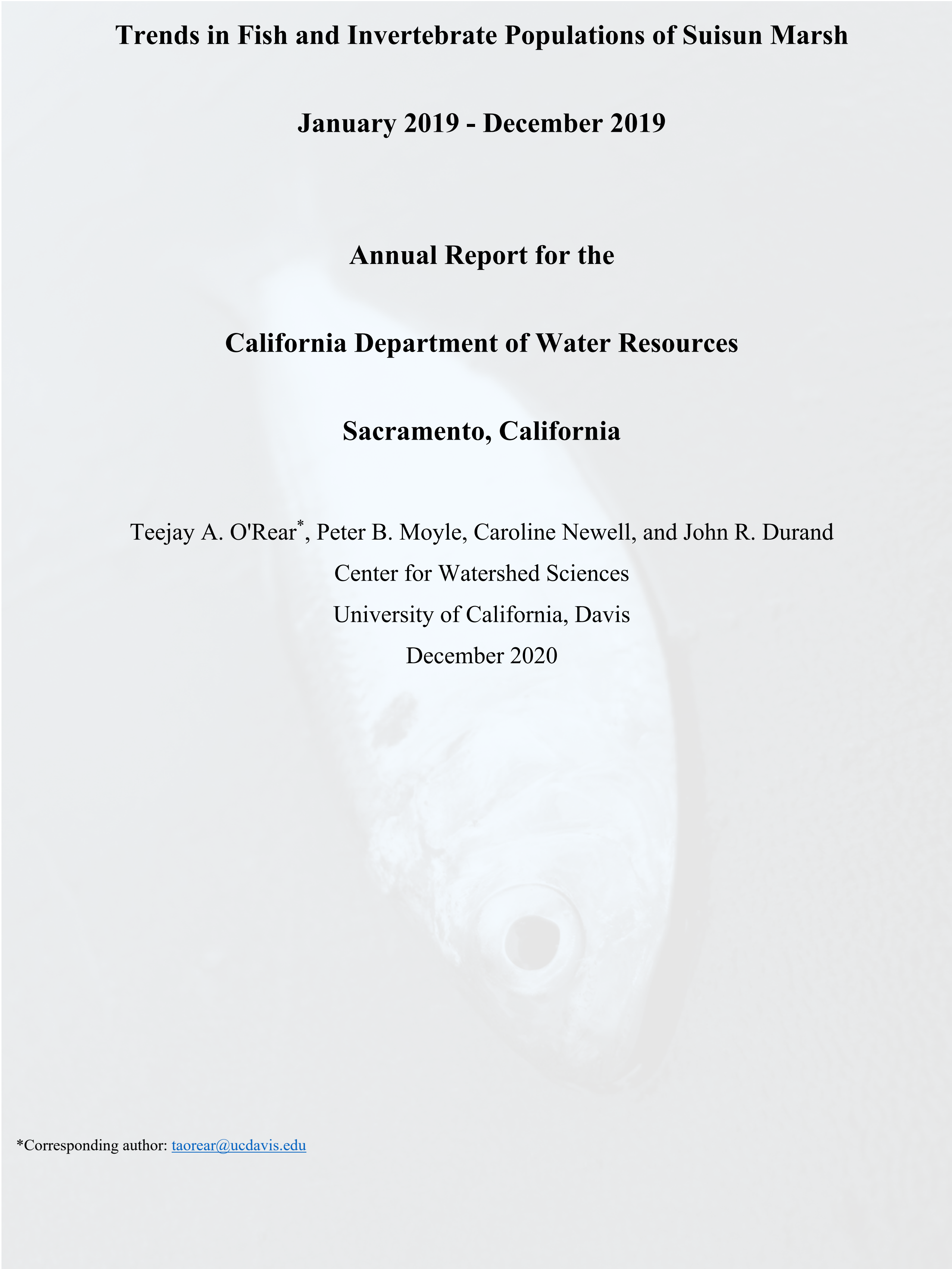

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2019 - December 2019

Annual Report for the

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Teejay A. O'Rear*, Peter B. Moyle, Caroline Newell, and John R. Durand
Center for Watershed Sciences
University of California, Davis
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*Corresponding author: taorear@ucdavis.edu

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 environmental and anthropogenic factors affecting fish distribution and abundance.

After the fairly dry year of 2018, Suisun Marsh was once again subjected to very wet conditions in 2019. Delta outflow was higher than average throughout most of the year, with Yolo Bypass flooding in winter and spring, resulting in very low salinities within Suisun Marsh. Two recent patterns recurred in 2019: 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 2019 strengthened three common patterns: (1) warmer water corresponds to larger populations of non-native species; (2) higher flows and lower salinities are favorable for many fishes, whether native or non-native; and (3) Suisun Marsh is disproportionately valuable to fishes of conservation importance. Numbers of three non-native invertebrates - Black Sea jellyfish (*Maeotias marginata*), overbite clam (*Potamocorbula amurensis*), and Siberian prawn (*Palaemon modestus*) - were very high 2019. Abundances of most fish species, both native and non-native, increased from 2018 to 2019, especially those tolerant of warmer water. In particular, non-native fishes that eat zooplankton and spawn in fresh water - threadfin shad (*Dorosoma petenense*), American shad (*Alosa sapidissima*), Mississippi silverside (*Menidia audens*), and striped bass (*Morone saxatilis*) - were very abundant, in contrast to abundances in the estuary's main axis, which saw much fewer numbers relative to long-term averages. Many common native fishes also increased in numbers from 2018 to 2019, including Chinook salmon (*Oncorhynchus tshawytscha*), threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*), and tule perch (*Hysterocarpus traski*). Sacramento splittail (*Pogonichthys macrolepidotus*) were extraordinarily abundant in 2019, posting their highest-ever abundance in beach seines, an especially remarkable occurrence given that none were captured in the California Department of Fish and Wildlife (CDFW) Fall Midwater Trawl Survey. In contrast, negligible numbers of native smelts (which generally require cool water) in the greater estuary were mirrored by very low abundances in Suisun Marsh. Thus Suisun Marsh appears crucial to maintaining populations of valuable fishes, both native and non-native, particularly zooplanktivorous fishes tolerant of warm water.

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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 managed wetlands targeted at waterfowl, with the rest of the acreage consisting of tidal sloughs, marsh plains, 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 juvenile marine fishes; the marsh is also a migratory corridor for anadromous fishes such as Chinook salmon (*Oncorhynchus tshawytscha*; Vincik 2002).

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 (Matern *et al*. 2002), 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); and (3) enhancing ecological understanding of key species in the marsh (*e.g.*, Brown and Hieb 2014). Secondary objectives have included supporting research by other investigators through special collections (*e.g.,* Liu *et al.* 2013); providing background information for fine-scale 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); serving as a baseline for upcoming restoration and for ancillary studies of intertidal habitats (*e.g.*, Williamson *et al.* 2015); documenting invasions of new species [*e.g.*, alligatorweed (*Alternanthera philoxeroides*); Walden *et al.* 2019)]; contributing to general estuarine knowledge through publication of peer-reviewed papers (*e.g.,* Schroeter *et al.* 2015); 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 structure of 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 structure 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 (O'Rear *et al.* 2019, Colombano *et al.* 2020). 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.* 2019). 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") compared to the Suisun Marsh Fish Study 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) utilizing identical nets to the Suisun Marsh Fish Study 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 (Williamson *et al.* 2015). Baumsteiger *et al.* (2017, 2018) showed increased annual numbers of both Black Sea jellyfish 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 documenting and understanding the biology of the estuary, 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 2019 with average conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2019 to annual averages, noting abundance changes between 2018 and 2019; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2019, 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).

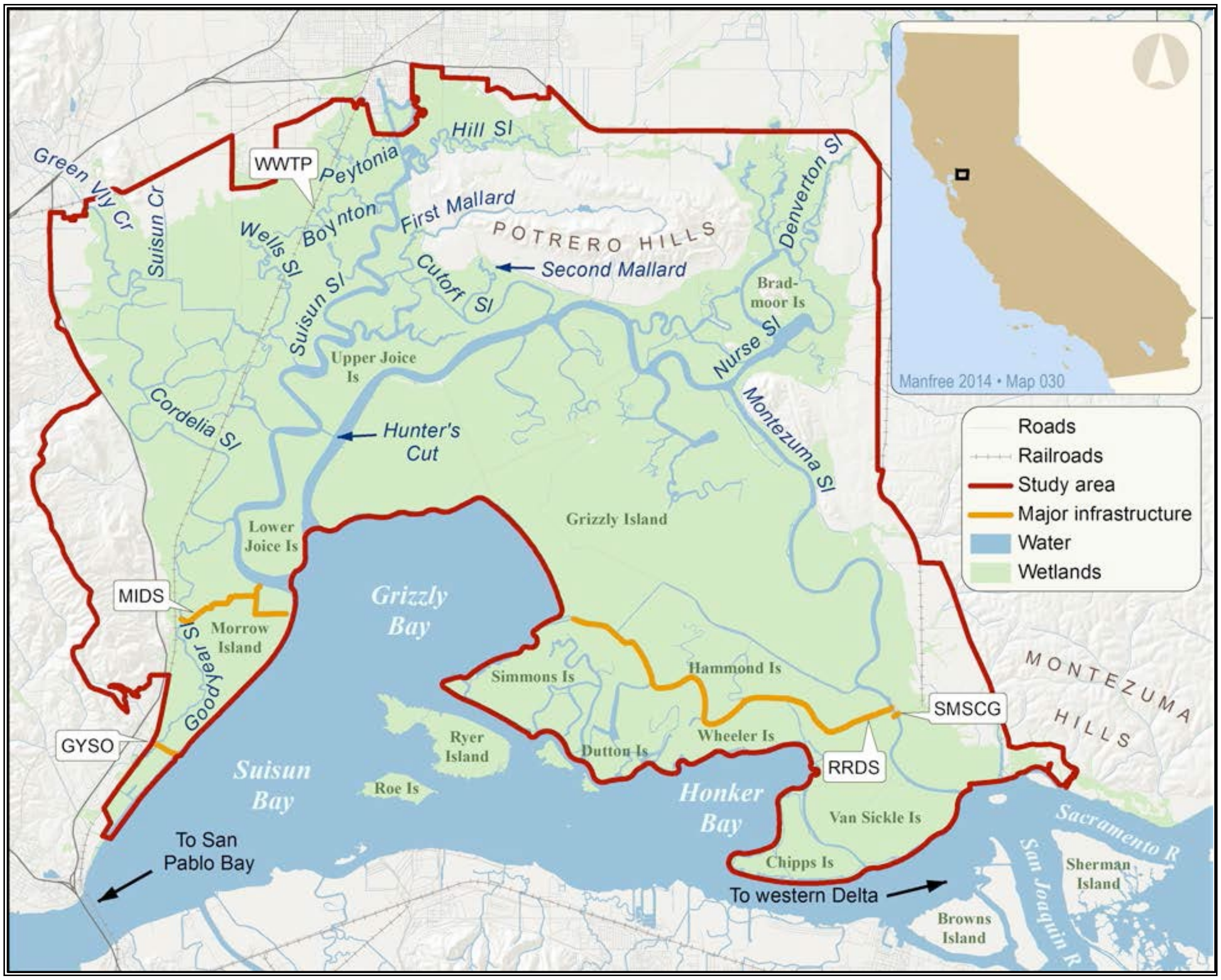

Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point 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*), tules (*Schoenoplectus* spp.) and cattails (*Typha* 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 marsh plains regularly flooded by high tides. 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 occur with storms. Substrates in all sloughs are generally fine organics, although a few sloughs also have bottoms partially comprised of coarser materials (*e.g.*, Denverton Slough; Matern *et al.* 2002), and the larger, deeper sloughs (*e.g.*, Montezuma Slough) can have sandy channel beds.

Salinities in Suisun Marsh's waterways are on the fresher side of brackish [annual average whole-marsh salinity equaling about 4 parts per thousand (ppt)] and are 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 in Suisun Marsh is partially a function of Delta outflow, with lower outflows corresponding to higher clarity in the marsh (Moyle *et al.* 1986, O'Rear and Moyle 2008, 2014). Since about 2000, clarities during summer and autumn have generally been higher than average, likely due to sediment-trapping by both invasive aquatic plants in the Delta and dams (Schoellhamer *et al*. 2016). 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).

Several water management facilities alter the hydrology and water quality of the marsh. State Water Project and Central Valley Project dams and diversions 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 managed 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 managed 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, primarily 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 managed 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 fish and macroinvertebrate 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 food-web players, either as competitors [Black Sea jellyfish (Wintzer *et al.* 2011)], 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, prickly sculpin, and threespine stickleback are typically the most abundant native fishes, with threespine stickleback often being especially numerous in managed wetlands (Williamson *et al.* 2015). 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. 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). Three additional sites in Denverton, Nurse, and Montezuma sloughs (DV1, NS1, and MZ6, respectively; Figure 2) were trawled in 2019 that were part of the Arc Project (O'Rear and Moyle 2016); 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 (Figure 2), where smooth shores have allowed effective sampling. No sampling occurred in May because of personnel injury, and no seining occurred at DV2 in April because cows crowded and fouled inshore water and landing beaches.

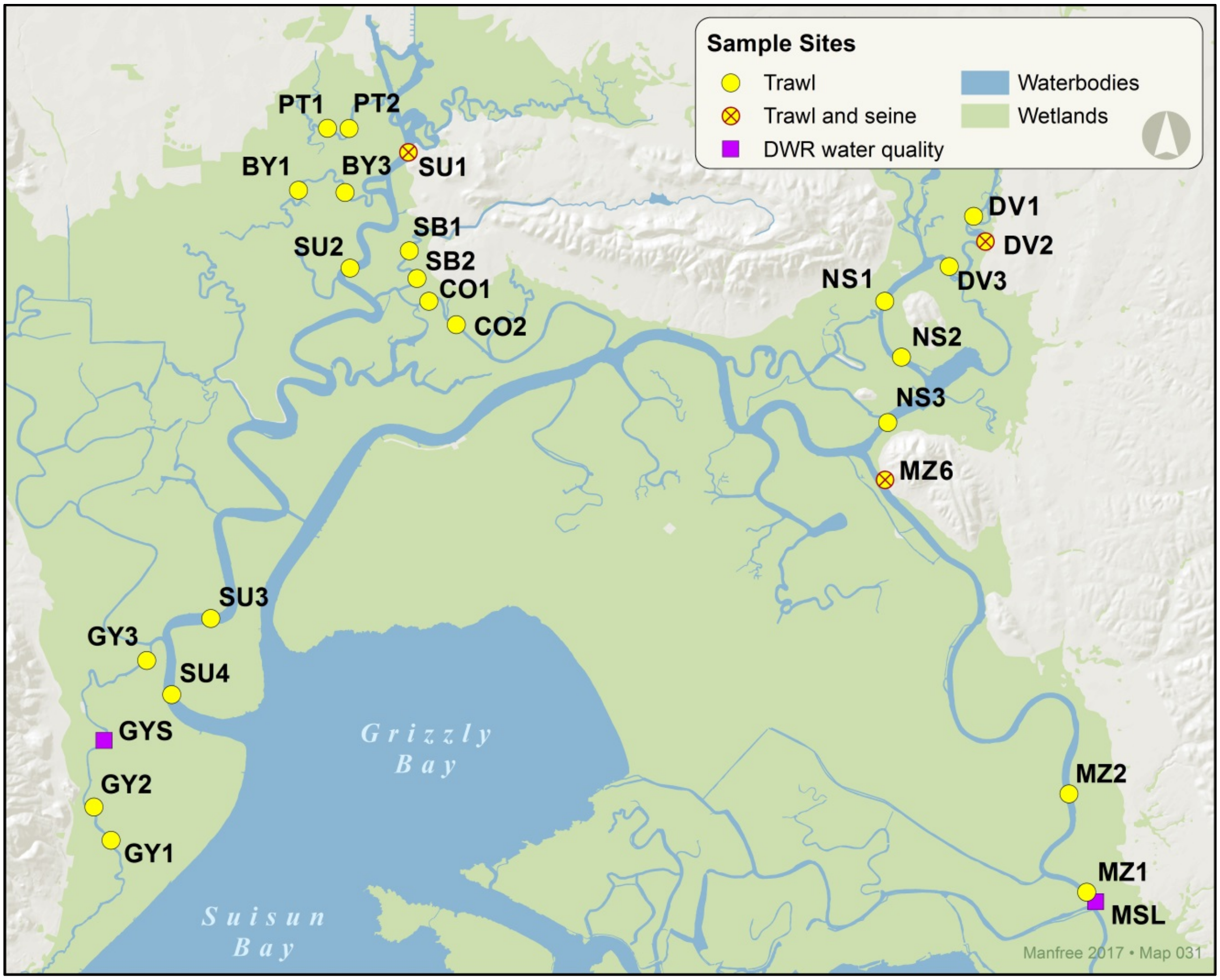

Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report (map by Amber Manfree).

