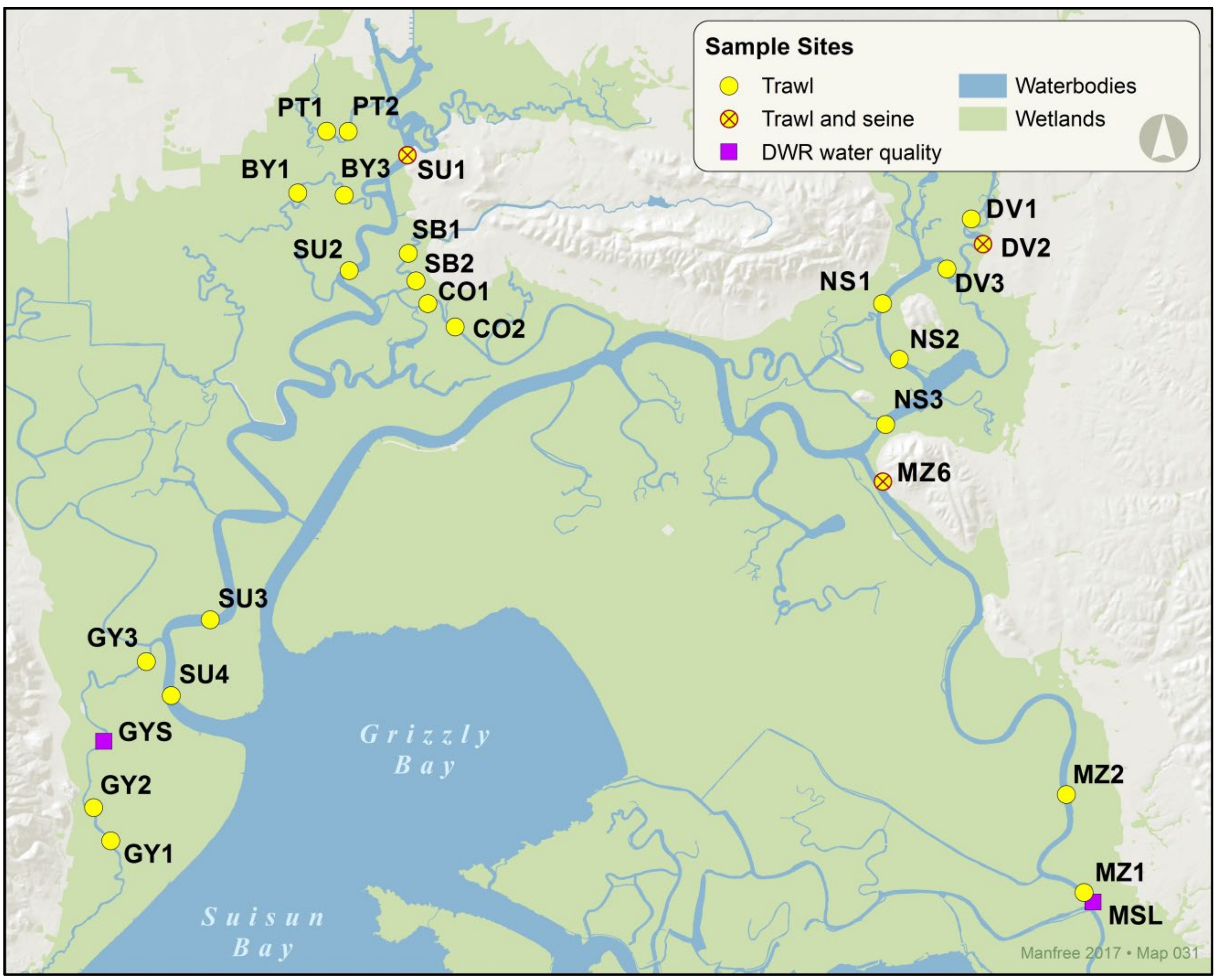

Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report [map by Manfree (2017)].

Data analysis

For this report, catch-per-unit-effort (CPUE) values were calculated differently depending on the type of comparison. For comparisons made among calendar years, CPUE for beach seines and otter trawls was calculated as

$$CPUE = \frac{annual\ number\ of\ fish\ caught\ in\ trawls\ or\ seines}{annual\ number\ of\ trawls\ or\ seines}$$

to remain consistent with previous reports (*e.g.*, Schroeter *et al.* 2006); CPUE values for invertebrates were also calculated likewise, with the annual number of individuals for the invertebrate of interest substituting for "annual number of fish." Slough-to-slough CPUE values for select species were calculated similarly except that, to account for unequal effort, minutes rather than number of trawls were used in the denominator. For monthly comparisons, to account for unequal effort among sloughs, CPUE values for otter trawls were calculated as

$$CPUE_{ij} = \frac{\sum_{i=1}^{n} \frac{number\ of\ fish_{ij}}{number\ of\ trawls_{ij}}}{n}$$

where i = slough, j =month, and n is the number of sloughs; once again, CPUE values for beach seines and for invertebrates were calculated likewise. Age classes of fishes except Sacramento splittail and striped bass were determined from peaks and valleys in length-frequency graphs. Sacramento splittail age classes were determined following length-frequency-age analyses by Matern and Sommer (unpublished). Age-0 striped bass were classified as those fish belonging to the length-frequency-graph peak corresponding to the smallest size classes after May, adults were considered fish larger than 423 mm SL, and all others were classified as "juveniles." To describe geographic distribution, the proportion of the 2023 catch or CPUE from the sampled sloughs was computed for dominant species, and annual CPUE with minutes as the denominator was calculated for each slough for age classes of striped bass and Sacramento splittail. Monthly water-quality averages for 2023 were calculated as for CPUE values, with the sum of the measurements of the water-quality parameter of interest (*e.g.*, Secchi depth, water temperature) substituting for "number of fish." The Net Delta Outflow Index ("Delta outflow"), a proxy for water leaving the Delta, was calculated by summing river flows entering the Delta, channel depletions, in-Delta diversions, and State Water Project, Central Valley Project, and Contra Costa Water District exports. Delta outflow was obtained from DWR (2024) and the U.S. Bureau of Reclamation (USBR 2024).

Monthly water-quality results of 2023 were graphed and compared to averages for all years of the study. Fifteen-minute salinity and water temperature data from DWR fixed stations, GYS and MSL (Figure 2), were graphed with the water-quality data collected during fish sampling to provide additional context. These two stations were chosen because they were the DWR stations closest to the fish-sampling sites, and they were in sloughs that exhibited opposing extremes of habitat conditions (*e.g.*, slough cross-sectional area, geographical position). Annual CPUE values for otter trawls and beach seines were graphed, as were monthly CPUE values for dominant invertebrate and fish species.

Catch of all fishes and by each method from 1979 to 2023 is found in Appendix C; annual catch of each slough and number of trawls/seines in each slough (including Montezuma Wetlands) in 2023 are found in Appendix D and E. Code used for querying the database is found in Appendix F.

RESULTS AND DISCUSSION

Abiotic Conditions

Hydrology

Calendar-year 2023 saw the return of wet conditions after three years of drought. Delta outflow in 2023 was above the average for all years of the study except during late winter and in the year's last two months (Figure 3). From January through September, outflow in 2023 was like that in 2011 (Figure 3), with high flows throughout spring when most fishes spawn. Both Yolo Bypass and the Cosumnes River floodplain flooded during spring, providing spawning habitat for fishes such as Sacramento splittail and common carp (Sommer *et al.* 1997, Moyle *et al.* 2004; Feyrer *et al.* 2006; Ogaz *et al.* 2022; DWR 2024*a*).

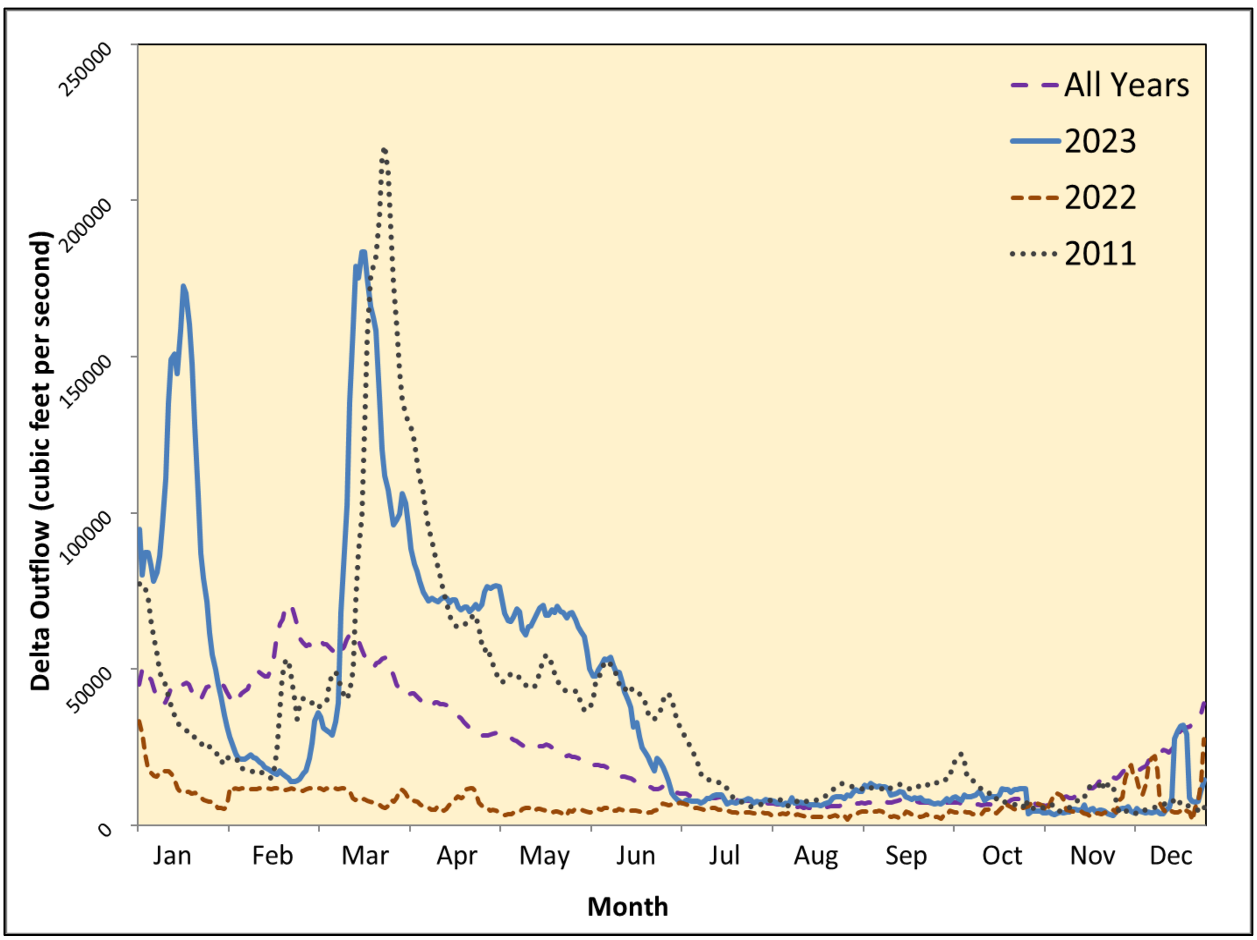

Figure 3. Daily Delta outflow in 2023, 2022, 2011, and the average for all years of the study (1980 – 2023; DWR, USBR 2024).

Salinity

The high outflows in 2023 resulted in lower-than-average salinities in all months but December (Figure 4). Monthly average salinity remained very low until climbing from June to August, thereafter declining from August to October with commencement of Suisun Marsh Salinity Control Gates (SMSCG) operations to meet objectives of the *Delta Smelt Resiliency Strategy* (California Natural Resources Agency 2016, DWR 2024*b*) and DWR's incidental take permit (CDFW 2020). All sites were affected by operations, though differentially. Salinities at sites closer to the gates (*e.g.*, Nurse Slough, Cutoff Slough) dropped substantially from August to September and then less so from September to October (Figure 5). Sites further from the gates (*e.g.*, upper Denverton Slough, Peytonia Slough) were often opposite, showing little change in the first month but then a greater salinity decrease in the second month, reflecting a delayed response. Boynton and lower Suisun sloughs were unique, with salinities increasing from September to October in both (Figure 5). For Boynton Slough, the uniqueness was likely due in part to high evaporation rates at the head of the slough coupled with diversion of fresh wastewater-treatment water from the slough to managed wetlands in October (Siegel *et al.* 2011). For lower Suisun Slough, coincidence of weak tides in October with its close location to Grizzly Bay seemed the likely culprits; a continuous water-quality gauge ("GOD") just downstream of the SU4 site showed a similar pattern (USBR 2024*a*). Gate operations then ceased until late November, and salinities increased substantially again to close out the year. Salinities recorded by the fish study were within the bounds of the two water-quality stations throughout the year, although they tended to the fresher side of the eastern Montezuma Slough gauge given the preponderance of sites in the marsh's eastern and northern sections (Figure 6). Salinity range was rather low in the first six months of the year, after which they broadened considerably with rapidly increasing salinities in Goodyear Slough and lower Suisun Slough (Figure 4), which was where the highest monthly salinity was always located (with the year's highest salinity, 9.4 ppt, occurring in lower Suisun Slough in December). The freshest water was usually in Montezuma Wetlands or eastern Montezuma Slough, with the year's lowest value recorded in Montezuma Wetlands (0.1 ppt in March).

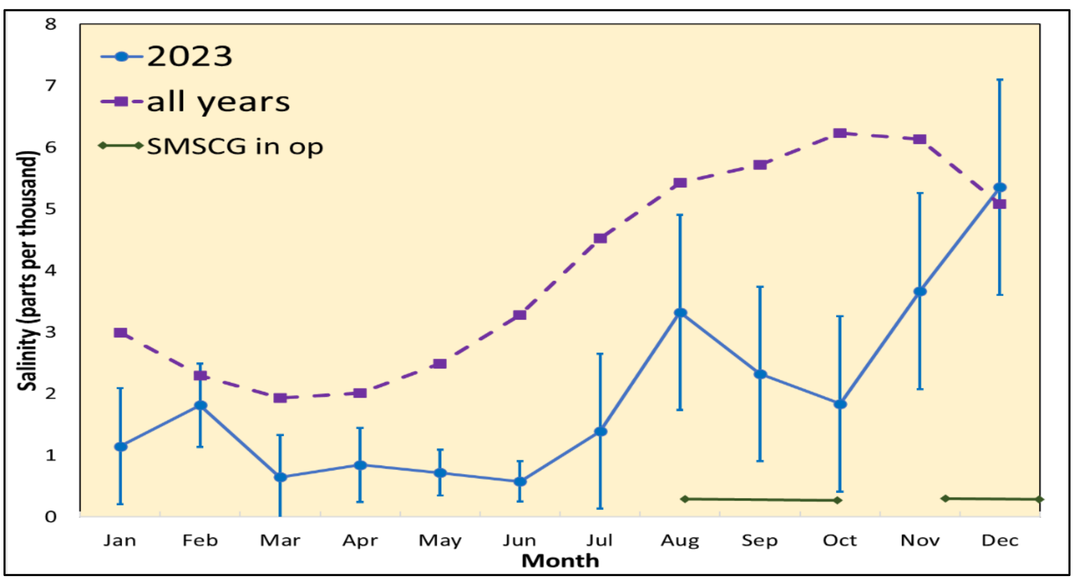

Figure 4. Monthly average salinity in 2023 and for all years of the study (1980 - 2023); error bars are standard deviations in 2023. Solid olive bars show when the SMSCG were operating in 2023.

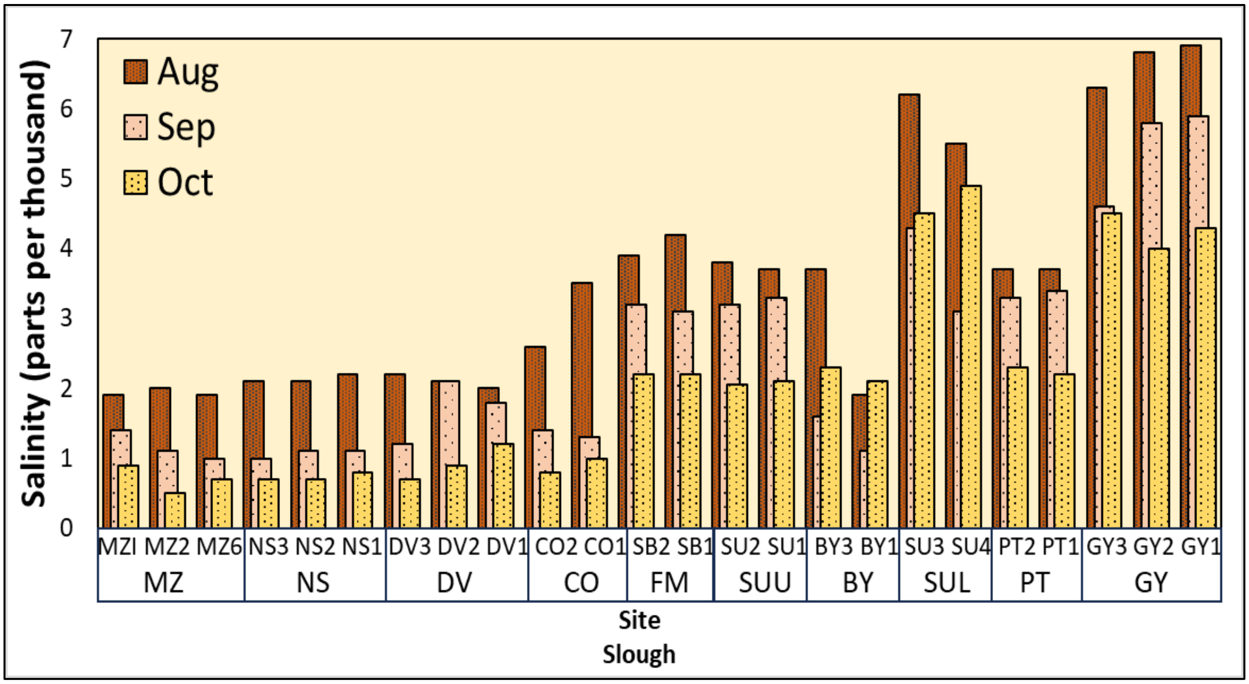

Figure 5. Salinities for Suisun Marsh Fish Study sites during summer-autumn operation of SMSCG, ordered left to right by increasing distance from the SMSCG ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV = Denverton Slough, "FM" = First Mallard Slough "GY" = Goodyear Slough, "MZ" = eastern Montezuma Slough, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SUL" = lower Suisun Slough, and "SUU" = upper Suisun Slough).

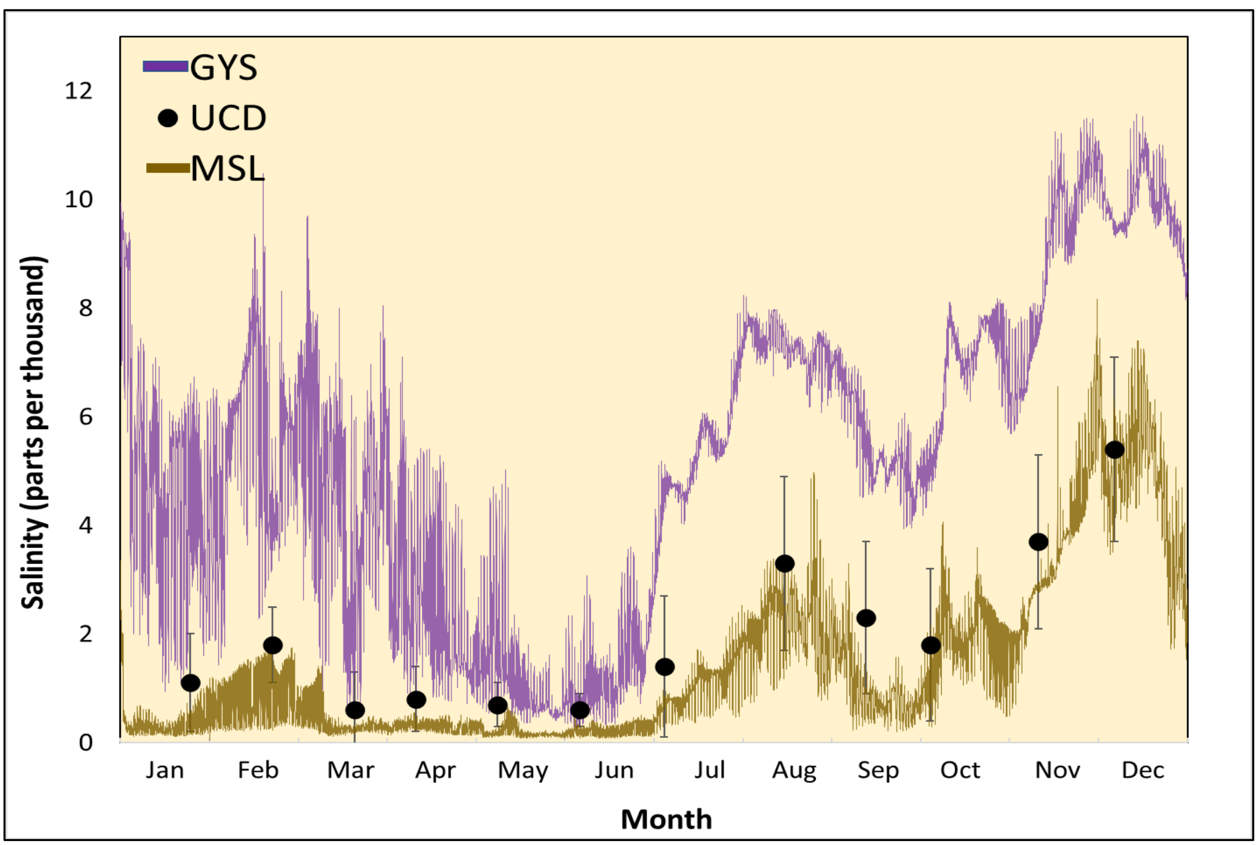

Figure 6. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations of the Suisun Marsh Fish Study ("UCD ") during 2023.

