

UC Davis

UC Davis Previously Published Works

Title

Suisun Marsh Fish Study Trends in fish and invertebrate populations of Suisun Marsh
January 2016 -December 2016.

Permalink

<https://escholarship.org/uc/item/11k1z4rc>

Authors

O'Rear, Teejay Alexander
Moyle, Peter B

Publication Date

2018

Data Availability

The data associated with this publication are available upon request.

Peer reviewed



SUISUN MARSH FISH STUDY

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2016 - December 2016

Annual Report for the

California Department of Water Resources

Sacramento, California

Teejay A. O'Rear and Peter B. Moyle

Department of Fish, Wildlife, and Conservation Biology

Center for Watershed Sciences

University of California, Davis

May 2018

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.

The return of wetter conditions and associated floodplain inundation in 2016 changed Suisun Marsh's environment and thus the biotic community. High outflows in March reduced salinities in the marsh considerably while also lowering water transparency. However, lower-than-average outflows during late spring and early summer contributed to elevated salinities and water transparencies that extended well into autumn. Dissolved oxygen (DO) concentrations were hospitable for most fishes except for rather low values in localized areas of the marsh in April and in autumn. 2016 was a warm year, especially during winter and in November, the latter of which likely contributed to the below-average DO values in that month.

Fish and invertebrate abundances in 2016 appeared to respond substantially to the elevated flows and to the warmer, fresher conditions. Non-native overbite clam (*Potamocorbula amurensis*) numbers crashed in 2016 after attaining their highest abundance in the study's history in 2015, a pattern that also occurred when wet conditions returned in 2011 following a four-year drought. The elevated spring outflows in 2016 likely contributed to higher numbers of Siberian prawn (*Palaemon modestus*) and two warm-water non-native fishes of the Pelagic Organism Decline [threadfin shad (*Dorosoma petenense*) and striped bass (*Morone saxatilis*)] by both increasing transport of upper-estuary individuals into Suisun Marsh and improving spawning conditions for all three species. Sacramento splittail (*Pogonichthys macrolepidotus*) responded strongly to the wetter conditions, with young-of-year abundance the third-highest in the study's history and abundance for all ages combined the highest ever. Conversely, native species associated with cool water fared poorly: California bay shrimp (*Crangon franciscorum*), delta smelt (*Hypomesus transpacificus*), and longfin smelt (*Spirinchus thaleichthys*) were all at some of their lowest-ever abundances. While such low numbers of cool-water native species were recorded in other surveys in the estuary as well, species that were notably abundant in Suisun Marsh during 2016 (*e.g.*, Sacramento splittail and threadfin shad) were also low in abundance in the greater estuary, highlighting the importance of Suisun Marsh for desirable fishes and invertebrates.

TABLE OF CONTENTS

Introduction.....	4
Methods.....	5
Results and Discussion.....	10
Abiotic Conditions.....	10
Trends in Invertebrate Distribution and Abundance.....	15
Trends in Fish Distribution and Abundance.....	19
Conclusion.....	29
Acknowledgements.....	29
References.....	30
Appendices.....	33

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.* 2014, Moyle *et al.* 1986). 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 fish 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 Revised Suisun Marsh Monitoring Agreement (Agreement Number 4600000634). 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.*, Moyle *et al.* 2014, Rosenfield and Baxter 2007); 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; Meek *et al.* 2012, Wintzer *et al.* 2011a, b, c); 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, Moyle *et al.* 2013); 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.

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. The decline was partly due to 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 time 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 the drought and high salinity harming native fishes. Matern *et al.* (2002) found results similar to Meng *et al.* (1994): fish diversity was highest in small sloughs, and native fish abundances continued to fall.

Recent studies have enhanced understanding of Suisun Marsh's aquatic ecosystem. Isotope studies by Schroeter *et al.* (2015) found that many consumers in the marsh are generalists and that submerged aquatic vegetation may be a significant carbon subsidy to upper trophic levels. Surveys in and around a restored tidal marsh (Blacklock Island) and a managed 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 fishes in the managed wetland relative to the restored marsh, suggesting managed wetlands can provide benefits to desirable fishes while still supporting waterfowl (Williamson *et al.* 2015). Finally, data accumulating from an ongoing companion study, (the "Arc Project") utilizing in part the same sampling methods as the Suisun Marsh Fish Study, are revealing that the marsh still provides vital habitat for at-risk native species, especially Sacramento splittail. 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).

This report's purpose was to (1) compare water-quality conditions between 2016 and typical conditions in Suisun Marsh; (2) compare abundances of important invertebrates and important fishes in 2016 to study averages, noting abundance changes between 2015 and 2016; (3) describe the pattern in monthly abundance of notable fishes and invertebrates in 2016, 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 (O'Rear and Moyle 2015, DWR 2001). The marsh is contiguous with the northern boundary of Suisun, Grizzly, and Honker bays and is central to the 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 Cut connect Suisun and Montezuma sloughs (Figure 1). Tributaries to Suisun Slough, from north to south, are Peytonia, Hill, Boynton, Shelldrake, 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>).

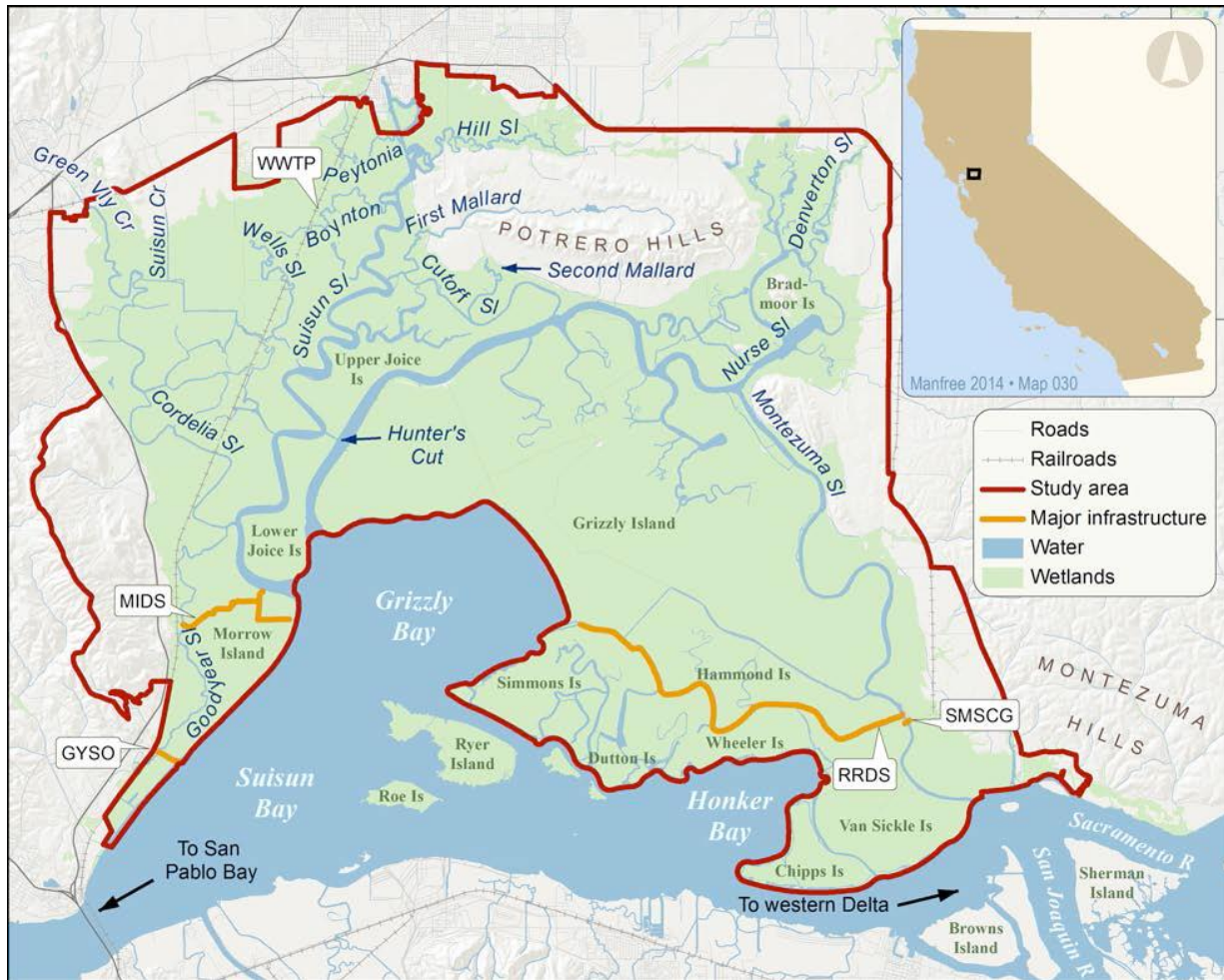


Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point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

The amount of fresh water flowing into Suisun Marsh is the major determinant of its salinity. Fresh water enters the marsh primarily from the western Delta through Montezuma Slough, although small creeks, particularly on the northwest 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; consequently, marsh salinities are lowest in these seasons. Salt water enters the marsh mainly through lower Suisun

and lower Montezuma sloughs from Grizzly Bay via tides, although the effect of the tides is more pronounced on water-surface elevation than on salinity throughout much of the year (Matern *et al.* 2002). During extreme tides, water depths can change as much as 2 m over a tidal cycle, often dewatering much of the smaller sloughs at low tide and overtopping dikes at high tide.

Several water management facilities alter the hydrology and water quality of the marsh. State Water Project and Central Valley Project water-pumping facilities in the southern Delta affect the timing and magnitude of freshwater flow into Suisun Marsh (DWR 1984). The Suisun Marsh Salinity Control Gates, located in Montezuma Slough just downstream of the confluence of the Sacramento and San Joaquin rivers, inhibit saltwater intrusion into the marsh during flood tides, providing fresher water for diked wetlands (DWR 2001; Figure 1). Numerous water control structures, most of which are unscreened for fish, are located throughout the marsh; they are opened in early autumn for flooding wetlands to attract wintering waterfowl, with water diverted from adjacent subtidal sloughs. Most water control structures remain open to some extent (or are reopened) during winter and spring, mainly to maintain water elevations in the wetlands, to leach salts from wetland soils, and to promote growth of desired waterfowl plants (DWR 1984). Diversions are restricted in some sloughs of the marsh during winter and spring to reduce entrainment of salmon and smelt. 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 dissolved-oxygen (DO) concentration is high (*e.g.*, 6 - 7 mg/L; Siegel *et al.* 2011).

Sampling

Since 1980, juvenile and adult fish have been sampled monthly at standard sites within subtidal sloughs of Suisun Marsh. Originally, 47 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). We continued sampling two additional sites in Denverton and Nurse sloughs (DV1 and NS1, respectively; Figure 2) in 2016 that were sampled as part of the Arc Project (O'Rear and Moyle 2016) as well as a historic site (MZ6); their data were included in monthly and slough-to-slough comparisons 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. In Denverton, upper Suisun, and eastern Montezuma 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, μ S) 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 transparency (Secchi depth, cm), tidal stage (ebb, flood, high, low), and water depths (m) were also recorded.