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. Dissolved oxygen (DO) parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also measured with the PRO2030. Water clarity (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 returned to the water. Sensitive native species were processed first and immediately released. 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 were 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.

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, O’Rear and Moyle 2015, O’Rear *et al.* 2019); CPUE values for invertebrates were calculated likewise, with the annual number of individuals for the invertebrate of interest substituting for "annual number of fish." For monthly comparisons, to account for unequal effort among sloughs, CPUE values for otter trawls were calculated as

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

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. For monthly CPUE values, both site catches and efforts were summed within a slough (*e.g.*, SB1 + SB2 = SB; Figure 1 and 2) except for Montezuma and Suisun sloughs, which were separated into two “sloughs” because water quality differed among faraway sites (*i.e.*, SU1 + SU2 = upper Suisun, SU3 + SU4 = lower Suisun, MZ1 + MZ2 = Montezuma Slough, and MZ6 = Montezuma new; Figure 1 and 2; Matern *et al.* 2002). 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 2019 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 2019 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 2020).

Monthly water-quality results of 2019 were graphed and compared to averages for all years of the study. To provide additional context, 15-minute salinity and water temperature data from DWR fixed stations, GYS and MSL (Figure 2), were graphed with the salinity and temperature data collected during fish sampling. These two stations were chosen because they were the DWR stations closest to the fish-sampling sites, and they were in sloughs that exhibit 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. Slough CPUE values for age classes of splittail and striped bass were also graphed.

Catch of all fishes and by each method from 1979 to 2019 are found in Appendix A; annual catch of each slough and number of trawls/seines in each slough in 2019 are found in Appendix B and C. Code used for querying the database is found in Appendix D.

RESULTS AND DISCUSSION

Abiotic Conditions

Delta Outflow

Calendar-year 2019 earned DWR's "wet year" classification (DWR 2020), with Delta outflow higher than average for most months (Figure 3). Outflow was moderate and variable in January, thereafter increasing and remaining very high until returning to average in late June. Yolo Bypass was flooded to some degree from January through April, overlapping the spawning period of Sacramento splittail (Feyrer *et al.* 2006). Outflow was about average in July, but it was relatively high from August to November, for pushing saltier water further west. In the year's last two months, outflow spiked once moderately but was otherwise rather low.

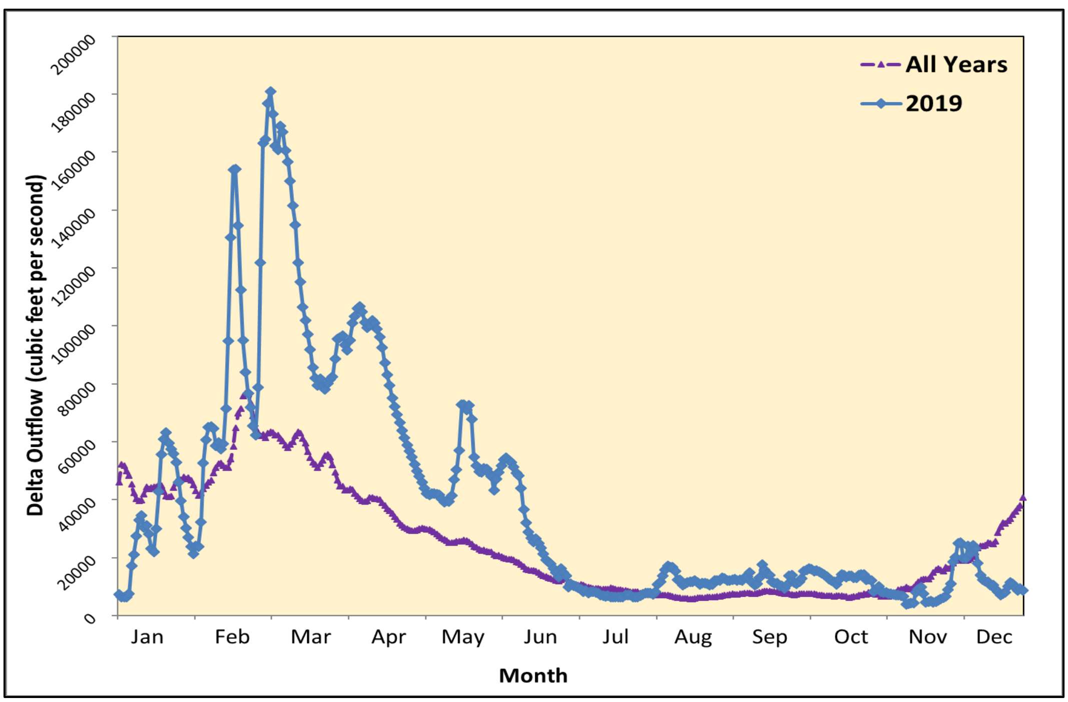

Figure 3. Daily Delta outflow in 2019 and the average for all years of the study (1980 – 2019; DWR 2020).

Salinity

Below-average annual salinity (2.4 ppt) in Suisun Marsh (Figure 4) in 2019 corresponded to the high outflow. Monthly average salinity was low in the first half of the year, thereafter increasing steadily until attaining its peak in November, although that peak (5.0 ppt) was still below the typical year's average (6.2 ppt). As usual, salinity dropped in December with the onset of autumn rains and subsequent increases in outflow. The wet year minimized the need for the Suisun Marsh Salinity Control Gates, which only operated for early January and late November. Salinities recorded by the fish study were within the bounds of the two water-quality stations throughout the year (Figure 5). Salinity varied throughout the marsh in all months, albeit variability was at its lowest in June when it ranged only about 1 ppt. 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, 8.3 ppt, occurring in upper Goodyear Slough in January) except in June, when the highest value was measured in Peytonia Slough. In every month of 2019, the freshest water was in eastern Montezuma Slough, our closest site to the Delta.

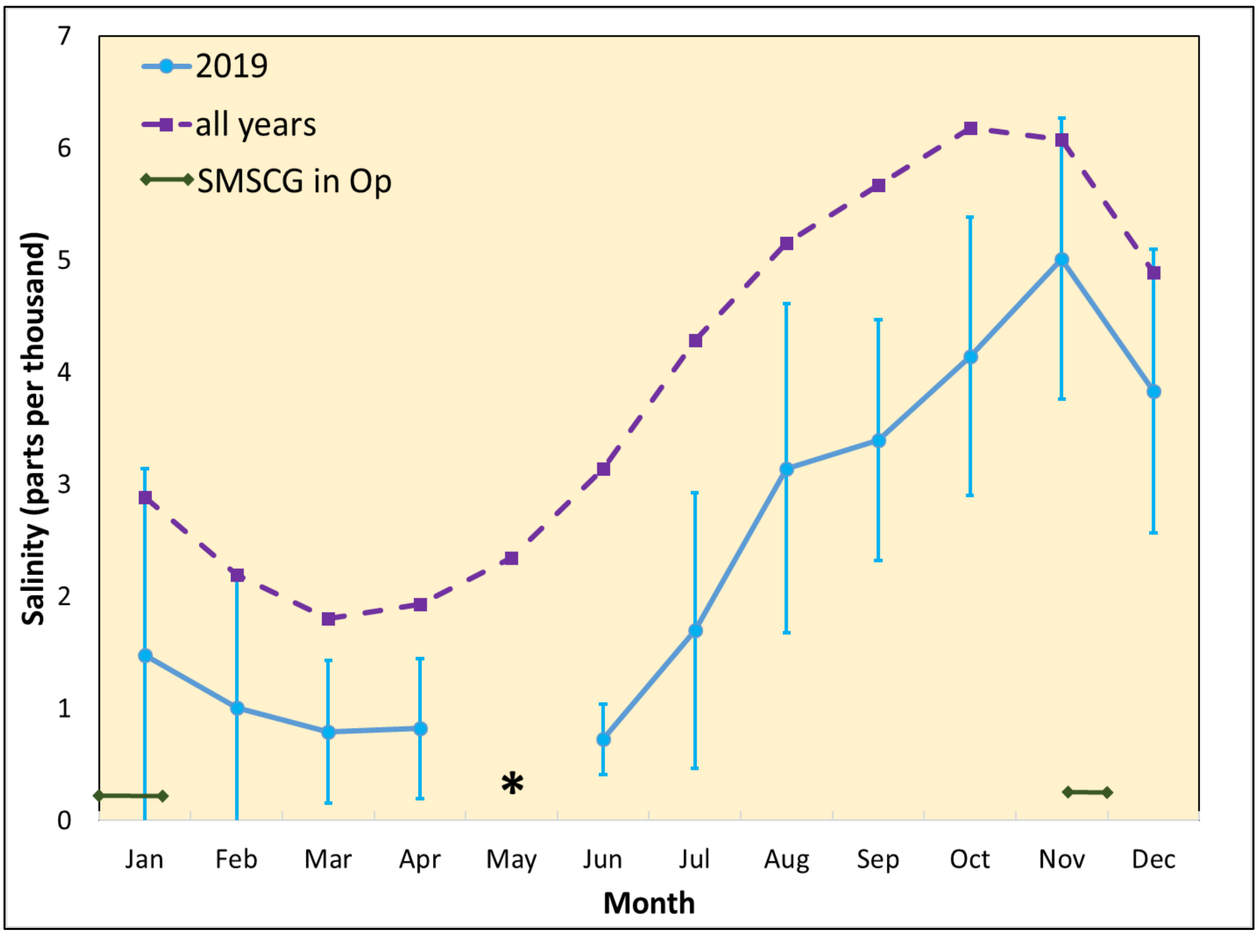

Figure 4. Monthly average surface salinity in 2019 and for all years of the study (1980 - 2019); error bars are standard deviations in 2019. Olive bar shows when the SMSCG were operating in 2019 (* = no samples).

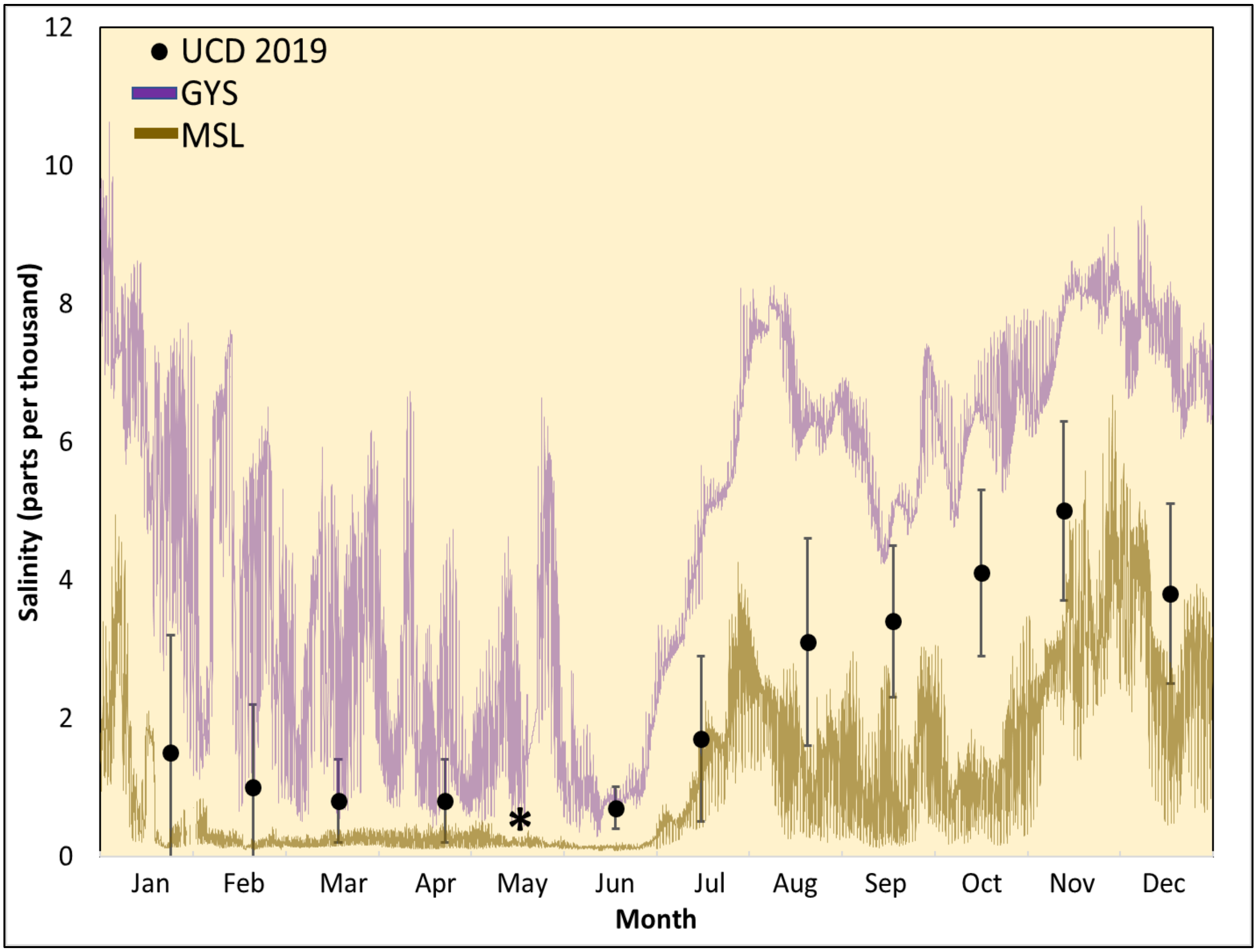

Figure 5. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations of the Suisun Marsh Fish Study ("UCD Sal"). Note no GYS data were recorded for a few days in mid-June and from late September through early October (* = no Suisun Marsh Fish Study samples).

Dissolved Oxygen (DO)

Average monthly DO concentrations did not vary substantially throughout 2019, always being higher than 5 mg/L (Figure 6). DO was highest in winter, declined mildly through spring until hitting the year's minimum in June, and then slightly increased to year's end (Figure 6). Trends in minimum and maximum monthly DO concentrations appeared to have little relationship, sometimes increasing together (*e.g.,* February - March, June - July; Figure 6) and sometimes diverging (*e.g.*, January - February, March - April). The lowest monthly DO concentration occurred nine times in upper Goodyear Slough and once each in Peytonia and First Mallard sloughs - all three being small, dead-end sloughs. Highest concentrations were either in large sloughs close to the estuary's mainstem (eastern Montezuma and lower Suisun sloughs) 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, Jr. *et al*. 1990), which occurred in April in upper Goodyear Slough (GY1; Figure 2) where DO concentration was 1.2 mg/L.

