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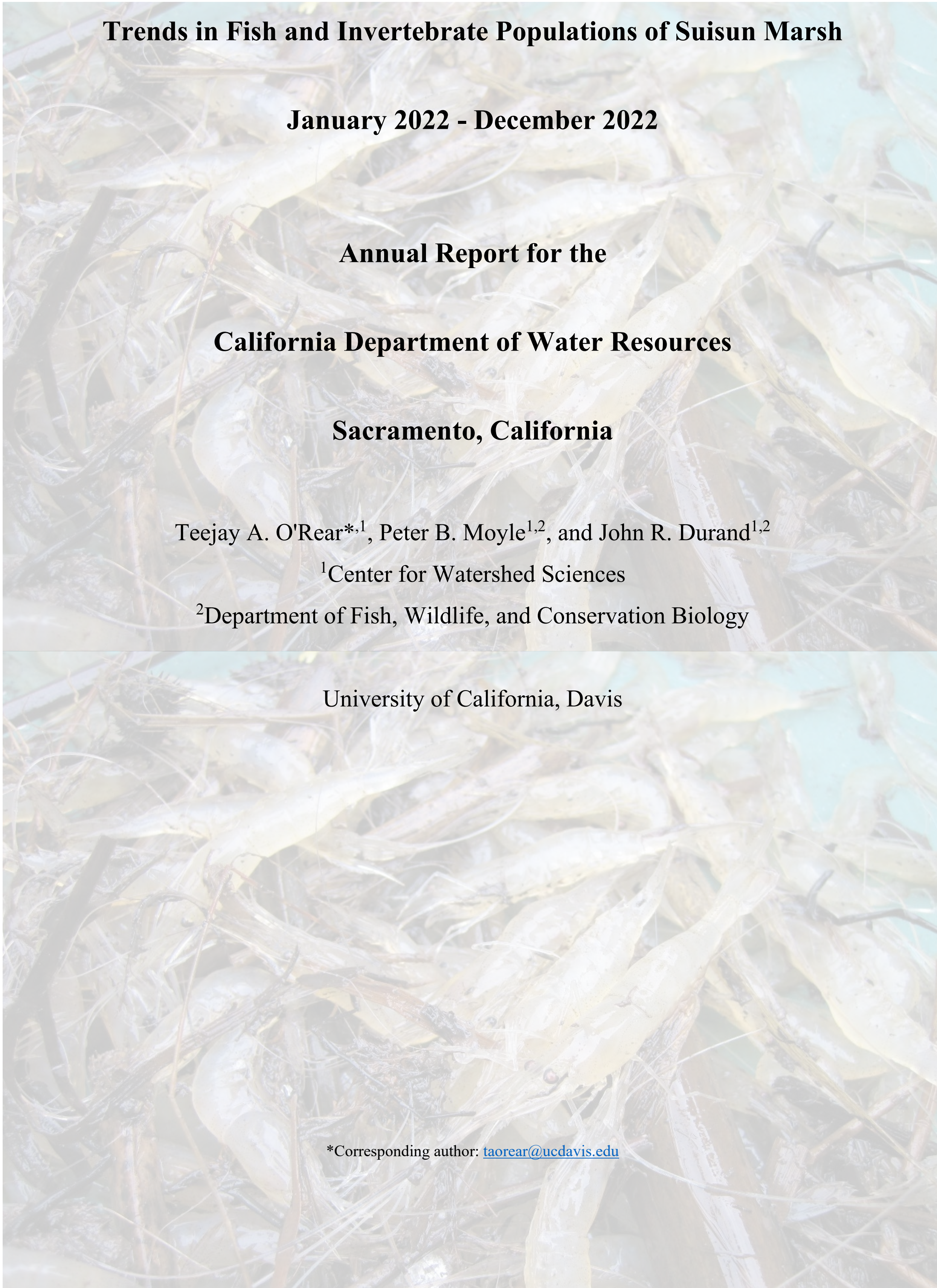

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2022 - December 2022

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.

Calendar-year 2022 extended a drought beginning in 2020. Delta outflow was lower than average for nearly the entire year (and accompanied by little floodplain inundation), resulting in higher-than-average salinities within Suisun Marsh. The water was often warmer and clearer than usual in 2022. Dissolved-oxygen concentrations were sufficient for all marsh fishes, becoming stressful only for adult striped bass (*Morone saxatilis*) in one isolated reach of a small slough during a few warmer months.

Catches in 2022 reflected the warm, dry, salty year, while also highlighting the sensitivity of the aquatic community to outflow and salinity. Clams and shrimps were both abundant, with elevated salinities favorable for California bay shrimp (*Crangon franciscorum*) and overbite clam (*Potamocorbula amurensis*) but not high enough to affect numbers of Siberian prawn (*Palaemon modestus*), which reached its highest-ever abundance in 2022. Recruitment was poor for fishes that spawn in fresher waters upstream of Suisun Marsh: American shad (*Alosa sapidissima*), threadfin shad (*Dorosoma petenense*), Sacramento splittail (*Pogonichthys macrolepidotus*), and striped bass. While numbers of age-0 splittail were low, older age classes were very abundant. For the third consecutive year, age-0 longfin smelt (*Spirinchus thaleichthys*) numbers were high in spring but dwindled to zero during summer, consistent with the fish being a cool-water species that migrates to San Francisco Bay and the ocean. Although native marine fishes were again present in 2022, they were not as abundant as in 2021 when April and summer outflows were slightly lower. Instead, non-native gobies and the non-native Mississippi silverside (*Menidia audens*) increased in abundance during 2022. In sum, the catches in 2022 reflected the nuanced association between outflow (and thus salinity) and the entire aquatic community, and reinforced the importance of Suisun Marsh for Sacramento splittail and juvenile longfin smelt. The year also highlighted that Suisun Marsh can provide a sanctuary for fishes when other areas of the estuary suffer from red tides or toxic conditions, as occurred in San Francisco Bay during summer.

TABLE OF CONTENTS

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 (*Oncorhynchus tshawytscha*; 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 the 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);
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 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). 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. 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). Further, 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 2022 with average conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2022 to annual averages, noting abundance changes between 2021 and 2022; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2022, 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).

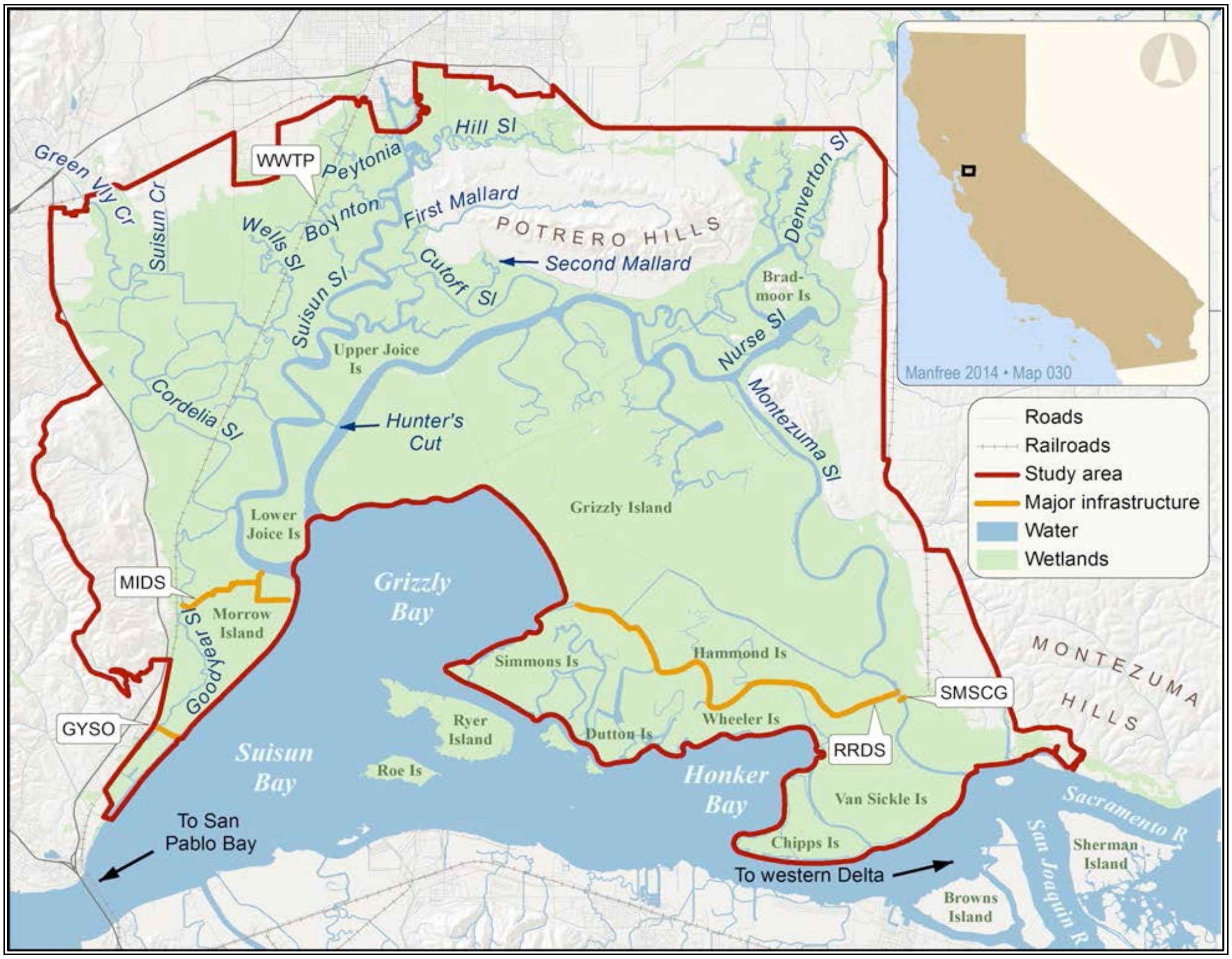

Figure 1. Suisun Marsh study area ["GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point 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 the marsh 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). 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. 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), for pelagic fishes, 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 the non-native overbite clam 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 originally 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 zooplankton concentrations (Montgomery *et al*. 2015), especially in wet years (O'Rear *et al.* 2021). 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 2022, with those data included in monthly and slough-to-slough comparisons. Sampling in September 2022 was limited to only a few seines due to personnel emergencies. Influence of the loss of September samples on annual comparisons was likely minimal for most species given that abundances during that month are usually average between August and October (O'Rear and Moyle 2008, Baumsteiger *et al.* 2017, Colombano *et al.* 2020); notable exceptions are discussed below.

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. For each site, 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 macroinvertebrate 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 shrimp species, 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.

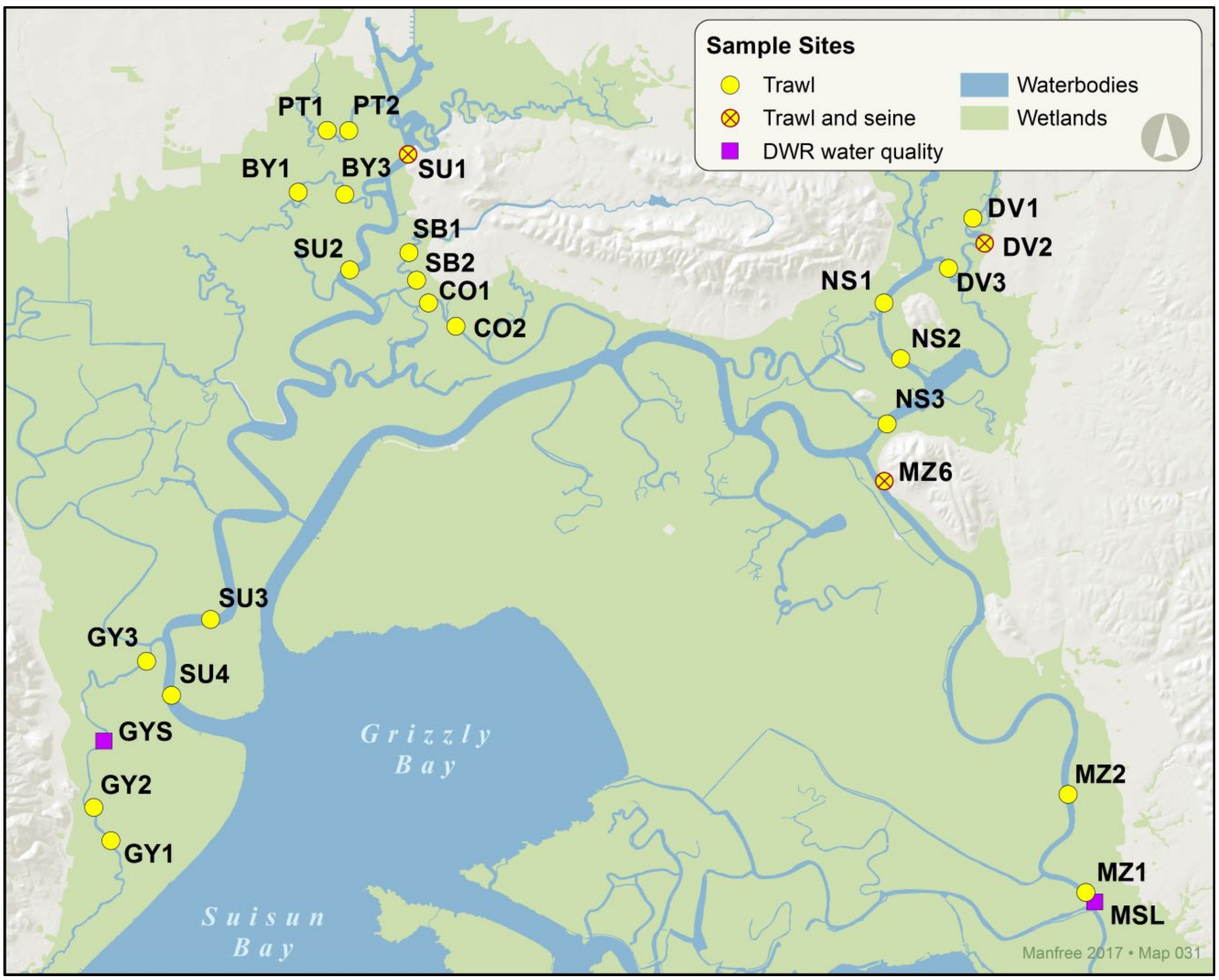

Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report [map by Manfree (2017)].

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 April, adults were considered fish larger than 423 mm SL, and all others were classified as "juveniles." To describe geographic distribution, the proportion of the 2022 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 2022 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 the DWR (DWR 2023).

Monthly water-quality results of 2022 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 2022 is found in Appendix C; annual catch of each slough and number of trawls/seines in each slough (including Montezuma Wetlands) in 2022 are found in Appendix D and E. Code used for querying the database is found in Appendix F.

RESULTS AND DISCUSSION

Abiotic Conditions

Hydrology and Delta Outflow

Calendar-year 2022 extended the latest drought to three years, with outflow considerably below the average for the study period (1980 - 2022; Figure 3) except for a few short periods in autumn. Outflow was low and relatively stable from late January through October, although higher in April, June, and July compared to 2021 (Figure 3). A few storms elevated outflow for short periods in November and December. While Yolo Bypass did not flood in 2022, the Cosumnes River floodplain did for several weeks spanning late April and early May, providing a spawning opportunity for Sacramento splittail (Sommer *et al.* 1997, Moyle *et al.* 2004; Feyrer *et al.* 2006; DWR 2023*a*).

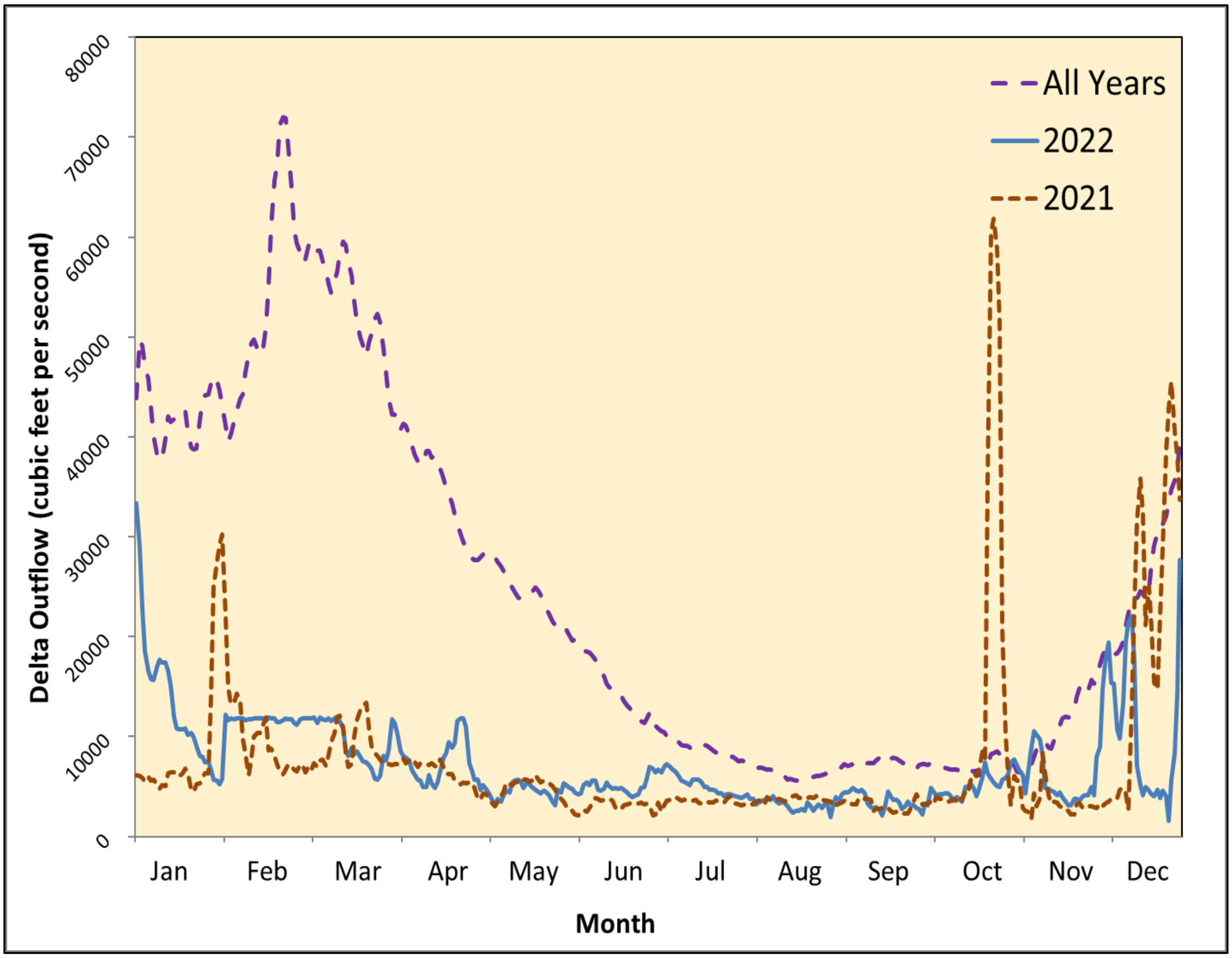

Figure 3. Daily Delta outflow in 2021, 2022, and the average for all years of the study (1980 – 2022; DWR 2023).

