Title
Trends in fish and invertebrate populations of Suisun Marsh January 2021 - December 2021.

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Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2021 - December 2021

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, is 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.

Like in 2020, Suisun Marsh was subjected to very dry conditions in 2021. Delta outflow was lower than average throughout most of the year (and accompanied by no floodplain inundation), resulting in higher-than-average salinities within Suisun Marsh. Two increasingly common conditions recurred in 2021, a new normal: the water was warmer than average, and the water was clearer than average in summer and autumn. Dissolved-oxygen concentrations were consistent throughout the year, with only one low value being recorded, in a small, dead-end slough.

Fish and invertebrate catches in Suisun Marsh in 2021 told three main stories: (1) dry years result in lower fish catches and a shift from freshwater-spawned species to marine-derived fishes; (2) small, dead-end sloughs are key for supporting abundant fish populations; and (3) Suisun Marsh is disproportionately valuable to fishes of conservation importance. With the higher salinities more within their tolerance range, numbers of the native California bay shrimp (*Crangon franciscorum*) and the non-native overbite clam (*Potamocorbula amurensis*) were both quite high. Many native and non-native fishes were less abundant than usual in 2021, mainly those needing fresh water to spawn: the native, floodplain-spawning Sacramento splittail (*Pogonichthys macrolepidotus*) and non-native fishes that spawn in fresh water [threadfin shad (*Dorosoma petenense*), American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*)]. Still, at least for splittail, numbers were higher in Suisun Marsh than in the estuary's main axis relative to long-term averages. The lower catches of fishes dependent on fresh water for reproduction were mitigated in part by increases in several fishes that can spawn in marine and brackish waters: staghorn sculpin (*Leptocottus armatus*), yellowfin goby (*Acanthogobius flavimanus*), and shokihaze goby *Tridentiger barbatus*). Further, many marine species increased in abundance in 2021 [Pacific herring (*Clupea pallasi*) and plainfin midshipman (*Porichthys notatus*)] or were captured for the first time in the study's history [jacksmelt (*Atherinops californiensis*) and arrow goby (*Clevelandia ios*)]. Many age-0 longfin smelt (*Spirinchus thaleichthyes*), a native zooplankton-eating anadromous species on the California Endangered Species Act, were caught in Suisun Marsh in spring, coincident with high opossum-shrimp numbers. Large fish catches most frequently occurred in small, dead-end sloughs where plankton concentrations have often been higher. Thus Suisun Marsh in 2021 was a premonition of what the future - given increasing sea level, more-frequent droughts, and warmer temperatures - may look like: a place where invertebrate and fish assemblages are increasingly dominated by marine species that still remains very important for endangered and endemic species, especially Sacramento splittail and longfin smelt.

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INTRODUCTION

Suisun Marsh is a brackish-water marsh bordering the northern edges of Suisun, Grizzly, and Honker bays in the San Francisco Estuary (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). Much of the marsh area is diked wetlands, with the rest of the acreage consisting of tidal sloughs, tidal wetlands, and grasslands (DWR 2001). The marsh's central location in the northern San Francisco Estuary makes it 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 key 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 through special collections (*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 (winter seasonals, spring/summer seasonals, and residents) that differed in timing of abundance peaks, primarily due to differences in life history. 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.* 2019, 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 ancillary studies to the Suisun Marsh Fish Study have enhanced understanding of often ignored but important animals and habitats of 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 at-risk 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. Consequently, the Suisun Marsh Fish Study remains instrumental in enhancing understanding of the estuary's biology, 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 2021 with average conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2021 to annual averages, noting abundance changes between 2020 and 2021; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2021, pointing out unusual occurrences; and (4) describe the geographic distribution of fishes and invertebrates.

METHODS

Study Area

Suisun Marsh is a mosaic of landscape types totaling about 38,000 hectares, with about 9% of the acreage comprised of tidal sloughs (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).

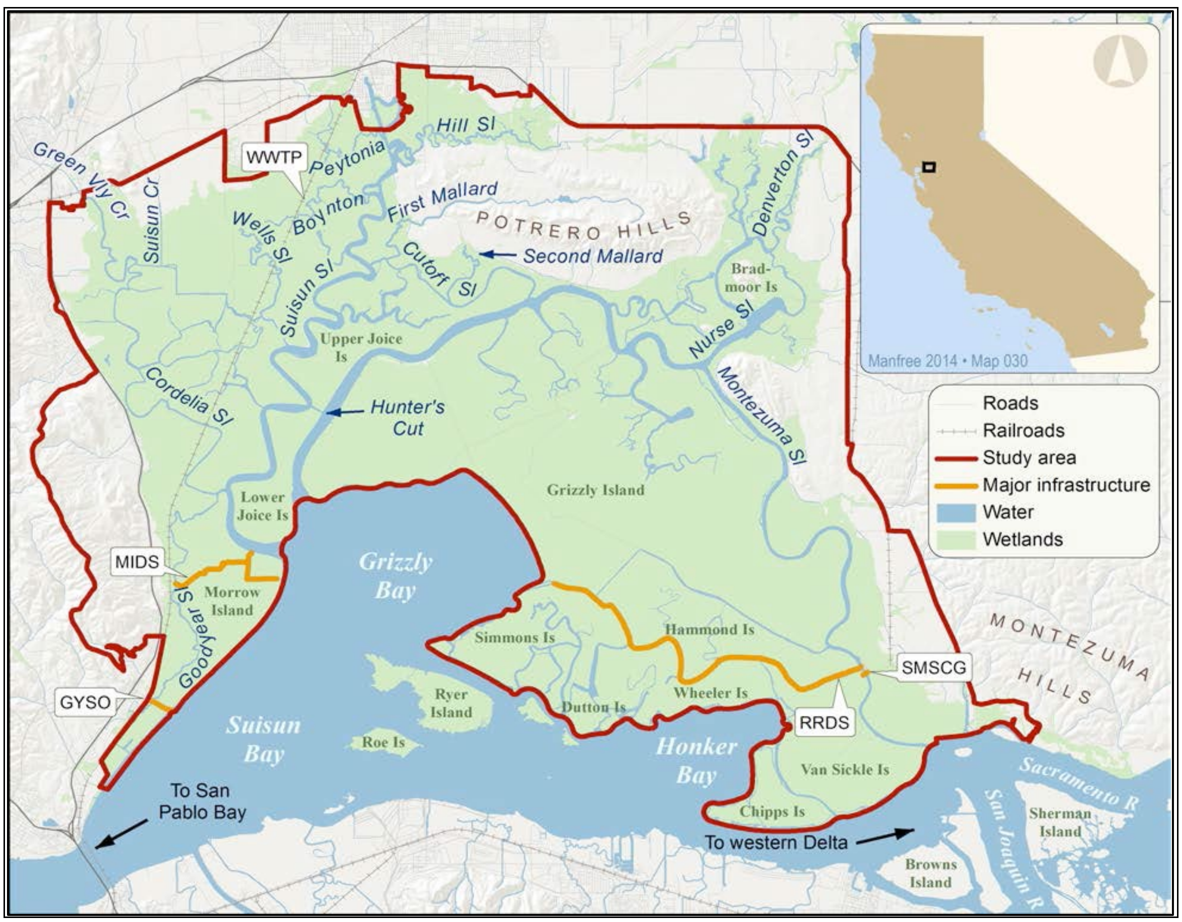

Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point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

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.). Most sloughs in the marsh are diked to some extent, although some small sloughs (*e.g.,* First Mallard) within the Rush Ranch preserve are undiked and thus have wetlands regularly flooded by high tides. 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. Submerged aquatic plants, dominated by sago pondweed (*Stuckenia* spp.), are found throughout the marsh but are restricted to shallow, subtidal shoals.

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).

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 managed 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 discharged into sloughs from managed 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 is high and carrying high sediment loads (*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, likely 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 Montezuma Slough just downstream of the confluence of the Sacramento and San Joaquin rivers, inhibit saltwater intrusion into the marsh during flood tides, thereby providing fresher water for diked wetlands (DWR 2001; Figure 1). The gates began operating in 1988 (DWR 2001). Numerous water control structures, most of which are unscreened for fish, are located throughout the marsh; they are opened in early autumn for flooding 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). Native and non-native shrimps [California bay shrimp and Siberian prawn (*Palaemon modestus*), 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, Columbano *et al.* 2021)]. Two bottom fishes - Sacramento splittail and prickly sculpin (*Cottus asper*) - and two littoral fishes - threespine stickleback (*Gasterosteus aculeatus*) and tule perch (*Hysterocarpus traski* - are typically the most abundant native fishes, 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 anadromous species with juveniles that eat zooplankton (American shad, striped bass), and Japanese estuarine small-bodied gobies. The small bottom fishes (prickly sculpin and the gobies) and threespine stickleback are the fishes most frequently eaten by Suisun Marsh's primary piscivores, adult white catfish and striped bass (O'Rear 2012, O'Rear and Moyle 2015*b*). Two small-bodied fishes native to the Mississippi River system [threadfin shad and Mississippi silverside (*Menidia audens*)] are often the most abundant inshore fish species in Suisun Marsh. 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.* 2020). 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 productivity 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 comparisons 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. Sampling in a newly restored wetland complex (Montezuma Wetlands; Appendix B) occurred throughout 2021, results of which can be found in Platzer *et al.* (2022).

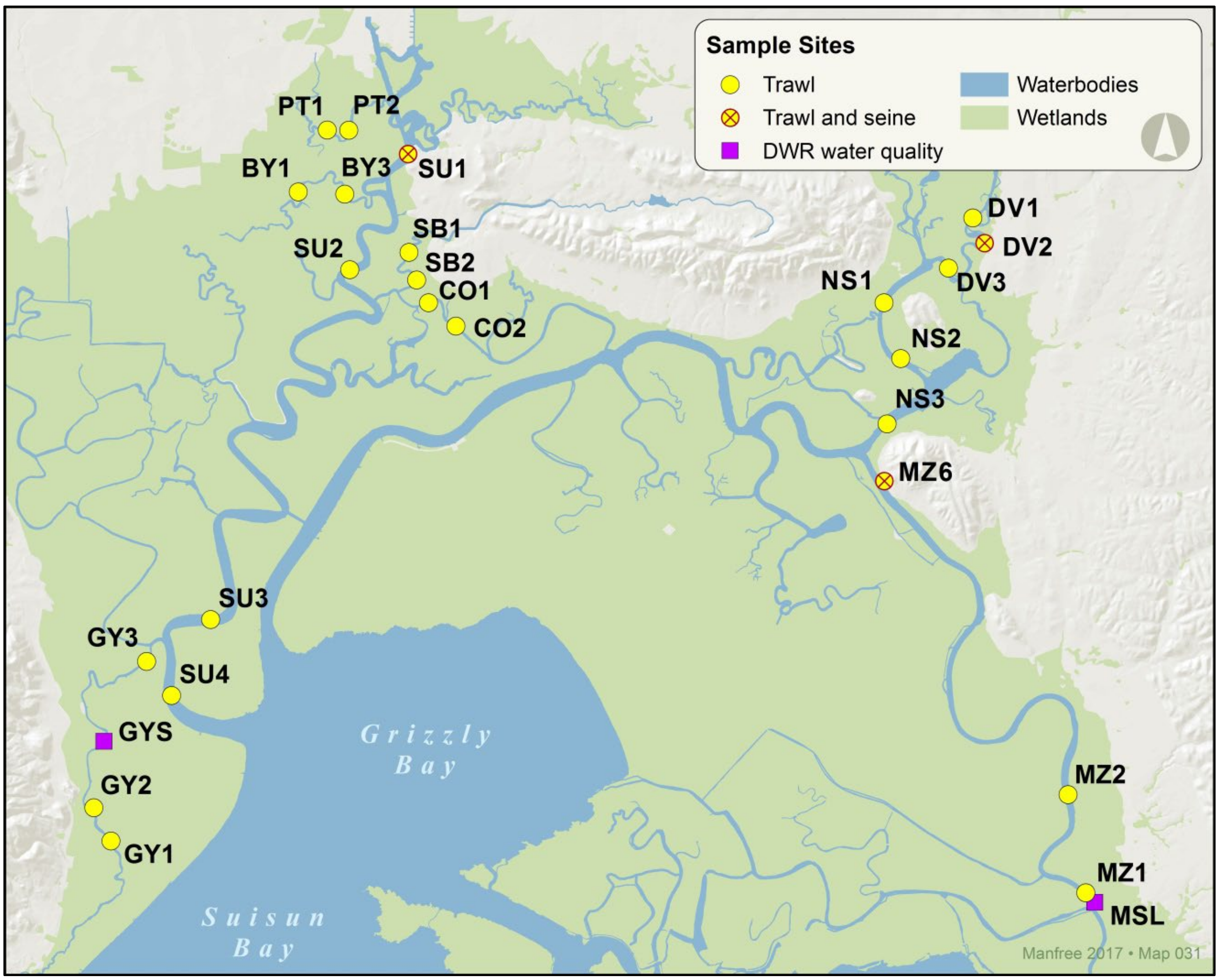

Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report (map by Amber Manfree).

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.

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

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

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 2021 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 2021 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's Dayflow website (DWR 2022).

Monthly water-quality results of 2021 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 2021 are found in Appendix C; annual catch of each slough and number of trawls/seines in each slough (including Montezuma Wetlands) in 2021 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 2021 continued the very dry conditions seen in 2020, with daily Delta outflow in 2021 well below the average for all years of the study (1980 - 2021; Figure 3) except in late October and late December. A storm in late January mildly raised Delta outflow, but from then through mid-October, outflow remained low and varied little (Figure 3). Outflows far surpassed typical values from an exceptional storm in late October, declined again to very low levels in November, and then rebounded to usual values in December. Neither Yolo Bypass nor the Cosumnes River floodplain, critical spawning areas for Sacramento splittail (Sommer *et al.* 1997, Moyle *et al.* 2004), flooded during the spawning period (late January - May; Feyrer *et al.* 2006; DWR 2022*a*).

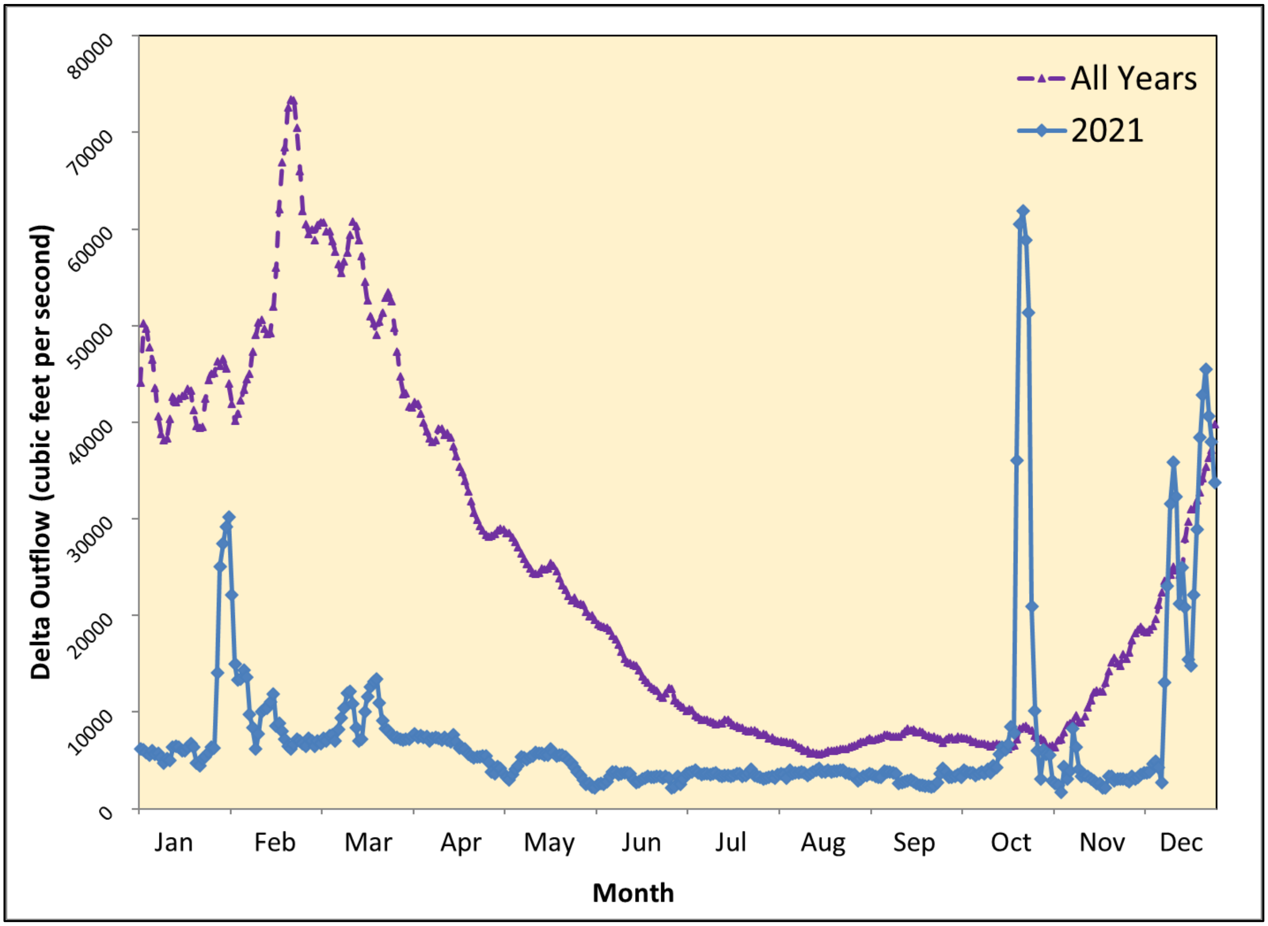

Figure 3. Daily Delta outflow in 2021 and the average for all years of the study (1980 – 2021; DWR 2022).

