Title

Trends in fish and invertebrate populations of Suisun Marsh January 2020 - December 2020.

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Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2020 - December 2020

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. 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 anthropogenic factors affecting fish and large-invertebrate distribution and abundance.

After the wet year of 2019, Suisun Marsh was subject to very dry conditions in 2020. Delta outflow was lower than average throughout the year (and accompanied by little floodplain inundation), resulting in higher-than-average salinities within Suisun Marsh. Two increasingly common conditions recurred in 2020: 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 in September.

Fish and invertebrate catches in Suisun Marsh in 2020 reinforced three common phenomena: (1) lower flows and higher salinities are unfavorable for many common marsh fishes, whether native or non-native, but not for some non-native invertebrates; (2) small, dead-end sloughs are key for supporting abundant fish populations; and (3) Suisun Marsh is disproportionately valuable to fishes of conservation importance. Numbers of two non-native invertebrates - overbite clam (*Potamocorbula amurensis*) and Siberian prawn (*Palaemon modestus*) - were very high 2020, but overbite clam, which outcompetes pelagic fishes for plankton, was restricted to large sloughs. Nearly all fish species, both native and non-native, were less abundant than usual in 2020, although numbers of some native species were likely biased low because no samples were collected in April and May. Fishes needing fresh water to spawn, specifically the native, floodplain-spawning Sacramento splittail (*Pogonichthys macrolepidotus*) and non-native fishes that eat zooplankton and spawn in fresh water [threadfin shad (*Dorosoma petenense*), American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*)] were less abundant; nevertheless, their numbers were higher in Suisun Marsh than in the estuary's main axis relative to long-term averages. 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, which had not happened since 2013. Large fish catches most frequently occurred in small, dead-end sloughs where plankton concentrations have often been higher. Thus Suisun Marsh remains crucial for sustaining populations of valuable fishes, both native and non-native, particularly zooplanktivorous fishes that are migratory and/or tolerant of warm water, and Sacramento splittail.

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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 for euryhaline-freshwater, estuarine, and marine fishes; the marsh is also a migratory corridor for anadromous fishes such as Chinook salmon (*Oncorhynchus tshawytscha*; Vincik 2002). Suisun Marsh also provides 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 to monitor 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, and (3) the Suisun Marsh Preservation Agreement 2015 (Agreement Number 4600000633), formerly the Revised Suisun Marsh Monitoring Agreement. 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). Other objectives have included (1) evaluating the effects of the Suisun Marsh Salinity Control Gates on fishes and invertebrates (Matern *et al*. 2002, Beakes *et al.* 2020), which began operating in 1988 (DWR 2001); (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*, Stompe *et al.* 2020); and (3) enhancing understanding of the life history and ecology of key species in the marsh (*e.g.*, Brown and Hieb 2014, Colombano *et al.* 2020*b*). Secondary objectives have included supporting research by other investigators through special collections (*e.g.,* Liu *et al.* 2012); 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); evaluating restoration (*e.g.*, Aha *et al.* 2021, Williamshen *et al.* 2021); documenting invasions of new species [*e.g.*, alligatorweed (*Alternanthera philoxeroides*); Walden *et al.* 2019)]; contributing to the general understanding of estuarine systems through publication of peer-reviewed papers (*e.g.,* Schroeter *et al.* 2015, Colombano *et al.* 2021); training undergraduate and graduate students in estuarine studies and fish sampling; and providing a venue for managers, biologists, and others 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 reducing habitat suitability for common native marsh 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. Non-native fish abundances displayed no apparent long-term trend because the significant decline of both striped bass and threadfin shad was offset by occasional booms of the recently introduced shimofuri goby (*Tridentiger bifasciatus*; Matern *et al.* 2002). Since Matern *et al.* (2002), fish abundances have often been at higher levels, particularly in wet years (O'Rear *et al.* 2019, Colombano *et al.* 2020*a*). The most recent fish introduction - shokihaze goby (*Tridentiger barbatus*) in 1999 - has contributed little to the abundances since, while common, annual numbers have usually been quite low (~78 fish per year; O'Rear, unpublished data). 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, the most hospitable region in the freshwater part of the estuary for native fishes (Nobriga *et al.* 2005, Sommer and Mejia 2013), by a companion study (the "Arc Project"; Durand *et al.* 2020) 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 rarely addressed but prominent components of Suisun Marsh. Isotope work by Schroeter *et al*. (2015) found that many fishes and invertebrates in the marsh are dietary generalists and that submerged aquatic vegetation may be a significant carbon source for some of them. Surveys in and around a restored tidal wetland (Blacklock Island) and a managed wetland (Luco Pond) found higher fish abundances, higher fish diversity, and a higher proportion of native fish in the managed wetland relative to the restored wetland, suggesting managed wetlands can provide benefits to desirable fishes while still supporting waterfowl (Williamshen *et al.* 2021). Further, Aha *et al.* (2021) found Chinook salmon smolts grew better in a managed wetland than in an undiked slough. Baumsteiger *et al.* (2017, 2018) showed increased 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) associated with warmer, saltier water in Suisun Marsh. 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 2020 with average conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2020 to annual averages, noting abundance changes between 2019 and 2020; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2020, 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).

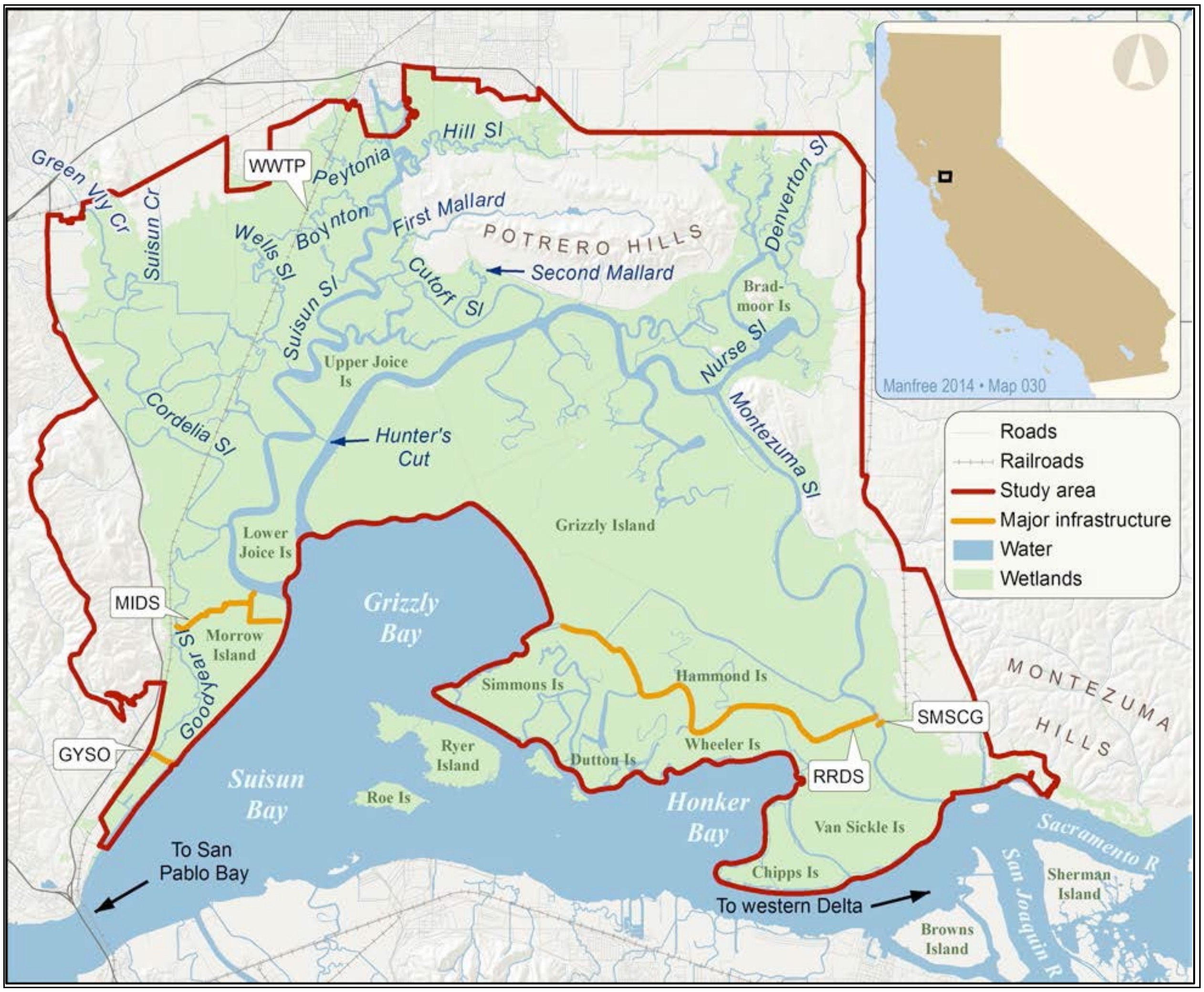

Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point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

The amount of fresh water flowing into Suisun Marsh is the major determinant of its salinity. Fresh water enters the marsh primarily from the western Delta through Montezuma Slough, although small creeks, particularly on the northwest (Ledgewood and McCoy creeks) and west (Suisun and Green Valley creeks) 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; consequently, marsh salinities are 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). During extreme tides, water depths can change as much as 2 m over a tidal cycle, often dewatering much of the smaller sloughs at low tide and overtopping dikes when high tides coincide with storms or high runoff.

Several water management facilities alter the hydrology and water quality of the marsh. State Water Project and Central Valley Project 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, providing fresher water for diked wetlands (DWR 2001; Figure 1). 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, to leach salts from wetland soils, and to promote growth of desired waterfowl plants (DWR 1984). Diversions are restricted in 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. 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 dissolved-oxygen (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, warm temperatures (O'Rear *et al.* 2019). Native and non-native shrimps [California bay shrimp (*Crangon franciscorum*) and Siberian prawn, respectively] along with the non-native overbite clam and Black Sea jellyfish comprise the bulk of the invertebrate catch in most years. These invertebrates are important, either as competitors [Black Sea jellyfish (Wintzer *et al.* 2011*b*)], as fish food [the shrimps (Nobriga and Feyrer 2008)], or both [overbite clam (Feyrer *et al*. 2003, Zeug *et al.* 2014)]. Sacramento splittail, tule perch (*Hysterocarpus traski*), prickly sculpin (*Cottus asper*), and threespine stickleback (*Gasterosteus aculeatus*) 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 from Atlantic Ocean watersheds, particularly anadromous species with juveniles dependent on zooplankton (American shad, striped bass); Japanese estuarine small-bodied gobies; and, in inshore areas, small-bodied fishes native to the Mississippi River system [threadfin shad and Mississippi silverside (*Menidia audens*)]. 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*). 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. 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 D) began in November 2020; those data were not analyzed or discussed because of the short sampling period, although they will be in next year's report. No sampling occurred in March and April because of the coronavirus pandemic.

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 (DO) 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, 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 are only considered from 2002 onward. Crustaceans from the order 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. Organic material was classified (emergent/terrestrial-plant detritus, mud, wood, and submersed aquatic plants/algae, with submersed plants identified to species) and then estimated for volume.

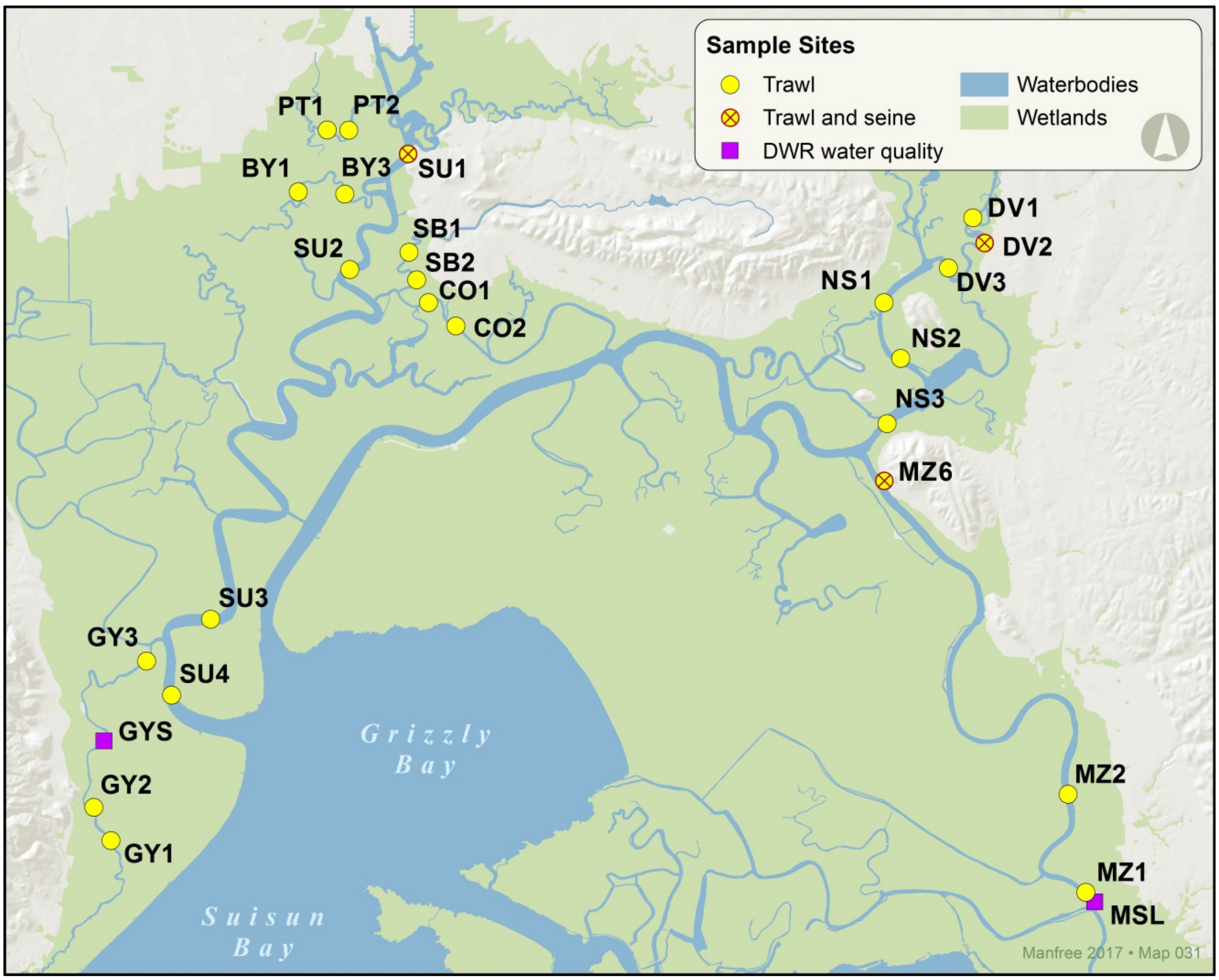

Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report (map by Amber Manfree).

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 2020 otter trawl catch 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 2020 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 2021).

Monthly water-quality results of 2020 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 2020 are found in Appendix A; annual catch of each slough and number of trawls/seines in each slough (including Montezuma

Wetlands) in 2020 are found in Appendix B and C. Code used for querying the database is found in Appendix E.

RESULTS AND DISCUSSION

Abiotic Conditions

Hydrology and Delta Outflow

Calendar-year 2020 was much drier than both the previous wet year and the typical year, with daily Delta outflow in 2020 always below the average for all years of the study (1980 - 2020; Figure 3). A few storms in late winter and in spring mildly spiked Delta outflow, but from late May through November, outflow was persistently low until a storm in December caused a final mild spike (Figure 3). At no time in 2020 did Yolo Bypass, a critical spawning habitat for Sacramento splittail (Sommer *et al.* 1997, Moyle *et al.* 2004), flood, although two small flooding events did occur on the smaller floodplain of the Cosumnes River in March and April (DWR 2020).