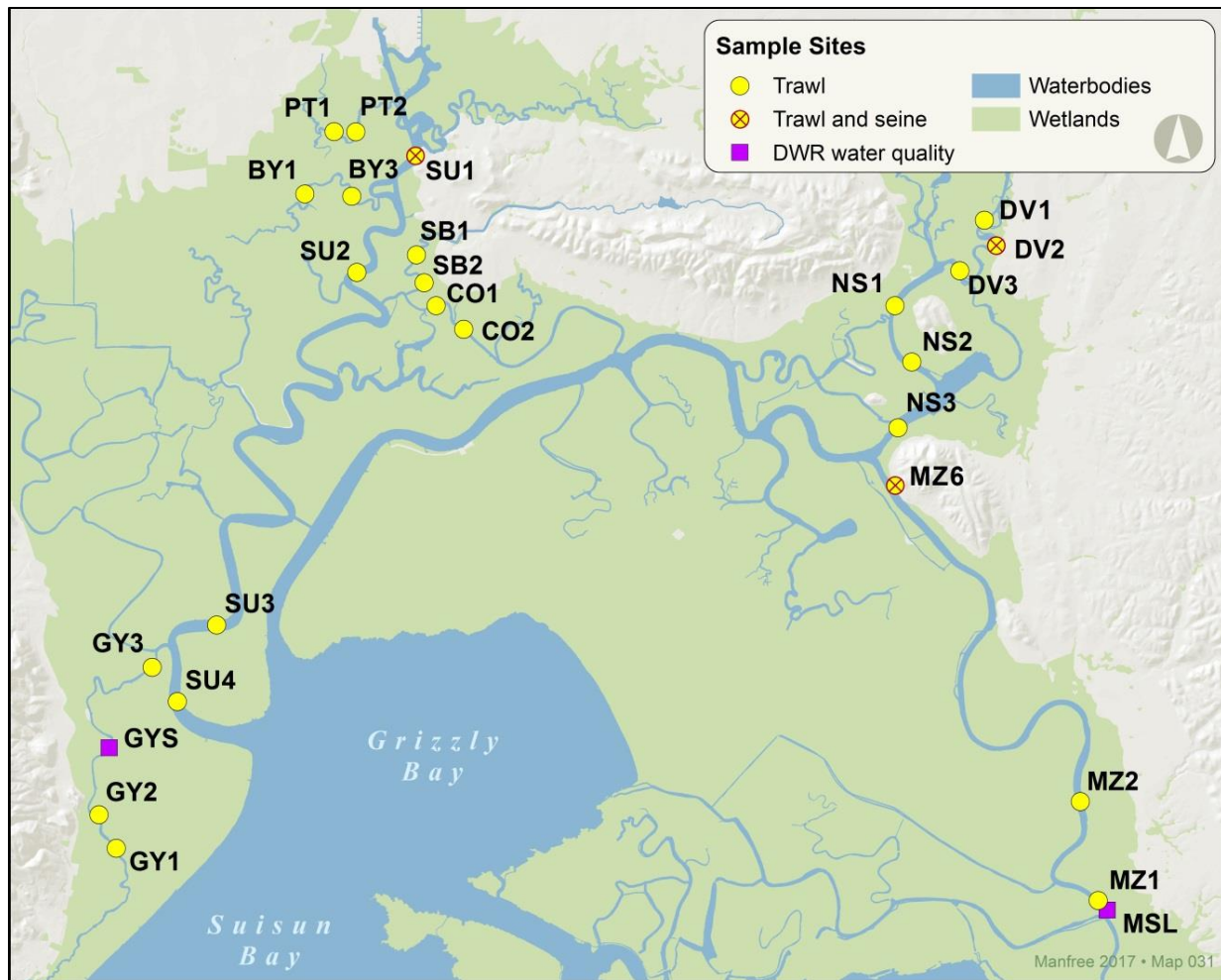


Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report.

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 (*Maeotias marginata*), Siberian prawn, oriental shrimp (*Palaemon macrodactylus*), California bay shrimp, Harris mud crab (*Rhithropanopeus harrisi*), 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

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

to remain consistent with previous reports (*e.g.*, Schroeter *et al.* 2006); CPUE values for invertebrates were also calculated likewise, with the annual number of individuals for the invertebrate of interest substituting for "annual number of fish." Slough-to-slough CPUE values for select species were calculated similarly except that, to account for unequal effort, minutes rather than number of trawls were used in the denominator. For monthly comparisons, to account for unequal effort among sloughs, CPUE values for otter trawls were calculated as

$$CPUE_{ij} = \frac{\sum_{i=1}^n \frac{\text{number of fish}_{ij}}{\text{number of trawls}_{ij}}}{n}$$

where i = slough, j = month, and n is the number of sloughs; once again, CPUE values for beach seines and for invertebrates were calculated likewise. Age classes of fishes except Sacramento splittail and striped bass were determined from peaks and valleys in length-frequency graphs. Sacramento splittail age classes were determined following length-frequency-age analyses by Matern and Sommer (unpublished). Age-0 striped bass were classified as those fish belonging to the length-frequency-graph peak corresponding to the smallest size classes after April, adults were considered fish larger than 423 mm SL, and all others were classified as "juveniles." To describe geographic distribution, the proportion of the 2016 otter trawl catch from the sampled sloughs was computed for dominant species, and annual CPUE with minutes as the denominator was calculated for each slough for age classes of striped bass and Sacramento splittail. Monthly water-quality averages for 2016 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 2017a).

Annual CPUE values for otter trawls and beach seines were graphed, as were monthly CPUE values for dominant invertebrate and fish species. Monthly water-quality results of 2016 were graphed and compared to averages for all years of the study. Fifteen-minute salinity and water temperature data from DWR fixed stations, GYS and MSL (Figure 2), were graphed with the water-quality data collected during fish sampling to provide additional context. These two stations were chosen because they were the DWR stations closest to the fish-sampling sites, and they were in sloughs that exhibited opposing extremes of habitat conditions (*e.g.*, slough cross section, geographical position).

Catch of all fishes and by each method from 1979 to 2016 are found in Appendix A; annual catch of each slough and number of trawls/seines in each slough in 2016 are found in Appendix B and C.

RESULTS AND DISCUSSION

Abiotic Conditions

Delta Outflow

Since 2011, 2016 was the first year with periods of above-average Delta outflow (Figure 3). Two atmospheric river events in March and December (DWR 2017*b*) contributed to very high outflows, with the first event resulting in flooding of Yolo Bypass, an important spawning habitat for Sacramento splittail, for much of March. Thereafter, Delta outflow dropped below the average for the study period from mid-spring to about mid-summer (Figure 3). Outflow remained low from mid-summer to early October, and small storms from mid-October through November mildly elevated outflow.

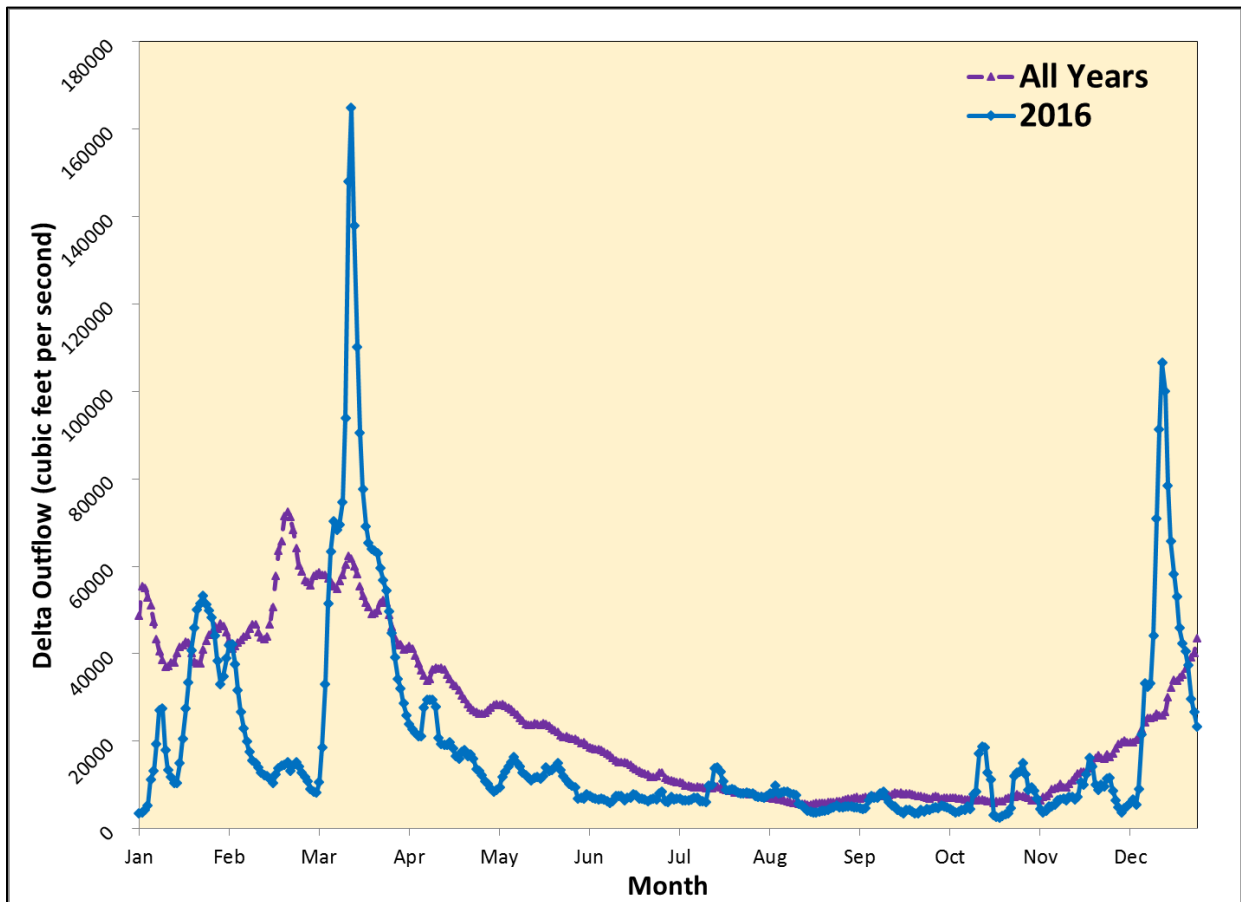


Figure 3. Daily Delta outflow in 2016 and the average for all years of the study (1980 – 2016; DWR 2017*a*).