Salinity

The low outflows in 2021 translated to a salty year in Suisun Marsh, with an annual average salinity from the fish study (6.7 ppt) higher than usual (4.0 ppt for 1980 - 2021; Figure 4). Monthly average salinity was above average in every month but November (Figure 4), increasing at a greater-than-average rate from April until September when the Suisun Marsh Salinity Control Gates began operations a month early (DWR 2021). Salinities recorded by the fish study were within the bounds of the two water-quality stations throughout the year (Figure 5). Because of low outflows, the Suisun Marsh Salinity Control Gates were run in all months except June, July, August, and briefly in November and December following storms (Figure 4). Salinities notably decreased at most sites after commencement of gate operations in September except in Boynton Slough (Figure 6), likely because fresh water from the wastewater-treatment plant was diverted from the slough to adjoining diked wetlands (Siegel *et al.* 2011). A range of salinities existed in Suisun Marsh all months in 2021 (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, 15.5 ppt, occurring in upper Goodyear Slough in July). The freshest water was either in upper Boynton Slough, near the wastewater-treatment-plant discharge point, or in eastern Montezuma Slough, at our sites closest to the Delta.

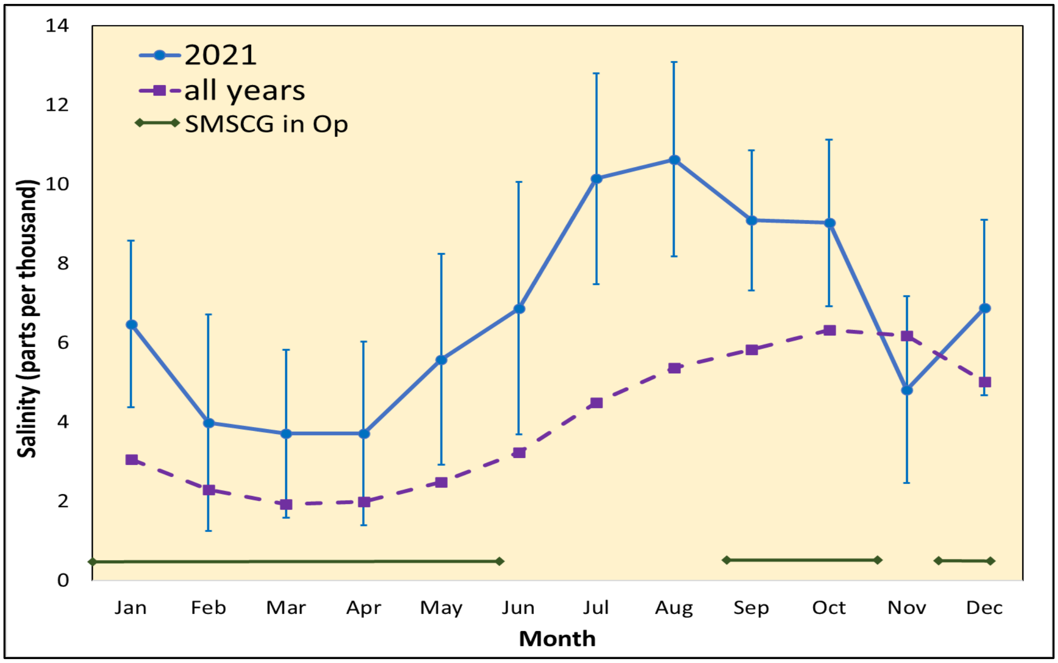

Figure 4. Monthly average salinity in 2021 and for all years of the study (1980 - 2021); error bars are standard deviations in 2021. Olive bars show when the SMSCG were operating in 2021.

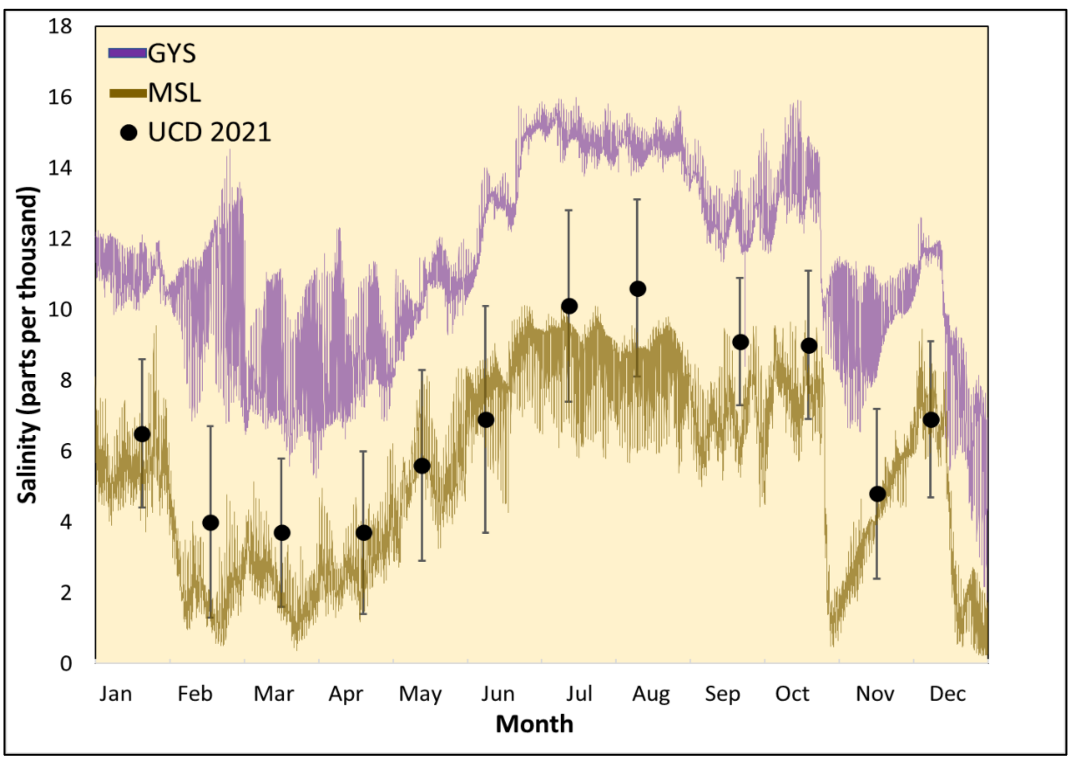

Figure 5. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations of the Suisun Marsh Fish Study ("UCD 2021").

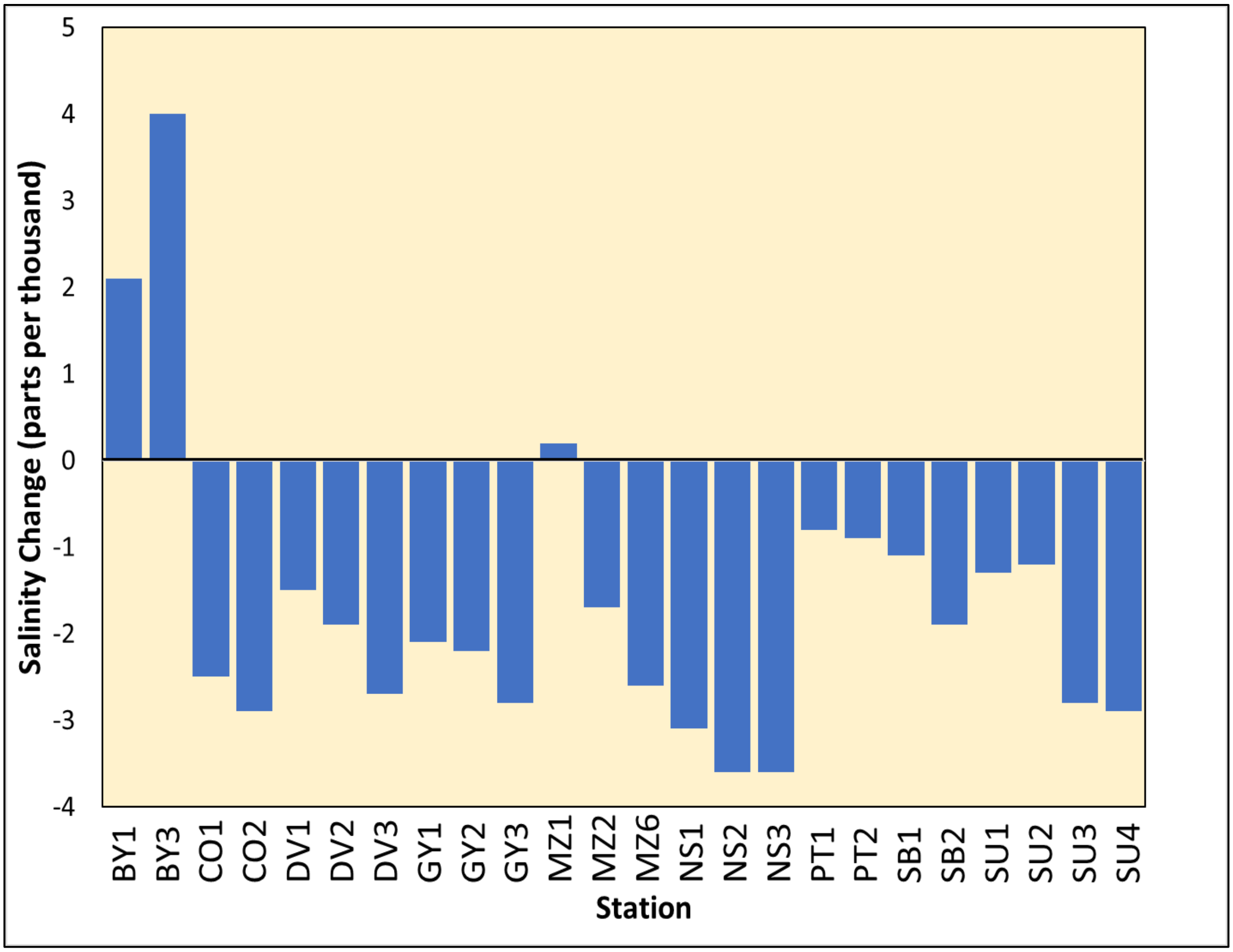

Figure 6. Site salinity change between August and September 2021 from SMSCG operation ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "MZ" = Montezuma Slough, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "SU" = Suisun Slough. Site locations in Figure 2).

Dissolved Oxygen (DO)

Oxygen levels throughout Suisun Marsh in 2021 were nearly always hospitable for all fishes (>5 mg/L; Moyle 2002). Average monthly DO concentrations exhibited a mild decline throughout the year and hovered close to the long-term average, with 2021's values always being higher than 5 mg/L (Figure 7). Trends in minimum and maximum monthly DO concentrations paralleled each other well except in September, when minimum DO dropped substantially while maximum DO remained unchanged. The lowest monthly DO concentration occurred five times in upper Goodyear Slough, six times in Boynton Slough, and once in First Mallard Slough - all three being small, dead-end sloughs. Highest monthly concentrations were scattered, frequently being in eastern Montezuma Slough (five months) but also in Denverton, Goodyear, Nurse, Peytonia, and Suisun sloughs. Only once was DO concentration found below 3 mg/L, a critical value for tule perch (Cech, Jr. *et al.* 1990), which occurred in September in upper Goodyear Slough (GY1 and GY2; Figure 2) where DO concentration averaged 1.3 mg/L.

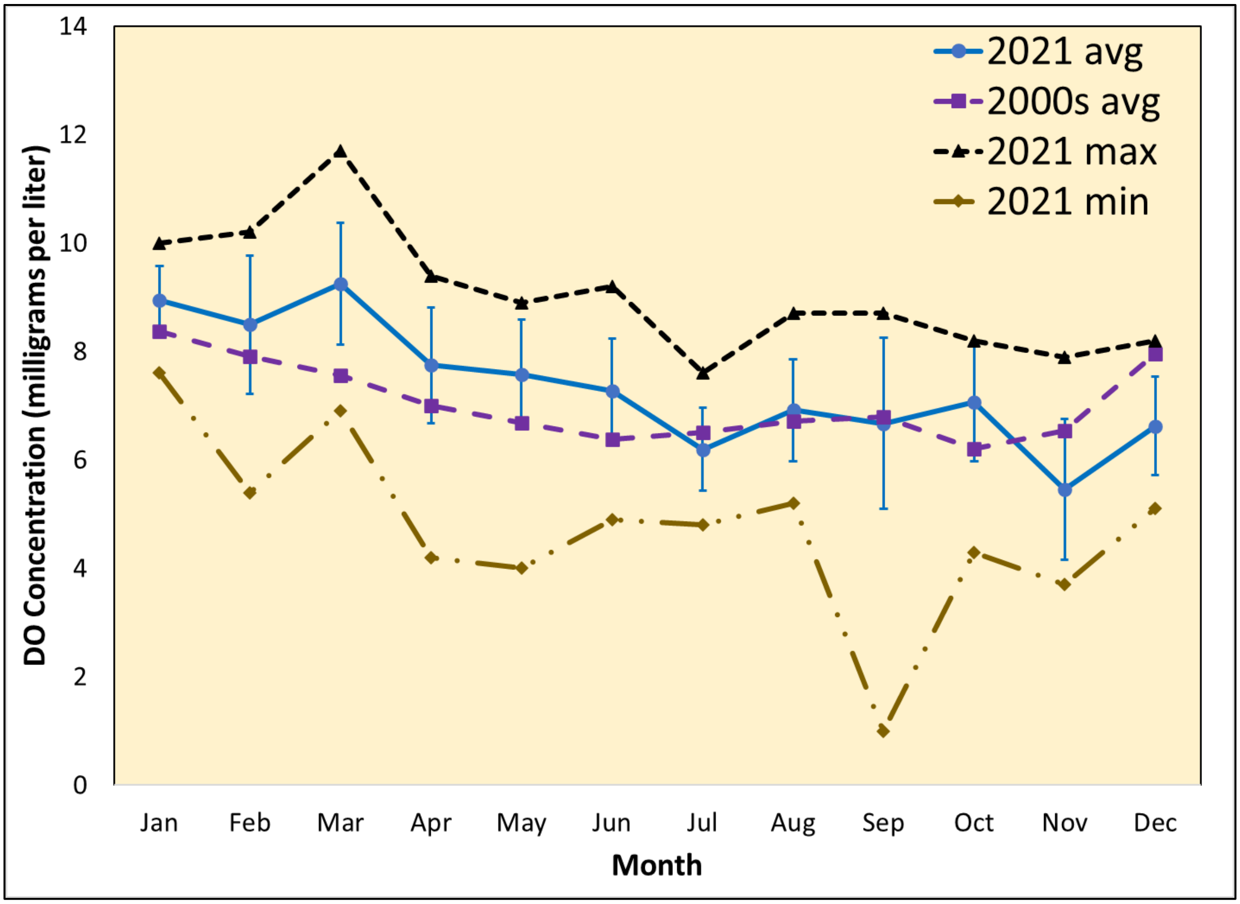

Figure 7. Monthly average DO concentration in 2021 and for the 2000s (2000 - 2021), maximum DO concentration in 2021, and minimum DO concentration in 2021. Error bars are standard deviations in 2021.

Water Temperature

Overall, 2021 was a warm year (HPRCC 2022), although our sampling frequently coincided with short cool periods that did not correspond to wider regional trends. Monthly average water temperature was mildly warmer in January and February, a bit colder than expected in March, and then again warmer than average in April, consistent with regional patterns (Figure 8). However, May through August found our 2021samples cooler than both our average and regional temperatures, the last of which, in general, were very warm. The disparity was especially notable in June, when our sampling coincided with a cool spell between two very warm periods (Figure 9). Measurement error was not a factor since quality-assurance procedures conducted between sampling found agreement between our probe and continuous gauges (O'Rear, unpublished data). From September through November, temperature patterns between our samples and regional trends were more consistent, with September being about average, October being abnormally cool, and November being warmer than average. In December, however, patterns diverged again, with the month being much cooler than usual but our sampling occurring during a warm spell. Consistent with greater sensitivity of smaller sloughs to air temperature than larger sloughs, continuous gauges showed water temperature fluctuated more and reached more extreme values in Goodyear Slough than in eastern Montezuma Slough (Figure 9). Our values only partially mirrored this pattern, with the highest temperature in a small slough (24.7°C in Denverton Slough in June) but the lowest in a large slough, eastern Montezuma (9.2°C in January).

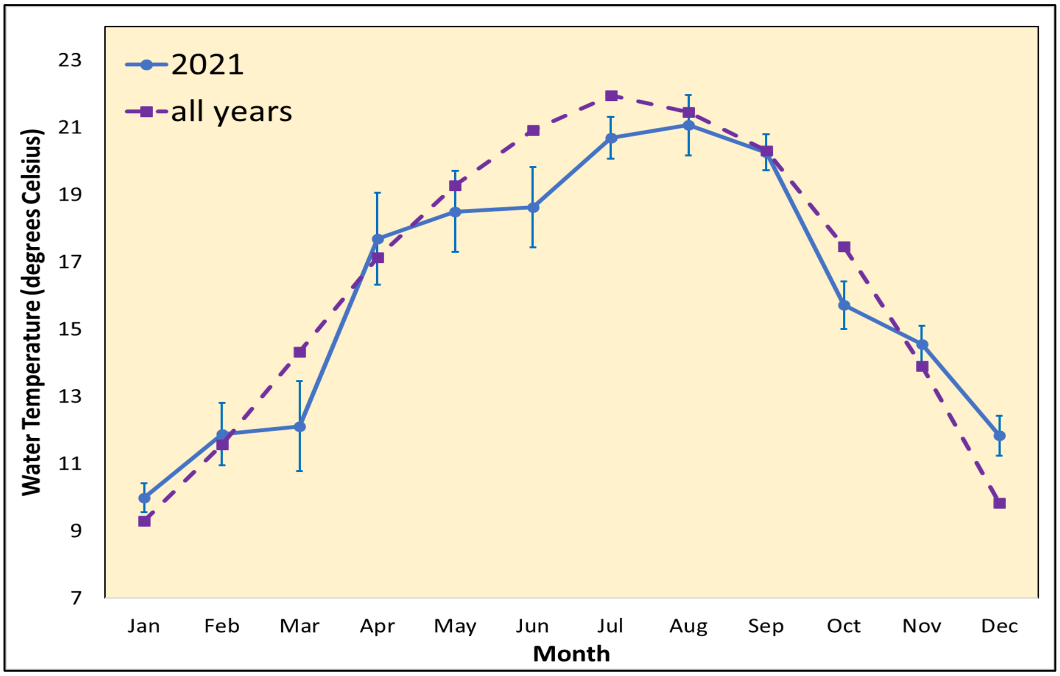

Figure 8. Monthly average water temperature in 2021 and for all years of the study (1980 - 2021); error bars are standard deviations in 2021.