Dissolved Oxygen (DO)

Oxygen levels throughout Suisun Marsh in 2023 were nearly always hospitable for all fishes (>5 mg/L; Moyle 2002). Average monthly DO concentrations were rather typical: they exhibited a mild decline from January through June, after which they vacillated mildly until notably increasing in December (Figure 7). Trends in minimum and maximum monthly DO concentrations were similar except in October, when a near-anoxic value (0.7 mg/L) was recorded in upper Boynton Slough at the BY1 station during late ebb tide close to noon. The lowest monthly DO concentration always occurred in the upstream reaches of small, dead-end sloughs (Boynton, Denverton, First Mallard, or Goodyear). Highest monthly concentrations were always close to the estuary's main axis (*i.e.,* the confluence of the Sacramento-San Joaquin rivers and the bays), either in lower Suisun Slough or Montezuma Wetlands.

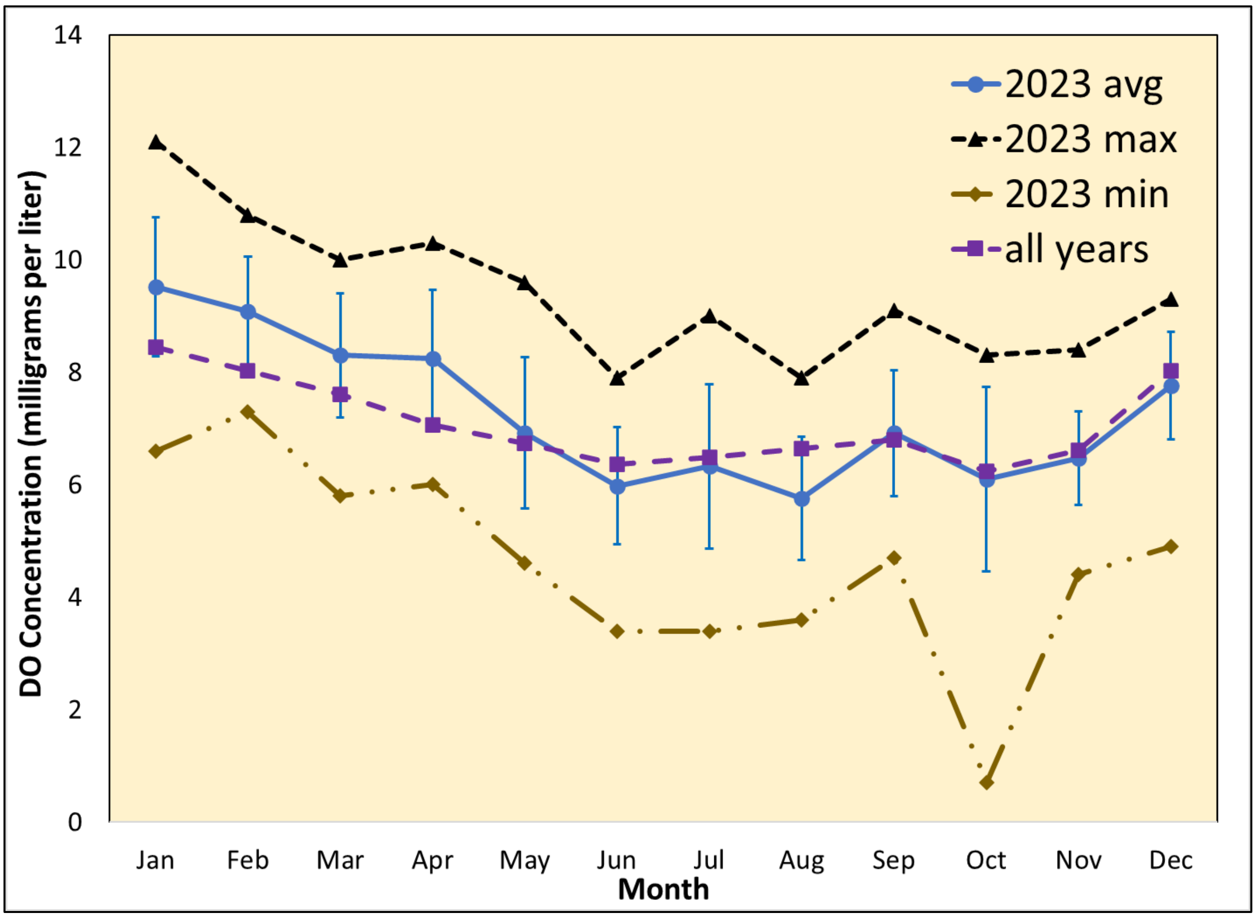

Figure 7. Monthly average DO concentration in 2023 and for the 2000s (2000 - 2023), maximum DO concentration in 2023, and minimum DO concentration in 2023. Error bars are standard deviations in 2023.

Water Temperature

Overall, temperatures in 2023 were anomalous given warming of both the climate and estuary (Bashevkin *et al.* 2022): they were notably cool through the first half of the year [High Plains Regional Climate Center (HPRCC) 2024; Figure 8], and, like Delta outflow, similar to 2011 (O'Rear and Moyle 2012). Nevertheless, the pattern did not continue, with higher-than-average temperatures through the year's second half, particularly in autumn (Figure 8). Consistent with greater sensitivity of smaller sloughs to air temperature than larger sloughs, continuous gauges showed water temperature fluctuated more and reached more-extreme values in Goodyear Slough than in eastern Montezuma Slough (Figure 9). The difference between the two gauges was especially pronounced in April and early May, when temperatures in Goodyear exceeded tolerance levels (~20°C) of some native fishes (Moyle 2002). Fish-study values reflected this pattern, with most-extreme temperatures in small sloughs (24.2°C in Boynton in August, and 6.7°C in Denverton in January).

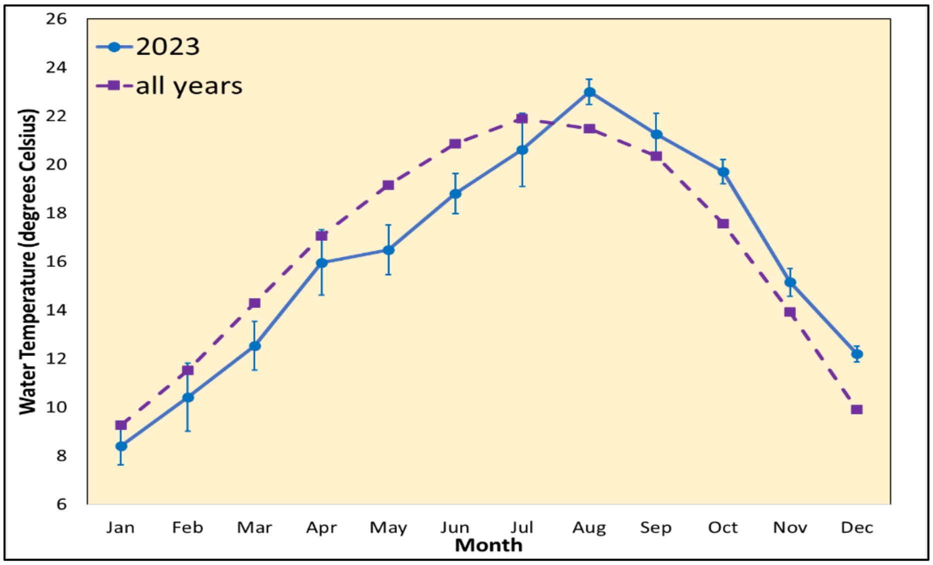

Figure 8. Monthly average water temperature in 2023 and for all years of the study (1980 - 2023); error bars are standard deviations in 2023.

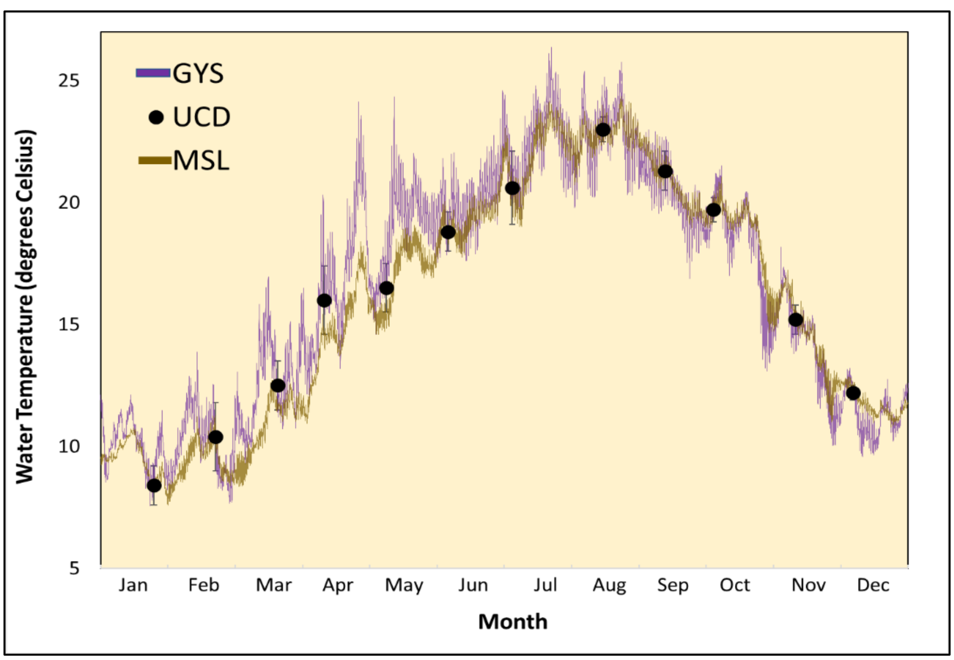

Figure 9. Fifteen-minute water temperature from fixed stations in Goodyear Slough and Montezuma Slough, with average monthly temperatures and standard deviations from the Suisun Marsh Fish Study during 2023 (codes as in Figure 6).

Water Clarity

Average monthly water clarity differed from the typical trend in several ways (Figure 10). Clarity was very low in January, concurrent with the first large pulse of Delta outflow, after which February and March clarities were average. Clarities were above average in April and May despite higher-than-average Delta outflow, likely due in part to most sediment having been flushed through with the earlier high flows (Schoelhamer *et al.* 2016). Clarities then declined to average values in June and July, coinciding with some of the year's largest tides. They then increased in August and September, dropped to average values again in October and November, and then reached the year's peak in December. The clearest water was most often in eastern Montezuma Slough/Wetlands (six months), although the year's highest clarity (70 cm) was recorded in middle Nurse Slough (NS2; Figure 2) in December. Except in February, lowest water monthly water clarity was always in a small slough, with the lowest value (10 cm) occurring in Montezuma Wetlands in March.

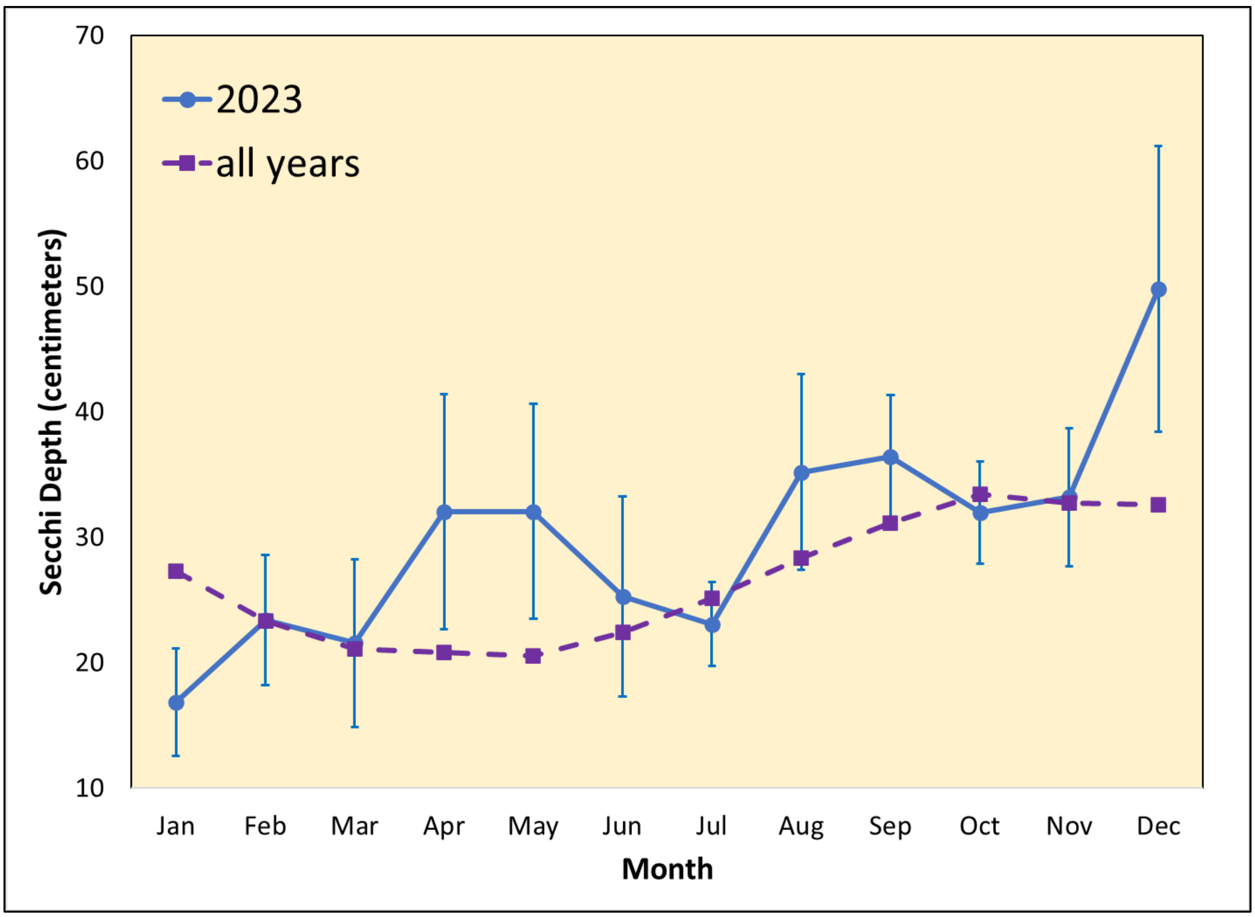

Figure 10. Monthly average water clarity in 2023 and for all years of the study (1980 - 2023); error bars are standard deviations in 2023.

Trends in Invertebrate Distribution and Abundance

Opossum Shrimp

Opossum shrimp numbers were rather low in 2023, with the year's CPUE (0.9 rank per trawl) only half the value of 2022 (1.8 rank per trawl) and lower than the all-years average (1.3 rank per trawl; Figure 11). Monthly CPUE nearly doubled from January to February, then declined moderately with some variability through the year's remainder (Figure 12). Aside from the very high catch in February, the monthly pattern was typical (Moyle *et al.* 1986, O'Rear *et al.* 2022, 2023). Opossum shrimp were prevalent in all sloughs, with highest CPUE values again in Nurse and Denverton sloughs (O'Rear *et al*. 2022, 2023), consistent with higher pelagic productivity far into the northeast marsh (Montgomery *et al.* 2015).

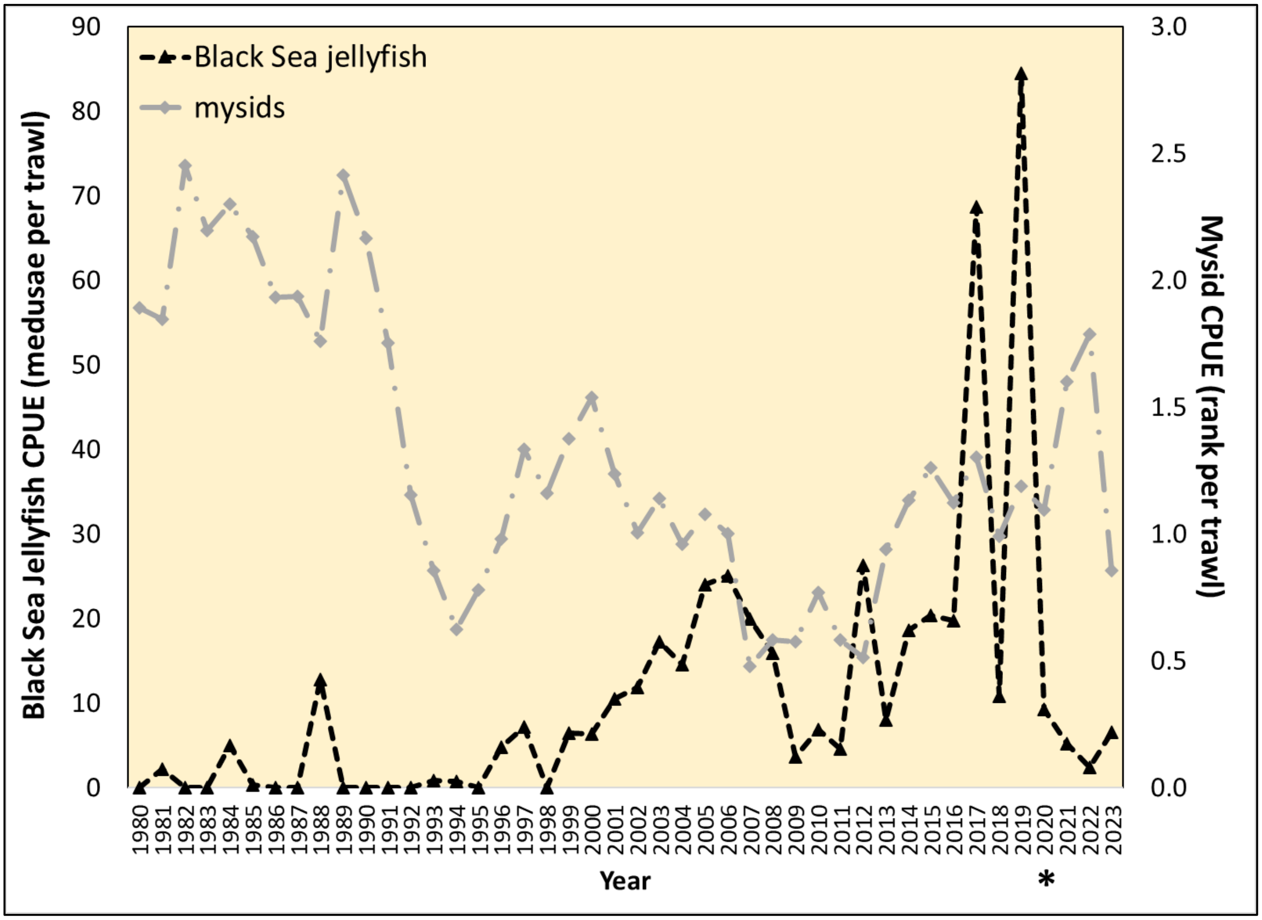

Figure 11. Annual CPUE of Black Sea jellyfish and opossum shrimp (* = no March or April samples).

Black Sea Jellyfish

Relatively few Black Sea jellyfish medusae were caught in 2023, with CPUE (6.5 medusae per trawl; Figure 11) well below values for both 2022 and all years (2.4 and 11 medusae per trawl, respectively), although the 2022 value is likely biased low (O'Rear *et al.* 2023). Medusae did not appear until August, attained highest numbers in September, dropped precipitously through October and November, then disappeared in December (Figure 12). Medusae were captured in most sloughs, with 92% of the year's catch coming from Goodyear and lower Suisun sloughs, in contrast with the previous dry year when the bulk of the catch came from eastern Montezuma Slough (O'Rear *et al*. 2023). Few medusae were caught in other sloughs, with none being caught in Denverton Slough - a common occurrence (O'Rear *et al.*

2023). The patterns reflect the importance of salinity on medusae abundance as well as their tendency to be most abundant close to the main axis of the estuary (Baumsteiger *et al.* 2018), with their distribution inhibited by SMSCG operations in summer (Beakes *et al.* 2020).