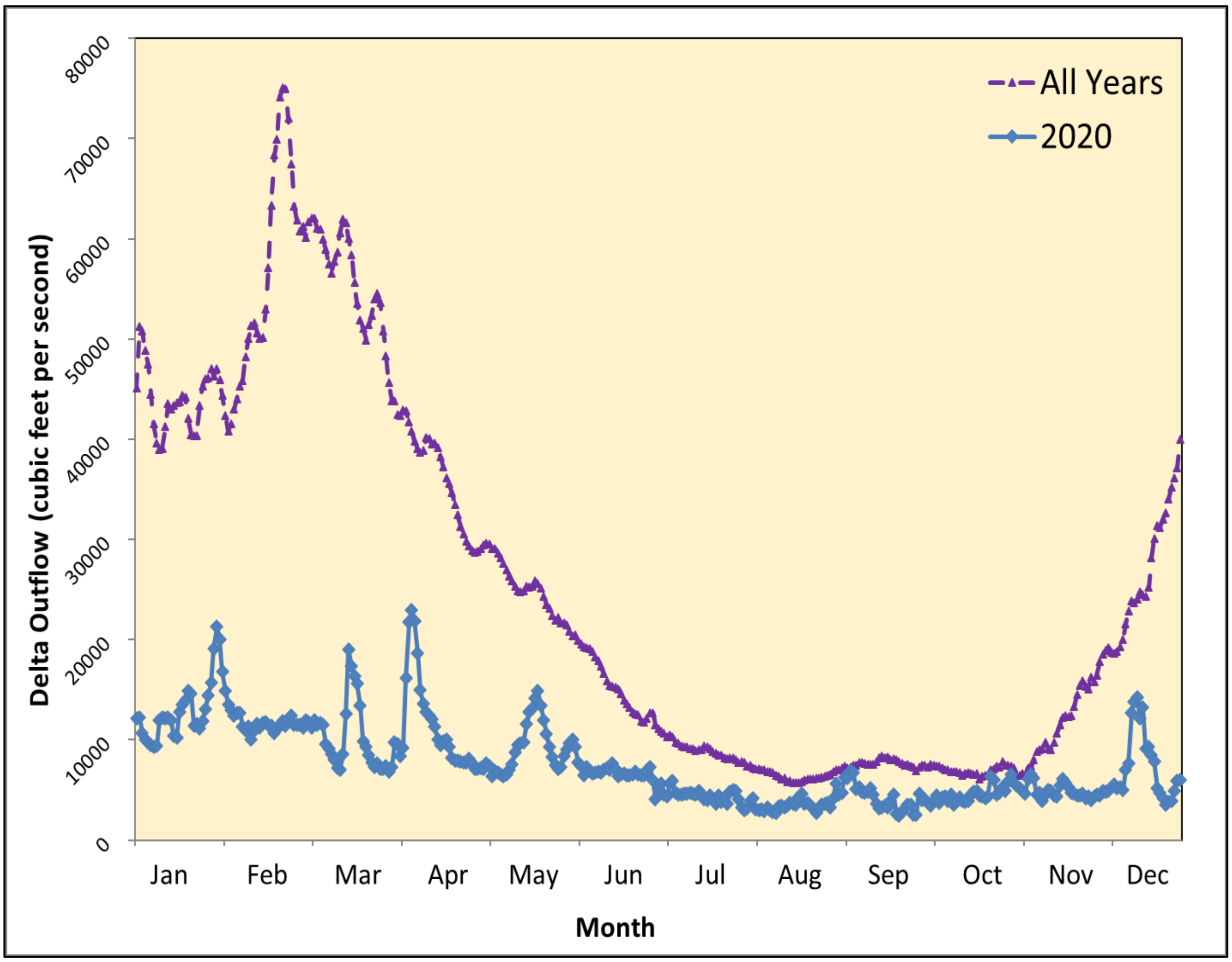

Figure 3. Daily Delta outflow in 2020 and the average for all years of the study (1980 – 2020; DWR 2021).

Salinity

The dry year in 2020 resulted in an annual average salinity (5.4 ppt) higher than usual (3.9 ppt for 1980 - 2020; Figure 4). Monthly average salinity was at typical levels in January, February, and May (Figure 4), thereafter increasing and remaining well above normal except in September, when the Suisun Marsh Salinity Control Gates began operations a month early (DWR 2021) and notably reduced salinities in Montezuma, Nurse, Cutoff, and lower First Mallard sloughs (Figure 5). Because of low outflows, the Suisun Marsh Salinity Control Gates were operated to some extent in all months except June, July, and August (Figure 4). Salinities recorded by the fish study were within the bounds of the two water-quality stations throughout the year (Figure 6). A range of salinities existed in Suisun Marsh all months in 2020 (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, 12.4 ppt, occurring in upper Goodyear Slough in October). The freshest water was in upper Boynton Slough, near the wastewater-treatment-plant discharge point, from June through September; in all other months, the freshest water was in eastern Montezuma Slough, our sites closest to the Delta.

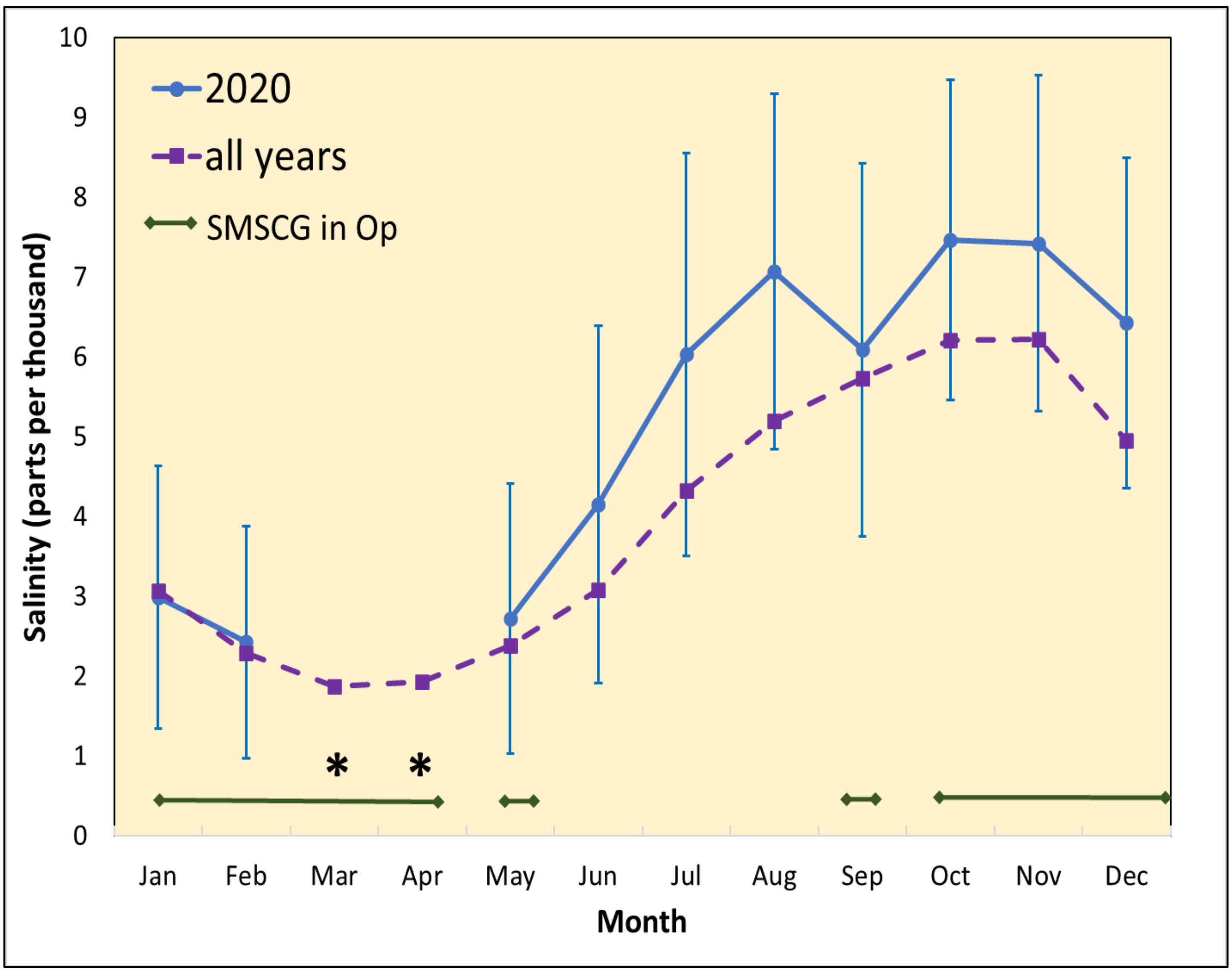

Figure 4. Monthly average salinity in 2020 and for all years of the study (1980 - 2020); error bars are standard deviations in 2020. Olive bars show when the SMSCG were operating in 2020 (* = no samples).

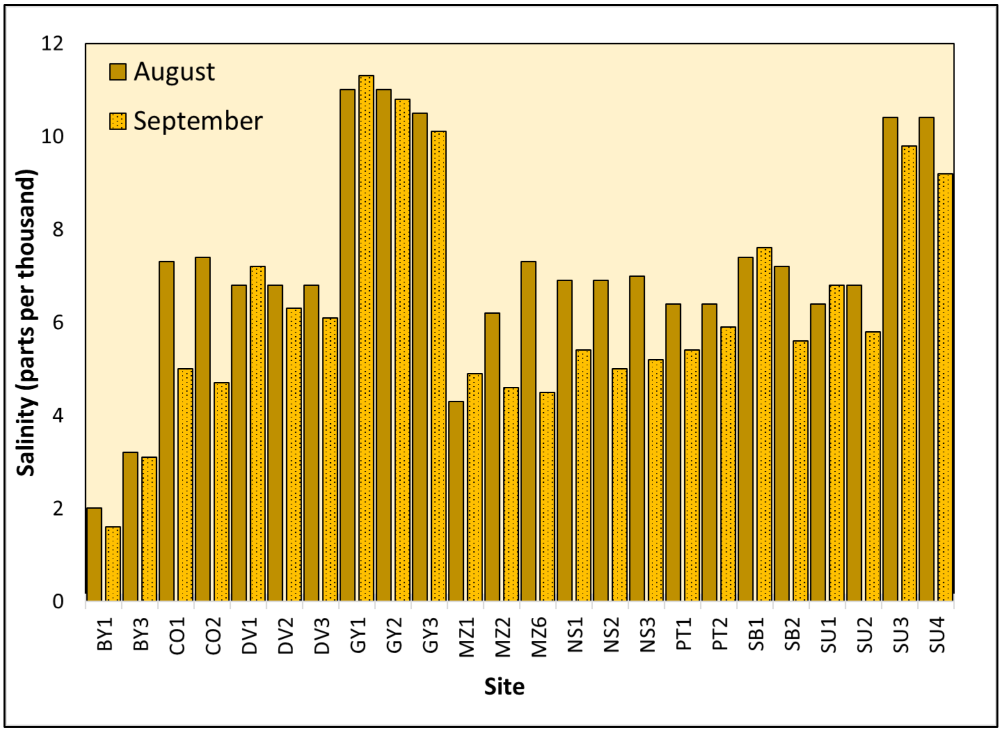

Figure 5. Site salinity in August and September 2020 before and after SMSCG operation, respectively ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "MZ" = Montezuma Slough, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "SU" = Suisun Slough. Site locations in Figure 2).

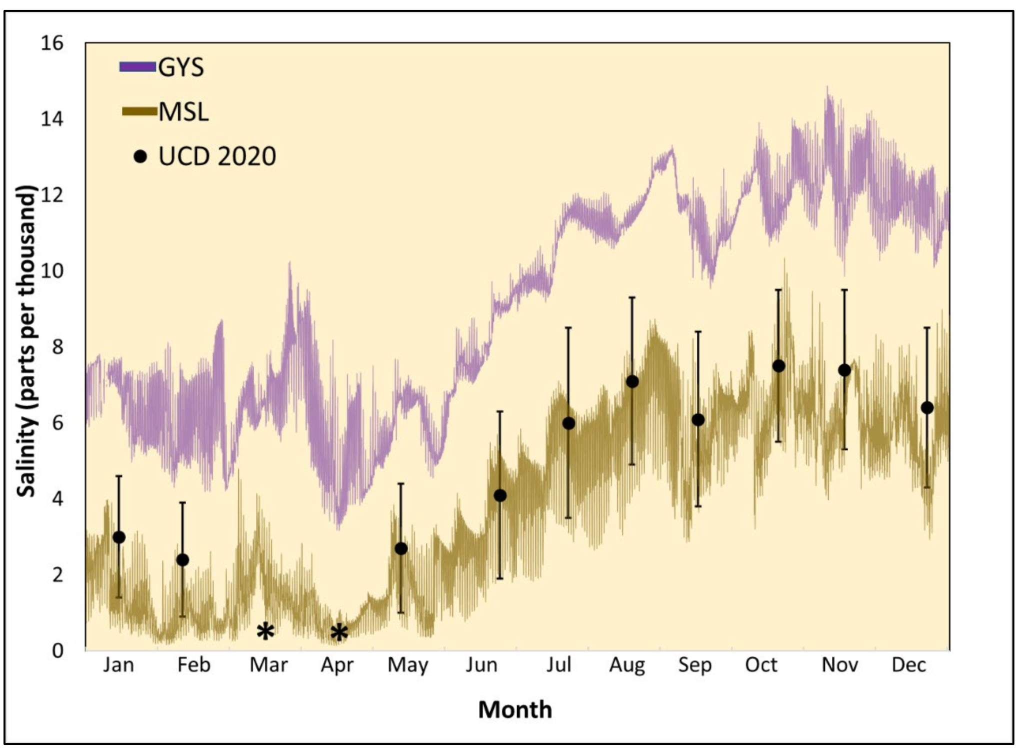

Figure 6. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations of the Suisun Marsh Fish Study ("UCD Sal"; * = no Suisun Marsh Fish Study samples).

Dissolved Oxygen (DO)

Average monthly DO concentrations did not vary substantially throughout 2020, always being higher than 5 mg/L (Figure 7). DO was highest in winter, hovered at lower levels from spring through early autumn, and then rose notably in the year's last two months (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 six times in upper Goodyear Slough, twice in Boynton Slough, and twice in First Mallard Slough - all three being small, dead-end sloughs. Highest concentrations were either in eastern Montezuma Slough or in the largest small slough we sample, Nurse (Figure 2). Only once was DO concentration found below 3 mg/L, a critical value for tule perch (Cech *et al*. 1990), which occurred in September in upper Goodyear Slough (GY2; Figure 2) where DO concentration was 1.6 mg/L.

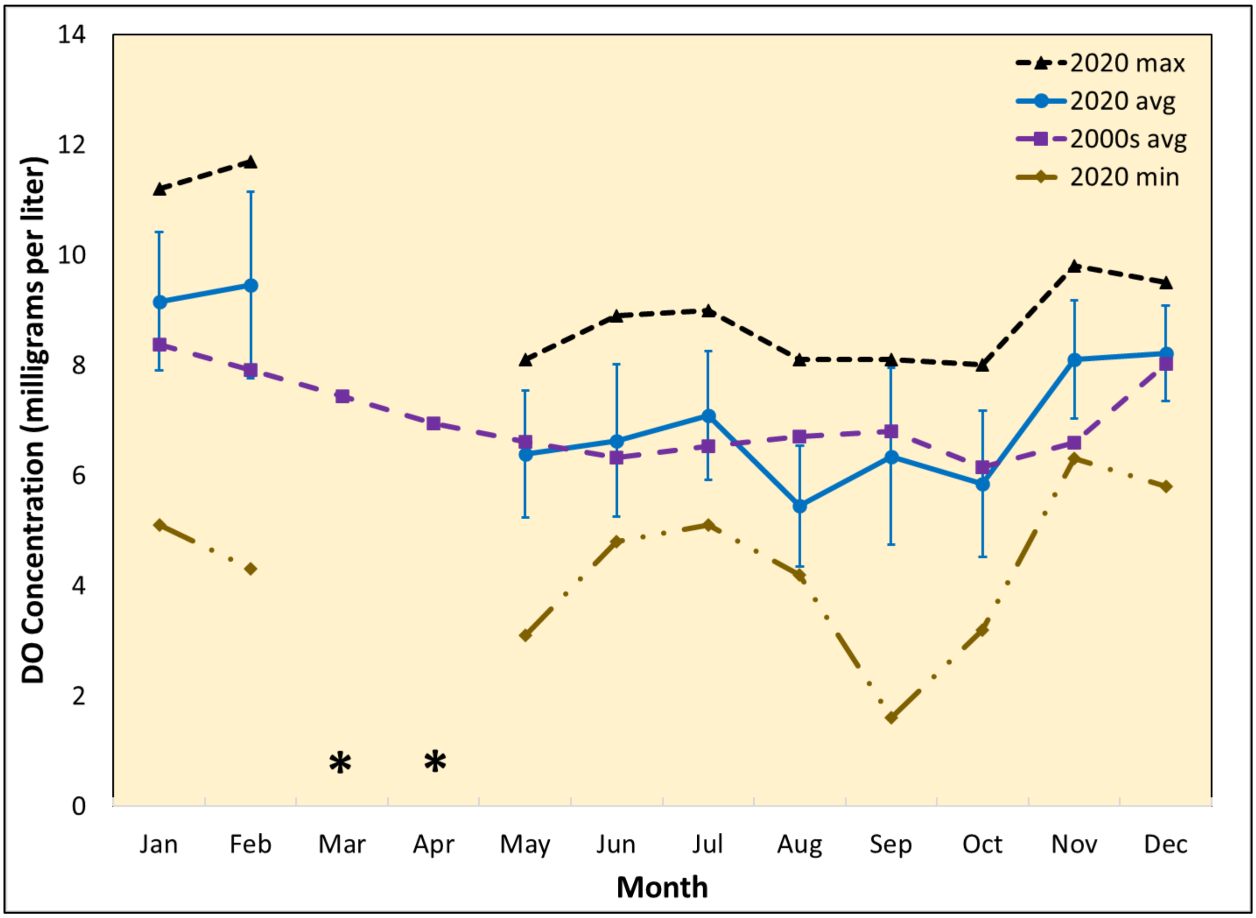

Figure 7. Monthly average DO concentration in 2020 and for the 2000s (2000 - 2020), maximum DO concentration in 2020, and minimum DO concentration in 2020. Error bars are standard deviations in 2020 (* = no samples).