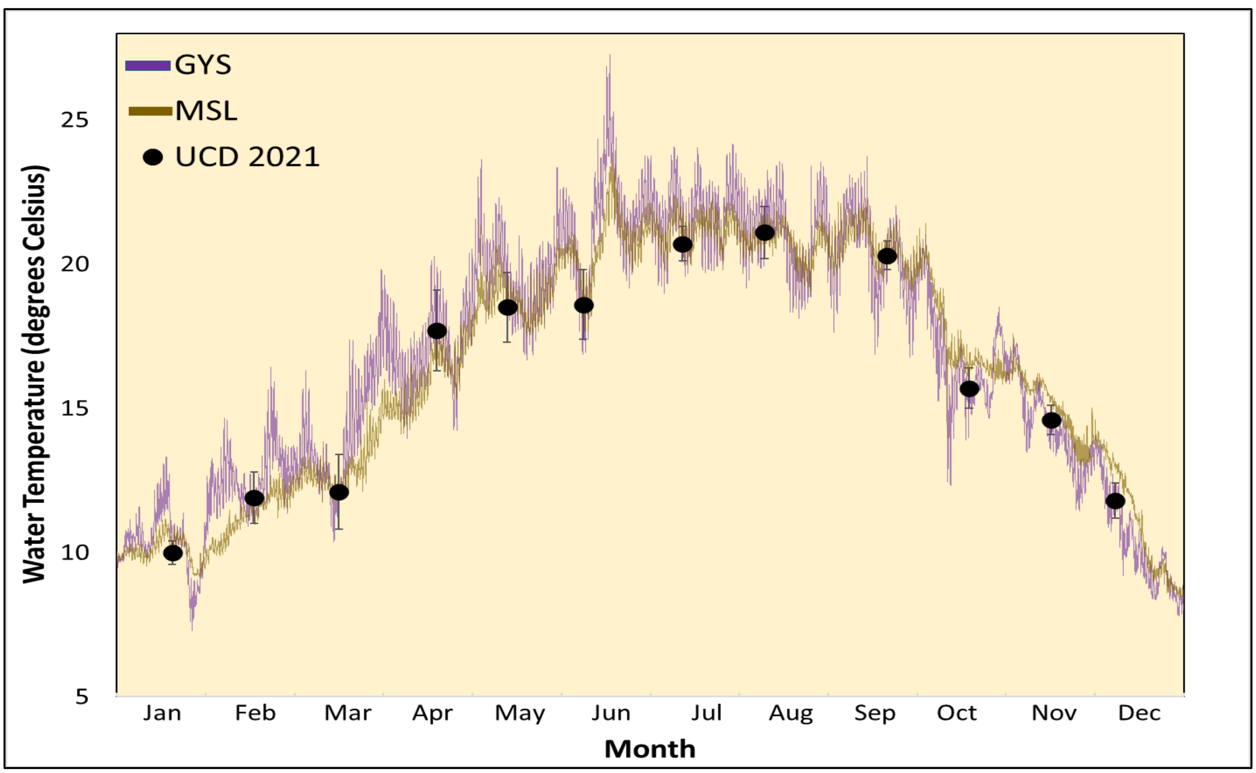

Figure 9. Fifteen-minute water temperature from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly temperatures and standard deviations from the Suisun Marsh Fish Study ("UCD 2021").

Water Clarity

Average monthly water clarity was higher than usual during all of 2021 except in November, following the highest outflows for the year (Figure 10). The pattern in monthly clarity was fairly typical, with lower values early in the year followed by increasing values through summer and autumn, with clarity peaking in October. The clearest water was in eastern Montezuma Slough or in the site in Nurse Slough closest to Montezuma (NS3; Figure 2) in all but one month, with the year's highest clarity (71 cm) recorded in December. Lowest clarity was mostly in small sloughs (10 of 12 months) and Suisun Slough, with the lowest clarity measured being 15 cm in lower Goodyear Slough in February.

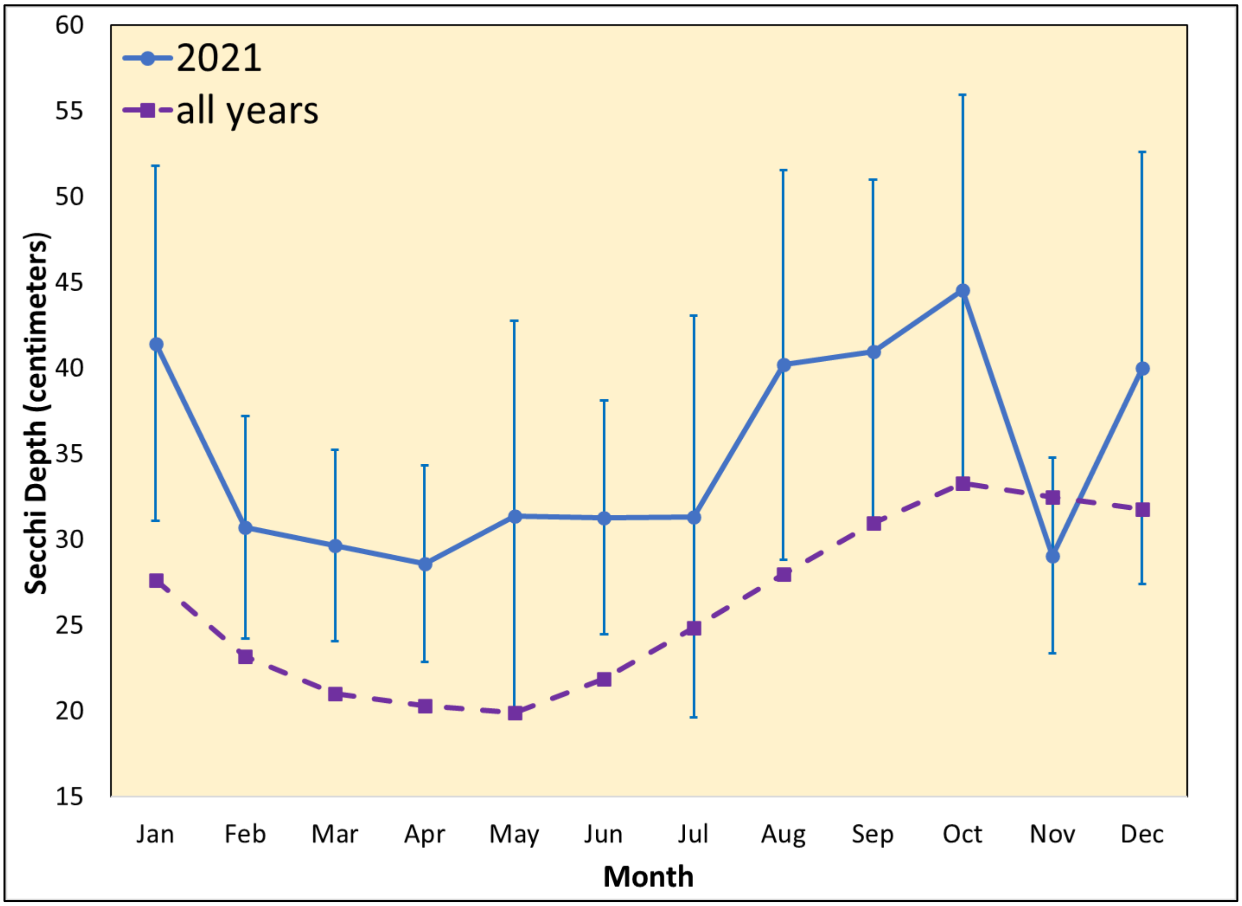

Figure 10. Monthly average water clarity in 2021 and for all years of the study (1980 - 2021); error bars are standard deviations in 2021.

Trends in Invertebrate Distribution and Abundance

Opossum Shrimp

Opossum shrimp were very abundant in 2021, with the year's CPUE (1.6 rank per trawl) reaching its highest value since 1991 (1.8 rank per trawl) and exceeding the all-years average (1.3 rank per trawl; Figure 11). Monthly CPUE increased relatively steadily until peaking in July, thereafter plummeting through August to September, after which it continued to decline but at a much lower rate (Figure 12). The monthly pattern was fairly typical except for peak abundance occurring in July in 2021, when it is usually reached April - June (Moyle *et al.* 1986, O'Rear *et al.* 2020, 2021). Opossum shrimp were prevalent in all sloughs, although they were most abundant in Denverton (0.52 rank per minute), a small slough, and least abundant in Montezuma Slough (0.15 rank per minute), a large slough, consistent with Montgomery *et al.* (2015).

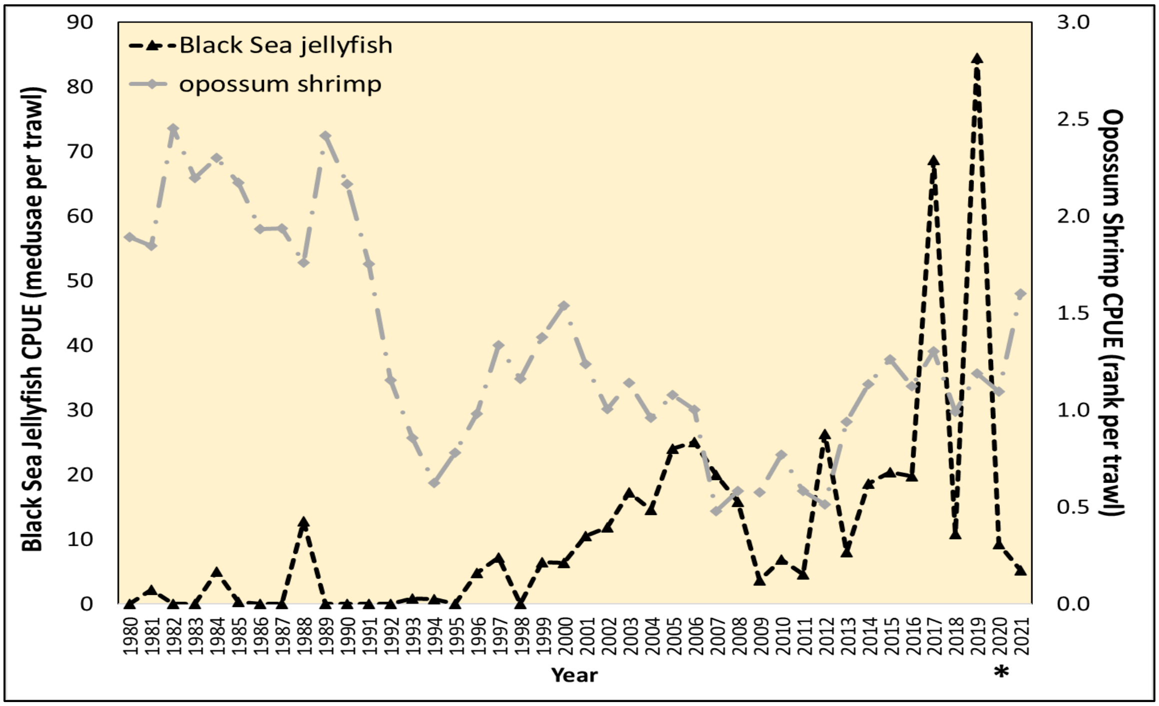

Figure 11. Annual CPUE of Black Sea jellyfish and opossum shrimp (* = no March or April samples).

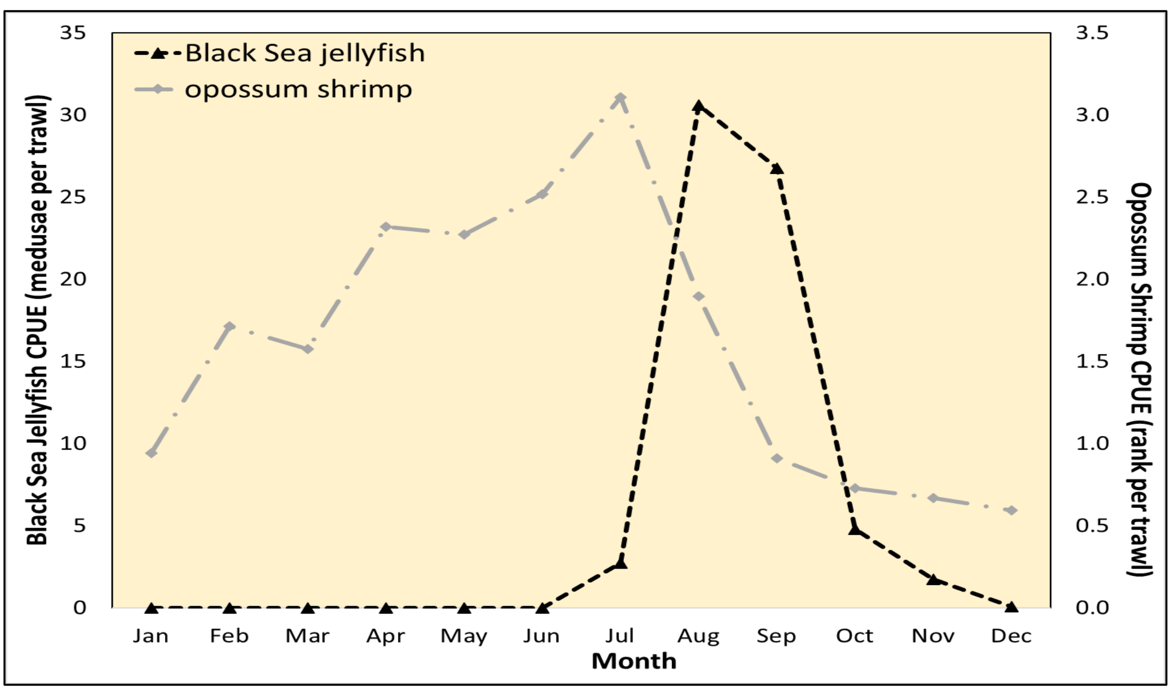

Figure 12. Monthly average CPUE of Black Sea jellyfish and opossum shrimp in Suisun Marsh in 2021.

Black Sea Jellyfish

Black Sea jellyfish medusae were not abundant in 2021, with CPUE (5.3 medusae per trawl; Figure 11) well below values for both 2020 and all years (9.3 and 11.3 medusae per trawl, respectively). Medusae first appeared in July, attained highest numbers in August and September, dropped precipitously through October and November, then disappeared in December (Figure 12) - a usual pattern (Baumsteiger *et al.* 2018). Medusae were captured in all sloughs, although about two-thirds of the catch (69%; 1,000 individuals) came from the large Montezuma Slough. In contrast, only three medusae were caught in two very long, small sloughs - Goodyear and Denverton (Figure 2) - consistent with Baumsteiger *et al.* (2018), where sloughs far from the main corridors of the marsh, Suisun and Montezuma sloughs, frequently have the lowest abundances. Also, only eight medusae were captured in lower Suisun Slough, likely because salinities exceeded favorable levels (~10 ppt; Baumsteiger *et al.* 2018) for most of the bloom period (July - October).

Clams

<u>Overbite Clam</u>

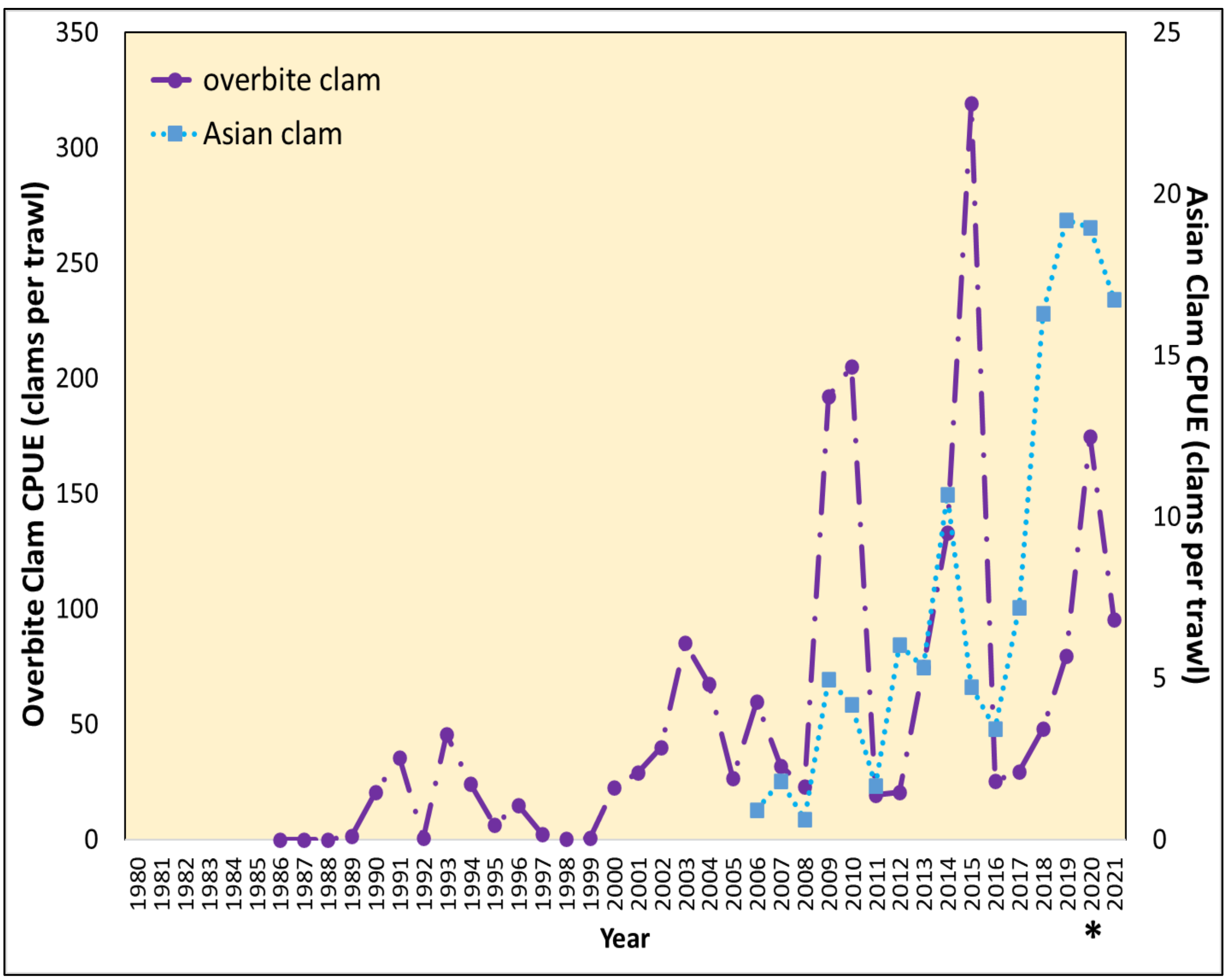

Figure 13. Annual CPUE of overbite clam and Asian clam (* = no March or April samples).