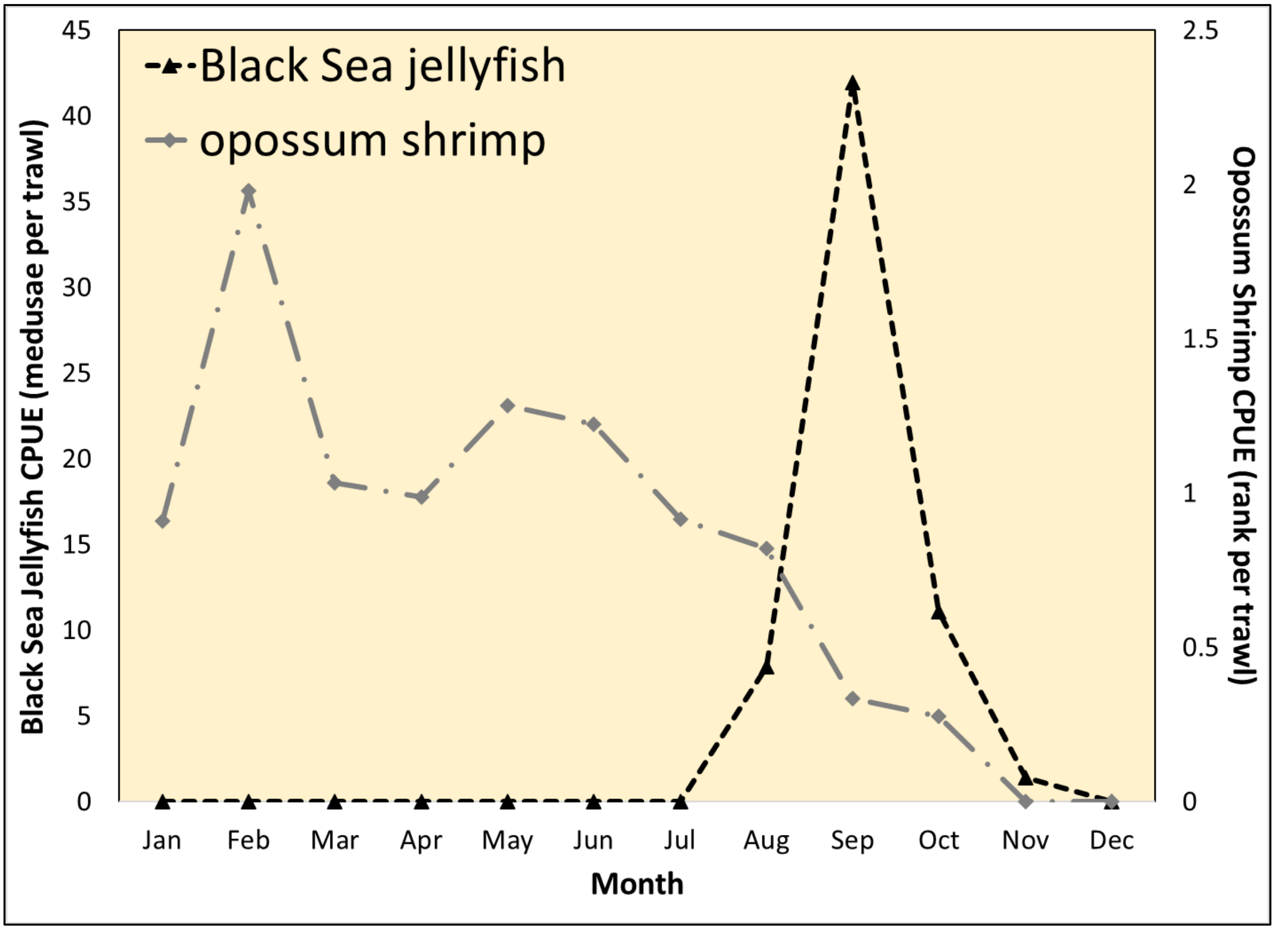

Figure 12. Monthly average CPUE of Black Sea jellyfish and opossum shrimp in Suisun Marsh in 2023.

Clams

Overbite Clam

Overbite clam numbers in 2023 were among the lowest they have been since their introduction in 1986 (Figure 13), with the year's CPUE (6 clams per trawl) much lower than values for both 2022 and all years (68 and 54 clams per trawl, respectively). Few overbite clam were present in the marsh until late summer when salinities reached favorable conditions (≥3 ppt; Nicolini and Penry 2000), and they peaked two months later than in an average year (Baumsteiger *et al*. 2017; Figure 14). Consistent with the typical pattern, nearly all overbite clam (92% of the catch, 1,590 individuals) came from Suisun Slough or the GY3 site, which is the closest small-slough site to a large slough and one of the saltiest. Aside from the lower Goodyear Slough site, overbite clam was nearly absent in small sloughs, with none captured in Denverton and First Mallard sloughs. Catches in 2023 reinforced that overbite clam is inhibited in Suisun Marsh by small sloughs (Baumsteiger *et al.* 2017) and fresh water, with the effect magnified by SMSCG operations in summer.

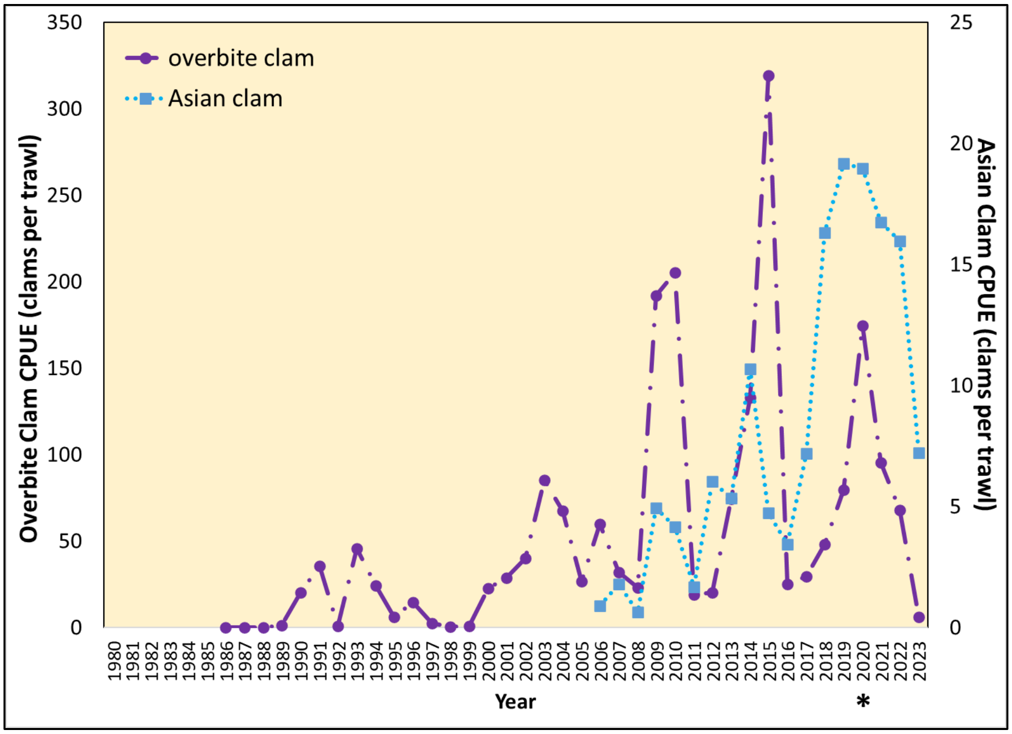

Figure 13. Annual CPUE of overbite clam and Asian clam (* = no March or April samples).

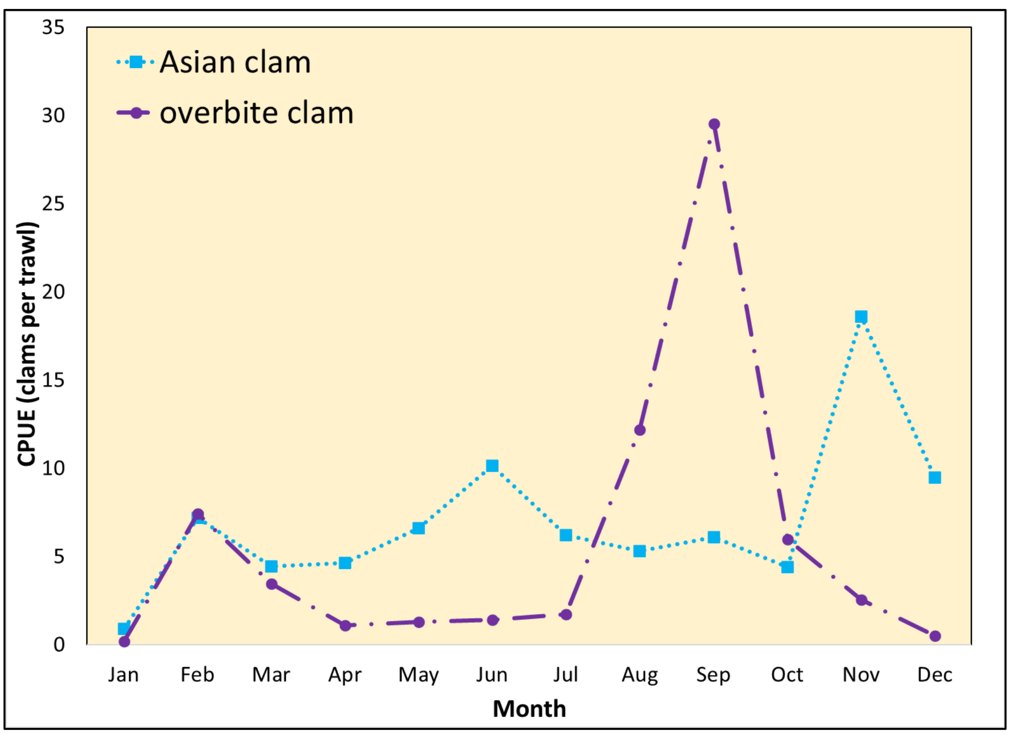

Figure 14. Monthly average CPUE of overbite clam and Asian clam in Suisun Marsh in 2023.

<u>Asian Clam</u>

Asian clam numbers in 2023 were about average, with CPUE close to the all-year's value (7 and 8 clams per trawl, respectively) and below 2022's value (16 clams per trawl; Figure 13).

Monthly patterns between overbite clam and Asian clam were dissimilar, with Asian clam CPUE relatively consistent throughout the year except in January and November, when very low and high numbers were caught, respectively (Figure 14). Geographic distribution of the clams was rather complementary. While abundant in two big sloughs - eastern Montezuma and upper Suisun - which, together, hosted 39% (790 individuals), Asian clam was also very abundant in fresher, smaller sloughs (Cutoff and Peytonia), where 42% of the year's catch was made. They were sparse in the saltier southwest region of the marsh (Goodyear and lower Suisun sloughs), where only 2% of the catch was made. These patterns reflect two key differences between the clam species: Asian clam is less tolerant of higher salinities than overbite clam (Evans *et al.* 1979, Zierdt Smith *et al.* 2023); and Asian clam can subsist well on both detritus and plankton (Schroeter *et al.* 2015, Modesto *et al.* 2023), while overbite clam is primarily a plankton-eater (Alpine and Cloern 1992, Greene *et al.* 2011).

Shrimps

<u>California Bay Shrimp</u>

California bay shrimp numbers were a little low in 2023, with the annual CPUE below both the all-years average and 2022's value (21, 27, and 39 shrimp per trawl, respectively; Figure 15). Monthly CPUE was negligible from January through June, after which it rose concurrent with increasing salinities and remained moderate through the year's remainder (Figure 16). Lower Suisun and Goodyear sloughs hosted a disproportionate number of California bay shrimp [68% of the year's catch (4,044 individuals)], similar to overbite clam. Other large-slough stations (*i.e.*, Montezuma and upper Suisun sloughs) also had numbers of the shrimp (24% of the year's catch), while the fresher, small sloughs had relatively few. The timing and location of the catches reflected the shrimp's association with moderately salty water (Cloern *et al.* 2017) and predilection for coarser substrate in the larger sloughs.

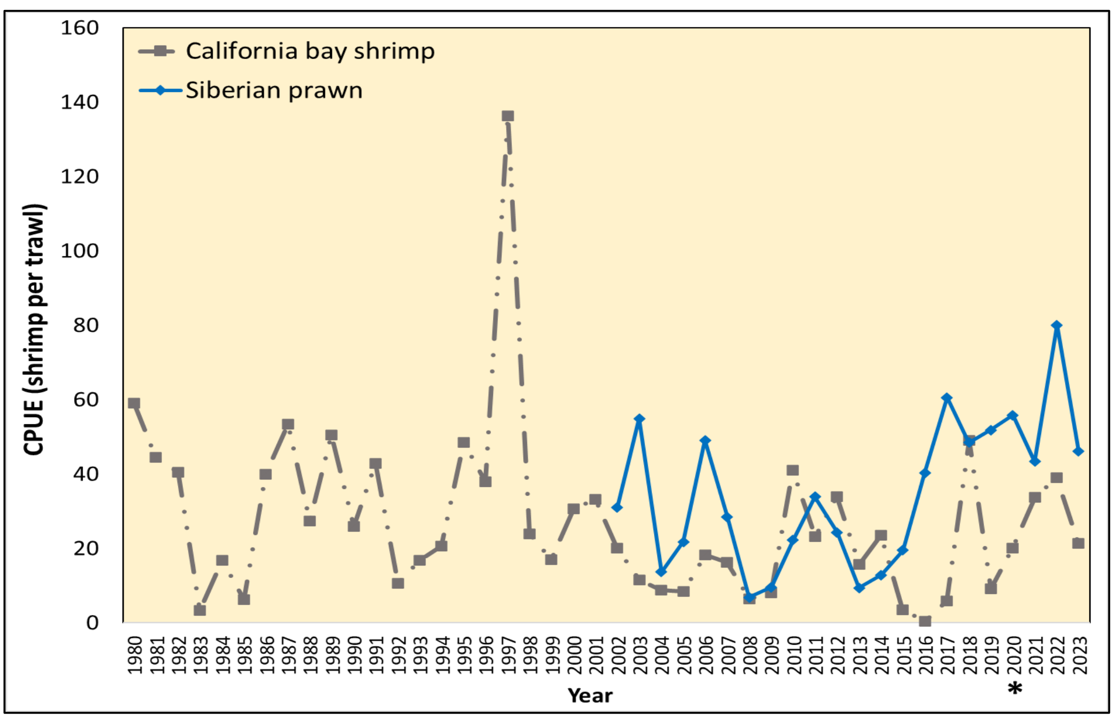

Figure 15. Annual CPUE of California bay shrimp and Siberian prawn (* = no March or April samples).

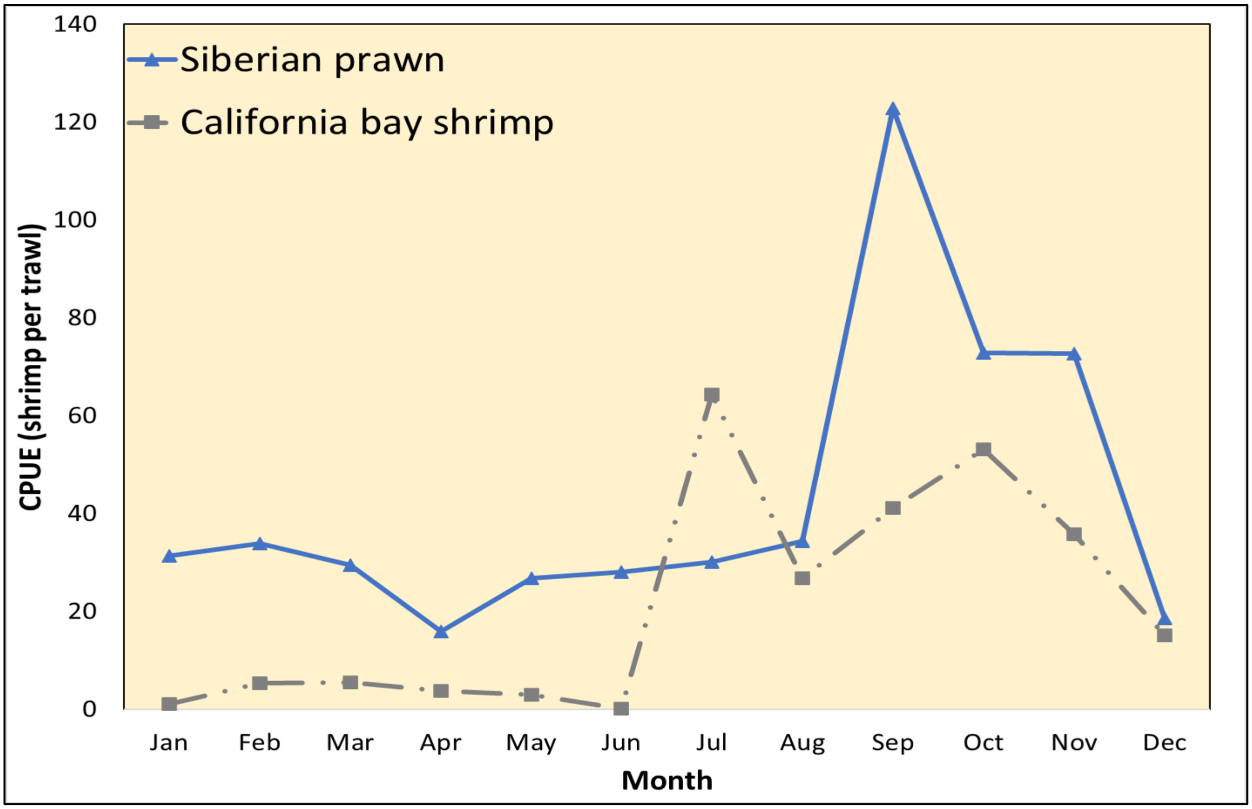

Figure 16. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2023.

<u>Siberian Prawn</u>

Siberian prawn were abundant in 2023, with 2023 CPUE higher than the all-years average since their introduction though considerably below 2022's record-high CPUE (46, 35, and 80 shrimp per trawl, respectively; Figure 15). Numbers were quite stable from January through July, after which they peaked dramatically in September, then falling to end at a moderate level in December (Figure 16). The prawn was common everywhere but was notably abundant where California bay shrimp was not, with high numbers in Boynton, Denverton, and Nurse sloughs (1,170, 1654, and 1650 individuals, respectively). Such patterns reflect that Siberian prawn is mainly a freshwater shrimp that can tolerate moderate salinities (Brown and Hieb 2014, Tiffan and Hurst 2016).

Trends in Fish Distribution and Abundance

Otter Trawls

Fish abundance in 2023 was about average, close to both the all-years average and 2022's CPUE (21, 24, and 23 fish per trawl, respectively; Figure 17). CPUEs for both native and non-native fishes were similar across 2023, 2022, and all-years averages (natives: 10, 12, and 10 fish per trawl, respectively; non-natives: 11, 11, and 14 fish per trawl, respectively). Despite the similarities in CPUE, the notable species shifted (Table 1). Native marine fishes present in 2022 [northern anchovy, plainfin midshipman (*Porichthys notatus*), arrow goby, bay pipefish (*Sygnathus leptorhynchus*)] were absent in 2023. Longfin smelt and tule perch also declined substantially, although increases in starry flounder (*Platichthys stellatus*) and fishes needing fresh water for spawning [*e.g.*, Sacramento pikeminnow, Sacamento splittail] muted the drop in native CPUE. For non-natives, increases in freshwater fishes tolerant of moderate salinities and muddy water (common carp and black crappie) and pelagic fishes (threadfin shad, American shad, and striped bass) nearly equaled steep declines in the gobies [yellowfin, shokihaze (*Tridentiger barbatus*), and shimofuri (*Tridentiger bifasciatus*); Table 1].

Table 1. Change in annual otter trawl CPUE of 13 marsh fishes (% change is relative to 2022 CPUE, such that a 100% increase indicates that the value has doubled; species in bold are native; "all years" is the average for 1980 - 2023).