Salinity

Average annual salinity in 2016 was closer to the average of the study’s history (4.5 and 3.9 ppt, respectively) than that of the previous three years (5.5, 6.9, 7.0 ppt, in 2013, 2014, and 2015, respectively). Average monthly salinities in Suisun Marsh in 2016 corresponded with changes in Delta outflow: salinities were lowest in March coincident with the atmospheric-river

storm, increased slightly above the average in late spring and summer following below-average outflows from April to July, and dropped to the study's all-years average by December (Figure 4). Relatively high salinities in October precipitated operation of the SMSCG, which persisted until early December, and, in combination with the autumn storms, appeared to notably decrease salinities. Salinities recorded by the fish study were within the bounds of the two continuous-water quality stations for all months (Figure 5). Nevertheless, fish study salinities were closer to the MSL gauge's values than the GYS gauge's values in June and July, and again in November and December, the former due to very low salinities in Boynton Slough (which receives WWTP discharge), and the latter due to low-salinity water in eastern Montezuma, lower Nurse, and Cutoff sloughs. The change in monthly salinity in 2016 was similar to that for all years of the study, although the increase from September to October and then the decrease to November were both rather severe (Figure 4). A large range of salinities was present in Suisun Marsh during most months of 2016, with variability least in April and May following the year's peak outflow. The saltiest water in 2016 was always in the southwest marsh in Goodyear and lower Suisun sloughs; the freshest water was found in eastern Montezuma Slough during winter, spring, and autumn, and in upper Boynton Slough near the WWTP discharge during summer.

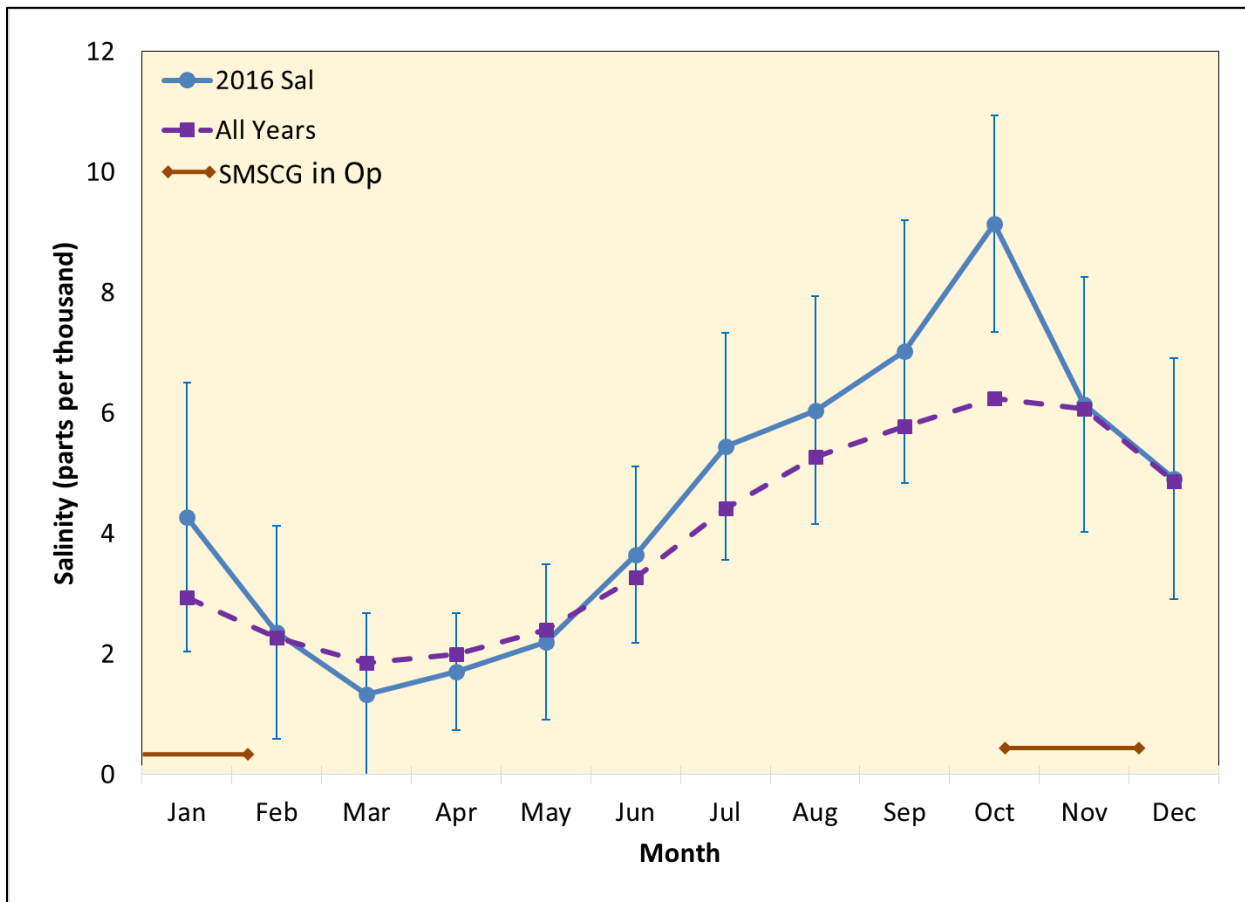


Figure 4. Monthly average salinity in 2016 and for all years of the study (1980 - 2016); error bars are standard deviations in 2016. Brown bars show when the SMSCG were operating in 2016.

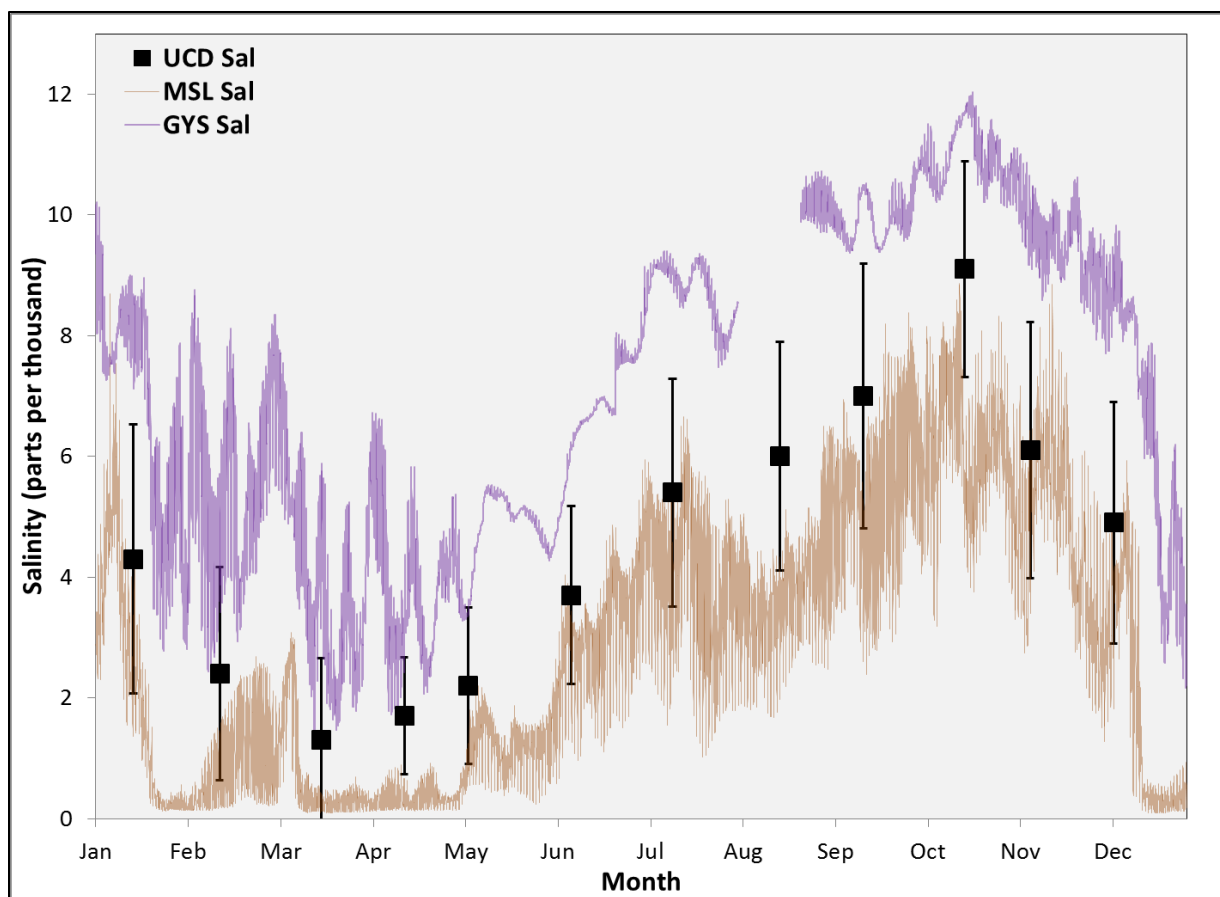


Figure 5. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average monthly salinities and standard deviations from the Suisun Marsh Fish Study ("UCD Sal"). Note no data were recorded by the GYS gauge from August 3 to August 24.

Dissolved Oxygen (DO)

DO concentrations in the marsh are affected by decomposition of organic material, temperature, salinity, wind, 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, likely due to enhanced mixing of surface and subsurface water layers. 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 has been occasionally observed to contain low DO concentrations and may compound regional low DO concentrations in some areas of the marsh (Siegel *et al.* 2011). Likewise, draining wetlands in spring by discharging to the sloughs can also depress marsh DO levels (Siegel *et al.* 2011), though not nearly to the extent of that which occurs in autumn. Consequently, marsh DO is usually high in winter, lower in spring and summer, and lowest in autumn.

Average DO concentrations in 2016 were fairly consistent until September, following the average for all years that DO has been measured (2000 – 2016; Figure 6). DO values in September 2016 were notably above average, declined to normal levels in October, and then fell to the year's lowest average monthly value in November, likely due in part to the abnormally warm water (see below). DO values were highest in the coldest months (January, February, and December; Figure 6).

The minimum trend in DO in 2016 mirrored the trend in average DO concentration (Figure 6); however, the trend in maximum DO in 2016 opposed the average from March to May (Figure 6). In all months, the lowest monthly DO concentrations were at small-slough stations well into the marsh's interior (*i.e.*, BY1, GY1, PT1, and SB1; Figure 2), with the year's lowest value recorded (2.6 mg/L) at the PT1 site on November 9 during mid-ebb tide. The DV2 station had the highest DO value in 2016 (11.2 mg/L), which occurred on April 12 during late ebb tide. Large sloughs – lower Suisun and Montezuma (Figure 1) – usually had the highest monthly DO concentrations.