Overbite clams were abundant in 2021 (Figure 13), with the year's CPUE (95 clams per trawl) lower than 2020's value but higher than the all-years value (175 and 55 clams per trawl, respectively). Monthly CPUE of overbite clams displayed the typical pattern: low early in the year, highest in summer, and then low again in autumn (Figure 14; Baumsteiger *et al*. 2017, O'Rear *et al.* 2020). The timing of high overbite clam numbers co-occurred quite closely with highest densities of Black Sea jellyfish medusae, reflecting a shared requirement for salinities higher than 3 ppt for certain life stages (Nicolini and Penry 2000). Geographic distribution of the two invertebrates was dissimilar, however, with nearly all overbite clams (98% of the catch, 25,944 individuals) coming from 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% (52 individuals) of 2021's catch (26, 440 individuals) came from the combination of Boynton, Cutoff, Denverton, First Mallard, Nurse, and Peytonia sloughs (Figure 2).

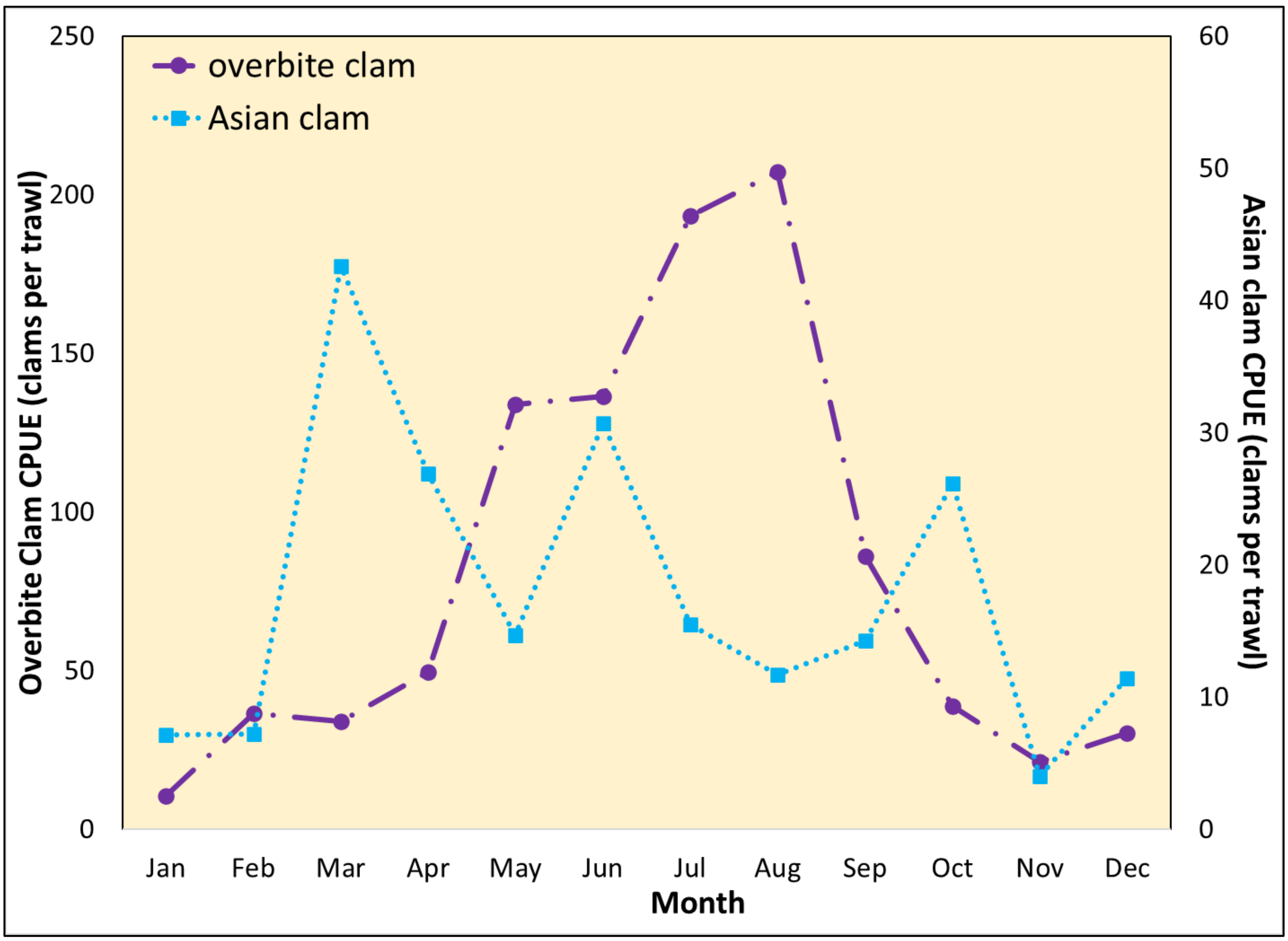

Figure 14. Monthly average CPUE of overbite clam and Asian clam in Suisun Marsh in 2021.

Asian Clam

Like overbite clam, Asian clam was abundant in 2021, with CPUE close to 2020's value (17 and 19 clams per trawl, respectively) and well above the average for 2006 - 2021 (8 clams per trawl; Figure 13). Similarities between the two clams stopped there. Asian clam monthly CPUE did not display a clear pattern - it was quite variable, with peak catches occurring in late winter, late spring, and autumn (Figure 14). Geographic distribution of the clams was rather complementary. While very abundant in two big sloughs - eastern Montezuma and upper Suisun - which, together, hosted 55% (2,577 individuals), Asian clam was also very abundant in smaller sloughs with freshwater inputs (Boynton and Peytonia), where 30% 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 5% 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 2021, with the annual CPUE above both the all-years average and 2020's value (34, 27, and 20 shrimp per trawl, respectively; Figure 15). Monthly CPUE was negligible in January and February but then reached a peak in May; thereafter, numbers generally declined, with some variability, to the year's end (Figure 16). Most California bay shrimp - 66% of the annual catch (6,179 individuals) - were captured in large sloughs, with only 157 individuals (2% of year's catch) coming from three small sloughs: Boynton, Denverton, and First Mallard. Like overbite clam, the one small-slough site that hosted very high bay shrimp numbers (1,515 individuals) was the one in the saltier southwest region of the marsh closest to a large slough: GY3. 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.

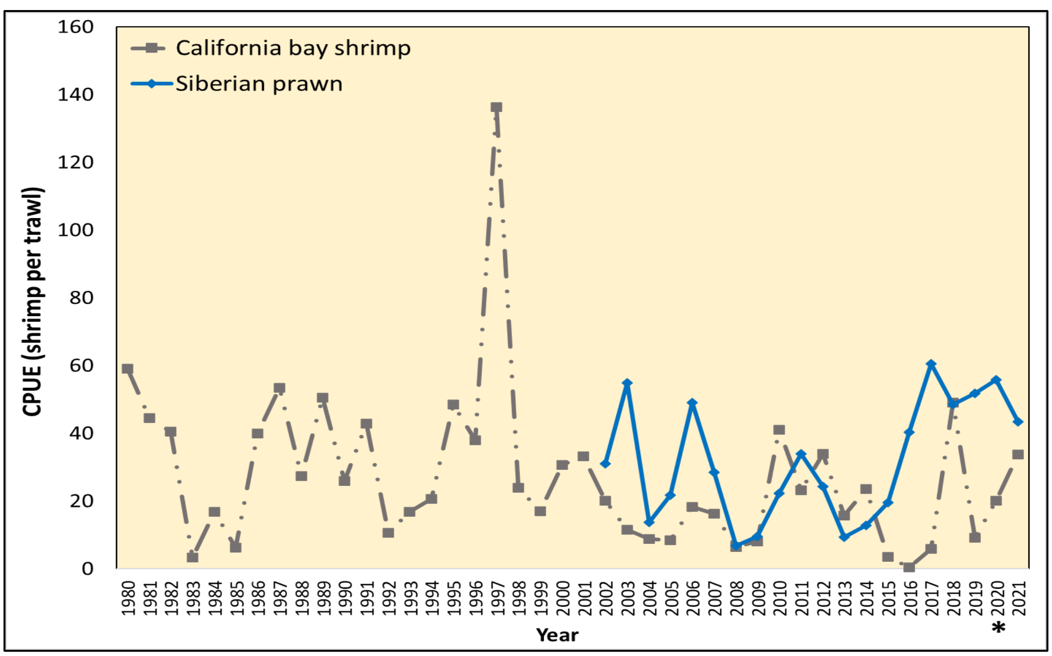

Figure 15. Annual CPUE of California bay shrimp and Siberian prawn (* = no March or April samples).

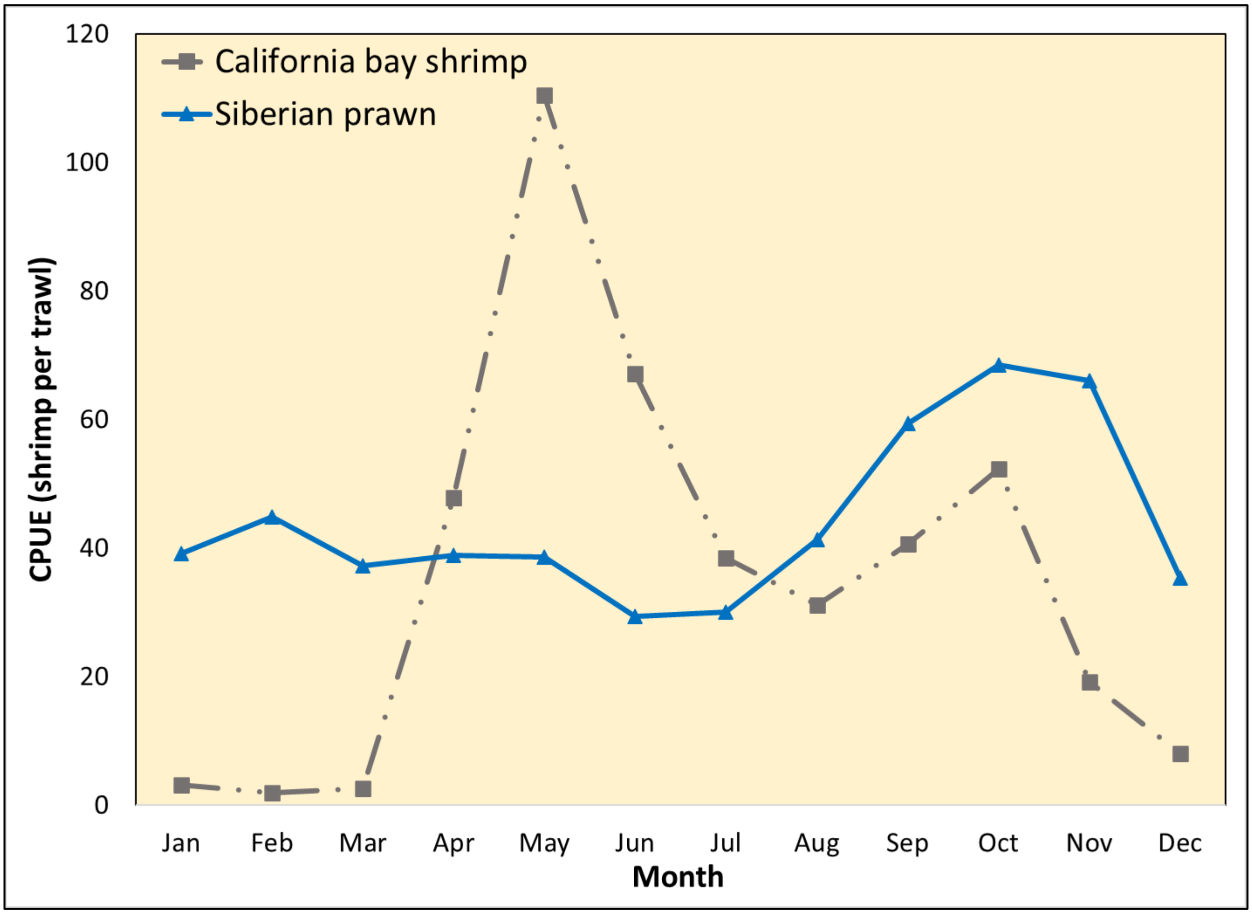

Figure 16. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2021.

<u>Siberian Prawn</u>

Siberian prawn were abundant again in 2021 (43 shrimp per trawl), lower than in 2020 (56 shrimp per trawl) but higher than the average of 2002 - 2021 (32 shrimp per trawl; Figure 15). Numbers were remarkably consistent through the year's first eight months, after which they increased moderately during autumn before declining again in December (Figure 16). Somewhat complementing geographic distribution of California bay shrimp, Siberian prawn were common in all sloughs of the marsh, being especially abundant in Boynton, Peytonia, and upper Suisun sloughs [12% (1,503 individuals), 13% (1,576 individuals), and 39% (4,763 individuals) of 2021's catch, respectively]. Numbers in the saltier southwest marsh were notably lower when salinities were at their maximum from July through October (*e.g.*, only 11 individuals being captured in Goodyear Slough during that period), but they increased notably in November after outflow increased and salinities decreased. 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 2021 (18 fish per trawl) was mildly low, close to the 2020 CPUE and below the all-years average (17 and 24 fish per trawl, respectively; Figure 17). CPUE for both native and non-native fishes was similar between 2020 and 2021 (natives: 7 and 9 fish per trawl, respectively; non-natives: 10 and 9 fish per trawl, respectively), and both were below all-years averages (natives: 10 fish per trawl; non-natives: 14 fish per trawl). However, the composition of both fish groups changed between the years. While CPUE of Sacramento splittail and tule perch remained relatively unchanged between the two years, numbers of longfin smelt and threespine stickleback increased dramatically (Table 1). Also, two native benthic fishes that spawn in saltier waters west of Suisun Marsh - staghorn sculpin and arrow goby - increased substantially, with 2021 being the first year ever in the study's history with arrow goby being caught. The difference between 2020 and 2021 for threespine stickleback, staghorn sculpin, and longfin smelt was partially attributable to no samples in March and April 2020; however, numbers for stickleback and staghorn sculpin were still higher in adjoining months in 2021 and comparable for longfin smelt, so the difference was true but inflated by the fewer samples. Three native marine species - plainfin midshipman, northern anchovy (*Engraulis mordax*), and Pacific herring (*Clupea pallasi*) - were also present, though their numbers were low (7, 5, and 17 individuals, respectively). For non-natives, severe declines in striped bass and threadfin shad, both of which spawn in fresh water, were largely compensated by dramatic increases in two more benthic estuarine fishes, yellowfin goby and shokihaze goby (Table 1). Shokihaze goby reached its highest-ever abundance in 2021 since its introduction in 1999.

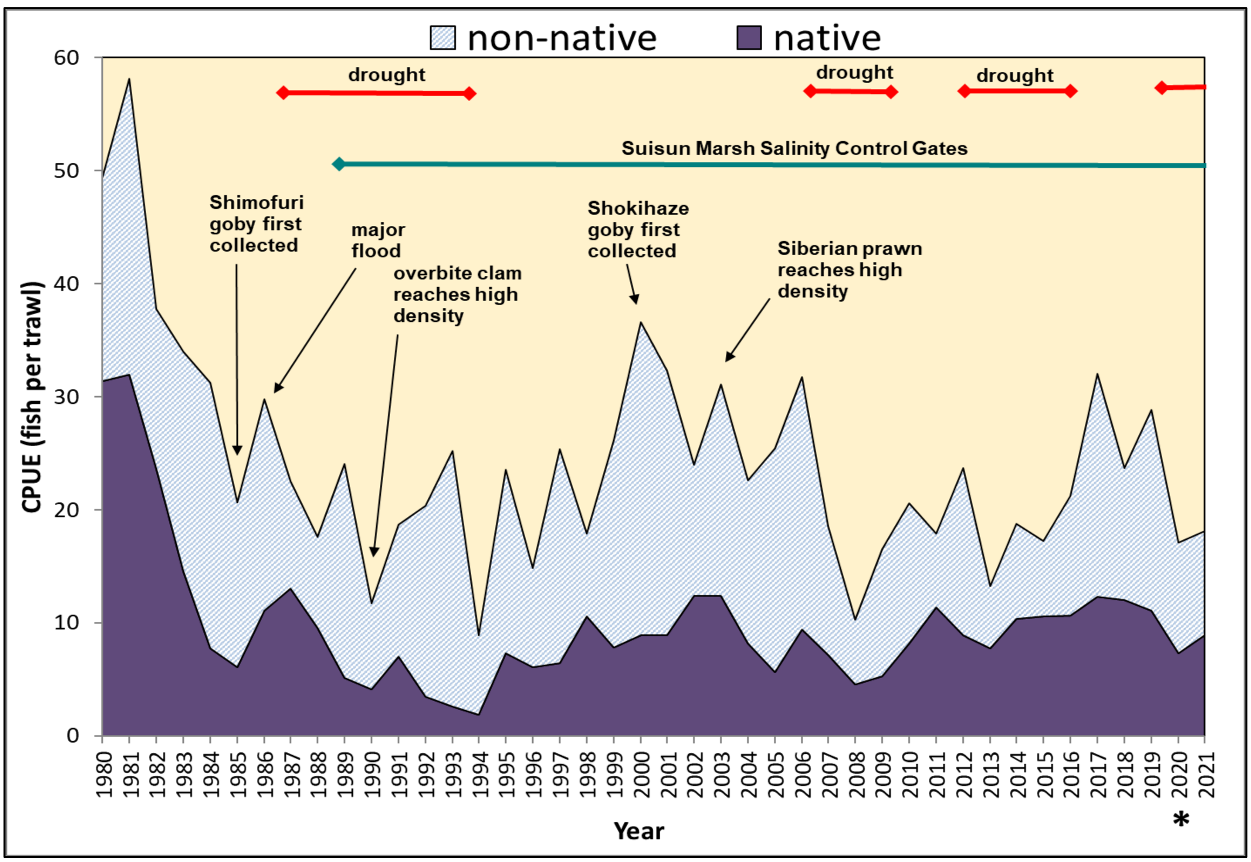

Figure 17. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted (* = no March or April samples).