Species	All Years CPUE	2023	2022	2023/2022 % Change
Sacramento splittail	**3.90**	**8.77**	**6.10**	**+44%**
Sacramento pikeminnow	**0.02**	**0.1**	**0.02**	**+400%**
longfin smelt	**1.06**	**0.07**	**1.96**	**-96%**
tule perch	**1.99**	**1.41**	**2.47**	**-43%**
starry flounder	**0.2**	**0.77**	**0.11**	**600%**
threadfin shad	0.41	0.91	0.38	+139%
American shad	0.19	0.29	0.22	+32%
common carp	0.49	0.93	0.12	+675%
striped bass	8.42	5.78	2.49	+132%
black crappie	0.23	0.34	0.08	+325%
shimofuri goby	1.29	1.09	1.85	-41%
yellowfin goby	2.15	0.99	2.13	-54%
shokihazi goby	0.26	0.28	3.02	-91%

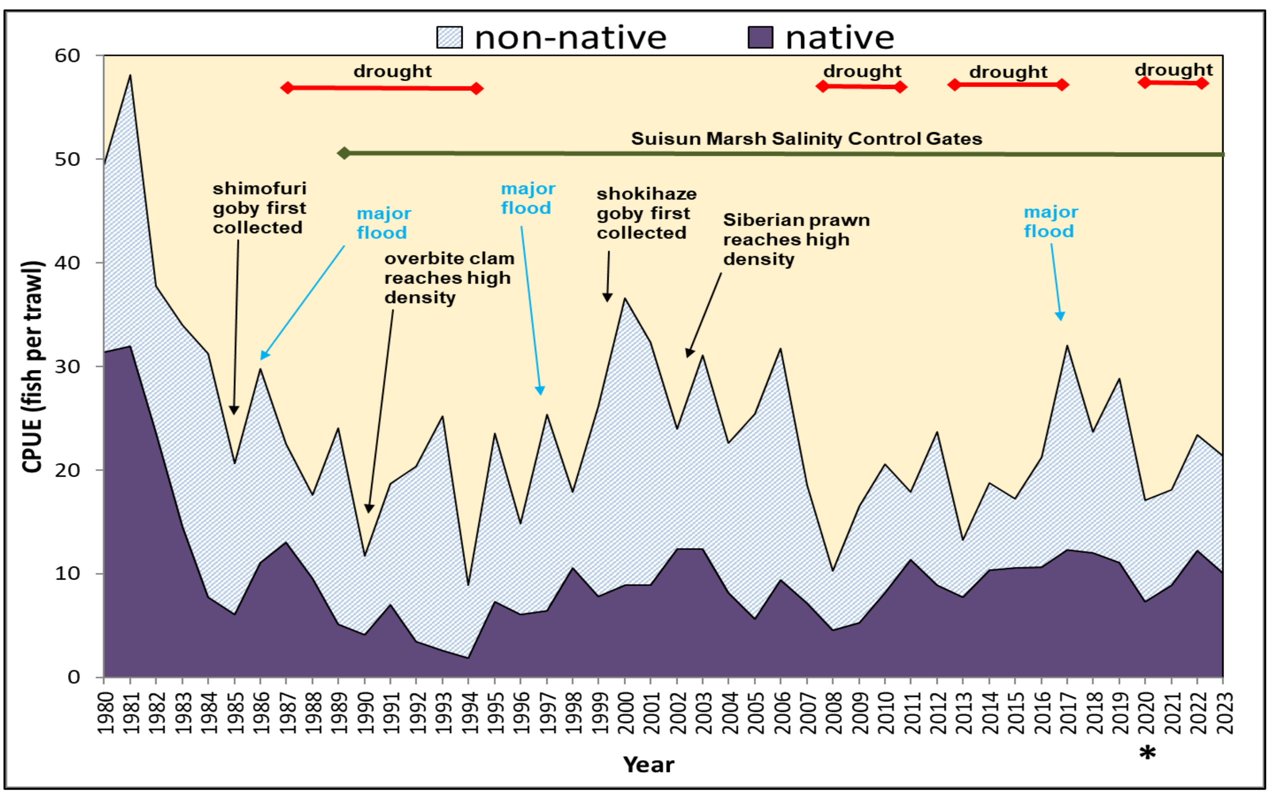

Figure 17. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted (* = no March or April samples).

Beach Seines

The number of inshore fish was typical in 2023, close to the all-years average but below the 2022 value (54, 61, and 87 fish per haul, respectively; Figure 18). The rise in native fish from 2022 to 2023 was relatively substantial (4 fish per seine haul), mainly due to a dramatic increase in Sacramento splittail (Table 2), nearly all of which were age-0 fish (99.6%). Like in the otter trawl, river-spawning fishes (Sacramento pikeminnow, Chinook salmon) and benthic fishes (starry flounder, staghorn sculpin) increased while the two littoral fishes (tule perch and threespine stickleback) decreased. Non-native CPUE sharply declined because of much lower Mississippi silverside numbers as well as fewer gobies (Table 2). The freshwater and pelagic fishes that increased in the otter trawl also rose in the beach seine, with the rise in threadfin shad especially notable (Table 2).

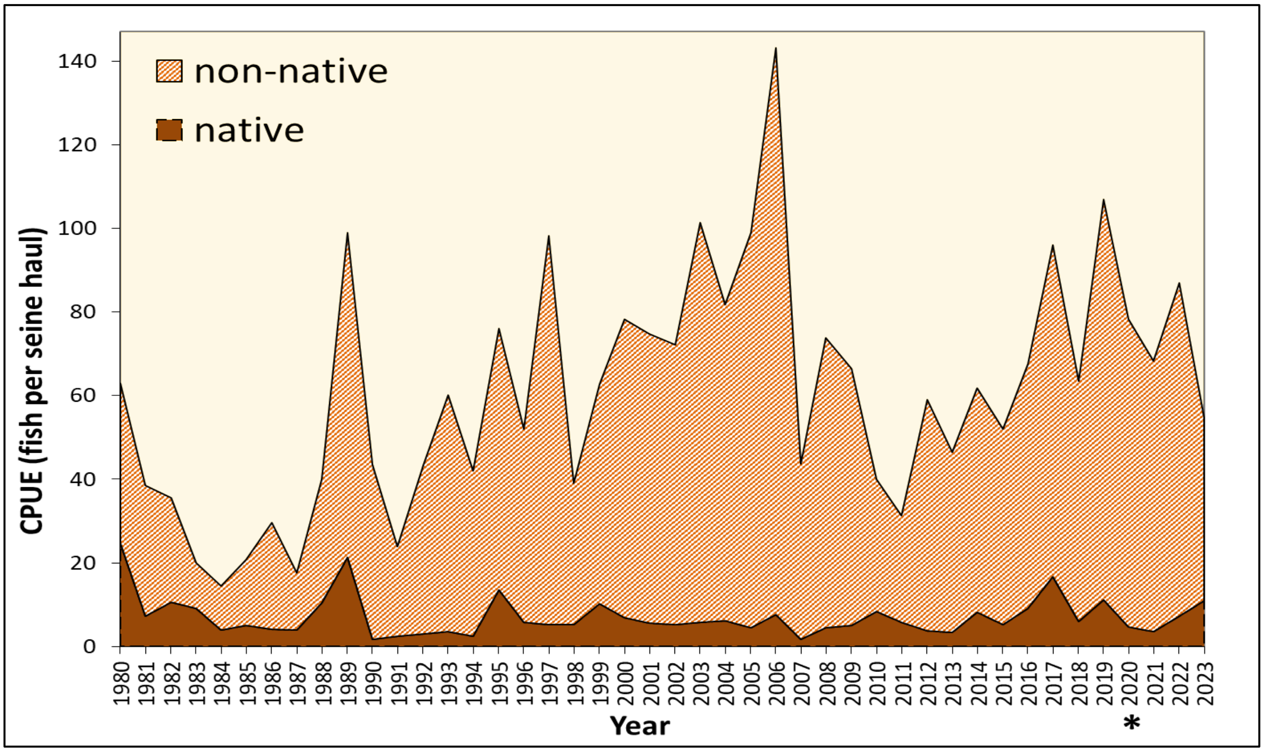

Figure 18. Annual beach seine CPUE of native and non-native fishes (* = no March or April samples).

Table 2. Percent change in annual beach seine CPUE of 13 marsh fishes (% change is relative to 2022 CPUE, such that a 100% increase indicates that the value has doubled; native species in bold; "all years" is the average for 1980 - 2023).

Species	All Years CPUE	2023	2022	2023/2022 % Change
Sacramento splittail	**2.14**	**6.68**	**0.81**	**+725%**
Sacramento pikeminnow	**0.10**	**.54**	**0.01**	**+5300%**
Chinook salmon	**0.13**	**0.22**	**0**	+∞
threespine stickleback	**1.69**	**0.54**	**3.34**	**-84%**
staghorn sculpin	**1.57**	**1.05**	**0.59**	**+78%**
tule perch	**0.81**	**1.07**	**1.76**	**-39%**
starry flounder	**0.11**	**0.4**	**0.16**	**+150%**
threadfin shad	2.62	5.56	0.97	+473%

Species	All Years CPUE	2023	2022	2023/2022 % Change
common carp	0.2	0.3	0.14	+114%
Mississippi silverside	37.69	25.60	67	-62%
striped bass	5.54	5.45	2.25	+142
black crappie	0.08	0.12	0	+∞
yellowfin goby	6.09	5.65	7.90	-28%
shimofuri goby	0.86	0.23	1.09	-79%

Fish Species of Interest

<u>Fishes of the Pelagic Organism Decline</u>

DELTA AND LONGFIN SMELT

For the eighth consecutive year, no Delta smelt were captured by the Suisun Marsh Fish Study (Figure 19); none were captured in the estuary-wide Summer Townet Survey and Fall Midwater Trawl Survey (CDFW 2024), although some were captured in the marsh's large sloughs by the U. S. Fish and Wildlife's (USFWS) Enhanced Delta Smelt Monitoring program (USFWS 2024). Delta smelt were still absent in the Suisun Marsh Fish Study during 2023 despite (1) continued stockings in the Sacramento River near Rio Vista (Katherine Sun, personal communication); (2) operation of the Suisun Marsh Salinity Control Gates through critical summer and autumn months; and (3) similar flow and temperature conditions to 2011, the last year in which many Delta smelt were captured by the Suisun Marsh Fish Study (Figure 19).

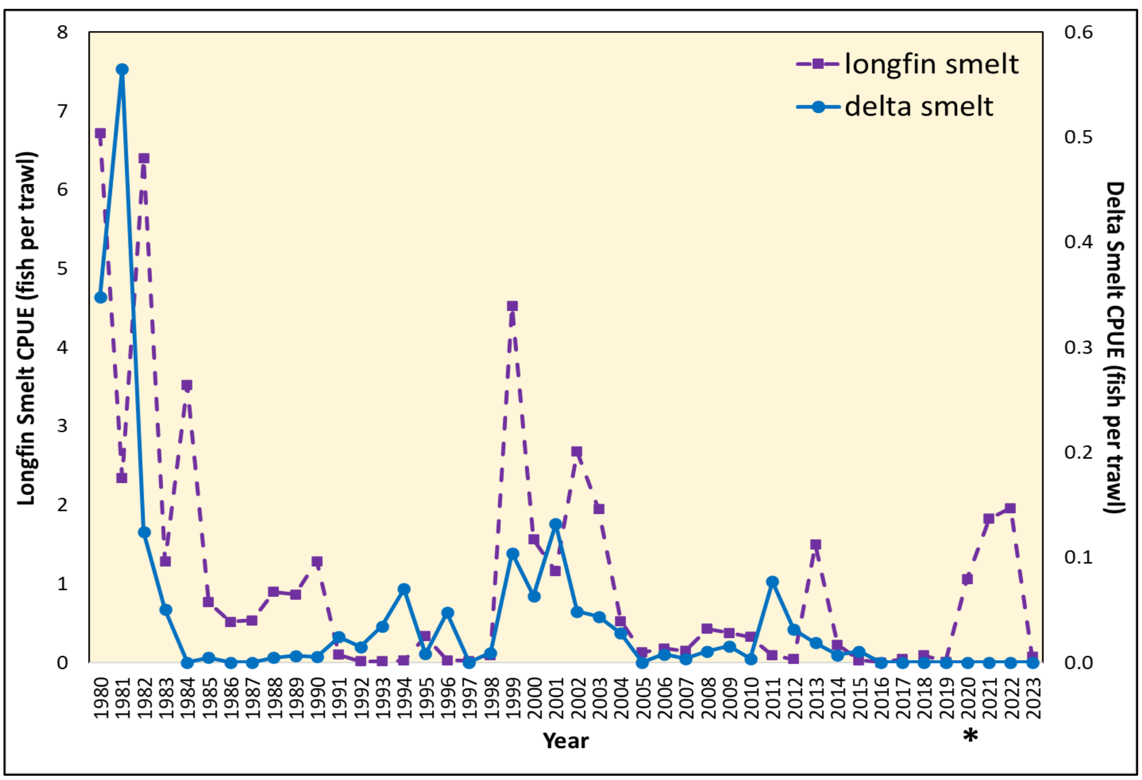

Figure 19. Annual CPUE of the smelts of the Pelagic Organism Decline (* = no March or April samples).

Longfin smelt numbers in 2023 were low, with the 2023 CPUE much lower than for 2022 or the all-years average (Figure 19; Table 1). Eighty percent (16 fish) were from the 2023 year class (SL range = 31-67 mm), and most of those (75%) were caught in either a large slough or close to the estuary's main axis. Age-0 fish were first caught in May, with either one or a few caught in the following months until October, when seven were captured. None were caught in November and December. The four age-1 fish (SL range = 57-87 mm) were captured in winter (January and February) at stations close to the bays (*i.e.*, eastern Montezuma and lower Suisun sloughs). These patterns were consistent with the bulk of spawning occurring downstream of Suisun Marsh in wet years (USFWS 2022), and longfin smelt's association with cool temperatures (Tobias and Baxter 2023).

THREADFIN AND AMERICAN SHAD

As is typical for wet years, threadfin shad were very abundant in 2023, with 2023 CPUE for beach seine and otter trawl above both average and 2022 values (Figure 20; Table 1 and 2). Geographic distribution in the otter trawl was similar to previous years, with many fish caught in fresher waters of the eastern marsh (74%, 320 individuals, with 51% of the year's catch coming from just Denverton Slough) and virtually none in the saltier southwest (2%; Appendix D). Geographic distribution in beach seines was similar, with 93% of the year's catch coming from Denverton Slough and Montezuma Slough/Wetlands but only 7% coming from upper Suisun Slough (Appendix D). The abundance and distribution of threadfin shad in 2023 were consistent with (1) their preference for fresher water (Feyrer *et al.* 2007, 2009), which was likely enhanced by summer and early-autumn operation of the SMSCG, and (2) high zooplankton densities in small, dead-end sloughs (Montgomery *et al.* 2015).

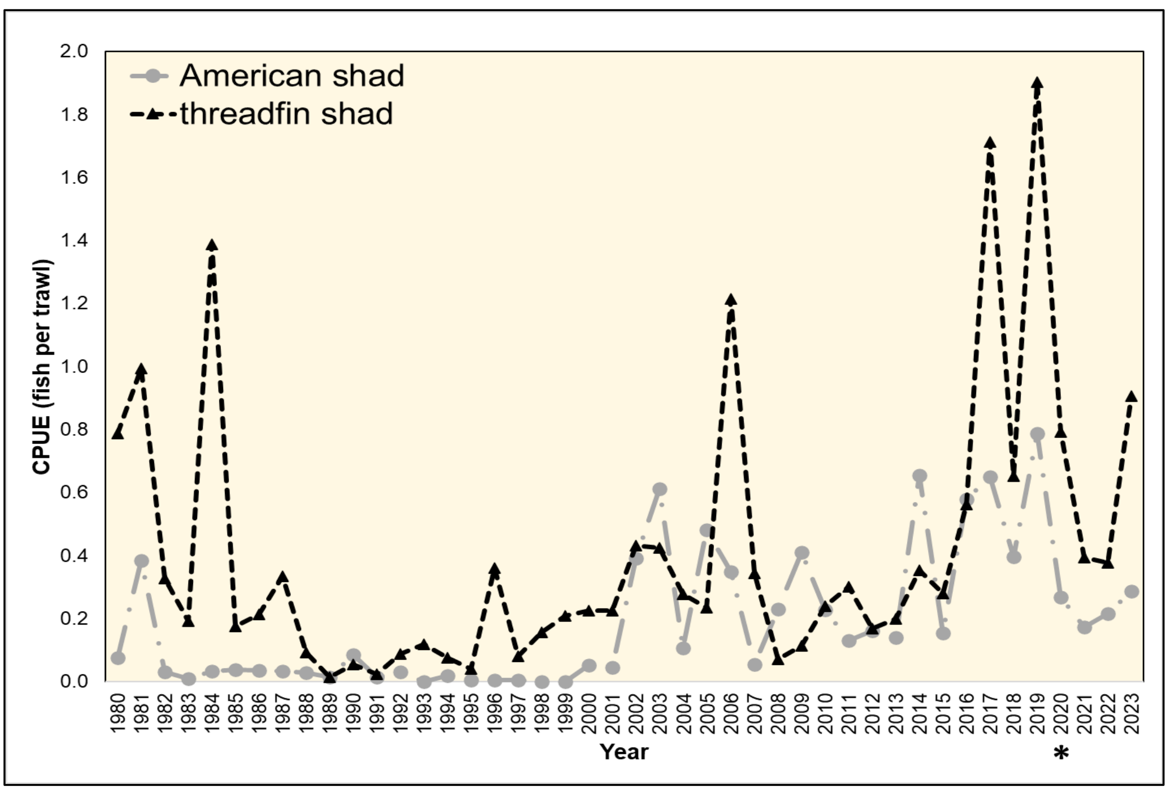

Figure 20. Annual CPUE of the shads of the Pelagic Organism Decline (* = no March or April samples).

American shad were relatively abundant in 2023. Otter-trawl CPUE in 2023 was above both the all-years average and 2022's value (0.29, 0.19, and 0.22 fish per trawl, respectively; Figure 20). Nevertheless, numbers in 2023 were lower than in previous warm, wet years (2006, 2017, 2019; Figure 20). Unlike 2022 when age-1 fish dominated the catch, all American shad in 2023 were age-0 fish. American shad were captured in most sloughs but especially in Montezuma Slough/Wetlands (70%, 102 fish). These patterns were consistent with both good and bad conditions for American shad in 2023: higher river flows enhancing spawning area, but cool temperatures through the late spring/early summer spawning period delaying the onset of spawning (Marcy 1972).

STRIPED BASS

Like for American shad, striped bass CPUE in 2023 improved relative to 2022 and long-term averages in both gear types, but not to the extent of warm, wet years (Figure 21; Table 1 and 2). Age-0 fish first occurred in both net types in June, a month later than usual; remained abundant in July; then declined drastically in the beach seine but less so in the otter trawl through the year's remainder (Figure 22). Juvenile striped bass generally declined through the year (Figure 22), consistent with dispersal throughout both the marsh - where they were common in most sloughs, both small and large (Figure 23) - and the estuary (Calhoun 1952, Able *et al.* 2012). Age-0 fish in trawls were typically more abundant in smaller sloughs, particularly Denverton and Goodyear, although they were most abundant in lower Suisun Slough (Figure 23). Age-0 fish in beach seines were abundant in Denverton, Montezuma, and upper Suisun sloughs (Appendix D), which is unusual in that most years find the highest inshore abundances in Denverton and the lowest in upper Suisun (O'Rear *et al.* 2023). The catches in 2023 reflected responses to temperature and flow similar to American shad, which striped bass evolved with along the Atlantic Coast. The moderate catches of age-0 fish in otter trawls from August through October were consistent with continued recruitment of fish into the marsh facilitated by SMSCG operations (Beakes *et al.* 2020). Additionally, zooplankton abundance was likely improved in the large sloughs because of both low overbite clam numbers and high flows delivering zooplankters from the Delta to Suisun (Hassrick *et al.* 2023).

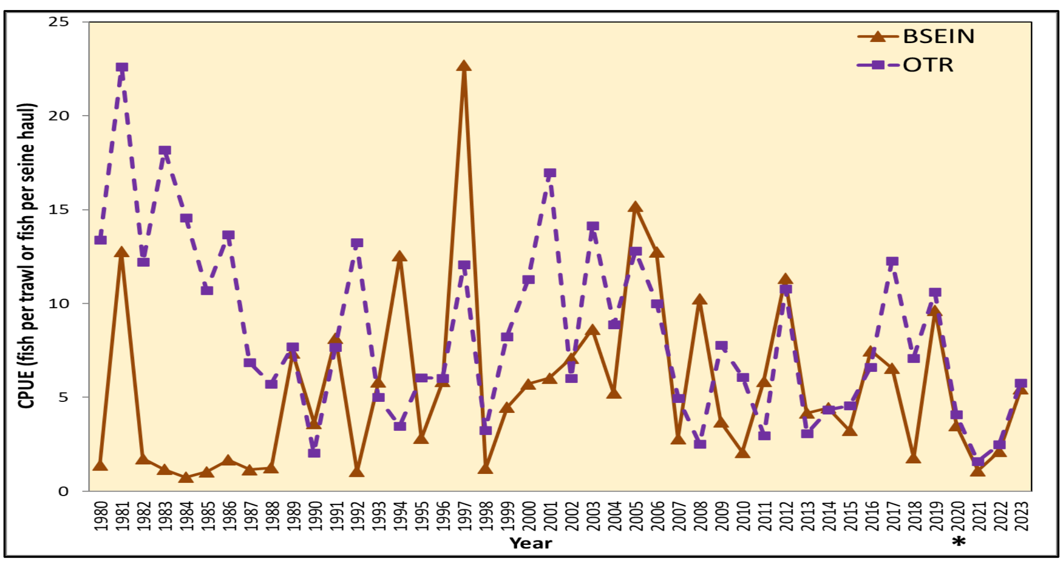

Figure 21. Annual CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine; * = no March or April samples).