Water Temperature

Overall, 2020 was a warm year (HPRCC 2021). Monthly average water temperature was typical in January, a bit cooler than expected in February, and thereafter frequently warmer than usual, especially in August (Figure 8). Consistent with greater sensitivity of smaller sloughs to air temperature than larger sloughs, water temperature fluctuated more and reached more extreme values in Goodyear Slough than in eastern Montezuma Slough (Figure 9). Similarly, the fish study recorded its lowest (8.3°C) and highest (25.9°C) water temperatures in small sloughs: upper Goodyear in December and upper Denverton in August, respectively.

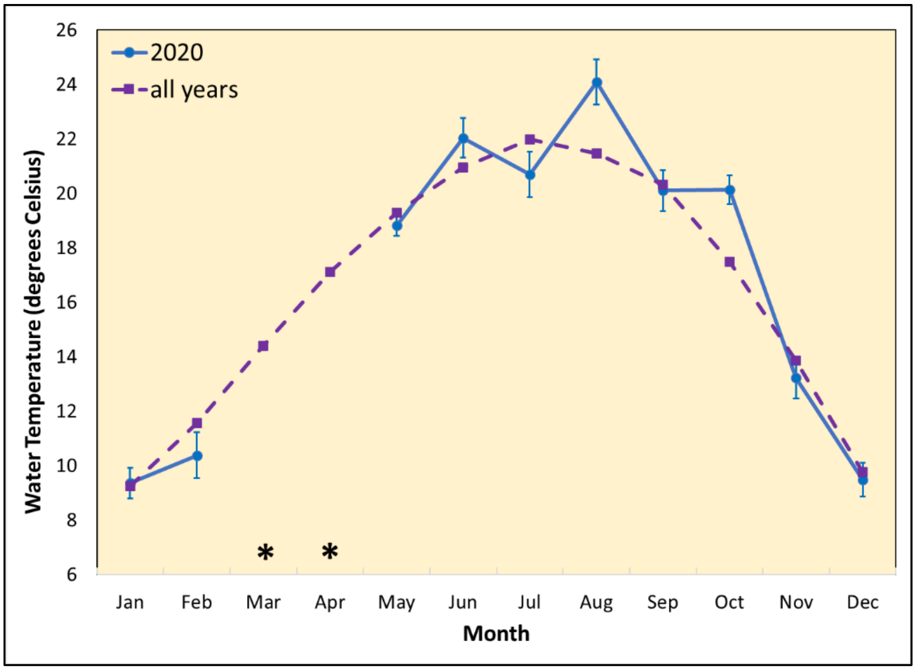

Figure 8. Monthly average water temperature in 2020 and for all years of the study (1980 - 2020); error bars are standard deviations in 2020 (* = no samples).

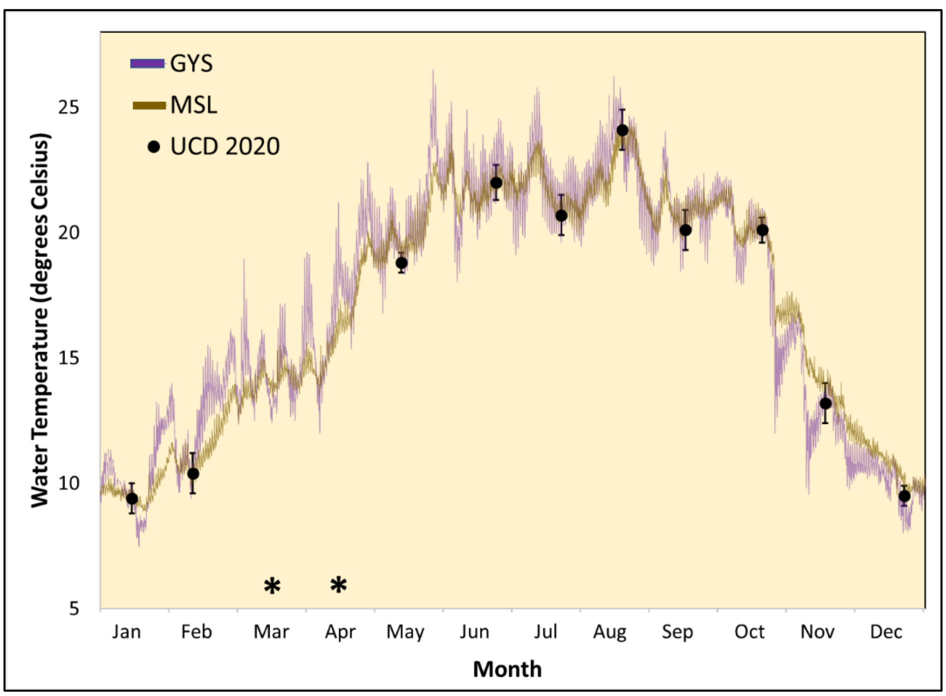

Figure 9. Fifteen-minute water temperature from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly temperatures and standard deviations from the Suisun Marsh Fish Study ("UCD Sal"; * = no Suisun Marsh Fish Study samples).

Water Clarity

Average monthly water clarity was higher than usual during all of 2020 (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; however, highest clarity was measured in December in 2020, likely due in part to low Delta outflow. The clearest water was in eastern Montezuma Slough in all but one month, with the year's highest clarity (99 cm) recorded in August; that value was the highest recorded in the study's 40-year history. Lowest clarity was split fairly evenly between small sloughs (6 of 10 months) and Suisun Slough, with the lowest clarity measured being 18 cm in upper Suisun, lower Goodyear, and Cutoff sloughs in February, September, and October, respectively.

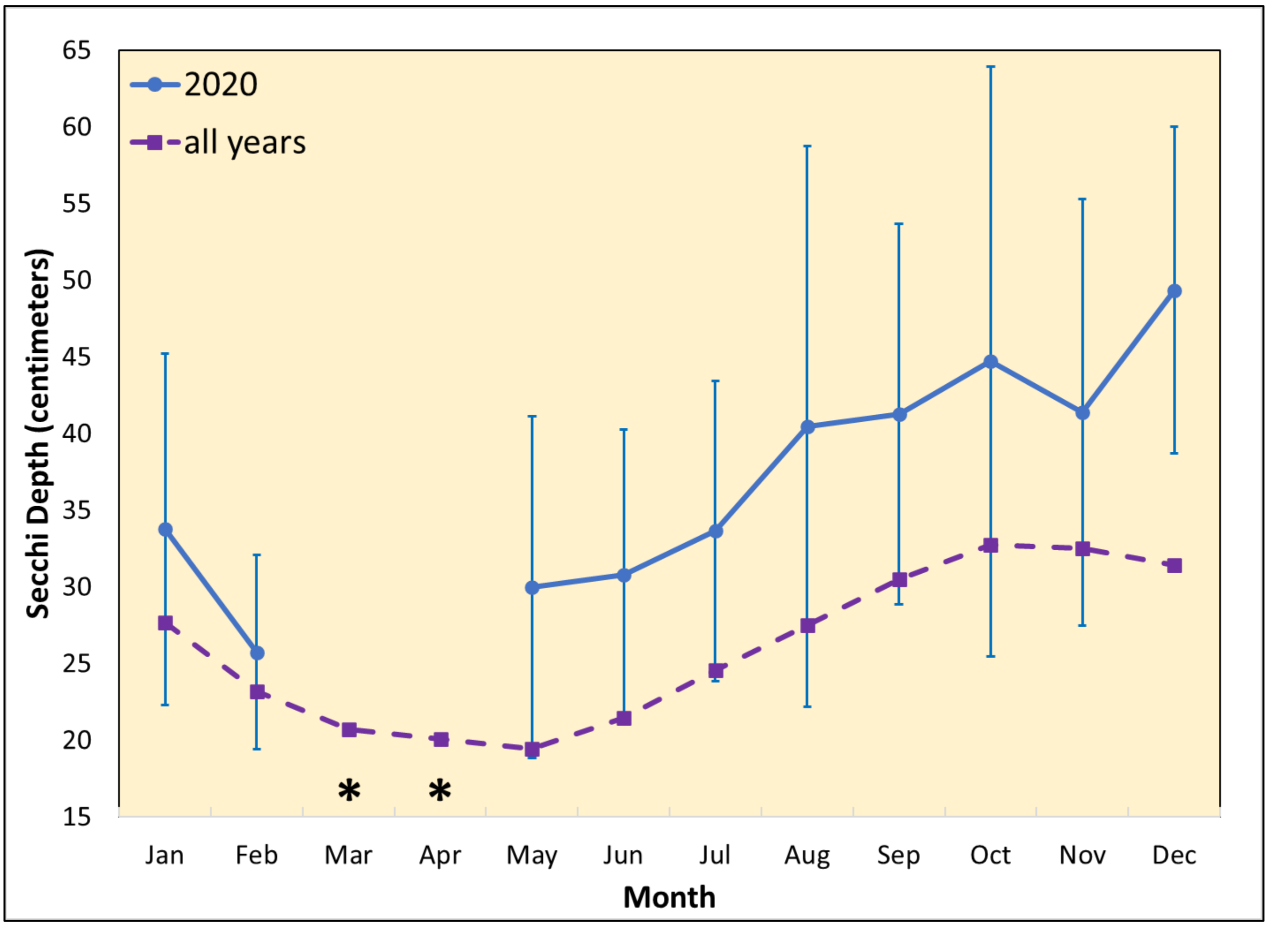

Figure 10. Monthly average water clarity in 2020 and for all years of the study (1980 - 2020); error bars are standard deviations in 2020 (* = no samples).

Trends in Invertebrate Distribution and Abundance

Black Sea Jellyfish

Black Sea jellyfish medusae CPUE in 2020 (9.3 medusae per trawl) was much lower than in 2019 and close to the average for all years of the study (84.5 and 11.4 medusae per trawl, respectively; Figure 11), an anomaly given that medusae are generally more abundant in dry, warm years (Baumsteiger *et al.* 2018). Numbers of medusae first appeared in July, peaked in August and September, and persisted into October (Figure 12). Medusae were captured in all sloughs, although nearly a third of the catch (31%; 683 individuals) came from upper Suisun Slough (SU1 and SU2; Figure 2). In contrast, three very long, small sloughs - Boynton, Goodyear, and Denverton (Figure 2) - hosted only 4% (96 individuals) of the catch, 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 of medusae.

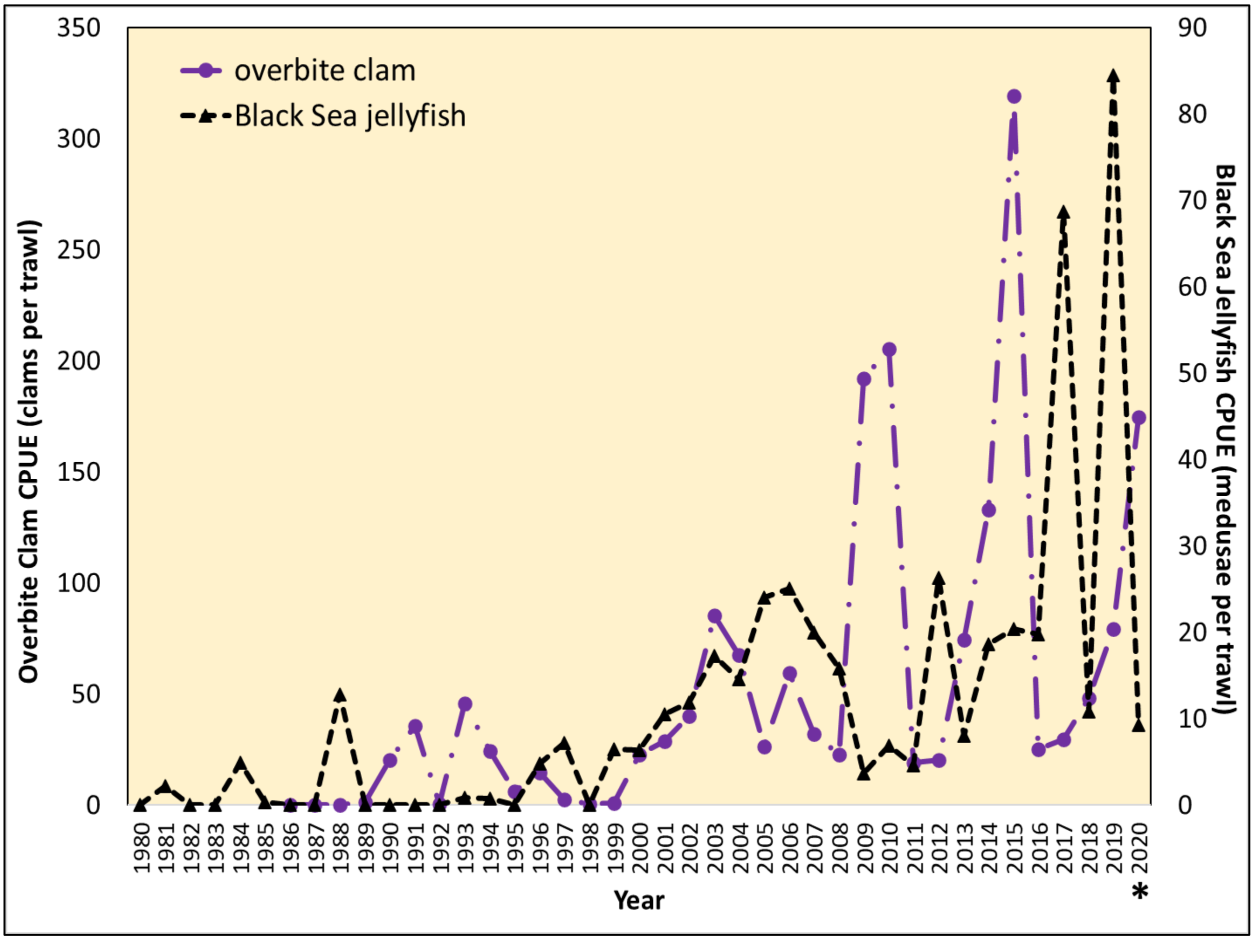

Figure 11. Annual CPUE of Black Sea jellyfish and overbite clam (* = no April/May samples).

Overbite Clam

Overbite clams were very abundant in 2020 (Figure 11), with the year's CPUE (175 clams per trawl) considerably higher than both 2019's value and the all-years value (80 and 53 clams per trawl, respectively). Monthly CPUE of overbite clams displayed the typical pattern: low early in the year, at high levels in summer and early autumn, and then low again in late autumn (Figure 12; 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 somewhat similar, with many overbite clams in upper Suisun Slough (14,142 individuals; 34% of the catch) and none in

Denverton or Boynton Slough, although the hotspot for overbite clams was lower Suisun Slough (SU3 and SU4; Figure 2), which hosted 56% of the year's catch (23,481 individuals). While present in both small and large sloughs, overbite clams were much less abundant in small sloughs, a recurring pattern (Baumsteiger *et al.* 2017): of 4,217 overbite clams caught in small sloughs, 4,163 (99%) of those came from the lower Goodyear Slough site (GY3), which is the closest small-slough site to Suisun Slough (Figure 2).