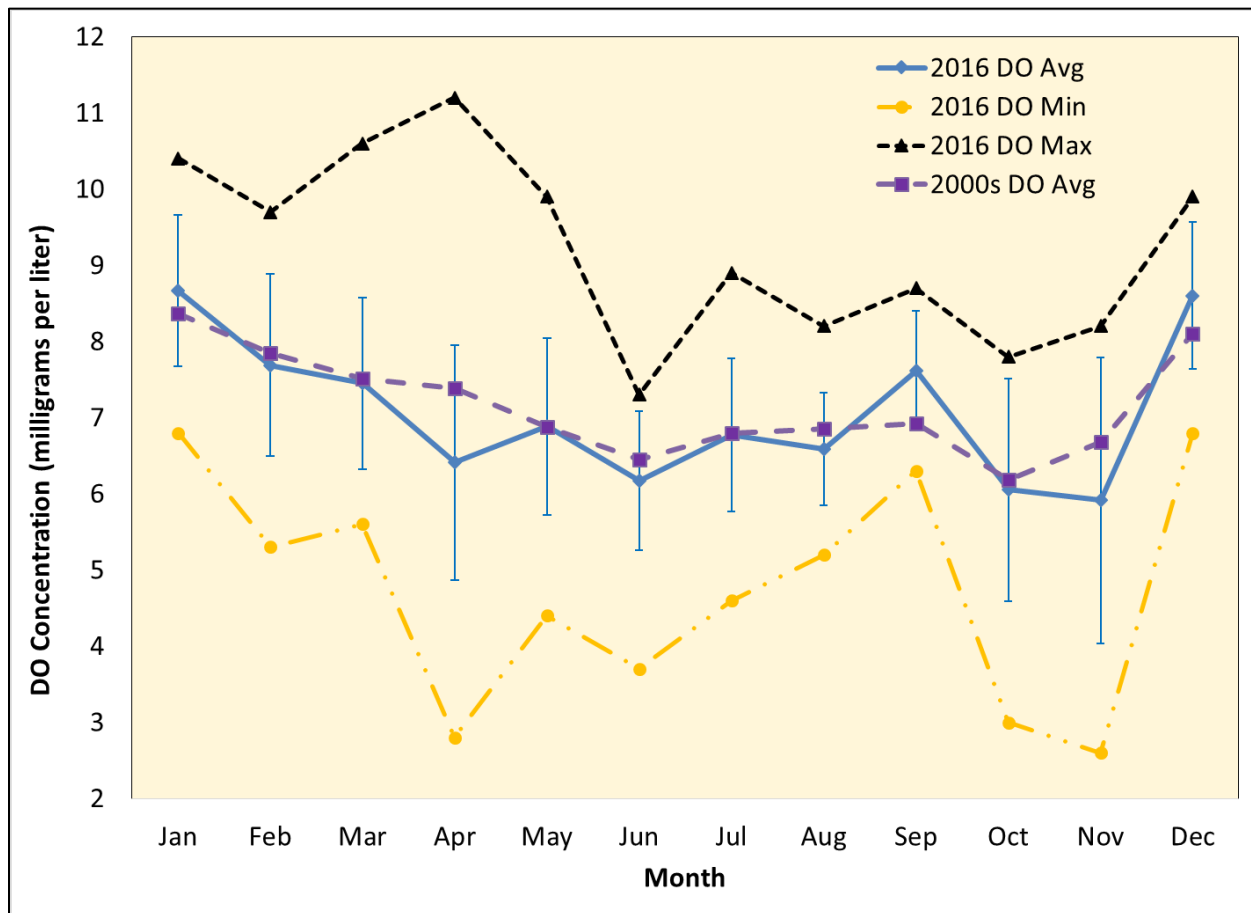


Figure 6. Monthly average DO concentration in 2016 and for the 2000s (2000 - 2016), maximum DO concentration in 2016, and minimum DO concentration in 2016. Error bars are standard deviations in 2016.

Water Temperature

Calendar year 2016 was warm, particularly from January to April and in November (DWR 2017b). Concomitantly, average monthly water temperatures in 2016 were elevated relative to the all-years average during winter and especially in November (Figure 7), with water temperatures a bit cooler than normal in August and September. The highest and lowest annual temperatures recorded by the fish study were found at small-slough stations (at the DV2 and GY1 stations in July and December, respectively), consistent with the GYS station showing considerably greater temperature fluctuations than the MSL station (Figure 8).

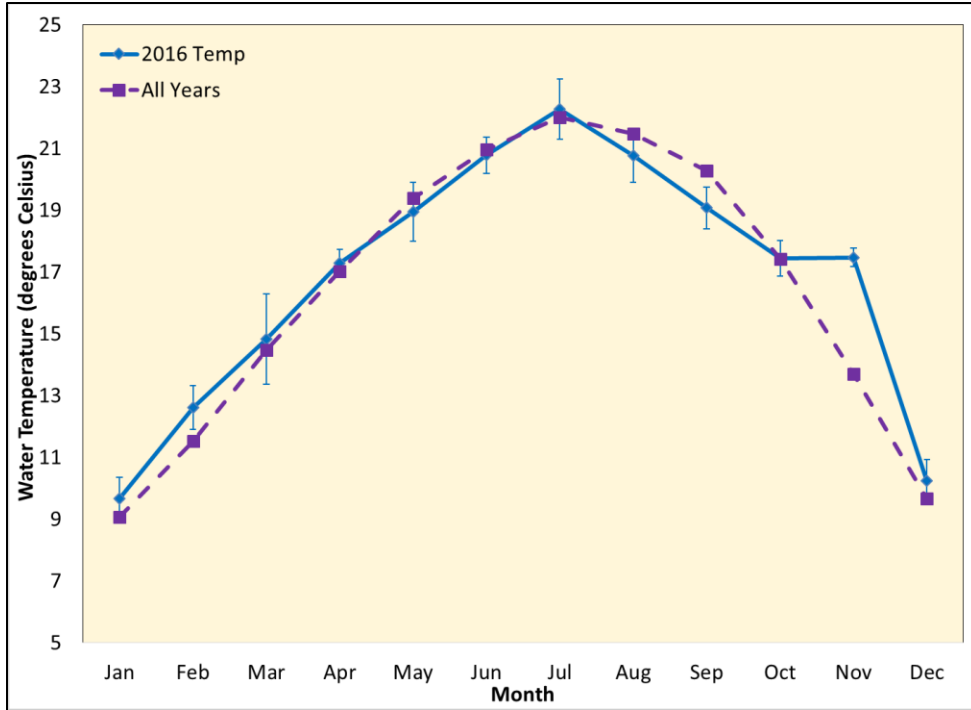


Figure 7. Monthly average water temperature in 2016 and for all years of the study (1980 - 2016); error bars are standard deviations in 2016.

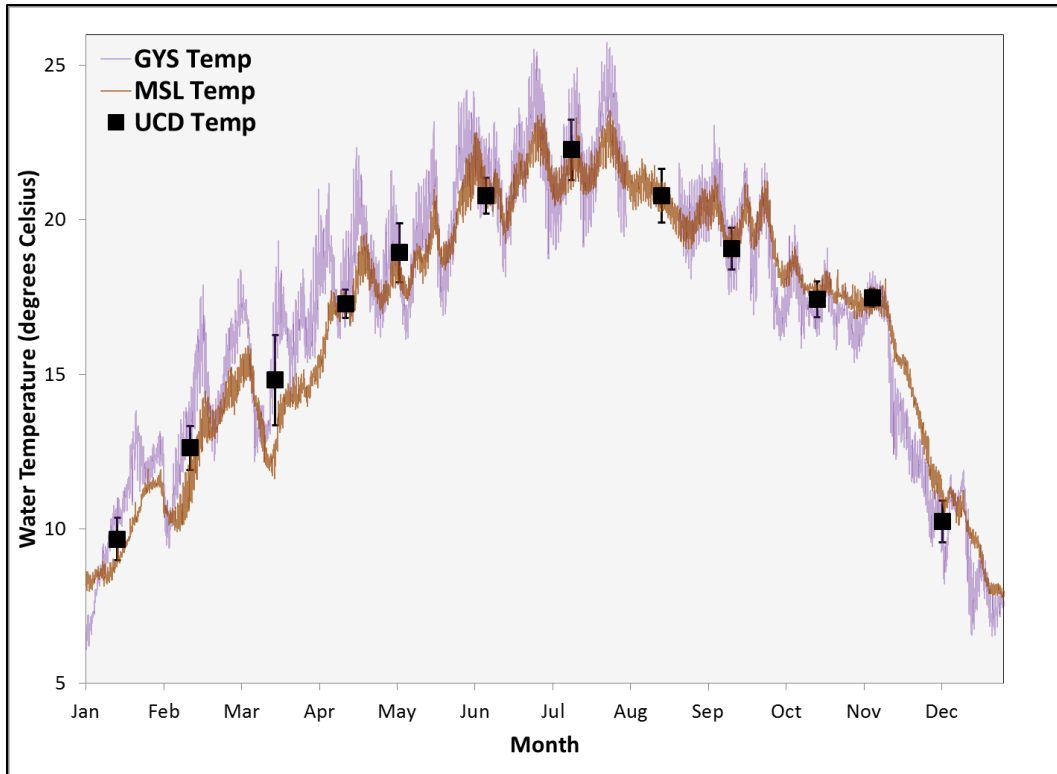


Figure 8. Fifteen-minute water temperatures from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with monthly average temperatures and standard deviations from the Suisun Marsh Fish Study ("UCD Temp"). Note no data were recorded by the GYS gauge from August 3 to August 24.

Water Transparency

Water transparency is partially a function of Delta outflow, with lower outflows corresponding to higher transparencies in the marsh (O'Rear and Moyle 2014a, 2008, Moyle *et al.* 1986). The first half of 2016 generally reflected this relationship, with monthly average transparencies in 2016 close to the all-years average (Figure 9). Nevertheless, monthly transparencies in the latter half of 2016 were notably higher than average, a pattern that has been seen in Suisun Marsh consistently since about 2000, roughly when sediment supply to the San Francisco Estuary became limiting (Schoelhamer 2011). After March, highest transparencies were recorded in large sloughs, either eastern Montezuma (seven months) or Suisun (two months) sloughs. Lowest transparencies occurred in either small sloughs or Suisun Slough. Monthly variability in transparencies was present in most months of 2016, especially from October to December (Figure 9) coincident with both moderately variable Delta outflow and flood-up/water-management periods for managed wetlands.