Salinity

The low outflows in 2022 translated to a salty year in Suisun Marsh, with an annual average salinity (5.9 ppt) higher than usual (4.1 ppt for 1980 - 2022; Figure 4) but lower than in 2021 (6.7 ppt; O'Rear *et al.* 2022). Monthly average salinity was above average in every month but January (Figure 4), increasing at a greater-than-average rate from June through August, then falling thereafter with commencement of Suisun Marsh Salinity Control Gates operations (DWR 2023). 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 given the preponderance of sites in the marsh's eastern and northern sections (Figure 5). Because of low outflows, the Suisun Marsh Salinity Control Gates were run in all months except in January and the summer months; they were closed in August for maintenance (Figure 4). A range of salinities existed in Suisun Marsh during all months in 2022 (Figure 4). Highest salinities were always recorded in the southwest marsh close to Grizzly Bay in either Goodyear or lower Suisun Slough (with the year's highest salinity, 14.2 ppt, occurring in lower Suisun Slough in October). The freshest water was either in upper Boynton Slough, near the wastewater-treatment-plant discharge point, or in eastern Montezuma Slough, at sites closest to the Delta.

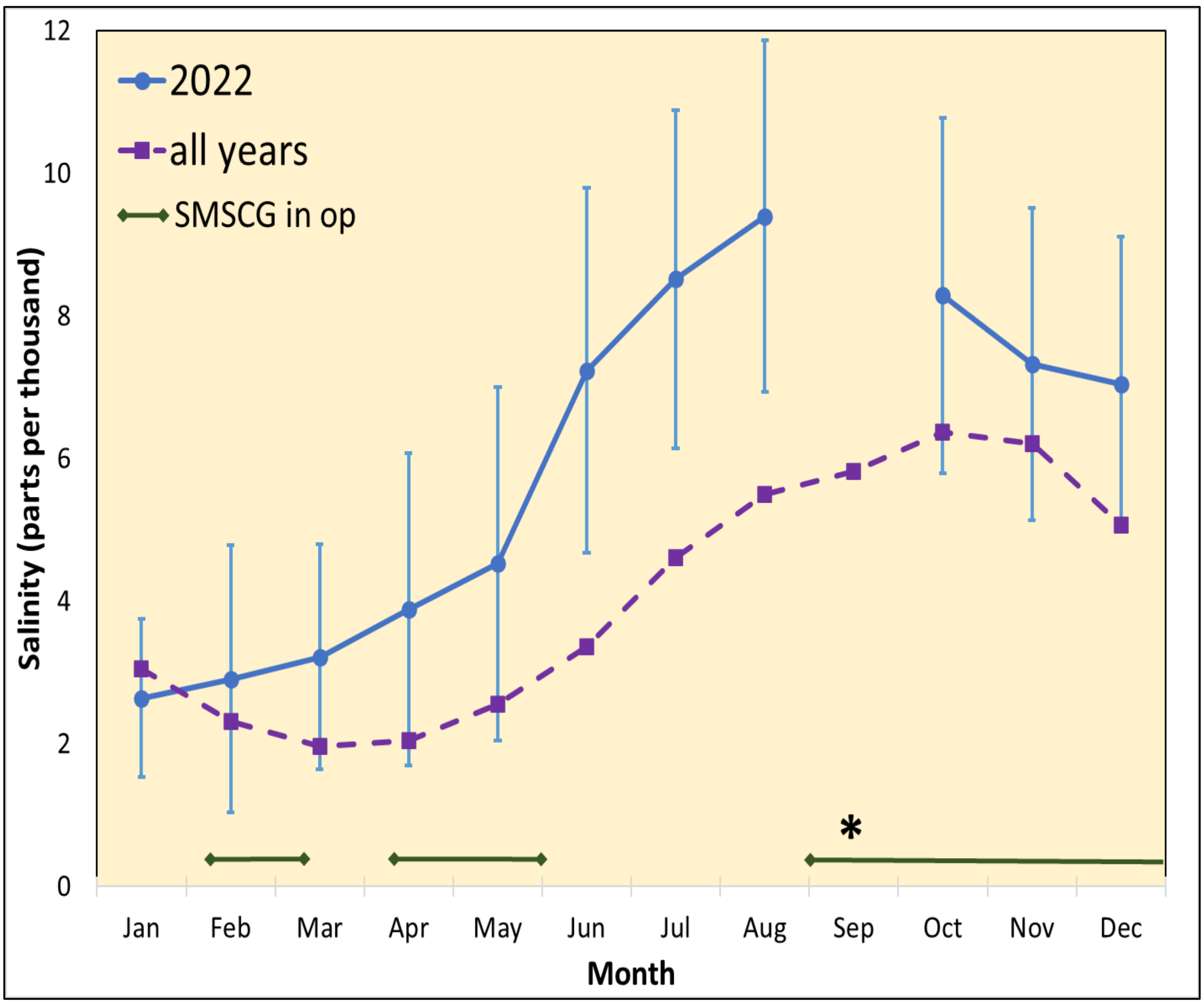

Figure 4. Monthly average salinity in 2022 and for all years of the study (1980 - 2022); error bars are standard deviations in 2022. Olive bars show when the SMSCG were operating in 2022 (* = no September 2022 samples).

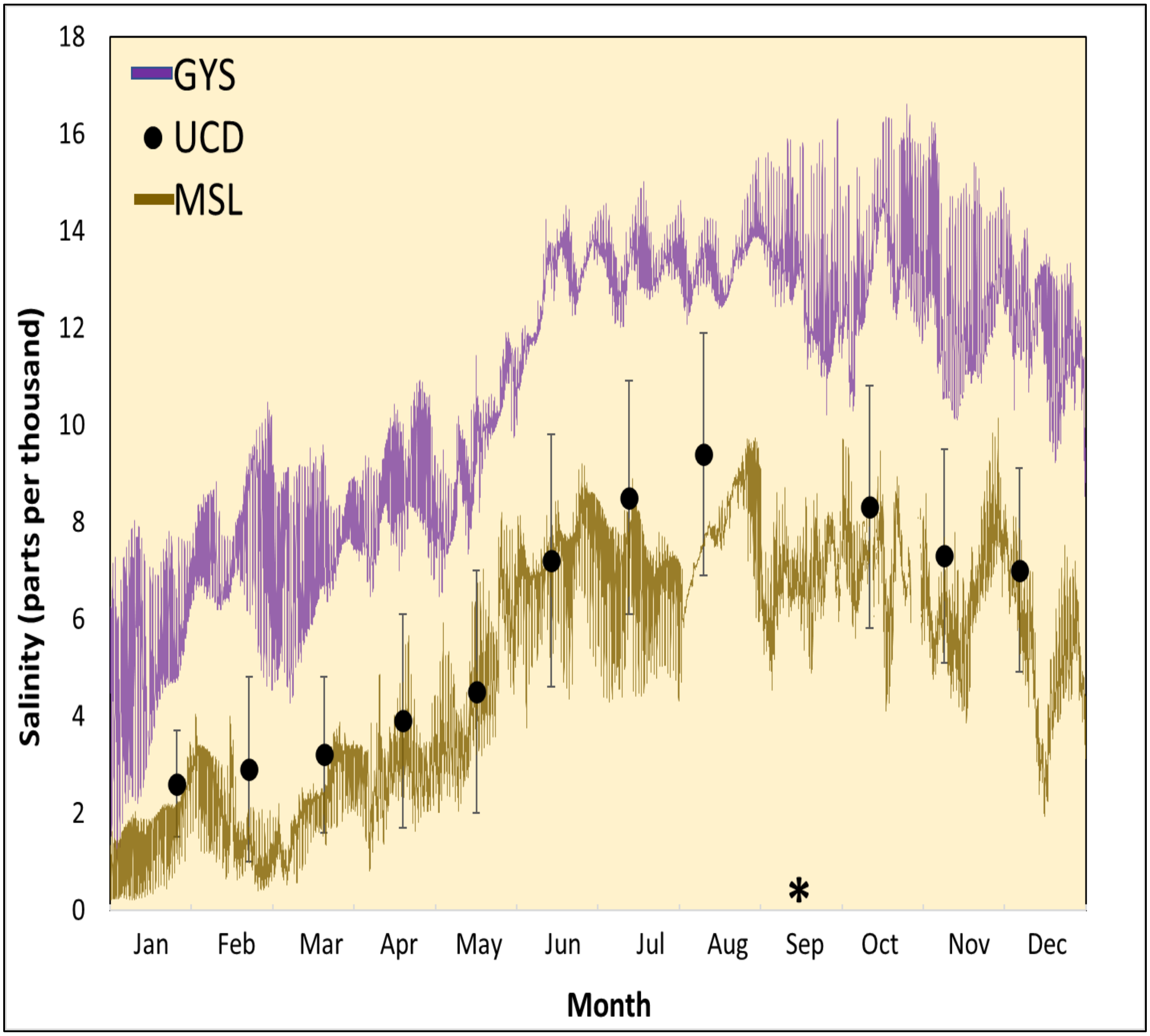

Figure 5. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations of the Suisun Marsh Fish Study ("UCD ") during 2022 (* = no September 2022 samples for Suisun Marsh Fish Study).

Dissolved Oxygen (DO)

Oxygen levels throughout Suisun Marsh in 2022 were nearly always hospitable for all fishes (>5 mg/L; Moyle 2002). Average monthly DO concentrations exhibited a mild decline from January through August, with values close to the long-term average, and then rising with cooling water through the year's last three months (Figure 6). Trends in minimum and maximum monthly DO concentrations were quite similar. The lowest monthly DO concentration occurred six times in upper Goodyear Slough, twice in Boynton Slough, twice in First Mallard Slough, and once in Denverton Slough - all small, dead-end sloughs. Highest monthly concentrations were in eastern Montezuma Slough/Wetlands through most of the year (nine of 11 months). Never did DO fall below 3 mg/L, a critical value for tule perch (Cech, Jr. *et al*. 1990).

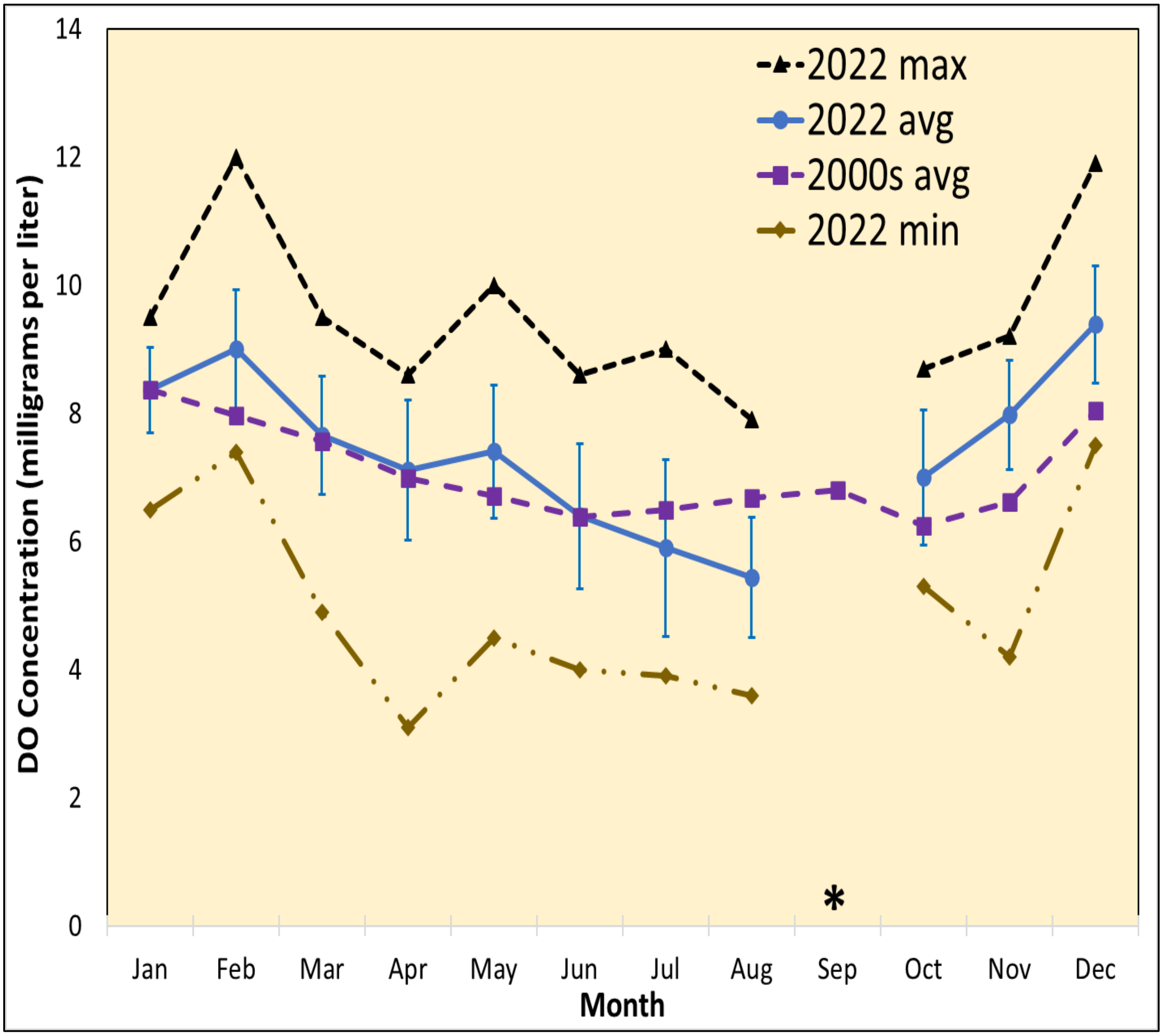

Figure 6. Monthly average DO concentration in 2022 and for the 2000s (2000 - 2022), maximum DO concentration in 2022, and minimum DO concentration in 2022. Error bars are standard deviations in 2022 (* = no September 2022 samples).

Water Temperature

Overall, 2022 was a warm year [High Plains Regional Climate Center (HPRCC) 2023]. Measurements from the fish study generally agreed, with January, March, and October notably warmer than usual (Figure 7). However, some mismatches occurred, with sampling days occurring during short cool periods in February and April (Figure 7 and 8), months which otherwise were quite warm (HPRCC 2023). 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 8). Fish-study values reflected this pattern, with most-extreme temperatures in small sloughs (23.7°C in First Mallard in June, and 8.9°C in Denverton in December).

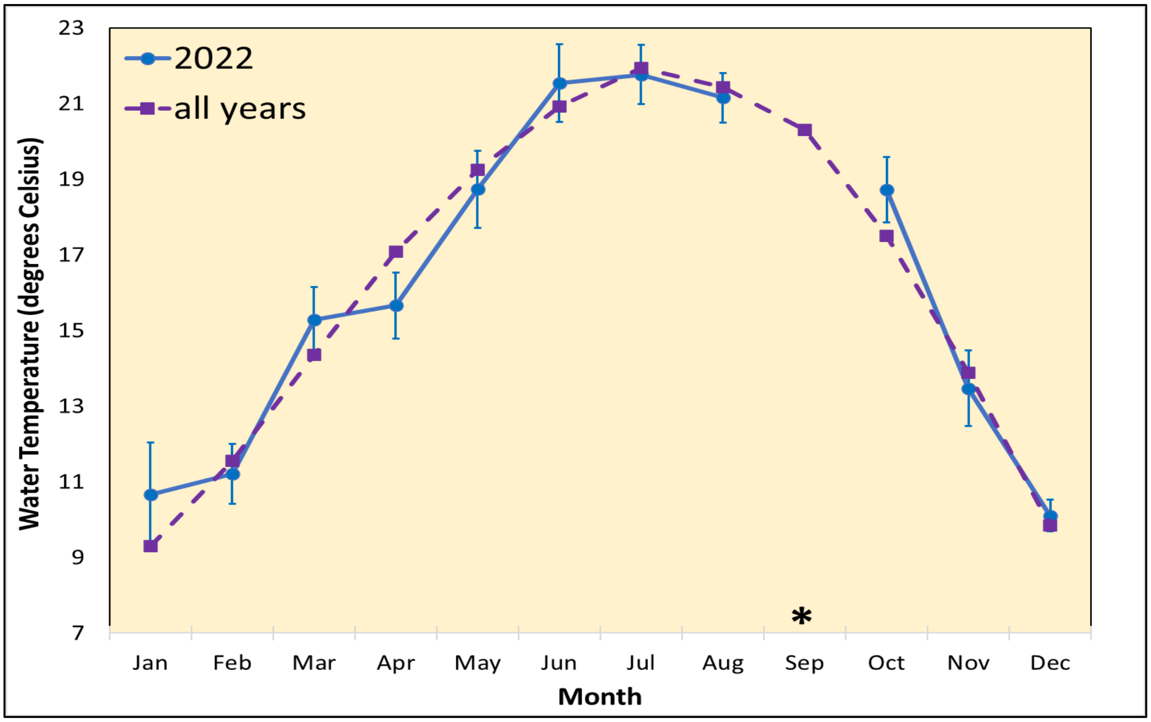

Figure 7. Monthly average water temperature in 2022 and for all years of the study (1980 - 2022); error bars are standard deviations in 2022 (* = no September 2022 samples).