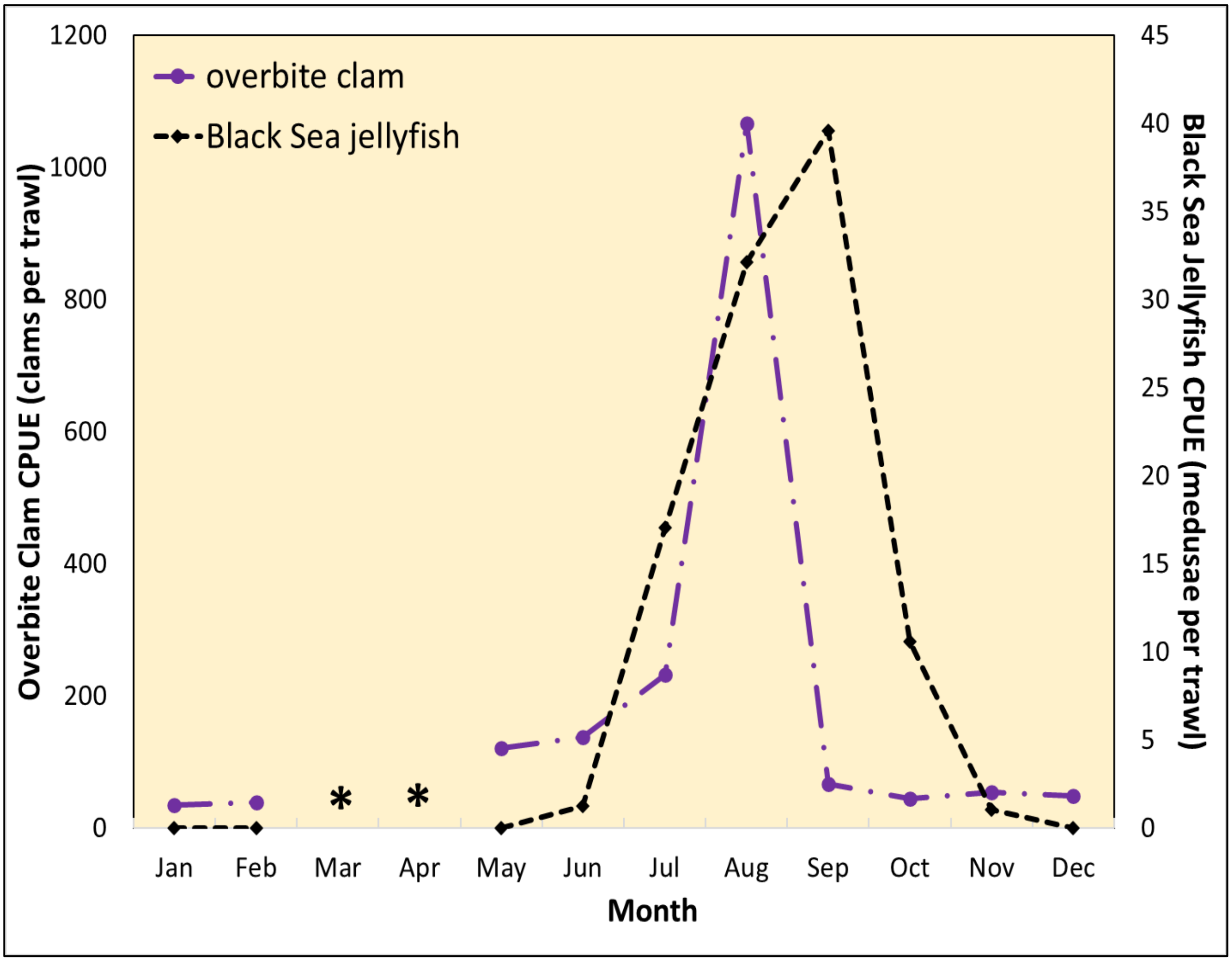

Figure 12. Monthly average CPUE of Black Sea jellyfish and overbite clam in Suisun Marsh in 2020 (* = no samples).

Shrimps

California Bay Shrimp

California bay shrimp numbers were moderate in 2020, with the annual CPUE close to the all-years average and over double 2019's value (20, 27, and 9 shrimp per trawl, respectively; Figure 13). Monthly CPUE was negligible in January and February but then reached a peak in May; thereafter, numbers oscillated considerably (Figure 14). Most California bay shrimp - 71% of the annual catch (3,420 individuals) - were captured in large sloughs, with only 40 individuals (1% of year's catch) coming from three small sloughs: Boynton, Denverton, and First Mallard. The year's improved numbers relative to 2019 and the geographic distribution were consistent with the shrimp's association with moderately salty water (Cloern *et al.* 2017) and a predilection for coarser substrate in the larger sloughs.

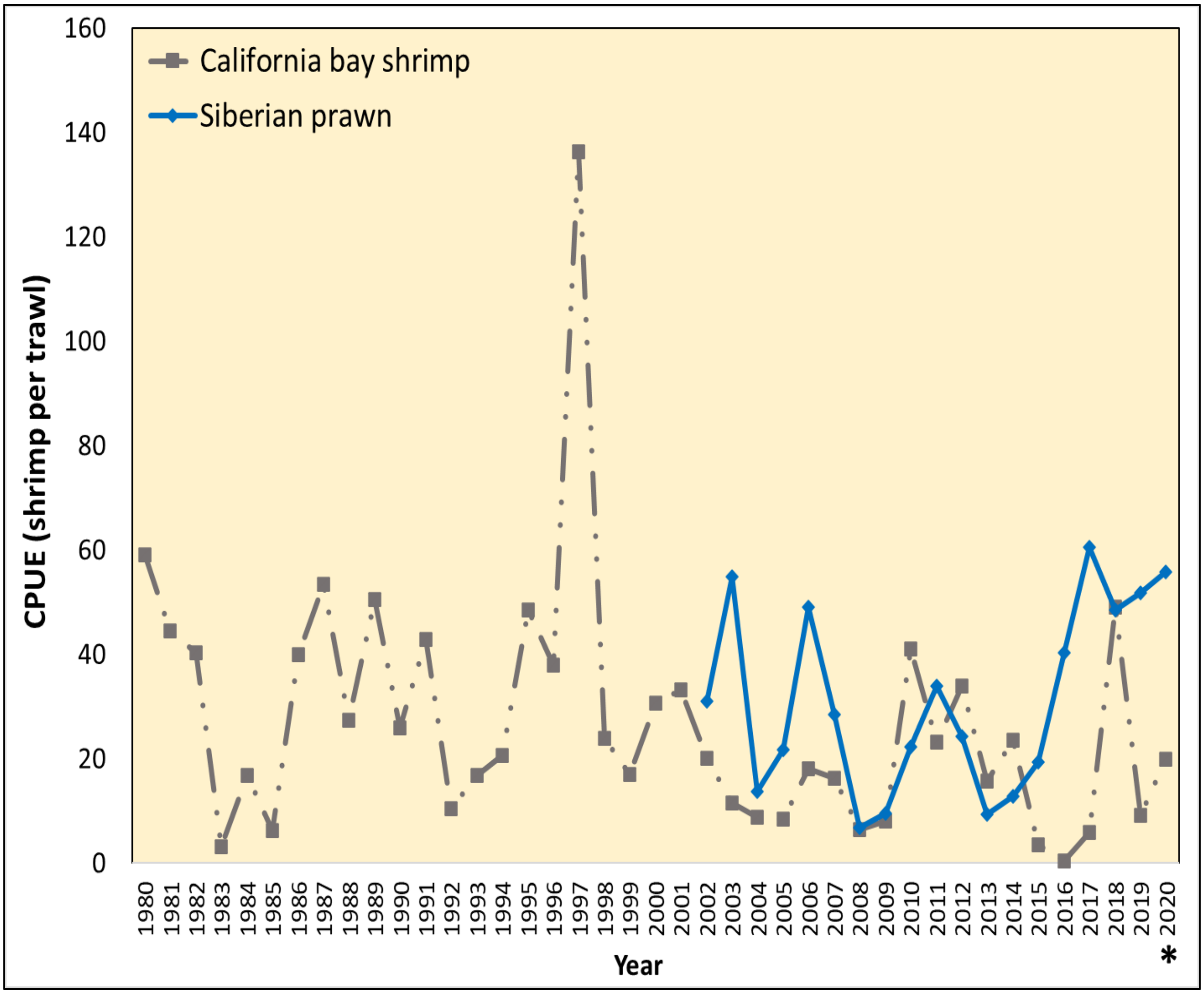

Figure 13. Annual CPUE of California bay shrimp and Siberian prawn (* = no April/May samples).

Siberian Prawn

Siberian prawn were very abundant in 2020 (52 shrimp per trawl), reaching their second-highest annual CPUE in since their introduction (Figure 13). Numbers roughly increased from spring to early autumn, after which they declined moderately (Figure 14). Unlike California bay shrimp, Siberian prawn were common in all sloughs of the marsh, with Boynton, Denverton, and upper Suisun sloughs hosting the highest numbers [17% (2,398 individuals), 16% (2,230 individuals), and 34% (4,738 individuals) of 2020's catch, respectively]. The lower prawn numbers in the last three months of 2020, which was not seen in 2019, was consistent with unfavorable salinities for the species (Brown and Hieb 2014).

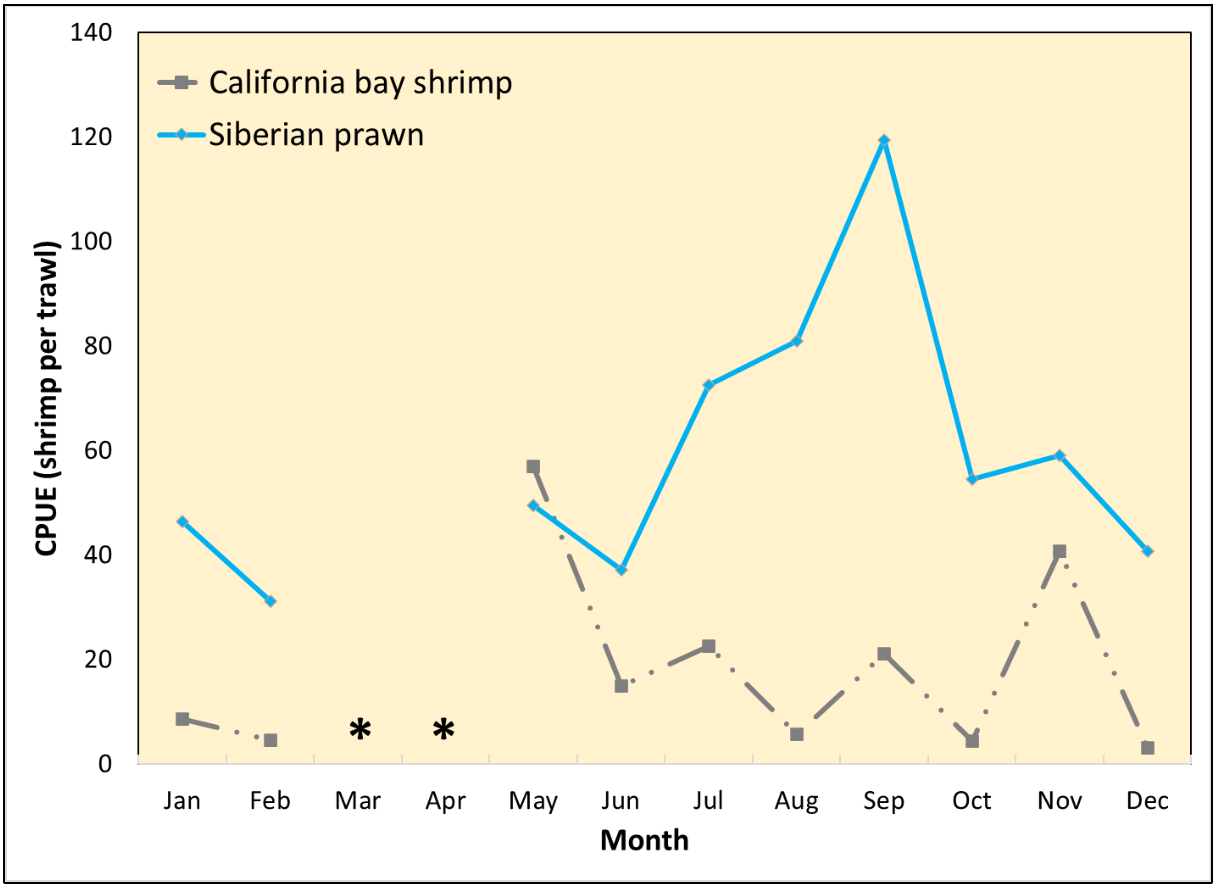

Figure 14. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2020 (* = no samples).

Trends in Fish Distribution and Abundance

Otter Trawls

Fish abundance in 2020 (17 fish per trawl) was moderately low, below both the 2019 CPUE and the all-years average (29 and 25 fish per trawl, respectively; Figure 15). The decline in CPUE in 2020 was due to drops in both native and non-native fish numbers (Table 1). Native fish CPUE in 2020 fell four fish per trawl from 2019 (7 and 11 fish, respectively) and was below the all-years average (10 fish per trawl), although the 2020 CPUE was partially attributable to no sampling occurring during the early recruitment period (early spring) for some species [*i.e.*, threespine stickleback, prickly sculpin, and staghorn sculpin (*Leptocottus armatus*); Moyle *et al.* 1986, Matern *et al.* 2002]. Splittail were mainly responsible for the change between 2019 and 2020 in native fish numbers, decreasing by 889 individuals, although their 2020 CPUE was still above their all-years average (Table 1). (Unlike the sculpins and stickleback, splittail do not begin recruiting until May and so their CPUE was less affected by the sampling cancellations.) The overall decline in native fish numbers was muted by increase in longfin smelt (Table 1). Non-native fish abundance dropped more precipitously from 2019 to 2020, from 18 to 10 fish per trawl, driven most strongly by fishes needing fresh water to spawn [*e.g.*, common carp (*Cyprinus carpio*; Lam and Sharpa 1985), two shad species (Hendricks 1961), and striped bass

(Moyle 2002)]. White catfish (*Ameiurus catus*), in contrast, increased, but that was due to one very large, anomalous catch in one trawl.

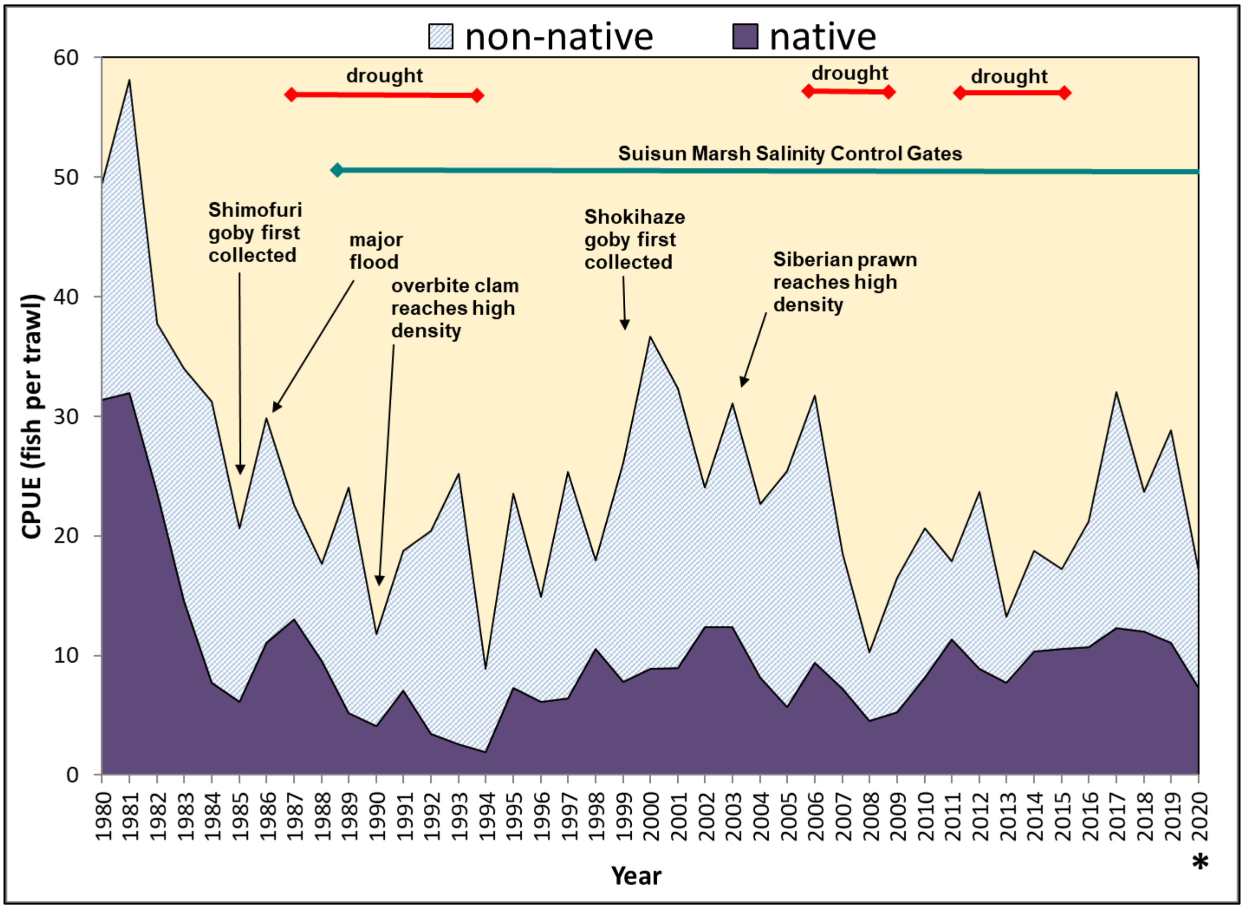

Figure 15. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted (* = no April/May samples).

Table 1. Percent change in annual otter trawl CPUE of 11 common marsh fishes (% 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 - 2020; no samples in April and May 2020).