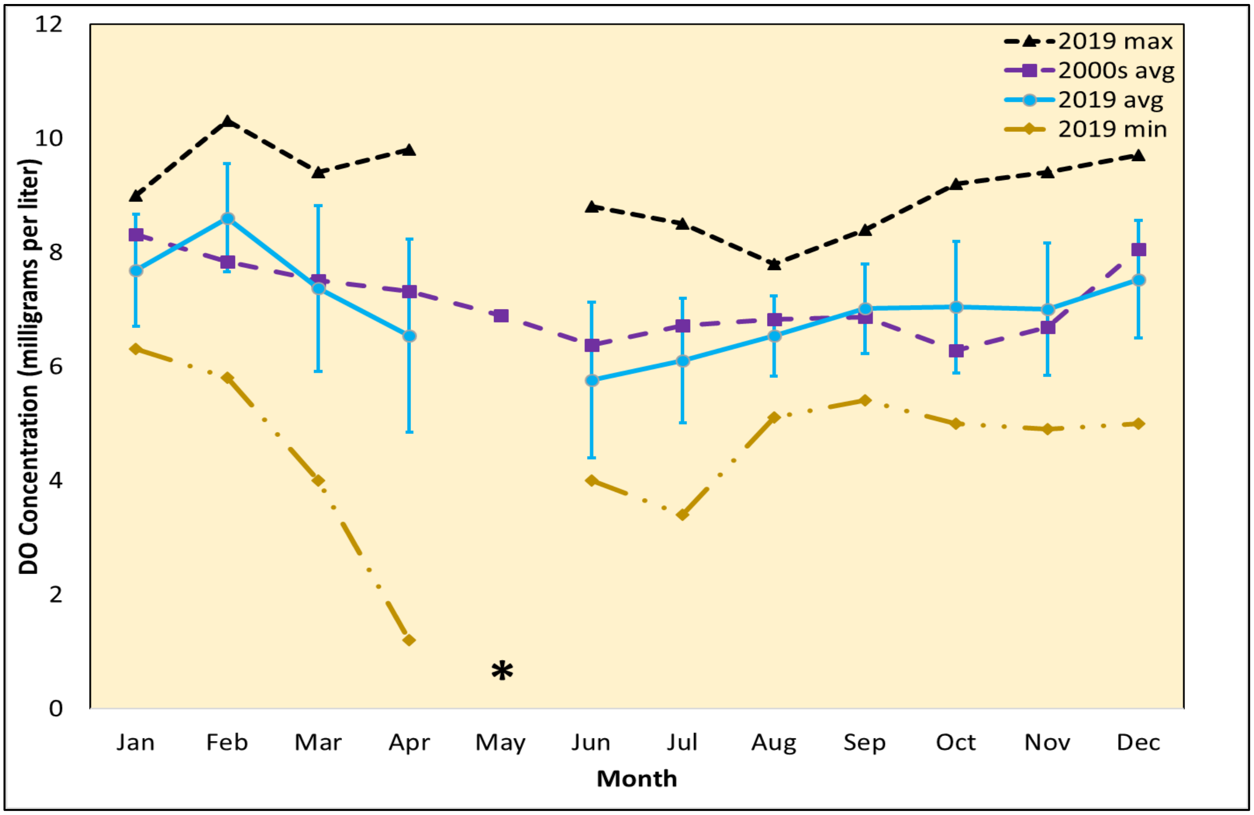

Figure 6. Monthly average DO concentration in 2019 and for the 2000s (2000 - 2019), maximum DO concentration in 2019, and minimum DO concentration in 2019. Error bars are standard deviations in 2019 (* = no samples).

Water Temperature

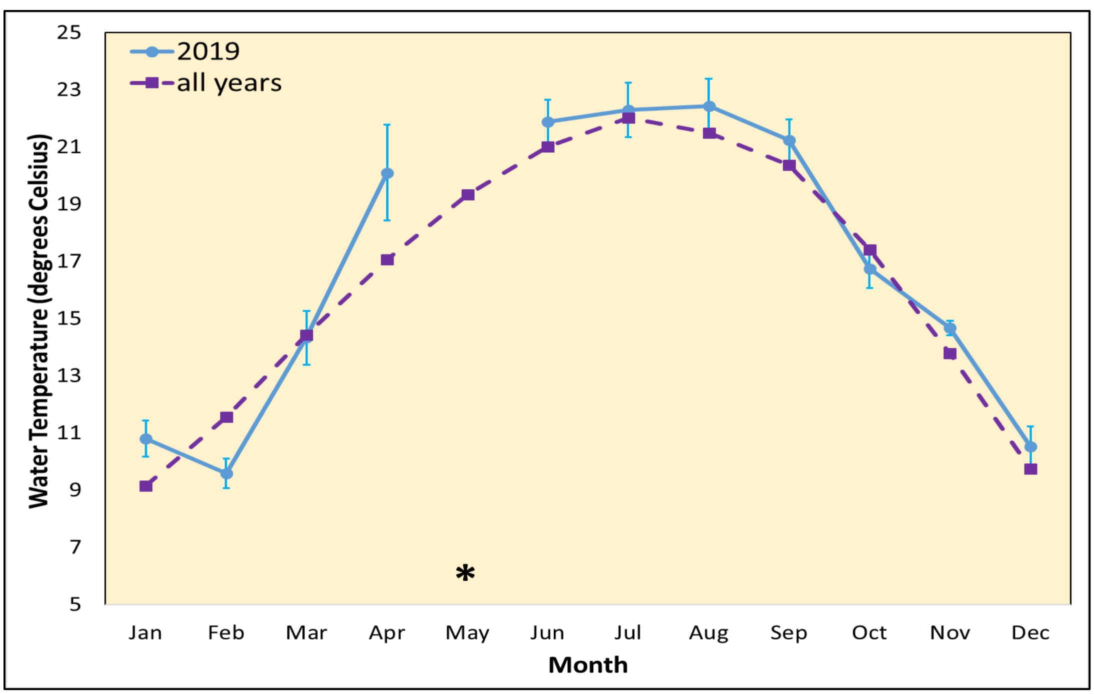

Figure 7. Monthly average water temperature in 2019 and for all years of the study (1980 - 2019); error bars are standard deviations in 2019 (* = no samples).

Overall, 2019 was a warm year. Abnormally warm water in January cooled to the lowest temperature of the year in February, after which it warmed above average and remained at higher values through spring, summer, and early autumn (Figure 7). Water temperature dipped mildly below normal in October but once again rose above average values in the year's final two months. 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 8). Similarly, the fish study recorded its lowest water temperature (8.2°C) in a small slough, upper Denverton, in February, but the highest value (25.5°C) was measured in a large slough (Montezuma) in August, an unusual occurrence.

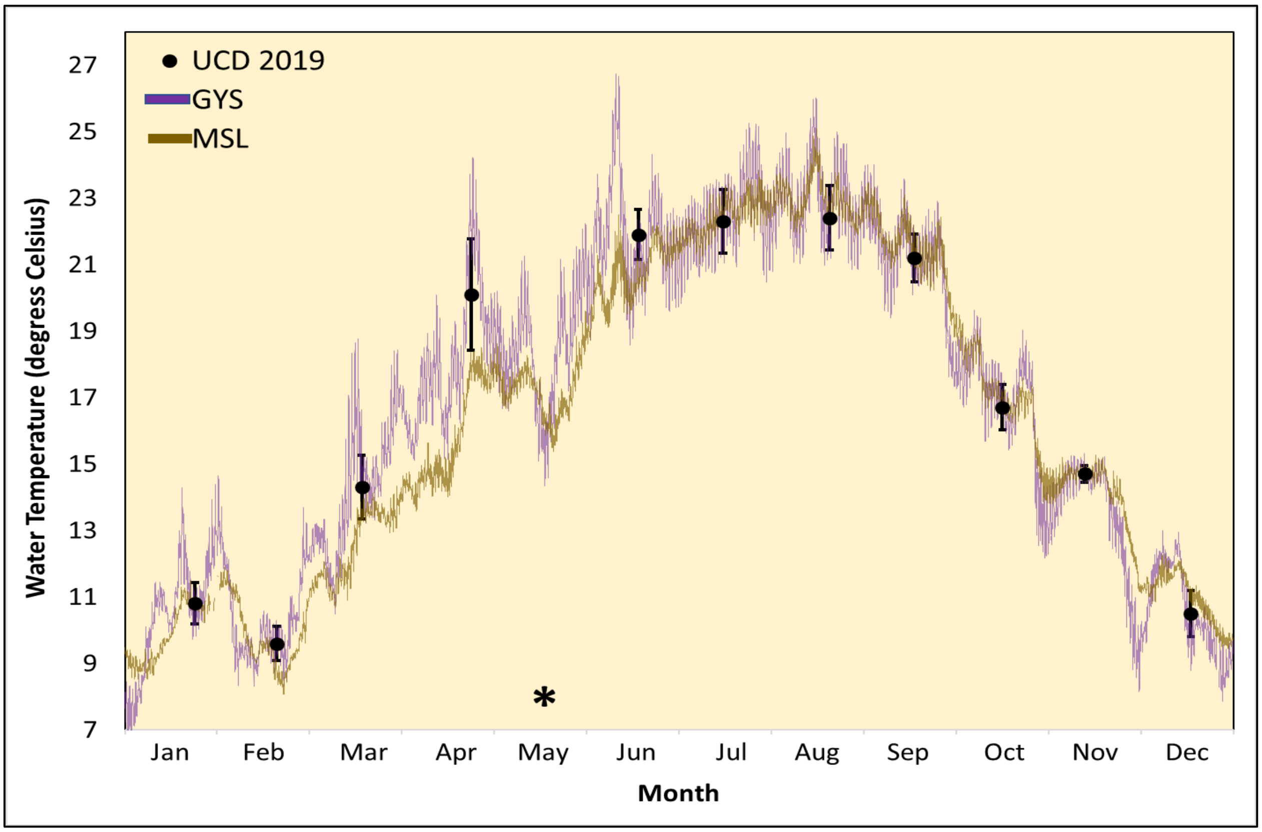

Figure 8. Fifteen-minute water temperature from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly temperatures and standard deviations from the Suisun Marsh Fish Study ("UCD Sal"). (* = no Suisun Marsh Fish Study samples).

Water Clarity

Despite the wet year, water clarity was generally higher than average in most months of 2019 (Figure 9). Clarity was quite stable in the first three months of the year and then notably increased above average in April, a seemingly unusual pattern given both the typical trend in water clarity and the high Delta outflow, but not unexpected based on the unavailability of sediment late in wet seasons of recent years due to dams and aquatic weeds (Morgan-King *et al.* 2013). Clarity returned to average in June and was somewhat lower than usual in July, but then it climbed and remained relatively high through the rest of the year. The clearest water was usually in large sloughs (eight of the 11 months), with the year's highest clarity (62 cm) recorded in eastern Montezuma Slough in October. However, lowest clarity was split fairly evenly between small (5 of 11 months) and large sloughs, with the lowest clarity (12 cm) found in the southwest marsh (Goodyear and lower Suisun Slough) in June.

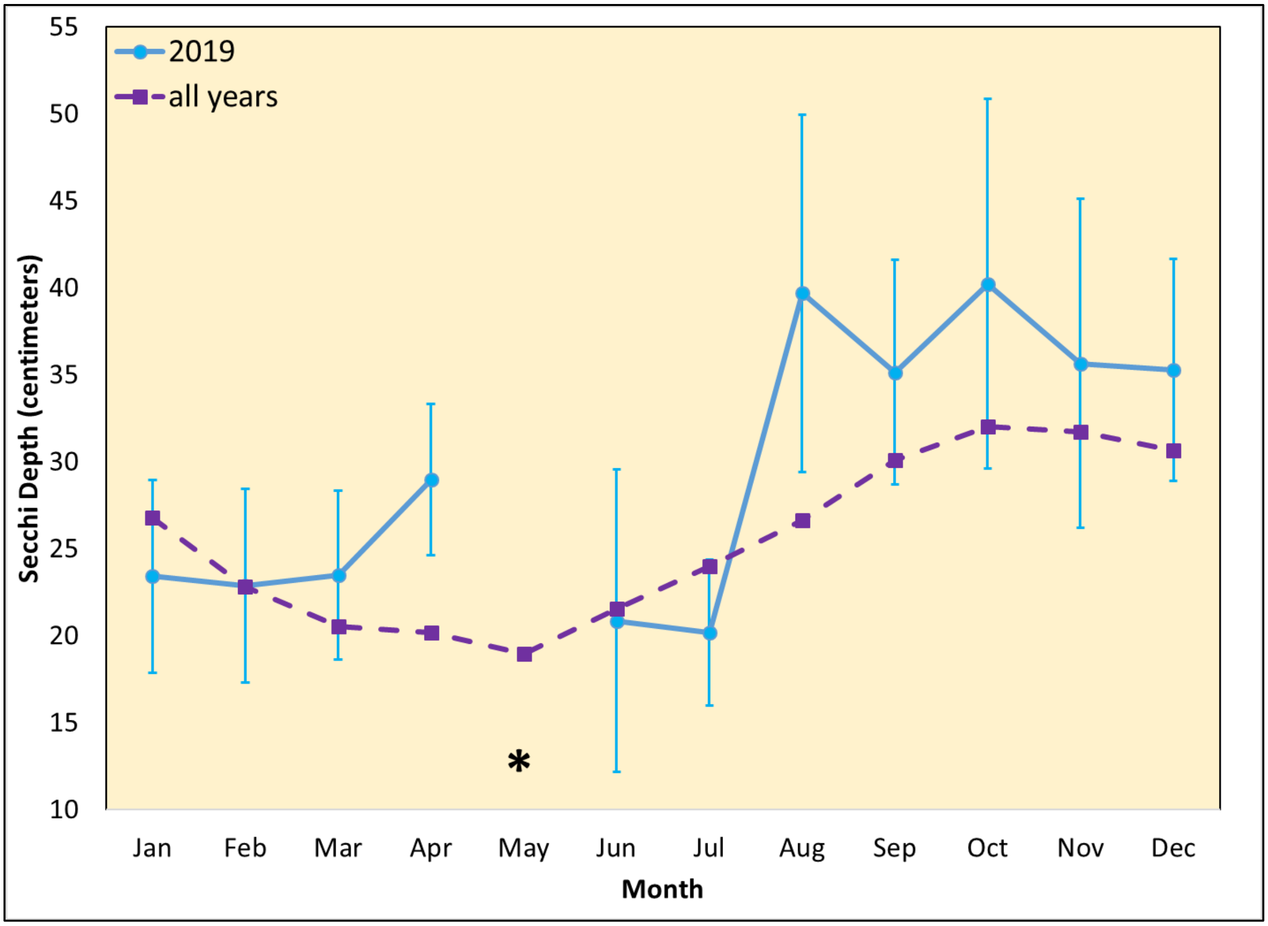

Figure 9. Monthly average water clarity in 2019 and for all years of the study (1980 - 2019); error bars are standard deviations in 2019 (* = no samples).

Trends in Invertebrate Distribution and Abundance

Black Sea Jellyfish

Black Sea jellyfish medusae were more abundant in 2019 than they had ever been in the study's history (Figure 10), far more abundant (85 medusae per trawl) than the all-years average or 2018's CPUE (both 11 medusae per trawl). Nevertheless, medusae were only abundant during August and September, being either absent or at negligible numbers for all other months (Figure 11), due to salinities not being high enough (3 ppt) until August and to the cooler water in October (Baumsteiger *et al.* 2018). Medusae were captured in all sloughs in the marsh, although most - 82% (17,593 individuals) of the year's catch - came from Suisun Slough. Few were caught in eastern Montezuma Slough close to the Delta (0.2% of 2019's catch), where salinity was often too low. Black Sea jellyfish were also sparse in Denverton Slough (0.1% of 2019's catch).