Table 1. Percent change in annual otter trawl CPUE of 10 marsh fishes ("spawning salinity" refers to salinities most spawning occurs in; % increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled; species in bold are native; "all years" is the average for 1980 - 2021).

Species	Spawning Salinity	All Years CPUE	2020	2021	2021/2020 % Change
Sacramento splittail	**freshwater**	**3.31**	**3.91**	**4.00**	**+2%**
longfin smelt	**freshwater**	**1.10**	**1.00**	**1.80**	**+80%**
threespine stickleback	**all**	**1.46**	**0.07**	**0.51**	**+629%**
staghorn sculpin	**saltwater**	**0.23**	**0.00**	**0.31**	**+7,774%**
arrow goby	**saltwater**	**0.00**	**0.00**	**0.18**	**∞**
tule perch	**fresh-brackish**	**1.99**	**1.23**	**1.29**	**+5%**
threadfin shad	freshwater	0.40	0.75	0.39	-48%
striped bass	freshwater	8.62	3.87	1.60	-59%
yellowfin goby	brackish	2.17	1.1	2.60	+136%
shokihazi goby	brackish	0.20	0.68	2.16	+218%

Beach Seines

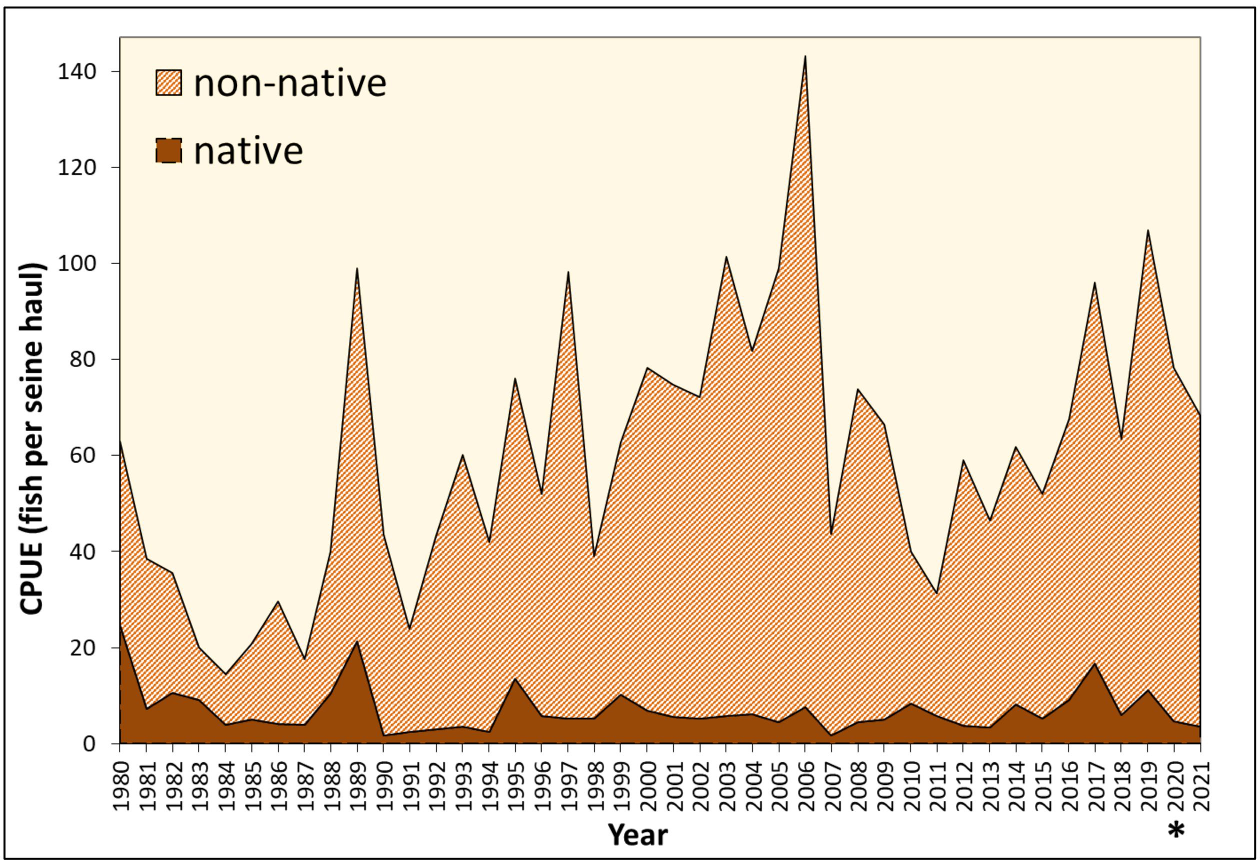

Figure 18. Annual beach seine CPUE of native and non-native fishes (* = no March or April samples).

Inshore fish were somewhat more abundant than usual in 2021, but annual beach seine CPUE (68 fish per seine haul) was not very different from values for either 2020 or all years (78 and 60 fish per seine haul, respectively; Figure 18). The change in native fishes from 2020 to 2021 was quite small (1.6 fish per seine haul), although, as for the otter trawl, the composition changed. A substantial drop in splittail was muted by large increases in staghorn sculpin and threespine stickleback (Table 2). For the reasons discussed for the otter trawl, lack of samples in March and April 2020 only partially explain the rise in stickleback and staghorn sculpin. Similar to the otter trawl, a marine species never captured before in the study's history made its appearance in 2021: jacksmelt (*Atherinops californiensis*), with six age-0 fish captured in beach seines in June. Non-native CPUE dropped mildly, about 9 fish per seine haul, from 2020 to 2021 for largely the same reasons as for the otter trawl: drastic declines in threadfin shad and striped bass mostly offset by much higher numbers of yellowfin goby (Table 2). Mississippi silverside numbers were high and virtually unchanged between the years (Table 2).

Table 2. Percent change in annual beach seine CPUE of nine common marsh fishes (("spawning salinity" refers to salinities most spawning occurs in; % increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled; native species in bold; "all years" is the average for 1980 - 2021).

Species	Spawning Salinity	All Years CPUE	2020	2021	2021/2020 % Change
Sacramento splittail	**freshwater**	**2.06**	**3.87**	**1.90**	**-51%**
threespine stickleback	**all**	**1.68**	**0.10**	**0.43**	**+330%**
staghorn sculpin	**saltwater**	**1.61**	**0.02**	**0.43**	**+2050%**
tule perch	**fresh-brackish**	**0.78**	**0.46**	**0.60**	**+30%**
threadfin shad	freshwater	2.58	2.65	0.65	-75%
Mississippi silverside	fresh-brackish	37.3	59.78	60.42	+1%
striped bass	freshwater	5.62	3.49	1.10	-68%
yellowfin goby	brackish	6.07	1.51	6.78	+349%

Fish Species of Interest

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

DELTA AND LONGFIN SMELT

For the sixth consecutive year, no delta smelt were captured by the Suisun Marsh Fish Study (Figure 19); likewise, none were captured in the Summer Townet Survey or the Fall Midwater Trawl Survey [California Department of Fish and Wildlife (CDFW) 2022].

Longfin smelt numbers in 2021 reached their highest level since 2003, with the year's CPUE nearly double the all-years average and well above 2020's value (Figure 19; Table 2). Three fish were of the 2020 year class (SL range = 88 - 100 mm) and the remainder from the 2021 year class, with the majority of age-0 fish caught in April and May (SL range = 22-37 mm) in Cutoff, lower Suisun, and eastern Montezuma sloughs (Figure 20). The fish in April in Cutoff Slough were captured close to high tide, when Montezuma Slough water reaches our CO2 site (Enright 2014). Few 2021 fish were caught in small, long, dead-end sloughs (*e.g.,* Boynton, Denverton, First Mallard, Goodyear, and Peytonia sloughs) far away from Grizzly Bay and the Sacramento River, and only one was caught in upper Suisun Slough. The most likely explanation for such patterns is that the bulk of longfin smelt spawning occurred close to but not in Suisun Marsh, and that most age-0 longfin smelt came into the marsh from fringing marshes of eastern Suisun Bay and the western Delta (Grimaldo *et al.* 2020; Figure 20). Some spawning may have occurred in Green Valley Creek but was unlikely given the dry year (Meng and Matern 2001). High opossum-shrimp densities (Figure 12) likely improved survival of age-0 fish (Barros *et al.* 2022), also contributing to the high springtime catches. Catches plummeted in June and remained very low until increasing slightly in December, with most fish in that period (72%) captured in lower Suisun Slough, consistent with both a downstream shift to saltier waters and/or mortality from, or avoidance of, high water temperatures (Figure 20). Return of age-0 fish after summer is fairly common (O'Rear *et al.*2020, 2021), showing that juvenile fish will inhabit the marsh whenever the water is cool. The three age-1 fish were only caught in winter (January) and autumn (September and October), and they were scattered: one was in Boynton Slough, one in Denverton Slough, and the third in lower Suisun Slough.

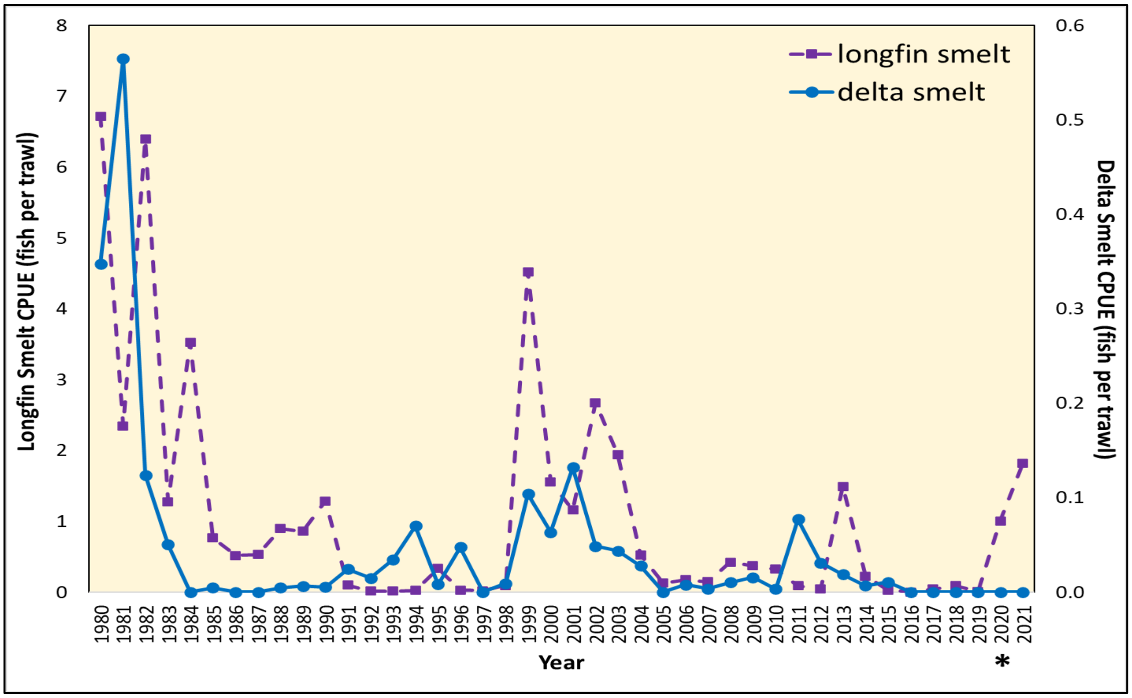

Figure 19. Annual CPUE of the smelts of the Pelagic Organism Decline (* = no March or April samples).

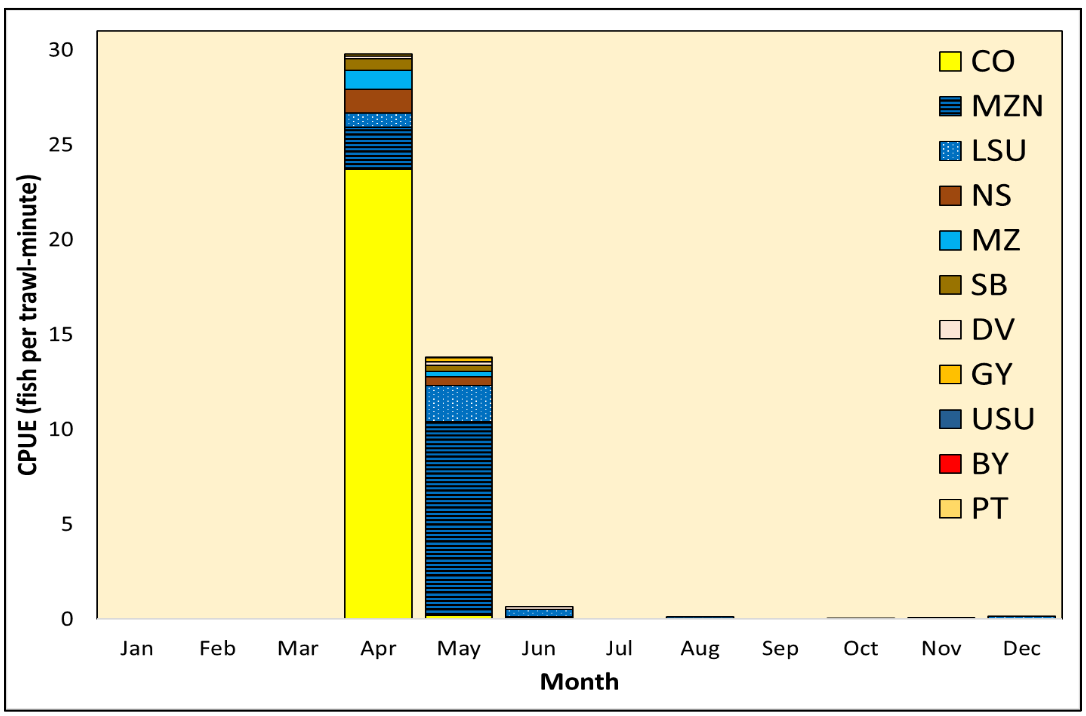

Figure 20. Monthly slough CPUE of age-0 longfin smelt in Suisun Marsh in 2021.

THREADFIN AND AMERICAN SHAD

Threadfin shad numbers in 2021 were rather low, close to the all-years average in trawls and below the average in beach seines; numbers in both gear types fell from 2020 to 2021 (Figure 21; Table 1 and 2). Geographic distribution was similar to previous years. Two small sloughs, Denverton and First Mallard, contained a disproportionate percentage of the otter-trawl catch (57%), while sloughs on the west side of the marsh - Peytonia, upper Suisun, Boynton, lower Suisun, and Goodyear - hosted only 17% of 2021's catch (Appendix B). Geographic distribution in the beach seine was similar, with 93% of the year's catch coming from Denverton Slough and eastern Montezuma Slough but only 7% coming from upper Suisun Slough (Appendix B). The abundance and distribution of threadfin shad in 2021 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).

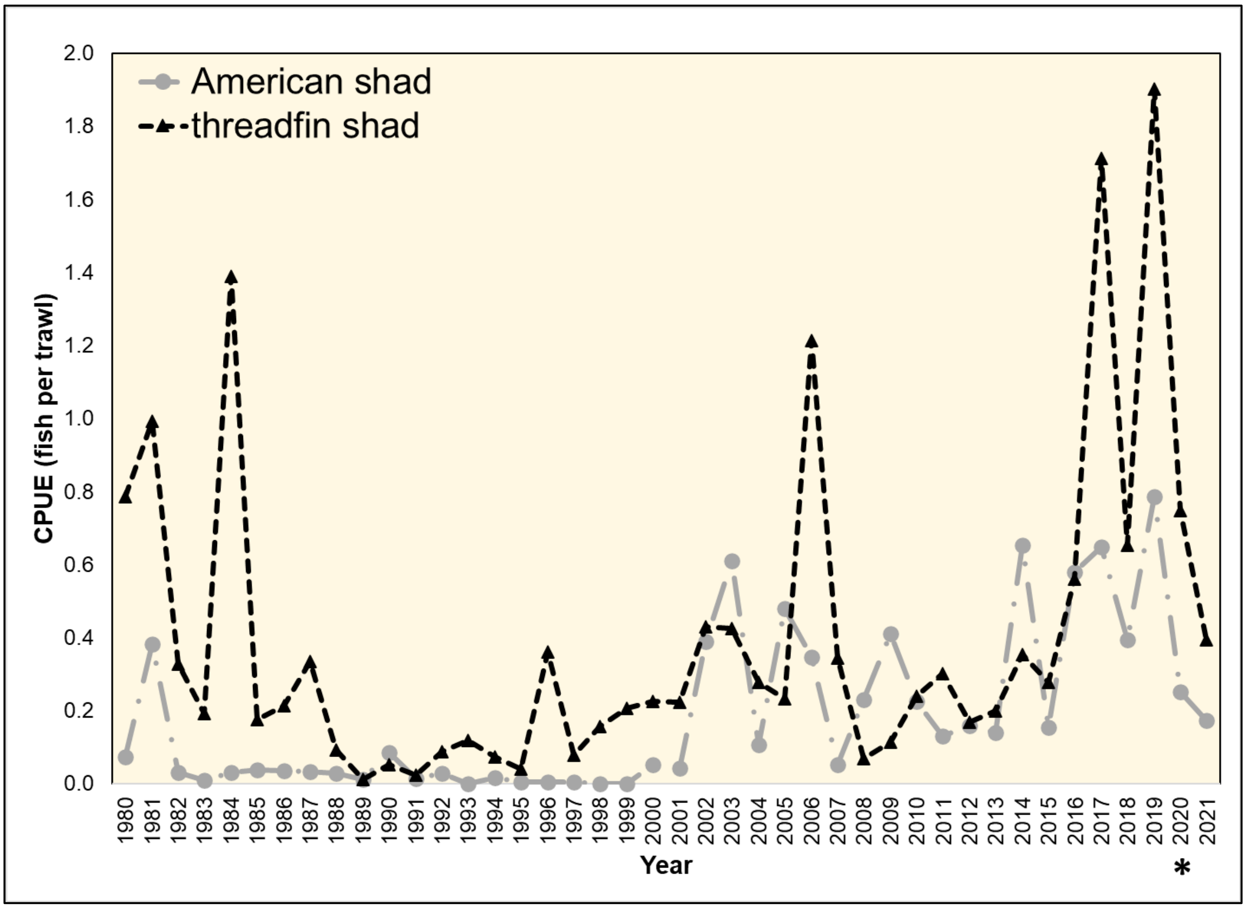

Figure 21. Annual CPUE of the shads of the Pelagic Organism Decline (* = no March or April samples).