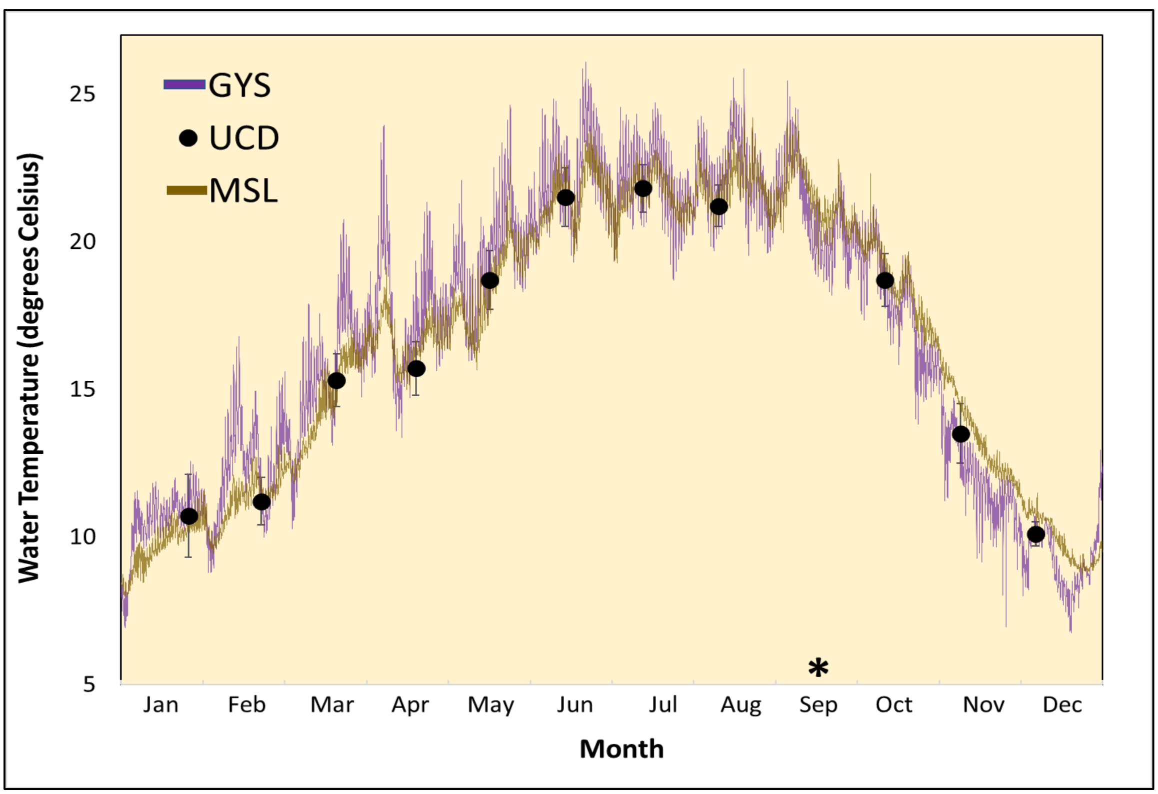

Figure 8. Fifteen-minute water temperature from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly temperatures and standard deviations from the Suisun Marsh Fish Study ("UCD") during 2022 (* = no September 2022 samples for Suisun Marsh Fish Study).

Water Clarity

Average monthly water clarity was higher than usual during all of 2022 except in January, following the highest outflows for the year (Figure 9). The pattern in monthly clarity was fairly typical for much of the year, with lower values early in the year and highest values in autumn, although the mild decline through summer was unusual. The clearest water was usually in eastern Montezuma Slough (eight of 11 months), with the year's highest clarity (75 cm) recorded there in November. Bucking the typical trend of lower clarities in sloughs further from the main axis of the estuary, seven of the 11 months found water clarity lowest in the two sites closest to Grizzly Bay (GY3 and SU4; Figure 2), with the lowest clarity (11 cm) occurring in lower Suisun Slough in August.

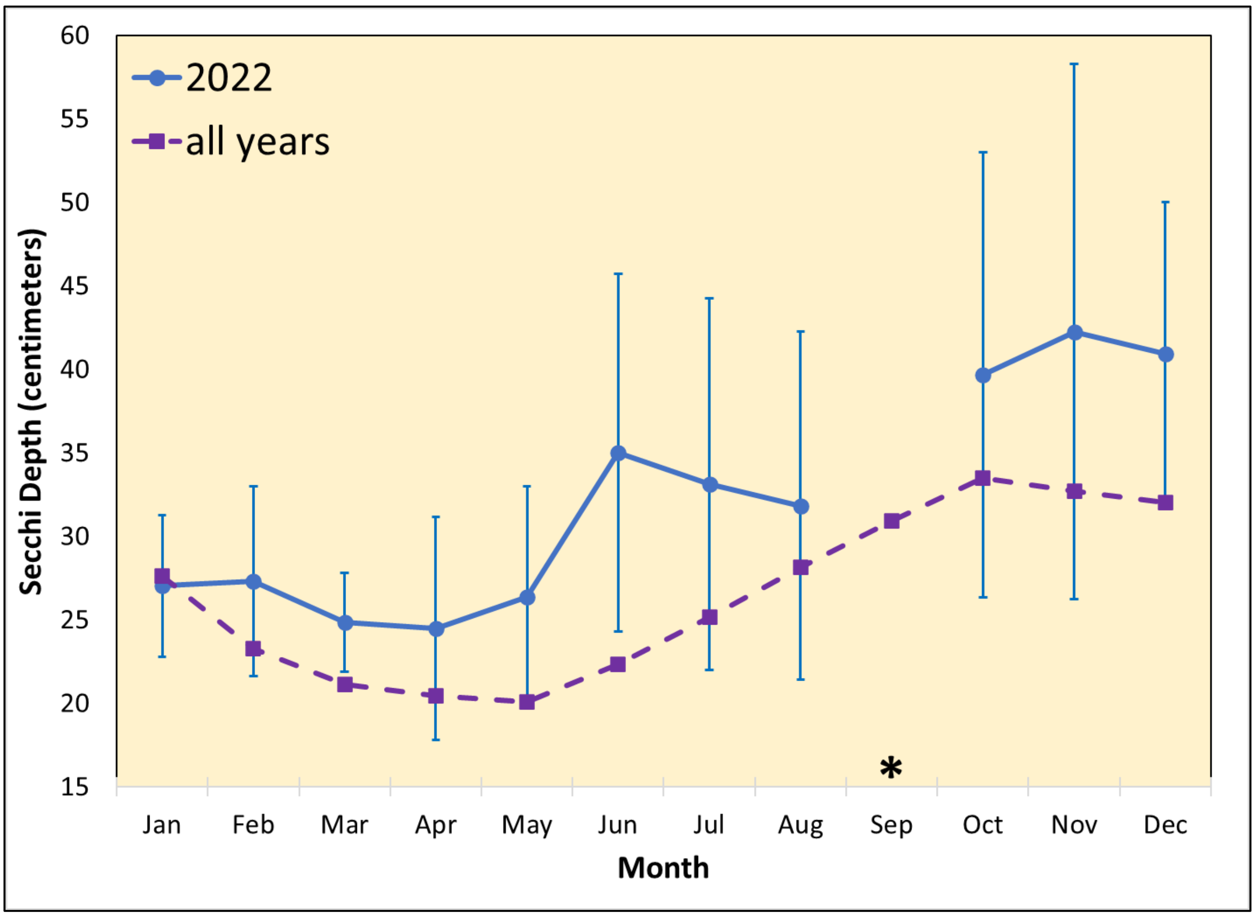

Figure 9. Monthly average water clarity in 2022 and for all years of the study (1980 - 2022); error bars are standard deviations in 2022 (* = no September 2022 samples).

Trends in Invertebrate Distribution and Abundance

Opossum Shrimp

Opossum shrimp were very abundant in 2022, with the year's CPUE (1.8 rank per trawl) reaching its highest value since 1990 (2.2 rank per trawl) and exceeding the all-years average (1.3 rank per trawl; Figure 10). Monthly CPUE generally rose from January until peaking in

May, then declined moderately and hovered at relatively low levels in autumn (Figure 11): a typical pattern (Moyle *et al.* 1986, O'Rear *et al.* 2020, 2021). Opossum shrimp were prevalent in all sloughs, with highest CPUE values in Nurse and Denverton sloughs, consistent with Montgomery *et al.* (2015).

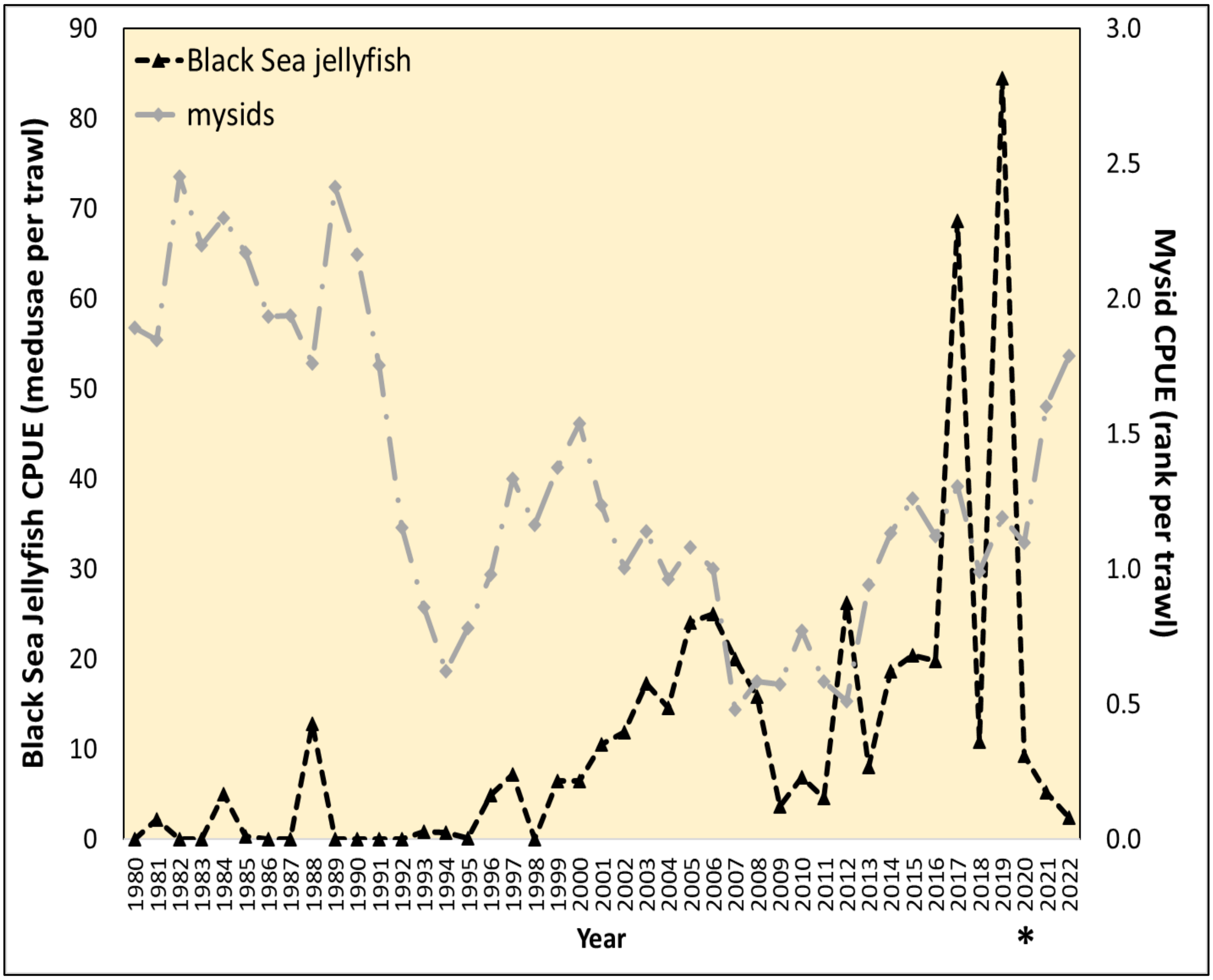

Figure 10. Annual CPUE of Black Sea jellyfish and opossum shrimp (* = no March or April samples).

Black Sea Jellyfish

Black Sea jellyfish medusae were not abundant in 2022, with CPUE (2.2 medusae per trawl; Figure 10) well below values for both 2021 and all years (5.3 and 11.1 medusae per trawl, respectively). Loss of September data likely biased the value for 2022 low (Baumsteiger *et al.* 2018). Medusae first appeared in July, attained highest numbers in August, dropped precipitously through October and November, then disappeared in December (Figure 11) - a usual pattern (Baumsteiger *et al.* 2018). Medusae were captured in most sloughs, with about two-thirds of the catch (67%; 447 individuals) coming from the two most easterly sites in Montezuma Slough (MZ1 and MZ2; Figure 2). In contrast, no medusae were caught in Denverton Slough and only three in upper Goodyear Slough (GY1 and GY2; Figure 2), consistent with sloughs far from the main corridors of the marsh, Suisun and Montezuma sloughs, frequently having the lowest abundances (Baumsteiger *et al.* 2018).

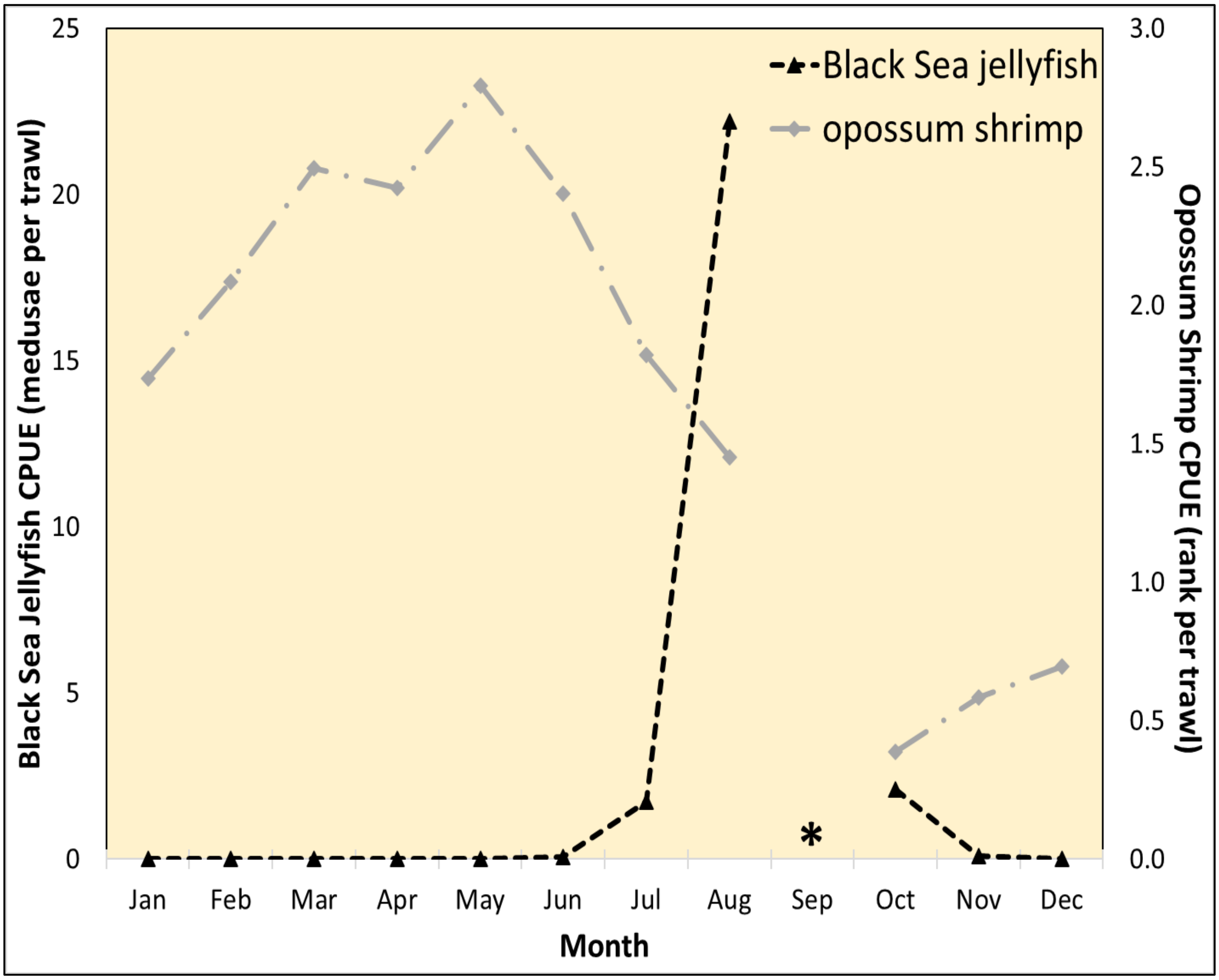

Figure 11. Monthly average CPUE of Black Sea jellyfish and opossum shrimp in Suisun Marsh in 2022 (* = no September samples).

Clams

Overbite Clam

Overbite clams were fairly abundant in 2022 (Figure 12), with the year's CPUE (68 clams per trawl) lower than 2021's value but higher than the all-years value (95 and 55 clams per trawl, respectively). Monthly CPUE of overbite clams veered from the usual pattern of peaking in summer; instead, highest numbers occurred in spring and autumn (Figure 13; Baumsteiger *et al.* 2017, O'Rear *et al.* 2020). Consistent with the typical pattern, nearly all overbite clams (94% of the catch, 17,331 individuals) came from lower Suisun Slough or the GY3 site, which is the closest small-slough site to a large slough and one of the saltiest. While present in both small and large sloughs, overbite clams were nearly absent in small sloughs, a recurring pattern (Baumsteiger *et al.* 2017): less than 1% (30 individuals) of 2022's catch came from the combination of Boynton, Cutoff, Denverton, First Mallard, Nurse, and Peytonia sloughs (Figure 2).