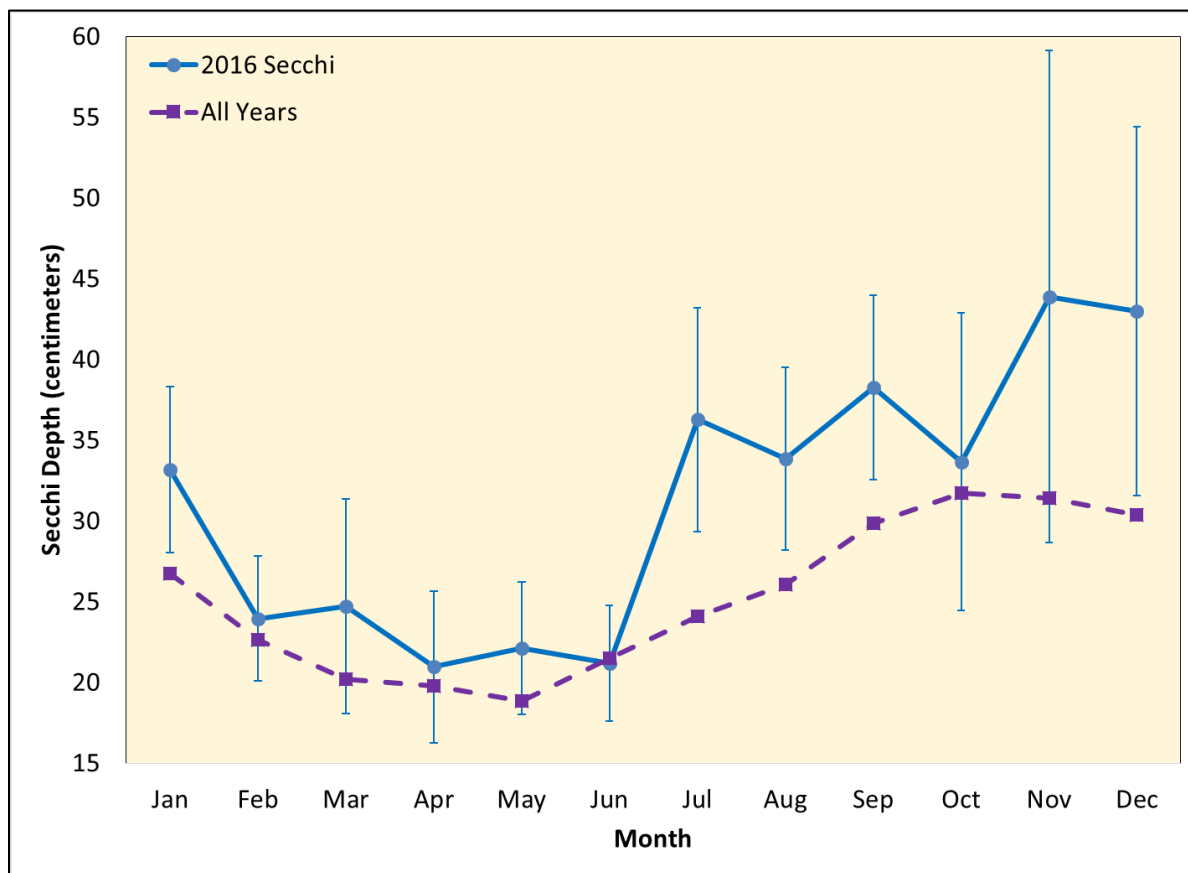


Figure 9. Monthly average water transparency in 2016 and for all years of the study (1980 - 2016); error bars are standard deviations in 2016.

Trends in Invertebrate Distribution and Abundance

Four plankton-feeding macroinvertebrates are commonly captured in high abundance in Suisun Marsh: California bay shrimp, Siberian prawn, Black Sea jellyfish, and overbite clam, of which only the bay shrimp is native. These invertebrates are important food-web components,

either as competitors [*e.g.*, Black Sea jellyfish (Wintzer *et al.* 2011), overbite clam (Feyrer *et al.* 2003)] or as fish food [*e.g.*, California bay shrimp and Siberian prawn (Nobriga and Feyrer 2008)].

Black Sea Jellyfish

Black Sea jellyfish medusa were very abundant in Suisun Marsh in 2016, with 2016's annual CPUE equal to 2015's value (20 medusae per trawl; Figure 10) and nearly triple the average for the entire study period (8 medusae per trawl). Monthly CPUE was typical, with large catches first occurring in July, high numbers continuing through September, and then steeply declining numbers through the remainder of the year (Figure 11). Medusae were abundant in all sloughs sampled except in Denverton Slough, which contributed only 26 of the 5,504 individual medusae captured in 2016

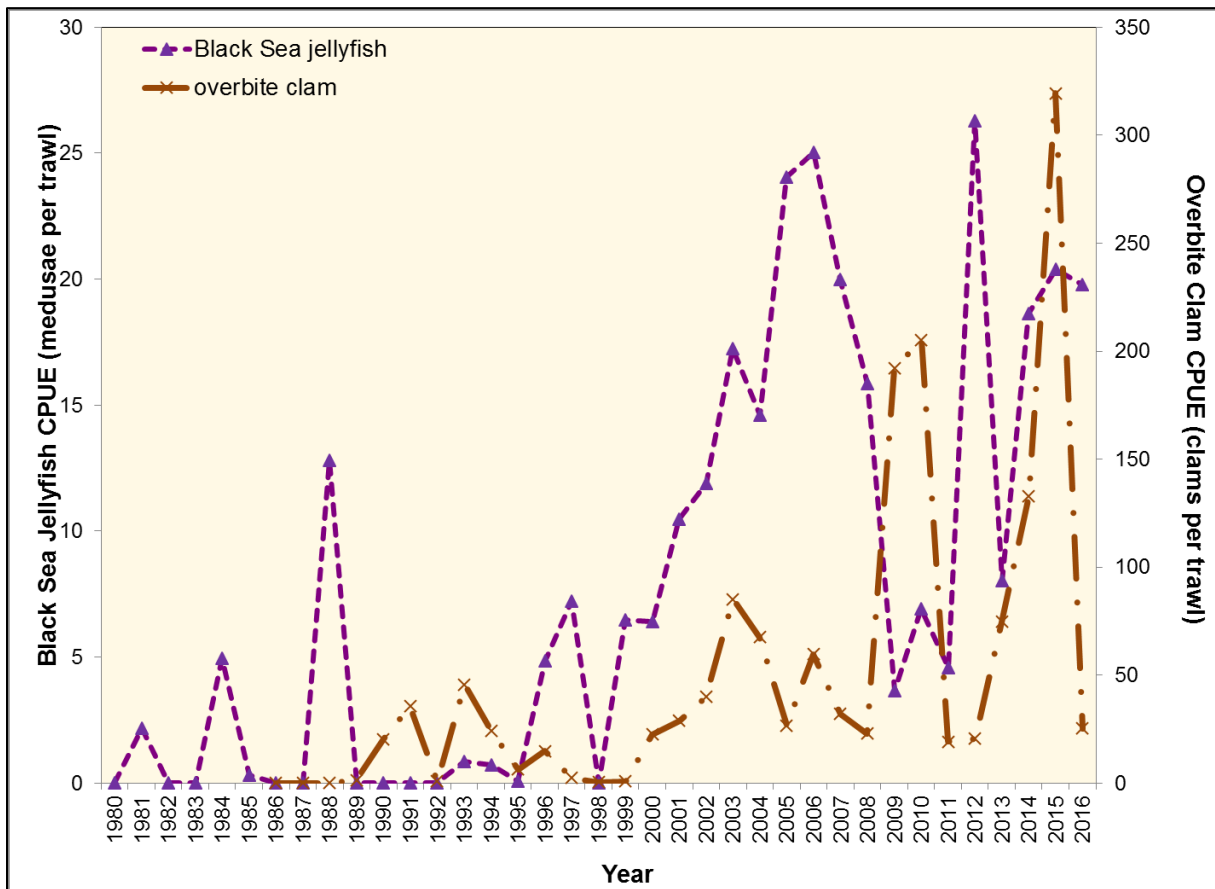


Figure 10. Annual otter trawl CPUE of Black Sea jellyfish and overbite clam.

Overbite Clam

Overbite clams were less abundant than normal in 2016 [25 clams per trawl in 2016 and an average of 49 clams per trawl for the period of the clam's presence in Suisun Marsh (1988-2016)], falling precipitously from the study's highest-ever value in 2015 (319 clams per trawl; Figure 10). Overbite clams were low in abundance for all months of 2016 except July (Figure

11), likely due in part to inhospitable salinities for successful recruitment occurring in winter and spring (Nicolini and Penry 2000). The severe decline in overbite clams with return of wet conditions in 2016 after escalating abundances since 2011, the last wet year, highlighted the importance of Delta outflow in regulating clam abundance in the marsh (Baumsteiger *et al.* 2017). While nearly all overbite clams in 2016 - 93% - were captured in Suisun Slough, far more were caught in upper Suisun Slough (SU1 and SU2; Figure 2) than in lower Suisun Slough (SU3 and SU4; Figure 1), the first time that had occurred since the clam's introduction. Calendar year 2016 marked the seventh year in a row in which a substantial proportion of the overbite clam catch came from upper Suisun Slough. Of the 7,009 overbite clams captured in 2016, only 32 came from the combined catch of Boynton, Cutoff, Denverton, Nurse, Peytonia, and First Mallard sloughs, further supporting previous patterns that smaller sloughs in the marsh are inhospitable to the clam (Baumsteiger *et al.* 2017, O'Rear and Moyle 2014a).

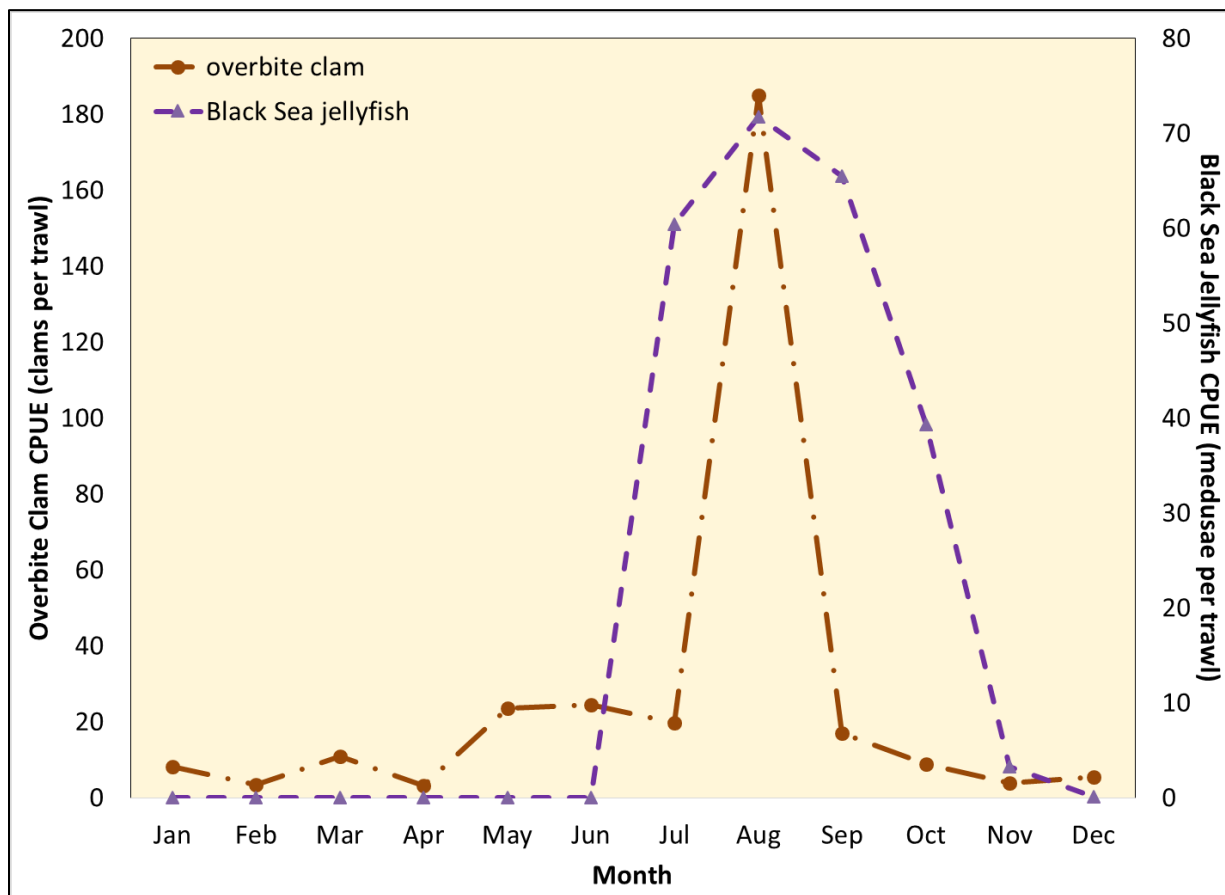


Figure 11. Monthly average CPUE of Black Sea jellyfish and overbite clam in Suisun Marsh in 2016.