American shad numbers were typical in 2021. Otter-trawl CPUE in 2021 was close to the all-years average but below 2020's value (0.17, 0.19, and 0.25 fish per trawl, respectively; Figure 20); beach seine CPUE values in 2021, 2020, and the average for all years were very similar (0.14, 0.13, and 0.16 fish per seine haul, respectively). Numbers in 2021 were notably lower than in the last two wet years, 2017 and 2019 (Figure 21). Unlike most years, age-0 fish did not dominate the catch: about half (45%) were from the 2020 cohort, and the remainder

(55%) from the 2021 cohort. American shad were captured fairly evenly across all sloughs. Low river flows for attracting adults and/or poor survival of early life stages seemed the likely culprits for the age-0 catches in 2021; age-1 fish may have lingered longer in Suisun Marsh than in typical years because of high numbers of opossum shrimp, an important food.

STRIPED BASS

Striped bass CPUE in 2021 fell to very low numbers in both net types relative to 2020 and the all-years average (Figure 22; 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 23). Change in age-0 CPUE in otter trawls was less dramatic, with fish first appearing in May, increasing moderately to the year's peak in June, then mildly declining through the rest of the year (Figure 23). 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 24) - and the estuary (Calhoun 1952, Able *et al.* 2012). Age-0 fish were more abundant in smaller sloughs, with CPUE highest in Denverton, Nurse, and First Mallard sloughs (Figure 24). Geographic pattern in beach seines was similar, with 82% of the year's catch coming from the small slough (Denverton; Appendix B). The distribution and relatively low numbers of age-0 striped bass in 2021 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.

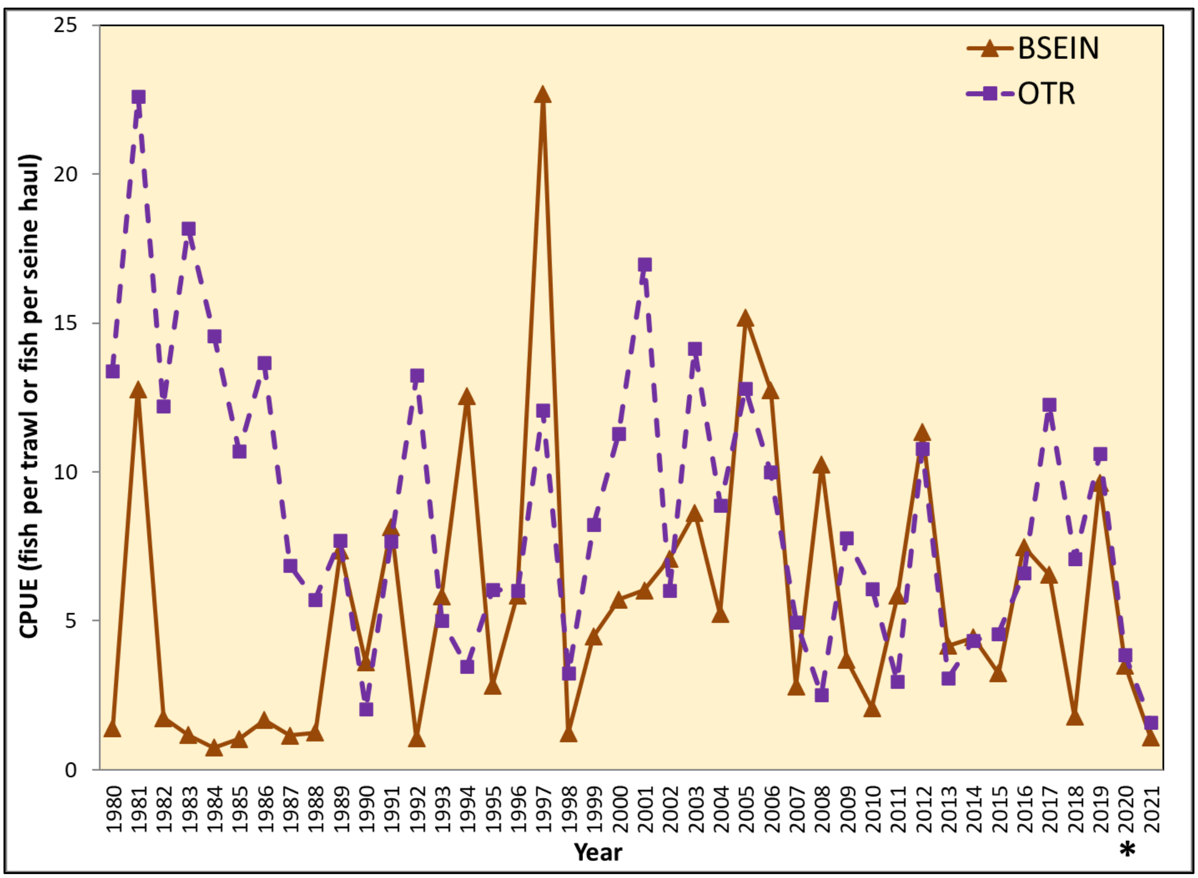

Figure 22. Annual CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine; * = no March or April samples).

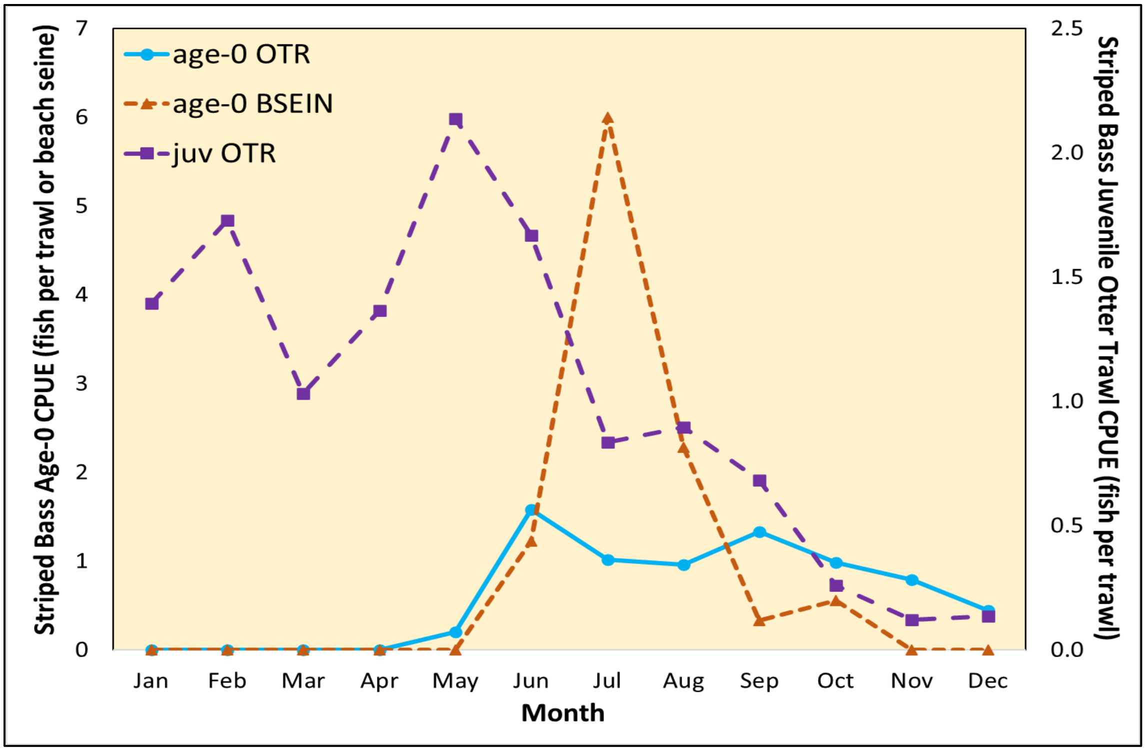

Figure 23. Monthly average CPUE of striped bass age classes (“juv” = juvenile; other codes as in Figure 22).

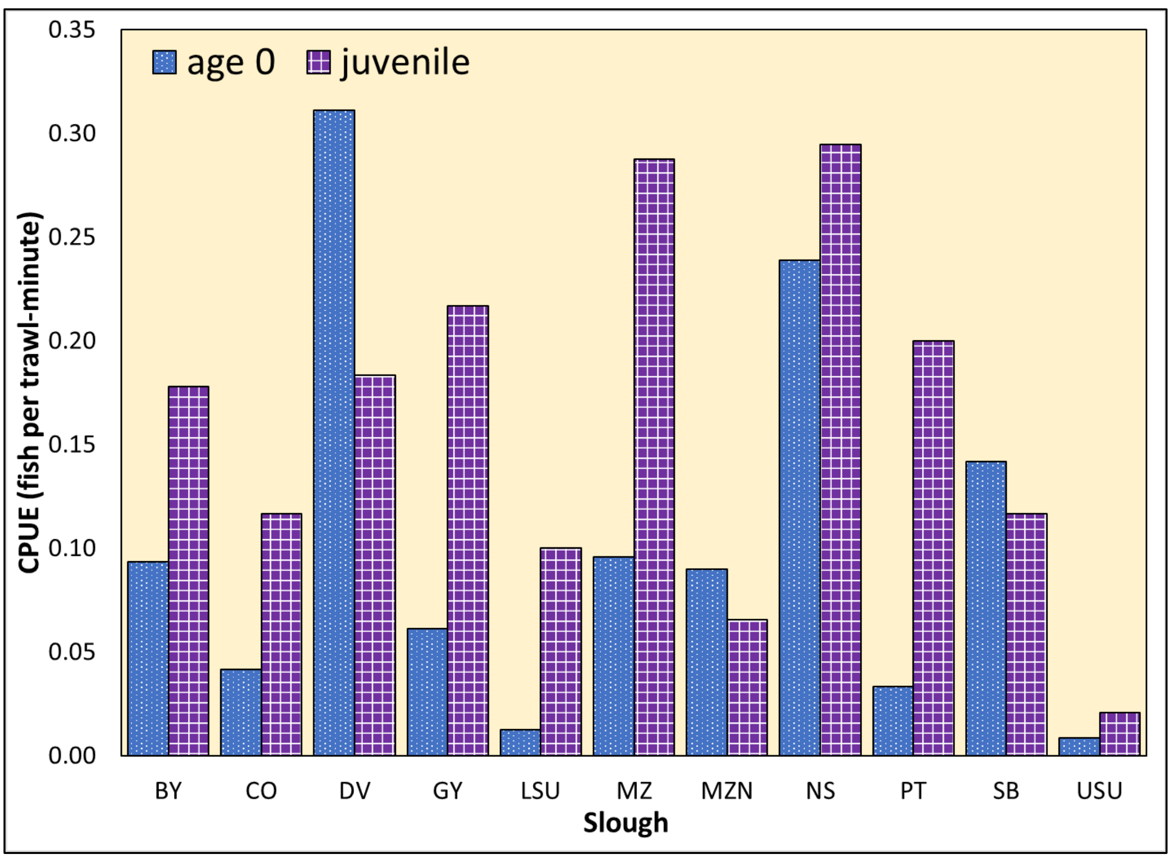

Figure 24. Average slough CPUE of age classes of striped bass in 2021 ("LSU" = lower Suisun Slough, "MZN" = Montezuma new, and "USU" = upper Suisun Slough; other codes as in Figure 5).

Sacramento Splittail

Splittail were relatively abundant in 2021. Otter-trawl CPUE in 2021 was mildly higher than values for both 2020 and the all-years average, and beach seine CPUE in 2021 was below that for 2020 but close to the all-years average (Figure 25, Table 1 and 2). The moderate splittail catches in Suisun Marsh were contrasted by none being captured by the Fall Midwater Trawl Survey (CDFW 2022), a recent recurring phenomenon (O'Rear *et al.* 2021). The population's age-class distribution changed little between 2020 and 2021, with fewer age-0 fish as compared to wetter years (*e.g.*, 2019; Figure 25). Splittail were most numerous in small sloughs (Figure 26), typically those where age-0 striped bass were also most abundant (Figure 24). In contrast, splittail were also very abundant in near-shore shallow water in a large slough (Montezuma), where 69% of the beach seine fish were captured (Appendix B). The patterns in 2021 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*).

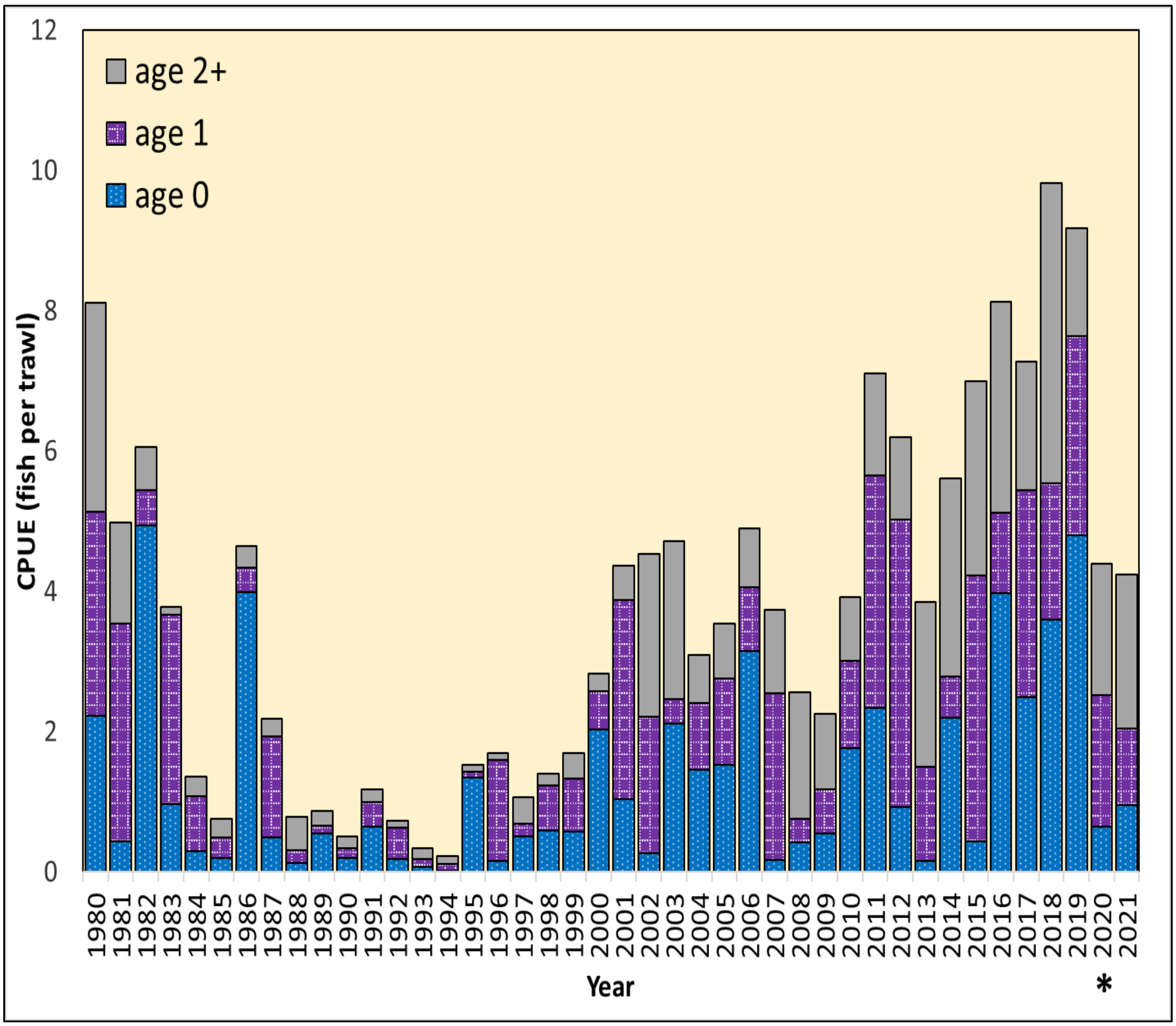

Figure 25. Annual CPUE of three age classes of Sacramento splittail (* = no March or April samples).

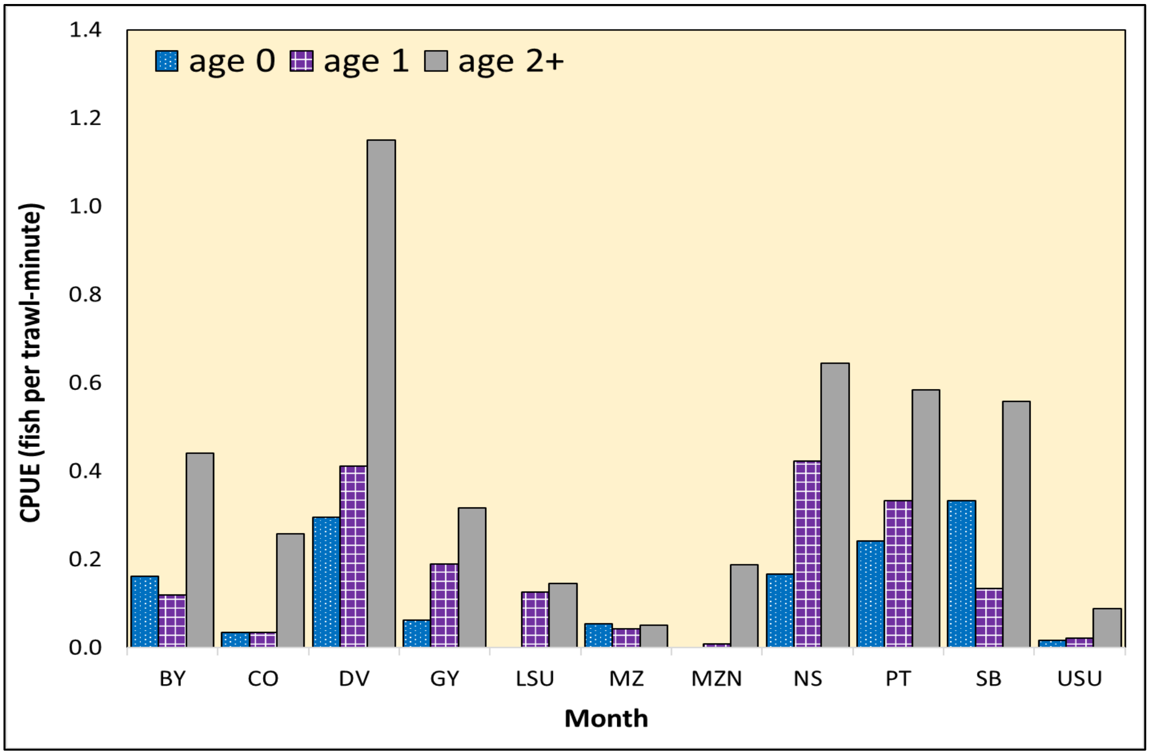

Figure 26. Average slough CPUE of age classes of splittail in 2021 (codes as in Figure 24).

