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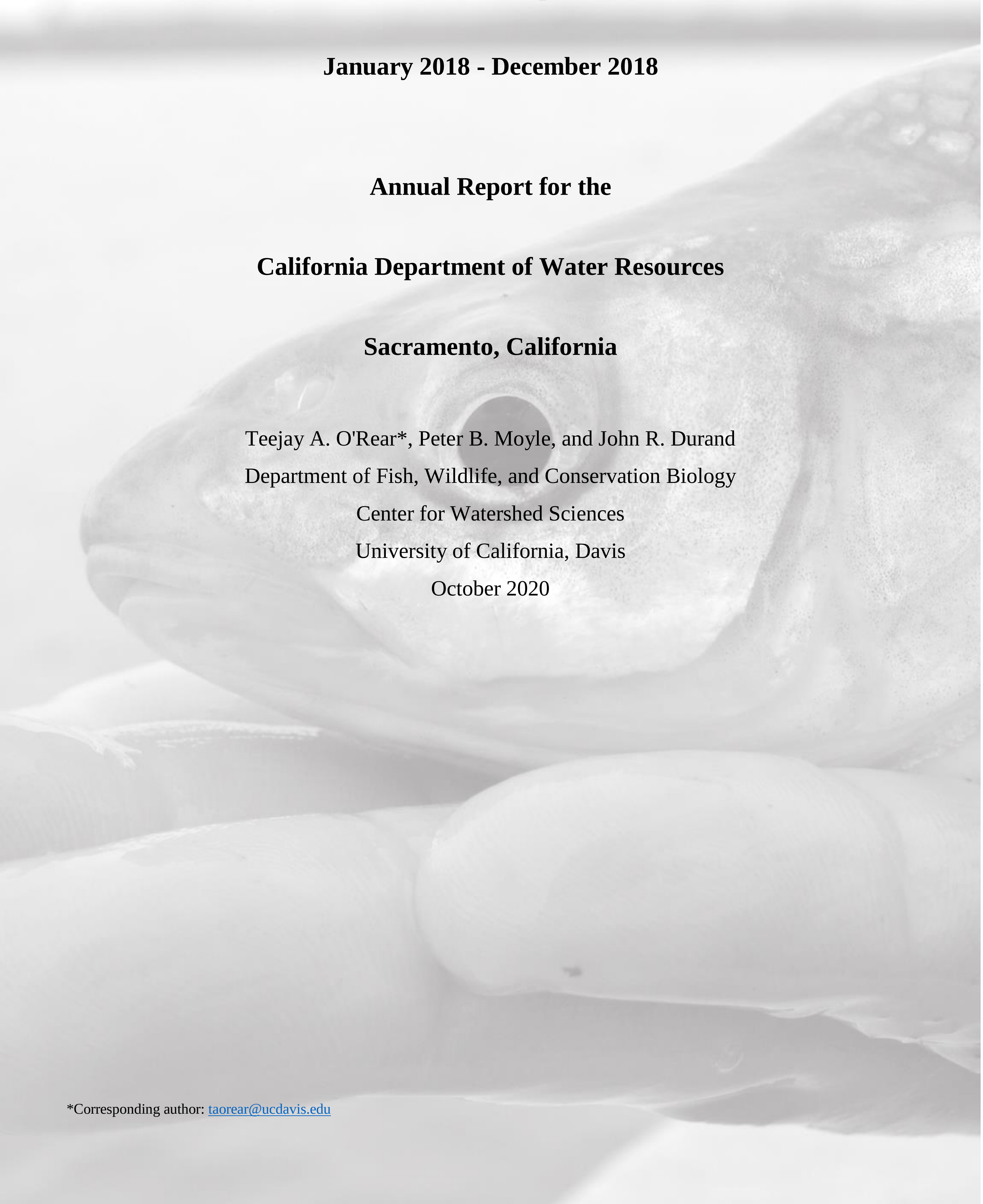

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2018 - December 2018

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 environmental and anthropogenic factors affecting fish distribution and abundance.

Abiotic conditions in Suisun Marsh during calendar-year 2018 returned to fairly typical levels following the very wet year of 2017. Delta outflow was generally low, with higher-than-average outflows only occurring in April when Yolo Bypass flooded. Salinities in 2018 were about average, in part because of Suisun Marsh Salinity Control Gates operations in late summer. Water temperatures were mild, being higher than average in winter and autumn and slightly below average during summer. Water transparencies were typical in winter and spring but, as has become a pattern since the early 2000s, were higher than average in summer and autumn. Dissolved-oxygen concentrations were consistent throughout the year, with only two instances of low values being recorded, both in dead-end sloughs.

Fish and invertebrate catches in Suisun Marsh in 2018 told two main stories: (1) many fishes benefit from higher flows and lower salinities in Suisun Marsh while some invasive invertebrates do not; and (2) Suisun Marsh is disproportionately valuable to fishes of conservation importance. Numbers of both Black Sea jellyfish (*Maeotias marginata*) and overbite clam (*Potamocorbula amurensis*) were low in 2018, likely due to the interaction of lower salinities and lower water temperatures suppressing recruitment, while both native and non-native shrimp abundances were higher than average. Abundances of nearly all fish species, both native and non-native, declined from the higher-flow year of 2017 to the lower-flow year of 2018. The fishes decreasing most in numbers were those requiring fresh water for spawning and/or those dependent on zooplankton for part of their lifecycle: non-native anadromous species [American shad (*Alosa sapidissima*) and striped bass *(Morone saxatilis*)], threadfin shad (*Dorosoma petenense*), and small-bodied benthic fishes with planktonic larvae. Nevertheless, relative abundances of the shads and striped bass in Suisun Marsh during 2018 were much higher than in the estuary’s main bays and rivers. Sacramento splittail (*Pogonichthys macrolepidotus*) were a notable exception, increasing in abundance from 2017 to their highest-ever abundance in the Suisun Marsh Fish Study’s history in 2018, an especially remarkable occurrence given that none were captured in California Department of Fish and Wildlife’s (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 sustaining populations of at-risk 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 diked wetlands managed for 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 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 understanding of the life history and ecology 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.* 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); serving as a baseline for upcoming restoration and for ancillary studies of off-channel habitats (*e.g.*, Williamson *et al.* 2015); contributing to the general understanding of estuarine systems 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 that exhibited seasonal trends in abundance, primarily due to differences in recruitment timing. 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). Notably, warm-water fishes that have become sparse in the estuary's rivers and bays since the early 2000s have either increased (*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 upper trophic levels. Surveys in and around a restored tidal marsh (Blacklock Island) and a diked wetland (Luco Pond) utilizing identical gear to the Suisun Marsh Fish Study found higher fish abundances, higher fish diversity, and a higher proportion of native fish in the diked wetland relative to the restored marsh, suggesting diked 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 changes in 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 2018 with average conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2018 to annual averages, noting abundance changes between 2017 and 2018; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2018, 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).

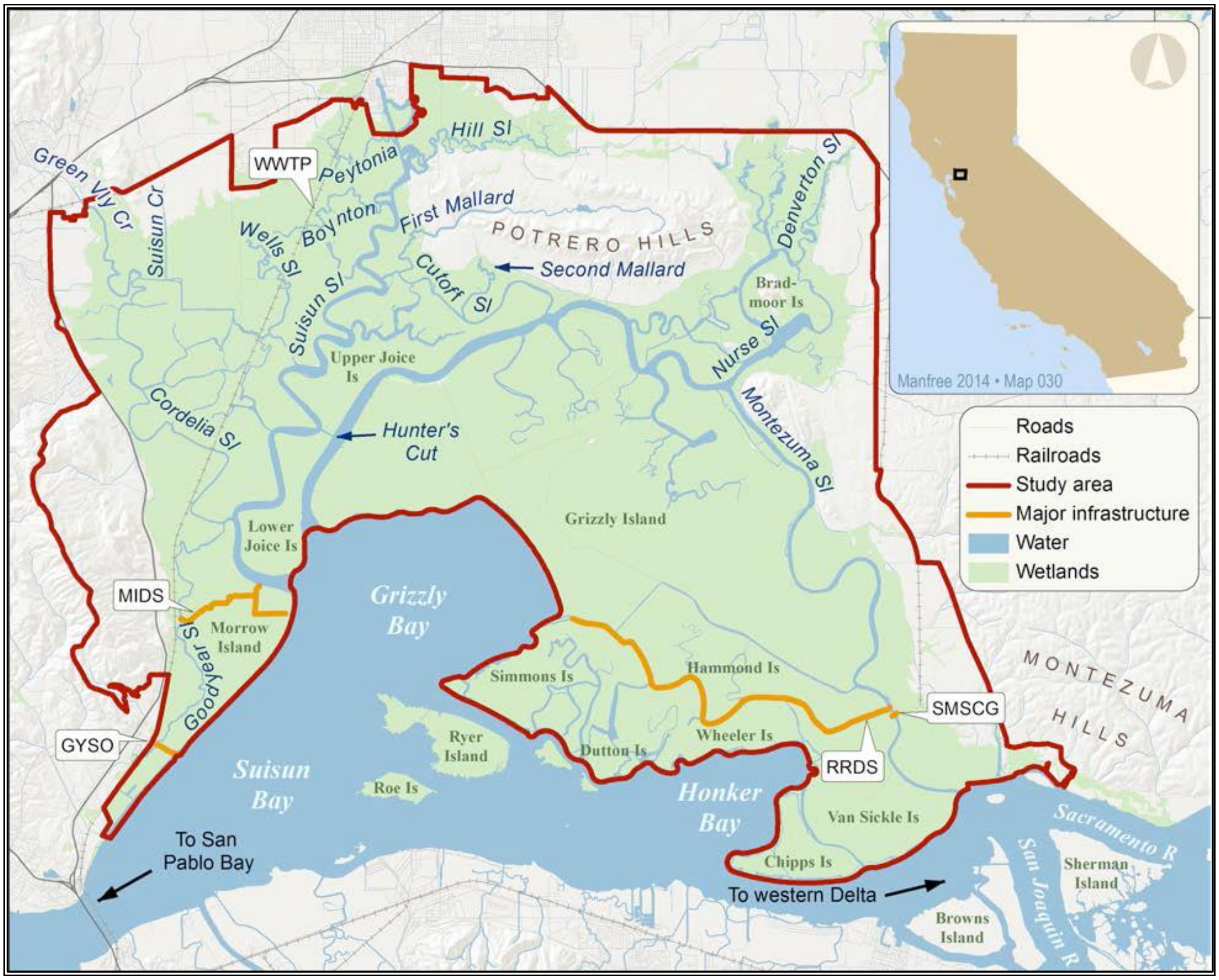

Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point 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 marsh plains regularly inundated 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 western 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 transparencies, especially compared to the Delta (Kimmerer 2004). Water transparency in Suisun Marsh is partially a function of Delta outflow, with lower outflows corresponding to higher transparencies in the marsh (Moyle *et al.* 1986, O'Rear and Moyle 2008, 2014). Since about 2000, transparencies 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).

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 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 diked wetlands to attract wintering waterfowl, with water diverted from adjacent subtidal sloughs. Most water control structures remain open to some extent (or are reopened) during winter and spring, 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 diked wetlands (Figure 1; DWR 2001). The

Fairfield-Suisun Sewer District discharges tertiary-treated wastewater into Boynton Slough (Figure 1); the wastewater's salinity is low, and DO concentration is high (*e.g.*, 6 - 7 mg/L; Siegel *et al.* 2011).

Suisun Marsh's fish and macroinverbrate 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 (*Palaemon modestus*), respectively] along with the non-native overbite clam and Black Sea jellyfish comprise the bulk of the invertebrate catch in most years. These invertebrates are important food-web players, either as competitors [Black Sea jellyfish (Wintzer *et al.* 2011)], 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 (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 native to Atlantic Ocean watersheds, particularly anadromous species with juveniles that eat zooplankton (American shad, striped bass), and Japanese estuarine small-bodied gobies. The small benthic species (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 is 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). Two additional sites in Denverton and Nurse sloughs (DV1 and NS1, respectively; Figure 2) were trawled in 2018 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 site also included in annual calculations. Several historic trawl sites were resurrected for the Arc Project (site MZ6; Figure 2) and a Proposition 1 study (the "Complete Marsh Project"; sites HL2 and PT3), and two new trawl sites created in 2017 (SD2 in Sheldrake Slough and SUVOL in Suisun Slough; Figure 2). Data from the MZ6 site were included in all calculations, while data from the PT3, HL2, and SUVOL sites were included in annual calculations. Data from the Sheldrake Slough site were not included in any calculations because SD2 was sampled intermittently (Appendix C) and was outside the sampling space at the study's beginning (Schroeter *et al.* 2006). Beach seines have been conducted at the DV2, MZ6, and SU1 sites, where smooth shores have allowed effective sampling. No sampling occurred in April because of personnel illnesses.

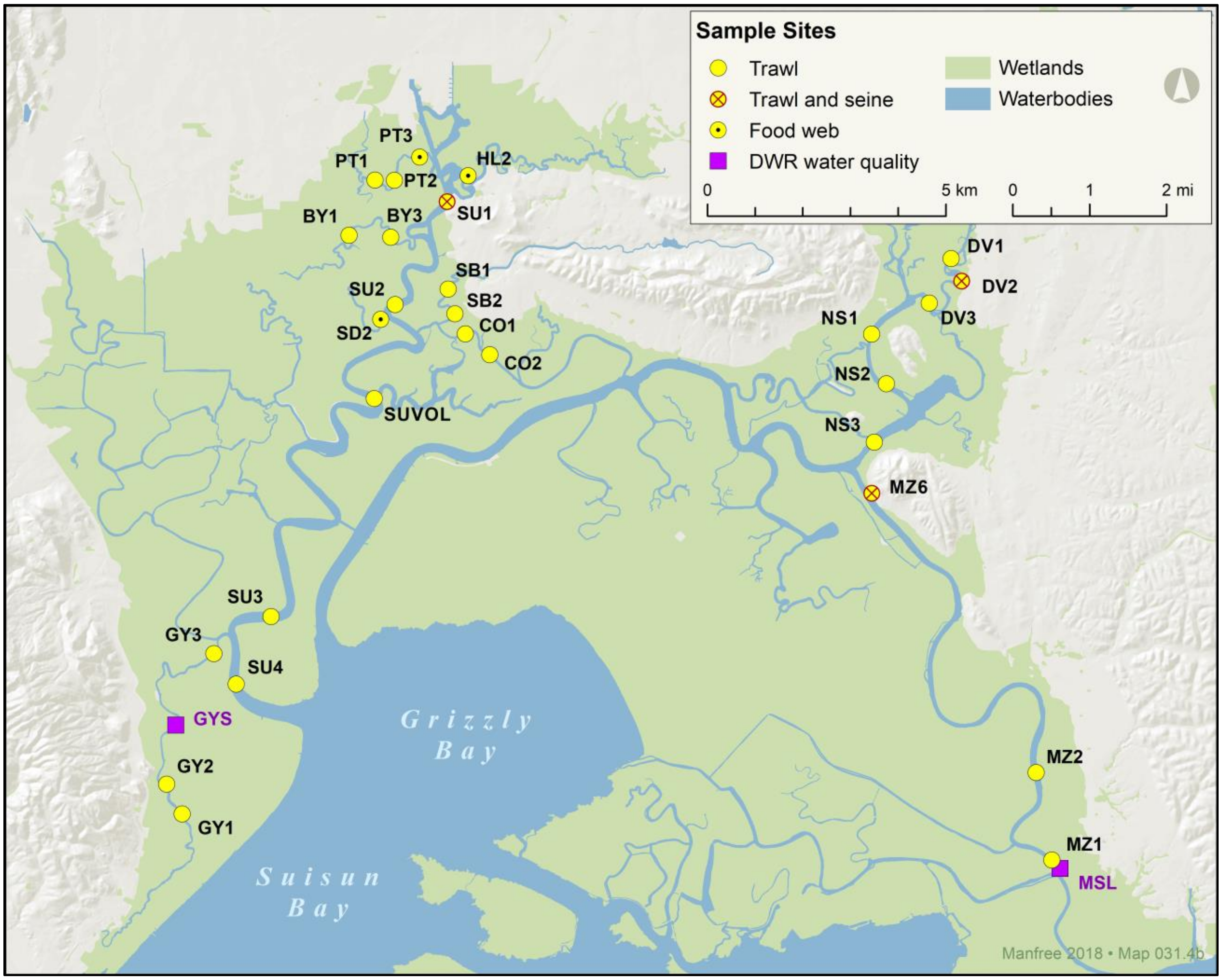

Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report.