California Bay Shrimp

California bay shrimp were nearly absent in Suisun Marsh in 2016, exhibiting the lowest annual CPUE in the study's history (0.5 shrimp per trawl), which was well below both 2015's value (3.5 shrimp per trawl) and the average for the entire study period (28 shrimp per trawl; Figure 12). Monthly CPUE was basically flat-lined in all of 2016 (Figure 13). Nearly all

California bay shrimp (88%) in 2016 were captured in Goodyear and lower Suisun sloughs in the southwest marsh, consistent with the bay shrimp's requirement for higher salinities (Krygier and Horton 1975). Given the positive association between California bay shrimp abundance and Delta outflow (Hatfield 1985), the poor catch in 2016 likely reflected unfavorable coastal conditions for the shrimp (Cloern *et al.* 2010).

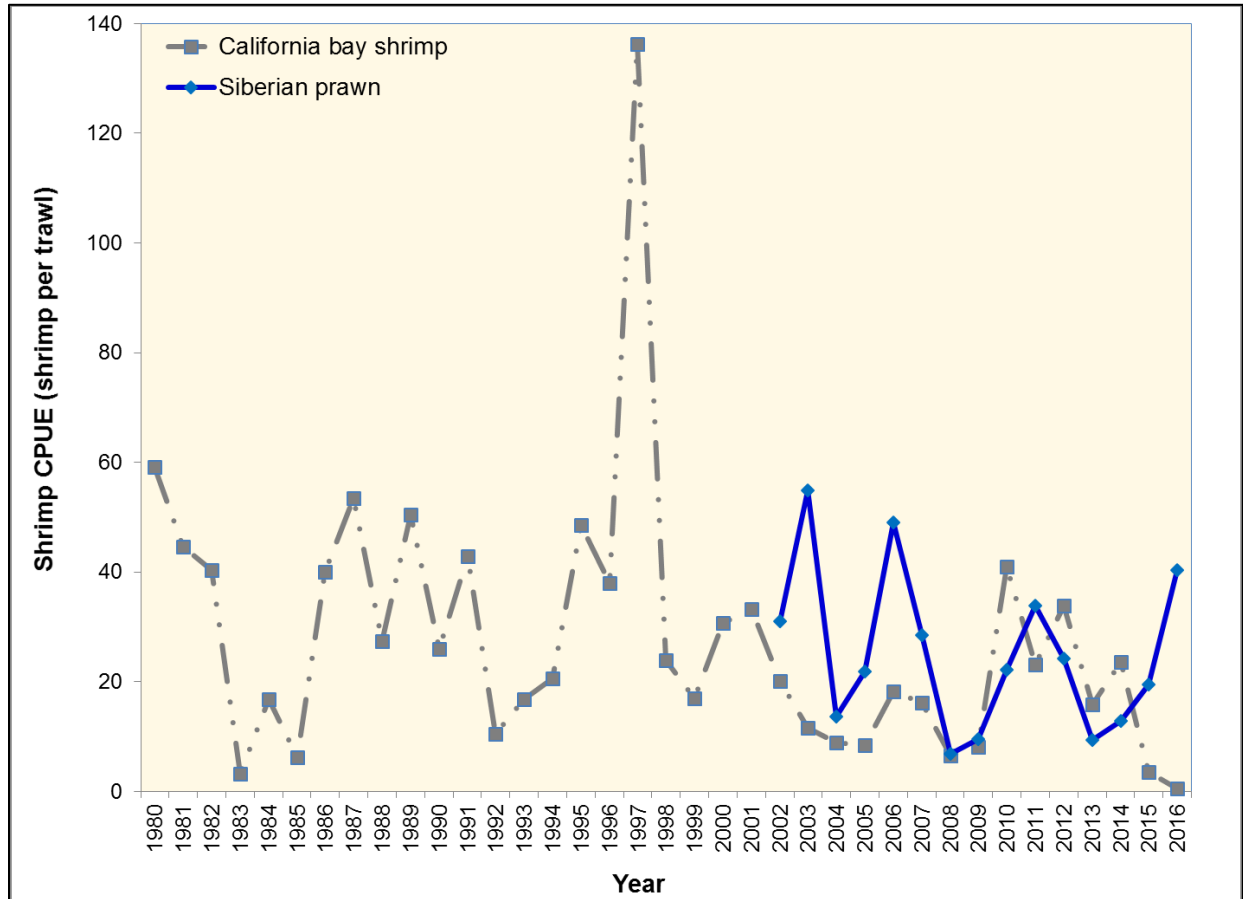


Figure 12. Annual otter trawl CPUE of California bay shrimp and Siberian prawn.

Siberian Prawn

Siberian prawn were more abundant than usual in 2016 (Figure 12), with a CPUE higher than both 2015 and the annual average since the shrimp's introduction (40, 19, and 25 shrimp per trawl in 2016, in 2015, and for 2002-2016, respectively). Monthly CPUE in 2016 increased rapidly from January to May, after which it varied at moderate levels for the rest of the year (Figure 13). Siberian prawn were relatively ubiquitous in the marsh but were especially abundant in the northeastern region, with Nurse and Denverton sloughs together accounting for 50% of 2016's catch. The increasing CPUE in winter and spring before the spawning period was consistent with higher Delta outflows transporting upper-estuary shrimp into the marsh (Brown and Hieb 2014).

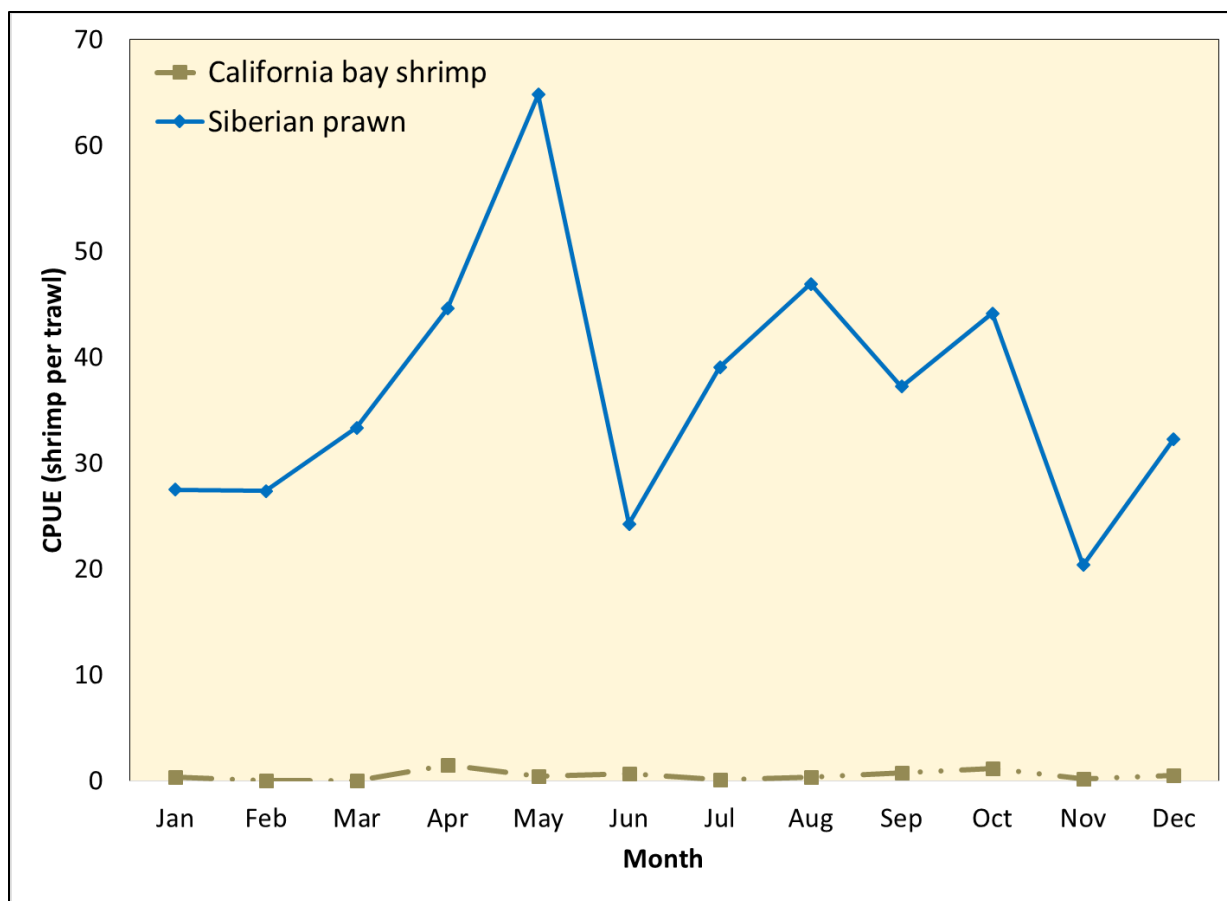


Figure 13. Monthly average CPUE of California bay shrimp and Siberian prawn in Suisun Marsh in 2016.