Species	All Years CPUE	2019	2020	2020/2019 % Change
Sacramento splittail	**3.30**	**7.41**	**3.91**	**-47%**
longfin smelt	**1.04**	**0.01**	**1.00**	**+9900%**
threespine stickleback	**1.48**	**0.40**	**0.07**	**-83%**
prickly sculpin	**1.13**	**1.44**	**0.46**	**-68%**
threadfin shad	0.40	1.90	0.75	-61%
American shad	0.19	0.79	0.25	-68%
common carp	0.50	0.24	0.13	-46%
white catfish	0.59	0.22	0.54	+145%
striped bass	8.79	10.63	3.87	-64%
black crappie	0.23	0.55	0.32	-42%
shokihazi goby	0.15	0.30	0.68	+127%

Beach Seines

Inshore fish were more abundant than usual in 2020, with the annual beach seine CPUE (78 fish per seine haul) higher than the CPUE for the all-years average but lower than that for 2019 (60 and 107 fish per seine haul, respectively; Figure 16). Most native and non-native fishes decreased from 2019 to 2020, with only a few increasing, and of those that increased, none by more than a few individuals. All native species declined in beach seines between 2019 and 2020; the main driver for the decline in native fish numbers was, again, splittail, although their CPUE in 2020 was still above average (Table 2). (As for the otter trawl, the native-fish beach seine CPUE was likely biased low due to no sampling occurring in April and May.) Several non-native fishes contributing to 2020's lower beach seine CPUE were those that affected the otter-trawl CPUE: American shad, threadfin shad, striped bass, and black crappie (*Pomoxis nigromaculatus*; Table 2). Yellowfin goby (*Acanthogobius flavimanus*) was also not very abundant in 2020 compared to both 2019 and the all-years average (Table 2). Mississippi silverside numbers dropped between the two years, too, but were still well above their all-years average (Table 2).

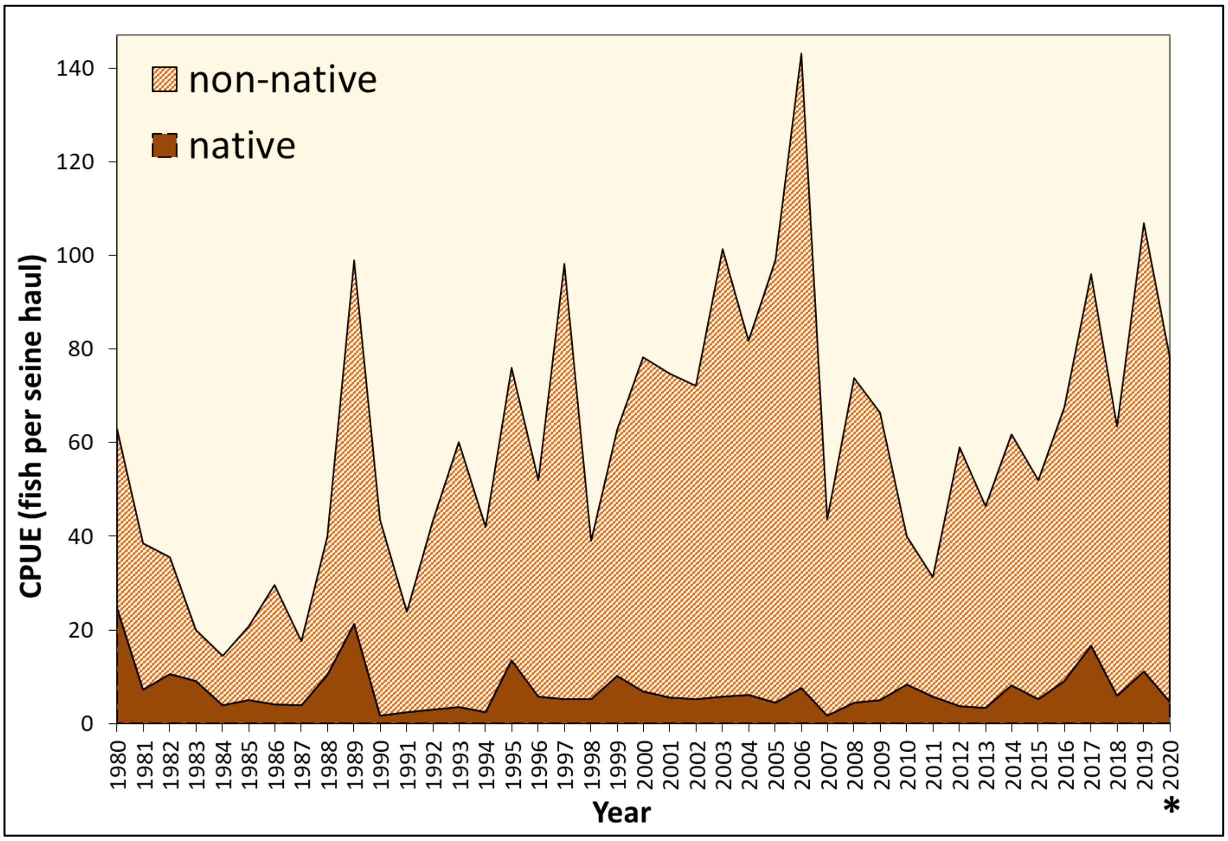

Figure 16. Annual beach seine CPUE of native and non-native fishes (* = no April/May samples).

Table 2. Percent change in annual beach seine CPUE of nine common marsh fishes (% 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 - 2020; no samples in April and May 2020).

Species	All Years CPUE	2019 CPUE	2020 CPUE	2020/2019 % Change
Sacramento splittail	**2.06**	**9.34**	**3.87**	**-59%**
Sacramento pikeminnow	**0.10**	**0.24**	**0.00**	**-100%**

Species	All Years CPUE	2019 CPUE	2020 CPUE	2020/2019 % Change
threespine stickleback	**1.71**	**0.61**	**0.10**	**-84%**
threadfin shad	2.63	7.55	2.65	-65%
American shad	0.16	0.47	0.13	-72%
Mississippi silversides	36.73	73.33	59.78	-18%
striped bass	5.73	9.64	3.49	-64%
black crappie	0.08	0.95	0.20	-79%
yellowfin goby	6.05	2.57	1.51	-41%

Fish Species of Interest

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

DELTA AND LONGFIN SMELT

For the fifth consecutive year, no delta smelt were captured by the Suisun Marsh Fish Study (Figure 17); likewise, none were captured in the Summer Townet Survey or the Fall Midwater Trawl Survey [California Department of Fish and Wildlife (CDFW) 2021].

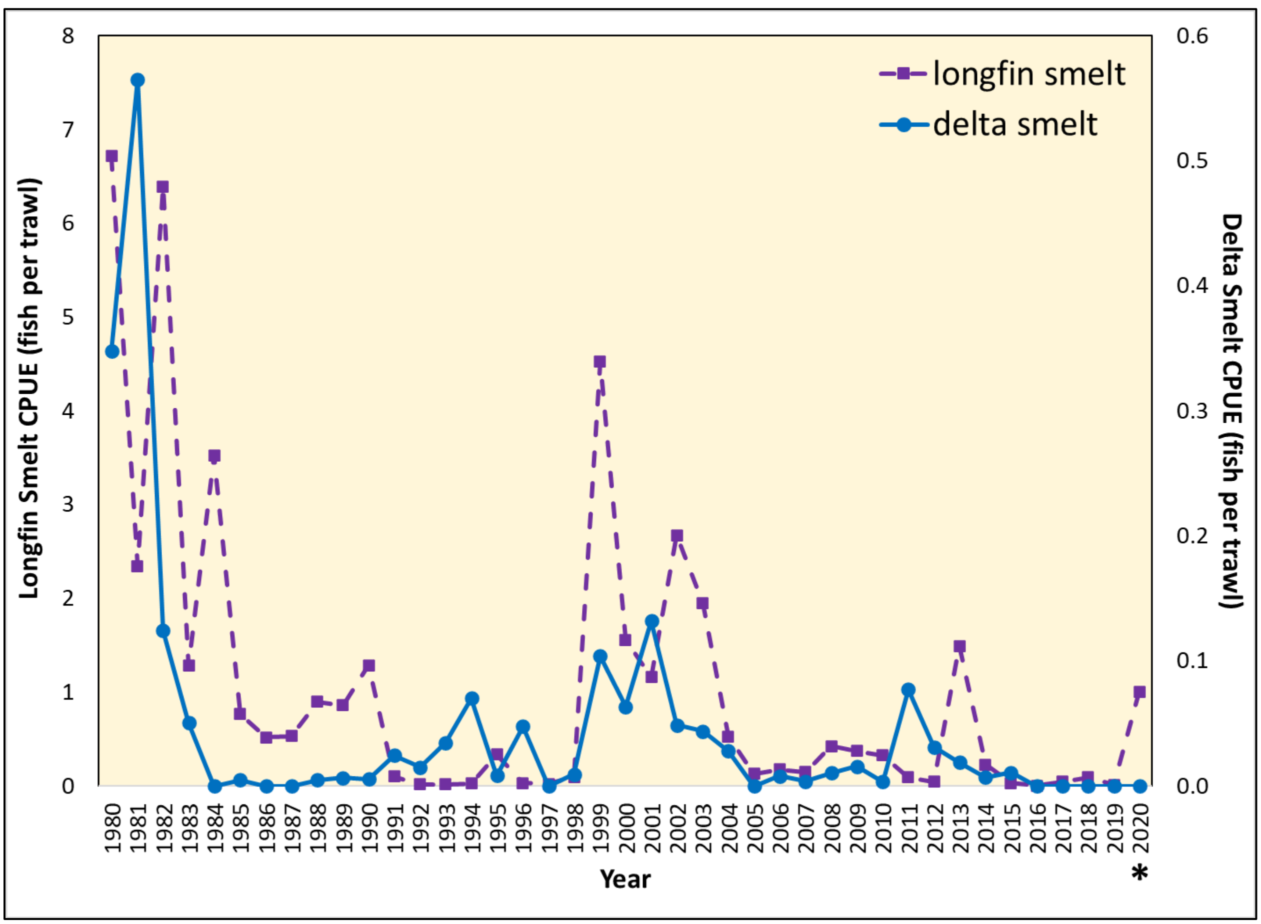

Figure 17. Annual Suisun Marsh Fish Study CPUE of the smelts of the Pelagic Organism Decline (* = no April/May samples).

Longfin smelt numbers were rather high in 2020 given trends in recent years, with the year's CPUE close to the average for all years of the study and well above 2019's value (Figure 17, Table 1). All but three fish were from the 2020 year class, with the majority caught in May in lower Suisun Slough and eastern Montezuma Slough (Figure 18). In contrast, very few were caught in small, long, dead-end sloughs (*e.g.,* Boynton, Denverton, Goodyear, and Peytonia sloughs) far away from Grizzly Bay and the Sacramento River, and none were caught in upper Suisun Slough, suggesting most age-0 longfin smelt recruited into Suisun Marsh from fringing marshes of Suisun Bay and the western Delta (Grimaldo *et al.* 2020; Figure 18). Catches plummeted in June and decreased through summer, with fish only captured in lower Suisun Slough, consistent with both a downstream shift to saltier waters and/or mortality due to high water temperatures (Figure 18). The three age-1 fish were all caught in lower Suisun Slough in January and December, reinforcing a common pattern in Suisun Marsh of longfin smelt being most abundant in sloughs near the estuary's main axis.

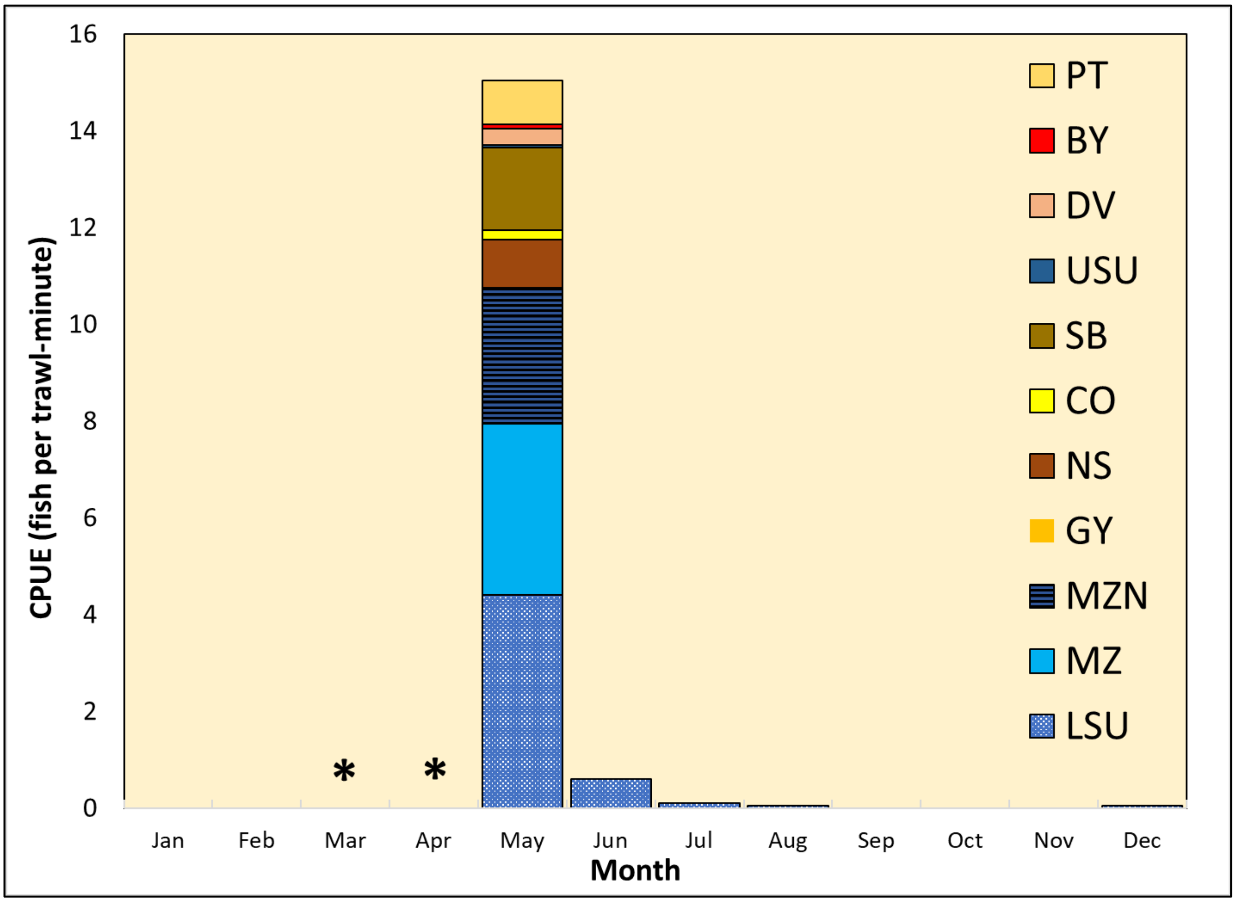

Figure 18. Monthly slough CPUE of age-0 longfin smelt in Suisun Marsh in 2020 ("LSU" = lower Suisun Slough, "MZN" = Montezuma new, and "USU" = upper Suisun Slough; other codes as in Figure 5; large sloughs in blue colors; * = no samples).

THREADFIN AND AMERICAN SHAD

Threadfin shad CPUE in 2020 dropped relative to the record-high number in 2019 (Figure 19), although CPUE in 2020 was still above that for all-years averages in both trawls and seines (Table 1 and 2). Nevertheless, geographic distribution in 2020 was similar to 2019. Two small sloughs, Denverton and First Mallard, contained a disproportionate percentage of the otter-trawl catch (60%), while sloughs on the west side of the marsh - Peytonia, upper Suisun, Boynton, lower Suisun, and Goodyear - hosted only 16% of 2020's catch (Appendix B). Geographic distribution in the beach seine was similar, with 67% and 25% of the year's catch coming from Denverton Slough and eastern Montezuma Slough, respectively, while only 8% of the catch came from upper Suisun Slough (Appendix B). The abundance and distribution of threadfin shad in 2020 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).