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 (ppt), and specific conductance (microSiemens, μS) were recorded with a Yellow Springs Instruments PRO2030 meter. 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 buckets. 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 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.

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 2018 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 2018 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 2019).

Monthly water-quality results of 2018 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 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 2018 are found in Appendix A; annual catch of each slough and number of trawls/seines in each slough in 2018 are found in Appendix B and C.

RESULTS AND DISCUSSION

Abiotic Conditions

Delta Outflow

Calendar-year 2018 was rather dry, with generally below-average Delta outflow for most months (Figure 3), consistent with DWR's "below-normal" classification for water-year 2018 (DWR 2019). The only period of notably high outflow in the first five months occurred in April, concurrent with Sacramento River flows rising high enough to spill water into Yolo Bypass for several days. Despite the short period of Yolo Bypass inundation, the timing may have been fortuitous since it occurred close to the typical spawning peak of Sacramento splittail (late March; Feyrer *et al*. 2006), which spawns on floodplains. From June to mid-November, outflow hovered at ~5,900 CFS and was generally below average. Storms in November and December elevated outflow, albeit mildly (Figure 3).

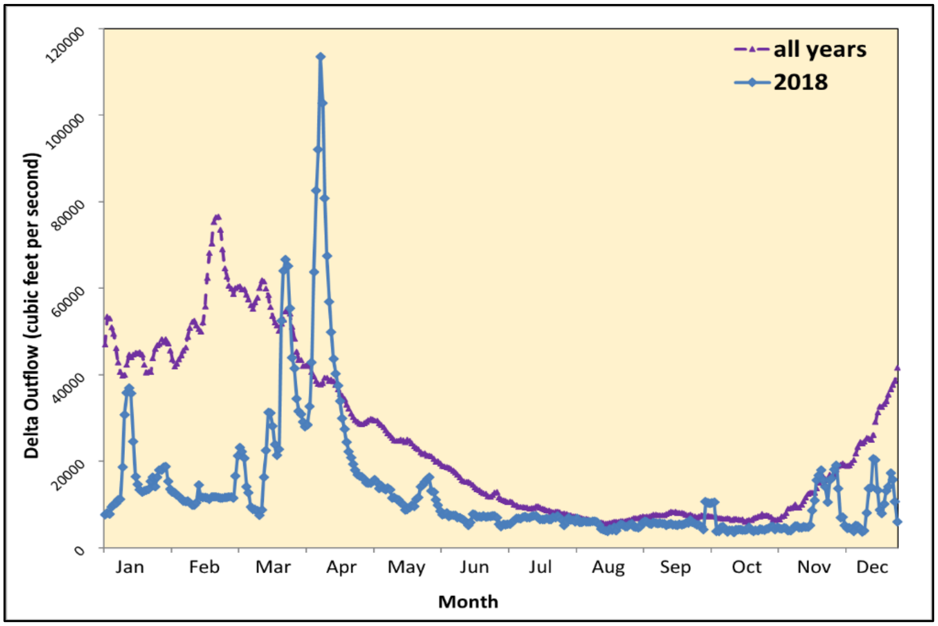

Figure 3. Daily Delta outflow in 2018 and the average for all years of the study (1980 – 2018; DWR 2019).

Salinity

Average annual salinity in 2018 was close to the average for all study years (4.4 and 3.9 ppt, respectively) despite the dry conditions. Salinity was higher than usual in January but dropped to average levels in February and March before reaching the year's minimum in May, following peak Delta outflow in April (Figure 3 and 4). Salinity increased more rapidly from May to July and then remained relatively stable through August and September, in part due to operation of the Suisun Marsh Salinity Control Gates for the Delta Smelt Resiliency Strategy (California Natural Resources Agency 2016; Figure 4). Coincident with low Delta outflow, salinity reached its annual maximum in October and November until declining again to average in December, after increases in Delta outflow. Salinities recorded by the fish study were within the bounds of the two water-quality stations for all months (Figure 5). Salinity varied widely in all months of 2018 (Figure 4). Highest monthly salinities were found in the southwest marsh in either Goodyear or lower Suisun Slough, with the maximum value for the year (13.3 ppt) recorded in upper Goodyear Slough in November. Lowest salinities were always in either Montezuma Slough or Boynton Slough, both with nearby sources of fresher water (the western Delta and the Fairfield-Suisun wastewater-treatment plant).

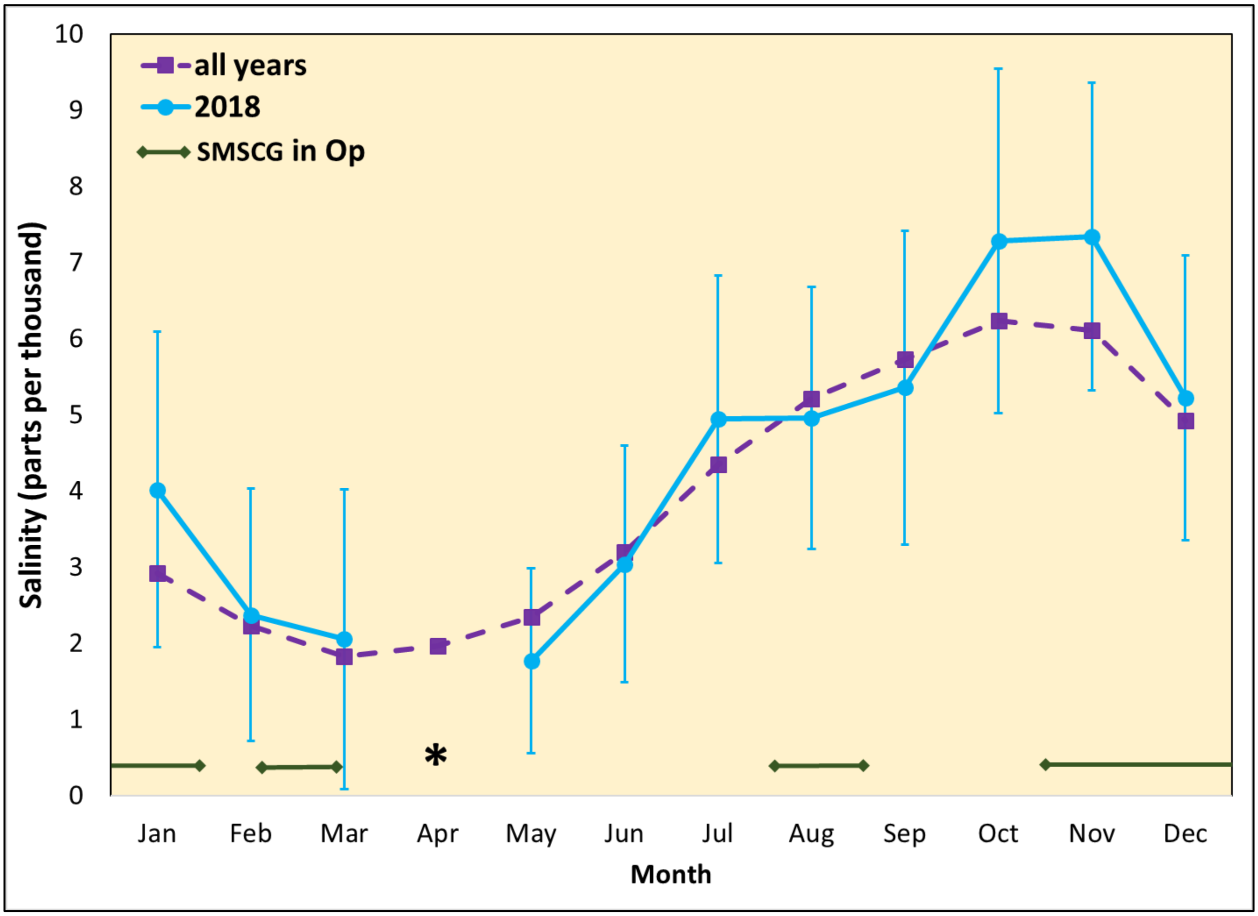

Figure 4. Monthly average surface salinity in 2018 and for all years of the study (1980 - 2018); error bars are standard deviations in 2018. Brown bar shows when the SMSCG were operating in 2018 (* = no samples).

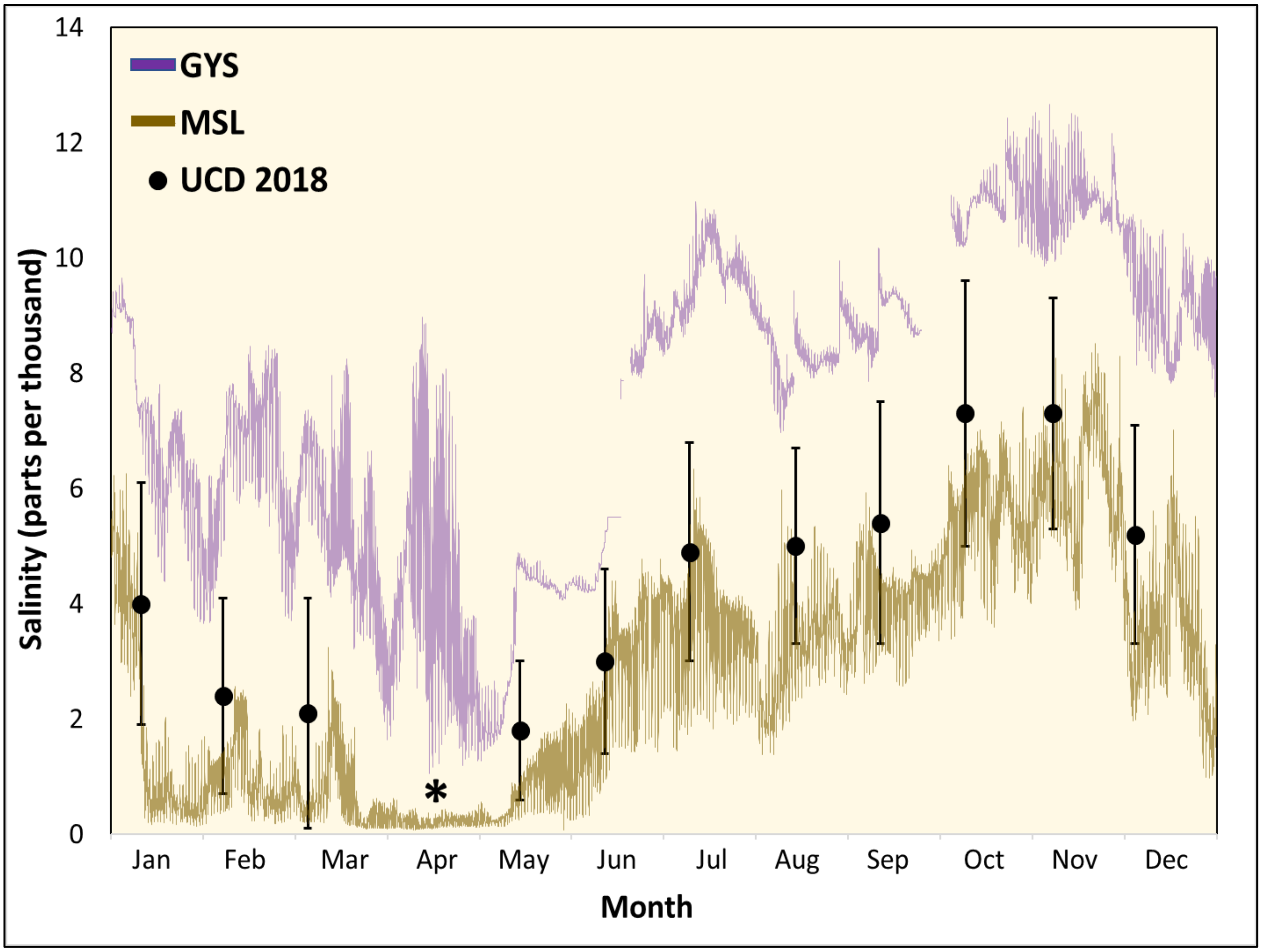

Figure 5. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations of the Suisun Marsh Fish Study ("UCD Sal"). Note no GYS data were recorded for a few days in mid-June and from late September through early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

Dissolved Oxygen

Average monthly DO concentrations were quite stable in 2018, reaching a minimum in summer rather than in autumn (Figure 6). Highest monthly averages coincided with the year's lowest water temperatures: January, December, and then an unusually cold March (see next section). Trends in minimum and maximum monthly DO concentrations roughly corresponded except in March and October, when the year's two lowest values were recorded (Figure 6). The lowest monthly DO concentrations always occurred in small, dead-end sloughs: five months in Goodyear Slough, three months in Peytonia Slough, two months in Boynton Slough, and one month in First Mallard Slough (Figure 1). In all months of 2018, highest monthly DO concentrations were measured in eastern Montezuma Slough. DO concentrations were always at or above 3 mg/L except in upper Goodyear Slough (*i.e.*, GY1 and GY2; Figure 2) in March and in Boynton Slough in October.

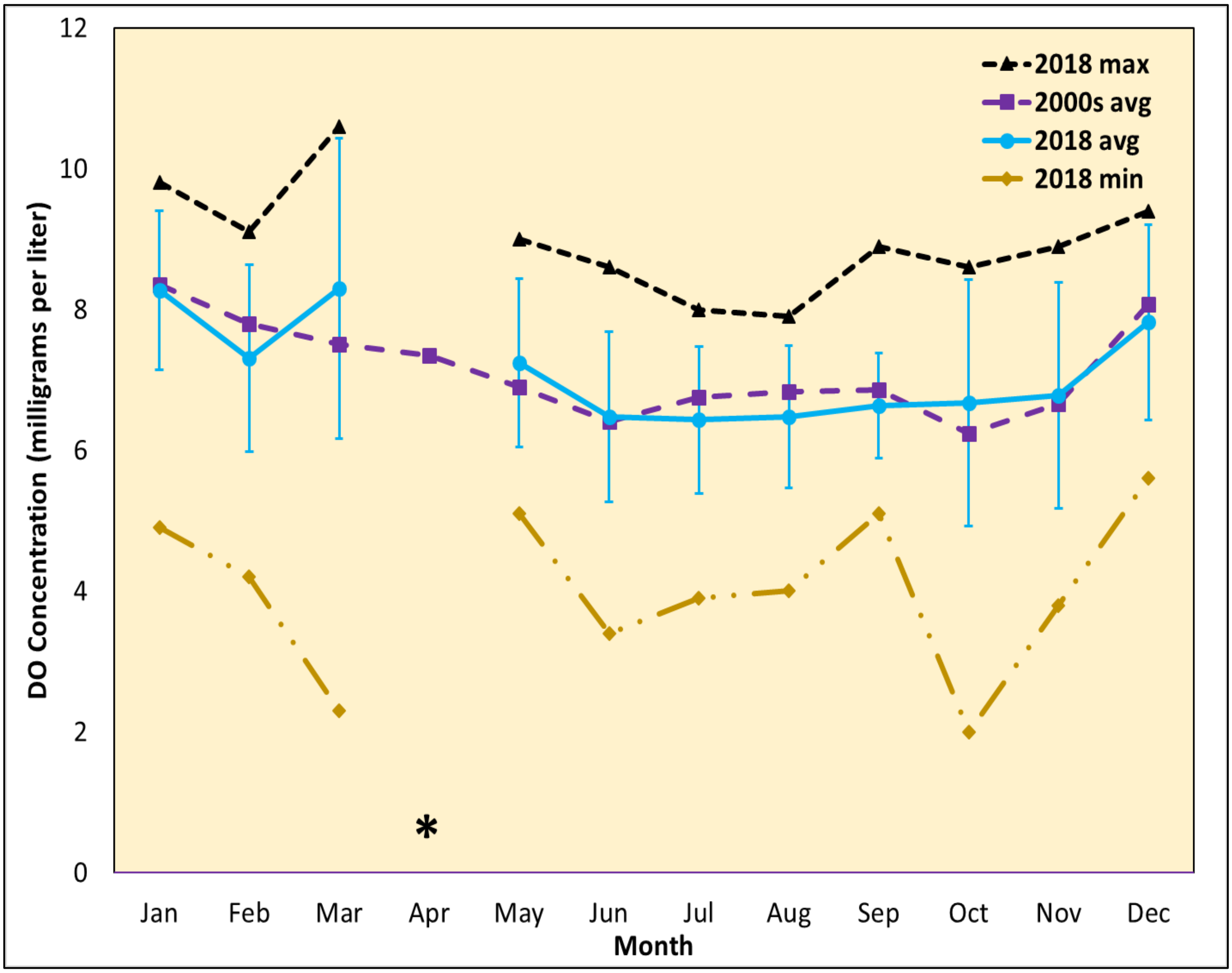

Figure 6. Monthly average DO concentration in 2018 and for the 2000s (2000 - 2018), maximum DO concentration in 2018, and minimum DO concentration in 2018. Error bars are standard deviations in 2018 (* = no samples).