Trends in Fish Distribution and Abundance

Otter Trawls

Annual otter trawl CPUE in 2016 was slightly below the average for the whole study period (24 fish per trawl), rising moderately from 17 fish per trawl in 2015 to 21 fish per trawl in 2016 (Figure 14). The slightly below-average CPUE in 2016 was due to non-native fishes, the CPUE of which was about 72% of the all-years average (11 and 15 fish per trawl, respectively). The native fish CPUE in 2016 was about the average for the whole study (11 and 10 fish per trawl, respectively). Non-native fishes increased considerably from about seven fish per trawl in 2015 to 11 fish per trawl in 2016, while native fish CPUE remained the same between the two years (Figure 14). The anadromous American shad (*Alosa sapidissima*) and striped bass, in addition to the estuarine shimofuri goby, were responsible for the increase in non-native CPUE from 2015 to 2016 despite the drop of white catfish (*Ameiurus catus*) to negligible numbers (Table 1). The decline of northern anchovy (*Engraulis mordax*) to a more normal value in 2016 after 2015's unusually high catch, coupled with a slight decline in tule perch (*Hysteroecarpus traski*) numbers, was offset by a resurgence in prickly sculpin (*Cottus asper*) abundance (Table 1).

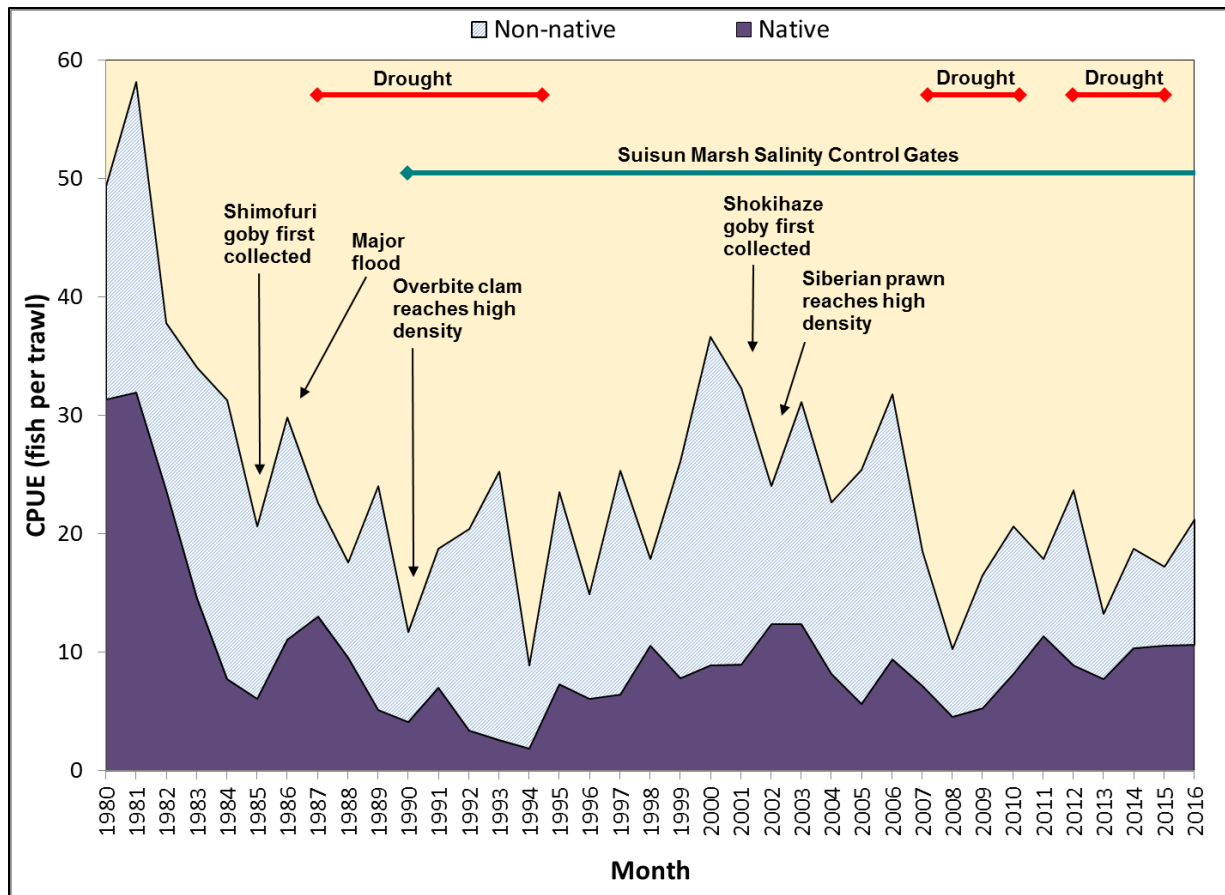


Figure 14. Annual otter trawl CPUE of native and non-native fishes, with important events highlighted.

Table 1. Percent change in annual otter trawl CPUE of seven 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 - 2016).

Species	All Years CPUE	2015 CPUE	2016 CPUE	2016/2015 % Change
northern anchovy	0.03	0.20	0.03	-87%
prickly sculpin	1.09	0.20	0.84	+313%
tule perch	2.09	2.51	2.23	-11%
American shad	0.02	0.15	0.58	+277%
striped bass	8.82	4.56	6.62	+45%
shimofuri goby	1.29	0.29	1.60	+452%
white catfish	0.62	0.43	0.07	-84%

Beach Seines

Annual beach seine CPUE in 2015 was higher than the average from 1980 to 2016 (57 fish per seine; Figure 15), increasing moderately from 2015 to 2016 (52 and 68 fish per seine, respectively). CPUE increased considerably for both non-native and native fishes from 2015 to 2016 (Figure 15); as usual, non-native fish, dominated by Mississippi silverside (*Menidia audens*), were far more abundant in seine hauls than native fish (Table 2). The increase in native fish CPUE was almost solely due to very high numbers of Sacramento splittail; Sacramento pikeminnow were also far more abundant than usual in 2016 (Table 2). For non-native fishes,

two pelagic species - striped bass and threadfin shad – increased substantially from 2015 to 2016, as well as yellowfin goby, while Mississippi silverside CPUE remained stable (Table 2).

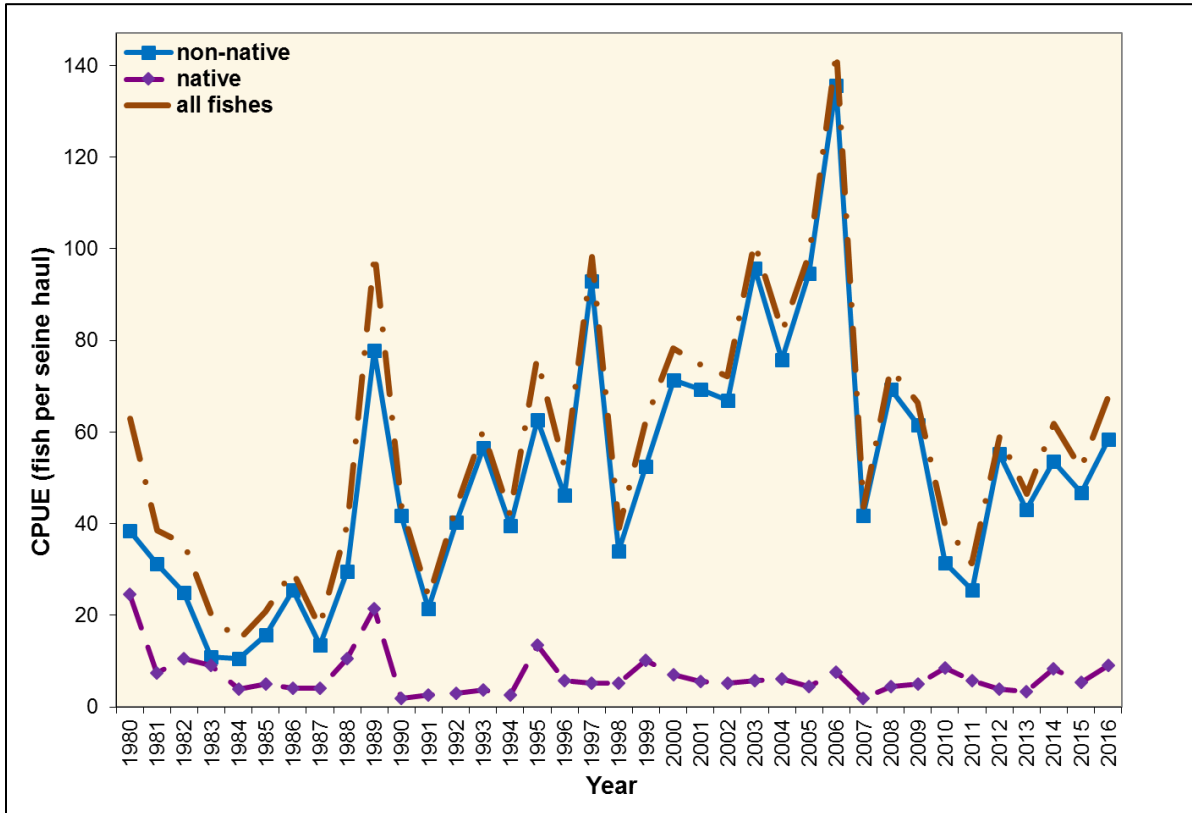


Figure 15. Annual beach seine CPUE of non-native, native, and both categories of fishes combined (“all fishes”).

Table 2. Percent change in annual beach seine CPUE of six 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	2015 CPUE	2016 CPUE	2016/2015 % Change
Sacramento pikeminnow	0.08	0.03	0.31	+933%
Sacramento splittail	1.55	2.30	5.69	+147%
threadfin shad	2.09	0.69	5.35	+675%
Mississippi silversides	34.56	39.36	41.46	+5%
striped bass	5.77	3.24	7.49	+131%
yellowfin goby	6.37	1.42	2.33	+64%

Fish Species of Interest

Fishes of the Pelagic Organism Decline

LONGFIN SMELT

Longfin smelt were virtually absent in Suisun Marsh during 2016 (Figure 16). The year’s otter trawl CPUE was the lowest value in the study’s history, with only two fish captured the entire year (Figure 16). The poor catch of longfin smelt in Suisun Marsh in 2016 reflected low abundances estuary-wide: the California Department of Fish and Wildlife’s (CDFW) Fall Midwater Trawl (FMWT) survey, which spans the main axis of the estuary, also posted very low

longfin smelt numbers for the year (CDFW 2017). Both fish – one age-0 fish captured in April and one adult captured in November – were caught in Denverton Slough.