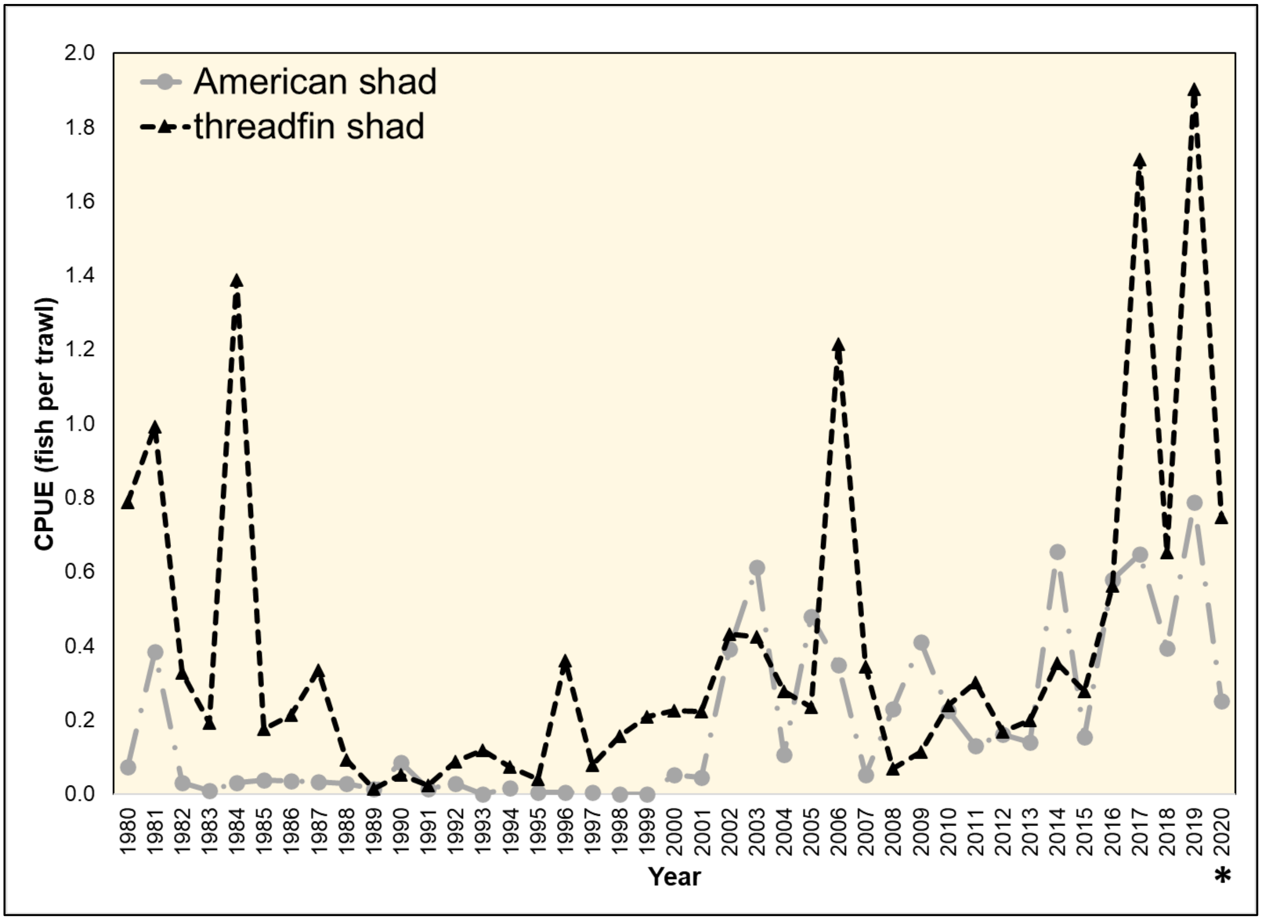

Figure 19. Annual CPUE of the shads of the Pelagic Organism Decline (* = no April/May samples).

Like threadfin shad, American shad also declined from 2019 to 2020 (Figure 19) in both trawls and seines (Table 1 and 2), though 2020 CPUE values were close to all-years averages. Nearly all fish captured (92%) in both net types were from the 2020 cohort. American shad were captured by otter trawl in most sloughs, although they were most abundant in the southwest marsh close to the estuary's main axis (*i.e.*, lower Suisun Slough and lower Goodyear Slough), where 33% of 2020's catch came from, and in Denverton Slough (25% of the catch). In beach seines, American shad were only captured in Denverton Slough (Appendix B). Their distribution was consistent with their migration from the main spawning grounds (the American, Feather, and Sacramento rivers) through the estuary's mainstem to the Pacific Ocean, as well as higher plankton densities in small, dead-end Denverton Slough.

STRIPED BASS

Striped bass CPUE in 2020 plummeted in both net types relative to 2019 (Figure 20), and abundances in 2020 were below all-years averages (Table 1 and 2). Very high numbers of age-0 fish occurred in seines in June, then rapidly declined through late summer into early autumn (Figure 21). The trend in mysids, an important prey for small striped bass (Feyrer *et al.* 2003, Bryant and Arnold 2007), was similar in the latter half of the year. In contrast, age-0 fish, while present in moderate numbers in June, July, and August, did not peak until September, after which they decreased dramatically to nearly negligible numbers in December (Figure 21). The high numbers of age-0 striped bass in September coincided with early operation of the Suisun Marsh Salinity Control Gates, similar to that observed in 2018 (Beakes *et* al. 2020, O'Rear *et al.* 2020). Juvenile striped bass generally declined through the year (Figure 21), consistent with dispersal throughout both the marsh (Figure 22) and the estuary (Calhoun 1952, Able *et al.* 2012). In contrast, age-0 fish were disproportionately abundant in smaller sloughs, with CPUE highest in Boynton, Denverton, Nurse, and Peytonia sloughs (Figure 22). Geographic pattern in beach seines was similar, with 88% 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 2020 was consistent with both low river flows and low Delta outflow supporting little reproduction/recruitment (Feyrer *et al.* 2007) and, similar to the two shad species, abundant zooplankton food in small, dead-end sloughs.

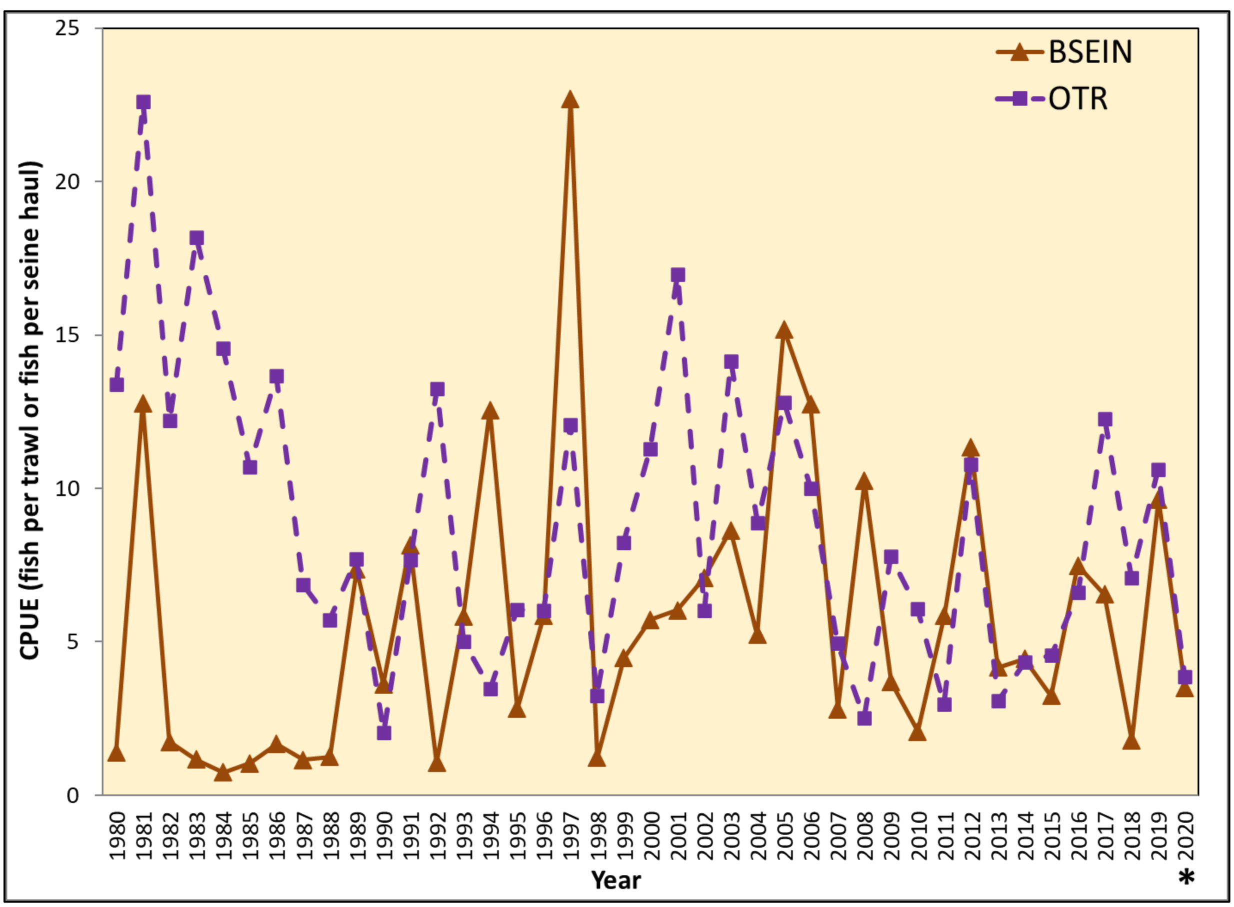

Figure 20. Annual CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine; * = no April/May samples).

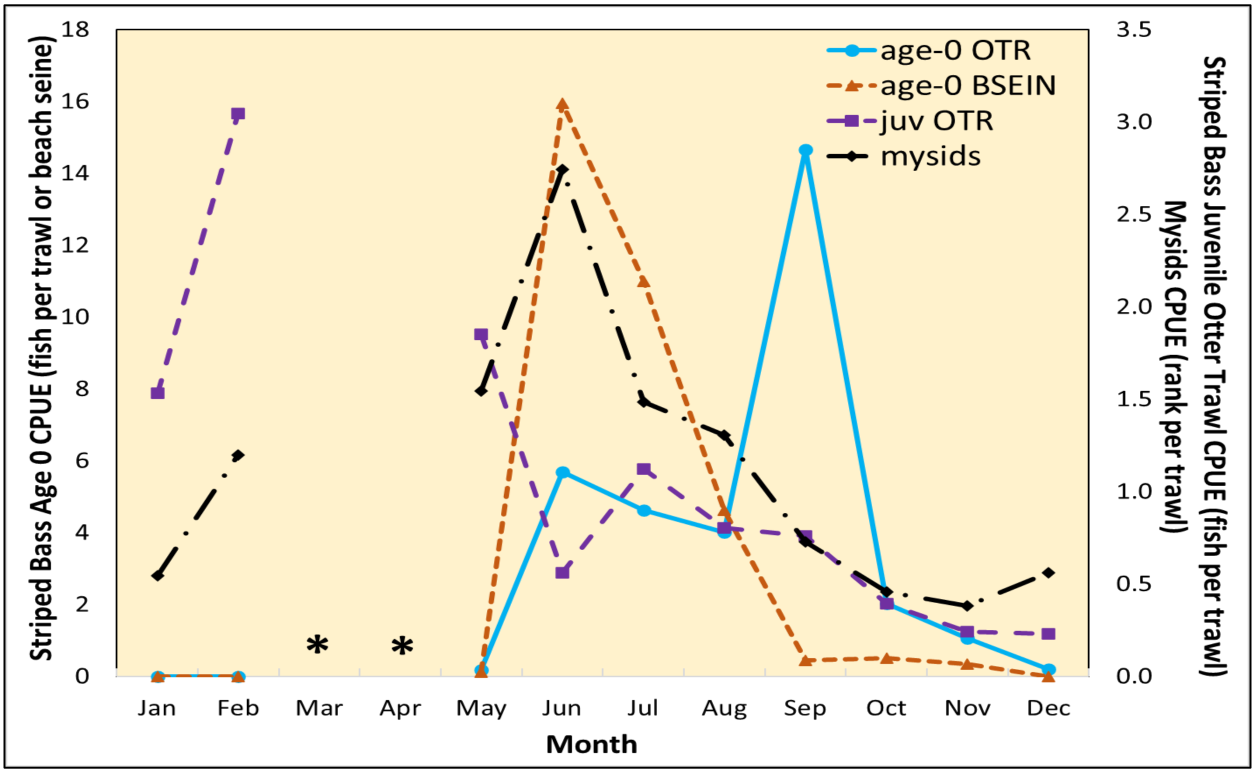

Figure 21. Monthly average CPUE of striped bass age classes and mysids (“juv” = juvenile; other codes as in Figure 18) in 2020 (* = no samples).

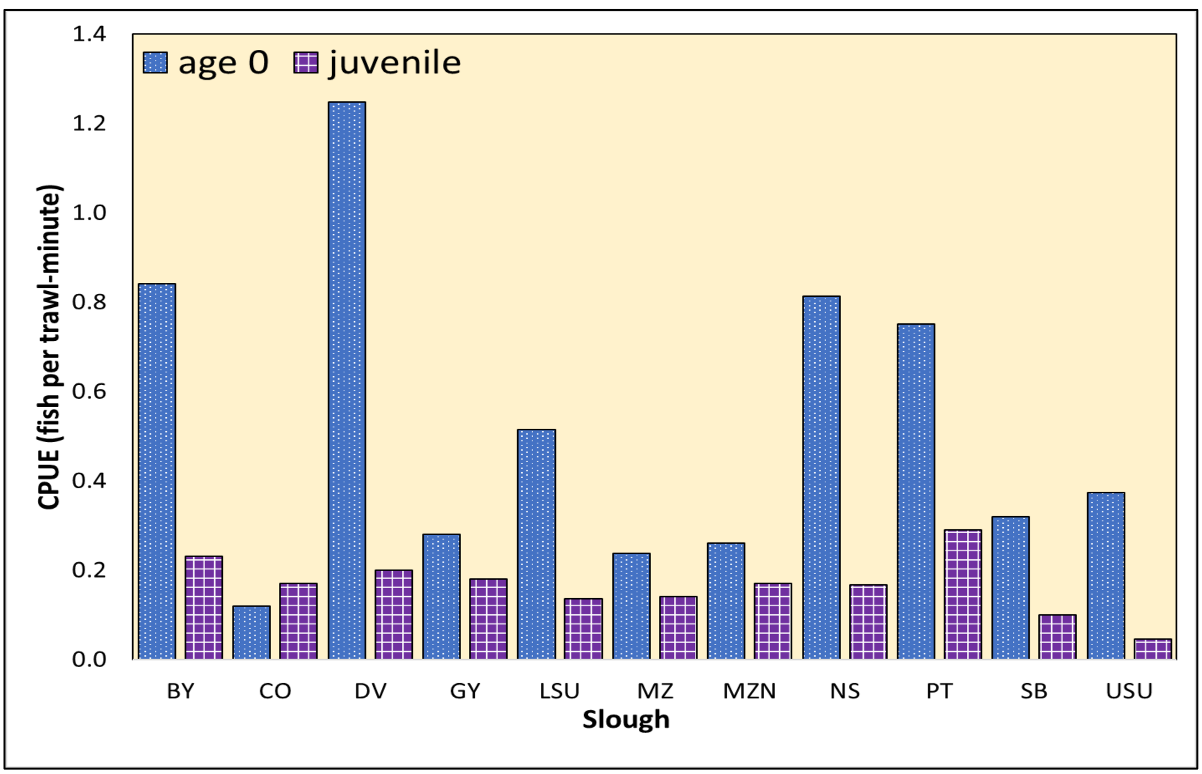

Figure 22. Average slough CPUE of age classes of striped bass in 2020 (codes as in Figure 5 and 18).

Sacramento Splittail

Like two other species that migrate to fresh water to spawn (American shad and striped bass), splittail numbers dropped considerably from 2019 to 2020 in both net types (Figure 23, Table 1 and 2). Nevertheless, both otter-trawl and beach seine CPUEs in 2020 were above all-years averages (Table 1 and 2). The moderate splittail catches in Suisun Marsh were contrasted by none being captured by the Fall Midwater Trawl Survey (CDFW 2021), a recent recurring phenomenon (O'Rear *et al.* 2021). The decline in the otter-trawl CPUE was mainly due to age-0 fish, which fell substantially from 2019 (4.8 fish per trawl) to 2020 (0.6 fish per trawl). Age-2+ abundance increased slightly from 2019 to 2020 (1.5 to 1.9 fish per trawl, respectively), though age-1 fish, those of the 2019 cohort, declined, an unexpected occurrence given the record-high recruitment in 2019 (Figure 23; O'Rear *et al.* 2021). Splittail were most numerous in small sloughs (Figure 24), typically those where age-0 striped bass were also most abundant (Figure 22). Splittail were also very abundant in near-shore shallow water in a large slough (Montezuma), where 81% of the beach seine fish were captured (Appendix B). The patterns in 2020 reflected (1) poor spawning conditions from minimal floodplain inundation in 2020 and (2) especially good conditions within the smaller sloughs of Suisun Marsh (Colombano *et al.* 2020*a*).