<u>Mississippi Silverside</u>

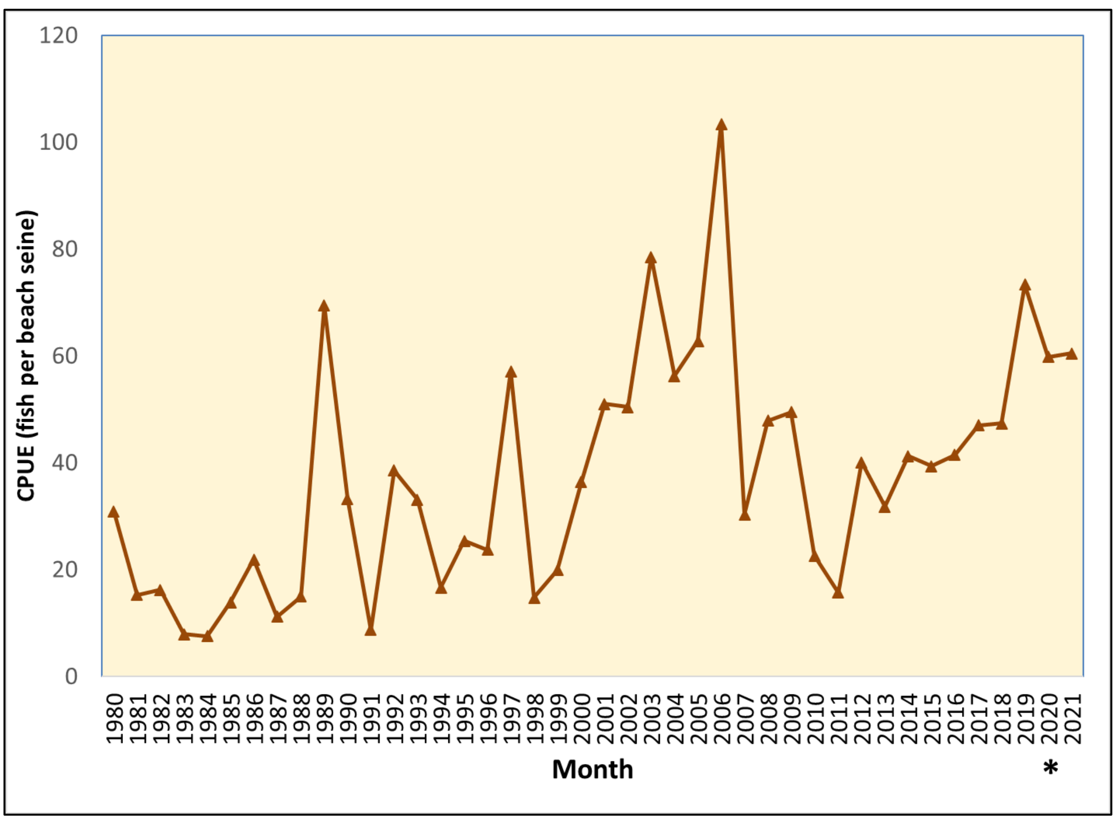

Figure 27. Annual CPUE of Mississippi silverside (* = no March or April samples).

Mississippi silverside annual beach seine CPUE was virtually unchanged between 2020 and 2021, still being quite high relative to the all-years average (Figure 27, Table 2). The trend in monthly abundance in the beach seines was fairly typical, declining in winter until reaching its minimum in spring, and then generally climbing through summer to year's end (Figure 28) with the continual addition of age-0 fish. 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 29). Mississippi silverside were abundant at all three seining beaches, with about half the year's catch (54%) coming from Denverton Slough and fewer in eastern Montezuma and upper Suisun sloughs (30% and 16%, respectively; Appendix B). The species, as is typical, was much less abundant in otter trawls except in First Mallard Slough, where 86% of the trawled fish were caught (Appendix B). The high numbers of silverside in 2021 were no surprise given their affinity for warm water (Hubbs 1982, Stoeckel and Heidinger 1988, Mahardja *et al.* 2016).

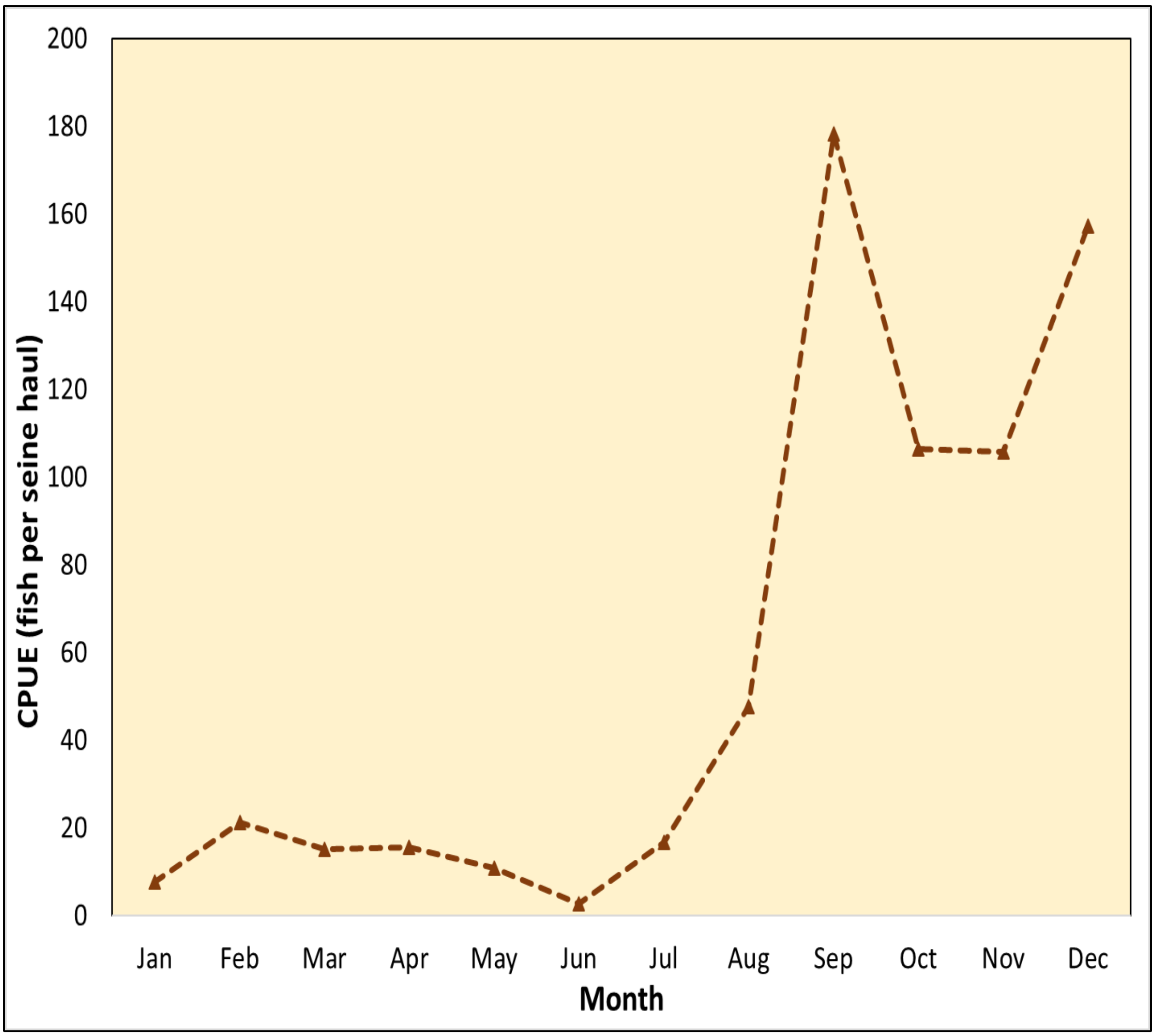

Figure 28. Monthly average CPUE of Mississippi silverside in 2021.

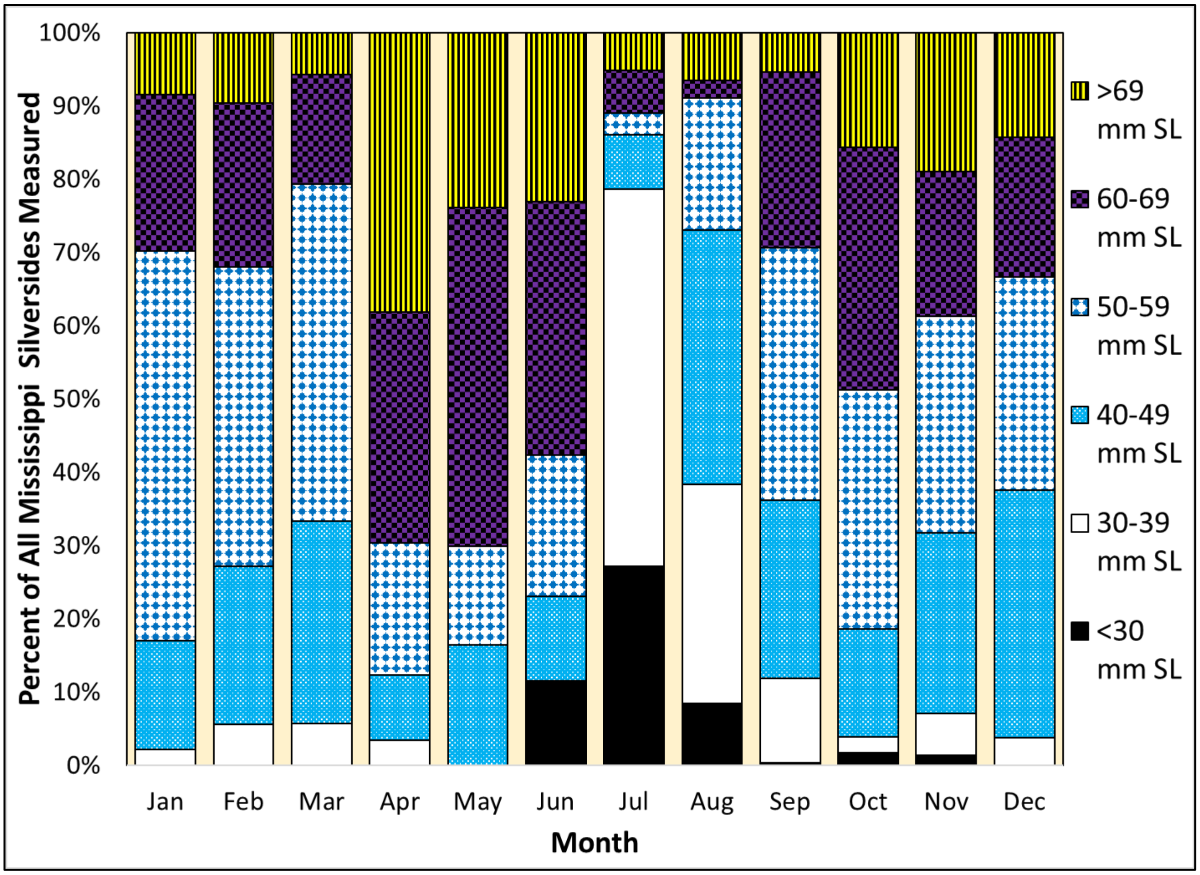

Figure 29. Monthly size-class distributions of Mississippi silverside captured in beach seines in 2021.

CONCLUSION

The dry-weather conditions of 2020 continued through 2021, bringing higher-than-average salinities that stimulated frequent operation of the Suisun Marsh Salinity Control Gates. It was also a warm year with water clarity higher than average during summer and autumn, recurring conditions in Suisun Marsh that have important implications for the future. Both native and non-native invertebrates were abundant in 2021, due in part to favorable salinities for California bay shrimp and overbite clam. As is common in drought years, many native and non-native fishes were less abundant than usual in Suisun Marsh during 2021, particularly fishes that spawn upstream in fresh water: 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. In contrast, many fishes - both native and non-native - spawned in marine waters were either captured for the first time ever in Suisun Marsh (jacksmelt, arrow goby) or had banner years (yellowfin goby, staghorn sculpin). Notably, springtime catches of age-0 longfin smelt were, for the second year in a row, very high, likely attributable in part to high opossum-shrimp densities. However, longfin smelt's disappearance during summer when food was abundant, and their reappearance during autumn, highlighted that warm water limits their distribution. With few exceptions, most fishes were most abundant in smaller sloughs where food (opossum shrimp) was most abundant and the most-inimical non-native species (Black Sea jellyfish, overbite clams) were least abundant. In sum, the Suisun Marsh Fish Study in 2021 (1) reinforced that it is vital to native species, particularly splittail and, in the cooler seasons, as rearing habitat for longfin smelt; and (2) a premonition of what the future will look like given sea-level rise and a warming climate, with warmer, saltier water and a higher proportion of the fish assemblage comprised of marine-born species.

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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 1), 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 2), 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 2; Appendix). 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.

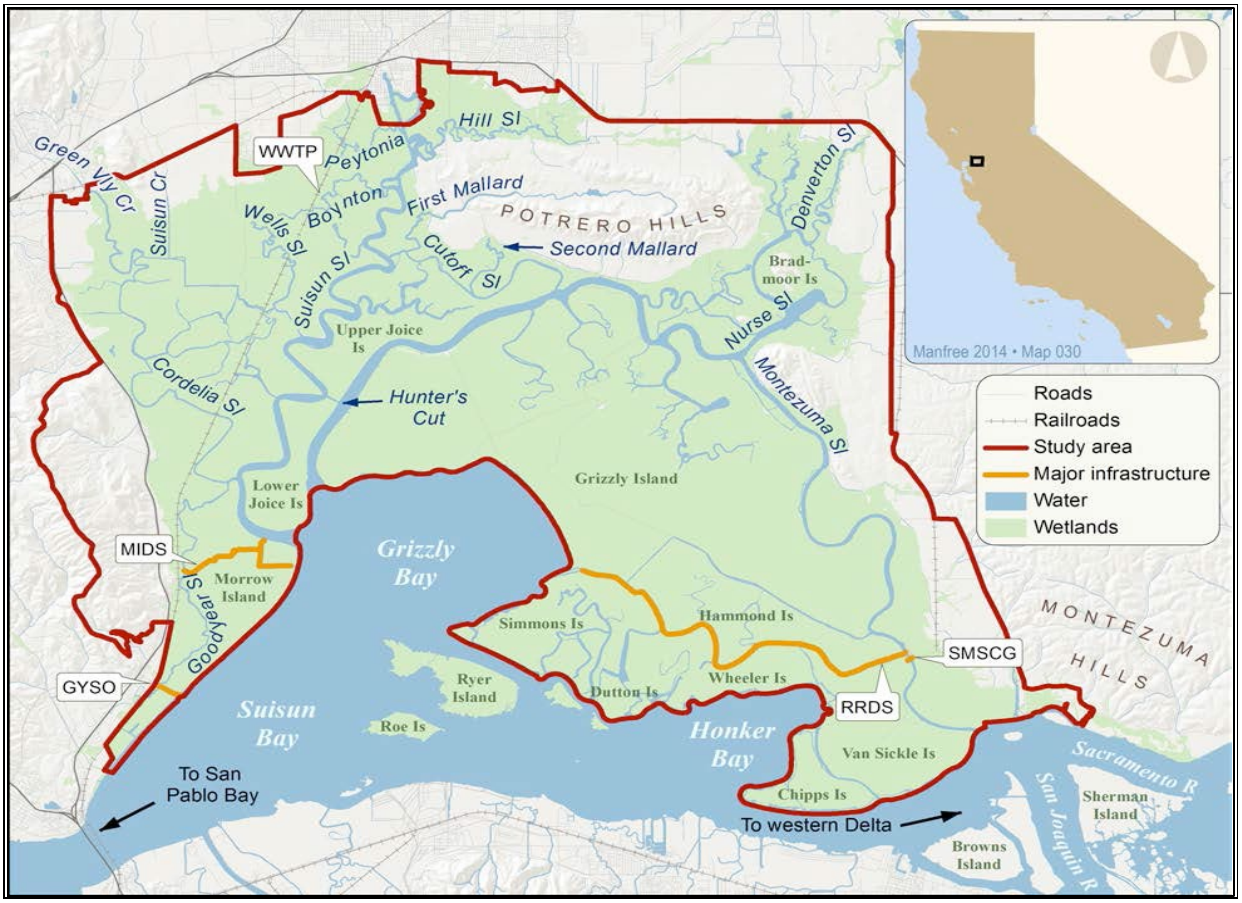

Figure 1. Suisun Marsh Fish Study sampling area (map: Manfree 2014).