Water Temperature

Unlike the previous four years, average monthly water temperatures were not considerably higher than average (Figure 7; O'Rear and Moyle 2015*c*, 2016, 2017; O'Rear *et al.* 2019). Water temperatures in winter and most of autumn were warmer than usual, but the water was especially cold in March and was not warmer than normal from May through September (Figure 7), the latter perhaps due partially to cooling by summertime wildfire smoke (David *et al.* 2018). Hottest and coldest water temperatures were measured in small sloughs (24°C in Cutoff Slough in July, and 9.3°C in Peytonia Slough in March). The very high and low temperatures recorded by the continuous monitoring station in Goodyear Slough is consistent with the greater sensitivity of smaller sloughs to temperature changes than larger sloughs (Figure 8).

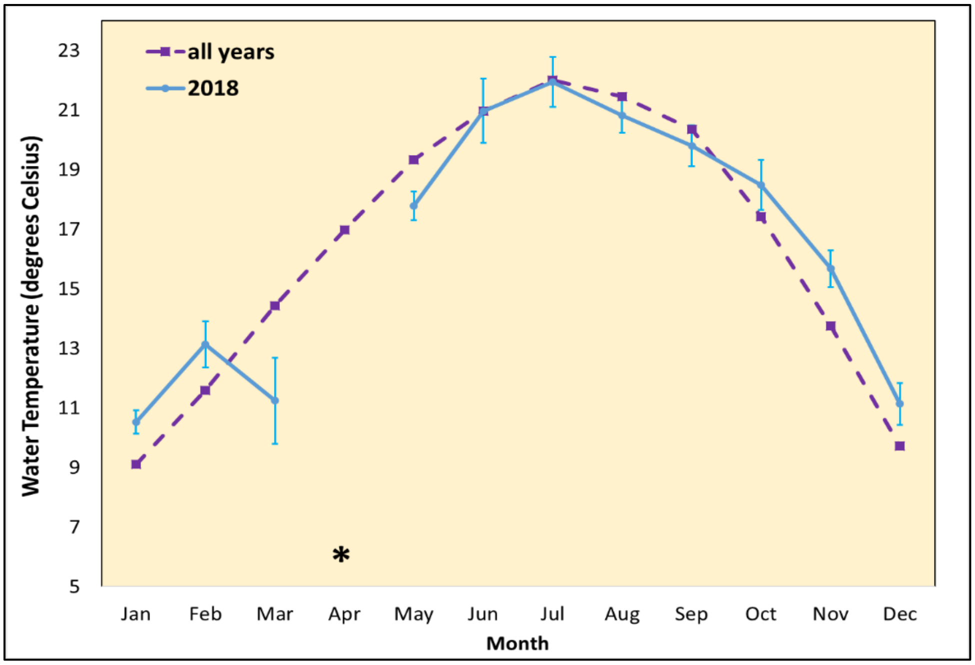

Figure 7. Monthly average water temperature in 2018 and for all years of the study (1980 - 2018); error bars are standard deviations in 2018 (* = no samples).

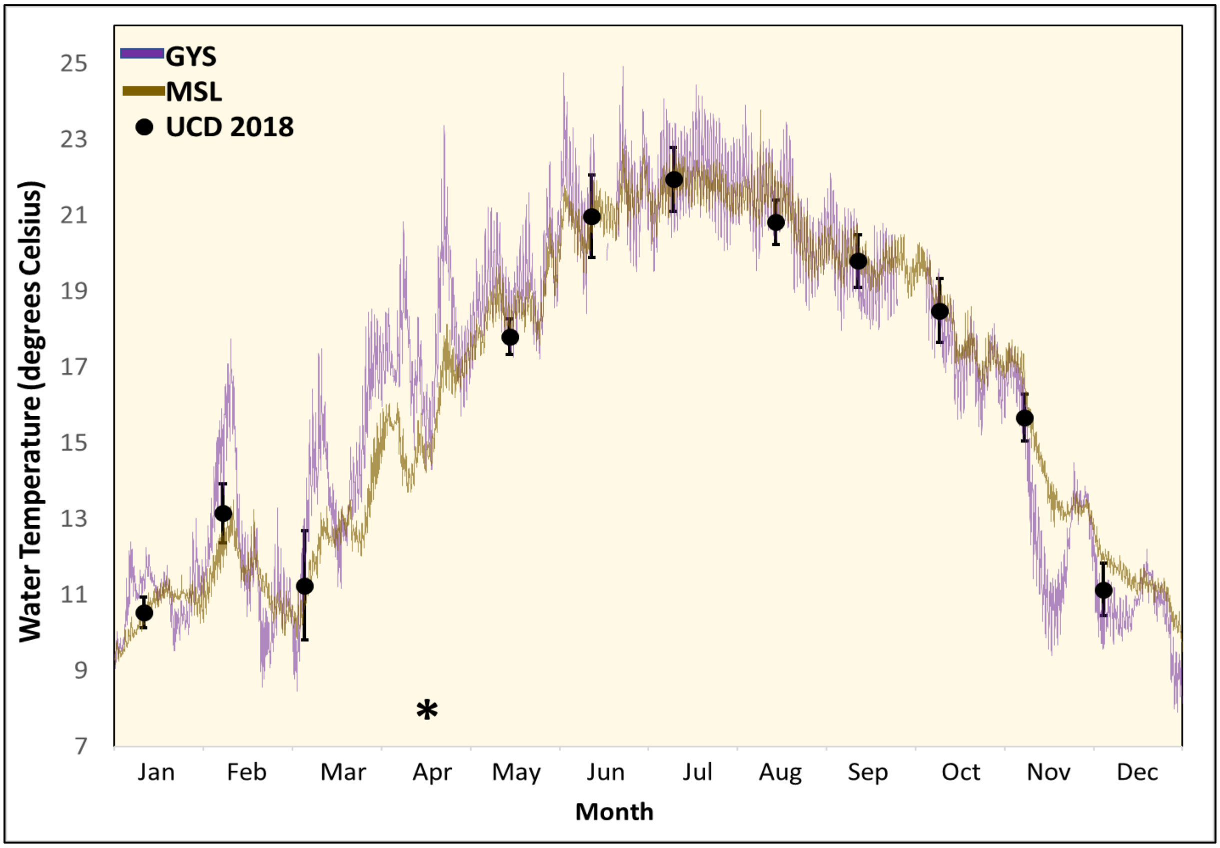

Figure 8. Fifteen-minute water temperature from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly temperatures and standard deviations from the Suisun Marsh Fish Study ("UCD Sal"). Note no GYS data were recorded for a few days in mid-June and from late September through early October (* = no Suisun Marsh Fish Study samples).

Water Transparency

Water transparencies in 2018 returned to the typical trend of recent years of higher-than-average values in summer and autumn after the relatively low values recorded in 2017 (O'Rear *et al.* 2019). Monthly Secchi values were above average in all months except May and June (Figure 9). Maximum monthly Secchi values were nearly always in large sloughs, mainly Montezuma (nine of 11 months), with the year's highest Secchi value (76 cm) recorded in eastern Montezuma Slough in November. Minimum values were always in small sloughs (Boynton, Cutoff, Denverton, Goodyear, and Peytonia; Figure 1), with the year's lowest transparency (10 cm) recorded in Goodyear Slough in May.

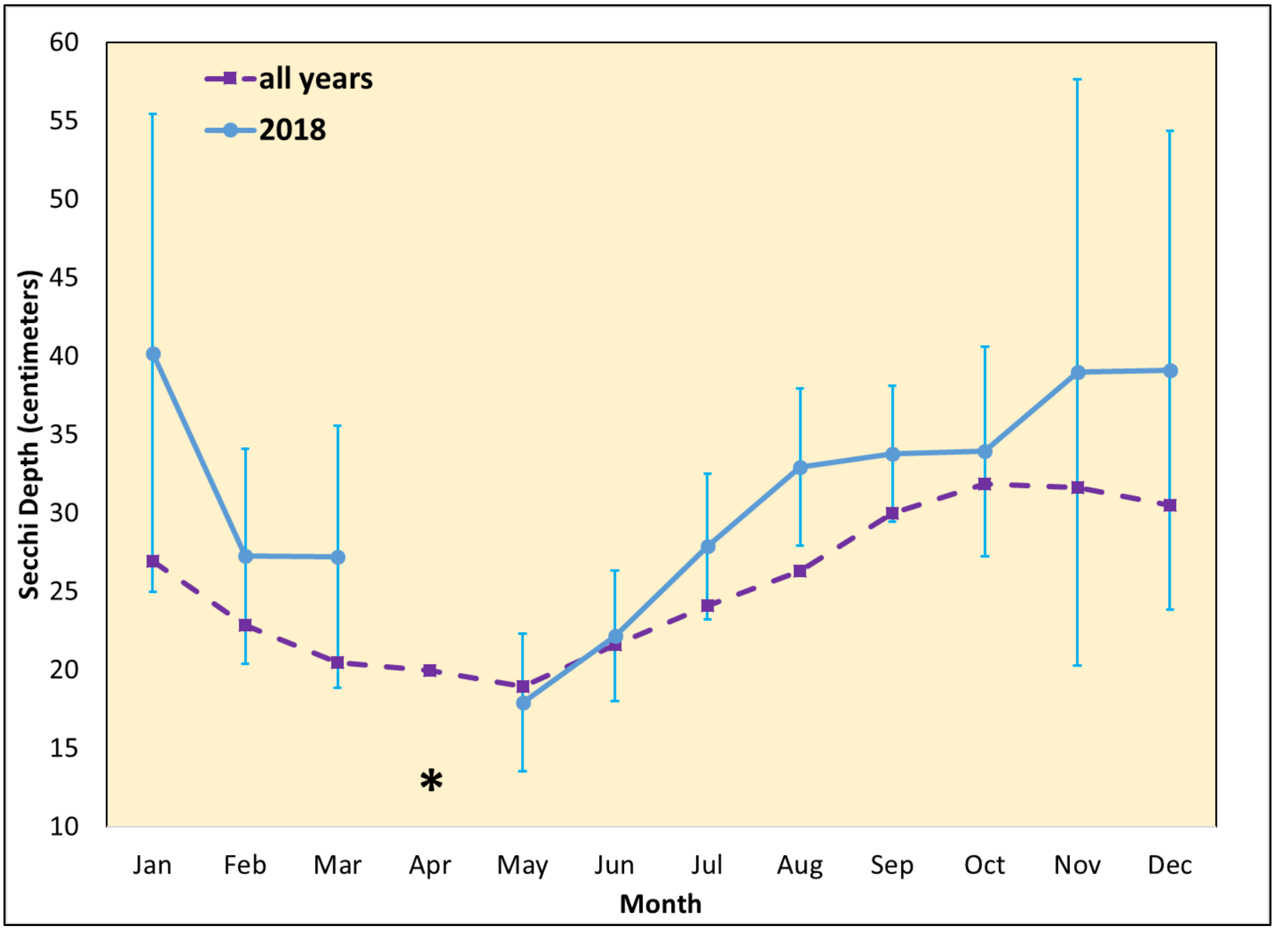

Figure 9. Monthly average water transparency in 2018 and for all years of the study (1980 - 2018); error bars are standard deviations in 2018 (* = no samples).

Trends in Invertebrate Distribution and Abundance

Black Sea Jellyfish

Black Sea jellyfish medusae numbers in 2018 were close to the average for all years of the study (11 and 10 medusae per trawl, respectively) and were far below 2017's study-high value (69 medusae per trawl; Figure 10). Medusae first appeared in trawls after June when average monthly salinity rose above 3 ppt, the value necessary for bloom formation

(Baumsteiger *et al.* 2018; Figure 11). Medusae abundance rose until peaking in August, remaining relatively high through October, then plummeting in November. Medusae were captured in all sloughs of the marsh but were especially abundant in upper Suisun Slough [30% (855 individuals) of the 2018 catch]. Two small sloughs (Denverton and Goodyear) very far from large sloughs (Montezuma and Suisun) had few medusae, with the combined catch of Denverton and Goodyear sloughs contributing only 3% (88 individuals) to the annual catch. Medusae were also sparse in eastern Montezuma Slough [2% (60 individuals) of 2018's catch], likely due in part to lower salinities induced by the Suisun Marsh Salinity Control Gates for the Delta Smelt Resiliency Strategy (Figure 4).

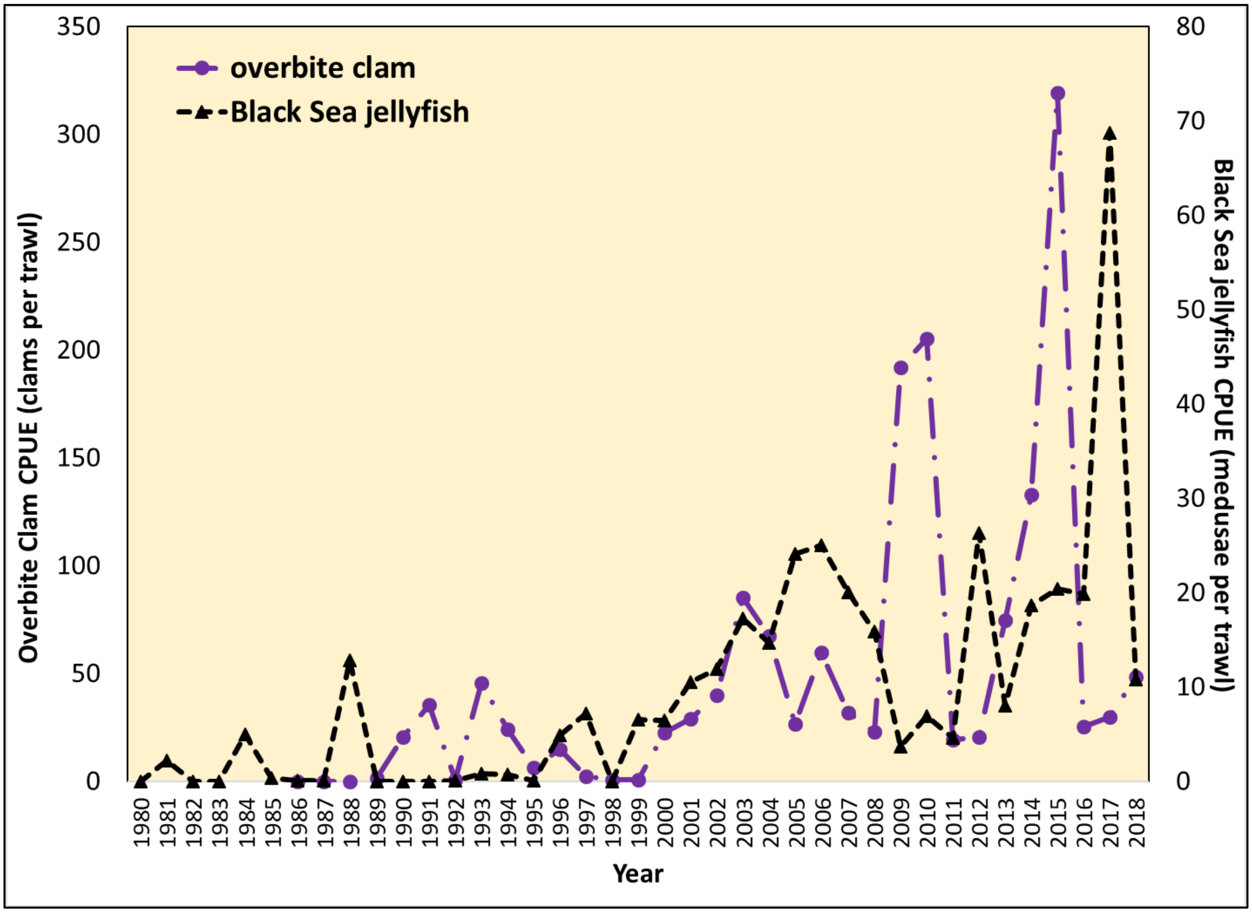

Figure 10. Annual CPUE of Black Sea jellyfish and overbite clam.