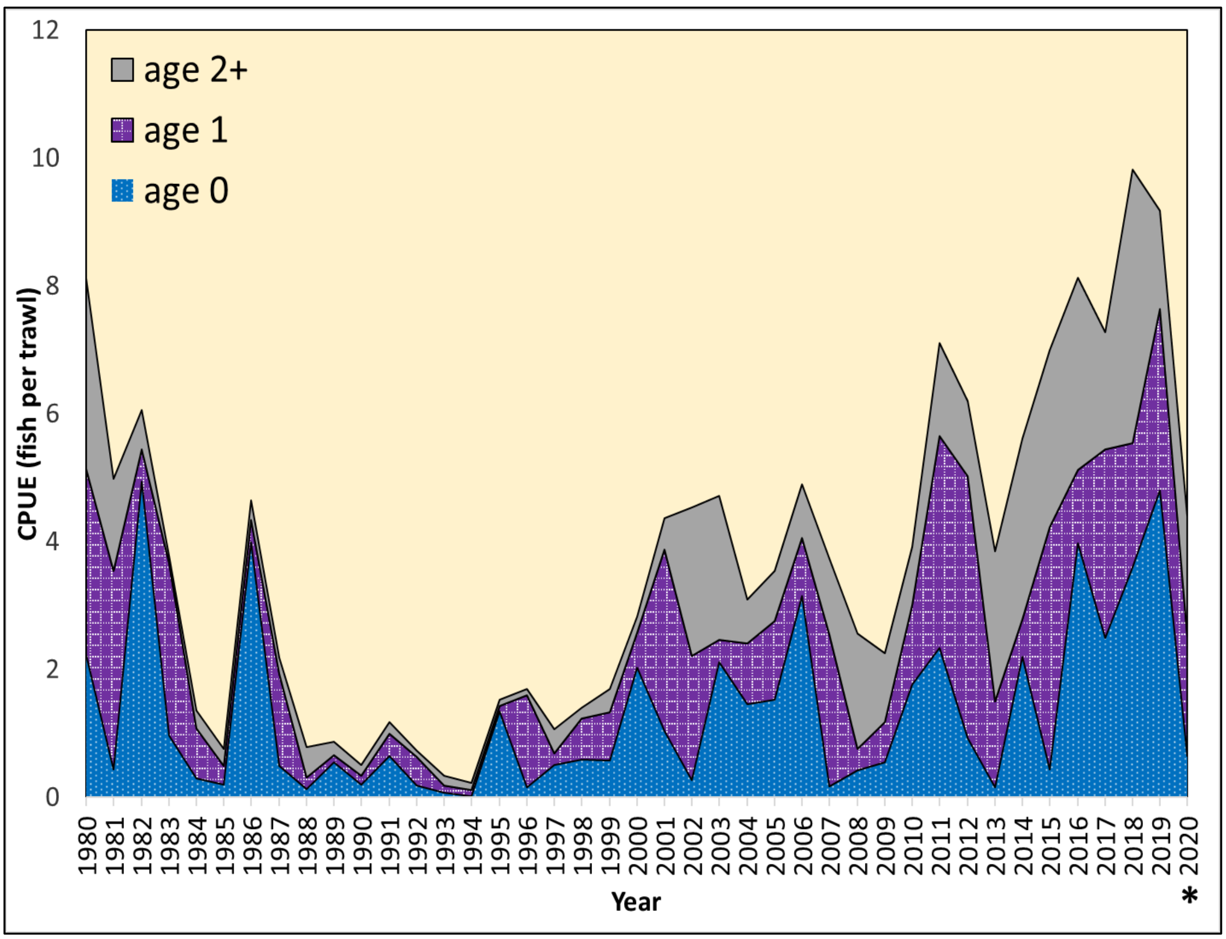

Figure 23. Annual CPUE of three age classes of Sacramento splittail (* = no April/May samples).

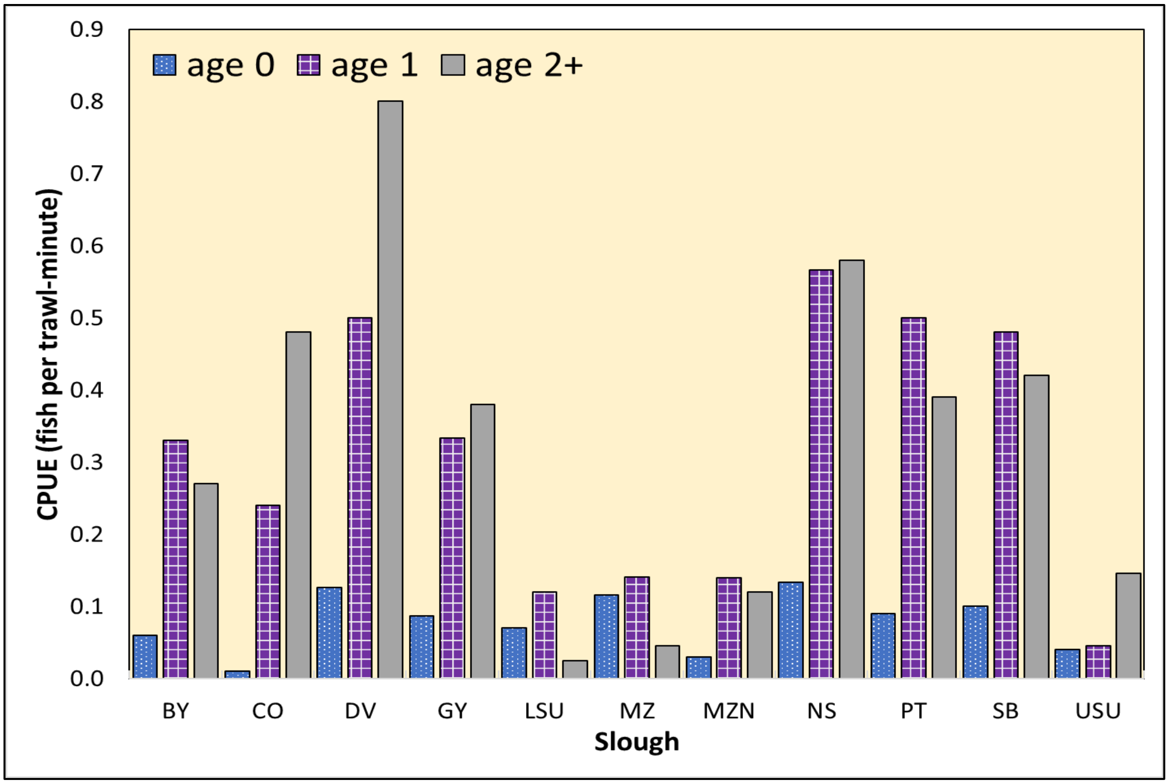

Figure 24. Average slough CPUE of age classes of splittail in 2020 (codes as in Figure 22).

<u>White Catfish</u>

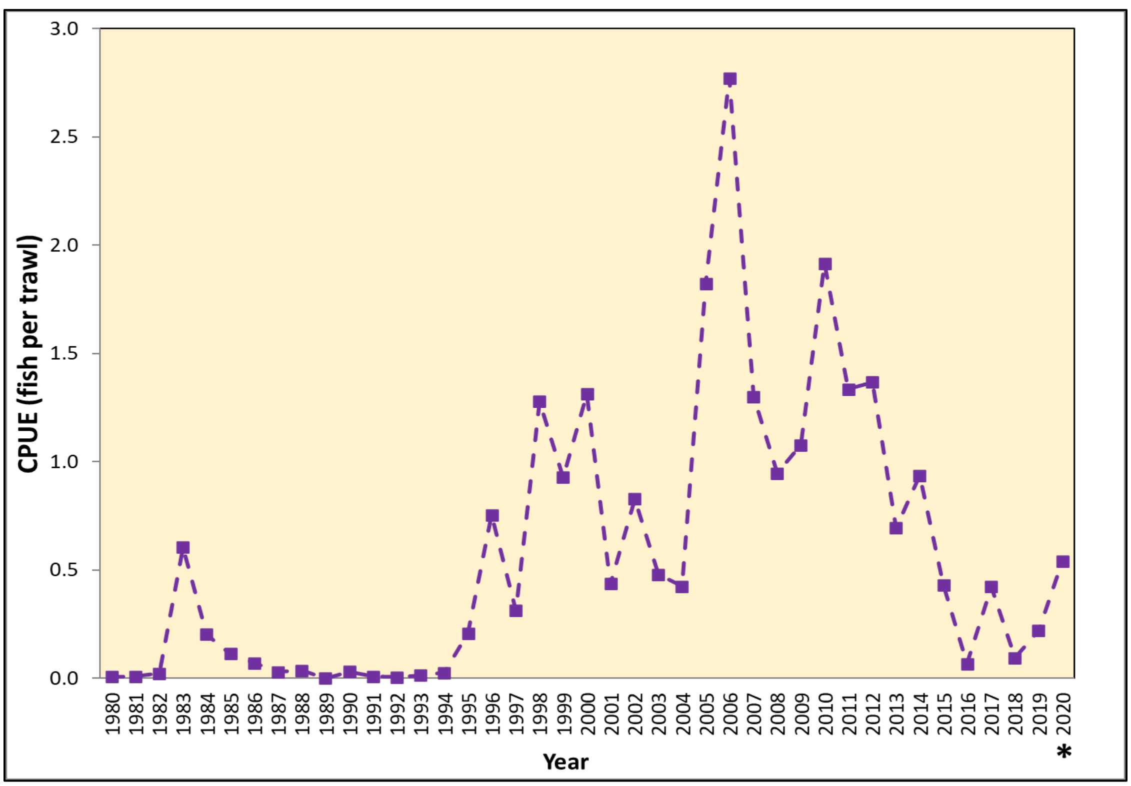

Figure 25. Annual CPUE of white catfish (* = no April/May samples).

White catfish, once one of the most abundant fish species in Suisun Marsh in the 2000s until the most recent prolonged drought (2012 - 2016; Figure 15), were again low in abundance in Suisun Marsh in 2020 (Figure 25). Unsuitable salinities for spawning within Suisun Marsh (<2 ppt; Perry and Avault, Jr. 1968, 1969) and low flows available for transporting small white catfish from rivers and the Delta into Suisun Marsh resulted in a catch of zero age-0 white catfish in 2020. With the exception of an extraordinary catch of 80 white catfish (59% of the year's catch) in one trawl in Denverton Slough in August, white catfish were not abundant anywhere, with none caught in the saltier southwest part of the marsh (*i.e.*, Goodyear and lower Suisun sloughs) where salinities are often unfavorable for the species (O'Rear and Moyle 2017).

Mississippi Silverside

Mississippi silverside annual beach seine CPUE dropped from 2019 to 2020 but was still quite high (Figure 26, Table 2), although 2020's CPUE was likely biased high because catches are often quite low in March and April (O'Rear *et al.* 2019, O'Rear *et al.* 2021). The trend in monthly abundance in the beach seines was typical, declining in winter until reaching its minimum in spring, and then generally climbing through summer to year's end (Figure 27) 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 that spawning may have begun as early as March and persisted into October (Figure 28). Mississippi silverside were abundant at all three seining beaches, with half the year's catch coming from eastern Montezuma Slough and the remainder split relatively evenly between Denverton and upper Suisun sloughs (28% and 23%, respectively; Appendix B). The species was rare in otter trawls except in First Mallard Slough, where 82% of the trawled fish were caught (Appendix B). The high numbers of silverside in 2020 were consistent with an expanded spawning period, given the warm year (Hubbs 1982, Stoeckel and Heidinger 1988, Middaugh and Hemmer 1992, Mahardja *et al.* 2016).

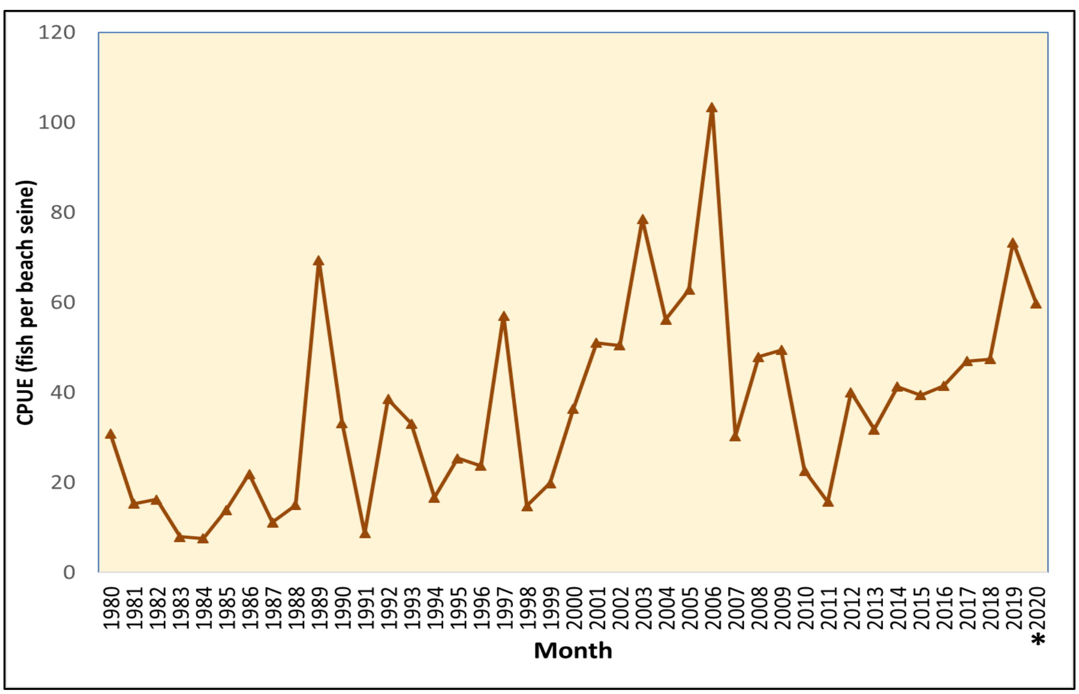

Figure 26. Annual CPUE of Mississippi silverside (* = no April/May samples).

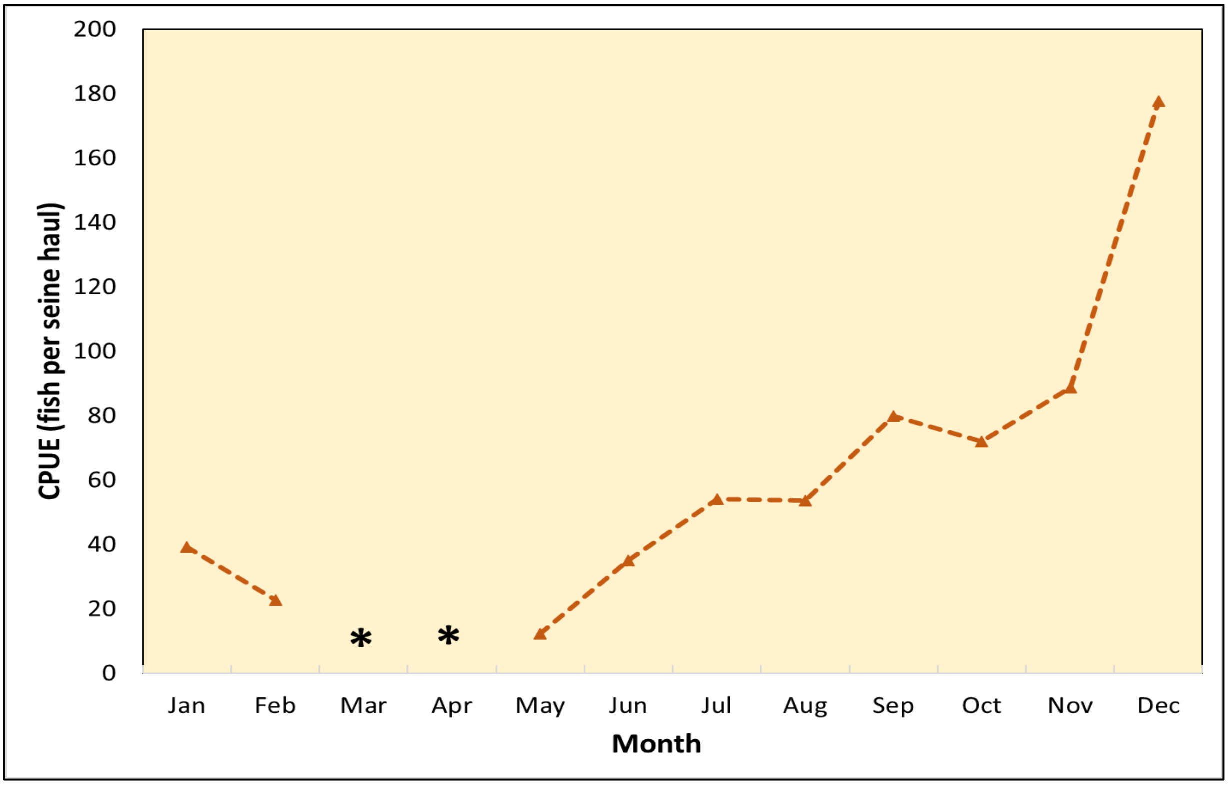

Figure 27. Monthly average CPUE of Mississippi silverside in 2020 (* = no samples).