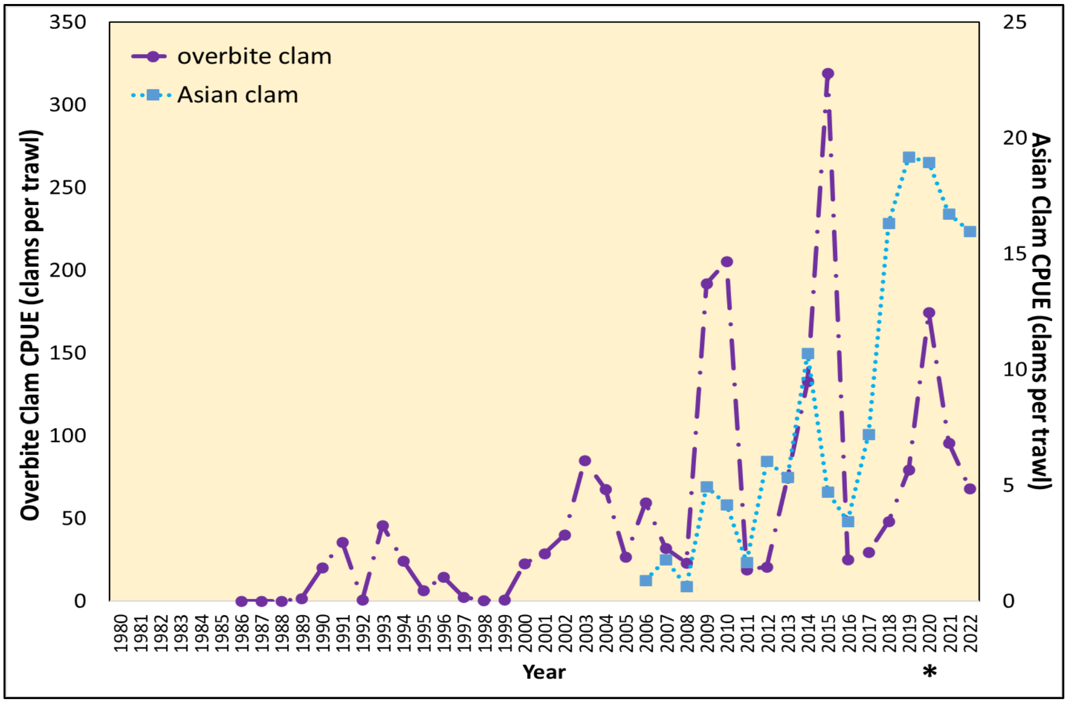

Figure 12. Annual CPUE of overbite clam and Asian clam (* = no March or April samples).

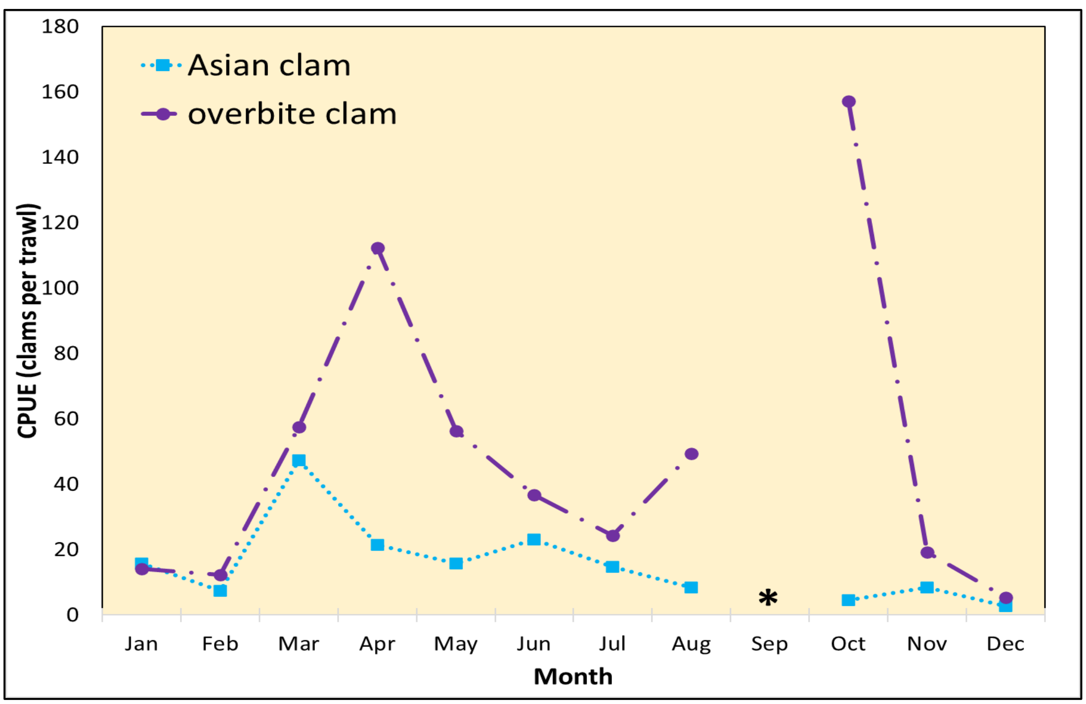

Figure 13. Monthly average CPUE of overbite clam and Asian clam in Suisun Marsh in 2022 (* = no September samples).

<u>Asian Clam</u>

Like overbite clam, Asian clam was abundant in 2022, with CPUE close to 2021's value (16 and 17 clams per trawl, respectively) and well above the average for 2006 - 2022 (8 clams per trawl; Figure 12). Monthly patterns between the two clams were dissimilar, with Asian clam CPUE highest in March and more stable than overbite clam CPUE (Figure 13). Geographic distribution of the clams was rather complementary. While very abundant in two big sloughs - eastern Montezuma and upper Suisun - which, together, hosted 68% (2,779 individuals), Asian clam was also very abundant in smaller sloughs with freshwater inputs (Boynton and Peytonia), where 24% 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 1% 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); and Asian clam can subsist well on both detritus and plankton (Schroeter *et al.* 2015), 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 were numerous in 2022, with the annual CPUE above the all-years average and similar to 2021's value (39, 27, and 34 shrimp per trawl, respectively; Figure 14). Monthly CPUE was negligible in January and February but then skyrocketed and peaked in May; thereafter, numbers plummeted and remained low through the year's remainder (Figure 15). Lower Suisun and lower Goodyear sloughs (SU3, SU4, and GY3; Figure 2) hosted a disproportionate number of California bay shrimp [55% of the year's catch (5,477 individuals)], similar to overbite clam. In contrast, very few were captured in small sloughs of the marsh's interior, with only 8% of the catch coming from Boynton, Denverton, First Mallard, upper Goodyear (GY1 and GY2; Figure 2), and Peytonia sloughs combined. The year's improved numbers and the geographic distribution were consistent with the shrimp's association with moderately salty water (Cloern *et al.* 2017) and predilection for coarser substrate in the larger sloughs.

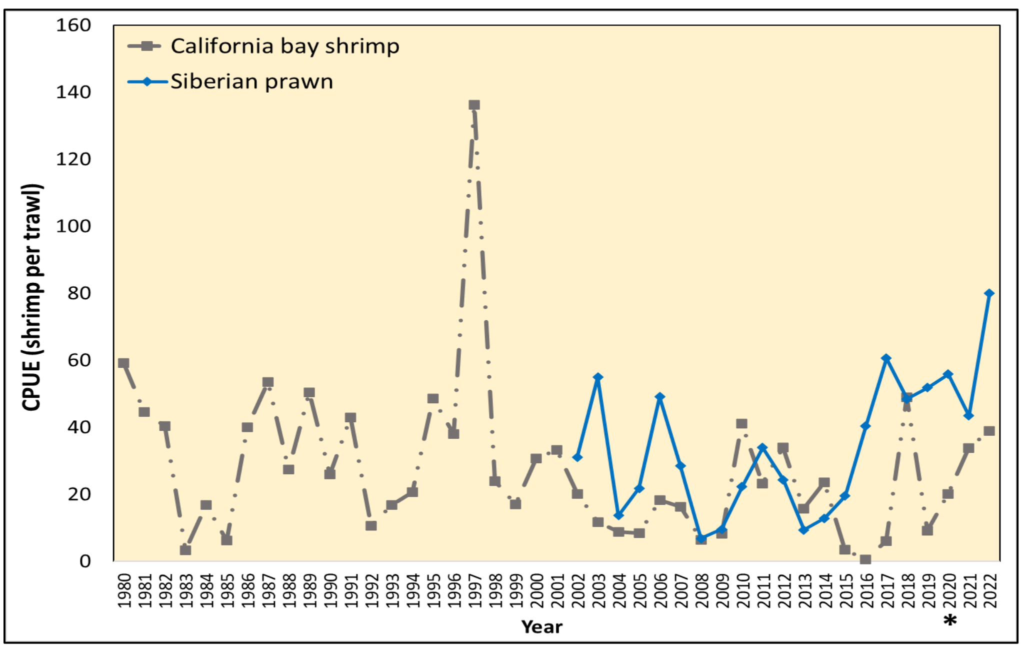

Figure 14. Annual CPUE of California bay shrimp and Siberian prawn (* = no March or April samples).

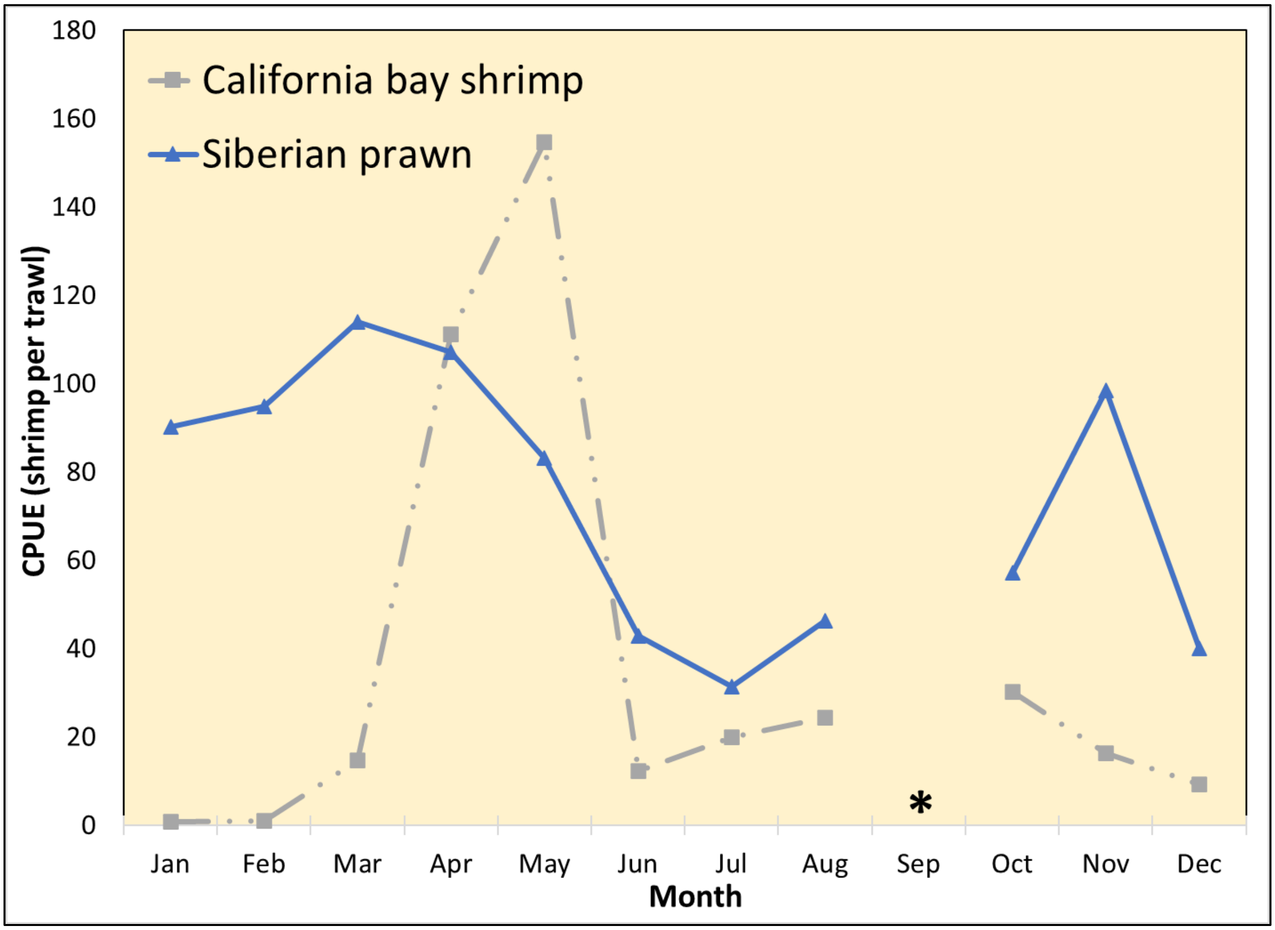

Figure 15. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2022 (* = no September samples).

<u>Siberian Prawn</u>

Siberian prawn reached their highest-ever abundance in 2022 (80 shrimp per trawl), higher than both the average of 2002-2022 and 2021's value (34 and 43 shrimp per trawl, respectively; Figure 14). Numbers rose mildly from January until peaking in March, after which they declined steadily until bottoming out in July (Figure 15). They rose again until attaining a second peak in November, then falling substantially in December. The geographic distribution of the two shrimp species mirrored that of the clams. While California bay shrimp dominated in the southwest marsh, Siberian prawn were common in all sloughs of the marsh but were especially abundant in Boynton, Peytonia, and upper Suisun sloughs [12% (2,470 individuals), 12%, and 25% of 2022's catch, respectively]. Such patterns corroborate a lower salinity tolerance of Siberian prawn (Brown and Hieb 2014) relative to California bay shrimp.

Trends in Fish Distribution and Abundance

Otter Trawls

Fish abundance in 2022 was very close to the all-years average (23 and 24 fish per trawl, respectively) and higher than 2021's value (18 fish per trawl; Figure 16). CPUE for both native and non-native fishes rose mildly from 2021 to 2022 (natives: 9 and 12 fish per trawl, respectively; non-natives: 9 and 11 fish per trawl, respectively), and with native CPUE higher and non-native CPUE lower than their all-years averages (10 and 14 fish per trawl, respectively). The above-normal numbers for native fishes was mainly from high catches of three common marsh fishes: Sacramento splittail, longfin smelt, and tule perch (Table 1). Although marine fishes were again present in 2022 [northern anchovy (*Engaulis mordax*), plainfin midshipman (*Porichthys notatus*), arrow goby (*Clevelandia ios*; first caught in Suisun Marsh in 2021), bay pipefish (*Sygnathus leptorhynchus*); Appendix D], their numbers were considerably lower than in 2021 and contributed little to 2022's value. For non-natives, mild declines in freshwater fishes tolerant of moderate salinities [common carp (*Cyprinus carpio*), white catfish (*Ameiurus catus*), and black crappie (*Pomoxis nigromaculatus*)] were offset by large catches in small benthic fishes [shimofuri goby (*Tridentiger bifasciatus*) and shokihaze goby (*Tridentiger barbatus*); Table 1], with shokihaze goby reaching its highest-ever abundance in 2022. CPUE for the common yellowfin goby in 2022 was about the same as values for 2021 and all years (Table 1). Mississippi silverside contributed to 2022's catch as well, an unusual occurrence given its affinity for inshore areas (Moyle 2022). Striped bass also increased from 2021 to 2022, but abundance was still well-below the all-years average.

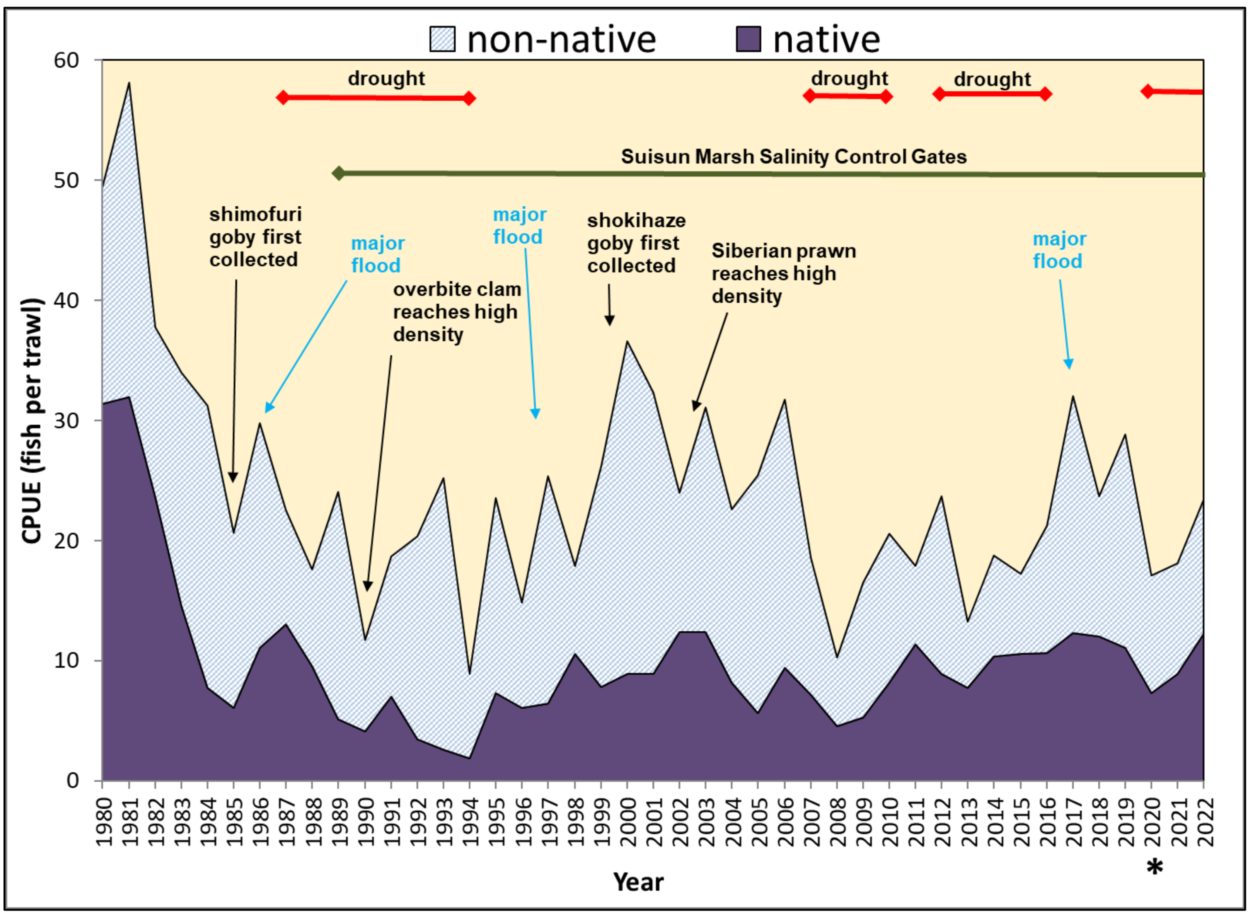

Figure 16. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted (* = no March or April samples).

Table 1. Change in annual otter trawl CPUE of nine marsh fishes (% change is relative to 2021 CPUE, such that a 100% increase indicates that the value has doubled; species in bold are native; "all years" is the average for 1980 - 2022).