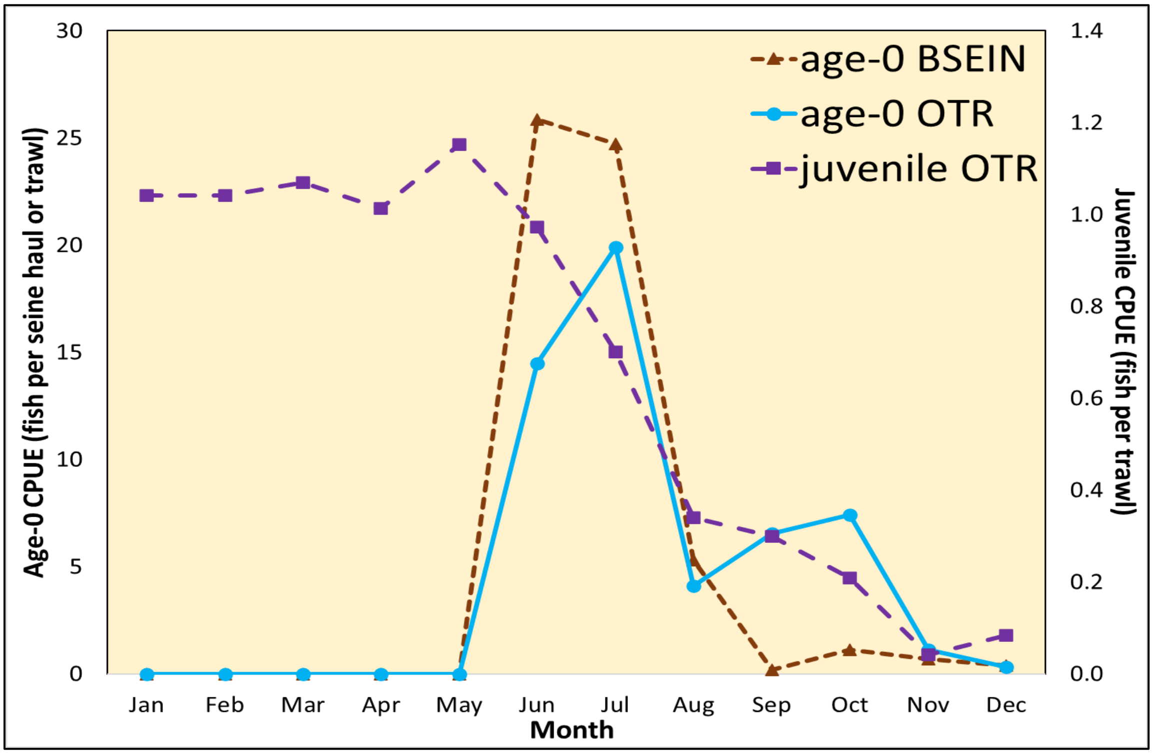

Figure 22. Monthly average CPUE of striped bass age classes (codes as in Figure 21).

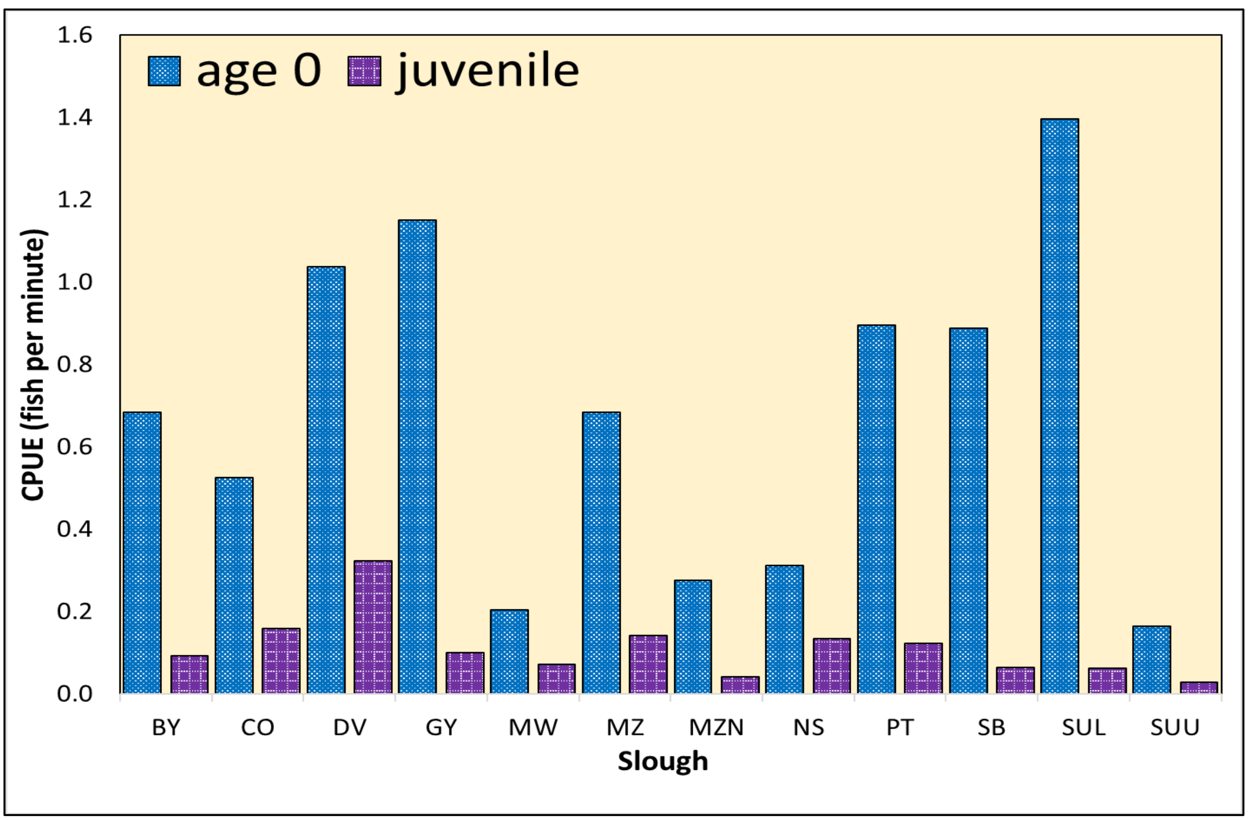

Figure 23. Average slough CPUE of age classes of striped bass in 2023 (codes as in Figure 5 except "MZN" = Montezuma Slough near Nurse Slough, "MW" = Montezuma Wetlands).

<u>Sacramento Splittail</u>

Splittail were very abundant in 2023. Otter-trawl CPUE in 2023 was above values for both 2022 and the all-years average, and the beach seine CPUE in 2023 was the third highest in the study's history (Figure 24, Table 1 and 2). The high splittail catches in Suisun Marsh were contrasted by none being captured by the estuary-wide Fall Midwater Trawl Survey (CDFW 2024), a recent recurring phenomenon (O'Rear *et al.* 2022). The abundance increase was driven by the highest-ever catch of age-0 fish (Figure 24); notably, catches of age-0 fish remained high in September and especially October, when they typically decrease. Splittail were most numerous in small sloughs (Figure 25), often those where age-0 striped bass were also most abundant (Figure 23). They were also abundant in near-shore shallow water in a large slough (Montezuma), where 33% of the beach seine fish were captured (Appendix D). The patterns in 2023 reflected (1) improved spawning conditions from extensive floodplain inundation and (2) especially good conditions within the smaller sloughs of Suisun Marsh (Colombano *et al.* 2020*a*). Additionally, as for striped bass and similar to 2018 (Beakes *et al.* 2020), the summer-autumn SMSCG operations likely augmented recruitment of splittail from the Delta into Suisun Marsh.

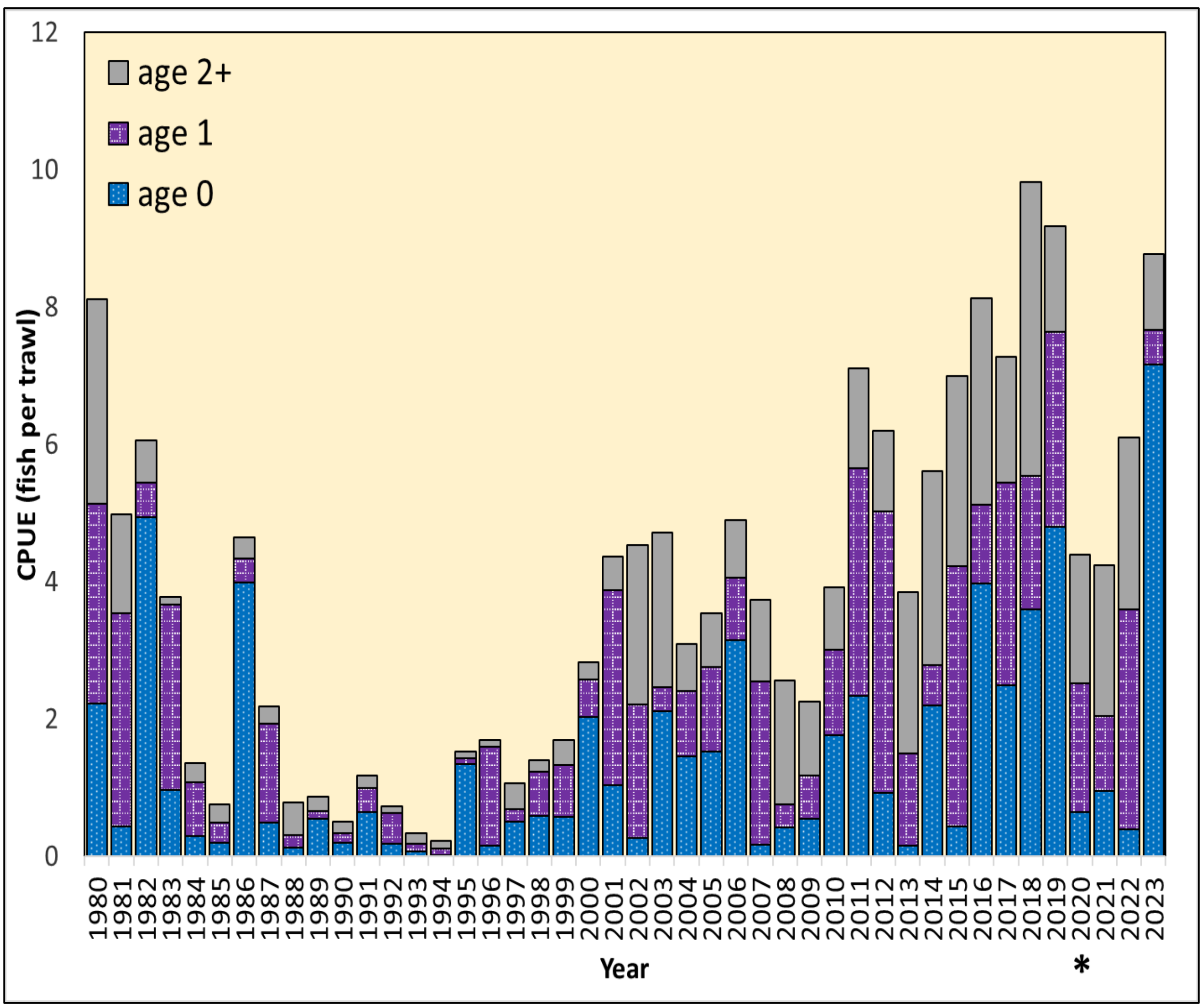

Figure 24. Annual CPUE of three age classes of Sacramento splittail (* = no March or April samples).

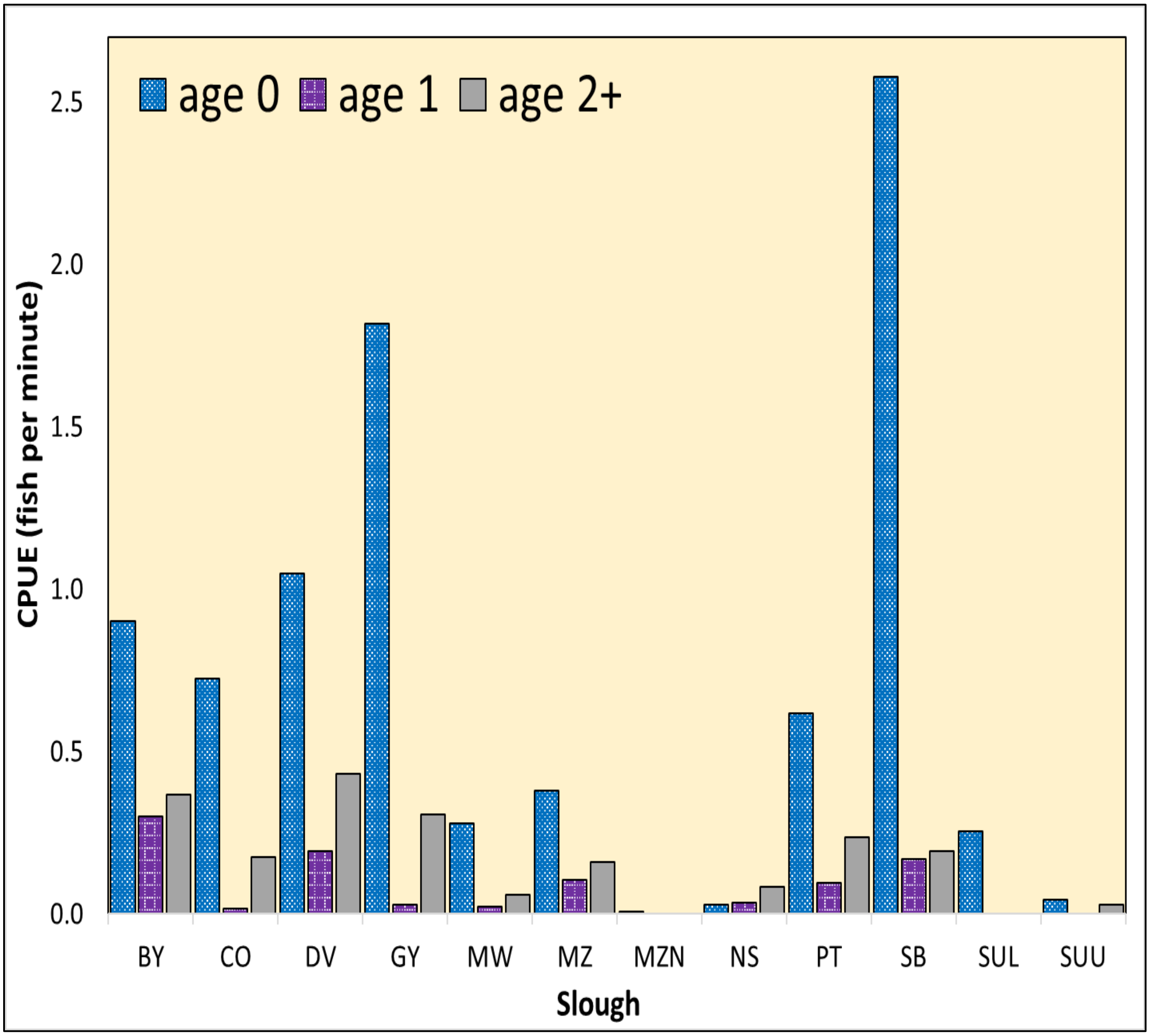

Figure 25. Average slough CPUE of age classes of splittail in 2023 (codes as in Figure 23).

<u>Chinook Salmon</u>

Chinook salmon smolts were quite abundant in 2023, with the beach seine annual CPUE reaching its highest value since 2002 (Figure 26). Although the otter trawl is less effective at catching smolts than the beach seine, smolts were still caught in otter trawls in 2023 (Figure 26). All but one smolt were fall-run fish, based on Harvey *et al.* (2014). In typical years, most smolts are captured in February, with some in January and March and negligible numbers in other months (Figure 27). Beach seine catch in 2023 veered from this pattern, with many captured in April and some even in May (Figure 27). All but one of the smolts was captured near or on the main migration corridor of Montezuma Slough (Appendix D). The abundance and spatiotemporal distribution of Chinook salmon smolts in 2023 were consistent with high flows enhancing survival while migrating through the rivers and Delta (Michel *et al.* 2015, Plumb *et al.* 2016), as well as cooler temperatures slowing outmigration (Ogaz *et al.* 2022).

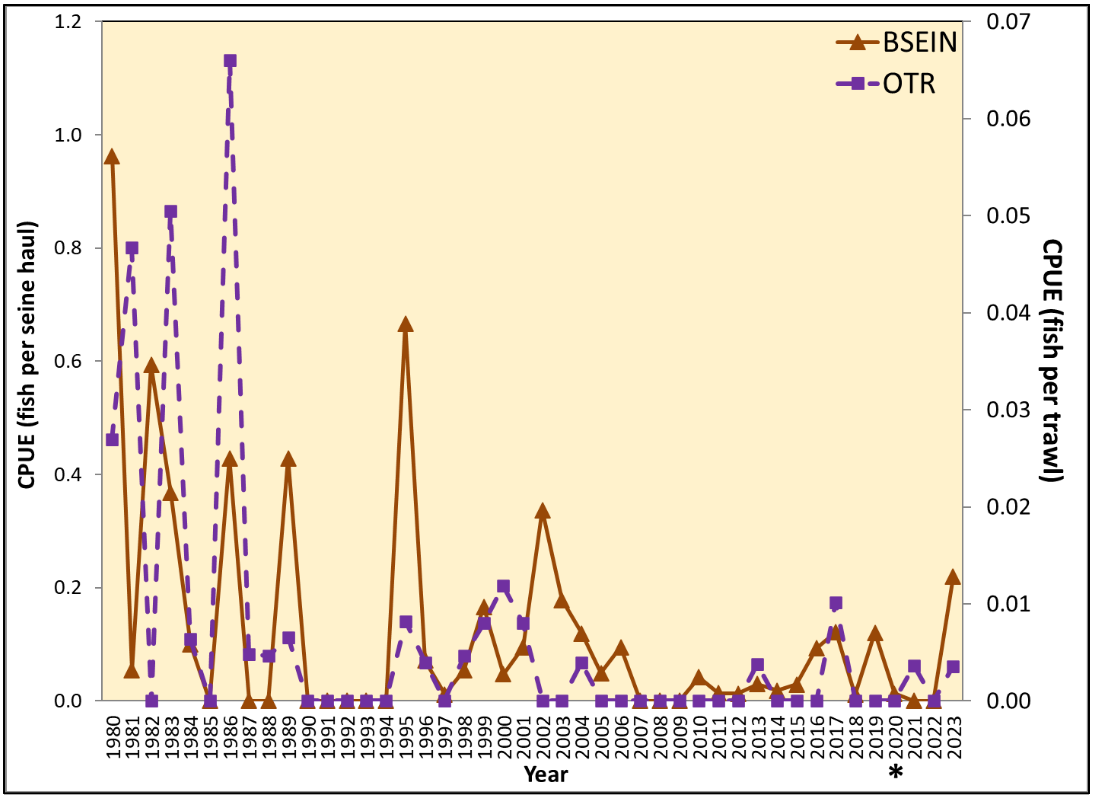

Figure 26. Annual CPUE of Chinook salmon (* = no March or April samples; codes as in Figure 21).

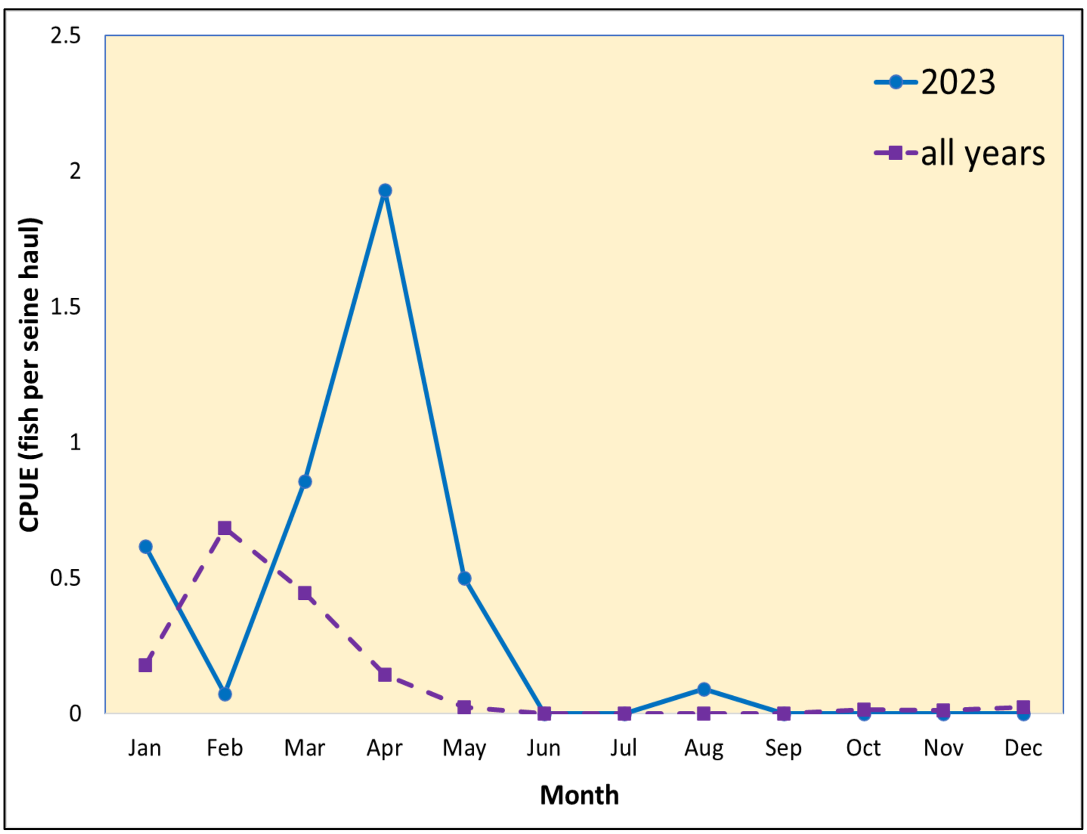

Figure 27. Monthly CPUE of Chinook salmon.