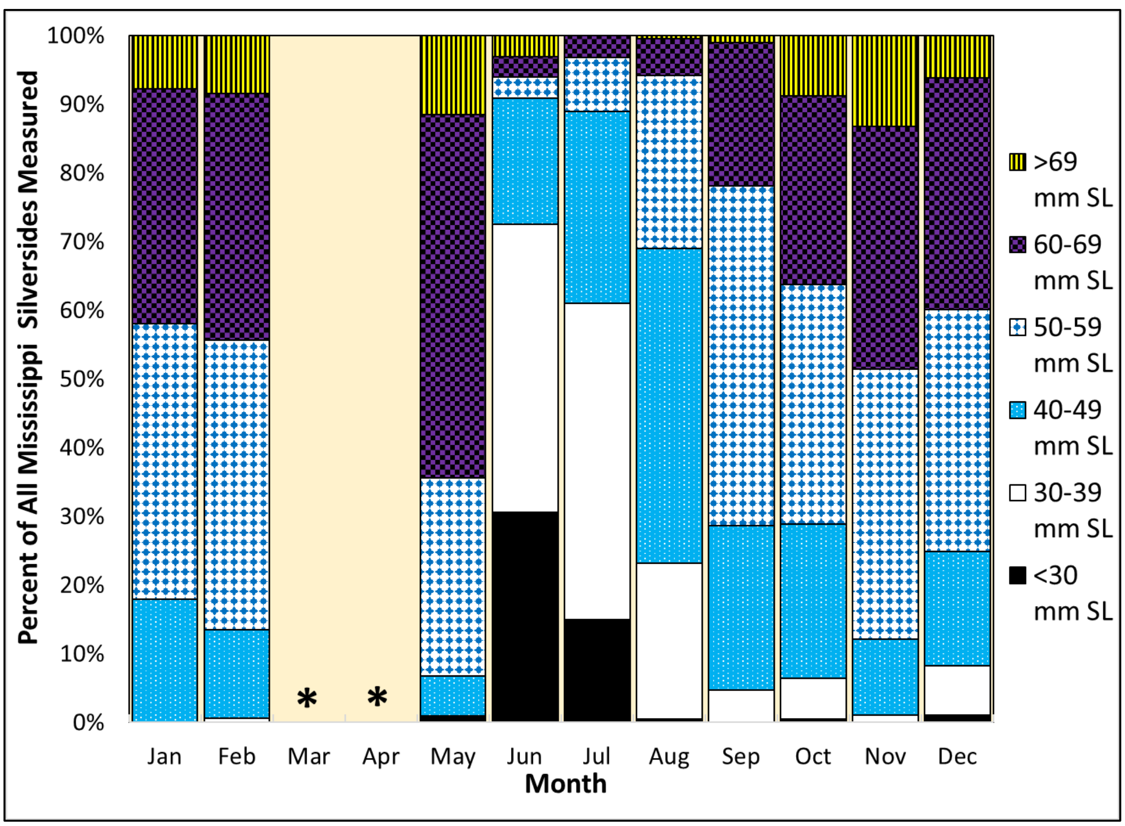

Figure 28. Monthly size-class distributions of Mississippi silverside captured in beach seines in 2020 (* = no samples).

CONCLUSION

After the wet year of 2019, dry weather conditions returned to Suisun Marsh in 2020, 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, two increasingly common conditions in Suisun Marsh. The invertebrate assemblage was dominated by non-native species: Siberian prawn, which is basically a freshwater shrimp that can tolerate moderate salinities; and overbite clam, which has been associated with warmer water. Numbers of the native California bay shrimp were moderate in 2020, due in part to higher salinities that are more conducive for the species. Nearly all native and non-native fishes were less abundant than usual in Suisun Marsh during 2020, especially migratory fishes that spawn upstream in fresh water: Sacramento splittail, striped bass, and American shad. Those three species, as well as the plankton-eating threadfin shad, were generally more abundant in small, dead-end sloughs rather than large sloughs. Numbers of several native fishes, however, were likely biased low because of the lack of samples in April and May. Several fishes, both native and non-native, that are generally most abundant in wet years were either not caught at all (delta smelt) or caught in low numbers (common carp and white catfish). A bright spot was the irruption of age-0 longfin smelt in spring, though whether those fish survived the warm year is unknown. Although fish numbers were rather low in 2020, they were still much better than those posted in the estuary's mainstem relative to all-years averages (CDFW 2021), especially for splittail. In sum, 2020 reflected (1) low flows limiting reproduction/recruitment of native and non-native fishes that spawn in fresh water and rear in Suisun Marsh; (2) the disproportionate value of small, dead-end sloughs for fishes; and (3) Suisun Marsh being the premier habitat for Sacramento splittail. Many results were not surprising given our current understanding of the San Francisco Estuary Watershed's ecology [*e.g.*, years of little floodplain inundation corresponding to low numbers of age-0 splittail, or high plankton abundances and thus high pelagic-fish abundances in dead-end sloughs with high residence times (Montgomery *et al.* 2015)], but anomalous catches (*e.g.*, high age-0 longfin smelt numbers in large Suisun Marsh sloughs in such a dry warm, year) reflected that we still have much to learn.

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APPENDIX A: 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 2020 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
striped bass	*Morone saxatilis*	98632	16999	30	115661
Mississippi silverside	*Menidia audens*	1537	114032		115569
Sacramento splittail	***Pogonichthys macrolepidotus***	**40907**	**6895**	**14**	**47816**
yellowfin goby	*Acanthogobius flavimanus*	21228	18369		39597
tule perch	***Hysterocarpus traski***	**23013**	**2647**	**6**	**25666**
threespine stickleback	***Gasterosteus aculeatus***	**18260**	**6886**	**6**	**25152**
shimofuri goby	*Tridentiger bifasciatus*	12190	2936	1	15127
prickly sculpin	***Cottus asper***	**12863**	**1213**	**1**	**14077**
threadfin shad	*Dorosoma petenense*	4765	8488	1	13254
longfin smelt	***Spirinchus thaleichthys***	**12165**	**54**	**5**	**12224**
white catfish	*Ameiurus catus*	6264	173	13	6450
common carp	*Cyprinus carpio*	5741	587	1	6329
staghorn sculpin	***Leptocottus armatus***	**2610**	**3485**		**6095**
Sacramento sucker	***Catostomus occidentalis***	**3599**	**137**	**5**	**3741**
black crappie	*Pomoxis nigromaculatus*	2752	275	1	3028
American shad	*Alosa sapidissima*	2215	498		2713
starry flounder	***Platichthys stellatus***	**2294**	**310**	**4**	**2608**
shokihaze goby	*Tridentiger barbatus*	1647	5	6	1658
black bullhead	*Ameiurus melas*	883	3		886
delta smelt	***Hypomesus transpacificus***	**665**	**144**	**4**	**813**
Pacific herring	***Clupea harengeus***	**485**	**116**		**601**
Sacramento pikeminnow	***Ptychocheilus grandis***	**194**	**351**		**545**
Chinook salmon	***Oncorhynchus tshawytscha***	**79**	**433**	**1**	**513**
western mosquitofish	*Gambusia affinis*	21	424		445
goldfish	*Carassius auratus*	325	70		395
northern anchovy	***Engraulis mordax***	**330**		**37**	**367**
channel catfish	*Ictalurus punctatus*	191	11		202
rainwater killifish	*Lucania parva*	39	154		193
hitch	***Lavinia exilicauda***	**129**	**16**		**145**
Sacramento blackfish	***Orthodon macrolepidotus***	**27**	**117**		**144**
white sturgeon	***Acipenser transmontanus***	**127**		**2**	**129**
white crappie	*Pomoxis annularis*	112			112
fathead minnow	*Pimephales promelas*	36	39		75
Pacific lamprey	***Lampetra tridentata***	**49**			**49**
bluegill	*Lepomis macrochirus*	26	22		48
bigscale logperch	*Percina macrolepida*	21	24		45

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
brown bullhead	*Ameiurus nebulosus*	34			34
wakasagi	*Hypomesus nipponensis*	14	12		26
golden shiner	*Notemigonus crysoleucas*	10	14		24
plainfin midshipman	***Porichthys notatus***	**21**			**21**
shiner perch	***Cymatogaster aggregata***	**17**			**17**
California halibut	***Paralichthys californicus***	**11**	**3**		**14**
rainbow trout	***Oncorhynchus mykiss***	**9**	**4**		**13**
green sunfish	*Lepomis cyanellus*	5	3		8
largemouth bass	*Micropterus salmoides*		6		6
surf smelt	***Hypomesus pretiosus***	**5**			**5**
Pacific sanddab	***Citharichthys sordidas***	**2**	**2**		**4**
river lamprey	***Lampetra ayresi***	**4**			**4**
speckled sanddab	***Citharichthys stigmaeus***	**4**			**4**
bay pipefish	***Sygnathus leptorhynchus***	**3**			**3**
green sturgeon	***Acipenser medirostris***	**3**			**3**
redear sunfish	*Lepomis microlophus*	2	1		3
white croaker	***Genyonemus lineatus***	**3**			**3**
hardhead	***Mylopharadon conocephalus***	**1**			**1**
longjaw mudsucker	***Gillichthys mirabilis***	**1**			**1**
striped mullet	***Mugil cephalus***		**1**		**1**
warmouth	*Lepomis gulosus*	1			1
Total		276571	185959	138	462668

APPENDIX B: 2020 CATCHES

Total 2020 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	
American shad	9		18	14	16		7		1	3	3	1	72
black bullhead			1										1
black crappie			80	1			1		9	7	2		100
bluegill			1							1			2
channel catfish							1	1					2
common carp	8	2	6	3					9	4	2	1	35
longfin smelt	**1**	**2**	**5**		**107**		**71**	**28**	**15**	**9**	**17**	**1**	**256**
Mississippi silverside			7	6		3					59		75
Pacific herring								**1**					**1**
prickly sculpin	**22**	**4**	**4**	**45**	**6**		**9**		**2**	**15**	**1**	**11**	**119**
Sacramento blackfish									**1**				**1**
Sacramento pikeminnow		**1**	**1**				**1**						**3**
Sacramento splittail	**66**	**73**	**214**	**120**	**43**		**60**	**29**	**192**	**98**	**100**	**46**	**1041**
Sacramento sucker	**11**	**4**	**3**	**3**				**1**	**2**	**8**	**6**		**38**
shimofuri goby	124	11	75	5	2		8	8	34	57	19	22	365
shokihaze goby	8	14	3	2	30		14	35	18	2		46	172
staghorn sculpin												**1**	**1**
starry flounder			**1**					**1**	**2**				**4**
striped bass	107	29	218	72	130		75	43	147	104	42	83	1050
threadfin shad	6	3	43	2	9		18		27	11	79	5	203
threespine stickleback	**1**	**2**		**9**				**1**		**4**	**1**		**18**
tule perch	**46**	**35**	**12**	**10**	**12**		**30**		**43**	**89**	**15**	**22**	**314**
wakasagi							1						1
western mosquitofish				2									2
white catfish	1	5	109				5	6	6	6		1	139
white sturgeon					**1**								**1**
yellowfin goby	26	15	6	33	98		9	9	10	23	16	37	282
Total	436	200	807	327	454	3	310	163	518	441	362	277	4298

Total 2020 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	
American shad	11				11
black crappie	17				17
bluegill				1	1
Chinook salmon	**1**				**1**
common carp	5		9		14
fathead minnow					0
golden shiner	1				1
largemouth bass			1		1
Mississippi silverside	1372	819	2458	1132	5781
prickly sculpin			**1**		**1**
rainwater killifish	1		1		2
Sacramento splittail	**43**		**269**	**9**	**321**
shimofuri goby	71		2	5	78
staghorn sculpin			**2**		**2**
striped bass	253		18	19	290
threadfin shad	147	1	56	17	221
threespine stickleback			**5**	**3**	**8**
tule perch	**3**		**31**	**4**	**38**
wakasagi	1				1
western mosquitofish	2			3	5
white catfish	1				1
yellowfin goby	26		11	88	125
Total	1955	820	2864	1281	6920

APPENDIX C: 2020 EFFORT

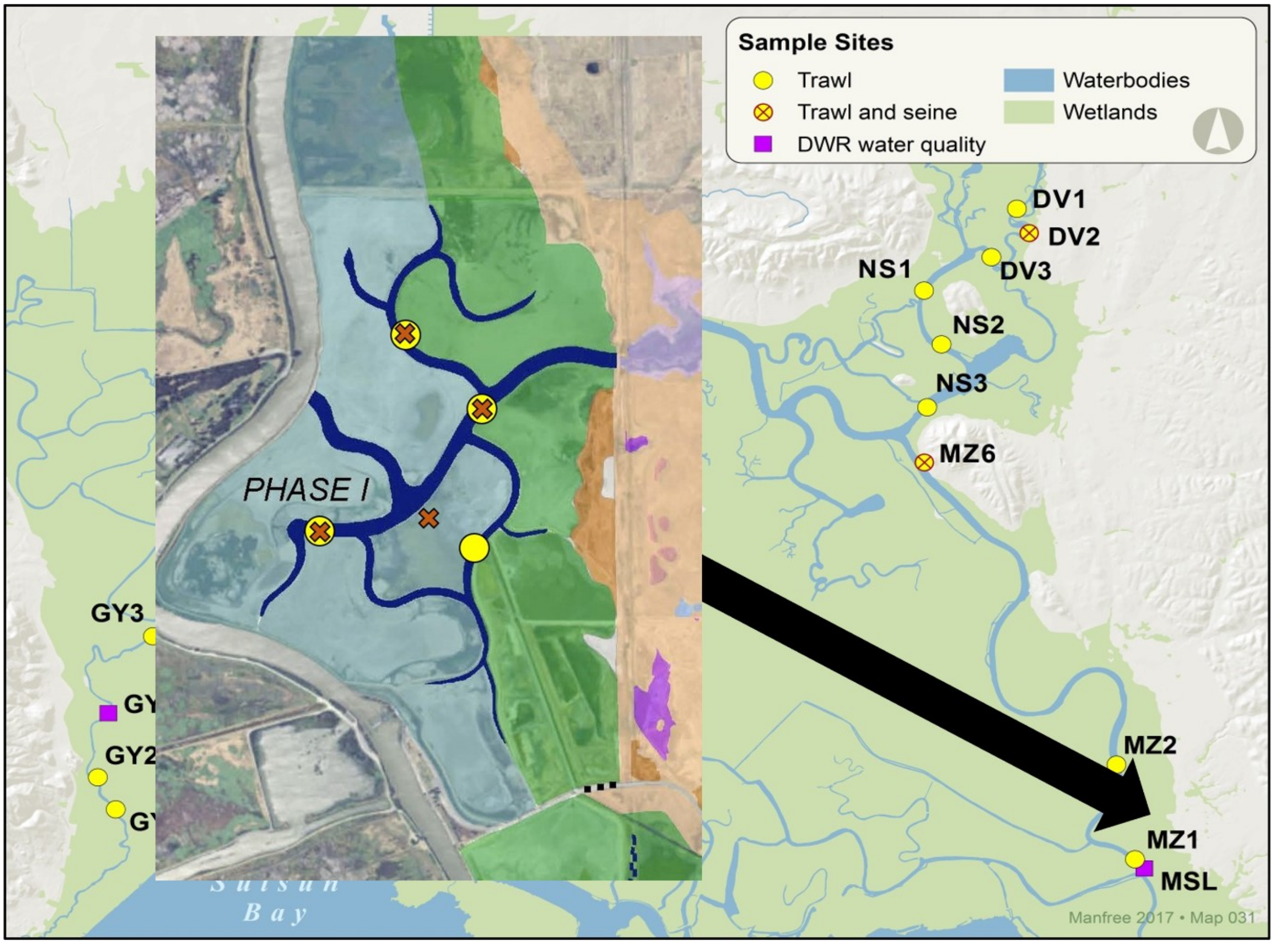
Number of otter trawls in each slough and each month in 2020.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	0	0	2	2	2	2	2	2	2	2	20
Cutoff	2	2	0	0	2	2	2	2	2	2	2	2	20
Denverton	3	3	0	0	3	3	3	3	3	3	3	3	30
Goodyear	3	3	0	0	3	3	3	3	3	3	3	3	30
Lower Suisun	2	2	0	0	2	2	2	2	2	2	2	2	20
Montezuma	2	2	0	0	2	2	2	2	2	2	2	2	20
Montezuma new	1	1	0	0	1	1	1	1	1	1	1	1	10
Montezuma Wetlands	0	0	0	0	0	0	0	0	0	0	4	4	8
Nurse	3	3	0	0	3	3	3	3	3	3	3	3	30
Peytonia	2	2	0	0	2	2	2	2	2	2	2	2	20
First Mallard	2	2	0	0	2	2	2	2	2	2	2	2	20
Upper Suisun	2	2	0	0	2	2	2	2	2	2	2	2	20
Total	24	24	0	0	24	24	24	24	24	24	28	28	248

Number of beach seines in each slough and each month in 2020.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	2	3	0	0	3	3	3	3	3	2	3	3	28
Montezuma Wetlands	0	0	0	0	0	0	0	0	0	0	5	7	12
Montezuma new	3	3	0	0	3	2	2	3	3	3	3	3	28
Upper Suisun	2	3	0	0	2	2	2	2	2	3	2	2	22
Total	7	9	0	0	8	7	7	8	8	8	8	8	90

APPENDIX D: MONTEZUMA WETLANDS SAMPLING SITES



APPENDIX E: 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)>#1/1/2020# And (Sample.SampleDate)<#1/1/2021#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
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)>#1/1/2020# And (Sample.SampleDate)<#12/31/2020#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```