Species	All Years CPUE	2022	2021	2022/2021 % Change
Sacramento splittail	**3.38**	**6.06**	**4.00**	**+52%**
longfin smelt	**1.08**	**1.96**	**1.82**	**+8%**
tule perch	**2.00**	**2.47**	**1.29**	**+91%**
arrow goby	**0.01**	**0.04**	**0.18**	**-81%**
Mississippi silverside	0.12	0.74	0.33	+126%
striped bass	8.48	2.49	1.60	+56%
shimofuri goby	1.29	1.85	1.11	+66%
yellowfin goby	2.17	2.13	2.60	-18%
shokihazi goby	0.26	3.02	2.16	+40%

Beach Seines

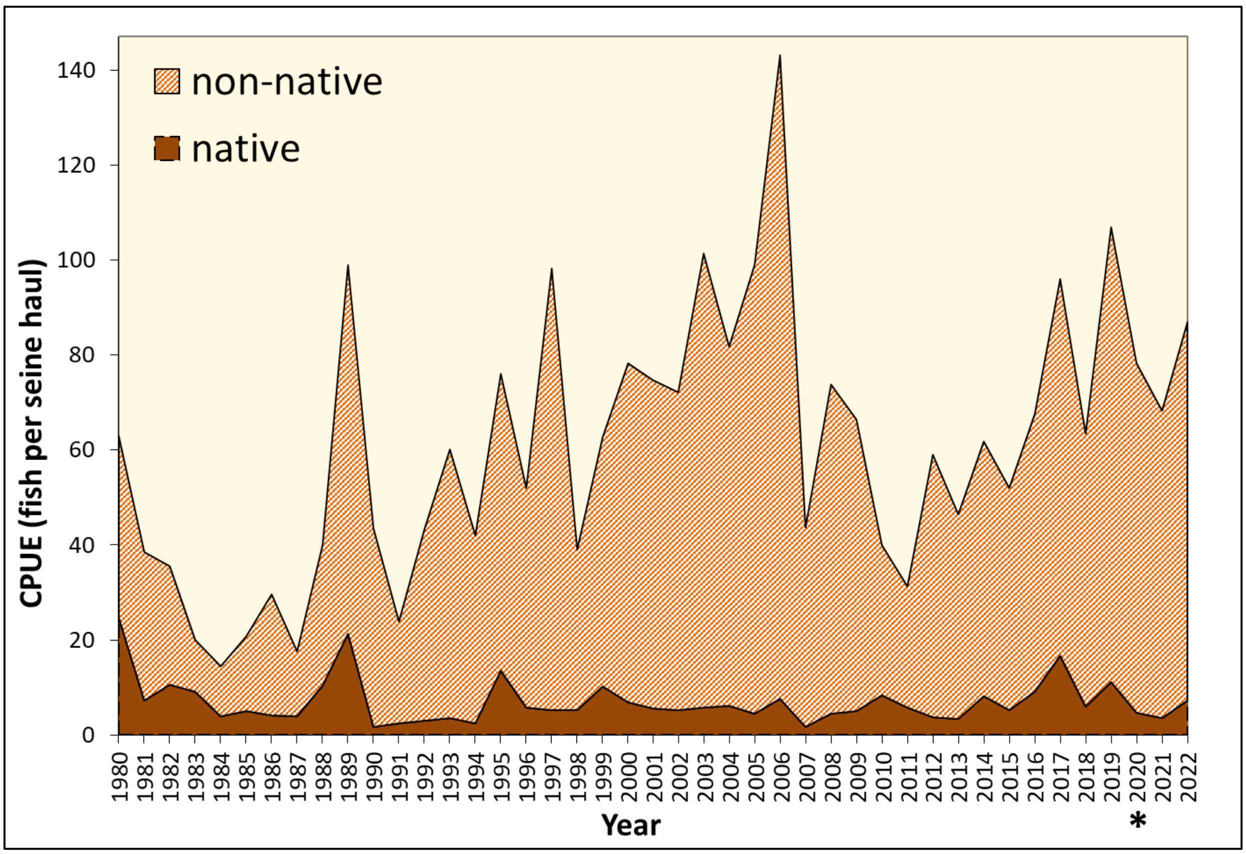

Figure 17. Annual beach seine CPUE of native and non-native fishes (* = no March or April samples).

Numbers of inshore fish were higher than usual in 2022, above the values for both 2021 and all years (87, 68, and 61 fish per haul, respectively; Figure 17). The change in native fishes from 2022 to 2021 was rather substantial (3.7 fish per seine haul), mainly due to increases in two littoral fishes [threespine stickleback and tule perch (Table 2)]. Non-native CPUE rose as well, by 15 fish per seine haul, caused primarily by elevated Mississippi silverside numbers but also mild increases in yellowfin goby and striped bass (Table 2). Threadfin shad numbers rose between the two years, but like striped bass, another pelagic species requiring fresh water to spawn, abundance was still well-below the average for all years of the study. Similar to the otter trawl, marine species were less prevalent than in 2021, with no jacksmelt (*Atherinops californiensis*; first caught in Suisun Marsh in 2021) captured in 2022 (Appendix D).

Table 2. Percent change in annual beach seine CPUE of eight marsh fishes (% change is relative to 2021 CPUE, such that a 100% increase indicates that the value has doubled; native species in bold; "all years" is the average for 1980 - 2022).

Species	All Years CPUE	2022	2021	2022/2021 % Change
Sacramento splittail	**2.03**	**0.81**	**1.76**	**-54%**
jacksmelt	**0.00**	**0.00**	**0.07**	-∞
threespine stickleback	**1.72**	**3.34**	**0.40**	**+735%**
tule perch	**0.80**	**1.76**	**0.56**	**+217%**
threadfin shad	2.55	0.97	0.60	+62%
Mississippi silverside	37.97	67.00	55.72	+20%
striped bass	5.55	2.25	1.01	+123%
yellowfin goby	6.10	7.90	6.26	+26%

Fish Species of Interest

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

DELTA AND LONGFIN SMELT

For the seventh consecutive year, no Delta smelt (*Hypomesus transpacificus*) were captured by the Suisun Marsh Fish Study (Figure 18); likewise, none were captured in the estuary-wide Summer Townet Survey and Fall Midwater Trawl Survey [California Department of Fish and Wildlife (CDFW) 2023]. Delta smelt were still absent in the Suisun Marsh Fish Study during 2022 despite experimental releases of 12,800 hatchery fish into Montezuma Slough in February 2022.

Longfin smelt numbers in 2022 exceeded 2021's moderate value, with the year's CPUE nearly double the all-years average (Figure 18; Table 1). Twenty-four fish were of the 2021 year class and the remainder (667 fish) from the 2022 year class, with the majority of age-0 fish caught in April and May (SL range = 20-45 mm) in large sloughs (Montezuma and lower Suisun) close to the estuary's mainstem (Figure 19). Considerably fewer 2022 fish were caught in small, long, dead-end sloughs [*e.g.,* Boynton, Denverton, First Mallard, upper Goodyear (GY1 and GY2; Figure 2), and Peytonia sloughs] far away from Grizzly Bay and the Sacramento River, and only five were caught in upper Suisun Slough (SU1 and SU2; Figure 2). Catches plummeted in June and were zero in July and August. Age-0 fish returned to the marsh after summer, with eight of the 10 autumn age-0 fish caught in Montezuma Slough and the three sites closest to Grizzly Bay (GY3, SU3, and SU4; Figure 2). The age-1 fish were caught from January through May, and then again in December, with all but one captured in Montezuma, lower Suisun, and lower Goodyear sloughs.

The timing and location of longfin smelt in the marsh during 2022 reflected both association with cool waters and presence of spawning adjacent to Suisun Marsh during dry years. The distribution of the age-0 fish was typical for low-outflow conditions (O'Rear *et al.* 2022), best explained by the bulk of longfin smelt spawning close to but not in Suisun Marsh, with most age-0 longfin smelt coming into the marsh from fringing marshes of eastern Suisun Bay and the western Delta (Grimaldo *et al.* 2020; Figure 19). Absence of both age classes in summer was consistent with a downstream shift to saltier waters and/or mortality from, or avoidance of, high water temperatures.

The relatively high number of age-0 fish in 2022 was unique within the last decade. The area of spawning habitat increases and moves downstream of Suisun Marsh during wet years (U. S. Fish and Wildlife Service 2022). Estuary-wide abundances are often higher in wet years and commonly followed by higher spawner abundances two years later when the fish mature (U. S. Fish and Wildlife Service 2022). In Suisun Marsh in the last decade, the three other years of high age-0 abundance within Suisun Marsh - 2013, 2020, and 2021 - were preceded by wet periods occurring when their parents were spawned (*i.e.,*, winter-spring in the two years previous: 2011, 2018, and 2019). In contrast, 2020 was a very dry year like 2022, suggesting abnormally high survival of early life-history stages during 2022. High densities of opossum shrimp, an important food of longfin smelt (Figure 11; Barros *et al.* 2022), likely contributed. Also, Suisun Marsh Salinity Control Gates operations could have increased age-0 numbers in the marsh if the center of spawning was upstream of Montezuma Slough, a scenario consistent with Grimaldo *et al.* (2020).

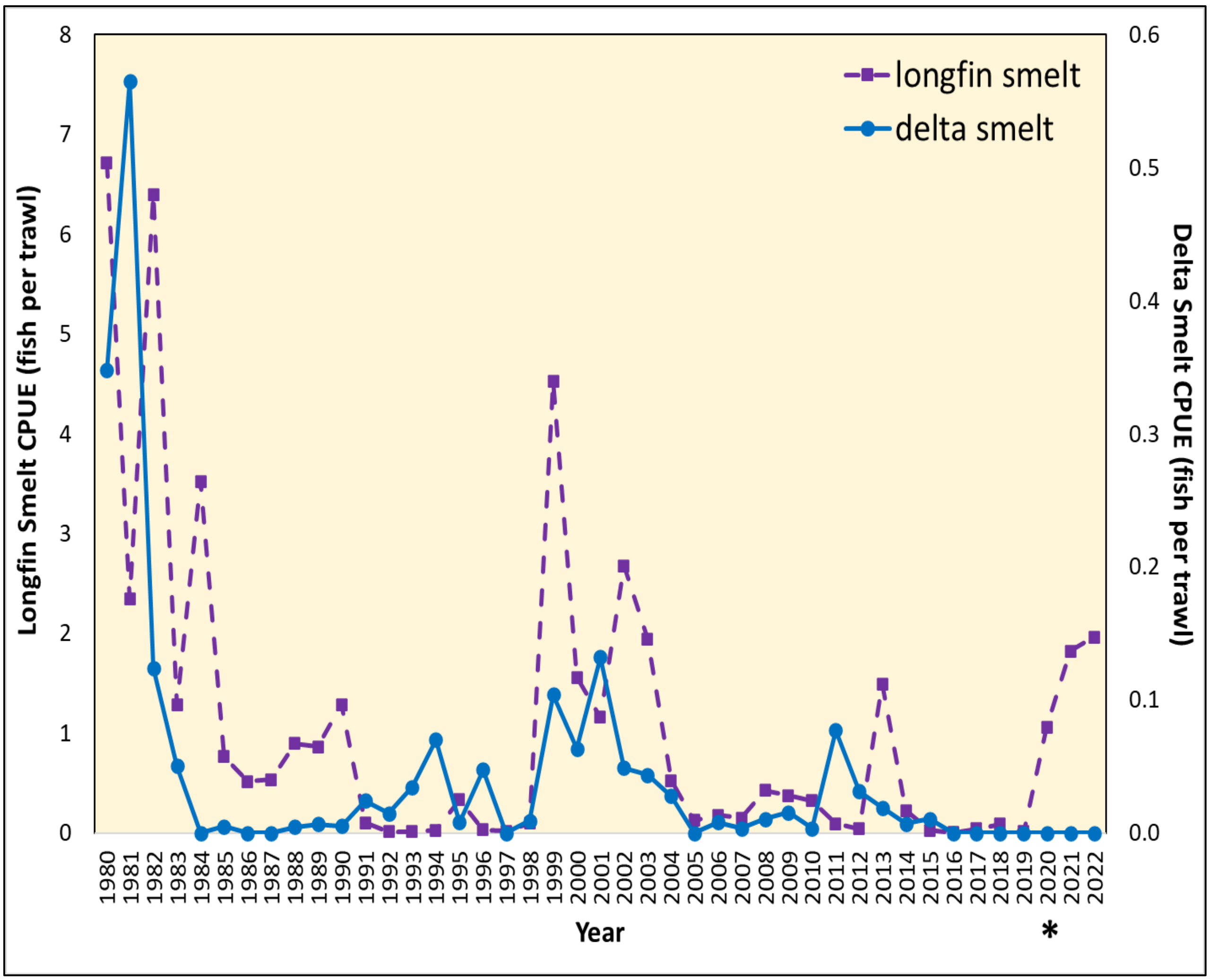

Figure 18. Annual CPUE of the smelts of the Pelagic Organism Decline (* = no March or April samples).

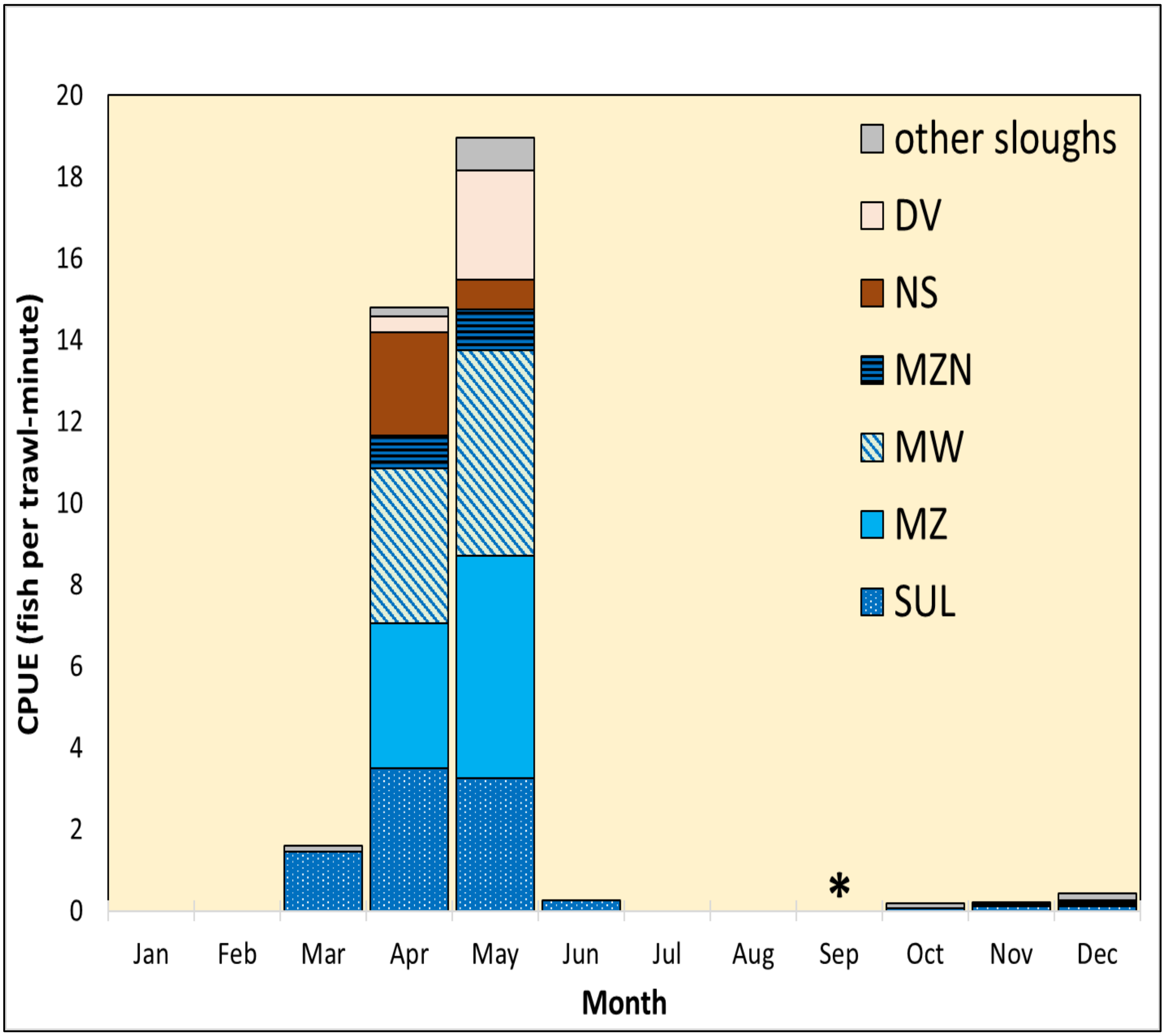

Figure 19. Monthly slough CPUE of age-0 longfin smelt in Suisun Marsh in 2022 ("DV" = Denverton Slough, "NS" = Nurse Slough, "MZN" = Montezuma Slough near Nurse Slough, "MW" = Montezuma Wetlands, "MZ" = eastern Montezuma Slough, and "SUL = upper Suisun Slough; *= no samples).

THREADFIN AND AMERICAN SHAD

Threadfin shad numbers in 2022 were rather low, close to the all-years average in trawls and below the average in beach seines; numbers in both gear types were rather similar between 2021 and 2022 (Figure 20; Table 2). Geographic distribution in the otter trawl was similar to previous years, with many fish caught in fresher waters of the eastern marsh (65%, 113 individuals) and virtually none in the saltier southwest (2%; Appendix D). Geographic distribution in beach seines was similar, with 92% 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 2022 were consistent with (1) their preference for fresher water (Feyrer *et al.* 2007, 2009) and (2) high zooplankton densities in small, dead-end sloughs (Montgomery *et al.* 2015).