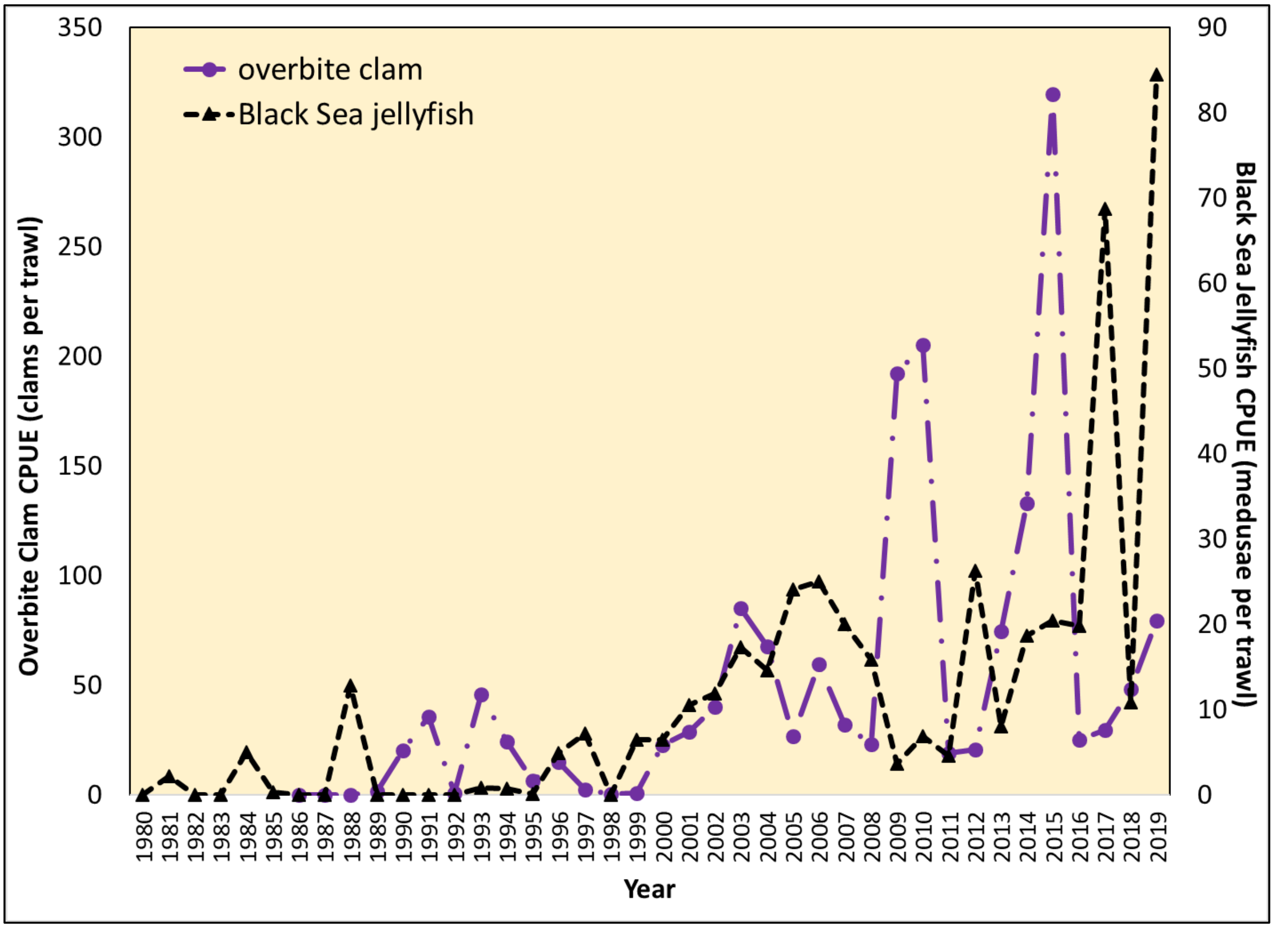

Figure 10. Annual CPUE of Black Sea jellyfish and overbite clam.

Overbite Clam

Overbite clams were quite abundant in 2019 (Figure 10), with the year's CPUE (80 clams per trawl) considerably higher than both 2018's value and the all-years value (48 and 50 clams per trawl, respectively). Overbite clams were abundant January through March (Figure 11), an unusual occurrence, but then reverted to the typical pattern of peak abundance in summer followed by lower numbers in autumn (Baumsteiger *et al.* 2017, O'Rear *et al.* 2020). High numbers of overbite clams co-occurred with the 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). Distribution of the two invertebrates was likewise similar: most overbite clams were captured in Suisun Slough (69% of 2019's catch; 13,881 individuals). While being caught in both small and large sloughs, overbite clams were much less abundant in small sloughs: of 5,985 overbite clams caught in small sloughs, 5,927 of those came from the GY3 site, which is the closest small-slough site to Suisun Slough (Figure 2). Five small sloughs - Boynton, Cutoff, Denverton, Peytonia, and First Mallard - each yielded no more than nine overbite clams for all 2019, reinforcing previous research demonstrating that small sloughs are inhospitable to the species (Baumsteiger *et al.* 2017).

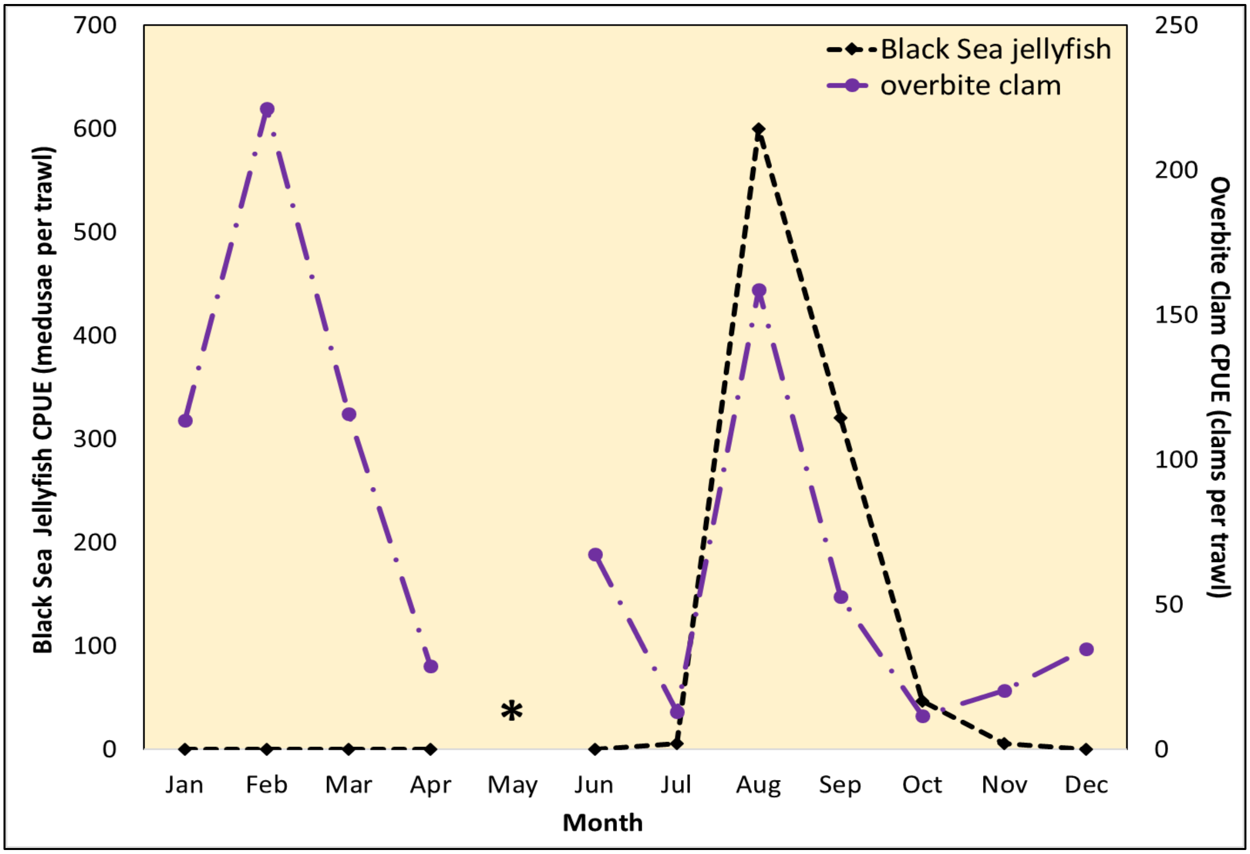

Figure 11. Monthly average CPUE of Black Sea jellyfish and overbite clam in Suisun Marsh in 2019 (* = no samples).

Shrimps

California Bay Shrimp

California bay shrimp numbers were low in 2019, with the annual CPUE well below both the all-years average and 2018's value (9, 27, and 49 shrimp per trawl, respectively; Figure 12). The species was nearly absent through most of the marsh in 2019's first six months (Figure 13), with just a few individuals captured in Suisun and Goodyear sloughs. Abundance hit a peak in July, declined to a very low value in September, and then mildly increased through the year's remainder. Most California bay shrimp - 80% of the annual catch (1,847 individuals) - were captured in large sloughs. The year's low numbers and the geographic distribution were consistent with the shrimp's association with moderately salty water (Cloern *et al.* 2017) and perhaps a predilection for coarser substrate in the larger, deeper sloughs.

Siberian Prawn

Siberian prawn were very abundant in 2019 (52 shrimp per trawl; Figure 12), well above the all-years average but close to 2018's value (30 and 48 shrimp per trawl, respectively). Though somewhat variable, numbers basically increased throughout the year, peaking in November (Figure 13). Unlike California bay shrimp, Siberian prawn were common in all sloughs of the marsh, with Denverton and upper Suisun sloughs hosting the highest numbers

[16% (2,117 individuals) and 33% (4,444 individuals) of 2019's catch, respectively]. The high numbers in 2019, in addition to high numbers in other wet years (2006, 2011, 2017; Figure 12), reinforced the importance of high outflow and lower salinities on the prawn's abundance in Suisun Marsh (Brown and Hieb 2014).

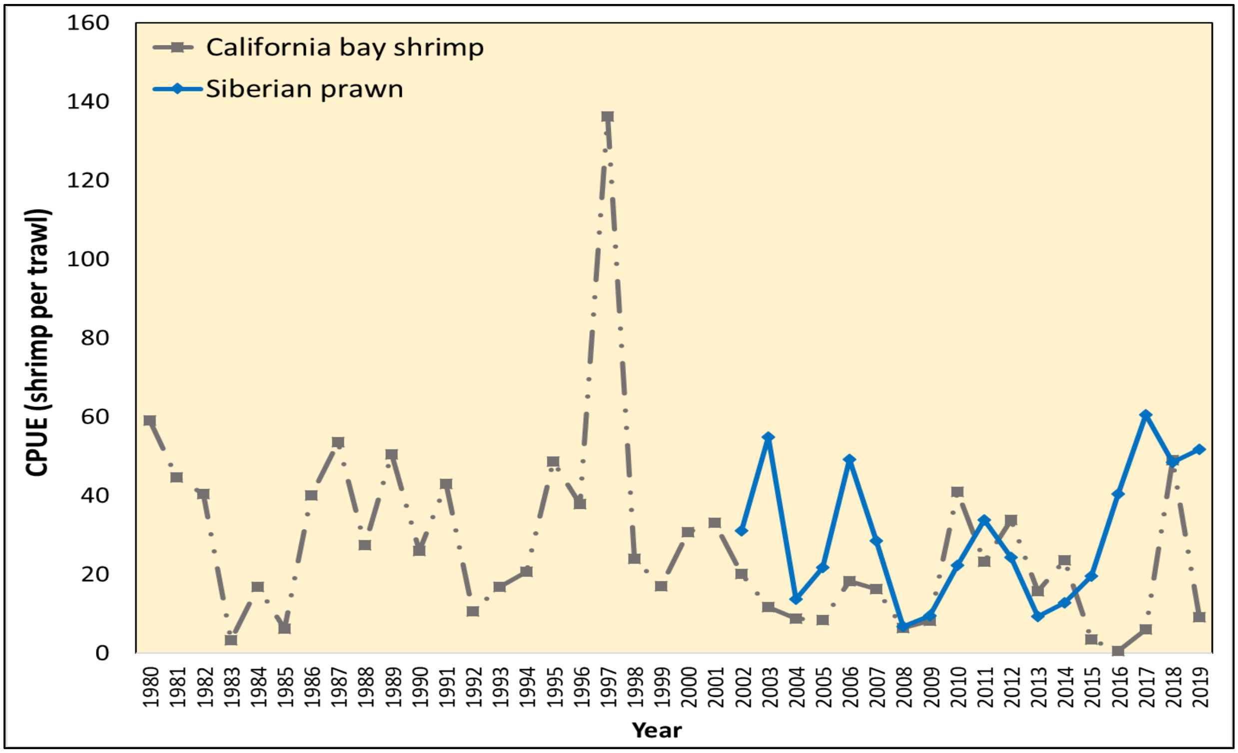

Figure 12. Annual CPUE of California bay shrimp and Siberian prawn.

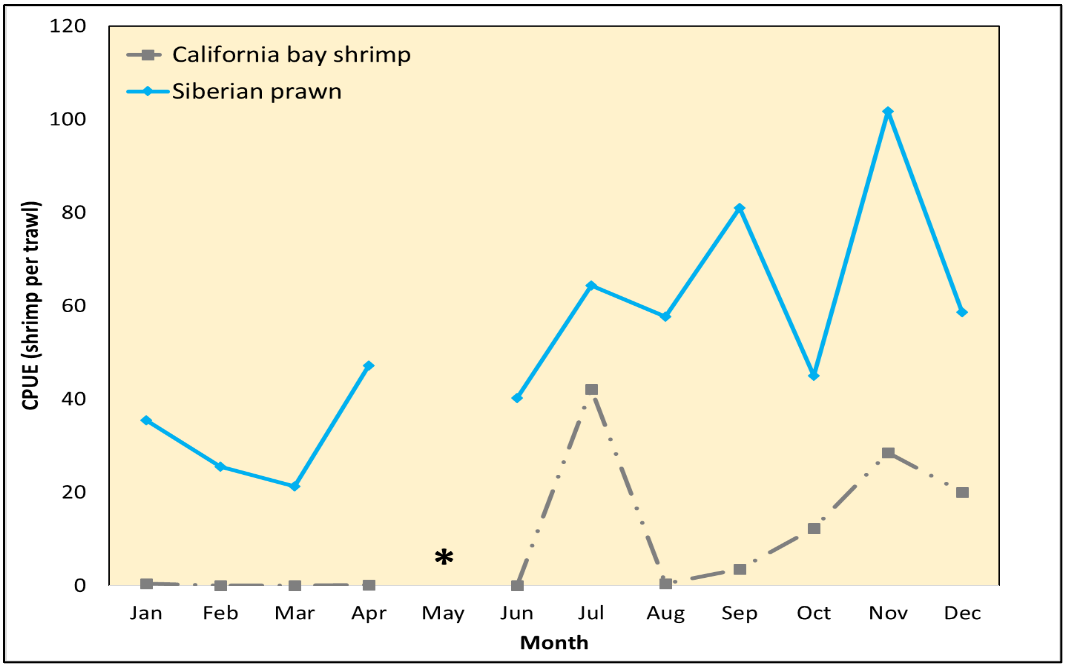

Figure 13. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2019 (* = no samples).

Trends in Fish Distribution and Abundance

Otter Trawls

Fish abundance in 2019 (29 fish per trawl) was moderately high, above both the 2018 CPUE and the all-years average (24 and 25 fish per trawl, respectively; Figure 14). The increase in CPUE in 2019 was due to a rise in non-native fish numbers, with the species contributing most being those needing plankton for substantial parts of their lives: American shad, threadfin shad, striped bass, Mississippi silverside, and shimofuri goby (Table 1). In contrast, common carp were notably low in numbers in 2019, with few age-0 fish captured; yellowfin goby numbers were lower than average as well (Table 1). Native fish numbers in 2019 dropped a fish per trawl from 2018 (11 and 12 fish, respectively) but was still above the all-years average (10 fish per trawl). Splittail drove the change between 2018 and 2019 in native fish numbers, decreasing by 542 individuals (Table 1). Numbers of other common native species (threespine stickleback, prickly sculpin, and tule perch) rose modestly between the two years (Table 1).