Overbite Clam

Like Black Sea jellyfish medusae, overbite clam abundance in 2018 was very close to the all-years average (48 and 49 clams per trawl, respectively; Figure 10), albeit higher than 2017's value (30 clams per trawl). The trend in overbite clam monthly abundance began increasing before that for Black Sea jellyfish but otherwise was similar to the jellyfish's trend (*e.g.*, peaking in early autumn; Figure 11), likely reflecting the two species' similar salinity requirements for key life stages (>3 ppt for Black Sea jellyfish medusae blooms, ~3 ppt for larval overbite clam survival; Nicolini and Penry 2000). Unlike Black Sea jellyfish medusae, overbite clams were not ubiquitous: 85% (11,309 individuals) of 2018's catch came from Suisun Slough, with most of the remainder [12% (1,650 individuals) of 2018's catch] coming from the lower Goodyear Slough site (GY3; Figure 2). Aside from the GY3 site and consistent with Baumsteiger *et al*. (2017), very few overbite clams were captured in small sloughs, with no clams caught at the CO1, DV3, and SB1 sites (Figure 2). While overbite clam numbers were moderate in 2018, CPUE of the Asian clam (*Corbicula fluminea*) reached its highest value (16 clams per trawl) since its numbers began to be recorded in 2006, albeit Asian clam's abundance was still much lower than that of overbite clam.

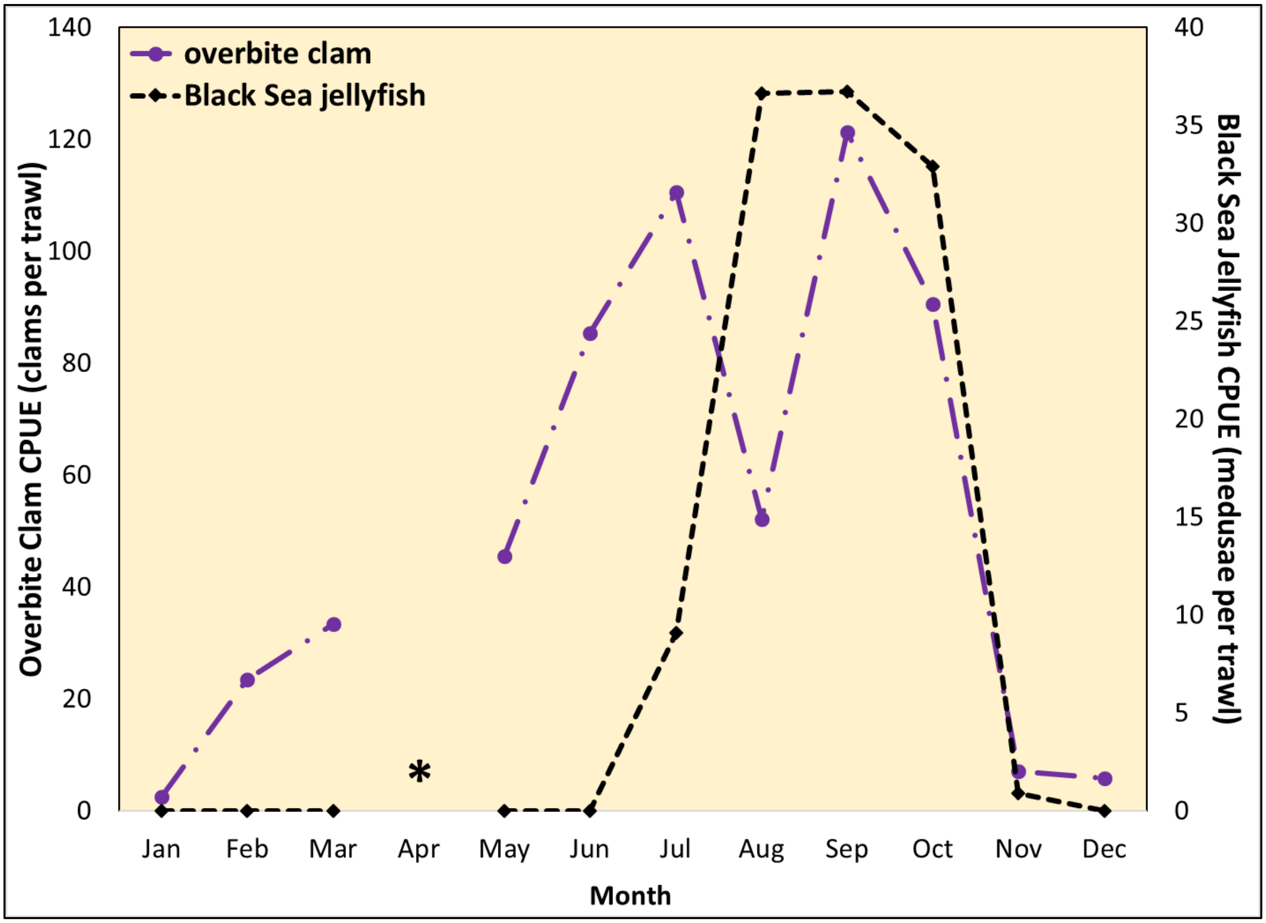

Figure 11. Monthly average CPUE of Black Sea jellyfish and overbite clam in Suisun Marsh in 2018 (* = no samples).

California Bay Shrimp

California bay shrimp were more abundant than usual in 2018 (49 shrimp per trawl in 2018 versus 28 shrimp per trawl for the all-years average), rebounding after three years of very low numbers (Figure 12). Numbers were low in the first three months of 2018, increased to moderate levels from May through July, and were generally high from August to the year's end (Figure 13), with higher shrimp numbers concomitant with moderately saline water in the marsh. While ubiquitous, bay shrimp tended to be more abundant in larger sloughs, with 54% (7,365 individuals) of 2018's catch coming from Suisun and Montezuma sloughs. Consistent with the species' association with moderate salinities (Cloern *et al*. 2017), the highest catch at a small slough site occurred at GY3 [13% (1,804 individuals) of 2018's catch], nearly triple the second-highest value for a small-slough site [NS3, with 4% (608 individuals) of 2018's catch].

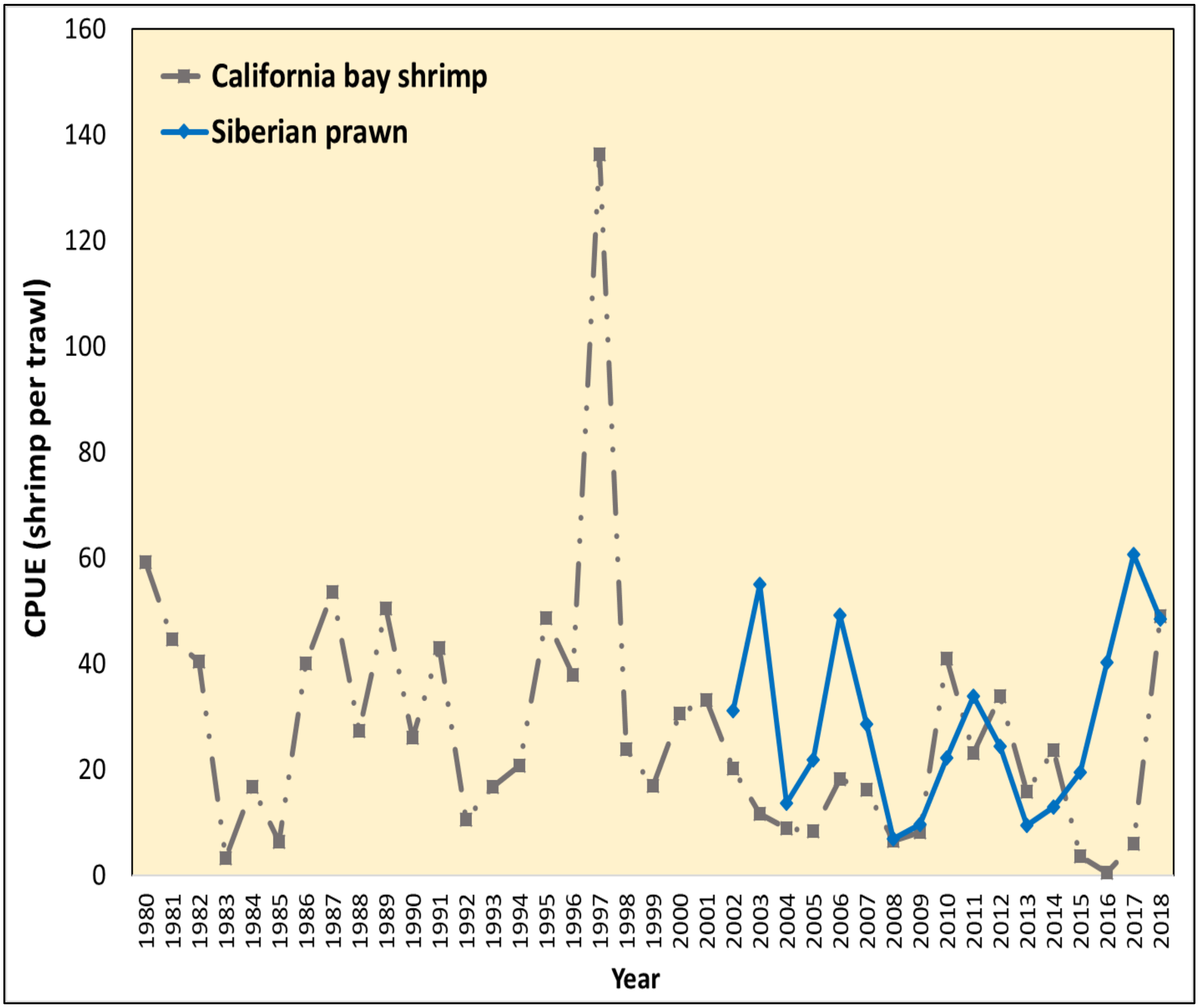

Figure 12. Annual CPUE of California bay shrimp and Siberian prawn.

Siberian Prawn

Like California bay shrimp, Siberian prawn were more abundant than average in 2018 (2018 CPUE = 48 shrimp per trawl, all-years average CPUE = 29 shrimp per trawl; Figure 12), albeit less so than in 2017 (61 shrimp per trawl). Monthly abundances were relatively stable through the year except in September, when abundance spiked moderately (Figure 13). Siberian prawns were common in all sloughs, with Denverton and upper Suisun sloughs tending to host larger numbers [16% (2,199 individuals) and 13% (1,794 individuals) of 2018's catch, respectively] than other sloughs, a somewhat different distribution than California bay shrimp.

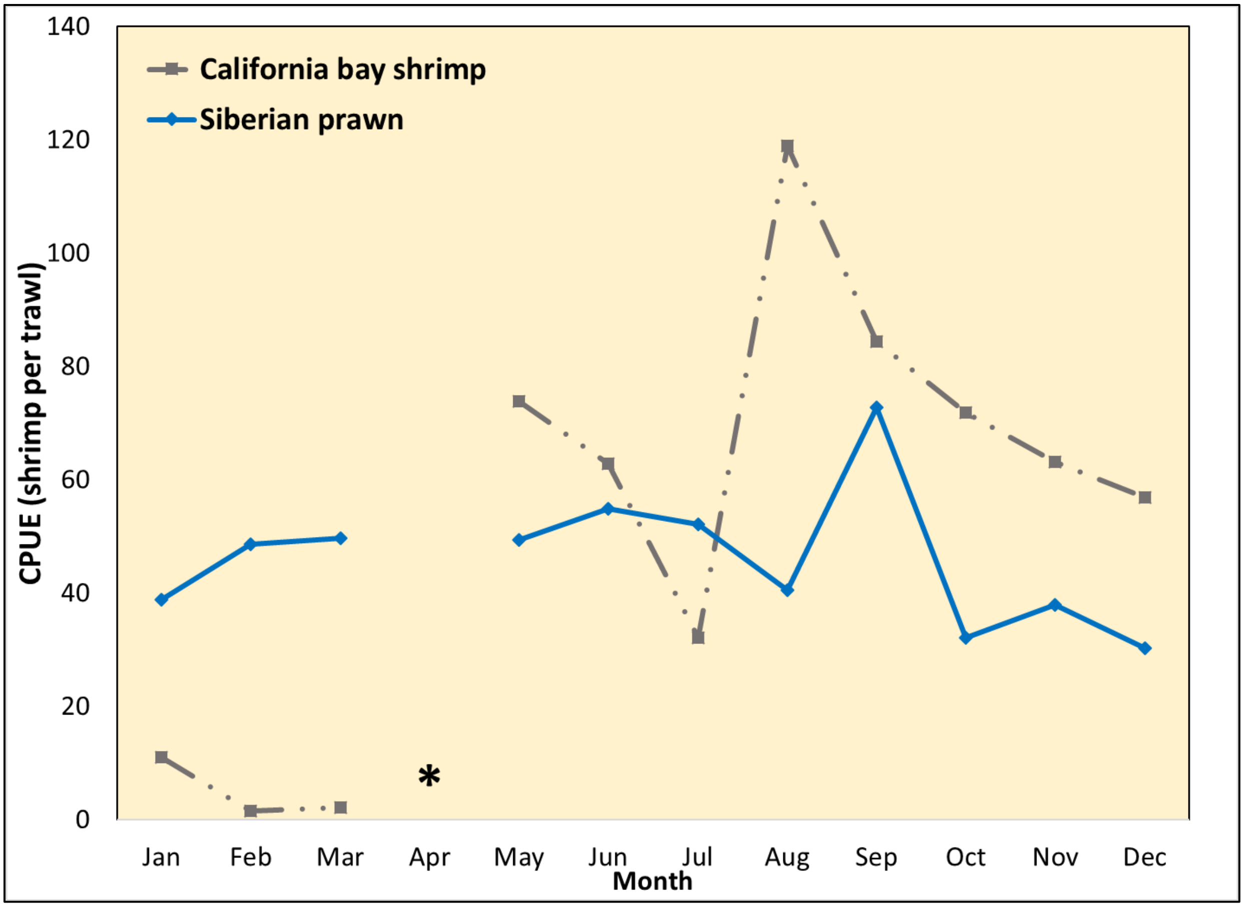

Figure 13. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2018 (* = no samples).

Trends in Fish Distribution and Abundance

Otter Trawls

Fish abundance in 2018 returned to normal (2018 CPUE = 24 fish per trawl, all-years average = 25 fish per trawl) after a noteworthy high catch in 2017 (32 fish per trawl; Figure 14). The decline was due to non-native fishes, which posted a lower CPUE value in 2018 (12 fish per trawl) than in either 2017 (20 fish per trawl) or for all years (15 fish per trawl). The non-native fish CPUE in 2018 was mainly due to lower numbers of fishes dependent on plankton: two goby species (shokihaze and shimofuri gobies; Table 1) that have pelagic larvae, and three species requiring fresh water for spawning (threadfin shad, American shad, and striped bass), suggesting zooplankton abundance was limiting. Nevertheless, abundances of striped bass and the two shad species in Suisun Marsh relative to all-years averages were much higher than those of the main axis of the estuary [the Fall Midwater Trawl and Summer Townet Survey; CDFW 2019]. For example, the summed indices of the two CDFW surveys for striped bass in 2018 was only 4% (43) of average for 1980-2018 (1072), while the CPUE in Suisun Marsh was 80% of average for the same period (Table 1). Negligible numbers of white catfish (*Ameiurus catus*) in 2018 were offset by a mild increase in common carp (Table 1). Most common native species, such as threespine stickleback and prickly sculpin, also decreased from 2017 to 2018, but the native fish

CPUE for 2018 was identical to that of 2017 (12 fish per trawl) and above the all-years average (10 fish per trawl) because of the study's highest-ever abundance of Sacramento splittail in 2018 (Table 1). The record splittail CPUE posted by the Suisun Marsh Fish Study was remarkable given none were captured in CDFW's Fall Midwater Trawl in 2018 (CDFW 2019), especially since splittail abundances in both surveys once varied together (Sommer *et al.* 1997). In contrast, the very low numbers of cool-water, zooplankton-eating native smelts [delta smelt (*Hypomesus transpacificus*) and longfin smelt (*Spirinchus thaleichthys*)] in Suisun Marsh mirrored those of the mainstem surveys (CDFW 2019; see below). Numbers of two common Suisun Marsh fishes, tule perch and yellowfin goby (*Acanthogobius flavimanus*), were both virtually unchanged between 2017 and 2018 though below all-years averages (Table 1).