Two dedicated people (Table 1) - the Principal Investigator and the Supervisor - have been the only ones paid on the study, with crews filled out with 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 1. 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

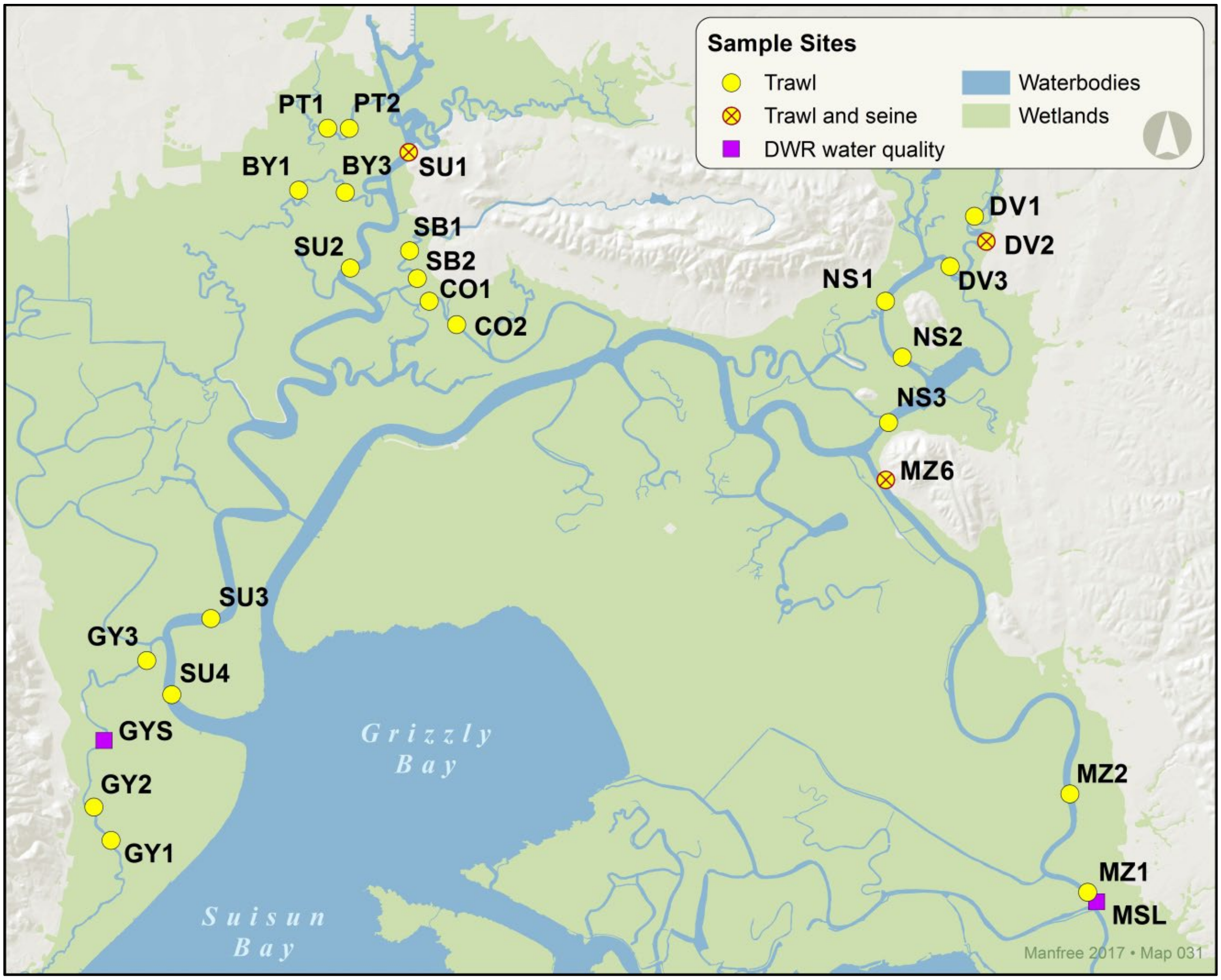

Figure 2. Currently sampled sites in Suisun Marsh and California Department of Water Resources (DWR) continuous water-quality monitoring stations used for data quality control (map: Manfree 2016).

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 2). 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 1).

Table 2. 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 1) 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

Water Quality and Depth Data

Several water-quality constituents and depths are recorded, but, as for invertebrates (described below), not all recordings began at the same time (Table 4). 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 4. 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 2). 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 3). As of April 2021, 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 2. 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 3. 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 2022.) 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.

<u>AgesBySizeMonth</u>

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

<u>Catch</u>

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

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

Catch_Entry

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

Depth

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

GearDetailsLookUp

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

MethodsLookUp

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

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

OrganismsLookUp

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

Predator

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

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

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

Sample

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

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

Prey Table

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

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

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

SeineEffort

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

SledEffort

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

StationsLookUp

Contains codes and descriptions of sample stations.

TransferLog

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

Trawl Effort

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

UnitsLookUp

Provides information on what unit each data number is in.

VariableCodesLookUp

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

VariablesLookUp

Explains many of the codes we use.

Database Queries

Catch Zero+

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

Catch Zero+ AgeClass

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

Catch Zero+ AgeClass Expansion

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

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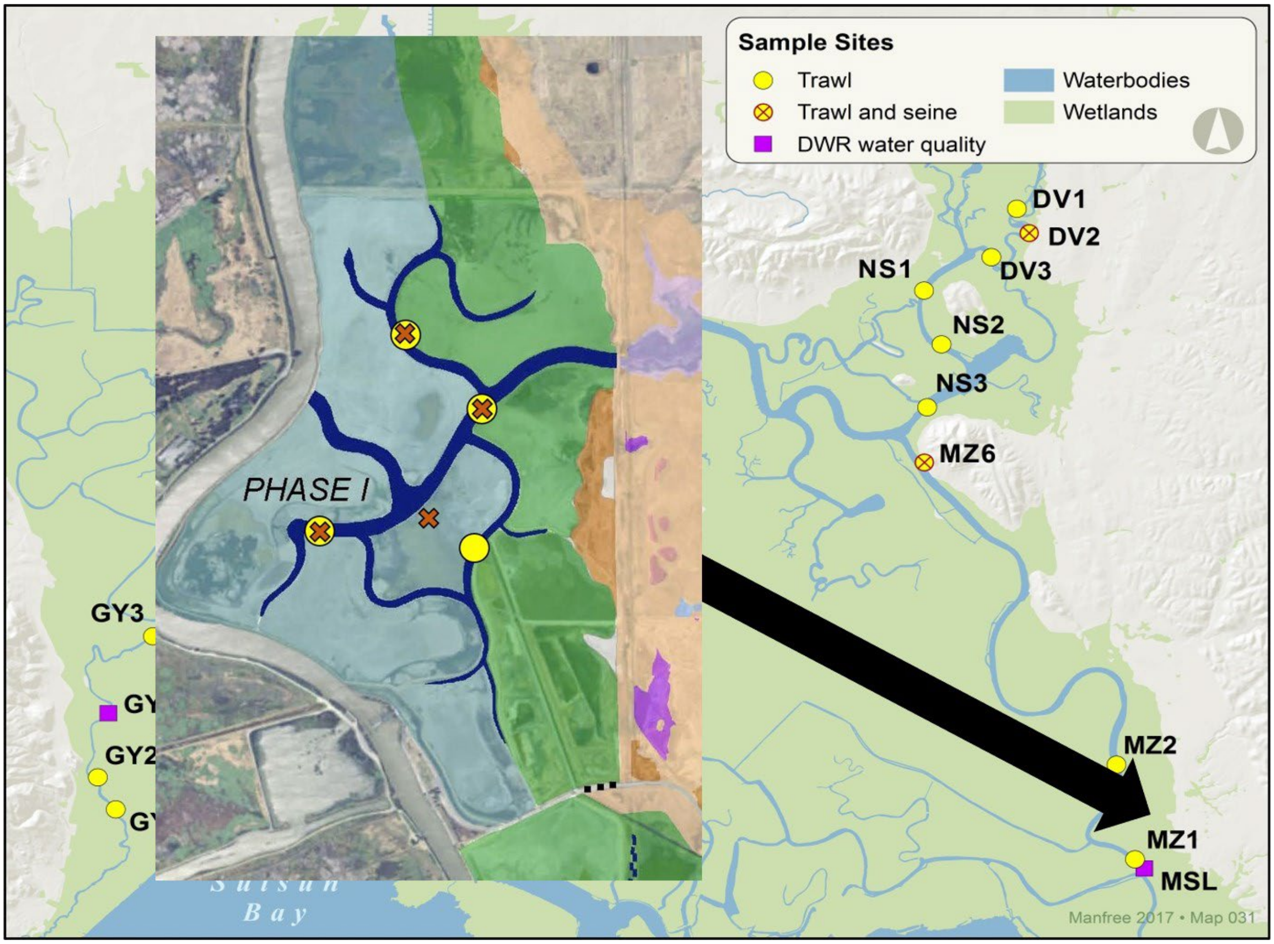
APPENDIX B: MONTEZUMA WETLANDS SAMPLING SITES



APPENDIX C: FISH CATCHES FOR ENTIRE STUDY PERIOD

Total number of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all methods from 1979 to 2021 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
Mississippi silverside	*Menidia audens*	1635	137418		139053
striped bass	*Morone saxatilis*	99151	17092	30	116273
Sacramento splittail	***Pogonichthys macrolepidotus***	**42175**	**7096**	**14**	**49285**
yellowfin goby	*Acanthogobius flavimanus*	21958	19059		41017
threespine stickleback	***Gasterosteus aculeatus***	**18403**	**8814**	**6**	**27223**
tule perch	***Hysterocarpus traski***	**23391**	**2698**	**6**	**26095**
shimofuri goby	*Tridentiger bifasciatus*	12540	3063	1	15604
prickly sculpin	***Cottus asper***	**13079**	**1298**	**1**	**14378**
threadfin shad	*Dorosoma petenense*	4931	8547	1	13479
longfin smelt	***Spirinchus thaleichthys***	**12684**	**54**	**5**	**12743**
white catfish	*Ameiurus catus*	6362	173	13	6548
common carp	*Cyprinus carpio*	5816	635	1	6452
staghorn sculpin	***Leptocottus armatus***	**2720**	**3529**		**6249**
Sacramento sucker	***Catostomus occidentalis***	**3634**	**137**	**5**	**3776**
black crappie	*Pomoxis nigromaculatus*	2827	291	1	3119
American shad	*Alosa sapidissima*	2274	510		2784
starry flounder	***Platichthys stellatus***	**2308**	**310**	**4**	**2622**
shokihaze goby	*Tridentiger barbatus*	2244	6	6	2256
western mosquitofish	*Gambusia affinis*	21	1196		1217
black bullhead	*Ameiurus melas*	887	3		890
delta smelt	***Hypomesus transpacificus***	**665**	**144**	**4**	**813**
Pacific herring	***Clupea harengeus***	**503**	**117**		**620**
Sacramento pikeminnow	***Ptychocheilus grandis***	**197**	**351**		**548**
Chinook salmon	***Oncorhynchus tshawytscha***	**80**	**434**	**1**	**515**
goldfish	*Carassius auratus*	325	71		396
northern anchovy	***Engraulis mordax***	**335**	**0**	**37**	**372**
channel catfish	*Ictalurus punctatus*	210	11		221
rainwater killifish	*Lucania parva*	40	159		199
hitch	***Lavinia exilicauda***	**138**	**16**		**154**
Sacramento blackfish	***Orthodon macrolepidotus***	**27**	**117**		**144**
white sturgeon	***Acipenser transmontanus***	**129**	**0**	**2**	**131**
white crappie	*Pomoxis annularis*	112	0		112
fathead minnow	*Pimephales promelas*	36	39		75
arrow goby	***Clevelandia ios***	**51**	**0**		**51**
Pacific lamprey	***Lampetra tridentata***	**49**	**0**		**49**

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
bluegill	*Lepomis macrochirus*	26	23		49
bigscale logperch	*Percina macrolepida*	21	24		45
brown bullhead	*Ameiurus nebulosus*	35	0		35
plainfin midshipman	***Porichthys notatus***	**28**	**0**		**28**
wakasagi	*Hypomesus nipponensis*	14	13		27
golden shiner	*Notemigonus crysoleucas*	12	15		27
shiner perch	***Cymatogaster aggregata***	**17**	**0**		**17**
California halibut	***Paralichthys californicus***	**11**	**3**		**14**
rainbow trout	***Oncorhynchus mykiss***	**9**	**5**		**14**
jacksmelt	***Atherinopsis californiensis***		**13**		**13**
bay pipefish	***Sygnathus leptorhynchus***	**3**	**6**		**9**
green sunfish	*Lepomis cyanellus*	5	3		8
largemouth bass	*Micropterus salmoides*	0	6		6
surf smelt	***Hypomesus pretiosus***	**5**	**0**		**5**
Pacific sanddab	***Citharichthys sordidas***	**2**	**2**		**4**
river lamprey	***Lampetra ayresi***	**4**	**0**		**4**
speckled sanddab	***Citharichthys stigmaeus***	**4**	**0**		**4**
green sturgeon	***Acipenser medirostris***	**3**	**0**		**3**
redear sunfish	*Lepomis microlophus*	2	1		3
white croaker	***Genyonemus lineatus***	**3**	**0**		**3**
hardhead	***Mylopharadon conocephalus***	**1**	**0**		**1**
longjaw mudsucker	***Gillichthys mirabilis***	**1**	**0**		**1**
striped mullet	***Mugil cephalus***	**0**	**1**		**1**
warmouth	*Lepomis gulosus*	1	0		1
Total		282144	213503	138	495785

APPENDIX D: 2021 FISH CATCHES

Total 2021 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold). "MW" = Montezuma Wetlands; all other codes as in Figure 5.

Species	Slough												Total
	BY	CO	DV	GY	LSU	MW	MZ	MZN	NS	PT	SB	USU	
Sacramento splittial	**85**	**39**	**334**	**102**	**65**	**70**	**35**	**24**	**222**	**139**	**123**	**30**	**1268**
yellowfin goby	57	17	19	61	149	3	185	24	33	53	63	66	730
shokihaze goby	2	3		9	285		8	41	8	1		240	597
longfin smelt	**1**	**239**	**8**	**6**	**67**	**10**	**27**	**125**	**26**		**9**	**1**	**519**
striped bass	32	19	90	52	27	26	92	19	96	28	31	7	519
tule perch	**23**	**46**	**45**	**13**	**15**	**8**	**53**	**1**	**93**	**28**	**20**	**33**	**378**
shimofuri goby	16	36	70	31	2		25	10	14	97	19	30	350
prickly sculpin	**9**	**5**	**8**	**37**	**5**	**75**	**8**	**3**	**2**	**53**	**3**	**8**	**216**
threadfin shad	12	4	50	2	3	38	13		13	7	23	1	166
threespine stickleback			**1**	**133**	**2**	**3**				**3**	**1**		**143**
staghorn sculpin	**1**			**2**	**25**	**24**	**27**	**1**	**6**	**2**	**4**	**18**	**110**
Mississippi silverside	3		3	5		6			1		79	1	98
white catfish	2		88			1		1	3	3			98
black crappie	5		44				4	1	13	7	1		75
common carp	11	5	22	2		6			7	10	8	4	75
American shad	9	1	4	6	5	11	8		2	2	8	3	59
arrow goby				**12**	**39**								**51**
Sacramento sucker	**5**	**7**	**4**			**2**			**3**	**6**	**8**		**35**
channel catfish			17						1			1	19
Pacific herring		**3**	**1**	**3**	**2**	**1**					**8**		**18**
starry flounder		**1**	**1**	**1**	**1**		**3**	**4**	**2**			**1**	**14**
hitch						**5**	**4**						**9**
plainfin midshipman					**5**							**2**	**7**
northern anchovy				**1**	**4**								**5**
black bullhead			3							1			4
Sacramento pikeminnow		**1**					**2**						**3**
golden shiner						2							2
white sturgeon												**2**	**2**
brown bullhead							1						1
Chinook salmon							**1**						**1**
rainwater killifish				1									1
Total	273	426	812	479	701	291	496	254	545	440	408	448	5573

Total 2021 beach seine catch of each fish species in Denverton, Montezuma, and upper Suisun sloughs (native species are in bold).

Species	Slough				Total
	Denverton	Montezuma Wetlands	Montezuma	upper Suisun	
Mississippi silverside	2705	6532	1489	821	11547
yellowfin goby	168	102	306	89	665
threespine stickleback	**26**	**220**	**4**	**6**	**256**
Sacramento splittail	**42**	**14**	**109**	**7**	**172**
striped bass	74	2	7	10	93
shimofuri goby	44	28	13	7	92
threadfin shad	33	5	17	4	59
western mosquitofish	1	57			58
prickly sculpin	**37**	**14**			**51**
tule perch	**32**		**4**	**14**	**50**
staghorn sculpin	**3**	**5**	**26**	**7**	**41**
common carp	9	5	1	11	26
jacksmelt		**7**	**5**	**1**	**13**
American shad	4			8	12
rainwater killifish	2		1	2	5
black crappie	1				1
bluegill		1			1
Chinook salmon		**1**			**1**
golden shiner	1				1
Pacific herring		**1**			**1**
steelhead		**1**			**1**
wakasagi			1		1
Total	3182	6995	1983	987	13147

APPENDIX E: 2021 EFFORT

Number of otter trawls in each slough and each month in 2021.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	2	2	2	2	2	2	2	2	2	2	24
Cutoff	2	2	2	2	2	2	2	2	2	2	2	2	24
Denverton	3	3	3	3	3	3	3	3	3	3	3	3	36
Goodyear	3	3	3	3	3	3	3	3	3	3	3	3	36
Lower Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma new	1	1	1	1	1	1	1	2	1	1	1	1	13
Montezuma Wetlands	4	4	4	4	4	4	4	4	4	4	4	4	48
Nurse	3	3	3	3	3	3	3	3	3	3	3	3	36
Peytonia	2	2	2	2	2	2	2	2	2	2	2	2	24
First Mallard	2	2	2	2	2	2	2	2	2	2	2	2	24
Upper Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Total	28	28	28	28	28	28	28	29	28	28	28	28	337

Number of beach seines in each slough and each month in 2021.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	3	3	3	3	3	3	3	3	3	2	2	34
Montezuma new	3	3	3	3	3	3	3	2	3	2	2	3	33
Montezuma Wetlands	8	8	7	7	7	7	7	7	7	7	7	7	86
upper Suisun	0	2	2	2	2	2	2	2	2	3	2	2	23
Total	14	16	15	15	15	15	15	14	15	15	13	14	176

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)>#1/1/2021# And (Sample.SampleDate)<#1/1/2022#) 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)>#1/1/2021# And (Sample.SampleDate)<#12/31/2021#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```