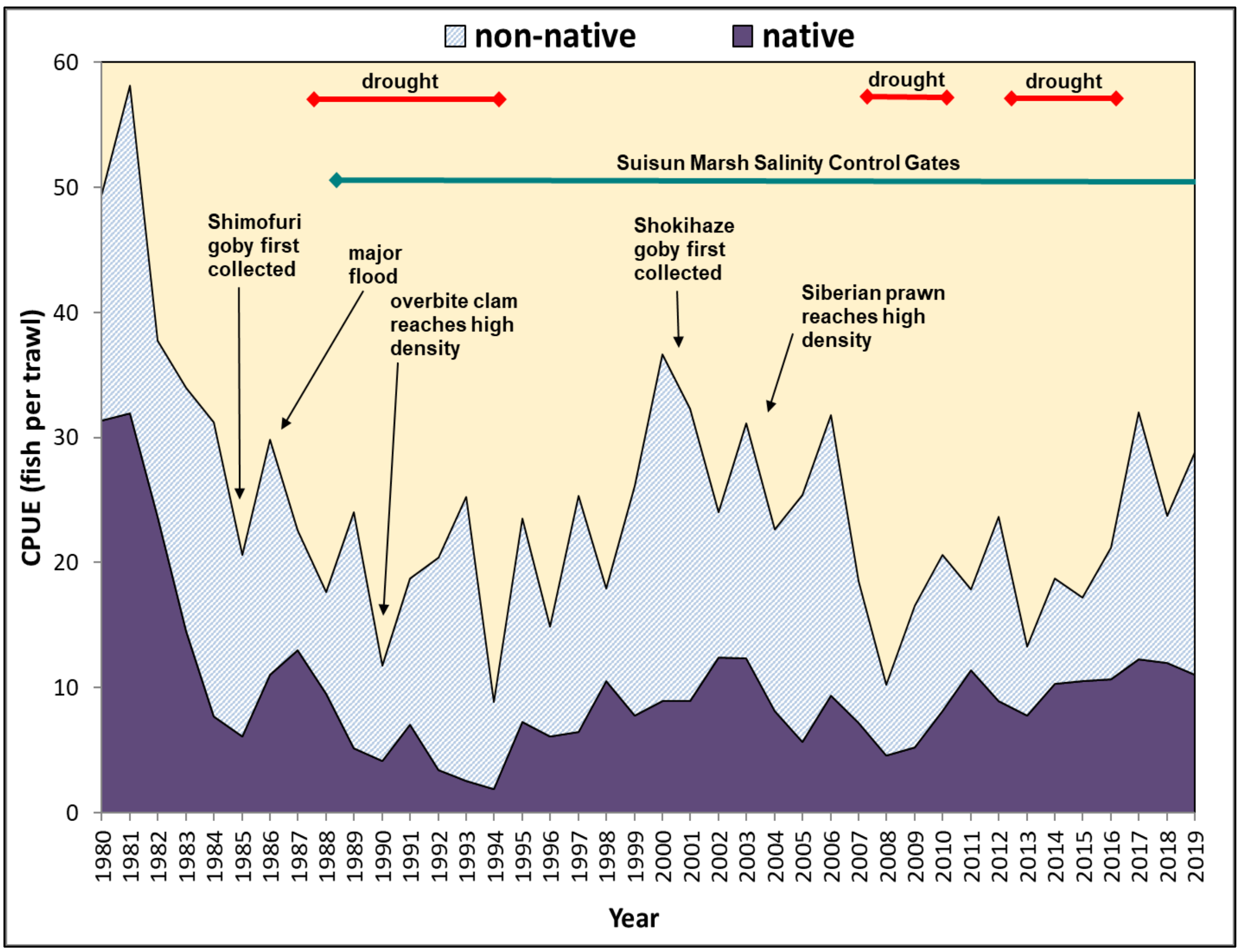

Figure 14. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted.

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 - 2019).

Species	All Years CPUE	2018	2019	2019/2018 % Change
Sacramento splittail	**3.30**	**8.78**	**7.41**	**-16%**
threespine stickleback	**1.51**	**0.28**	**0.40**	**+44%**
prickly sculpin	**1.15**	**1.10**	**1.44**	**+31%**
tule perch	**2.03**	**1.16**	**1.50**	**+29%**
threadfin shad	0.39	0.65	1.90	+192%
American shad	0.19	0.39	0.79	+99%
common carp	0.51	0.63	0.24	-61%
striped bass	8.91	7.08	10.63	+50%
shimofuri goby	1.28	0.60	1.54	+155%
Mississippi silverside	0.09	0.04	0.41	+1030%
yellowfin goby	2.19	1.37	1.18	-14%

Beach Seines

Inshore fish were very abundant in 2019, with the annual beach seine CPUE the second highest in the study's history (107 fish per seine haul; Figure 15) and well above the CPUE for 2018 and the average of all years (63 and 59 fish per seine haul, respectively). Both native and non-native fishes increased from 2018 to 2019, with non-natives rising more dramatically. The non-native fishes contributing to 2019's high beach seine CPUE were also those that increased the otter-trawl CPUE: American shad, threadfin shad, striped bass, and Mississippi silverside (Table 2). As with the otter trawl, common carp and yellowfin goby were less abundant than usual in beach seines (Table 2). Black crappie (*Pomoxis nigromaculatus*) were very abundant in beach seines, with all fish (79 individuals) but two being age 0, and all but one fish being captured in Denverton Slough, which abuts managed wetlands where black crappie are known to have spawned. Most freshwater or migratory natives increased moderately in beach seines between 2018 and 2019, including those that became more abundant in otter trawls (Table 2). Sacramento splittail was an exception, skyrocketing in 2019 and attaining its highest-ever abundance in beach seines, far above both that in 2018 and the all-years average (Table 2).

Table 2. Percent change in annual beach seine CPUE of 13 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 - 2019).

Species	All Years CPUE	2018 CPUE	2019 CPUE	2019/2018 % Change
Sacramento splittail	**2.02**	**4.81**	**9.34**	**+94%**
Sacramento pikeminnow	**0.10**	**0.01**	**0.24**	**+2045%**
Sacramento sucker	**0.06**	**0**	**0.11**	**N/A**
Chinook salmon	**0.13**	**0.01**	**0.12**	**972%**
threespine stickleback	**1.75**	**0.45**	**0.61**	**+37%**
prickly sculpin	**0.34**	**0.09**	**0.16**	**+74%**
tule perch	**0.79**	**0.28**	**0.46**	**+63%**
threadfin shad	2.63	3.01	7.55	+151%
American shad	0.16	0.11	0.47	+318%
common carp	0.20	0.28	0.12	-57%
Mississippi silversides	36.16	47.36	73.33	+55%

Species	All Years CPUE	2018 CPUE	2019 CPUE	2019/2018 % Change
striped bass	5.79	1.78	9.64	+443%
yellowfin goby	6.17	3.90	2.57	-34%

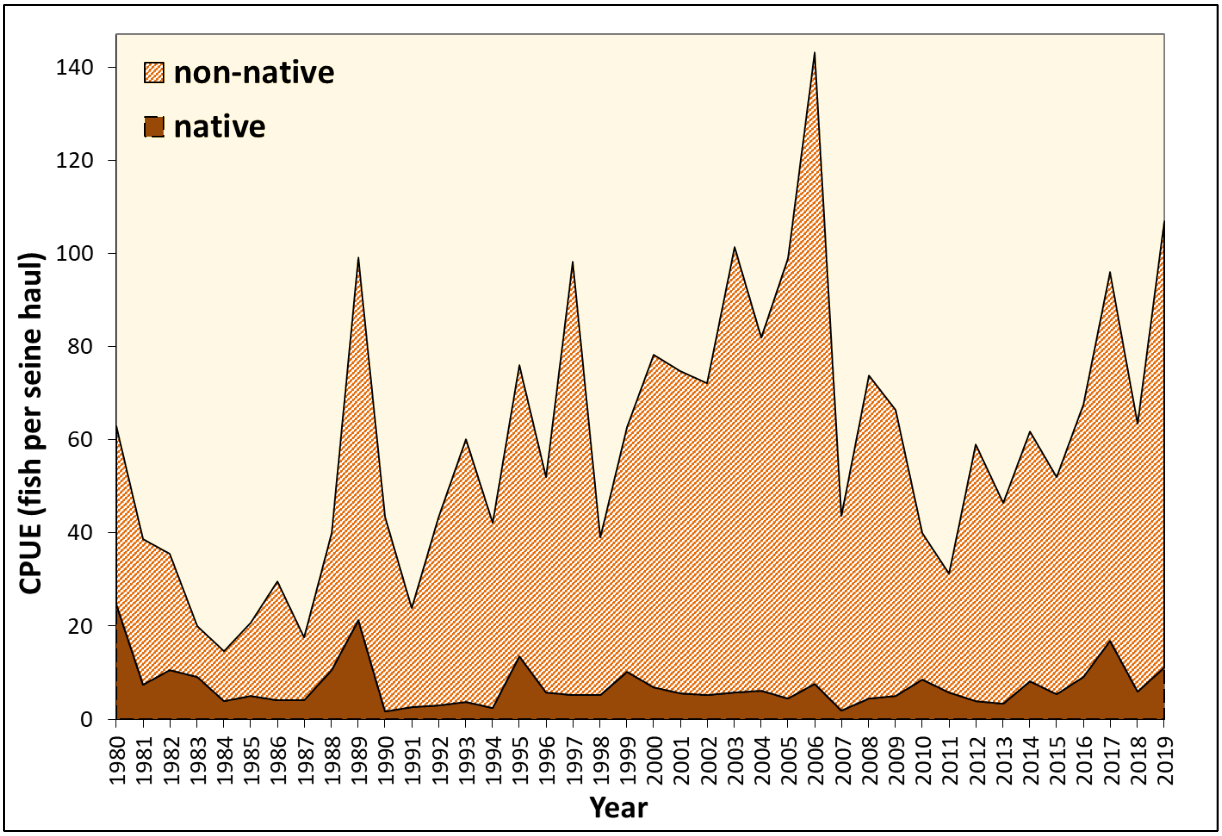

Figure 15. Annual beach seine CPUE of native and non-native fishes.

Fish Species of Interest

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

DELTA AND LONGFIN SMELT

For the fourth consecutive year, no delta smelt were captured by the Suisun Marsh Fish Study (Figure 16); likewise, none were captured in the Summer Townet Survey or the Fall Midwater Trawl Survey (CDFW 2020).

Longfin smelt numbers were very low in 2019, with the year's CPUE (0.01 fish per trawl) the second lowest in the study's history (Figure 16), well below both 2018's value (0.09 fish per trawl) and the all-years average (1.04 fish per trawl). The CDFW's Fall Midwater Trawl Survey likewise caught few fish (CDFW 2020). The three longfin smelt were age-0 fish measuring 60 - 65 mm SL captured in autumn. All three fish were caught at large-slough sites (SU4 and MZ2; Figure 2; Appendix B) close to Grizzly Bay and the Sacramento River, reinforcing a common pattern in Suisun Marsh of longfin smelt being most abundant in sloughs near the estuary's main axis.

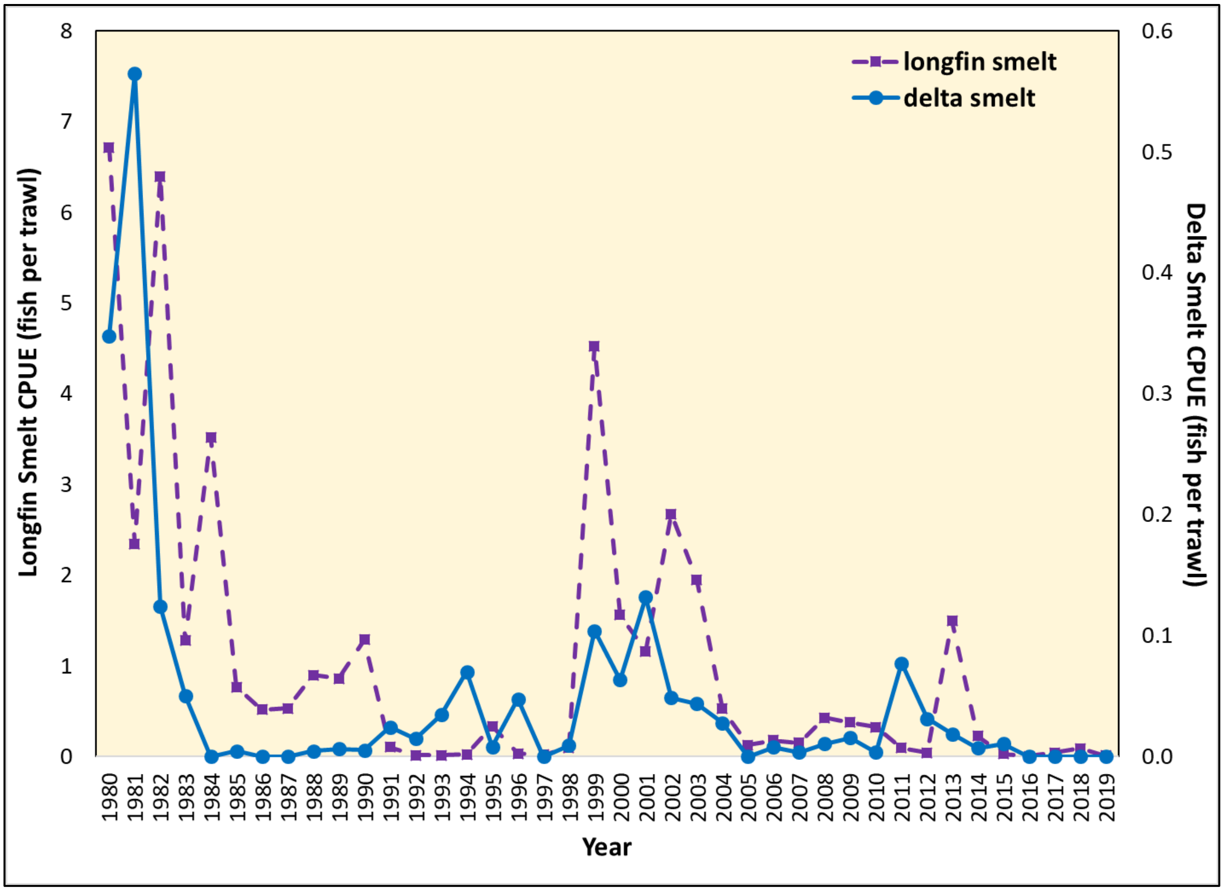

Figure 16. Annual CPUE of the smelts of the Pelagic Organism Decline.

THREADFIN AND AMERICAN SHAD

Threadfin shad had a banner year in Suisun Marsh during 2019, with their highest-ever annual otter-trawl CPUE (Figure 17, Table 1) and a very high beach seine CPUE (Table 2), despite continued low values in the Fall Midwater Trawl Survey (CDFW 2020). Eighty percent of the threadfin shad caught in otter trawls came from just two small sloughs: Denverton and First Mallard. In contrast, sloughs on the west side of the marsh - Peytonia, upper Suisun, Boynton, lower Suisun, and Goodyear - hosted only 6% of 2019's catch (Appendix B). Geographic distribution in the beach seine was similar, with 53% and 43% of the year's catch coming from Denverton Slough and eastern Montezuma Slough, respectively, while only 3% of the catch came from upper Suisun Slough (Appendix B). The abundance and distribution of threadfin shad in 2019 were consistent with (1) high outflow flushing fish from the Delta into Suisun Marsh (O'Rear *et al.* 2019), (2) favorably low salinities and warm temperatures for the species in Suisun Marsh (Hendricks 1961, Feyrer *et al.* 2007, 2009), and high zooplankton densities in small, dead-end sloughs (Montgomery *et al.* 2015).

Like threadfin shad, American shad reached their highest otter-trawl abundance ever in Suisun Marsh in 2019 (Figure 17, Table 1), and were also very numerous in seines (Table 2). Nearly all fish captured (97%) in both net types were from the 2019 cohort. American shad were captured by otter trawl in all sloughs, although they were notably abundant in lower Suisun Slough, where 40% of 2019's catch came from. In beach seines, American shad were far more abundant in Montezuma Slough (79% of the catch) than in Denverton or upper Suisun sloughs (both 10% of the catch; Appendix B). Their predominance in the large slough close to Grizzly Bay (lower Suisun Slough) and in the main corridor of Suisun Marsh (Montezuma Slough) reflected their migration from the main spawning grounds (the American, Feather, and Sacramento rivers) to the Pacific Ocean.