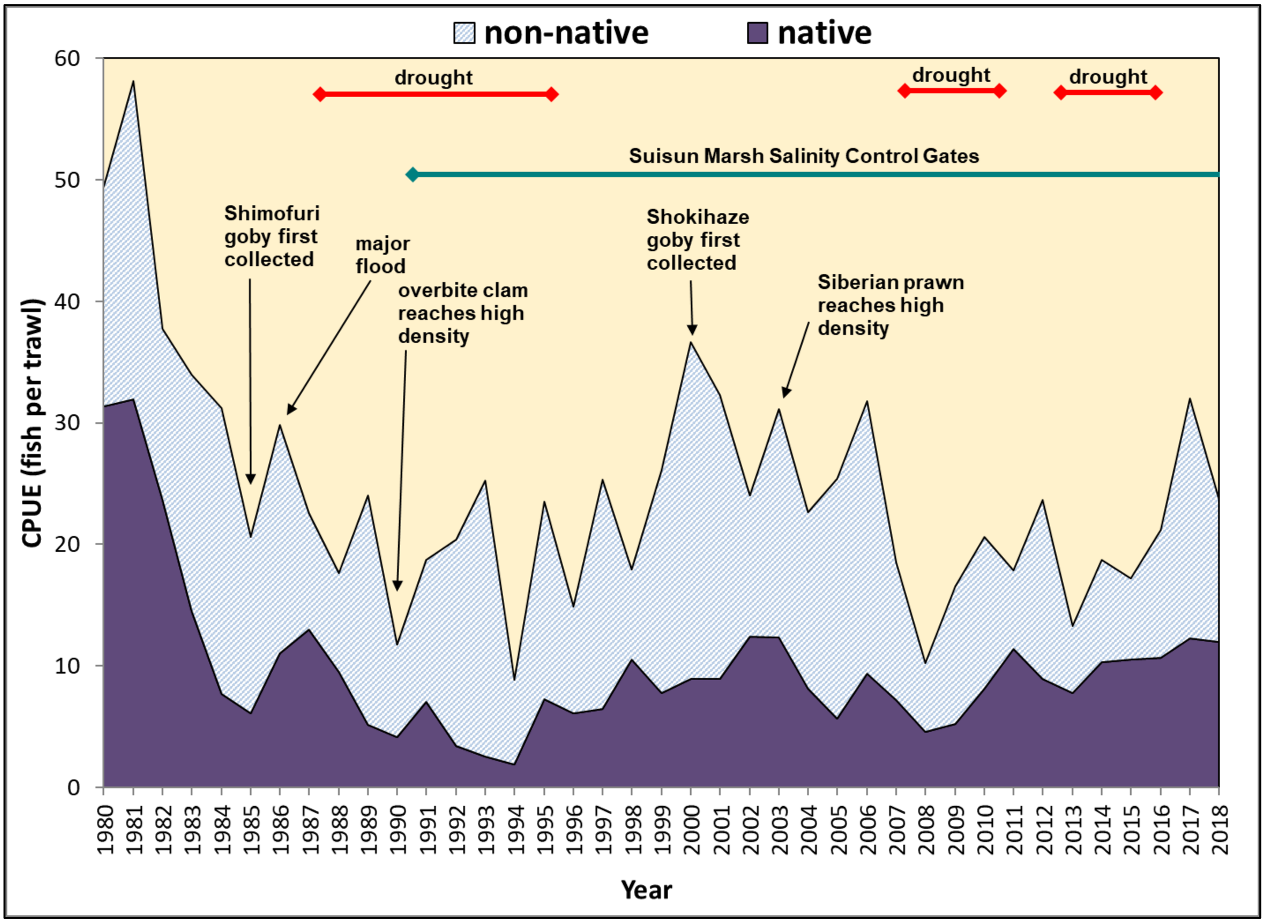

Figure 14. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted.

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 - 2018).

Species	All Years CPUE	2017	2018	2018/2017 % Change
Sacramento splittail	**3.03**	**5.98**	**8.78**	**+47%**
threespine stickleback	**1.58**	**1.24**	**0.28**	**-78%**
prickly sculpin	**1.14**	**3.23**	**1.10**	**-66%**
tule perch	**2.07**	**1.16**	**1.16**	**0**
threadfin shad	0.34	1.71	0.65	-62%

Species	All Years CPUE	2017	2018	2018/2017 % Change
American shad	0.16	0.65	0.39	-40%
common carp	0.51	0.38	0.63	+68%
white catfish	0.61	0.42	0.09	-78%
striped bass	8.91	12.27	7.08	-42%
shimofuri goby	1.29	1.56	0.60	-61%
shokihaze goby	0.12	1.1	0.49	-56%
yellowfin goby	2.24	1.25	1.37	+10%

Beach Seines

Similar to the otter trawl, beach seine CPUE in 2018 (63 fish per seine haul) declined to a more usual level (all-years average = 58 fish per seine haul) after 2017's high value (96 fish per seine haul; Figure 15). Both native and non-native fishes declined from 2017 to 2018, with the drop more severe for non-native fishes (Figure 15). For nearly all native fishes, CPUE in 2018 was lower than either the all-years CPUE or the CPUE in 2017, although Sacramento splittail abundance in 2018 was still well above the all-years average (Table 2). Decline in non-native fish numbers from 2017 to 2018 was due to three species that also declined in otter trawls: threadfin shad, American shad, and striped bass (Table 2). Non-native fish CPUE in 2018 nevertheless was higher than the all-years average (57 and 51 fish per seine haul, respectively), mainly because of stable numbers of both Mississippi silverside and yellowfin goby (Table 2).

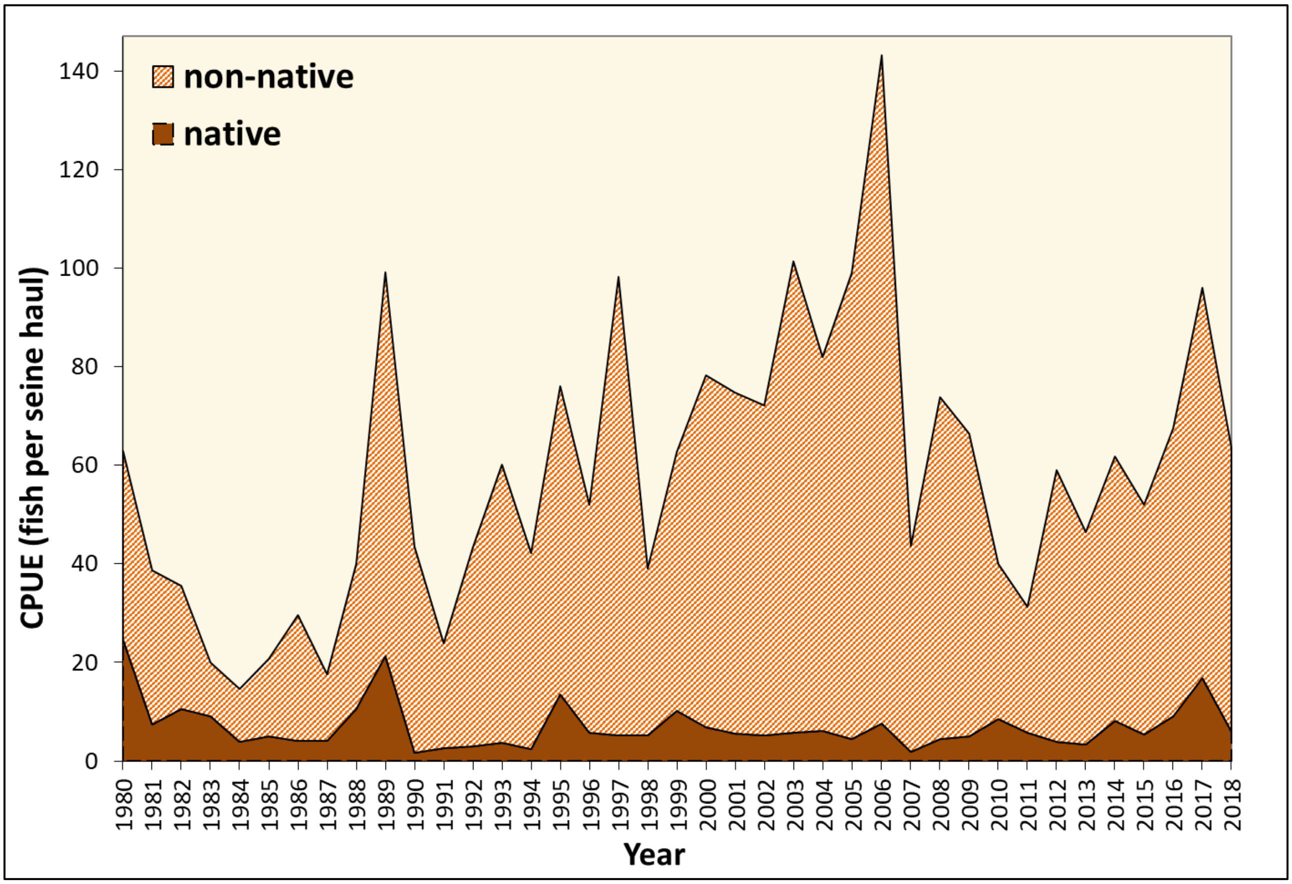

Figure 15. Annual beach seine CPUE of native and non-native fishes.

Table 2. Percent change in annual beach seine CPUE of 10 common marsh fishes (% increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled; native species in bold).

Species	All Years CPUE	2017 CPUE	2018 CPUE	2018/2017 % Change
Sacramento splittail	**1.83**	**9.20**	**4.81**	**-48%**
Sacramento pikeminnow	**0.09**	**0.83**	**0.01**	**-99%**
threespine stickleback	**1.78**	**1.96**	**0.45**	**-77%**
prickly sculpin	**0.34**	**2.22**	**0.09**	**-96%**
tule perch	**0.80**	**1.98**	**0.28**	**-86%**
threadfin shad	2.50	17.29	3.01	-83%
American shad	0.15	1.62	0.11	-93%
Mississippi silversides	35.20	46.98	47.36	+1%
striped bass	5.69	6.55	1.78	-73%
yellowfin goby	6.26	4.59	3.90	-15%

Fish Species of Interest

Fishes of the Pelagic Organism Decline

DELTA SMELT

For the third 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 (CDFW 2019).

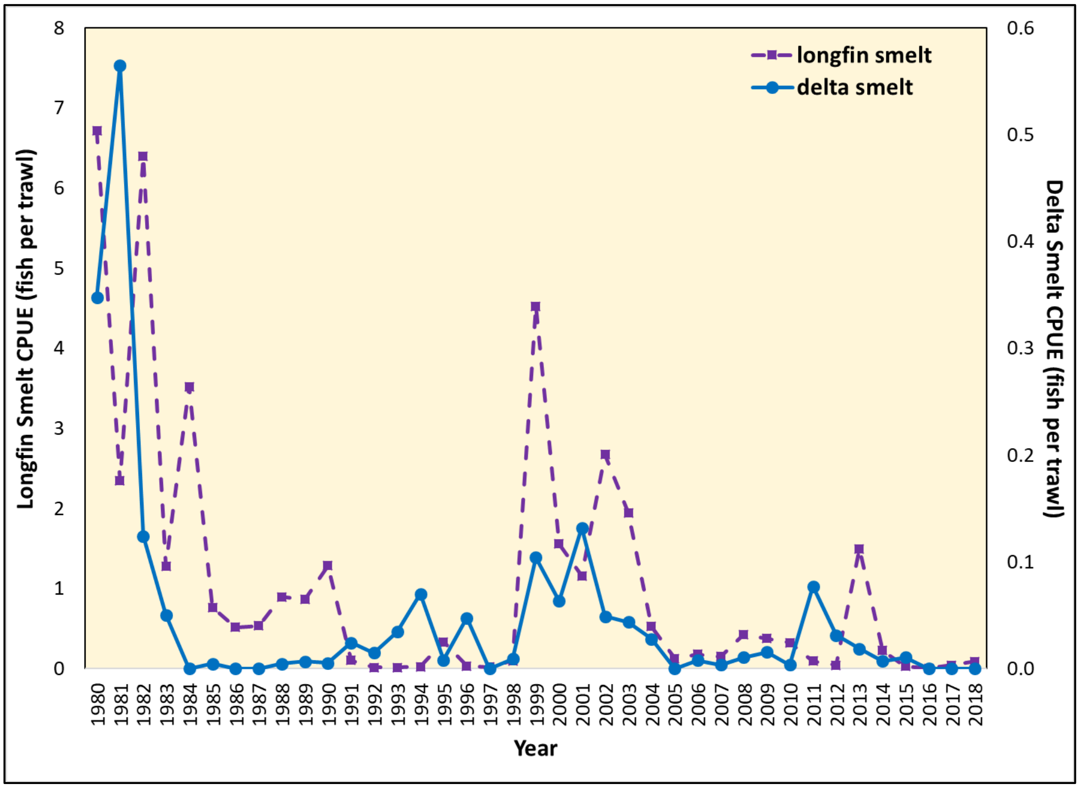

Figure 16. Annual CPUE of the smelts of the Pelagic Organism Decline.

LONGFIN SMELT

Longfin smelt numbers were low in 2018, with the annual CPUE (0.09 fish per trawl) well below the all-years average (1.07 fish per trawl) but higher than 2017's value (0.04 fish per trawl; Figure 16); CDFW's Fall Midwater Trawl also posted a very low longfin smelt abundance in 2018 (CDFW 2019). Age-0 fish were present spring through early summer and again in November (Figure 17), while age-1+ fish were present in Suisun Marsh only in cooler months (January, February, and November; Figure 17). Fifteen of the 16 age-0 longfin smelt caught in 2018 were from either lower Goodyear Slough or Suisun Slough from the confluence of Sheldrake Slough to Grizzly Bay (Figure 1). Eight of the nine age-1+ fish were from Montezuma Slough and from the same reach in Suisun Slough where age-0 fish were found (Figure 1). Distribution of both age classes reflected longfin smelt's predilection for large sloughs close to the estuary's main axis.

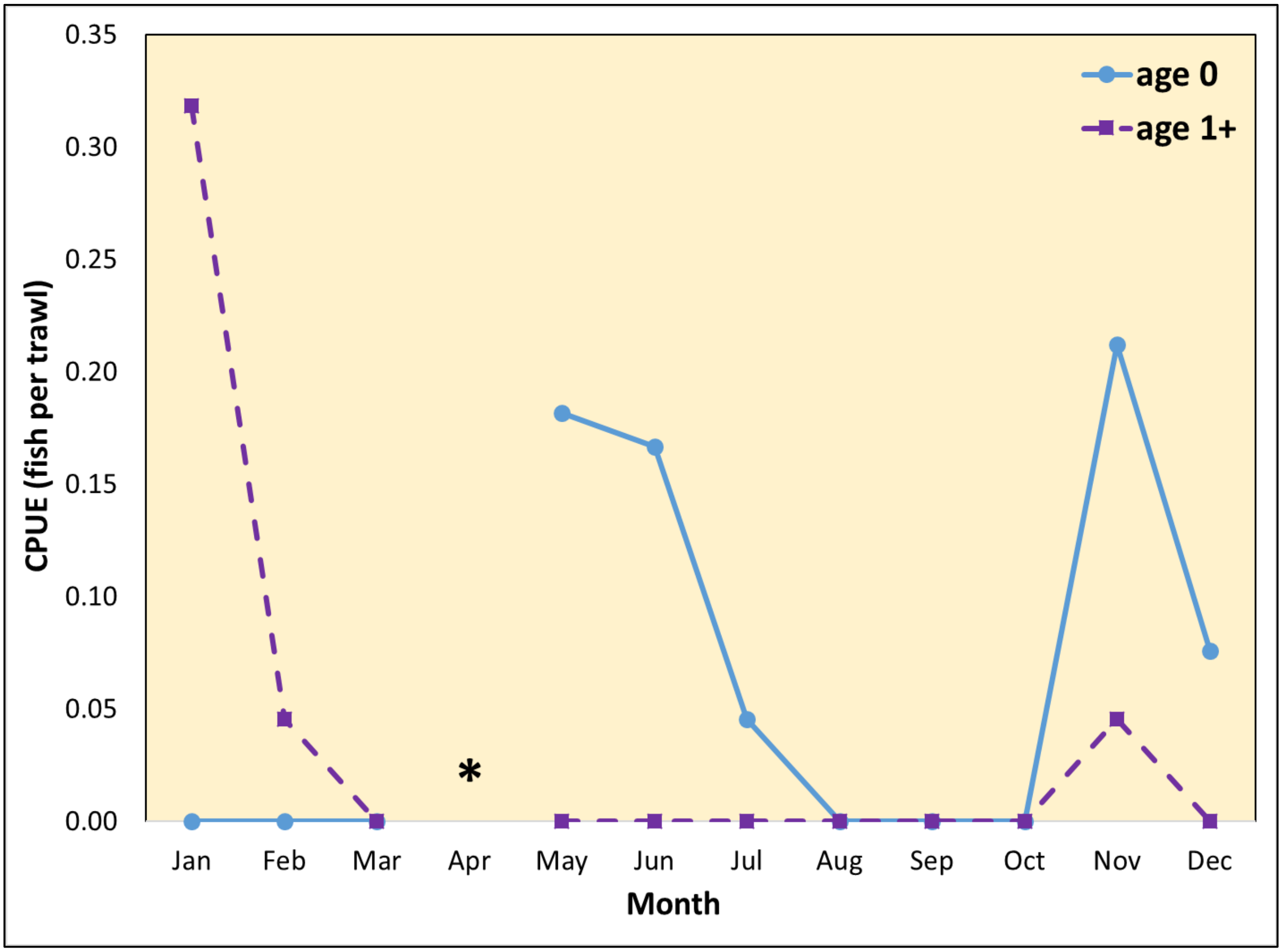

Figure 17. Monthly average CPUE of longfin smelt age classes.