Mississippi Silverside

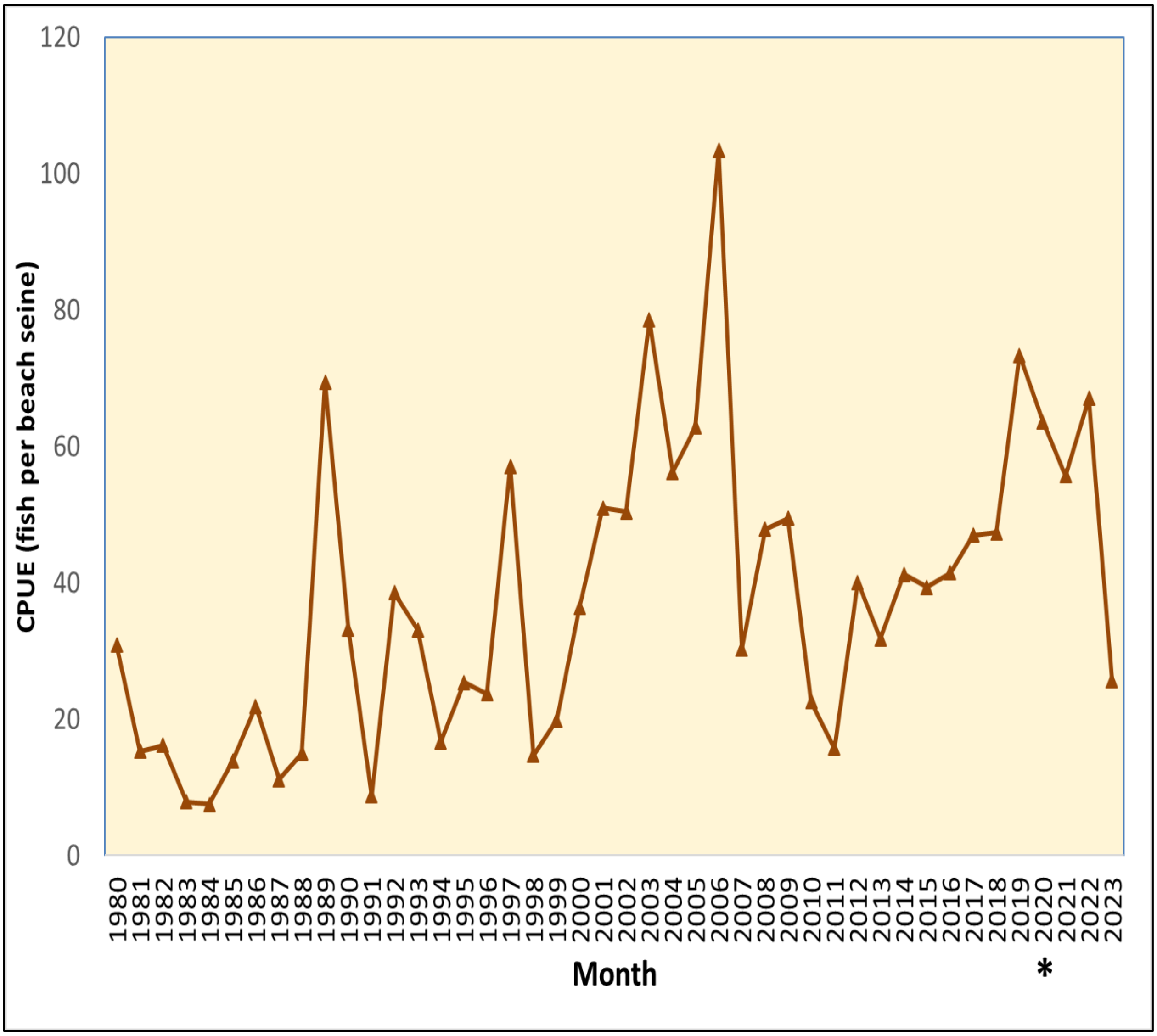

Figure 28. Annual CPUE of Mississippi silverside (* = no March or April samples).

Mississippi silverside plummeted in 2023, with the beach seine CPUE lower than values for both 2022 and the all-years average (Figure 28, Table 2). Mississippi silverside abundance had not been so low since 2011 (Figure 28). The trend in monthly abundance was fairly typical, with CPUE low in the first half of the year, peaking in August and September, at moderate levels in October and December, and anomalously low in November (Figure 29; O'Rear *et al.* 2021, 2022). A notable difference in 2023 was that catches did not begin rising substantially by July; additionally, numbers of age-0 fish first appeared in July (Figure 30), a month later than usual (*e.g.*, O'Rear *et al.* 201, O'Rear *et al.* 2023). Mississippi silverside were abundant at all four seining areas, being especially abundant in Montezuma Wetlands (74% of the year's catch; Appendix D). The patterns of Mississippi silverside in 2023 reflected delayed reproduction and reduced recruitment due to cool water (Hubbs 1982, Stoeckel and Heidinger 1988, Mahardja *et al.* 2016).

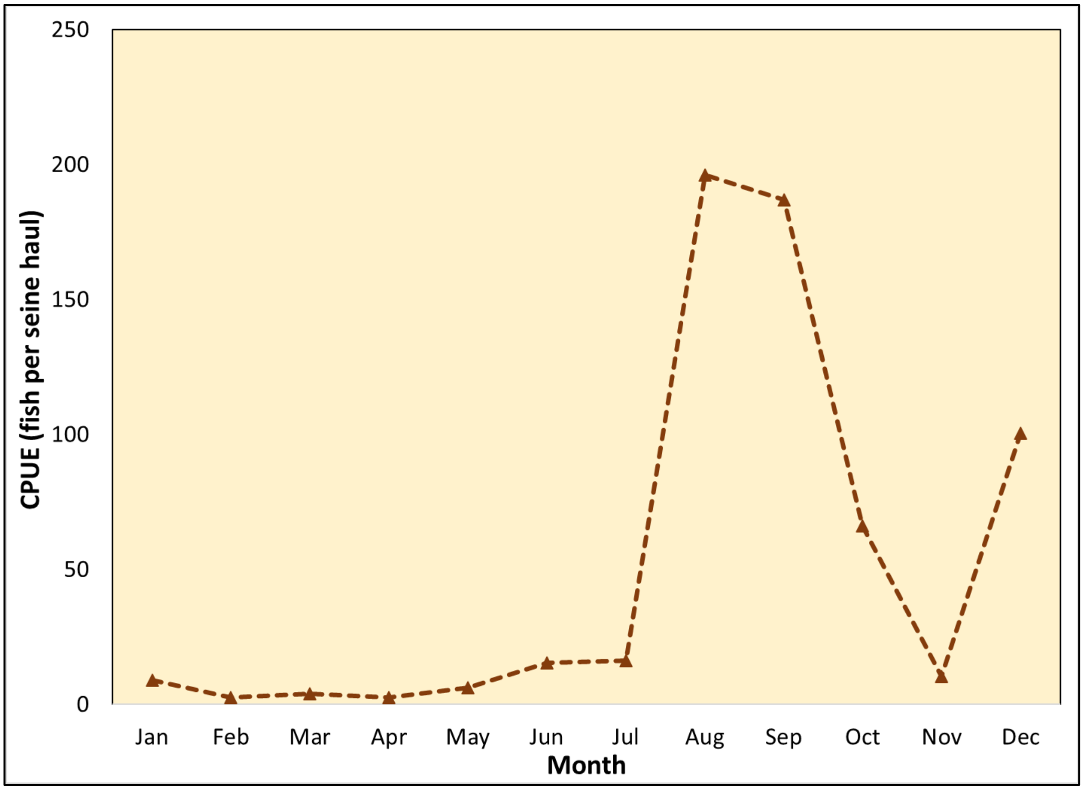

Figure 29. Monthly average CPUE of Mississippi silverside in 2023.

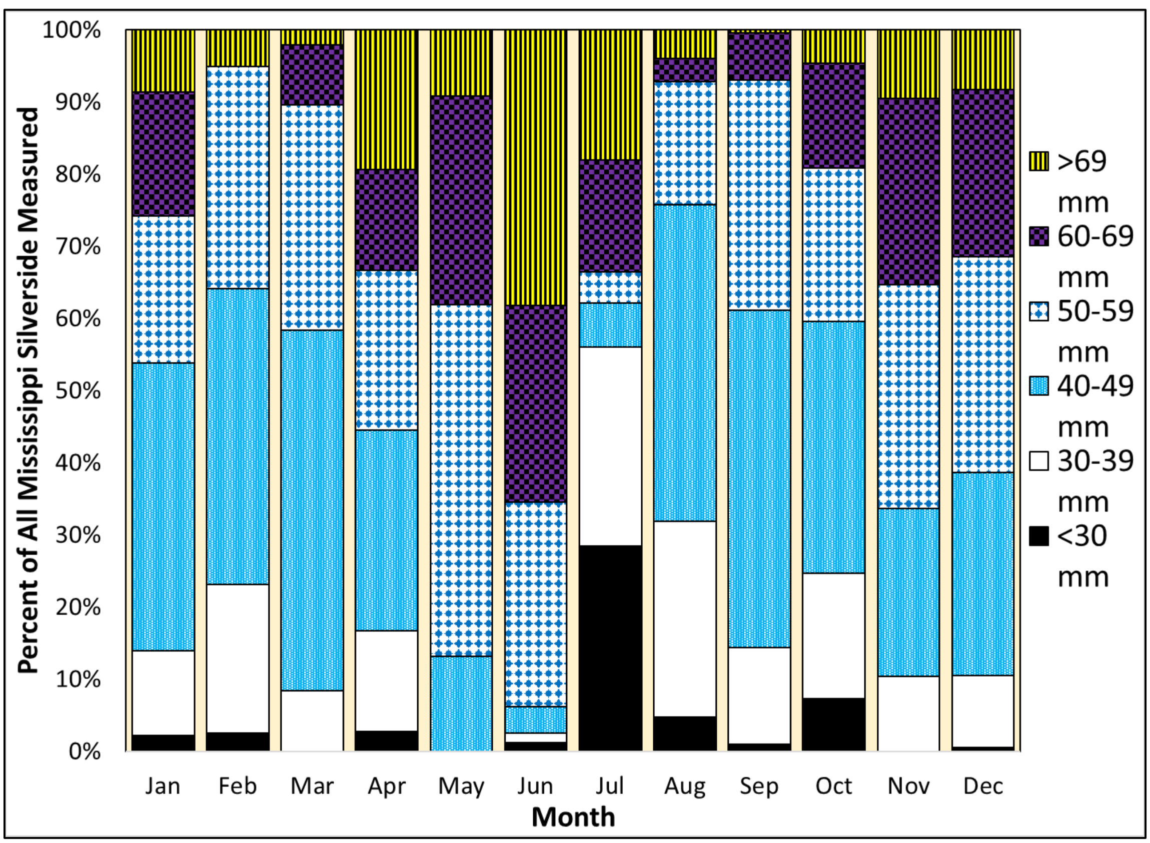

Figure 30. Monthly size-class distributions of Mississippi silverside captured in beach seines in 2023.

CONCLUSION

The three-year drought ended in 2023, with return of high outflows, substantial floodplain inundation, and lower-than-average salinities, the latter of which was extended in both space and time with operation of SMSCG during late summer and early autumn. It was, given recent trends, a surprisingly cool year, although the water was often clearer than usual even with the high outflows. Several native and non-native invertebrates were less abundant in 2023, due in part to salinities unfavorable for California bay shrimp and especially overbite clam and Black Sea jellyfish, conditions enhanced by additional operations of SMSCG. Additionally, marine fishes that appeared during the drought years vanished. In a reversal of the drought years, pelagic non-native fishes that spawn in fresh water and rear in Suisun Marsh increased: American shad, threadfin shad, and striped bass, with SMSCG operations appearing to increase recruitment for the latter two fishes. Black crappie, another non-native freshwater fish, also bumped up in 2023. In contrast, Mississippi silverside declined substantially, due in part to the cool water inhibiting reproduction. That cool water through spring allowed Chinook salmon smolts to linger far longer than usual. Age-0 splittail were extraordinarily abundant, reflecting the importance of flooding on splittail spawning, and common carp similarly increased. Few longfin smelt were captured due to high flows shifting spawning habitat downstream of the marsh. Those same flows were historically, especially when coupled with cool temperatures, favorable for Delta smelt, but even with return of such conditions coupled with summertime Suisun Marsh Salinity Control Gate operations and stocking of hatchery fish, none were caught for the eighth year in a row.

The Suisun Marsh Fish Study in many ways mirrored 2011, but - importantly - not all, reflecting the potential of the future marsh. High flows and cool temperatures still retain the ability to knock down plankton-eating non-natives, and can be enhanced through operation of the SMSCG during summer and autumn, thereby allowing more food for pelagic and anadromous fishes, such as the shads, Chinook salmon, and striped bass. Those high flows still promote warm-water fishes in Suisun Marsh, especially Sacramento splittail - Suisun Marsh remains the bastion of that species. Landscape changes in Suisun Marsh that can increase plankton food have potential to be utilized by desirable pelagic fishes, particularly in wet years. For non-pelagic desirable fishes not suffering for lack of food (*i.e.*, benthic and littoral fishes), splittail being the best example, Suisun Marsh remains a model of how a landscape in other regions of the estuary should look like. But what the high flows and cool temperatures were not able to do, even with management actions, was to increase the Delta smelt population enough to where the Suisun Marsh Fish Study could catch them; harmful effects of domestication (Lewis *et al.* 2022, LaCava *et al.* 2023) may have contributed to low spawning success and/or survival in the wild and therefore their absence in the Suisun Marsh Fish Study.

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APPENDIX A: SUISUN MARSH FISH STUDY METADATA DOCUMENT

Suisun Marsh Fish Study Database Metadata 1980 - 2020

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FIELD SAMPLING METHODS

Geographic and Temporal Scope

All sampling has occurred in Suisun Marsh (Figure A), mostly in subtidal sloughs. Sampling began in 1979, but standardized methods and stations were not implemented until 1980. Sampling has occurred monthly from January 1980 to the present at geographically fixed stations. Fixed stations have been necessary because snags preclude uninterrupted trawls in many sections of smaller sloughs. Originally, 48 stations were selected haphazardly that could be easily and safely sampled by boat and covered the breadth of Suisun Marsh to ensure capture of all variability in fish populations. However, the emphasis has been on sampling smaller sloughs because they exhibit greater variability in a smaller space than the marsh's two big sloughs (Suisun and Montezuma), and because only the big sloughs are sampled by other long-term monitoring projects such as California Fish and Wildlife's Fall Midwater Trawl. The 48 stations were sampled in 1980 and 1981. Water quality and catches were then compared across these stations to locate redundancies and thereby improve logistical efficiency while maximizing capture of variation by eliminating uninformative stations (Brown *et al*. 1981). Seventeen stations were then chosen and were continuously sampled from 1980 through 1993. Geographic scope was reassessed in 1994, when sampling was reinitiated in the northeast marsh in Denverton and Nurse sloughs at four stations (DV2, DV3, NS2, NS3; Figure B), in part to look for dwindling fish species [*e.g.*, delta smelt (*Hypomesus transpacificus*), Sacramento splittail (*Pogonichthys macrolepidotus*)]. Catches in Nurse and Denverton sloughs were found to be unique (Matern *et al.* 2002); thereafter, those four stations have been included in the regular sampling, with a total of 21 stations. In 2014, to complement continuous water-quality sampling from the salinity control gates to the very top of Denverton Slough (Montgomery *et al.* 2015), three more stations as part of the UC Davis Arc Project were added to the 21 stations, resulting in 24 stations that are currently sampled monthly (Figure B). These three additional stations (DV1, NS1, and MZ6) have also been retained because (1) they better captured gradients in water-quality conditions less discernable with the four stations (Montgomery *et al.* 2015), and (2) they surround areas slated for tidal restoration, increasing baseline information needed to assess restoration actions. Additionally, the transect from the MZ1 station in Montezuma Slough to the DV1 station also allows assessment of the extent of the impact of the salinity control gates (Beakes *et al.* 2020) in the most valuable area of the marsh for fishes (Moyle *et al.* 2014). Many other stations were sampled intermittently for small ancillary projects to the Suisun Marsh Fish Study.

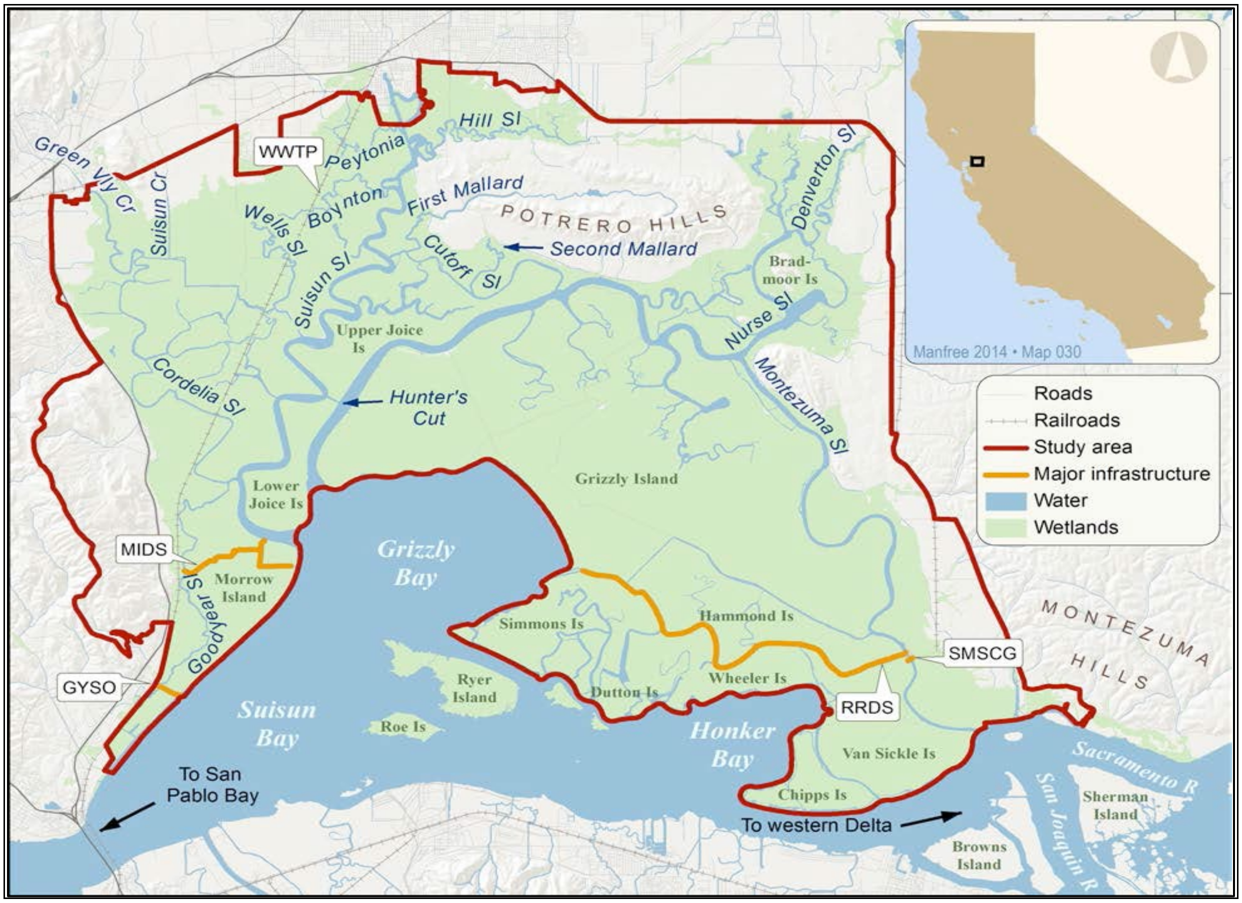

Figure A. Suisun Marsh Fish Study sampling area (map: Manfree 2014).

Two dedicated people (Table A) - the Principal Investigator and the Supervisor - have been the primary ones paid on the study, with crews filled out with part-time staff and/or volunteers, generally graduate students but also undergraduate students, agency employees, or any other person interested in Suisun Marsh. Most supervisors have been graduate students of Peter Moyle. Most crews have consisted of three people, often four, and sometimes only two if both people are well-versed in all aspects of the sampling.

Table A. Staff of the Suisun Marsh Fish Study.