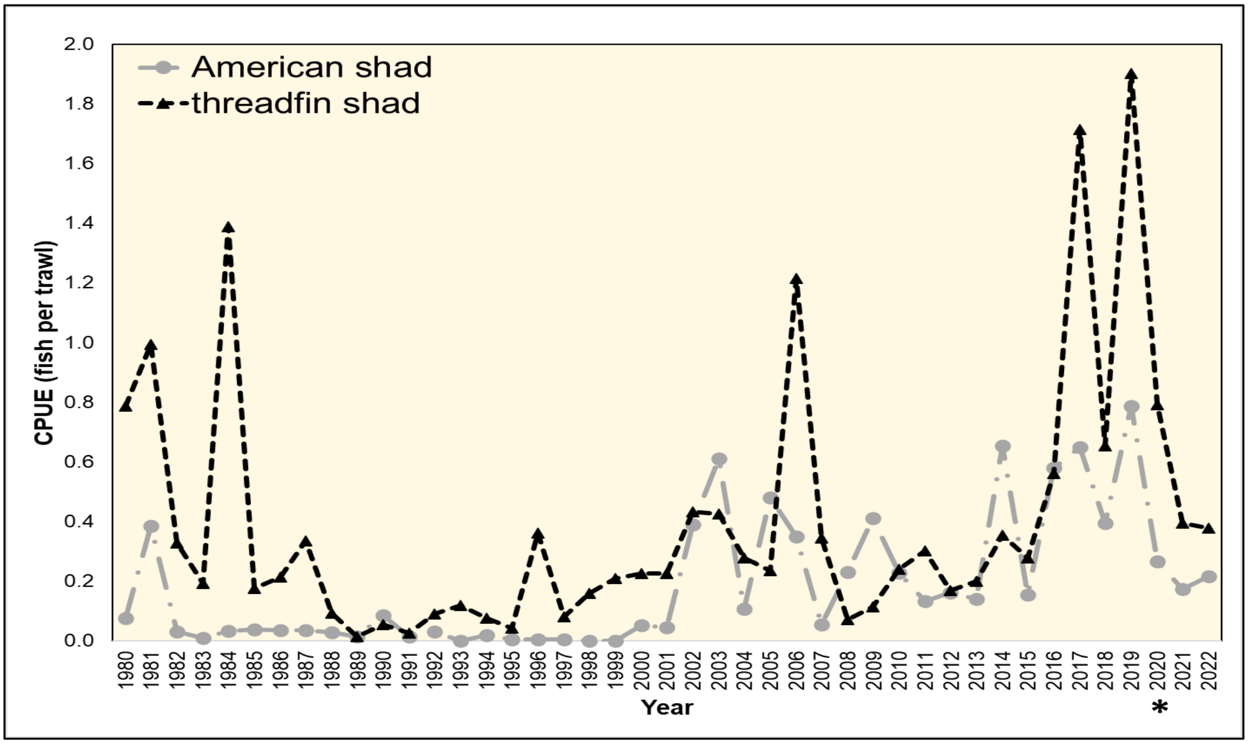

Figure 20. Annual CPUE of the shads of the Pelagic Organism Decline (* = no March or April samples).

American shad numbers were quite typical in 2022. Otter-trawl CPUE in 2022 was close to both the all-years average and 2021's value (0.22, 0.17, and 0.19 fish per trawl, respectively; Figure 20). Numbers in the years of this latest drought (2020 - 2022) were notably lower than in the last two wet years, 2017 and 2019 (Figure 20). Unlike most years, age-0 fish did not dominate the catch: more than half (59%) were from the 2021 year class. American shad were captured in all sloughs but especially in Montezuma Wetlands and Goodyear Slough (36% and 26% of the year's catch, respectively). Low river flows for attracting adults and/or poor survival of early life stages seemed the likely culprits for the age-0 catches in 2022. Age-1 fish may have lingered longer in Suisun Marsh than in typical years because of high numbers of opossum shrimp, an important food, and/or because of evolution of non-anadromous fish, as documented in the Columbia River population (Hasselman *et al.* 2018).

STRIPED BASS

Striped bass CPUE in 2022 was again very low relative to long-term averages in both gear types, though improved relative to 2021 (Figure 21; Table 1 and 2). Numbers of age-0 fish occurred in seines in June, increased rapidly to the year's peak in July, then declined drastically through autumn until none were caught in December (Figure 22). Change in age-0 CPUE in otter trawls was somewhat different, with fish first appearing in May, peaking in June, falling and rising in July and August, respectively, and then paralleling the beach seine in the year's last three months (Figure 22). Juvenile striped bass generally declined through the year (Figure 23), 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 were more abundant in smaller sloughs, with CPUE highest in Boynton and Peytonia sloughs (Figure 23). The pattern in beach seines was similar, with half (97 individuals) of the year's catch coming from the small slough (Denverton; Appendix D), although fair numbers were captured in eastern Montezuma Slough as well (33%). The distribution and relatively low numbers of age-0 striped bass in 2022 were consistent with low flows supporting little reproduction/recruitment (Feyrer *et al.* 2007) and, like for threadfin shad, abundant zooplankton food in small, dead-end sloughs.

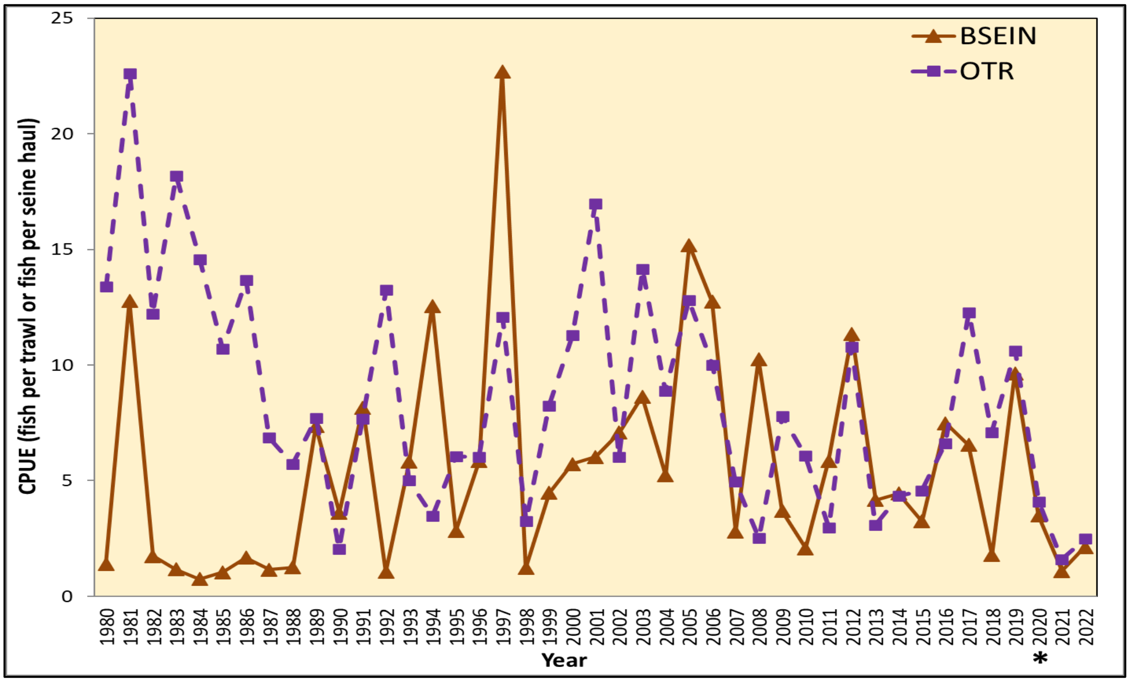

Figure 21. Annual CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine; * = no March or April samples).

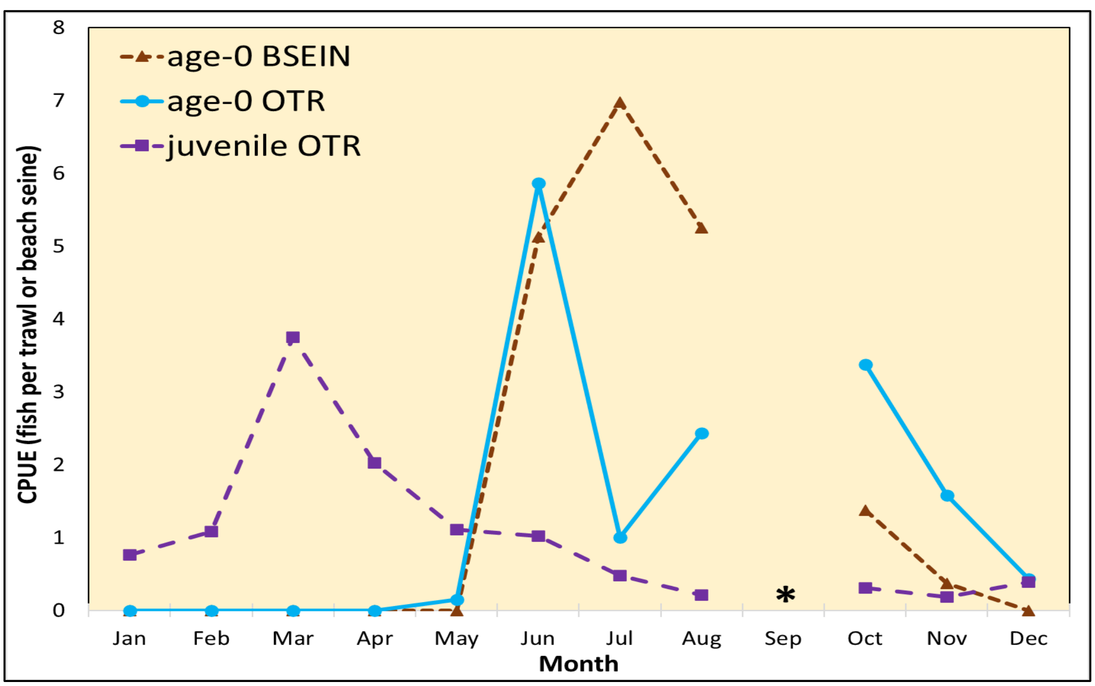

Figure 22. Monthly average CPUE of striped bass age classes ("juv" = juvenile; other codes as in Figure 21; *= no samples).

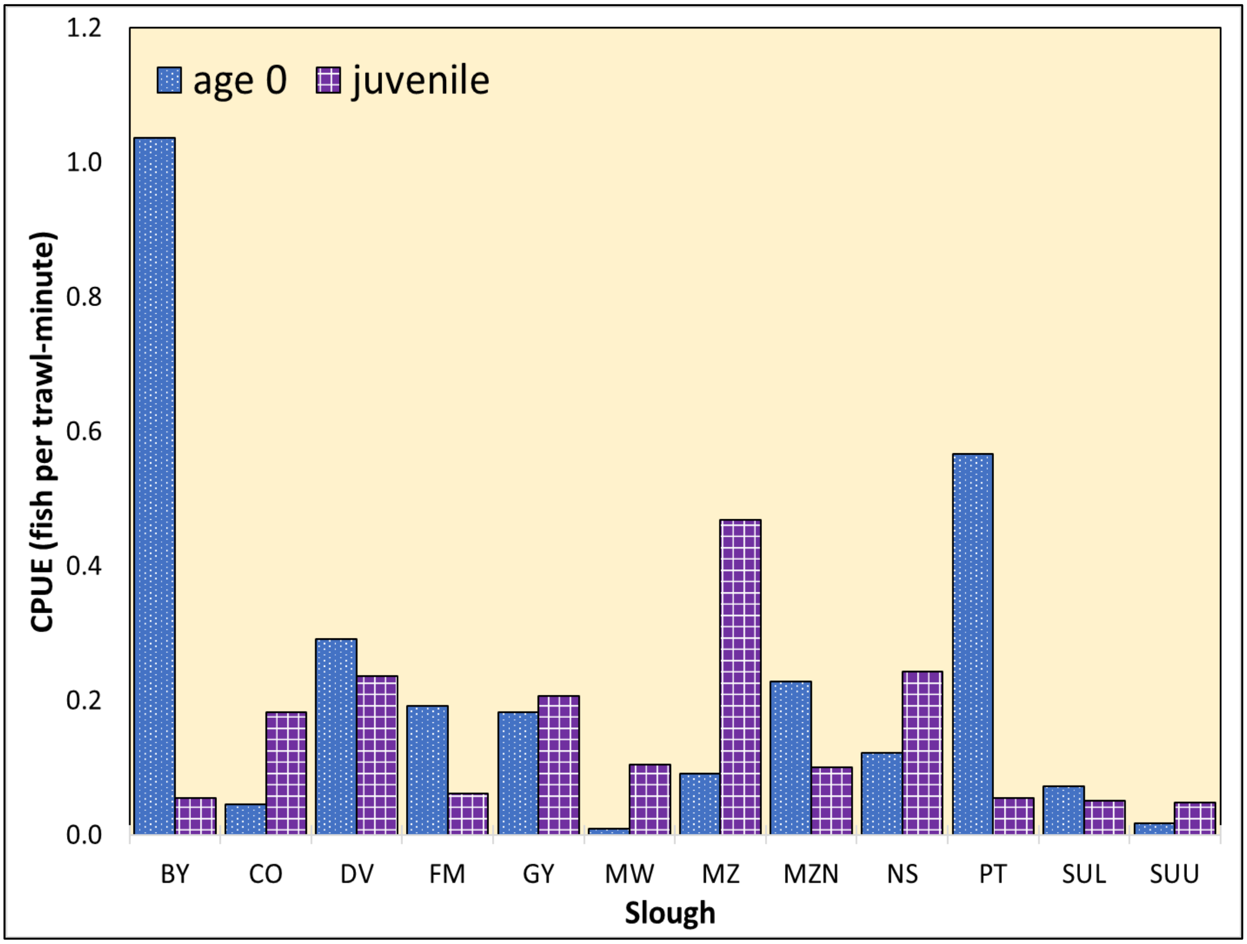

Figure 23. Average slough CPUE of age classes of striped bass in 2022 ("BY" = Boynton Slough, "CO" = Cutoff Slough, "FM" = First Mallard Slough "GY" = Goodyear Slough, "PT" = Peytonia Slough, and "SUU" = upper Suisun Slough; other codes as in Figure 19).

<u>Sacramento Splittail</u>

Splittail were quite abundant in 2022. Otter-trawl CPUE in 2022 was notably higher than values for both 2021 and the all-years average, although beach seine CPUE in 2022 was below that for 2021 and the all-years average (Figure 24, Table 1 and 2). The moderate splittail catches in Suisun Marsh were contrasted by none being captured by the estuary-wide Fall Midwater Trawl Survey (CDFW 2023), a recent recurring phenomenon (O'Rear *et al.* 2022). The abundance increase was driven by high numbers of adult (*i.e.* age 2+) but especially age-1 fish, the latter of which reached its fourth-highest abundance in the study's history (Figure 24). Typically, age-0 fish were few as compared to wetter years (*e.g.*, 2019). Splittail were most numerous in small sloughs (Figure 25), often those where age-0 striped bass were also most abundant (Figure 23). In contrast, splittail were also very abundant in near-shore shallow water in a large slough (Montezuma), where 75% of the beach seine fish were captured (Appendix D). The patterns in 2022 reflected (1) poor spawning conditions from minimal floodplain inundation and (2) especially good conditions within the smaller sloughs of Suisun Marsh (Colombano *et al.* 2020*a*). The high abundance of age-1 fish was consistent with longer transport times from upstream spawning areas (*e.g.*, the Cosumnes River floodplain) to the marsh in low-flow years.

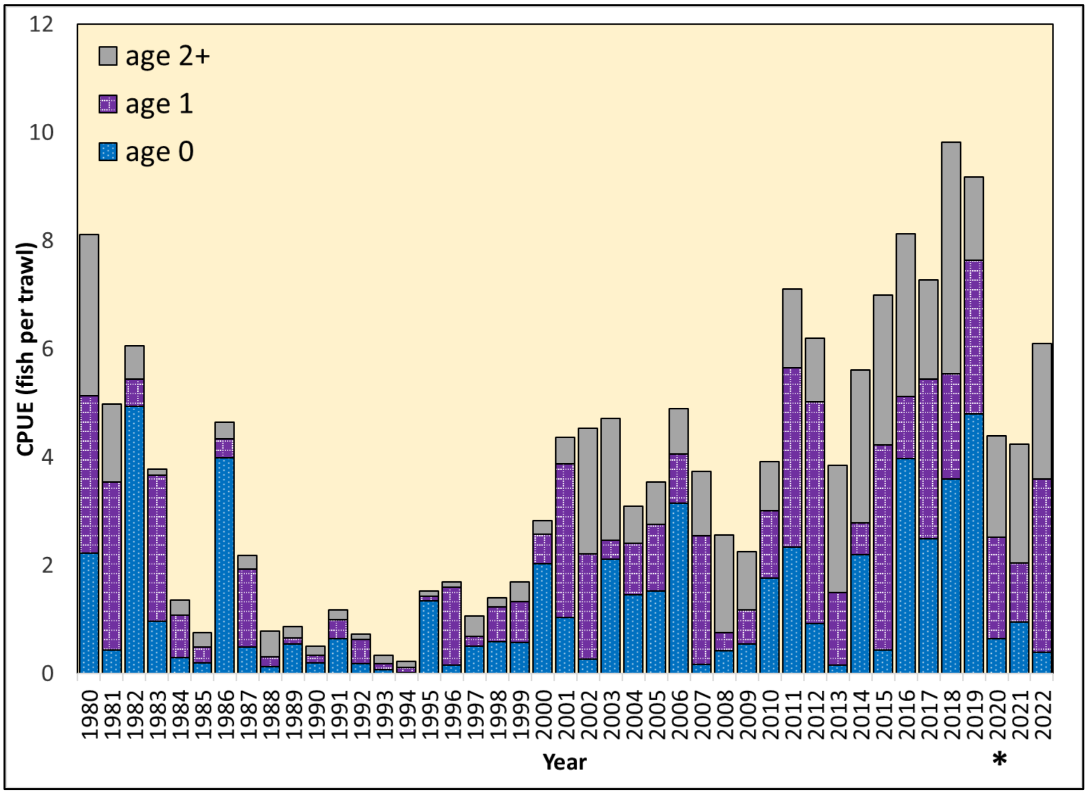

Figure 24. Annual CPUE of three age classes of Sacramento splittail (* = no March or April samples).