THREADFIN SHAD

Threadfin shad were more abundant than usual in both beach seines and otter trawls in 2018, although numbers dropped off considerably compared to 2017 (Table 1 and 2; Figure 18).

About 60% of the threadfin shad in the otter trawls were taken from sloughs in the eastern marsh (the Denverton, Nurse, and Montezuma sites; Figure 2) in 2018, although large catches were made further west in the SB1 trawl (Figure 2; 24% of 2018's catch) and in the SU1 beach seine (Figure 2; 35% of 2018's catch). Only 3% of 2018's catch came from the southwest marsh, which, when coupled with the other distributional patterns, reflected threadfin shad's penchant for fresher water (Meng and Matern 2001, Feyrer *et al.* 2007, Feyrer *et al.* 2009).

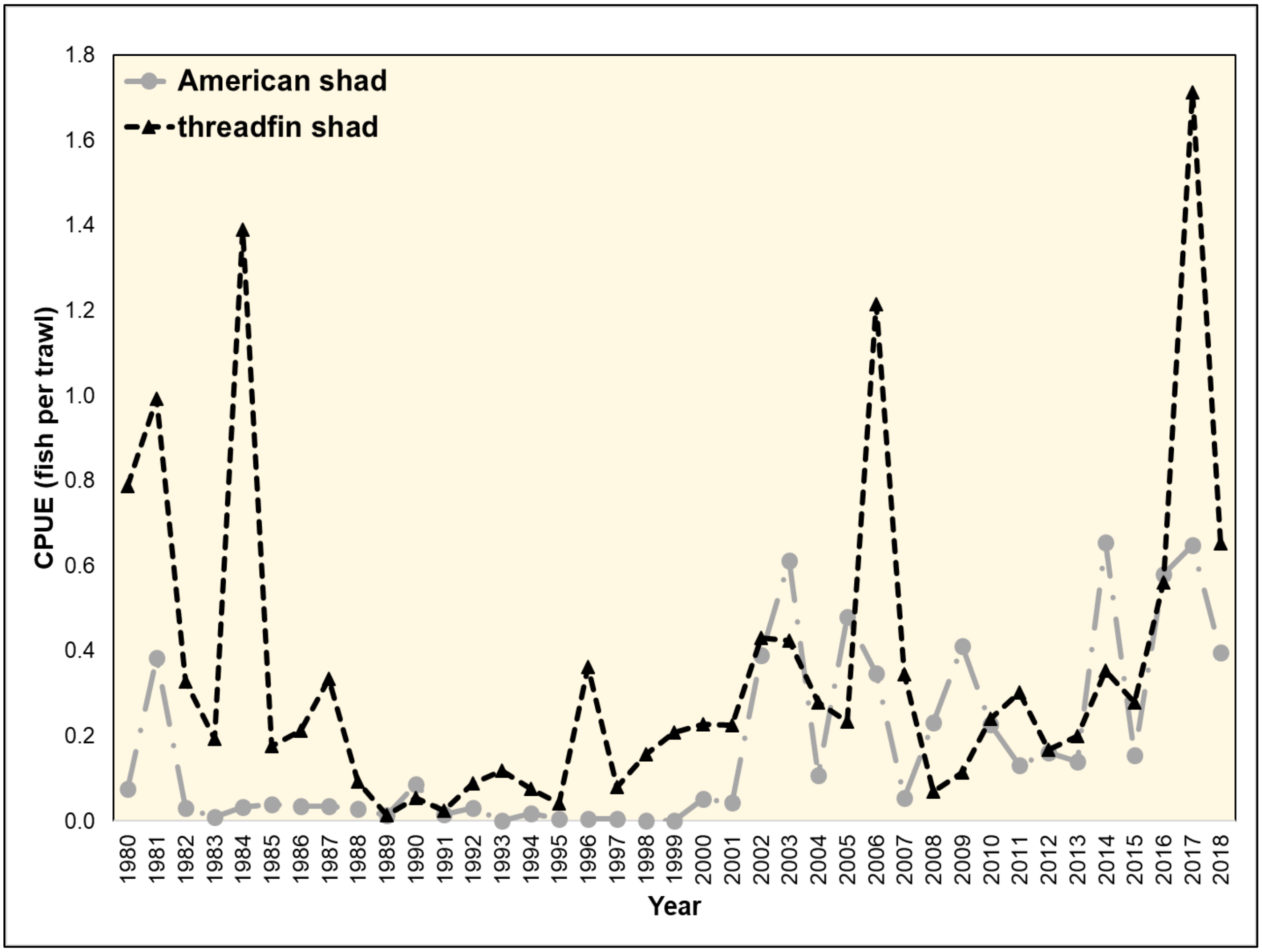

Figure 18. Annual CPUE of the shads of the Pelagic Organism Decline.

AMERICAN SHAD

Like threadfin shad, American shad abundance in 2018 declined to a more typical level after attaining record-high numbers in 2017, albeit still above the all-years average (Figure 18, Table 1). American shad were relatively evenly distributed throughout the marsh, being caught in otter trawls in all sloughs. In contrast, all but one American shad caught by beach seines were in the eastern marsh (the DV2 and MZ6, sites), consistent with age-0 fish spawned in the main breeding rivers (the Sacramento, Feather, and American) entering Suisun Marsh through eastern Montezuma Slough (Figure 1). All but one American shad captured in 2018 were of the 2017 or 2018 cohort.

STRIPED BASS

Striped bass were less abundant than average in 2018 in both otter trawls and especially beach seines, with numbers falling dramatically after large catches in both gear types in 2017 (Figure 19, Table 1 and 2). High numbers of age-0 fish first appeared in both gear types in June, the most typical month for peak catches (Figure 20; O'Rear and Moyle 2017, 2018). Monthly CPUE for both gear types declined in parallel from June to the year's end, concomitant with falling abundance of mysids, a major prey (Feyrer *et al.* 2003, Bryant and Arnold 2007), from June to September (Figure 20). However, abundances of age-0 fish in both gears remained relatively stable from August through September during Suisun Marsh Salinity Control Gates operations (Figure 4 and 20), which had not been observed in previous years (O'Rear and Moyle 2017, 2018, O'Rear *et al.* 2019), suggesting the management action may have either improved survival or extended the recruitment period. Monthly CPUE of juvenile striped bass generally fell through the year, consistent with dispersal throughout both the marsh (Figure 21) and the estuary (Calhoun 1952, Able *et al.* 2012). In contrast, age-0 fish were disproportionately abundant in two smaller sloughs, Denverton and First Mallard, and in lower Suisun Slough (Figure 21). Similarly, abundance of age-0 striped bass in seines in Denverton Slough (4.1 fish per seine haul) was nearly double that of upper Suisun Slough (2.2 fish per seine haul) and more than quadruple that of Montezuma Slough (0.9 fish per seine haul; Appendix B).

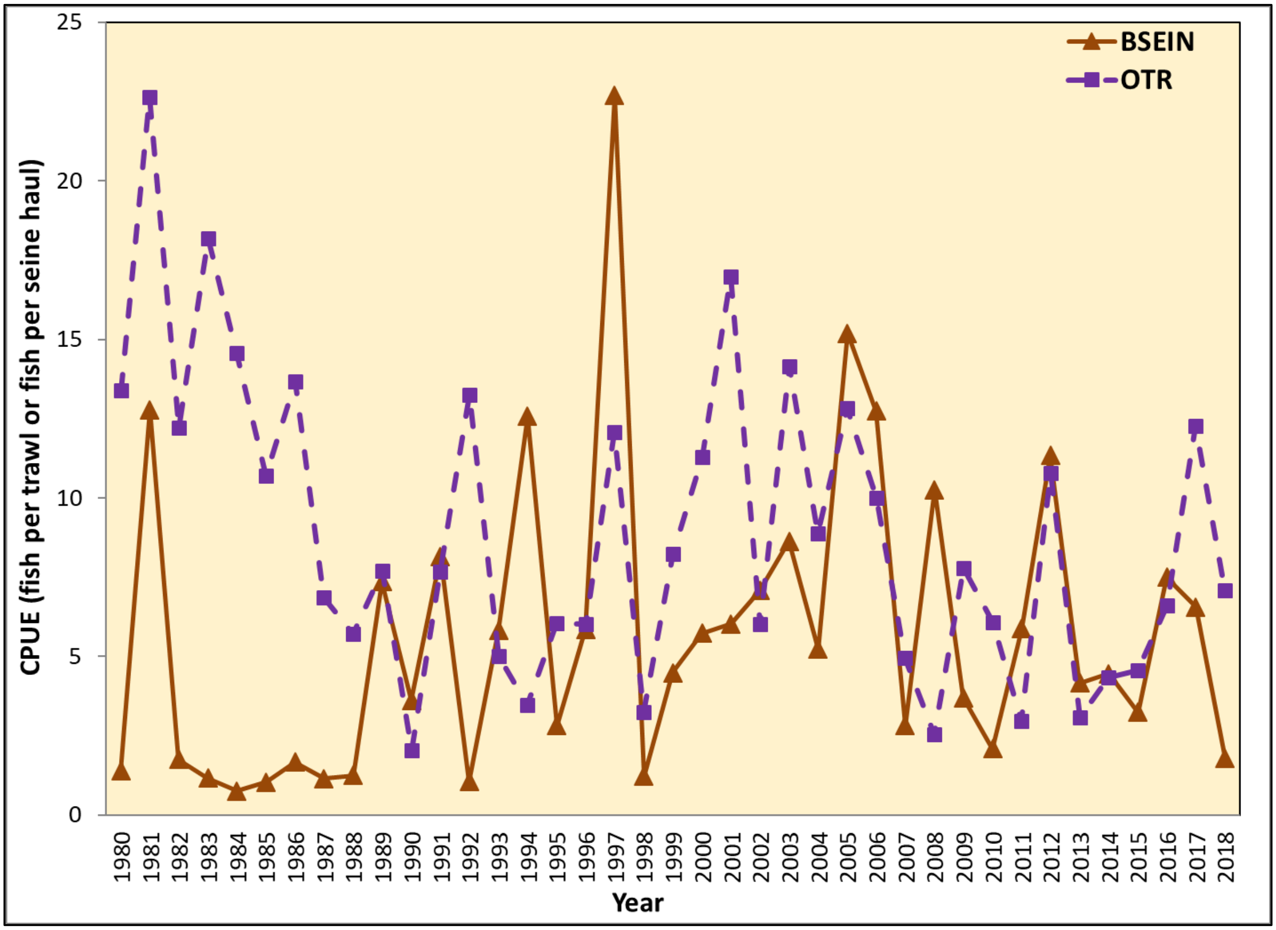

Figure 19. Annual CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine).

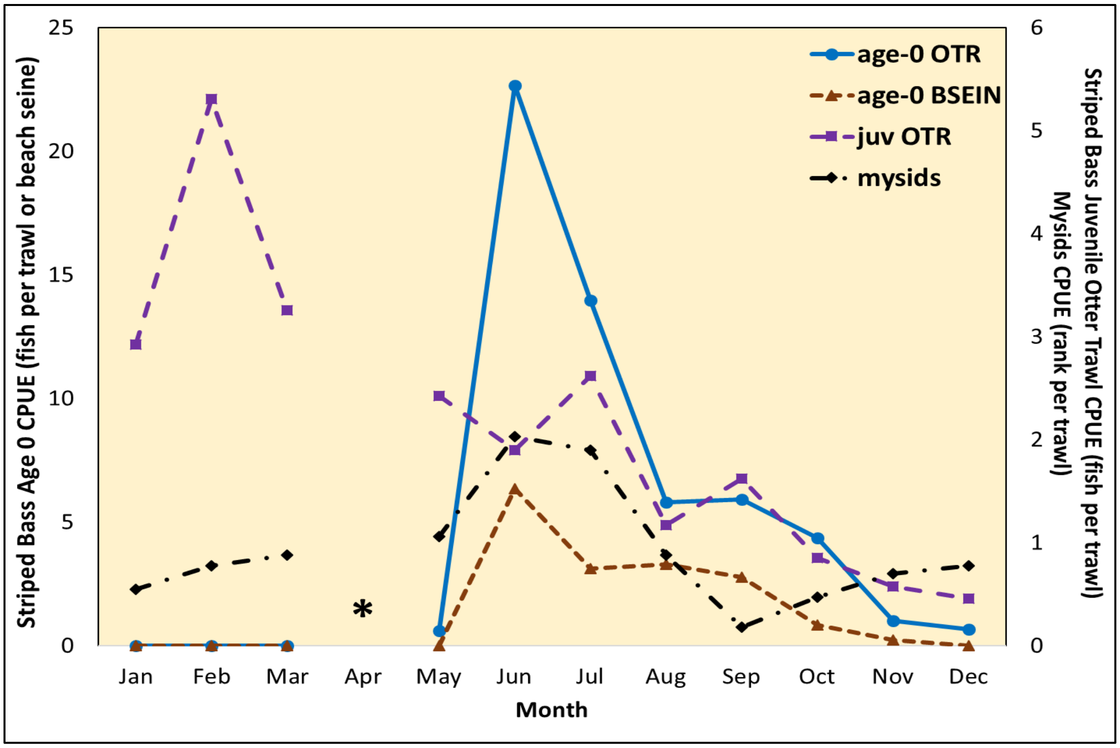

Figure 20. Monthly average CPUE of striped bass age classes and mysids (“juv” = juvenile; other codes as in Figure 18) in 2018 (* = no samples).