Period	Principal Investigator	Supervisor
1979	Peter Moyle	Donald Baltz
1980 - 1982	Peter Moyle	Robert Daniels
1983 - 1988	Peter Moyle	Bruce Herbold
1989 - 1992	Peter Moyle	Lesa Meng
1993 - 1999	Peter Moyle	Scott Matern
2000 - 2005	Peter Moyle	Robert Schroeter/Alison Stover
2006 - 2007	Peter Moyle	John Durand/Alpa Wintzer
2008 -	John Durand/Peter Moyle	Teejay O'Rear

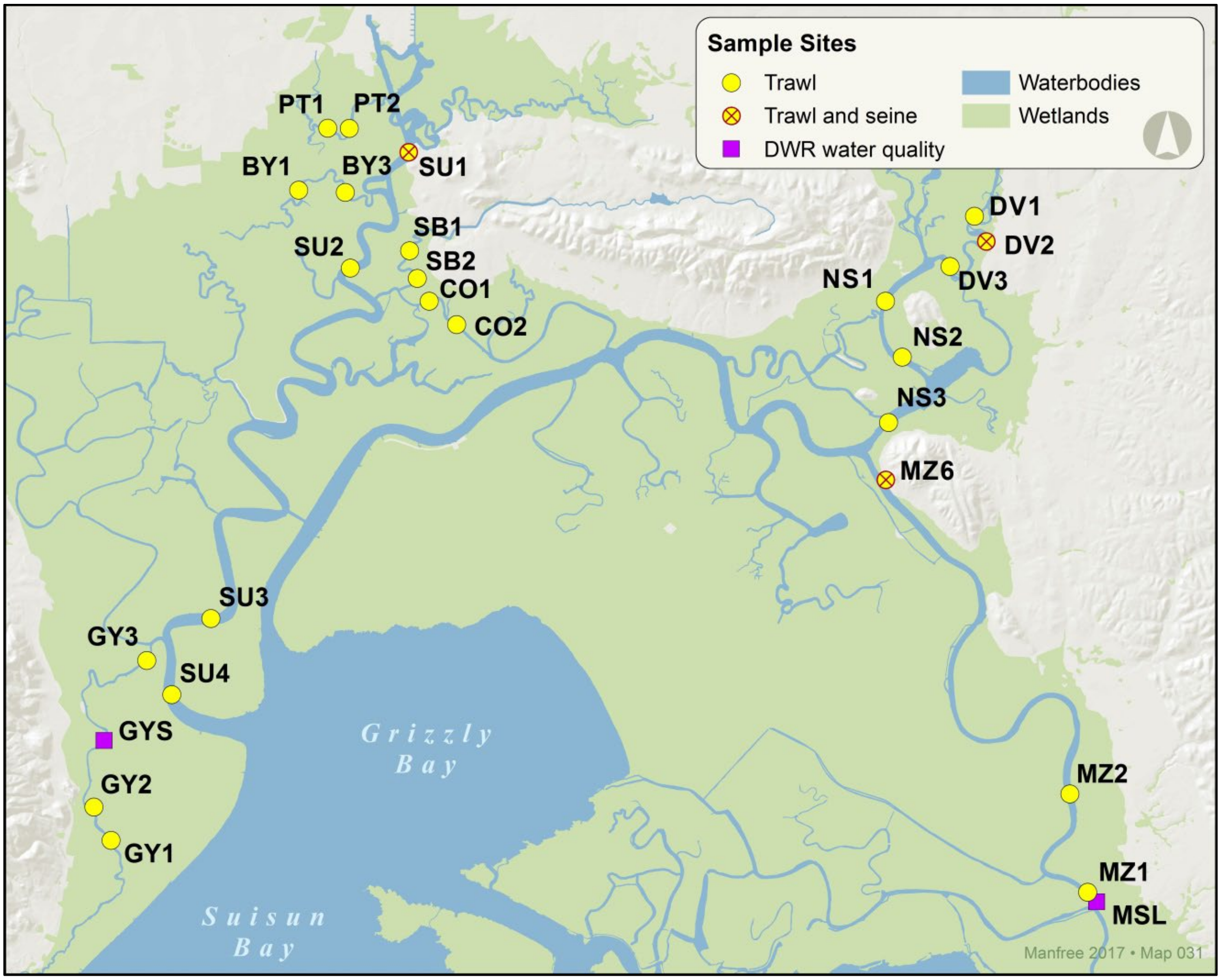

Figure B. Currently sampled sites in Suisun Marsh and California Department of Water Resources (DWR) continuous water-quality monitoring stations used for data quality control (map: Manfree 2016).

Sampling Gear

Four type of nets have been used as part of the Suisun Marsh Fish Study: otter trawls (=bottom trawl), midwater trawls, beach seines, and larval sleds (Table B). Originally, several other gear types were assessed (*e.g.*, gill nets), but otter trawls and beach seines captured the most fishes over the greatest area in the least amount of time. As a result, only otter trawls and beach seines have been used for continuous sampling – midwater trawls and larval sleds were used for smaller studies added to the Suisun Marsh Fish Study for short periods (Meng *et al.* 2001, Wintzer *et al.* 2011).

Beginning in October 2009, we began hook-and-line surveys, primarily for assessing diets of adult striped bass (*Morone saxatilis*), the apex predatory fish in Suisun Marsh. We found the hook-and-line sampling to be the most selective and least harmful among gears for the targeted species (*e.g.*, adult striped bass), as well as the most efficient for acquiring samples (*e.g.*, we have often been able to collect five fish in five minutes, equivalent to the time necessary to deploy a gill net). Hook-and-line sampling has been opportunistic, occurring when time allows between trawls and seines, usually when having to wait for an ideal tide for a sample (*e.g.,* mid-flood tide at the SU1 seine beach; Figure A).

Table B. Dimensions and specifications of nets used in the Suisun Marsh Fish Study.

Gear	Type	Physical Width (m)	Fishing width (m)	Height (m)	Length (m)	Diameter (m)	Main-body mesh (mm)	Main-body mesh type	Cod-end mesh (mm)	Cod-end mesh type	Main Supplier
beach seine	bagless, knotless	10	N/A	1.8	N/A	N/A	4.8	delta	N/A	N/A	Memphis Net
midwater trawl	four-seam	4.3	N/A	1.5	5.3	N/A	15.9	square	3.2	delta	Brunson Net
otter trawl	four-seam	4.3	3.9	1.5	5.3	N/A	15.9	square	3.2	delta	Brunson Net
larval sled	circular	N/A	N/A	N/A	3	0.68	0.5	square	N/A	N/A	N/A

Gear Deployment and Operation

Beach Seine

Two types of beach-seining techniques are used in Suisun Marsh: parallel beach seines ("P-seines") and "J-seines." P-seines are when the seine net remains parallel to shore during retrieval. J-seines are when the net remains perpendicular to shore during retrieval until being swept in during landing. J-seines are useful where the width of the landing beach is small. Procedures for fishing both seine types are similar:

1. One person for a J-seine, two people for a P-seine, wade from shore into deepest water possible without overtopping waders.
2. When seine is stretched out and tight (perpendicular to shore for J-seine, parallel to shore for P-seine), depths are recorded.
3. The two people pulling the seine walk the same speed, brails tipped back so lead line sweeps through sampling area before head rope.
4. Just before beaching the seine, the two people pulling the seines overlap the lead lines to create a bag, then haul it out of the water.
5. Fish are then quickly concentrated in the center of the net and then rolled out into a bucket of water.

Midwater Trawl (currently inactive method)

The midwater trawl's net and hardware were identical to the otter trawl's (Table A) but with one exception: two wood runners were mounted to the top of the trawl doors to act as hydrofoils that caused the trawl to plane up into the water column. Midwater trawls were deployed into the water by hand and towed for five minutes at 8 km/hr. At five minutes, the boat was stopped and the trawl retrieved by hand. All material captured by the trawl was then emptied into a bucket of water.

Otter Trawl

Otter-trawl operation is similar to that for midwater trawls. The otter trawl is deployed by hand into the water, with a mainline measuring more than three times the depth to ensure the trawl remains on the bottom. Trawls are towed at 4 km/hr for five minutes in small sloughs and 10 minutes in large sloughs [tow times for the two slough sizes were determined from species-accumulation curves (Moyle, unpublished data)]. As for the midwater trawl, when the time is up, the boat is stopped, the trawl retrieved by hand, and all material captured by the trawl is emptied into a bucket of water.

Larval Sled (currently inactive method)

The larval sled was towed at the water's surface by means of a "horizontal chassis with runners" (Meng *et al.* 2001). The sled was deployed by hand and towed for either five or 10 minutes at 4 km/hr. At the end of the tow, the larval sled was retrieved by hand, and larval fishes were placed into containers and preserved with a 5% formaldehyde solution.

Hook and Line

Hook-and-line sampling occurs opportunistically between trawl and seine samples. A large tub of water equipped with aerators and shade cloth is prepared before sampling commences. A habitat type is selected (*e.g.*, managed-wetland outflow, subtidal-channel confluence), and lines are cast by appropriately sized gear (*e.g.*, relatively large rods for striped bass) into the habitat for a fixed period, usually with artificial lures but occasionally with live bait on barbless and/or circle hooks. Hooked fish are brought to the boat as quickly as possible, with hook removal occurring under water, either in the waterway itself or in the aerated tub, to minimize air exposure. Only "legal adult" size - 18 inches total length (TL; 46 cm) - striped bass are retained.

Sample Processing

<u>Water Quality and Depth Data</u>

Several water-quality constituents and depths are recorded, but, as for invertebrates (described below), not all recordings began at the same time (Table C). Water quality has been measured mainly with Yellow Springs Instrument (YSI) handheld devices (YSI 30, YSI 85, and PRO2030), calibrated according to directions supplied by YSI. Currently, probes are refurbished about every six months. The probe is placed ~30 cm below the water surface until readings stabilize, and then values are written down on the sheet with the catch data. Secchi readings are taken by slowly lowering a 20-cm-diameter Secchi disk on the shaded side of the boat until the disk can no longer be seen by the naked eye. Depths are recorded from a depth-finder (currently a Humminbird Helix 9) during each otter trawl, once a minute for five-minute trawls, once every two minutes for 10-minute trawls. Tide stage – high, low, incoming, outgoing – are also noted on data sheets.

Salinity and conductivity measurements have had some discrepancies over the study's history. Prior to March 1997, all conductivity readings for otter trawls and beach seines were electrical conductivity; thereafter, all have been specific conductivity. The instruments and therefore the conductivity-salinity relationships were not very precise from the study's inception through 1995; thereafter, improvements in instruments resulted in much higher precision and tighter relationships between salinity and conductivity.

Table C. Starting recording years for abiotic parameters.

Parameter	First Year of Consistent Records
water temperature	1980
salinity	1980
Secchi depth	1980
dissolved-oxygen concentration	2000
dissolved-oxygen saturation	2000
depths	2002
tide	1995

Net Surveys

For larval-fish tows, fish were taken back to the lab and identified according to Wang (1986).

Material captured by the beach seine and the otter/midwater trawls is processed in the field and recorded on water-resistant paper. Fishes are identified according to Moyle (2002) and Wang (1986), measured for standard length, and then released back to the area of capture. If more than 30 individuals of a fish species are captured in a sample and the individuals to be measured are pulled from the bucket without regard to size, only the first 30 individuals are measured for length – the remainder are only counted, not measured. (Thirty individuals of a species per sample has been sufficient to reflect the abundance of size ranges and thus age classes, rendering measuring more than 30 individuals unnecessary and not an effective use of time.) In most cases, the approximate size range or age class of the unmeasured fish has been noted on the data sheets. In cases where individuals from a certain species cannot be randomly selected for measurement (*i.e.*, large-bodied fishes with multiple age classes abundant in Suisun Marsh: Sacramento splittail, striped bass, white catfish, common carp), all fish of that species are measured. (This most commonly occurs with Sacramento splittail – frequently the larger, older fish are on top and block the smaller, younger fish, so the larger fish have to be removed before the smaller fish can even be accessed.) Occasionally, very small post-larval fish – mainly gobies and herrings – are iced, taken to the lab, and identified under a dissecting microscope, again following Wang (1986).

Invertebrates are assessed in two ways. Larger invertebrates – clams, shrimps, crayfish, jellyfish, and crabs - are identified following Carlton (2007) and Pennak (2001) and then counted. However, identifying and counting all species of large invertebrates in otter trawls and beach seines did not begin at the same time (Table D). For smaller invertebrates – mysids, gammaroid amphipods, corophiid amphipods, isopods, and insects – a ranking is given rather than a count because counting each individual, when there can often be thousands, is a time sink, and our ranking system corresponds favorably with more detailed assessments (Meng *et al.* 1994, Feyrer *et al.* 2003, Schroeter 2008). Small invertebrates are only ranked in trawls and not in beach seines because tides do not allow enough time to assign an accurate rank for seines. Similar to larger invertebrates, ranks for smaller invertebrates did not begin to be recorded at the same time for all groups (Table E). As of April 2023, only mysids had been entered into the database.

Beginning in April 2014, type and estimated volume of non-animal material has been recorded (*e.g.*, mud, detritus from emergent-aquatic and terrestrial plants, aquatic weeds, wood).

Table D. Records for large invertebrates for otter trawl and beach seines.

Species (common name)	Species (Latin name)	First Year of Consistent Records in Trawls	First Year of Consistent Records in Seines
Black Sea jellyfish	*Maeotias marginata*	1981	2008
overbite clam	*Potamocorbula amurensis*	1986	2008
Asian clam	*Corbicula fluminea*	2006	2008
Siberian prawn	*Palaemon modestus*	2002	2008
California bay shrimp	*Crangon franciscorum*	1980	2008
Oriental shrimp	*Palaemon macrodactylus*	1980	2008
red swamp crayfish	*Procambarus clarkii*	2017	2013
soft-shell clam	*Macoma petalum*	2011	2011

Table E. Records for small invertebrates for otter trawl.

Group (common name)	Latin name	First Year of Consistent Records in Trawls
opossum shrimp	Mysida	1980
scuds	Gammaroidea	2014
scuds	Corophioidea	2014
pillbugs	Isopoda	2014
aquatic insects	Insecta	2014

Hook and Line Surveys

All fishes other than adult striped bass are immediately measured and released. When water temperature exceeds 18°C, striped bass longer than 66 cm TL are measured immediately and released, to minimize mortality. Similarly, any adult striped bass behaving as if severely stressed or injured (*e.g.*, bleeding, inability to maintain upright posture, lethargic) or hooked in the throat or gills (a rarity with the artificial lures) is either immediately released or killed and dissected for gut contents. Striped bass destined for gut-pumping are given at least 10 minutes to recuperate in the shade-cloth-covered, aerated tub. No more than five striped bass are kept in the tub.

When sufficiently recovered from the capture, striped bass are gut-pumped for diet items. A fish is selected, carefully and quickly removed from the water with wet hands, a deck-hose-powered copper tube with a silicone sheath on the tip is gently inserted into the fish's gut, and the pump is then turned on for 10 seconds, with the gut contents washed onto rectangular D-net. Two people are generally needed to support fish larger than 63 cm TL during the procedure. Most fish are then quickly submerged back into the waterway, head facing into current, held by the tail with one hand and supported by the belly with the other hand. Once the fish begins to swim vigorously, it is released. A small subset of fish is killed to verify complete flushing of gut contents by the gut pump; if possible, these fish are also sexed. Rarely a fish is killed that clearly has a diet item that cannot be removed by the gut pump, typically large crawdads or large spiny-rayed fishes (*e.g.*, striped bass).

Gut contents are immediately identified to the lowest-possible taxonomic level and, if a fish, measured for standard length. Decapods were measured for rostrum-telson length from October 2009 to November 2019 but thereafter for carapace length, to be comparable to a companion study in the North Delta (the Arc Project; Durand *et al.* 2020). (All rostrum-telson lengths should be converted to carapace lengths by 2024.) Severely digested fish and invertebrates are only counted. Numbers of smaller invertebrates eaten (*e.g.*, amphipods, isopods, mysids) are also only counted. If five fish are captured during one sample and the first three gut-pumped have very similar diets, the remaining two fish are only measured and returned to the waterway because we found early in the study that the information gained from gut-pumping the remaining two fish was negligible and thus not worth either the additional stress for the fish or the time spent processing the diet items (*e.g.*, a GY1 sample in January 2021 where fish #1 had eaten 42 threespine sticklebacks, fish#2 had eaten 33 threespine sticklebacks, and fish#3 had eaten 18 sticklebacks, with the sticklebacks from each fish being in the same size range; subsequently, a fourth fish was just measured and released). Only the first 15 individuals of a species is measured for standard length, with the remainder counted, to account for time constraints. All diet items are returned to the water.

Diets of striped bass were first recorded in October 2009. Data for hook-and-line sites that were sampled but yielded no fish were first recorded in April 2015. Until October 2017, striped bass smaller than 46 cm TL were not measured; thereafter, all striped bass regardless of size captured by hook-and-line were measured, but only adult-sized fish were gut-pumped.

DATABASE METHODS

Data Entry

Sampling most commonly occurs Monday – Thursday, with data entered into a Microsoft Access database the following Monday. During data entry, any unusual values are compared to values collected by other studies and, if the Suisun Marsh Fish Study's values are deemed inaccurate, are then corrected accordingly. For example, in July 2019, water temperature recorded by a YSI PRO2030 seemed unusually high for Suisun Marsh. The fish study's values were then compared to values recorded by continuous water-quality stations maintained by the California Department of Water Resources (DWR) and located at our sampling stations. The fish study's values were found to be 1.65ºC higher than the DWR stations. Further comparisons in lab with another PRO2030 as well as a YSI EXO sonde also showed the same difference in temperature. Therefore, 1.65ºC was deducted from each water temperature reading taken in July 2019 before data entry. Such adjustments are noted on the Excel spreadsheet used for the annual reports (described below). Once all data for the month have been entered, it is noted in the database name: "SuisunMarshFishYYYY_MM_DD_YY.accdb," where YYYY = the last year either new tables/complex queries were added, and MM_DD_YY = the last time data were entered/altered.

Data Storage

The Suisun Marsh Fish Study uses the principle of having data stored on several media types and in several locations. Data exist in three formats: on hardcopy data sheets, the Access database, and Excel spreadsheets, the latter of which are created each year to support annual reports (example: https://watershed.ucdavis.edu/library/suisun-marsh-fish-study-trends-fish-and-invertebrate-populations-suisun-marsh-january-2017). Original hard-copy data sheets are stored in binders in Room 1336 of the Academic Surge building on the UC Davis campus. Copies of hard-copy data sheets from 1999 to the present are stored in binders in Room 2101 of the Center for Watershed Sciences building. The database is stored in several areas: (1) the hard drive of a desktop computer in Room 2101; (2) an external hard drive in Room 2101; (3) on Google Drive; (4) an off-campus laptop; and (5) a continually maintained server in the Center for Watershed Sciences building. Excel spreadsheets for each year's reports are stored on the external hard drive and the off-campus laptop.

Database Quality Control

Database quality control occurs in three steps:

1. **Database Versus Hardcopy Datasheets.** The week after sampling, every record on the hard-copy data sheets for that week is compared to the database's data in the data-entry tables. Once a sample's data in the database matches the hard-copy data sheet perfectly, a box is checked that allows that sample's data to be transferred to the "permanent tables" where they are available for pre-written queries and data analysis.

2. **Accuracy of Data Transferred from Database to Flat File.** Once the week's data have been checked against the hard-copy data sheets and transferred to permanent tables, they are then copied into an Excel spreadsheet and then scanned for any unusual numbers for all organisms (*e.g.*, a Mississippi silverside measuring 500 mm standard length, a dissolved-oxygen concentration measuring 20 mg/L) and for all water-quality measurements. Plots are created for each water-quality parameter, and, where appropriate, regressions are created to identify errors. Suspect values are then double-checked both against the database and hard-copy data sheets, and, if consistent with the database and the hard-copy data sheet, are then compared to similar data taken by other studies (described next).

3. **Data Comparison to Other Data Sources.** Similar to the example described above in *Data Entry*, several water-quality values are compared to continuous water-quality stations (maintained by DWR and the Natural Estuarine Research Reserve System) that overlap the fish study's stations. Comparisons between data from DWR stations (Figure 2) and data from the fish study have been plotted and promulgated via the annual reports since 2013 (*e.g.*, Figure 5 and 8 of the report found here: https://watershed.ucdavis.edu/library/suisun-marsh-fish-study-trends-fish-and-invertebrate-populations-suisun-marsh-january-2013).

Concurrent with evaluating data quality after completion of the sampling year is updating this metadata document to report any changes to the study, which is noted in the file name by the years covered.

Data Accessibility/Promulgation

Once the data have gone through the three steps of quality control, they are then deemed appropriate for distribution. The data can be accessed through myriad routes: (1) the database can be attained by contacting the fish study's supervisor (currently Teejay O'Rear; taorear@ucdavis.edu; 530-304-0860) and also through the fish study's website on the Center for Watershed Sciences' website (https://watershed.ucdavis.edu/project/suisun-marsh-fish-study); (2) data can be directly plotted and downloaded onto a flat file at https://ucdstripedbassproject.shinyapps.io/IntegratedVisualizer/; and (3) station information can be found on the California Department of Fish and Wildlife website (https://map.dfg.ca.gov/metadata/ds1964.html).

Database Components

Database Tables

This section gives a brief description of the Access database's commonly used tables and thus also descriptions of data in flat files (*e.g.*, .csv, .xlsx) derived from the database.

AgesBySizeMonth

Age classification determined by size at time of capture; based on Manfree (2014*a*).

Catch

This table contains the organism (whether fish, shrimp, clam, detritus, etc) captured, the length (if a fish), the number caught at that size, and several other data types that are rarely, if ever, measured. Key is that these are quality-controlled data - they've been checked for accuracy against the hard-copy datasheets.

Column	Description	Units
OrganismCode	organism shorthand; code definitions in OrganismLookUp table	N/A
StandardLength	fish length from tip of jaw to end of vertebral column	millimeters
Dead	if fish captured was live or dead (rarely used)	N/A
Weight	mass (rarely used)	grams
Sex	male or female (rarely used)	N/A
Count	catch	number of individuals or rank (for smaller invertebrates such as mysids)
CatchComments	comments for specific organims	N/A
Volume	self-explanatory	milliliters
AgeClassforUnmeasuredFish	age class for unmeasured fish based on Manfree (2014)	N/A

Catch_Entry

This table contains the same data as the Catch table, but none of these data have been checked against the hard-copy datasheets.