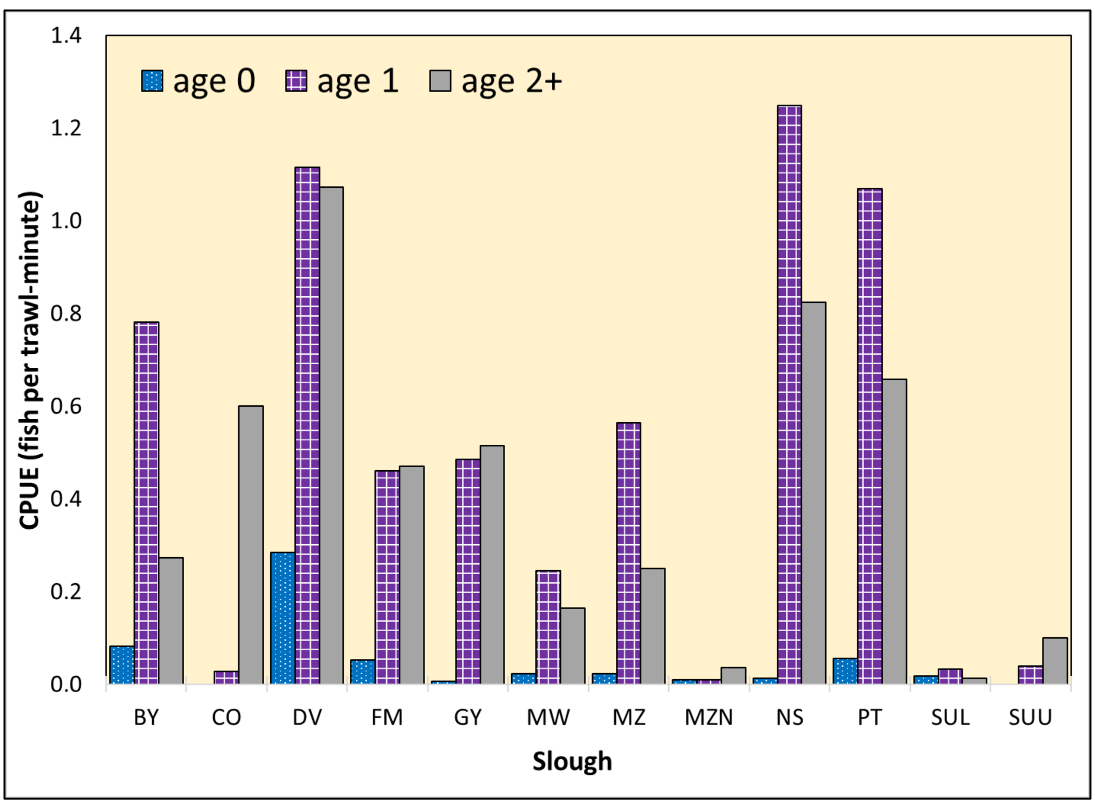

Figure 25. Average slough CPUE of age classes of splittail in 2022 (codes as in Figure 23).

Mississippi Silverside

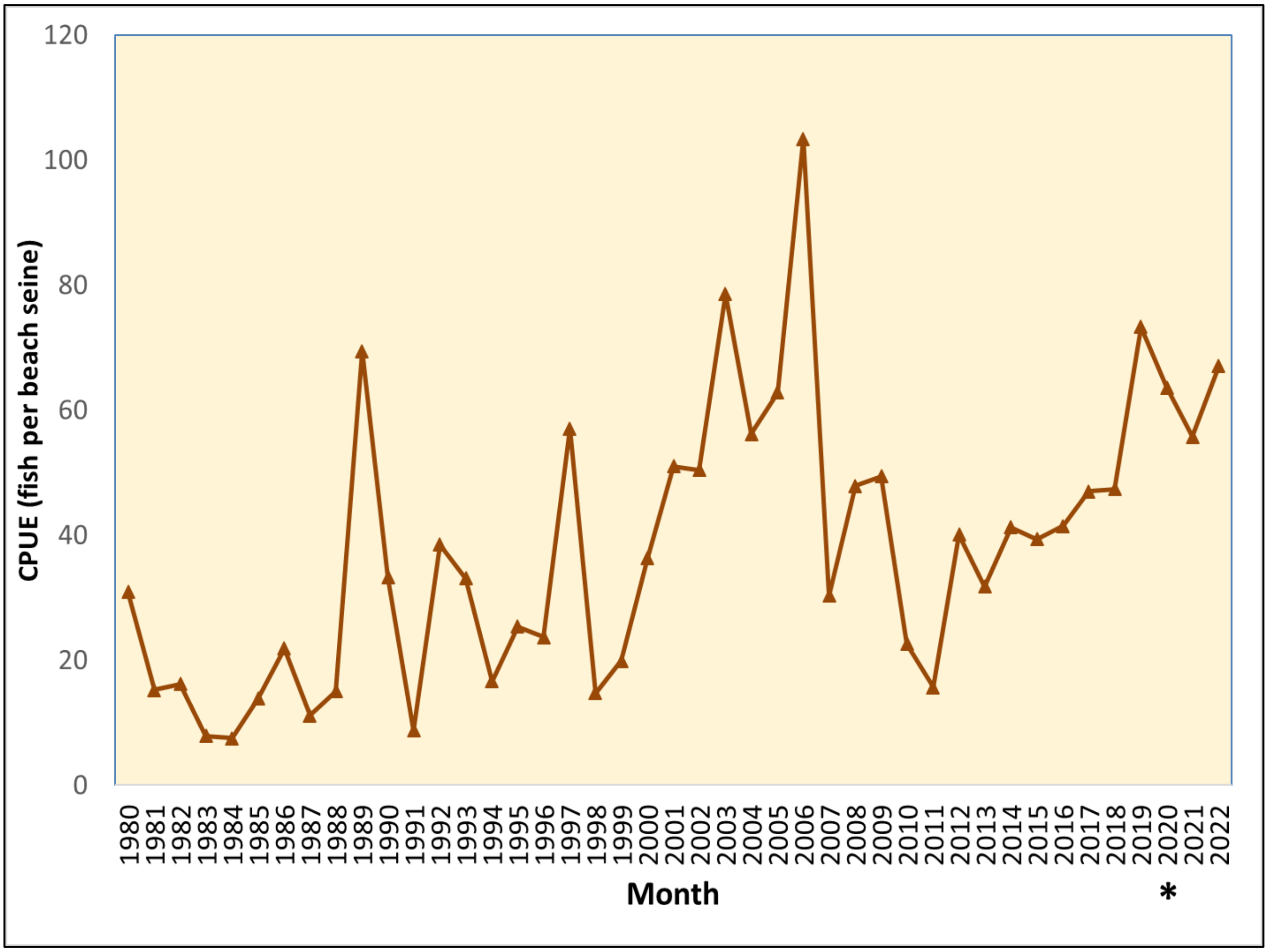

Figure 26. Annual CPUE of Mississippi silverside (* = no March or April samples).

Mississippi silverside were again very abundant near shore, with 2022 beach seine CPUE higher than values for both 2021 and the all-years average (Figure 26, Table 2). The trend in monthly abundance was fairly typical, with CPUE low in the first half of the year (except for an anomalously high catch in March), climbing through summer to autumn (Figure 27) with the continual addition of age-0 fish, and then crashing in November and December. Presence of fish about two months old (*i.e.*, those smaller than 30 mm SL; Hubbs 1982, Gleason and Bengston 1996) indicated spawning from April to September (Figure 28). Mississippi silverside were abundant at all four seining areas, with about half the year's catch (48%) coming from Denverton Slough and fewer in Montezuma Slough/Wetlands and upper Suisun Slough (Appendix D). The species, while always much less abundant in otter trawls, posted its highest-ever abundance in the gear type in 2022 (Table 1). The bulk of the otter-trawl fish were caught in small, dead-end sloughs (89% of the year's catch), which is typical given, in part, that the trawl there is rarely distant from shore. However, fish were also caught in large, wide lower Suisun Slough (Appendix D), which was unusual and had not occurred since 2006. The high numbers of silverside in 2022 were expected given their affinity for warm water (Hubbs 1982, Stoeckel and Heidinger 1988, Mahardja *et al.* 2016); the otter-trawl catch intimated that the fish may have saturated inshore areas.

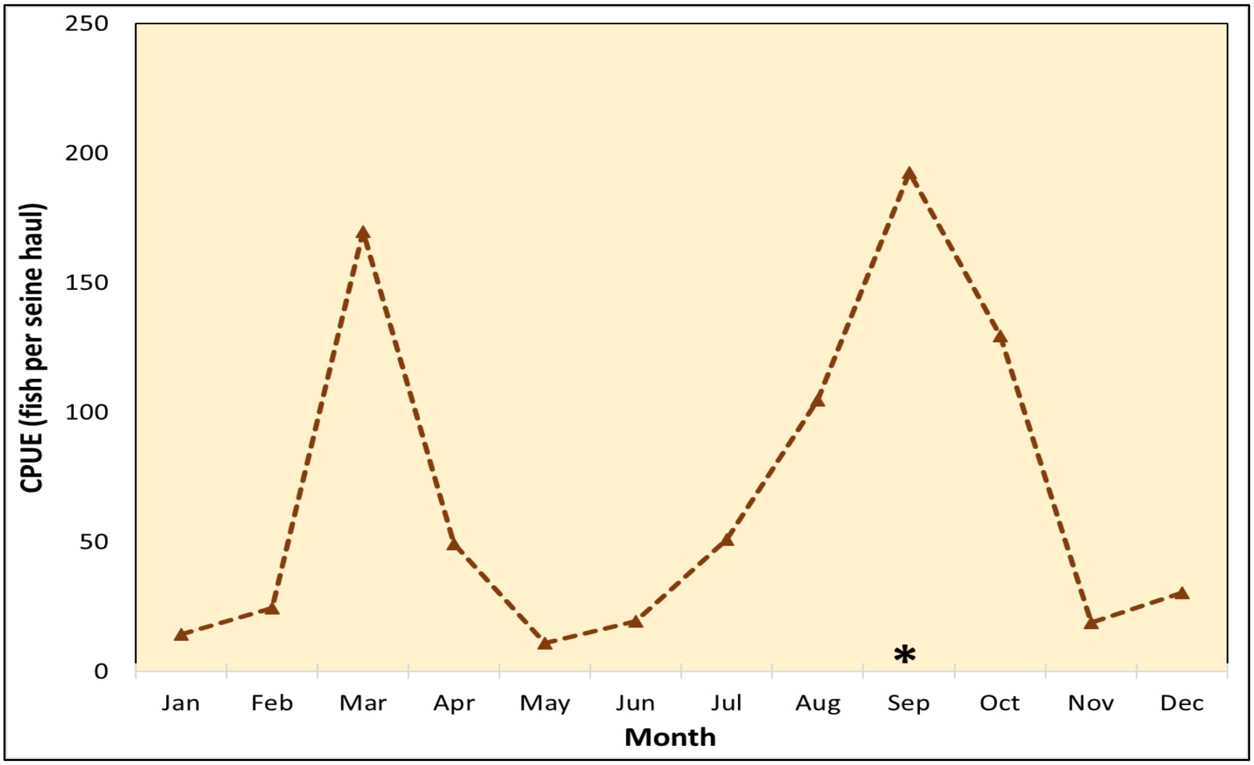

Figure 27. Monthly average CPUE of Mississippi silverside in 2022 (*= incomplete September samples).

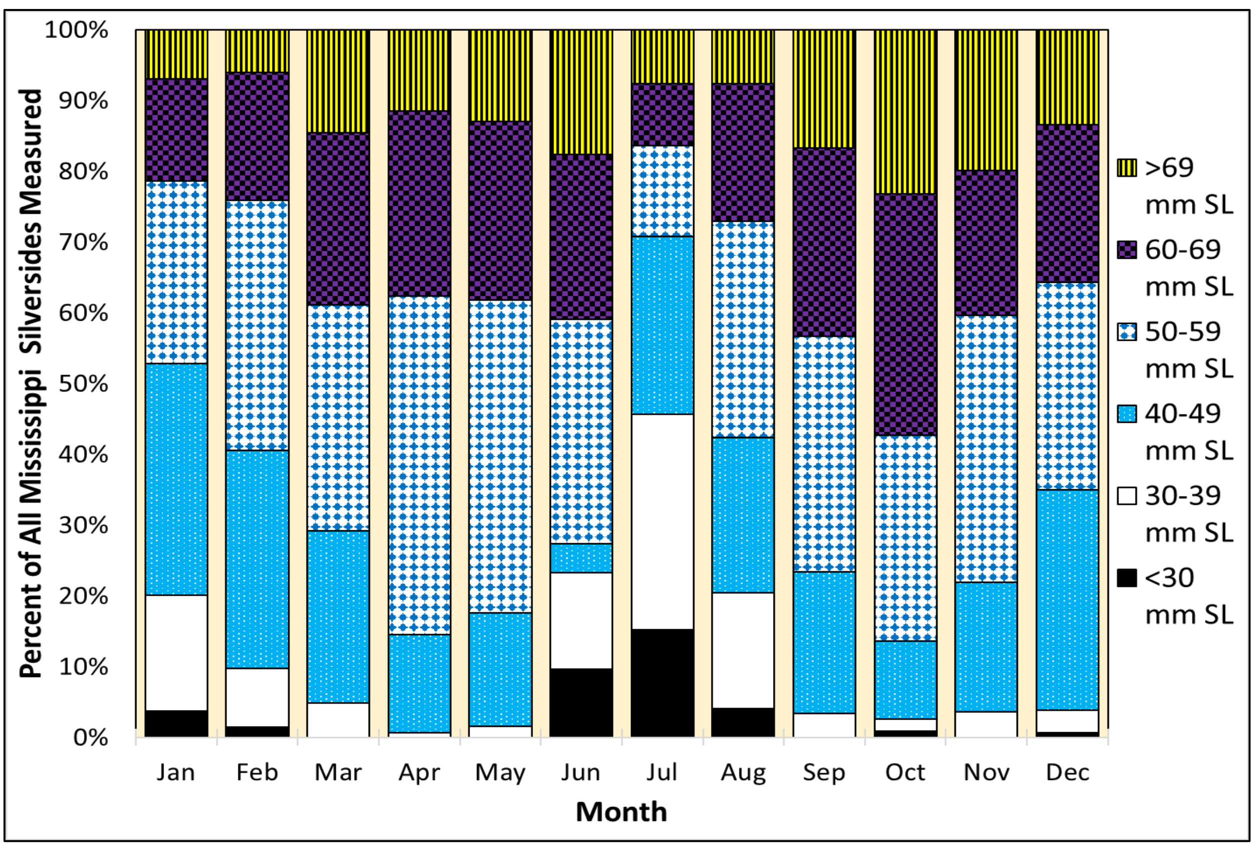

Figure 28. Monthly size-class distributions of Mississippi silverside captured in beach seines in 2022.

CONCLUSION

The drought continued for a third year, bringing higher-than-average salinities that prompted frequent operation of the Suisun Marsh Salinity Control Gates. It was also a warm year with water clarity higher than average for most of the year, recurring conditions in Suisun Marsh that have important implications for the future. Both native and non-native invertebrates were abundant in 2022, due in part to salinities favorable for California bay shrimp and overbite clam but still bearable by Siberian prawn. As is common in drought years, many fishes were less abundant than usual in Suisun Marsh during 2022, particularly fishes that spawn in fresh water and rear in Suisun Marsh: American shad, threadfin shad, and striped bass. Abundance of age-0 splittail, also, was quite low. Nevertheless, relative to long-term averages, splittail numbers in Suisun Marsh were far greater than that recorded in the main rivers and bays. Notably, springtime catches of age-0 longfin smelt were, for the third consecutive year, very high, likely due in part to high opossum-shrimp densities. However, longfin smelt's disappearance during summer when food was abundant, and their reappearance during autumn, reinforced that warm water limits their distribution. With few exceptions, most fishes were more abundant in smaller sloughs where food is often plentiful and the most-inimical non-native species (Black Sea jellyfish, overbite clams) least abundant. Although outflow in April and early summer was only marginally higher in 2022 than in 2021 (and salinity thus lower), the differences in much of the catch between the two years - increased numbers of Siberian prawn, and declines or absences of marine fishes - was suggestive of an acute sensitivity of the aquatic community to outflows. Notably, conditions in the marsh were suitable for many fishes while much of the estuary to the west suffered large fish kills due to a severe red tide (Ocean Protection Council 2022). In such years, Suisun Marsh could be a sanctuary for fishes tolerant of broad salinity, especially sturgeons and larger striped bass.

The Suisun March Fish Study in 2022 reinforced existing knowledge and added to our understanding, providing directions for the future. The message is mixed for both native and non-native species, ominous for anadromous species, and brighter for benthic fishes. The marsh remains an important nursery for young longfin smelt during dry years, but given a warming climate and an unknown adaptability, the period when they can inhabit the marsh will likely narrow. In contrast, consistently strong numbers of Sacramento splittail in the marsh, even in drought years, coupled with dismal numbers in the estuary's mainstem suggest that restoration actions for splittail would be more beneficial if focused outside, not inside, Suisun Marsh. The increase in duration and severity of droughts will compromise recruitment of striped bass, American shad, and threadfin shad into the marsh, which will be compensated by higher numbers of small benthic fishes and silversides. Whether the small benthic fishes and silversides will be non-native or native (*e.g.*, for gobies, non-native shokihaze goby or native arrow goby; for silversides, non-native Mississippi silverside or native jacksmelt) may very well be determined by subtle differences in outflow and its interaction with salinity.

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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.

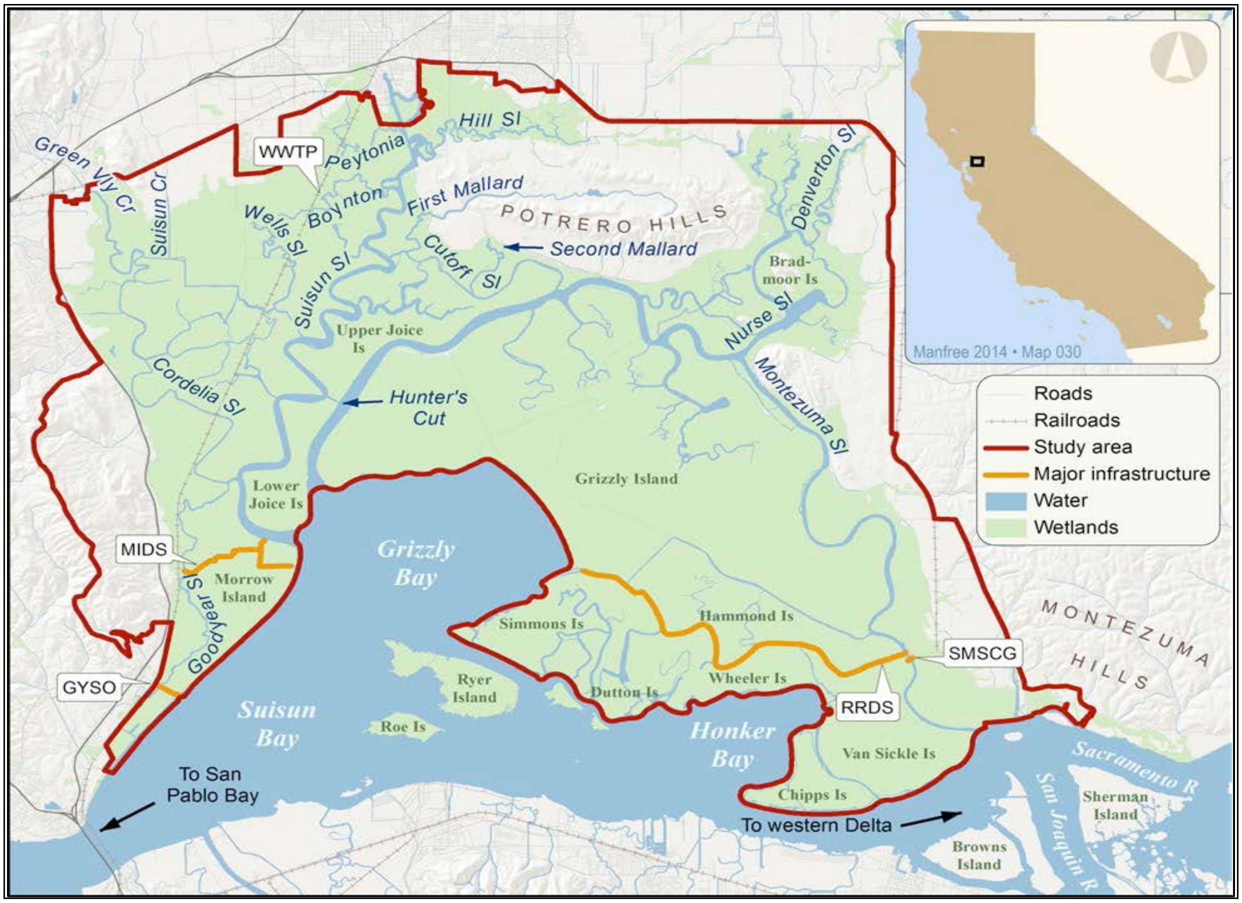

Figure A. Suisun Marsh Fish Study sampling area (map: Manfree 2014).