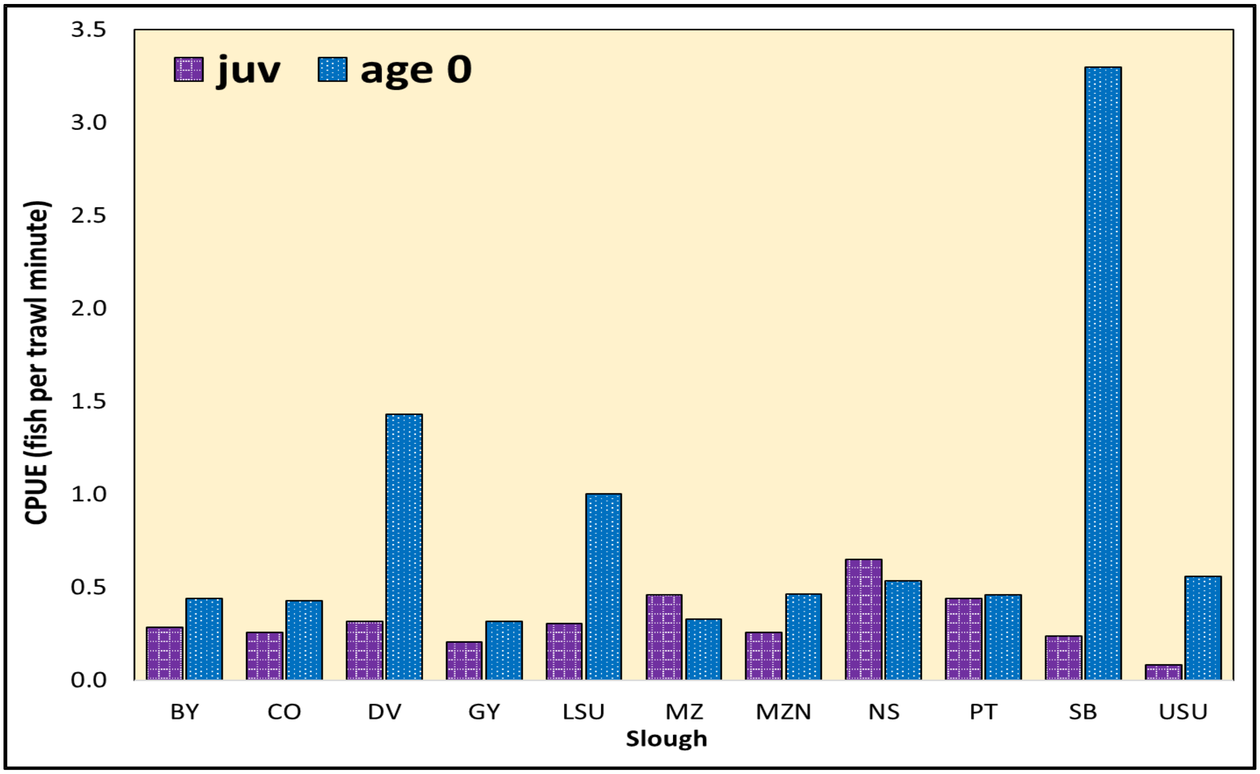

Figure 21. Average slough CPUE of age classes of striped bass in 2018 ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "LSU" = lower Suisun Slough, "MZ" = Montezuma Slough, "MZN" = Montezuma new, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "USU" = upper Suisun Slough).

Sacramento Splittail

Sacramento splittail achieved their highest-ever abundance in the study's history in 2018 (Figure 22, Table 1). All three age classes contributed to 2018's record value, with the age-2+ CPUE being the highest ever recorded, the age-0 CPUE being the fourth-highest recorded, and the age-1 CPUE (1.94 fish per trawl) being well above the all-years average (1.26 fish per trawl; Figure 22). Beach seine CPUE in 2018, of which age-0 fish comprised 87% of the catch, was also well above average (Table 2), reinforcing the high recruitment reflected in the otter trawl. Splittail were most numerous in shallow water, with small sloughs, particularly those in the northeast marsh (Denverton and Nurse sloughs; Figure 1 and 23), and inshore areas of large sloughs [*e.g.*, 68% of 2018's beach seine catch came from Montezuma Slough (Appendix B)] hosting more fish than deeper water (*i.e.*, otter trawl sites in Montezuma and Suisun sloughs).

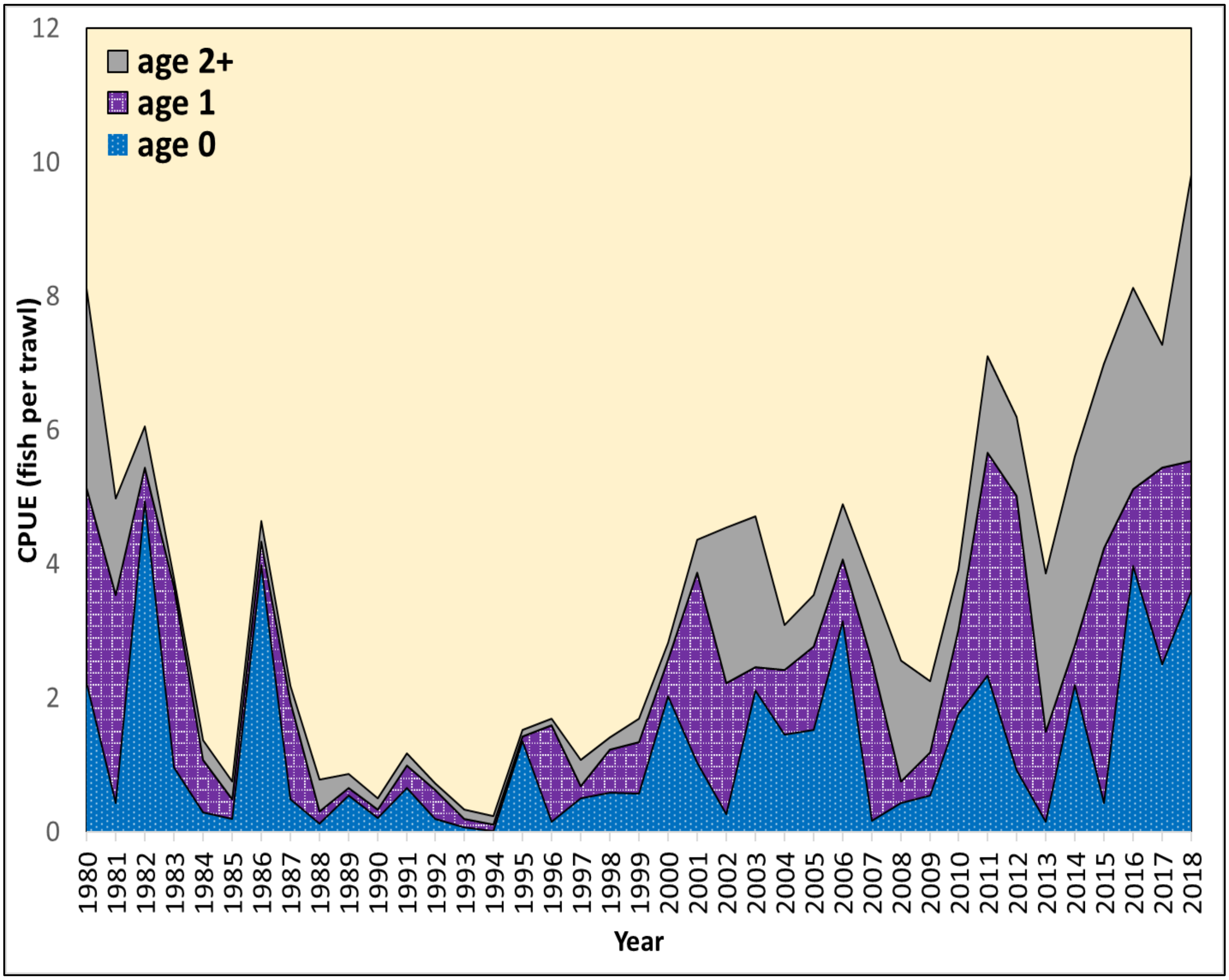

Figure 22. Annual CPUE of three age classes of Sacramento splittail.

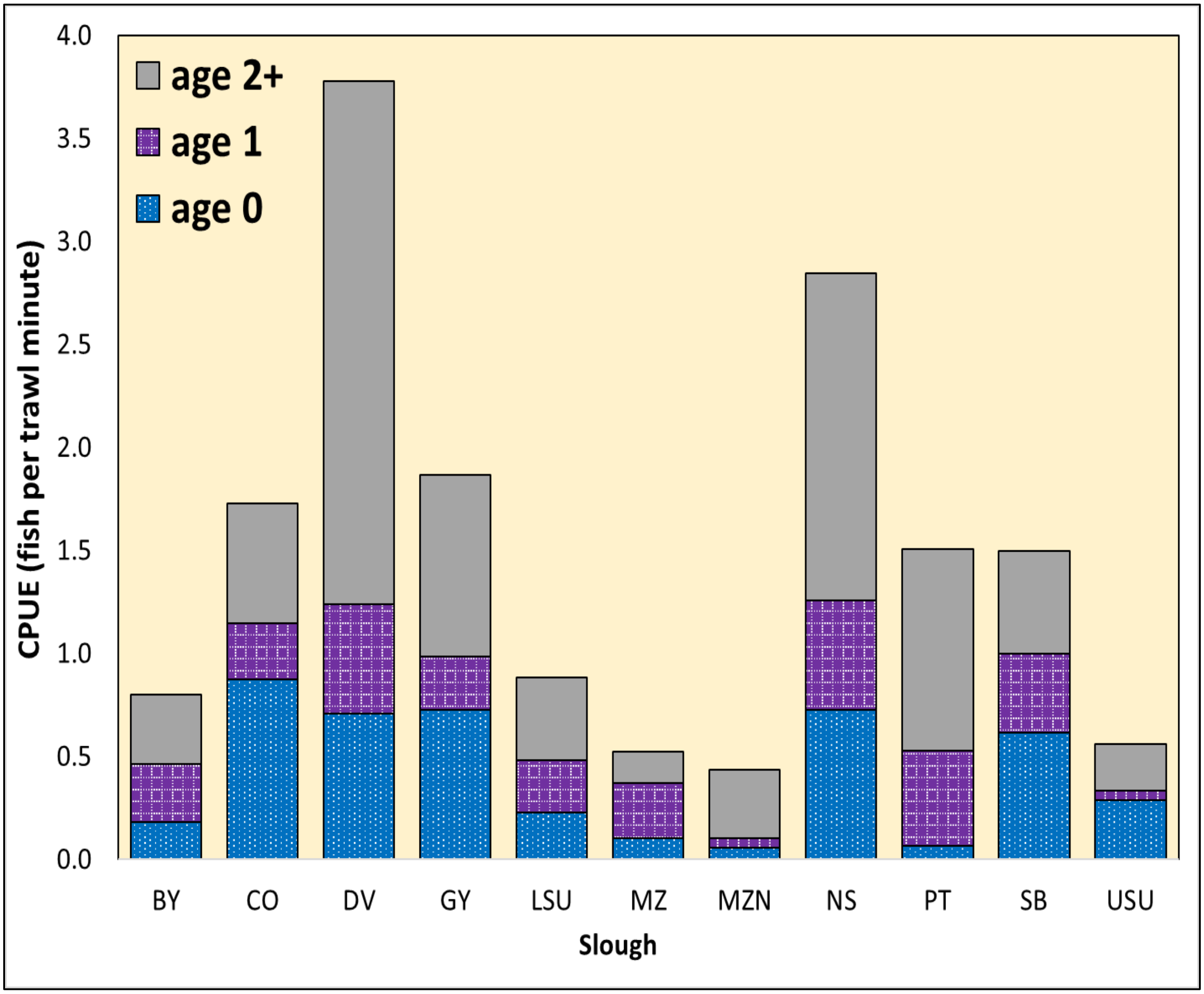

Figure 23. Average slough CPUE of age classes of splittail in 2018 (codes as in Figure 20).

<u>White Catfish</u>

From the mid-1990s through the midpoint of the 2012 – 2016 drought (Figure 14 and 24), the white catfish was one of the most abundant species in Suisun Marsh. However, by inhibiting reproduction in Suisun Marsh due to higher salinities (*i.e.*, >2 ppt; Perry and Avault, Jr. 1968, 1969) and by limiting recruitment into the marsh from fresher, upstream regions due to low flows, the 2012 – 2016 drought virtually eliminated the species by the drought's end in 2016 (Figure 24). The mild recruitment in the wet year of 2017 (Figure 24) was not enough to reestablish white catfish as an abundant Suisun Marsh fish: CPUE fell to a very low level again in 2018, well below the all-years average (Table 1). No age-0 white catfish were caught in 2018, consistent with salinities being too high and flows being too low during the reproductive/recruitment period (early summer). Only one white catfish (4% of 2018's catch) was caught in the saltier southwest marsh, reinforcing the importance of salinity on white catfish distribution and abundance in Suisun Marsh.

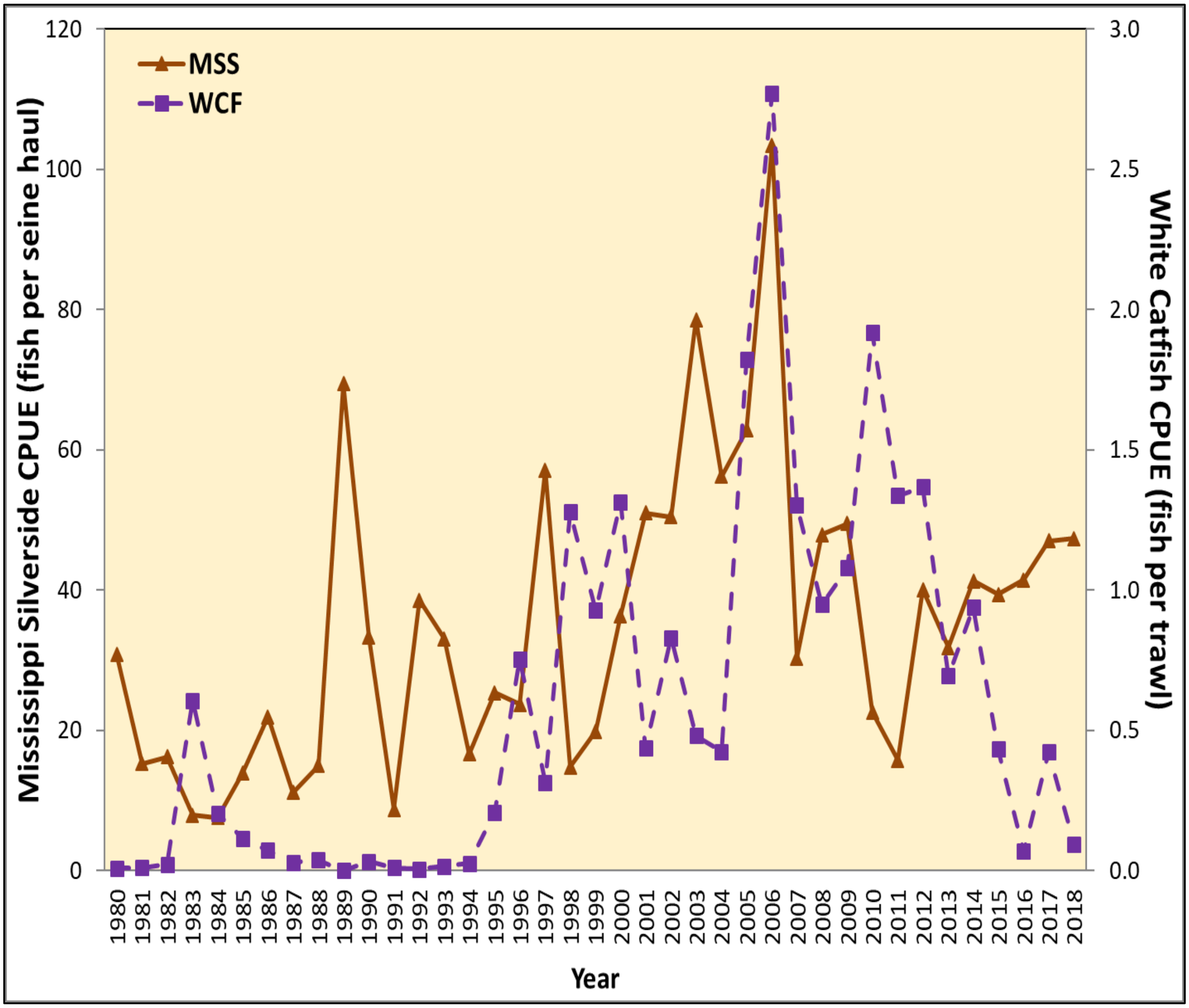

Figure 24. Annual CPUE of white catfish ("WCF") and Mississippi silverside ("MSS").

Mississippi Silverside

Mississippi silverside were abundant in 2018, with the year being the seventh in a row of remarkably consistent numbers (Figure 24). The trend in monthly abundance was typical: CPUE was high in winter, fell to a minimum in spring, and then rose to higher levels in summer and autumn (Figure 25; O'Rear *et al.* 2019). Presence of fish about two months old (*i.e.*, those smaller than 30 mm SL; Hubbs 1982, Gleason and Bengston 1996) suggested spawning occurred April through September (Figure 26), with the continuous recruitment reflected in the increasing monthly CPUE through summer to autumn (Figure 25). Mississippi silverside densities in dead-end sloughs (Denverton and upper Suisun, with 56 and 53 fish per seine haul, respectively; Figure 2, Appendix B and C) were higher than in the marsh's main corridor, Montezuma Slough (34 fish per seine haul).