Depth

These are the depths for the otter trawl; like the Catch/Catch_Entry tables, there's a Depth_Entry table that contains entered but not QC'd depths. Depth units are in meters.

GearDetailsLookUp

Contains records for measurements of our different sampling gear such as the otter trawl and larval sled (Table 2).

MethodsLookUp

Contains the sampling-method types, the corresponding codes, and whether that method type is currently active.

MethodCode	MethodName
BSEIN	beach seine
HKLN	hook and line
MWTR	midwater trawl
OTR	otter trawl
SLED	larval sled

OrganismsLookUp

This table contains the codes and all taxonomic information for any organism we may catch.

Predator

This table contains all information accompanying the capture of a fish with hook-and-line.

Column	Description	Units
FishNum	number of individuals of a species captured at that size	number of individuals
TL_in	fish length from tip of jaw to end of caudal fin tip	inches
Pumped	whether fish was gut-pumped	N/A
Dissected	whether fish was dissected for gut contents	N/A
TimeLanded	time fish was captured	hh:mm

Column	Description	Units
LureBaitSize	size of hook-and-line gear used	N/A
LureBaitCode	type of lure/bait used in sample	N/A
WaterSurface	water-surface condition when fish was captured	N/A
Weather	weather conditions when fish was captured	N/A
Tide	tide stage when fish was captured	N/A
Habitat	habitat type where fish was hooked	N/A
Angler	initials of person who caught the fish	N/A
Killed?	whether fish was killed for gut contents	N/A

Sample

This table contains the QC'd water-quality data, as well as the sample type, the date/time the sample was taken; the Sample_Entry table contains non-QC'd data.

Column	Description	Units
MethodCode	sample-type shorthand; codes in MethodsLookUp table	N/A
StationCode	station shorthand; codes in StationsLookUp table	N/A
SampleDate	self-explanatory	mm/dd/yyyy
SampleTime	self-explanatory	hh:mm:ss AM/PM
QADone	denotes whether data have been checked against hard-copy data sheet	N/A
GearID	basically equivalent to MethodCode; unused	N/A
WaterTemperature	measured ~30 cm below water surface	degrees Celsius
Salinity	measured ~30 cm below water surface	parts per thousand
DO	dissolved-oxygen concentration; measured ~30 cm below water surface	milligrams per liter
PctSaturation	DO percent saturation; measured ~30 cm below water surface	percent
Secchi	water clarity	centimeters
SpecificCond	measured ~30 cm below water surface	microSiemens
TideCode	tide phase at time of sampling (flood, ebb, high, low)	N/A
UserName	person who entered data	N/A
ElecCond	measured ~30 cm below water surface	microSiemens

Prey Table

This table contains the diet items of fish captured by hook-and-line and then gut-pumped and/or dissected for stomach contents.

Column	Description	Units
FoodCode	prey-ID shorthand; code definitions in OrganismLookUp table	N/A
PreyNum	number of individuals for given prey type	number of individuals
StdLen	fish length from tip of jaw to end of vertebral column; for decapods, rostrum-telson length	millimeters

Column	Description	Units
Comments	comments specific to prey type in same row	N/A

SeineEffort

This table contains the depths, seine types, lengths, and widths of the beach seines; all measurements in meters.

SledEffort

Contains the distances the larval sleds were towed as recorded by a General Oceanics mechanical flowmeter.

StationsLookUp

Contains codes and descriptions of sample stations.

TransferLog

Records when data were moved from the Xxxx_Entry tables to the Xxxx (*i.e.*, "permanent") tables.

Trawl Effort

Contains duration of midwater and otter trawls (in minutes) and distances covered (mainly for midwater trawls), as measured by the same flowmeter used for larval sleds.

UnitsLookUp

Provides information on what unit each data number is in.

VariableCodesLookUp

Contains additional descriptors of each sample, such as tide type and beach-seine type.

VariablesLookUp

Explains many of the codes we use.

Database Queries

Catch Zero+

Combines data from Catch, Sample, TrawlEffort, and a depth query to relate all organisms to water-quality data, effort, and average depths. Includes zeroes for each species not caught in a sample. Note that for fish, fish of same species and length for a sample are summed in the "Count" column.

Catch Zero+ AgeClass

Same as Catch Zero+ query but also includes age class for each fish record.

Catch Zero+ AgeClass Expansion

Same as CatchZero+ AgeClass query but creates a field for each fish caught. For example, in the Catch Zero+ query, if three striped bass measuring 50 mm standard length are caught in the same trawl, all three striped bass are collapsed into one record, with the number of fish denoted in the "Count" column – in this case, three. In the Catch Zero+ AgeClass Expansion query, however, all three striped bass measuring 50 mm caught in the same trawl are each given their own unique record, so that there are three records, each with a value of 1 in the "Count" column. Note that this does not apply to invertebrates.

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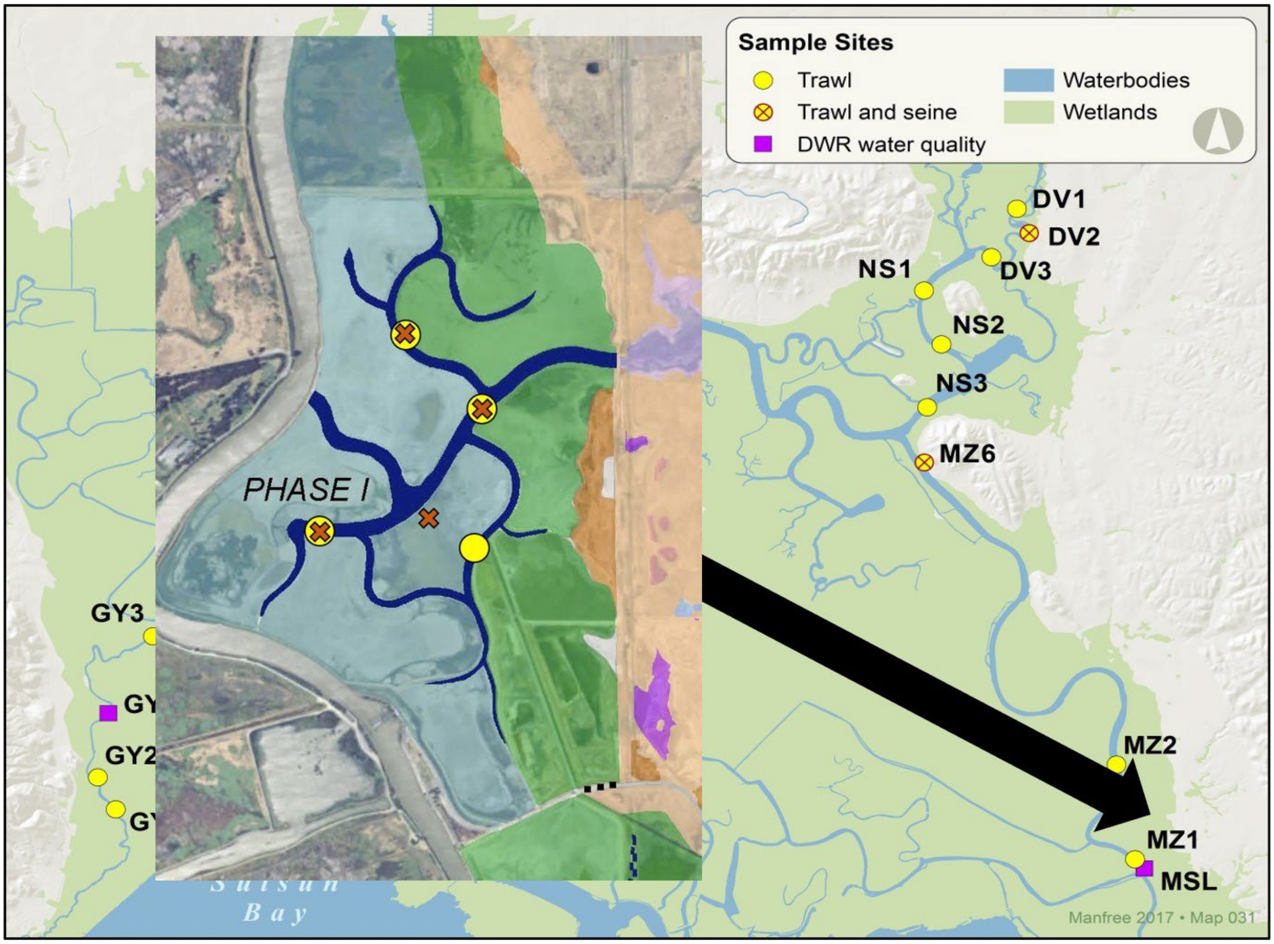
APPENDIX B: MONTEZUMA WETLANDS SAMPLING SITES



APPENDIX C: FISH CATCHES FOR ENTIRE STUDY PERIOD

Total number of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all three methods from 1979 to 2023 (native species in bold).

Common Name	Scientific Name	Beach Seine	Otter Trawl	Midwater Trawl	Total
Mississippi silverside	*Menidia audens*	157244	2066	0	159310
striped bass	*Morone saxatilis*	17801	101555	30	119386
Sacramento splittail	***Pogonichthys macrolepidotus***	**8011**	**45777**	**14**	**53802**
yellowfin goby	*Acanthogobius flavimanus*	20328	22781	0	43109
threespine stickleback	***Gasterosteus aculeatus***	**12204**	**18658**	**6**	**30868**
tule perch	***Hysterocarpus traski***	**2941**	**24470**	**6**	**27417**
shimofuri goby	*Tridentiger bifasciatus*	3356	13371	1	16728
prickly sculpin	***Cottus asper***	**1677**	**13578**	**1**	**15256**
threadfin shad	*Dorosoma petenense*	9144	5541	1	14686
longfin smelt	***Spirinchus thaleichthys***	**54**	**13395**	**5**	**13454**
common carp	*Cyprinus carpio*	689	6205	1	6895
white catfish	*Ameiurus catus*	173	6402	13	6588
staghorn sculpin	***Leptocottus armatus***	**3706**	**2787**	**0**	**6493**
Sacramento sucker	***Catostomus occidentalis***	**139**	**3691**	**5**	**3835**
western mosquitofish	*Gambusia affinis*	3695	21	0	3716
black crappie	*Pomoxis nigromaculatus*	301	3013	1	3315
shokihaze goby	*Tridentiger barbatus*	24	3093	6	3123
American shad	*Alosa sapidissima*	513	2508	0	3021
starry flounder	***Platichthys stellatus***	**357**	**2551**	**4**	**2912**
black bullhead	*Ameiurus melas*	3	888	0	891
delta smelt	***Hypomesus transpacificus***	**144**	**665**	**4**	**813**
rainwater killifish	*Lucania parva*	748	59	0	807
Sacramento pikeminnow	***Ptychocheilus grandis***	**459**	**239**	**0**	**698**
Pacific herring	***Clupea harengeus***	**132**	**503**	**0**	**635**
Chinook salmon	***Oncorhynchus tshawytscha***	**487**	**84**	**1**	**572**
goldfish	*Carassius auratus*	71	326	0	397
northern anchovy	***Engraulis mordax***	**0**	**340**	**37**	**377**
channel catfish	*Ictalurus punctatus*	11	210	0	221
hitch	***Lavinia exilicauda***	**16**	**144**	**0**	**160**
Sacramento blackfish	***Orthodon macrolepidotus***	**117**	**27**	**0**	**144**
white sturgeon	***Acipenser transmontanus***	**0**	**133**	**2**	**135**
white crappie	*Pomoxis annularis*	0	112	0	112
fathead minnow	*Pimephales promelas*	39	37	0	76
arrow goby	***Clevelandia ios***	**0**	**60**	**0**	**60**
bluegill	*Lepomis macrochirus*	25	31	0	56
Pacific lamprey	***Lampetra tridentata***	**0**	**49**	**0**	**49**
bigscale logperch	*Percina macrolepida*	26	21	0	47
wakasagi	*Hypomesus nipponensis*	14	22	0	36

Common Name	Scientific Name	Beach Seine	Otter Trawl	Midwater Trawl	Total
brown bullhead	*Ameiurus nebulosus*	0	35	0	35
golden shiner	*Notemigonus crysoleucas*	16	13	0	29
plainfin midshipman	***Porichthys notatus***	**0**	**29**	**0**	**29**
jacksmelt	***Atherinopsis californiensis***	**21**	**0**	**0**	**21**
shiner perch	***Cymatogaster aggregata***	**0**	**17**	**0**	**17**
rainbow trout	***Oncorhynchus mykiss***	**6**	**9**	**0**	**15**
California halibut	***Paralichthys californicus***	**3**	**11**	**0**	**14**
bay pipefish	***Sygnathus leptorhynchus***	**6**	**6**	**0**	**12**
green sunfish	*Lepomis cyanellus*	3	5	0	8
redear sunfish	*Lepomis microlophus*	2	6	0	8
hardhead	*Mylopharadon conocephalus*	5	2	0	7
largemouth bass	*Micropterus salmoides*	7	0	0	7
surf smelt	***Hypomesus pretiosus***	**0**	**5**	**0**	**5**
Pacific sanddab	***Citharichthys sordidas***	**2**	**2**	**0**	**4**
river lamprey	***Lampetra ayresi***	**0**	**4**	**0**	**4**
speckled sanddab	***Citharichthys stigmaeus***	**0**	**4**	**0**	**4**
green sturgeon	***Acipenser medirostris***	**0**	**3**	**0**	**3**
white croaker	***Genyonemus lineatus***	**0**	**3**	**0**	**3**
longjaw mudsucker	***Gillichthys mirabilis***	**0**	**1**	**0**	**1**
striped mullet	***Mugil cephalus***	**1**	**0**	**0**	**1**
warmouth	*Lepomis gulosus*	0	1	0	1
Total		244721	295569	138	540428

APPENDIX D: 2023 FISH CATCHES

Total 2023 otter-trawl catch of each fish species in each slough of Suisun Marsh (native species in bold; all codes as in Figure 23).

Species	Slough												Total
	BY	CO	DV	FM	GY	MW	MZ	MZN	NS	PT	SUL	SUU	
Sacramento splittail	**188**	**110**	**323**	**367**	**396**	**87**	**161**	**1**	**26**	**109**	**61**	**18**	**1847**
striped bass	93	82	254	120	230	67	198	38	80	117	382	49	1710
threadfin shad	23		224	72		29	64		3	12	8	1	436
tule perch	**83**	**28**	**72**	**32**	**76**	**6**	**30**	**2**	**19**	**63**	**1**	**4**	**416**
common carp	4	10	250	8	32	13			12	12	1	2	344
shimofuri goby	14	71	12	5	53	31	9	13	59	19	5	45	336
prickly sculpin	**21**	**52**	**5**	**14**	**49**	**2**	**12**	**3**	**29**	**18**	**14**	**69**	**288**
yellowfin goby	14	14	7	23	52	2	17	10	19	13	75	31	277
starry flounder		**13**	**5**	**9**	**18**	**2**	**26**	**53**	**19**	**3**	**43**	**25**	**216**
Mississippi silverside			90	77	5			1		3			176
black crappie	2		147				1		3	1			154
American shad	2	4	17		10	63	38	1	2	2	7		146
threespine stickleback	**5**	**3**	**1**	**3**	**88**	**2**	**4**	**1**		**2**	**8**	**6**	**123**
shokihaze goby	2	1					5	6	16		3	46	79
Sacramento sucker	**4**	**6**	**3**	**6**	**13**					**4**	**1**		**37**
Sacramento pikeminnow	**5**			**4**	**10**	**9**	**7**			**1**	**1**		**37**
staghorn sculpin	**1**	**2**		**2**	**11**	**1**	**1**	**2**			**7**	**4**	**31**
longfin smelt	**2**				**2**		**3**	**2**	**2**		**7**	**2**	**20**
white catfish			11				7						18
rainwater killifish			1			8	4			1	4		18
bluegill			4	1									5
Chinook salmon						**3**	**1**						**4**
redear sunfish			1				1		2				4
white sturgeon												3	**3**
hitch						2							**2**
wakasagi			1										1
black bullhead												1	1
bigscale logperch						1							1
fathead minnow	1												1
hardhead							**1**						**1**
Total	464	396	1428	743	1045	328	590	133	291	380	628	306	6732

Total 2023 beach seine catch of each fish species in Denverton, Montezuma, and upper Suisun sloughs, and Montezuma Wetlands (native species are in bold).

Species	Slough				Total
	Denverton	Montezuma Wetlands	Montezuma at Nurse	Suisun, upper	
Mississippi silverside	1355	6003	382	362	8102
Sacramento splittail	**253**	**294**	**275**	**20**	**842**
threadfin shad	230	60	188	38	516
striped bass	165	59	101	181	506
yellowfin goby	61	21	175	227	484
rainwater killifish	20	243	11	3	277
threespine stickleback	**15**	**195**	**14**	**15**	**239**
western mosquitofish		186	2	2	190
Sacramento pikeminnow	**8**	**63**	**35**	**1**	**107**
tule perch	**74**	**9**	**9**	**5**	**97**
staghorn sculpin	**15**	**2**	**51**	**20**	**88**
prickly sculpin	**36**	**14**	**1**	**3**	**54**
Chinook salmon	**2**	**35**	**16**		**53**
common carp	20	12	4	1	37
starry flounder	**11**		**15**	**7**	**33**
shimofuri goby	14	9	4	1	28
black crappie	10				10
hardhead		**4**	**1**		**5**
Sacramento sucker			2		**2**
American shad		1	1		2
Pacific herring	**2**				**2**
bluegill	2				2
bigscale logperch	1		1		2
golden shiner	1				1
largemouth bass			1		1
redear sunfish	1				1
wakasagi		1			1
Total	2296	7211	1289	886	11682

APPENDIX E: 2023 EFFORT

Number of otter trawls in each slough and each month in 2023.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	2	2	2	2	2	2	2	2	2	2	24
Cutoff	2	2	2	2	2	2	2	2	2	2	2	2	24
Denverton	3	3	3	3	4	3	3	3	3	3	3	3	37
First Mallard	2	2	2	2	3	2	2	2	2	2	2	2	25
Goodyear	3	3	3	3	3	3	3	3	3	3	3	3	36
Montezuma	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma at Nurse	1	1	1	1	1	1	1	1	1	1	1	1	12
Montezuma Wetlands	4	4	4	4	4	4	4	4	4	4	4	4	48
Nurse	3	3	3	3	3	3	3	3	3	3	3	3	36
Peytonia	2	2	1	2	2	2	2	2	2	2	2	2	23
Suisun, lower	2	2	2	2	2	2	2	2	2	2	2	2	24
Suisun, upper	2	2	2	2	3	2	2	2	2	3	2	2	26
Total	28	28	27	28	31	28	28	28	28	29	28	28	339

Number of beach seines in each slough and each month in 2023.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	3	3	3	3	2	2	2	2	2	2	2	29
Montezuma at Nurse	2	3	3	3	3	2	2	3	2	2	2	2	29
Montezuma Wetlands	6	6	6	6	6	6	5	4	4	4	5	5	63
Suisun, upper	2	2	2	2	2	2	2	2	2	2	2	2	24
Total	13	14	14	14	14	12	11	11	10	10	11	11	145

APPENDIX F: DATABASE QUERYING CODE

Water Quality

```
SELECT Sample.StationCode, Sample.SampleDate, Format([SampleDate],"yyyy") AS [Year],
Format([SampleDate],"mm") AS [Month], Sample.SampleTime, Sample.MethodCode,
Sample.WaterTemperature, Sample.Salinity, Sample.SpecificConductance, Sample.Secchi,
Sample.DO, Sample.PctSaturation, TrawlEffort.TowDuration
FROM Sample LEFT JOIN TrawlEffort ON Sample.SampleRowID =
TrawlEffort.SampleRowID
WHERE (((Sample.SampleDate)>#1/1/2023# And (Sample.SampleDate)<#12/31/2023#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```

```
SELECT Sample.StationCode, Sample.SampleDate, Format([SampleDate],"yyyy") AS [Year],
Format([SampleDate],"mm") AS [Month], Sample.SampleTime, Sample.MethodCode,
Sample.WaterTemperature, Sample.Salinity, Sample.SpecificConductance, Sample.Secchi,
Sample.DO, Sample.PctSaturation
FROM Sample
WHERE (((Sample.SampleDate)>#12/31/1979# And (Sample.SampleDate)<#1/1/2024#) AND
((Sample.MethodCode)="otr"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```

Organisms

```
SELECT Sample.StationCode, Sample.SampleDate, Format([SampleDate],"yyyy") AS Year,
Format([SampleDate],"mm") AS Month, Sample.SampleTime, Sample.MethodCode,
Catch.OrganismCode, Catch.Count, Catch.StandardLength, Sample.WaterTemperature,
Sample.Salinity, Sample.SpecificConductance, Sample.Secchi, Sample.DO,
Sample.PctSaturation, OrganismsLookUp.Phylum, OrganismsLookUp.Class,
OrganismsLookUp.Order, OrganismsLookUp.Native
FROM OrganismsLookUp INNER JOIN (Sample INNER JOIN Catch ON
Sample.SampleRowID = Catch.SampleRowID) ON OrganismsLookUp.OrganismCode =
Catch.OrganismCode
WHERE (((Sample.SampleDate)>#1/1/2023# And (Sample.SampleDate)<#12/31/2023#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```