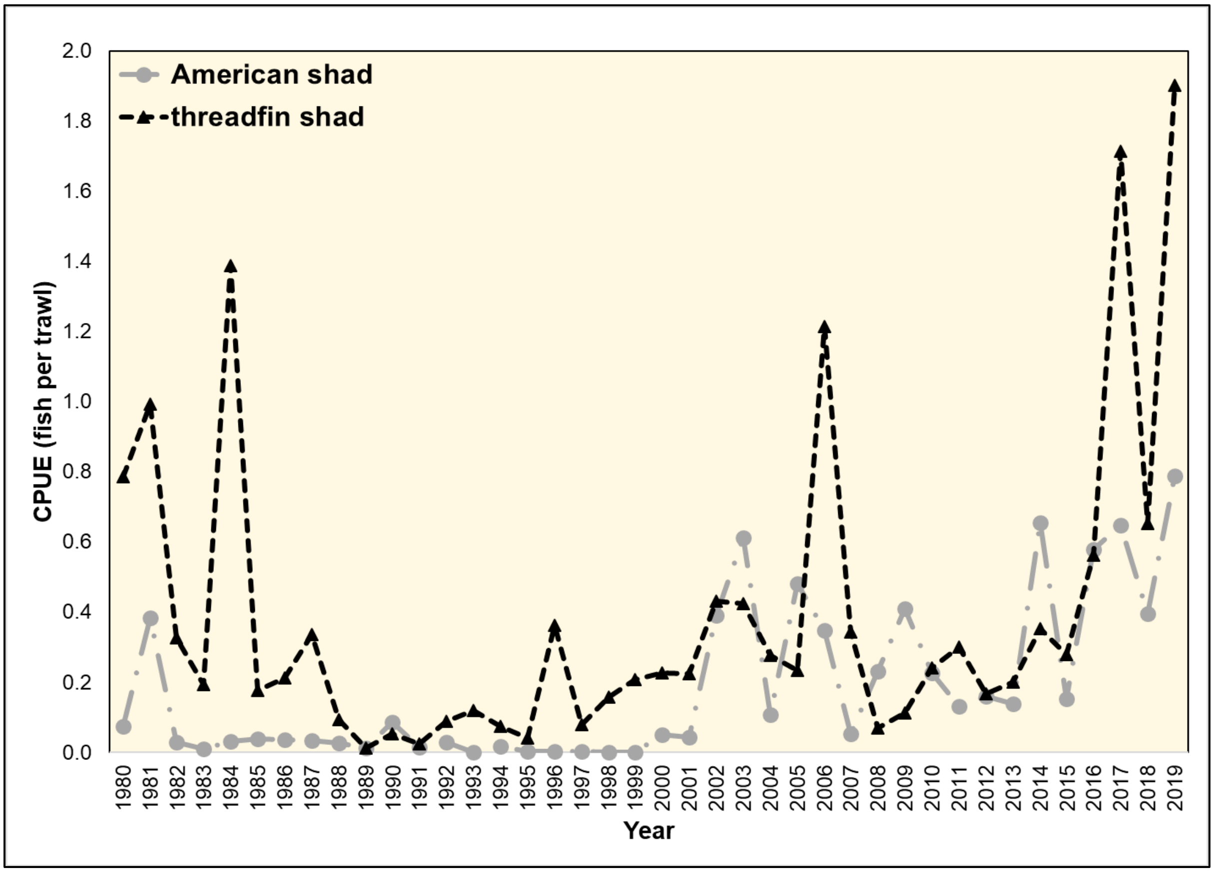

Figure 17. Annual CPUE of the shads of the Pelagic Organism Decline.

STRIPED BASS

Striped bass CPUE in 2019 in both net types rose relative to 2018, and abundances in 2019 were above all-years averages (Figure 18; Table 1 and 2). Very high numbers of age-0 fish occurred in both nets in June, then rapidly declined through late summer into early autumn (Figure 19). 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. Though variable in winter and early spring, the abundance of juvenile striped bass generally declined through the year (Figure 19), consistent with dispersal throughout both the marsh (Figure 20) and the estuary (Calhoun 1952, Able *et al.* 2012). In contrast, age-0 fish were disproportionately abundant in smaller sloughs, with CPUE highest in Goodyear, Peytonia, and First Mallard sloughs (Figure 20). Geographic pattern in beach seines was similar, with 60% of the year's catch coming from the small slough (Denverton), while the remaining 40% of the catch was split evenly between the two large sloughs (Montezuma and upper Suisun). The high numbers and distribution of age-0 striped bass in 2019, resembling that of threadfin shad, further suggests that beneficial high flows, low salinities, and warm temperatures (Feyrer *et al.* 2007) in 2019 co-occurred with sufficient zooplankton food, particularly in small, dead-end sloughs.

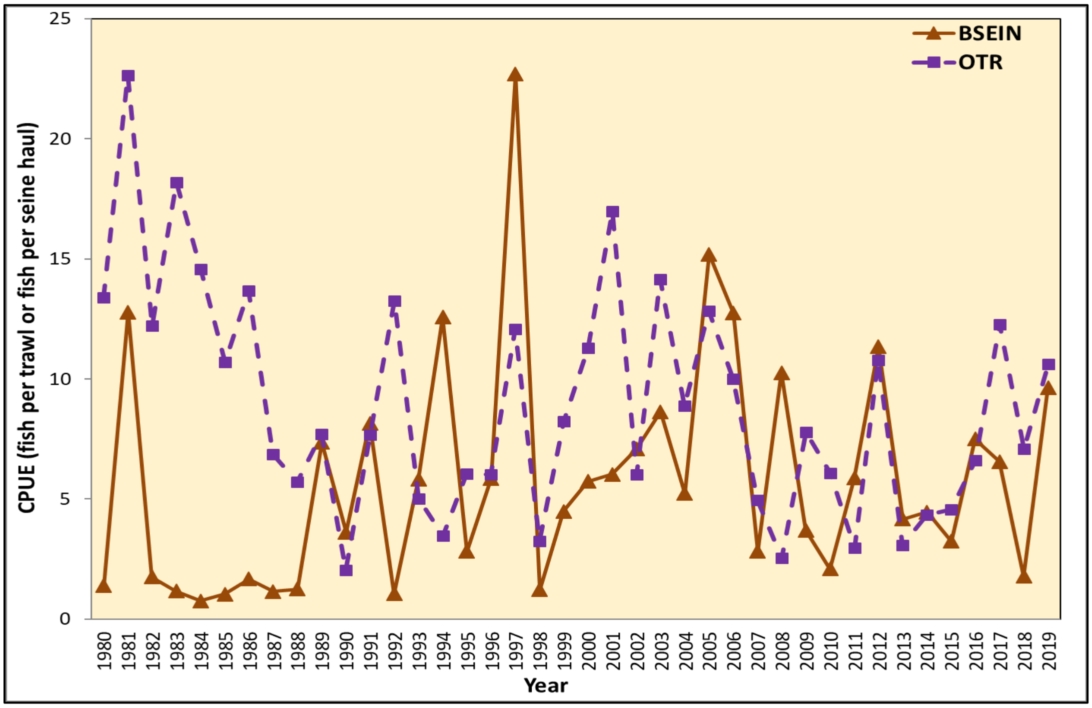

Figure 18. Annual CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine).

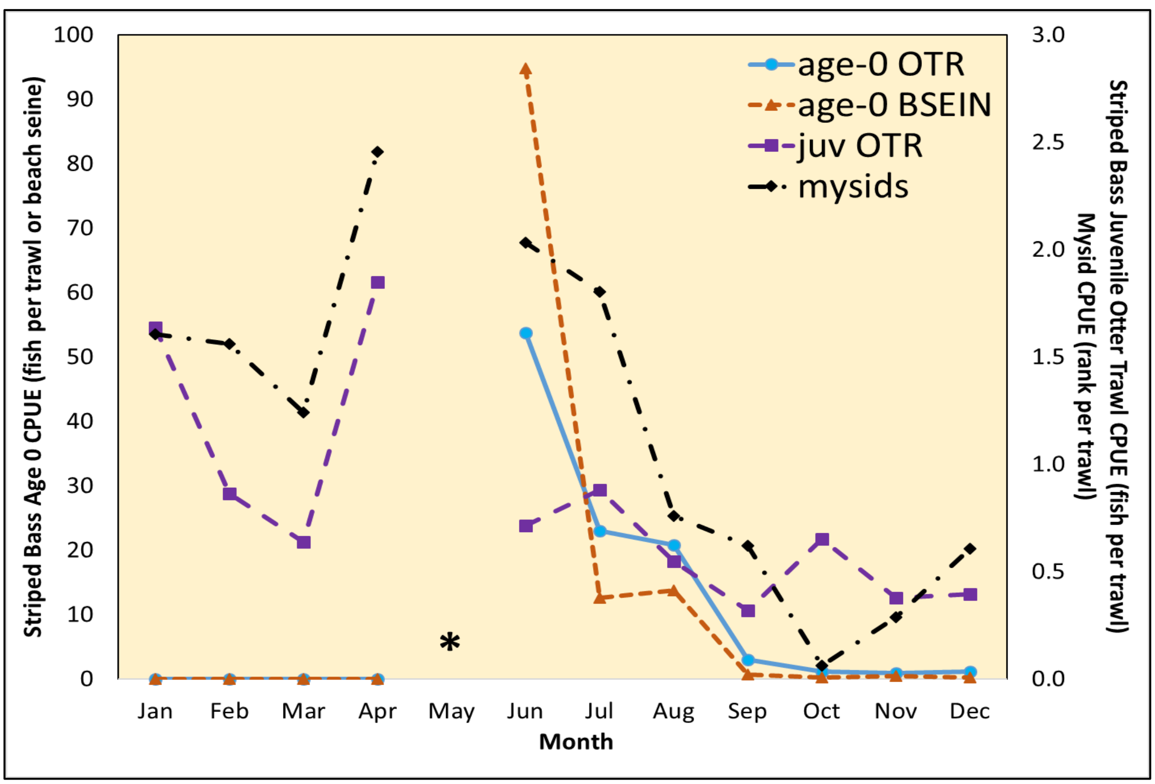

Figure 19. Monthly average CPUE of striped bass age classes and mysids ("juv" = juvenile; other codes as in Figure 18) in 2019 (* = no samples).

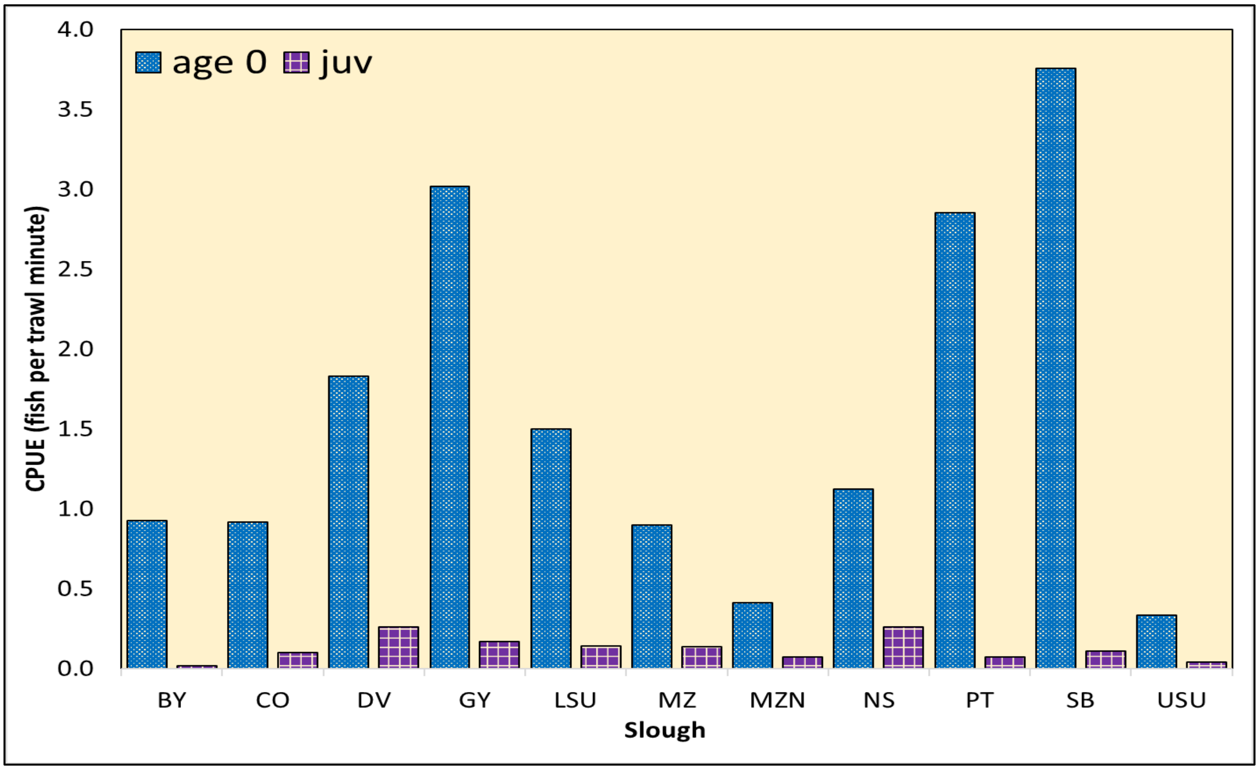

Figure 20. Average slough CPUE of age classes of striped bass in 2019 ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "LSU" = lower Suisun Slough, "MZ" = Montezuma Slough, "MZN" = Montezuma new, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "USU" = upper Suisun Slough).

<u>Sacramento Splittail</u>

Splittail were very abundant in 2019, with exceptionally high numbers in otter trawls and a record-high number in beach seines (Figure 21, Table 1 and 2). The wealth of splittail in Suisun Marsh was especially striking given none were captured by the Fall Midwater Trawl Survey (CDFW 2020), which once varied with Suisun Marsh catches (Sommer *et al.* 1997). A large influx of age-0 fish contributed most strongly to the year's catch in both nets, with only 1982 exhibiting a higher age-0 CPUE than 2019 (Figure 21), and 96% of the beach seine catch in 2019 comprised of age-0 fish. Age-1 fish were also very abundant, increasing by about a fish per trawl from 2018 to 2019 and was well above the all-years average. In contrast, age-2+ abundance markedly declined from 2018 to 2019 (4.2 to 1.5 fish per trawl, respectively), though it was still moderately high (Figure 21). Splittail were most numerous in small sloughs (Figure 22), typically those where striped bass were also most abundant (Figure 20). In contrast, splittail were also very abundant in near-shore shallow water in a large slough (Montezuma), where two-thirds of the beach seine fish were captured (Appendix B). They were also caught in numbers in Denverton Slough (31% of the catch) but were very sparse in upper Suisun Slough (3% of the catch), the beach seine location furthest from the main entry point into Suisun Marsh - eastern Montezuma Slough - for fishes emigrating from upstream areas. The patterns in 2019 reflected (1) favorable spawning conditions from vast, prolonged floodplain inundation; (2) high flows to deliver young splittail into Suisun Marsh; (3) good rearing conditions within Suisun Marsh

(Colombano *et al.* 2020); and (4) high mortality of adult fish, many of which were likely from the 2011 year class and thus close to their maximum lifespan (Feyrer *et al.* 2015).