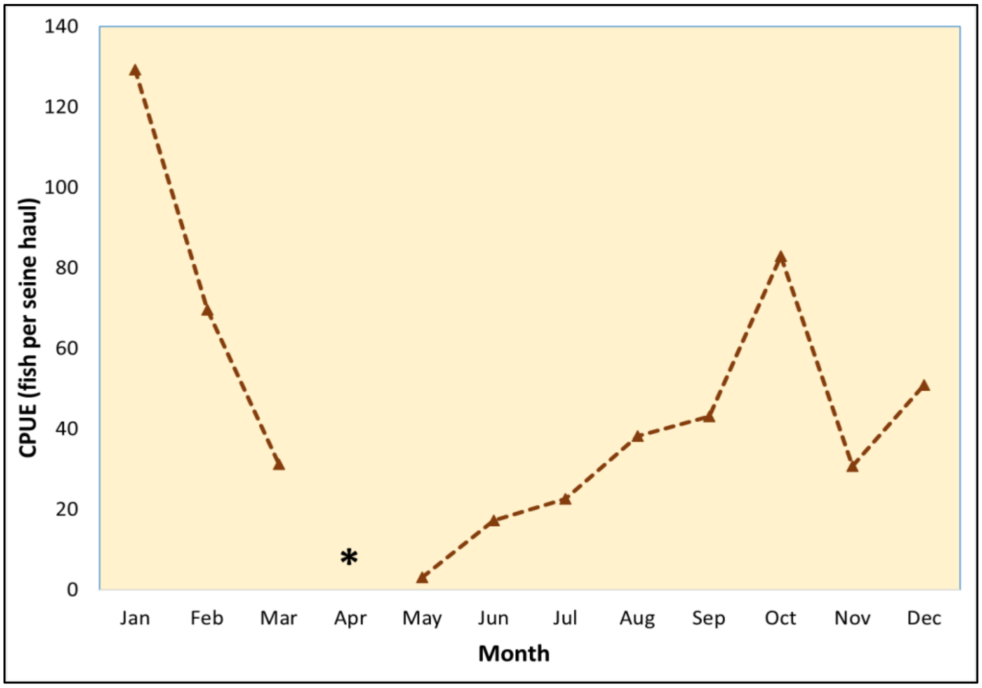

Figure 25. Monthly average CPUE of Mississippi silverside in 2018 (* = no samples).

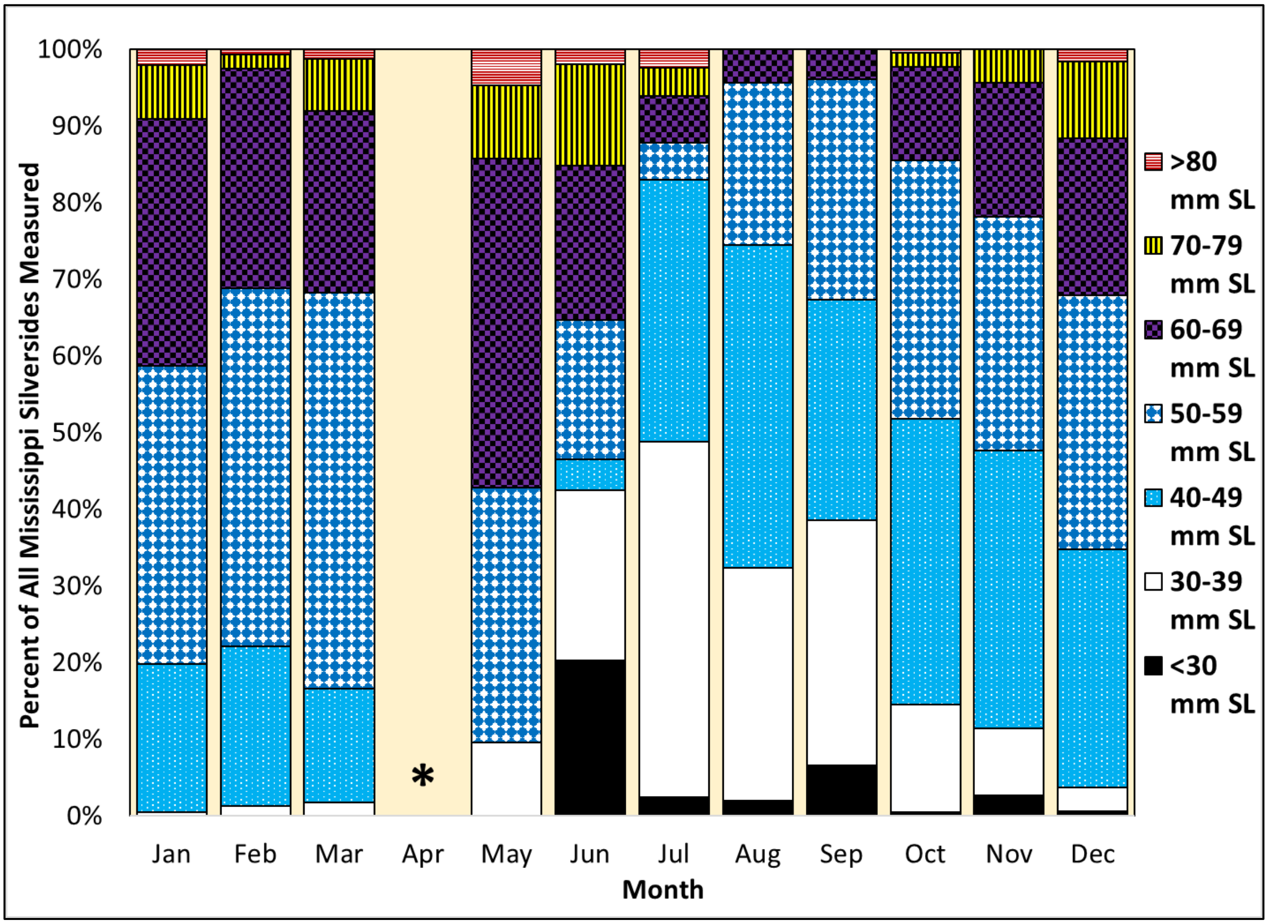

Figure 26. Monthly size-class distributions of Mississippi silverside captured in beach seines in 2018 (* = no samples).

CONCLUSION

Calendar-year 2018 found Suisun Marsh in a rather dry year with mild temperatures, with relatively clear water in summer and autumn, and with typical salinities, the latter due in part because of Suisun Marsh Salinity Control Gates operations in late summer as part of the Delta Smelt Resiliency Strategy. Abundances of plankton-eating Black Sea jellyfish medusae and overbite clams were rather low, likely a result of the combination of unfavorable salinities and water temperatures muting recruitment (Baumsteiger *et al.* 2017, 2018). In contrast, shrimp numbers were higher than average, with the distribution of the native California bay shrimp and non-native Siberian prawn generally complementing one another. After achieving very high numbers in the wet year of 2017, fish abundances returned to more typical levels in 2018 in both beach seines and otter trawls. Non-native fishes dependent on plankton (American shad, threadfin shad, striped bass, shimofuri and shokihaze gobies) declined from 2017 to 2018 but were still relatively abundant in Suisun Marsh in contrast to the main bays and rivers of the estuary. However, native smelts were virtually absent in both Suisun Marsh and the main bays/rivers. The negligible smelt numbers and lower numbers of native fishes after 2017 (threespine stickleback, prickly sculpin) were contrasted by the highest-ever abundance of Sacramento splittail in the study's history. In sum, the catches in 2018 highlighted (1) the importance of flows and associated salinities on abundances of invertebrates and fishes, with higher flows generally corresponding to more fish, both native and non-native; (2) the disproportionate importance of Suisun Marsh for warm-water planktivorous fishes, especially striped bass juveniles; and (3) that Suisun Marsh is the estuary's bastion 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 2018 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
American shad	*Alosa sapidissima*	2065	449		2514
bay pipefish	***Sygnathus leptorhynchus***	**3**			**3**
bigscale logperch	*Percina macrolepida*	20	7		27
black bullhead	*Ameiurus melas*	883	3		886
black crappie	*Pomoxis nigromaculatus*	2275	179	1	2455
bluegill	*Lepomis macrochirus*	22	20		42
brown bullhead	*Ameiurus nebulosus*	29			29
California halibut	***Paralichthys californicus***	**9**	**3**		**12**
channel catfish	*Ictalurus punctatus*	188	9		197
Chinook salmon	***Oncorhynchus tshawytscha***	**76**	**416**	**1**	**493**
common carp	*Cyprinus carpio*	5614	557	1	6172
delta smelt	***Hypomesus transpacificus***	**664**	**144**	**4**	**812**
fathead minnow	*Pimephales promelas*	36	38		74
golden shiner	*Notemigonus crysoleucas*	9	12		21
goldfish	*Carassius auratus*	306	51		357
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***	**11905**	**53**	**5**	**11963**
longjaw mudsucker	***Gillichthys mirabilis***	**1**			**1**
Mississippi silverside	*Menidia audens*	1322	101590		102912
northern anchovy	***Engraulis mordax***	**330**		**37**	**367**
Pacific herring	***Clupea harengeus***	**484**	**136**		**620**
Pacific lamprey	***Lampetra tridentata***	**48**			**48**
Pacific sanddab	***Citharichthys sordidas***	**3**	**2**		**5**
plainfin midshipman	***Porichthys notatus***	**21**			**21**
prickly sculpin	***Cottus asper***	**12279**	**1199**	**1**	**13479**
rainbow trout	***Oncorhynchus mykiss***	**9**	**4**		**13**
rainwater killifish	*Lucania parva*	38	150		188
redear sunfish	*Lepomis microlophus*	2	1		3
river lamprey	***Lampetra ayresi***	**3**			3
Sacramento blackfish	***Orthodon macrolepidotus***	**26**	**116**		**142**

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
Sacramento pikeminnow	***Ptychocheilus grandis***	**186**	**331**		**517**
Sacramento splittail	***Pogonichthys macrolepidotus***	**37004**	**5790**	**14**	**42808**
Sacramento sucker	***Catostomus occidentalis***	**3515**	**128**	**5**	**3648**
shimofuri goby	*Tridentiger bifasciatus*	11330	2802	1	14133
shiner perch	***Cymatogaster aggregata***	**17**			17
shokihaze goby	*Tridentiger barbatus*	1392	5	6	1403
speckled sanddab	***Citharichthys stigmaeus***	**3**			3
staghorn sculpin	***Leptocottus armatus***	**2593**	**3460**		**6053**
starry flounder	***Platichthys stellatus***	**2258**	**310**	**4**	**2572**
striped bass	*Morone saxatilis*	94215	15910	30	110155
striped mullet	***Mugil cephalus***		**1**		1
surf smelt	***Hypomesus pretiosus***	**5**			5
threadfin shad	*Dorosoma petenense*	3901	7638	1	11540
threespine stickleback	***Gasterosteus aculeatus***	**18159**	**6835**	**6**	**25000**
tule perch	***Hysterocarpus traski***	**22166**	**2570**	**6**	**24742**
wakasagi	*Hypomesus nipponensis*	13	11		24
warmouth	*Lepomis gulosus*	1			1
western mosquitofish	*Gambusia affinis*	18	366		384
white catfish	*Ameiurus catus*	6049	167	13	6229
white crappie	*Pomoxis annularis*	112			112
white croaker	***Genyonemus lineatus***	**3**			**3**
white sturgeon	***Acipenser transmontanus***	**126**		**2**	**128**
yellowfin goby	*Acanthogobius flavimanus*	20612	18173		38785
Total		262481	169658	138	432277

APPENDIX B: 2018 CATCHES

Total 2018 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold; “HL” = Hill Slough, “SD” = Sheldrake Slough, and other slough codes as in Figure 20).

Species	Slough													Total
	BY	CO	DV	GY	HL	LSU	MZ	MZN	NS	PT	SB	SD	USU	
American shad	11	6	9	8		27	5	3	21	5	11	17	4	127
bay pipefish				**1**										**1**
bigscale logperch		1												1
black bullhead			1											1
black crappie			67	1					32	2	1			103
bluegill			1	1										2
channel catfish							3	3						6
common carp	5	11	35	41	1	3			13	53	16	5	4	187
hitch							**1**							**1**
longfin smelt		**1**		**3**		**16**	**2**			**1**			**2**	**25**
Mississippi silverside			1	1							9	2		13
northern anchovy													**1**	**1**
Pacific herring						**1**								**1**
plainfin midshipman						**1**								**1**
prickly sculpin	**18**	**17**	**34**	**137**	**12**	**6**	**28**	**2**	**17**	**15**	**7**	**12**	**15**	**320**
rainwater killifish													1	1
Sacramento pikeminnow			**3**	**1**			**2**		**3**					**9**
Sacramento splttail	**88**	**190**	**623**	**308**	**17**	**194**	**115**	**48**	**469**	**203**	**202**	**69**	**123**	**2649**
Sacramento sucker	**9**	**4**		**2**			**1**		**2**	**14**	**17**	**3**	**3**	**55**
shimofuri goby	17	24	37	16	9	4	2	12	8	17	17	8	11	182
shokihaze goby	7	8	8		6	13	12	12	14	4			50	134
staghorn sculpin				**1**	**1**	**6**						**1**	**4**	**13**
starry flounder		**2**	**8**	**3**		**10**	**25**	**15**	**15**	**2**		**1**	**5**	**86**
striped bass	79	75	288	89	28	287	174	79	196	121	477	182	148	2223
threadfin shad		8	84	1		5	15		65		54	1	4	237
threespine stickleback	**9**	**4**	**1**	**19**			**1**		**1**	**22**	**6**		**14**	**77**
tule perch	**28**	**105**	**23**	**4**	**19**	**18**	**13**	**3**	**52**	**13**	**23**	**7**	**30**	**338**
wakasagi	2											1		3
white catfish			8	1			12	2		3			1	27
white sturgeon													**5**	**5**
yellowfin goby	30	22	8	39	10	80	59	12	22	30	18	1	49	380
Total	303	478	1239	677	103	671	470	191	930	505	858	310	474	7209

Total 2018 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	5	4	1	10
bigscale logperch	2			2
black crappie	17			17
channel catfish		2		2
Chinook salmon	**1**			**1**
common carp	14	6	5	25
goldfish	2			2
Mississippi silverside	1674	1101	1440	4215
prickly sculpin	**1**	**3**	**4**	**8**
Sacramento pikeminnow		**1**		**1**
Sacramento splittail	**78**	**291**	**59**	**428**
shimofuri goby	60	1	9	70
staghorn sculpin	**9**	**6**	**6**	**21**
striped bass	87	32	39	158
threadfin shad	66	108	94	268
threespine stickleback	**13**	**2**	**25**	**40**
tule perch	**2**	**9**	**14**	**25**
wakasagi	1			1
western mosquitofish		1	3	4
yellowfin goby	37	74	236	347
Total	2069	1641	1935	5645

APPENDIX C: 2018 EFFORT

Number of otter trawls in each slough and each month in 2018.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	2		2	2	2	2	2	2	2	2	22
Cutoff	2	2	2		2	2	2	2	2	2	2	2	22
Denverton	3	3	3		6	3	3	3	3	3	3	3	36
First Mallard	2	2	2		3	3	3	3	3	2	2	2	27
Goodyear	3	3	3		3	3	3	3	3	3	3	3	33
Hill					2	2	2	2	2				10
lower Suisun	2	2	2		2	2	2	2	2	2	2	2	22
Montezuma	2	2	2		2	2	2	2	2	2	2	2	22
Montezuma new	1	1	1		1	1	1	1	1	1	1	1	11
Nurse	3	3	3		5	3	3	3	3	3	3	3	35
Peytonia	2	2	2		3	3	3	3	3	2	2	2	27
Sheldrake					2	2	2	2	2				10
upper Suisun	3	3	3		2	2	2	2	2	2	2	2	25
Total	25	25	25	0	35	30	30	30	30	24	24	24	302

Number of beach seines in each slough and each month in 2018.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	3	3		2	3	3	3	3	2	3	2	30
Montezuma new	2	3	3		3	3	3	3	3	3	3	3	32
upper Suisun	3	2	3		2	2	3	2	2	3	3	2	27
Total	8	8	9		7	8	9	8	8	8	9	7	89