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

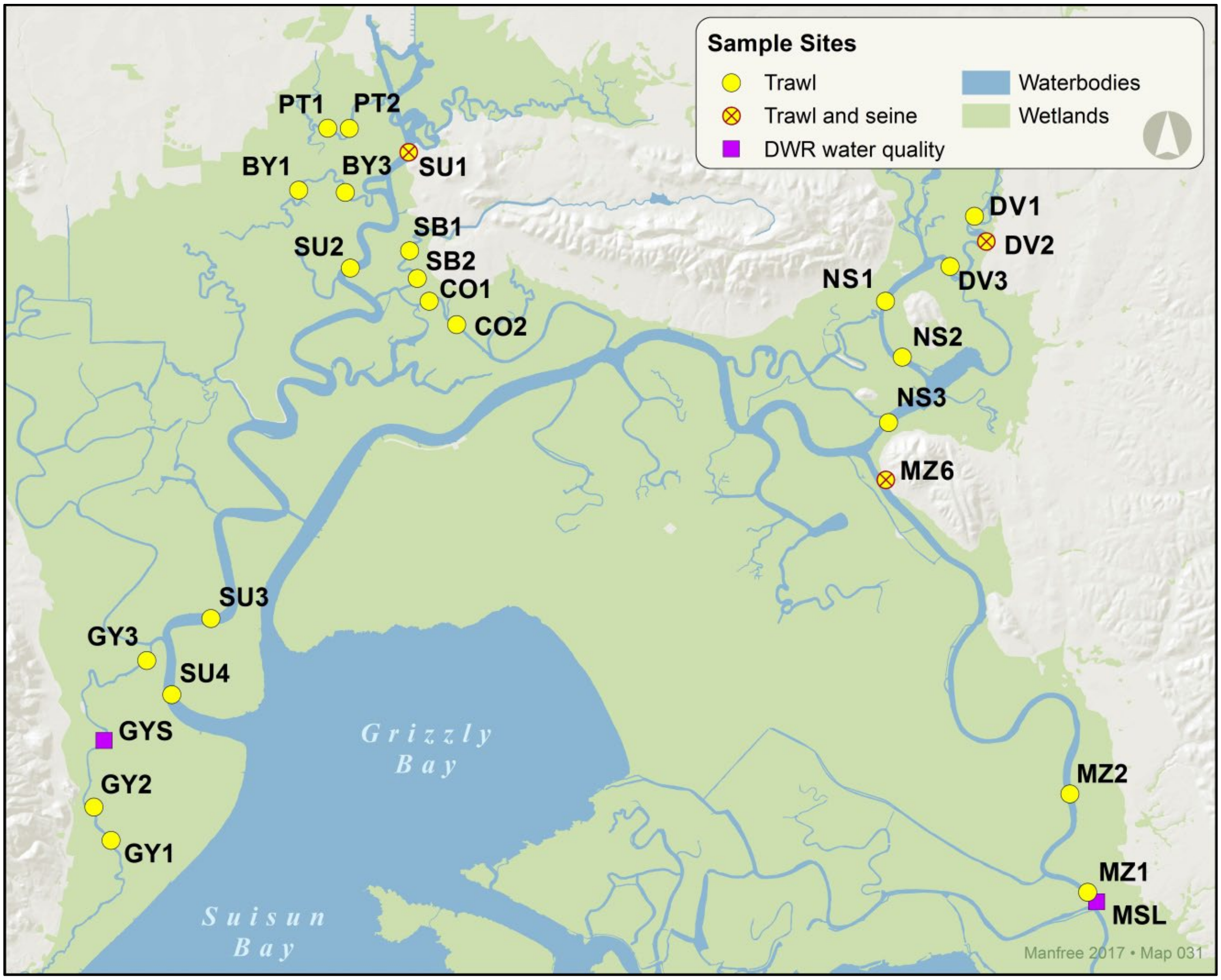

Figure B. Currently sampled sites in Suisun Marsh and California Department of Water Resources (DWR) continuous water-quality monitoring stations used for data quality control (map: Manfree 2016).

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

<u>SeineEffort</u>

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

<u>SledEffort</u>

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

<u>StationsLookUp</u>

Contains codes and descriptions of sample stations.

<u>TransferLog</u>

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

<u>Trawl Effort</u>

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.

<u>UnitsLookUp</u>

Provides information on what unit each data number is in.

<u>VariableCodesLookUp</u>

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

<u>VariablesLookUp</u>

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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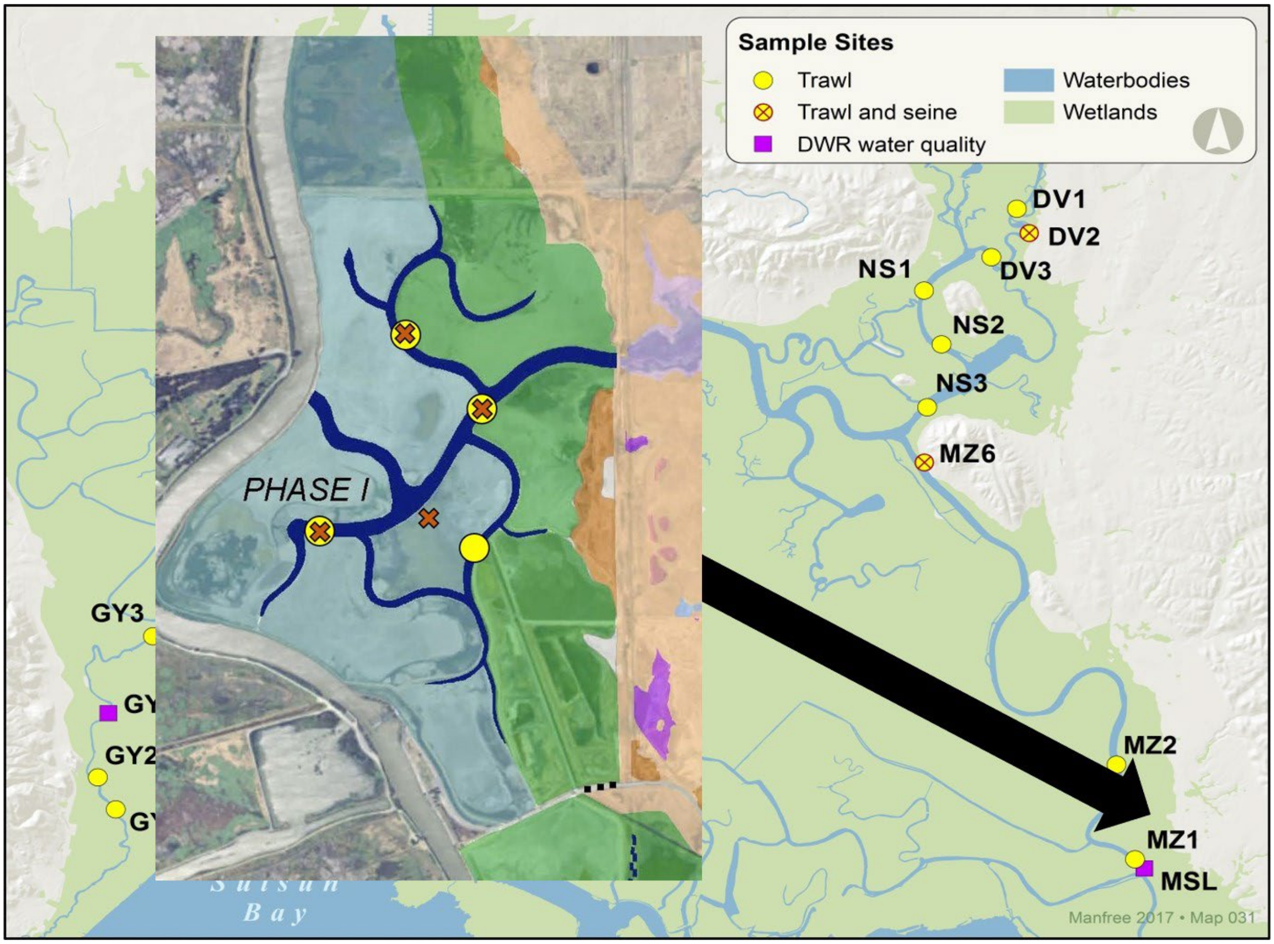
APPENDIX B: MONTEZUMA WETLANDS SAMPLING SITES



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 methods from 1979 to 2022 (native species in bold).

Common Name	Scientific Name	Beach Seine	Otter Trawl	Midwater Trawl	Total
Mississippi silverside	*Menidia audens*	149142	1890	0	151032
striped bass	*Morone saxatilis*	17295	99845	30	117170
Sacramento splittail	***Pogonichthys macrolepidotus***	**7169**	**43930**	**14**	**51113**
yellowfin goby	*Acanthogobius flavimanus*	19844	22504	0	42348
threespine stickleback	***Gasterosteus aculeatus***	**11807**	**18535**	**6**	**30348**
tule perch	***Hysterocarpus traski***	**2844**	**24054**	**6**	**26904**
shimofuri goby	*Tridentiger bifasciatus*	3328	13035	1	16364
prickly sculpin	***Cottus asper***	**1623**	**13290**	**1**	**14914**
threadfin shad	*Dorosoma petenense*	8628	5105	1	13734
longfin smelt	***Spirinchus thaleichthys***	**54**	**13375**	**5**	**13434**
white catfish	*Ameiurus catus*	173	6384	13	6570
common carp	*Cyprinus carpio*	652	5861	1	6514
staghorn sculpin	***Leptocottus armatus***	**3618**	**2756**	**0**	**6374**
Sacramento sucker	***Catostomus occidentalis***	**137**	**3654**	**5**	**3796**
western mosquitofish	*Gambusia affinis*	3503	21	0	3524
black crappie	*Pomoxis nigromaculatus*	291	2859	1	3151
shokihaze goby	*Tridentiger barbatus*	24	3014	6	3044
American shad	*Alosa sapidissima*	511	2362	0	2873
starry flounder	***Platichthys stellatus***	**324**	**2335**	**4**	**2663**
black bullhead	*Ameiurus melas*	3	887	0	890
delta smelt	***Hypomesus transpacificus***	**144**	**665**	**4**	**813**
Pacific herring	***Clupea harengeus***	**130**	**503**	**0**	**633**
Sacramento pikeminnow	***Ptychocheilus grandis***	**352**	**202**	**0**	**554**
Chinook salmon	***Oncorhynchus tshawytscha***	**434**	**80**	**1**	**515**
rainwater killifish	*Lucania parva*	471	41	0	512
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**	**142**	**0**	**158**
Sacramento blackfish	***Orthodon macrolepidotus***	**117**	**27**	**0**	**144**
white sturgeon	***Acipenser transmontanus***	**0**	**130**	**2**	**132**
white crappie	*Pomoxis annularis*	0	112	0	112
fathead minnow	*Pimephales promelas*	39	36	0	75
arrow goby	***Clevelandia ios***	**0**	**60**	**0**	**60**
Pacific lamprey	***Lampetra tridentata***	**0**	**49**	**0**	**49**
bluegill	*Lepomis macrochirus*	23	26	0	49
bigscale logperch	*Percina macrolepida*	24	21	0	45
brown bullhead	*Ameiurus nebulosus*	0	35	0	35

Common Name	Scientific Name	Beach Seine	Otter Trawl	Midwater Trawl	Total
wakasagi	*Hypomesus nipponensis*	13	21	0	34
plainfin midshipman	***Porichthys notatus***	**0**	**29**	**0**	**29**
golden shiner	*Notemigonus crysoleucas*	15	13	0	28
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
largemouth bass	*Micropterus salmoides*	6	0	0	6
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**
redear sunfish	*Lepomis microlophus*	1	2	0	3
white croaker	***Genyonemus lineatus***	**0**	**3**	**0**	**3**
hardhead	***Mylopharadon conocephalus***	**0**	**1**	**0**	**1**
longjaw mudsucker	***Gillichthys mirabilis***	**0**	**1**	**0**	**1**
striped mullet	***Mugil cephalus***	**1**	**0**	**0**	**1**
warmouth	*Lepomis gulosus*	0	1	0	1
Total		213503	282144	138	495785

APPENDIX D: 2022 FISH CATCHES

Total 2022 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold; all codes as in Figure X).

Species	Slough												Total
	BY	CO	DV	FM	GY	MW	MZ	MZN	NS	PT	SUL	SUU	
Sacramento splittail	**125**	**69**	**408**	**113**	**166**	**95**	**184**	**6**	**344**	**195**	**14**	**32**	**1751**
shokihaze goby	1	11		1	29		3	24	53		548	100	770
striped bass	120	26	90	30	69	29	123	36	60	68	27	15	693
longfin smelt		**3**	**46**	**4**	**9**	**177**	**186**	**19**	**49**	**1**	**191**	**6**	**691**
tule perch	**55**	**19**	**74**	**50**	**27**	**14**	**49**	**2**	**236**	**114**	**2**	**21**	**663**
yellowfin goby	68	35	7	75	124	1	22	15	17	43	102	37	546
shimofuri goby	44	113	12	25	47	13	6	8	25	120	12	69	494
Mississippi silverside	2		54	135	32	2				1	6		232
prickly sculpin	**14**	**30**	**12**	**17**	**82**	**2**			**1**	**33**	**2**	**18**	**211**
threadfin shad	22	3	55	18	2	29	22		7	13	1	2	174
threespine stickleback	**9**	**18**	**5**	**10**	**64**		**1**	**2**	**1**	**13**	**4**	**5**	**132**
American shad	6	1	4	6	23	32	5		2	4	3	2	88
common carp	6		11	8	2	8			7	2		1	45
staghorn sculpin	**1**	**3**		**3**	**7**	**1**	**9**	**2**	**4**		**3**	**3**	**36**
black crappie	1		26		1				3	1			32
starry flounder	**1**			**2**			**4**	**4**	**6**	**2**	**5**	**3**	**27**
white catfish		1	18			1		1		1			22
Sacramento sucker	**5**	**3**	**3**	**5**	**1**	**1**				**1**		**1**	**20**
arrow goby					**1**			**1**			**6**	**1**	**9**
wakasagi			3	3					1				7
northern anchovy			**1**		**3**						**1**		**5**
Sacramento pikeminnow	**2**	**1**					**1**		**1**				**5**
hitch							**3**				**1**		**4**
bay pipefish					**1**						**2**		**3**
goldfish	1												1
golden shiner						1							1
plainfin midshipman											**1**		**1**
rainwater killifish	1												1
white sturgeon											**1**		**1**
Total	484	336	829	505	690	406	618	120	817	612	932	316	6665

Total 2022 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	upper Suisun	
Mississippi silverside	3347	1736	1687	259	7029
yellowfin goby	167	119	342	115	743
western mosquitofish	1	704	1		706
threespine stickleback	**132**	**63**	**115**	**17**	**327**
striped bass	98	17	63	17	195
tule perch	**61**	**3**	**67**	**11**	**142**
shimofuri goby	57	44	18	11	130
threadfin shad	43	1	28	6	78
Sacramento splittail	**8**	**4**	**51**	**5**	**68**
rainwater killifish	11	34	7	5	57
staghorn sculpin	**8**	**4**	**34**	**5**	**51**
prickly sculpin	**45**		**3**		**48**
shokihaze goby		18			18
common carp	2	5		9	16
starry flounder	**9**	**1**	**4**		**14**
jacksmelt		**7**			**7**
American shad			1		1
rainbow trout		**1**			**1**
Sacramento pikeminnow			**1**		**1**
Total	3989	2761	2422	460	9632

APPENDIX E: 2022 EFFORT

Number of otter trawls in each slough and each month in 2022.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	2	2	2	2	2	2	0	2	2	2	22
Cutoff	2	2	2	2	2	2	2	2	0	2	2	2	22
Denverton	3	3	3	3	3	3	3	3	0	3	3	3	33
First Mallard	2	2	2	2	2	3	2	2	0	2	2	2	23
Goodyear	3	3	3	3	3	3	3	3	0	3	3	3	33
Montezuma	2	2	2	2	2	2	2	2	0	2	2	2	22
Montezuma new	1	1	1	1	1	1	1	1	0	1	1	1	11
Montezuma Wetlands	4	4	4	4	4	4	4	4	0	4	4	4	44
Nurse	3	3	3	3	3	3	3	3	0	3	3	3	33
Peytonia	2	2	2	2	2	2	2	2	0	2	2	2	22
lower Suisun	2	2	2	2	2	2	2	2	0	2	2	2	22
upper Suisun	2	2	2	2	2	3	2	2	0	2	2	2	23
Total	28	28	28	28	28	30	28	28	0	28	28	28	310

Number of beach seines in each slough and each month in 2022.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	3	2	2	3	3	2	3		3	2	2	28
Montezuma Wetlands	7	7	7	5	7	6	5	6	2	5	5	4	66
Montezuma new	3	3	3	3	3	3	2	2		3	2	2	29
upper Suisun	2	2	2	2	2	2	2	2		2	2	2	22
Total	15	15	14	12	15	14	11	13	2	13	11	10	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)>#1/1/2022# And (Sample.SampleDate)<#1/1/2023#) 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.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)>#1/1/2022# And (Sample.SampleDate)<#12/31/2022#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```