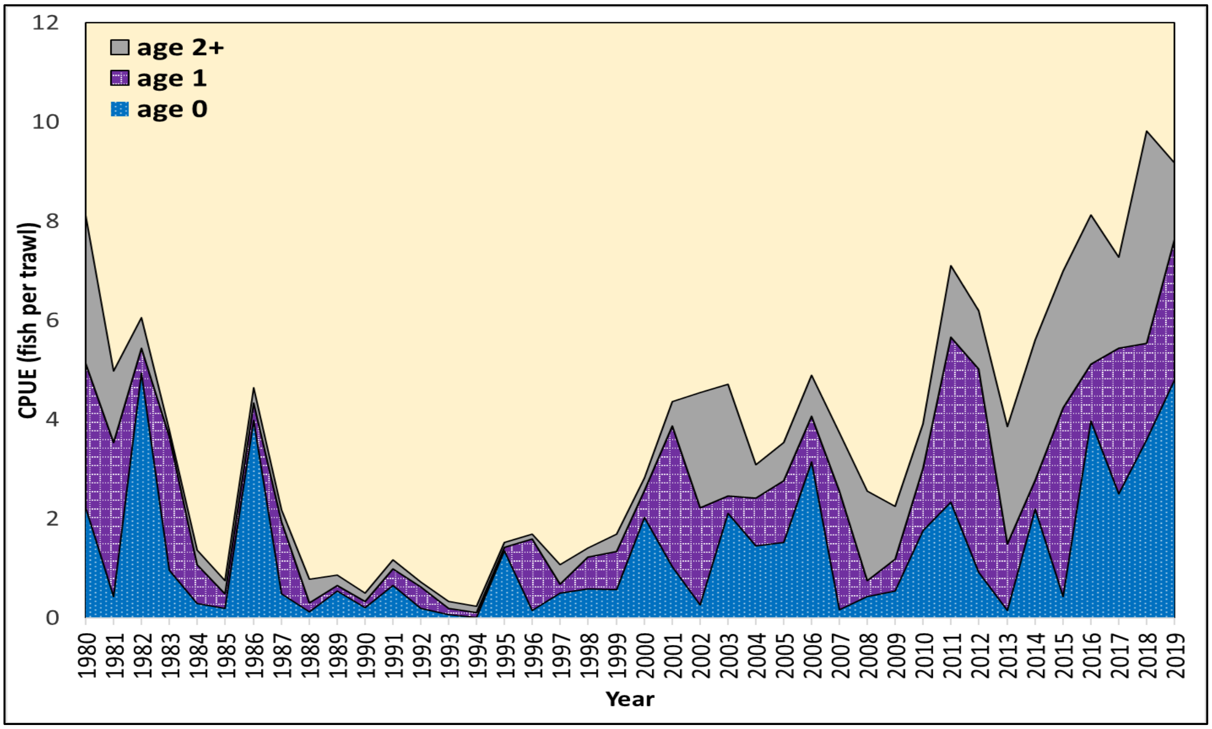

Figure 21. Annual CPUE of three age classes of Sacramento splittail.

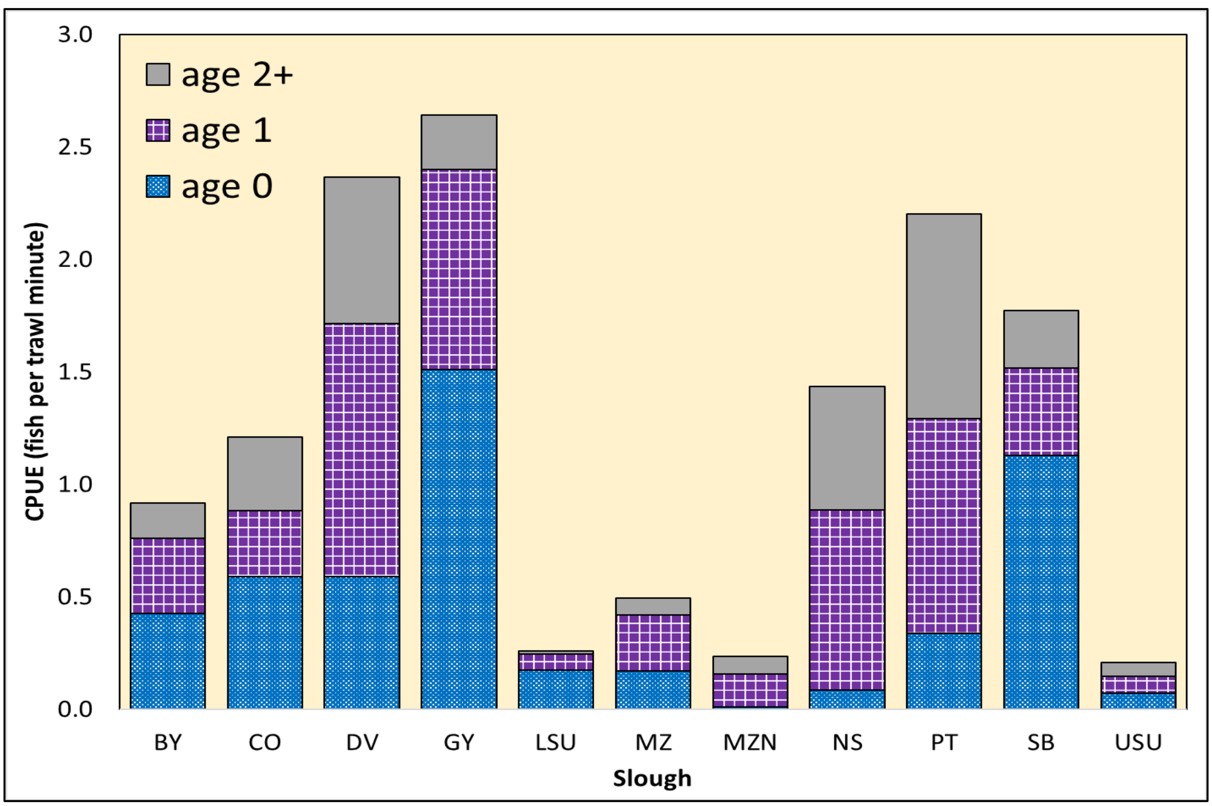

Figure 22. Average slough CPUE of age classes of splittail in 2019 (codes as in Figure 20).

White Catfish

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 14), were again low in abundance in Suisun Marsh in 2019 (Figure 23). Despite favorable salinities for spawning within Suisun Marsh (<2 ppt; Perry and Avault, Jr. 1968, 1969) and high flows available for transporting small white catfish from rivers and the Delta into Suisun Marsh, catch of age-0 fish was still considerably less than that of previous wet years (*e.g.*, 1998, 2005, 2006, 2011; O'Rear and Moyle 2012, O'Rear *et al.* 2019). Only four adult white catfish (*i.e.*, those > 185 mm SL) were captured in 2019; they were all quite small (202 - 210 mm SL), they were caught in August after the spawning period (early summer; Borgeson and McCammon 1967), and so they doubtfully spawned and contributed any age-0 fish to the catch. Such patterns reflect the importance of a substantial adult population within the marsh to take advantage of wet years and produce a lot of young, and possibly fewer white catfish available in the Delta to be flushed into Suisun Marsh in wet years (O'Rear, unpublished data).

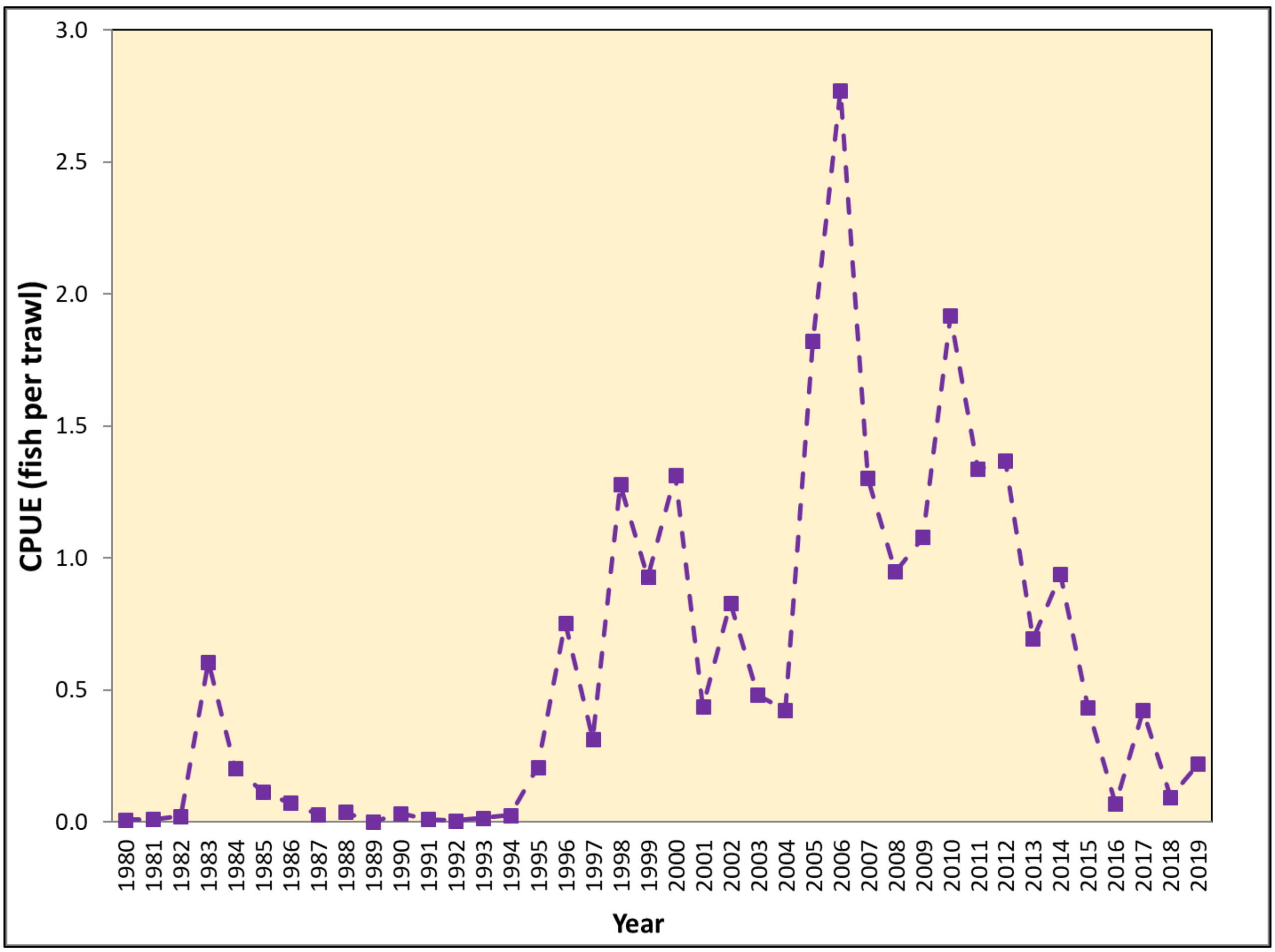

Figure 23. Annual CPUE of white catfish.

Mississippi Silverside

After seven years of remarkably stable numbers (2012 - 2018; Figure 24), Mississippi silverside annual beach seine CPUE changed dramatically in 2019 by increasing to its third-highest value in the study's history (Figure 24). Otter-trawl numbers were especially high as well, with 2019's value the second highest ever recorded. The trend in monthly abundance in the beach seines was rather typical, declining in winter until reaching its minimum in spring, and then generally climbing through summer to year's end (Figure 25), 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 that it persisted into September (Figure 26). Mississippi silverside were abundant at all three seining beaches, though more were caught at the small-slough site (Denverton; 42% of 2019's catch) than at the two large-slough sites (Montezuma and upper Suisun, each with 29% of the year's catch; Appendix B). The species was caught in trawls in throughout the marsh, with First Mallard Slough contributing the highest proportion (45%) to the 2019 catch (Appendix B). The high numbers of silverside in 2019 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), coupled with high zooplankton concentrations for improved growth and survival.

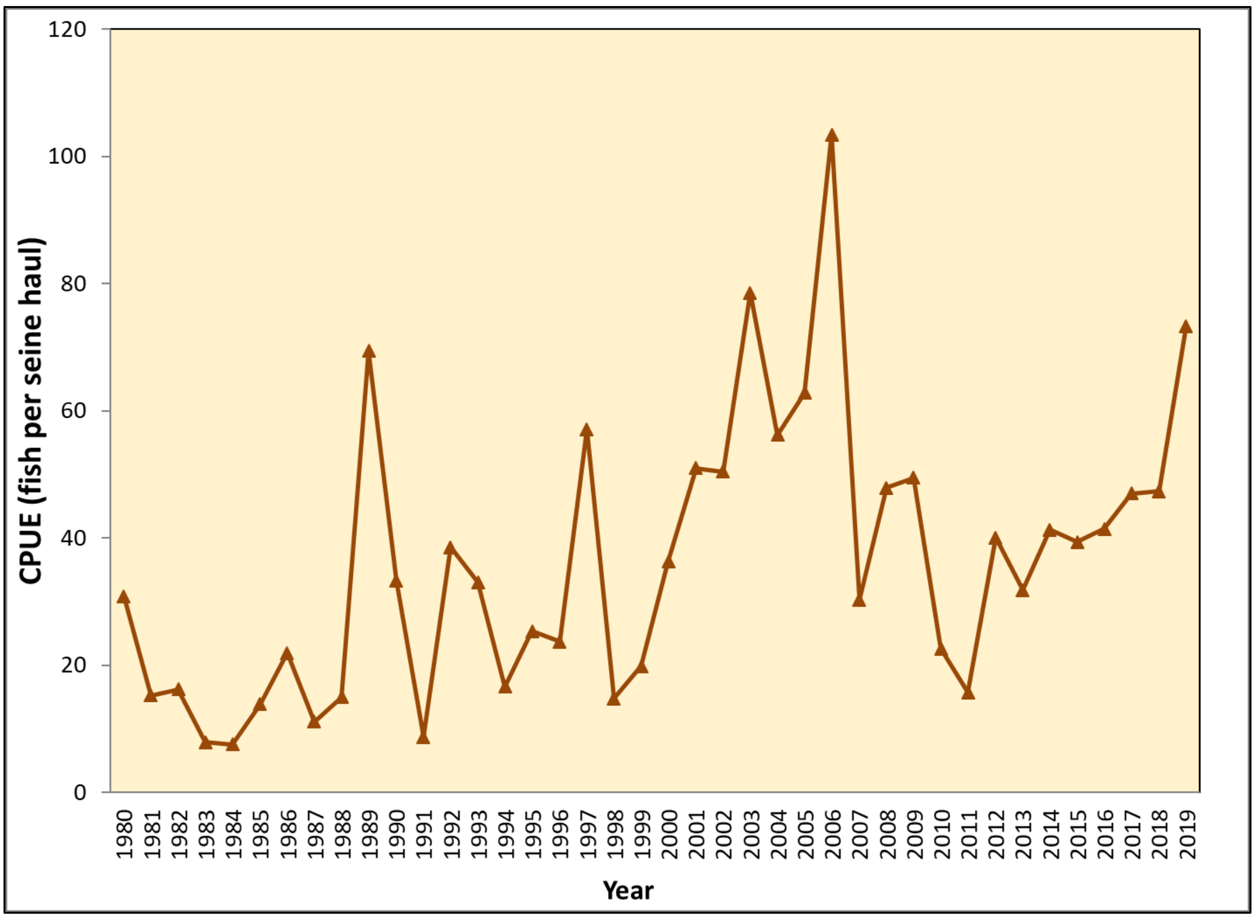

Figure 24. Annual CPUE of Mississippi silverside.

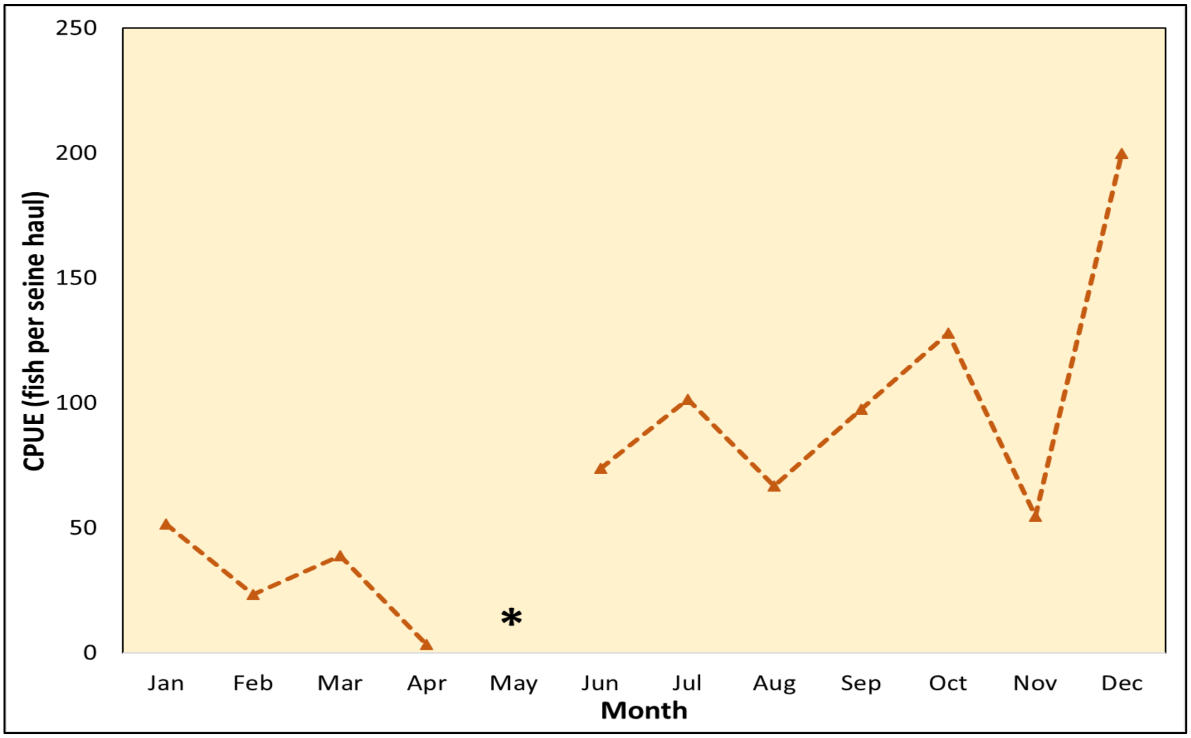

Figure 25. Monthly average CPUE of Mississippi silverside in 2019 (* = no samples).

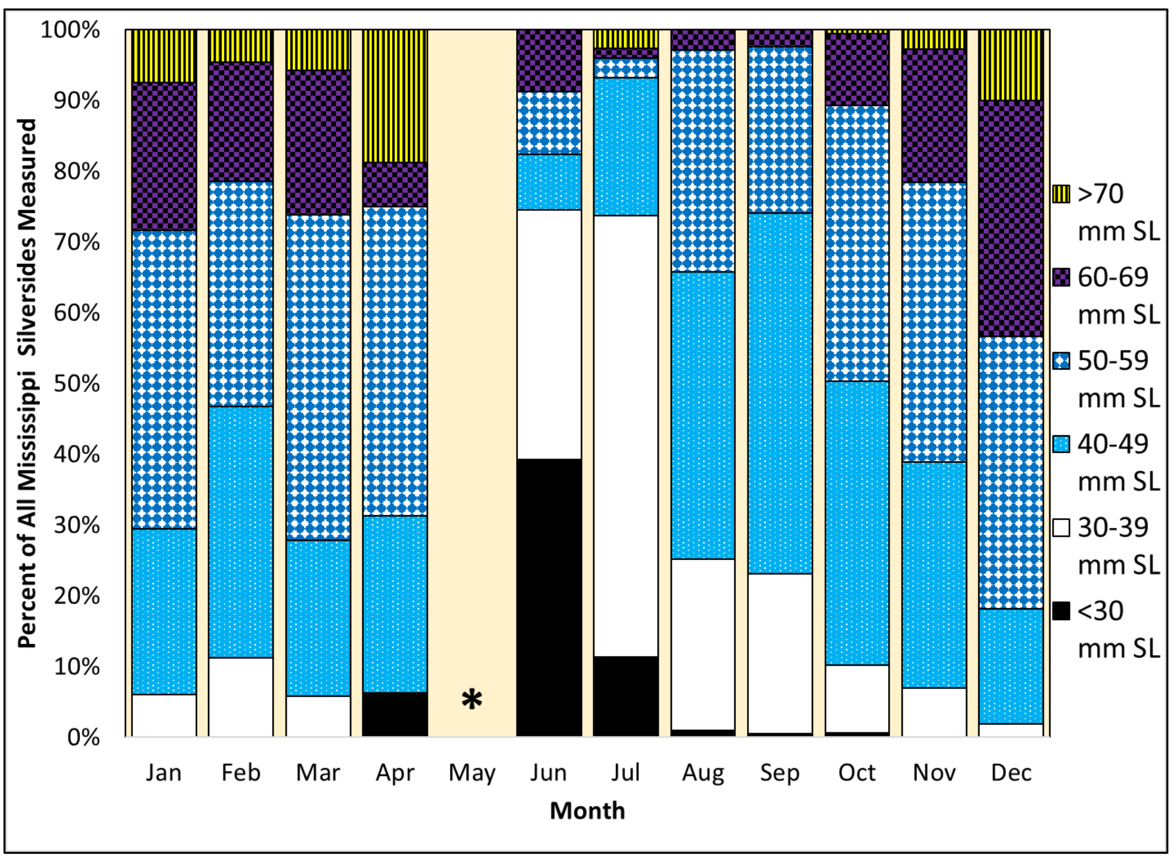

Figure 26. Monthly size-class distributions of Mississippi silverside captured in beach seines in 2019 (* = no samples).

CONCLUSION

Suisun Marsh was subjected to a wet year in 2019, which translated to high flows that reduced salinity well below average throughout the year. The low-salinity water minimized the need to operate the Suisun Marsh Salinity Control Gates, precluding evaluation of their effect on the aquatic community. 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 Black Sea jellyfish and overbite clam, both of which have been associated with warmer water. In contrast, numbers of the native California bay shrimp were negligible in 2019, in part because the water was too fresh in much of the year. In contrast, many native and non-native fishes were more abundant than usual in Suisun Marsh during 2019, particularly in small, dead-end sloughs. Non-native species that spawn in fresh water, eat zooplankton, and are tolerant of warm water - threadfin shad, American shad, Mississippi silverside, and striped bass - were all very numerous in Suisun Marsh in 2019 despite the shads and striped bass being relatively sparse in the estuary's main rivers and bays. Many native fishes also fared well in 2019, with prickly sculpin, tule perch, and threespine stickleback all being more abundant than in the drier year of 2018. Sacramento splittail was, as has been for many years now, the star of the native-fish assemblage, boasting very high numbers in the otter trawl and its highest-ever abundance in the beach seine. In contrast, two cool-water plankton-eating native fishes - longfin smelt and Delta smelt - were virtually absent, which has been a chronic trend throughout the northern reach of the estuary for many years now. Despite favorable water quality and hydrology, two warm-water, bottom-feeding freshwater fishes, common carp and white catfish, were not as abundant as expected. In sum, 2019 was consistent with (1) high Delta outflow promoting larger populations of Siberian prawn as well as both native and non-native fishes that spawn in fresh water; (2) warm water limiting native cool-water plankton-eaters (smelts) in space and time while concomitantly enhancing non-native plankton-eaters (Black Sea jellyfish, overbite clam, Mississippi silverside, American and threadfin shad), especially in large sloughs; and (3) Suisun Marsh being the premier habitat for Sacramento splittail.

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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 2019 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
American shad	*Alosa sapidissima*	2268	488		2756
bay pipefish	***Sygnathus leptorhynchus***	**3**			**3**
bigscale logperch	*Percina macrolepida*	20	9		29
black bullhead	*Ameiurus melas*	883	3		886
black crappie	*Pomoxis nigromaculatus*	2454	258	1	2713
bluegill	*Lepomis macrochirus*	24	21		45
brown bullhead	*Ameiurus nebulosus*	31			31
California halibut	***Paralichthys californicus***	**9**	**3**		**12**
channel catfish	*Ictalurus punctatus*	189	11		200
Chinook salmon	***Oncorhynchus tshawytscha***	**76**	**426**	**1**	**503**
common carp	*Cyprinus carpio*	5680	567	1	6248
delta smelt	***Hypomesus transpacificus***	**664**	**144**	**4**	**812**
fathead minnow	*Pimephales promelas*	36	38		74
golden shiner	*Notemigonus crysoleucas*	9	13		22
goldfish	*Carassius auratus*	308	70		378
green sturgeon	***Acipenser medirostris***	**3**			**3**
green sunfish	*Lepomis cyanellus*	5	3		8
hardhead	***Mylopharadon conocephalus***	**1**			**1**
hitch	***Lavinia exilicauda***	**124**	**16**		**140**
largemouth bass	*Micropterus salmoides*		3		3
longfin smelt	***Spirinchus thaleichthys***	**11908**	**53**	**5**	**11966**
longjaw mudsucker	***Gillichthys mirabilis***	**1**			**1**
Mississippi silverside	*Menidia audens*	1436	107676		109112
northern anchovy	***Engraulis mordax***	**330**		**37**	**367**
Pacific herring	***Clupea harengeus***	**484**	**136**		**620**
Pacific lamprey	***Lampetra tridentata***	**49**			**49**
Pacific sanddab	***Citharichthys sordidas***	**3**	**2**		**5**
plainfin midshipman	***Porichthys notatus***	**21**			**21**
prickly sculpin	***Cottus asper***	**12657**	**1212**	**1**	**13870**
rainbow trout	***Oncorhynchus mykiss***	**9**	**4**		**13**
rainwater killifish	*Lucania parva*	39	152		191
redear sunfish	*Lepomis microlophus*	2	1		3
river lamprey	***Lampetra ayresi***	**4**			**4**
Sacramento blackfish	***Orthodon macrolepidotus***	**26**	**116**		**142**
Sacramento pikeminnow	***Ptychocheilus grandis***	**188**	**351**		**539**

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
Sacramento splittail	***Pogonichthys macrolepidotus***	**38977**	**6565**	**14**	**45556**
Sacramento sucker	***Catostomus occidentalis***	**3548**	**137**	**5**	**3690**
shimofuri goby	*Tridentiger bifasciatus*	11727	2857	1	14585
shiner perch	***Cymatogaster aggregata***	**17**			**17**
shokihaze goby	*Tridentiger barbatus*	1467	5	6	1478
speckled sanddab	***Citharichthys stigmaeus***	**3**			**3**
staghorn sculpin	***Leptocottus armatus***	**2600**	**3469**		**6069**
starry flounder	***Platichthys stellatus***	**2285**	**310**	**4**	**2599**
striped bass	*Morone saxatilis*	97030	16710	30	113770
striped mullet	***Mugil cephalus***		**1**		1
surf smelt	***Hypomesus pretiosus***	**5**			5
threadfin shad	*Dorosoma petenense*	4400	8265	1	12666
threespine stickleback	***Gasterosteus aculeatus***	**18260**	**6886**	**6**	**25152**
tule perch	***Hysterocarpus traski***	**22549**	**2608**	**6**	**25163**
wakasagi	*Hypomesus nipponensis*	13	11		24
warmouth	*Lepomis gulosus*	1			1
western mosquitofish	*Gambusia affinis*	19	380		399
white catfish	*Ameiurus catus*	6116	172	13	6301
white crappie	*Pomoxis annularis*	112			112
white croaker	***Genyonemus lineatus***	**3**			**3**
white sturgeon	***Acipenser transmontanus***	**126**		**2**	**128**
yellowfin goby	*Acanthogobius flavimanus*	20911	18386		39297
Total		270113	178538	138	448789

APPENDIX B: 2019 CATCHES

Total 2019 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold).

Species	Slough											Total
	BY	CO	DV	GY	LSU	MZ	MZN	NS	PT	SB	USU	
American shad	27	18	6	19	80	5	26	1	11	10		203
black crappie	1		157					17	1	3		179
bluegill			0		1					1		2
brown bullhead			0			2						2
channel catfish			0			1						1
common carp	9	1	17	11	3	2		13	7	1	2	66
goldfish			0	1					1			2
longfin smelt			**0**		**2**	**1**						**3**
Mississippi silverside	3		15	15		30				51		114
Pacific lamprey						**1**						**1**
prickly sculpin	**80**	**25**	**26**	**113**	**22**	**11**	**5**	**17**	**46**	**12**	**21**	**378**
rainwater killifish			0	1								1
river lamprey								**1**				**1**
Sacramento pikeminnow		**1**	**0**							**1**		**2**
Sacramento splittail	**101**	**133**	**390**	**436**	**57**	**108**	**27**	**238**	**242**	**195**	**46**	**1973**
Sacramento sucker	**6**	**6**	**2**	**3**	**1**			**1**	**11**	**2**	**1**	**33**
shimofuri goby	98	20	63	8	2	7	19	115	32	12	21	397
shokihaze goby	2		3		24	9	2	3	3		29	75
staghorn sculpin			**0**		**2**		**2**			**3**		**7**
starry flounder			**3**		**4**	**12**	**2**	**2**			**4**	**27**
striped bass	104	112	345	535	361	246	55	228	322	425	82	2815
threadfin shad		9	214	3	18	51		12	6	186		499
threespine stickleback	**7**	**2**	**1**	**45**	**12**	**8**	**4**	**2**	**3**	**5**	**12**	**101**
tule perch	**44**	**74**	**56**	**9**		**25**	**1**	**53**	**76**	**35**	**10**	**383**
western mosquitofish			0							1		1
white catfish	3	1	35	1	1	5	1	1	15	1	3	67
yellowfin goby	23	5	10	24	147	12	3	15	12	9	39	299
Total	508	407	1343	1224	737	536	147	719	788	953	270	7632

Total 2019 beach seine catch of each fish species in Denverton, Montezuma, and upper Suisun sloughs (native species are in bold).

Species	Slough			Total
	Denverton	Montezuma new	upper Suisun	
American shad	4	31	4	39
bigscale logperch	1	1		2
black crappie	78	1		79
bluegill	1			1
channel catfish	1	1		2
Chinook salmon		**10**		**10**
common carp	3		7	10
golden shiner			1	1
goldfish	3		16	19
Mississippi silverside	2526	1769	1791	6086
prickly sculpin	**7**	**2**	**4**	**13**
rainwater killifish	1		1	2
Sacramento pikeminnow	**5**	**15**		**20**
Sacramento splittail	**239**	**509**	**27**	**775**
Sacramento sucker	**3**	**6**		**9**
shimofuri goby	37	2	16	55
staghorn sculpin	**1**	**3**	**5**	**9**
striped bass	484	156	160	800
threadfin shad	335	271	21	627
threespine stickleback	**10**	**20**	**21**	**51**
tule perch	**18**	**14**	**6**	**38**
western mosquitofish	1	1	12	14
white catfish	5			5
yellowfin goby	9	68	136	213
Total	3772	2880	2228	8880

APPENDIX C: 2019 EFFORT

Number of otter trawls in each slough and each month in 2019.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	2	2	0	2	2	2	2	2	2	2	22
Cutoff	2	2	2	2	0	2	2	2	2	2	2	2	22
Denverton	3	3	3	3	0	3	3	3	3	3	3	3	33
First Mallard	2	2	2	2	0	2	2	2	2	2	2	2	22
Goodyear	3	3	3	3	0	3	3	3	3	3	3	3	33
lower Suisun	2	2	2	2	0	2	2	2	2	2	2	2	22
Montezuma	2	2	2	2	0	2	2	2	2	2	2	2	22
Montezuma new	1	1	2	1	0	1	1	1	1	1	1	1	12
Nurse	3	3	3	3	0	3	3	3	3	3	3	3	33
Peytonia	2	2	2	2	0	2	2	2	2	2	2	2	22
upper Suisun	2	2	2	2	0	2	2	2	2	2	2	2	22
Total	24	24	25	24	0	24	24	24	24	24	24	24	265

Number of beach seines in each slough and each month in 2019.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	3	3	0	0	2	3	3	2	2	2	2	25
Montezuma new	3	2	3	3	0	3	3	2	3	3	3	3	31
upper Suisun	2	3	3	2	0	2	2	3	3	2	3	2	27
Total	8	8	9	5	0	7	8	8	8	7	8	7	83

APPENDIX D: 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)>#1/1/2019# And (Sample.SampleDate)<#1/1/2020#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```

Fishes and Invertebrates

```
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)>#1/1/2019# And (Sample.SampleDate)<#12/31/2019#) AND
((Sample.MethodCode)="otr" Or (Sample.MethodCode)="bsein"))
ORDER BY Sample.StationCode, Sample.SampleDate;
```