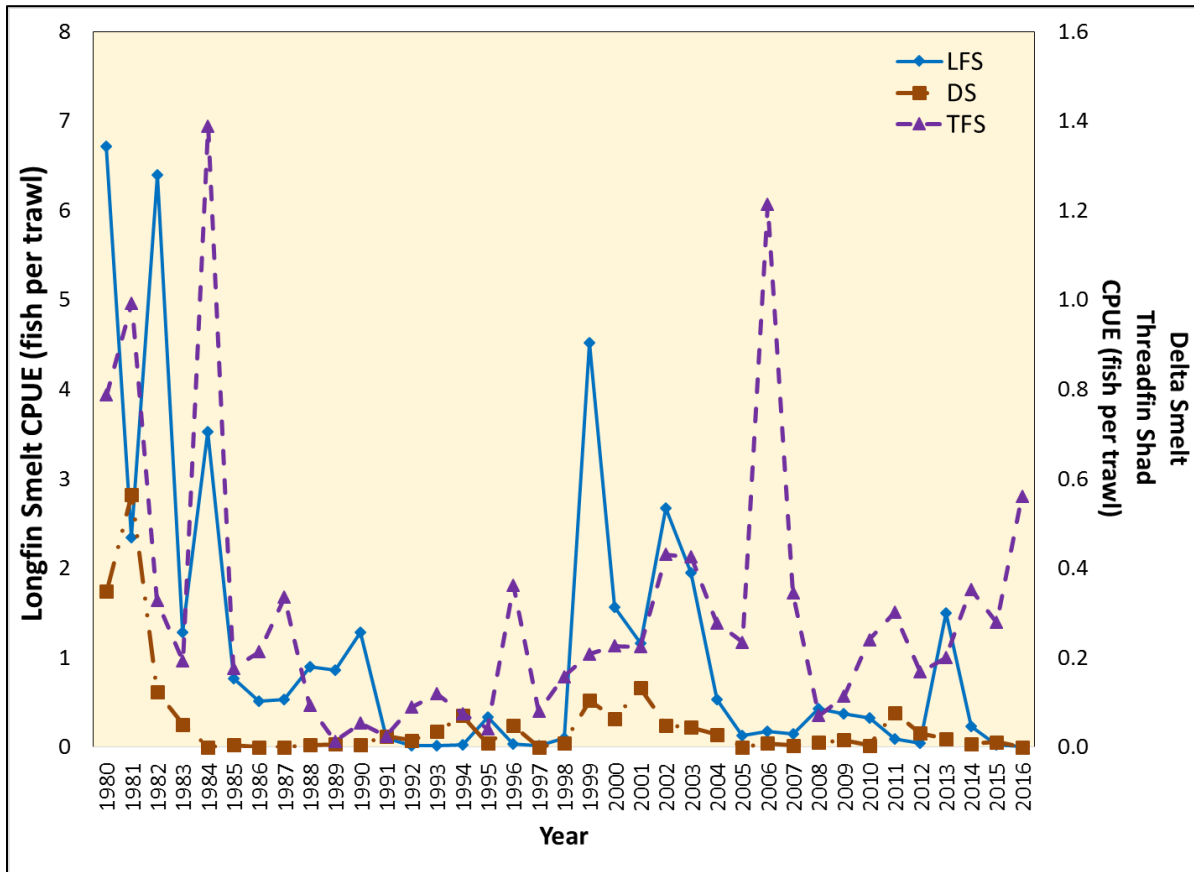


Figure 16. Annual otter trawl CPUE of three fishes of the Pelagic Organism Decline ("DS" = delta smelt, "TFS" = threadfin shad, and "LFS" = longfin smelt).

DELTA SMELT

Delta smelt otter trawl CPUE in 2016 was zero (Figure 16), with no delta smelt captured in any type of gear for the entire year. Calendar year 2016 was the first year since 1987 with no delta smelt captured by the study. Similar low numbers of delta smelt were recorded throughout the estuary in 2016 (CDFW 2017).

THREADFIN SHAD

Threadfin shad were very abundant in 2016, with 2016's otter trawl CPUE well above both 2015's and the fish study's all-years-average values (0.6, 0.3, and 0.3 fish per trawl, respectively; Figure 16). Threadfin shad were also very abundant in beach seines, with CPUE in 2016 more than double the average value for the entire study period (5.4 and 2.1 fish per seine, respectively). The CPUE values for both gear types in 2016 were the highest recorded since 2006 (Figure 16). Threadfin shad were far more abundant in the eastern marsh, with 91% of the otter trawl catch in 2016 coming from Denverton, Nurse, and eastern Montezuma sloughs (Figure 2). Distribution among the three seining beaches matched that of the otter trawls, with 197 and 261 fish captured in Denverton and Montezuma sloughs, respectively, in contrast to 61 fish taken in

upper Suisun Slough. The high CPUEs in 2016 were expected given the association of threadfin shad with fresher, warmer water (O'Rear and Moyle 2014b, Feyrer *et al.* 2009, Feyrer *et al.* 2007, Meng and Matern 2001), albeit the increase in Suisun Marsh in 2016 with return of higher outflows was higher than expected given FMWT indices (CDFW 2017).

STRIPED BASS

Striped bass were fairly abundant in Suisun Marsh in 2016, with annual CPUE values reaching their highest point since 2012 (Figure 17). Otter trawl CPUE in 2016 increased relative to 2015 (7 and 5 fish per trawl, respectively) but was still below the all-years average (9 fish per trawl). Annual beach seine CPUE increased substantially from 2015 to 2016 (3.2 and 7.5 fish per seine) and was also above the all-years average (6 fish per seine; Figure 17). Age-0 monthly beach seine CPUE was very high in June and July, thereafter dropping rapidly to negligible numbers by the year's end (Figure 18). The pattern for age-0 monthly otter trawl CPUE was similar to that for the beach seine except that (1) the otter trawl pattern began a month before the beach seine pattern and (2) the decline in the otter trawl CPUE after peaking was not as severe as that seen in the beach seine (Figure 18). The peak in the age-0 beach seine CPUE occurred with a decline in the otter trawl CPUE of both age-0 striped bass and mysids, an important prey of striped bass (Bryant and Arnold 2007, Feyrer *et al.* 2003), similar to that seen in 2012 (O'Rear and Moyle 2014a). Juvenile monthly otter trawl CPUE was fairly variable but displayed a general decline from the beginning to the end of 2016 (Figure 18). Although ubiquitous, geographic distribution of age-0 striped bass among sampled sloughs was disparate, with CPUE especially high in Denverton and First Mallard sloughs (Figure 19). Juvenile striped bass were distributed fairly evenly among sloughs though were slightly more abundant in the northeast marsh (*i.e.*, Denverton and Nurse sloughs) than elsewhere (Figure 19).

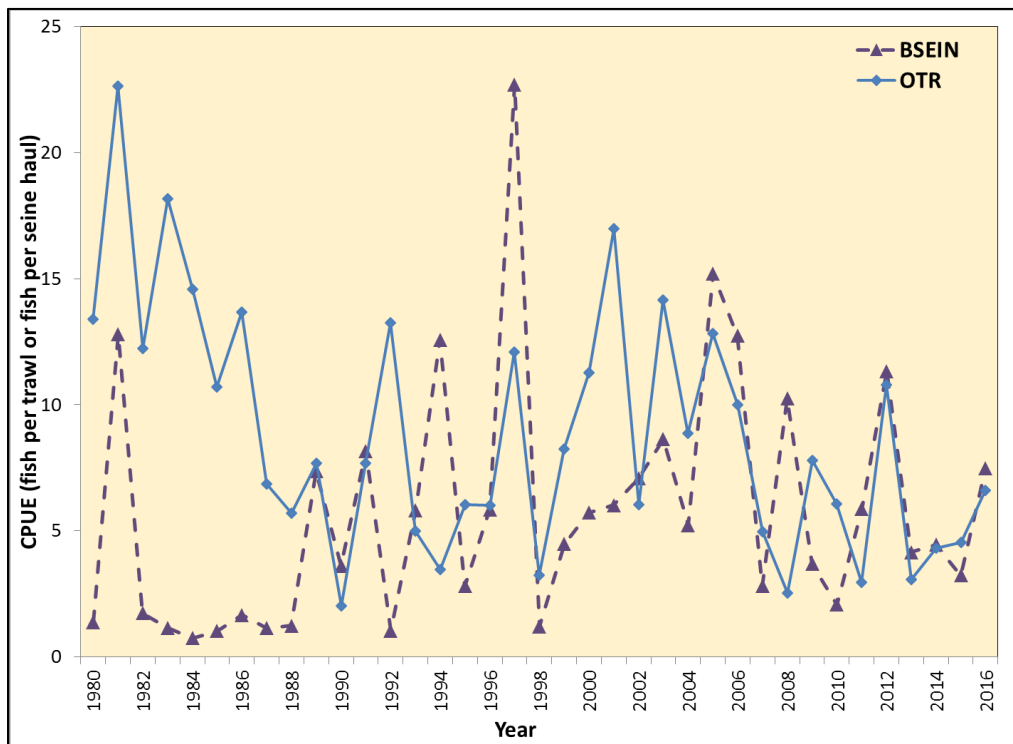


Figure 17. Annual otter trawl and beach seine CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine).

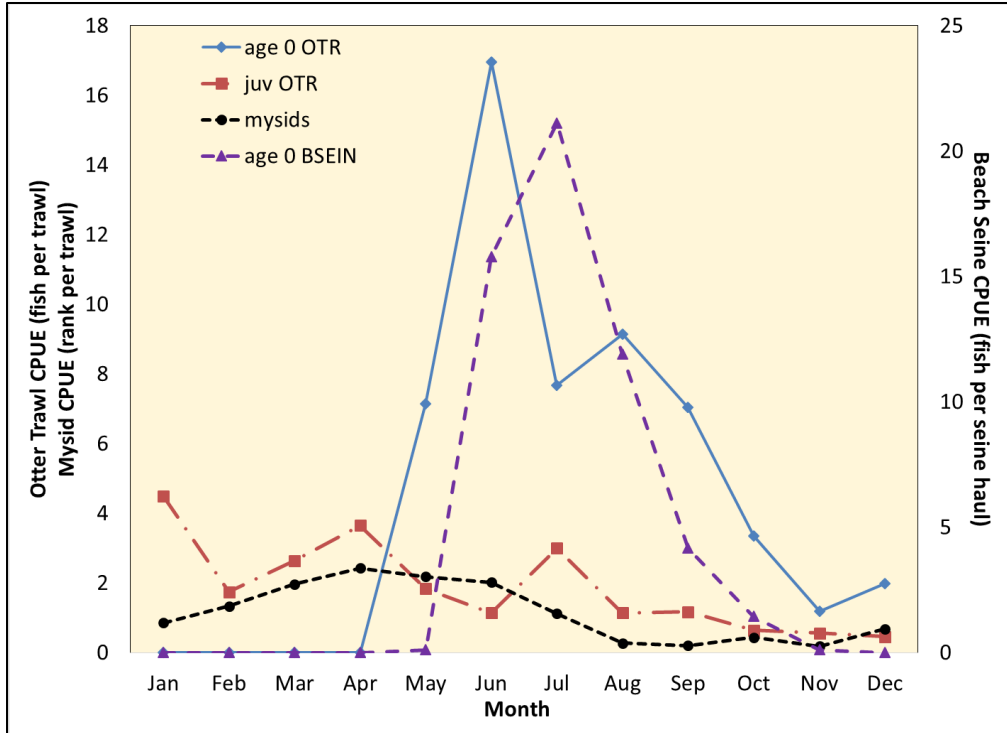


Figure 18. Monthly average CPUE of striped bass age classes and mysids (“juv” = juvenile; other codes as in Figure 17) in 2016.

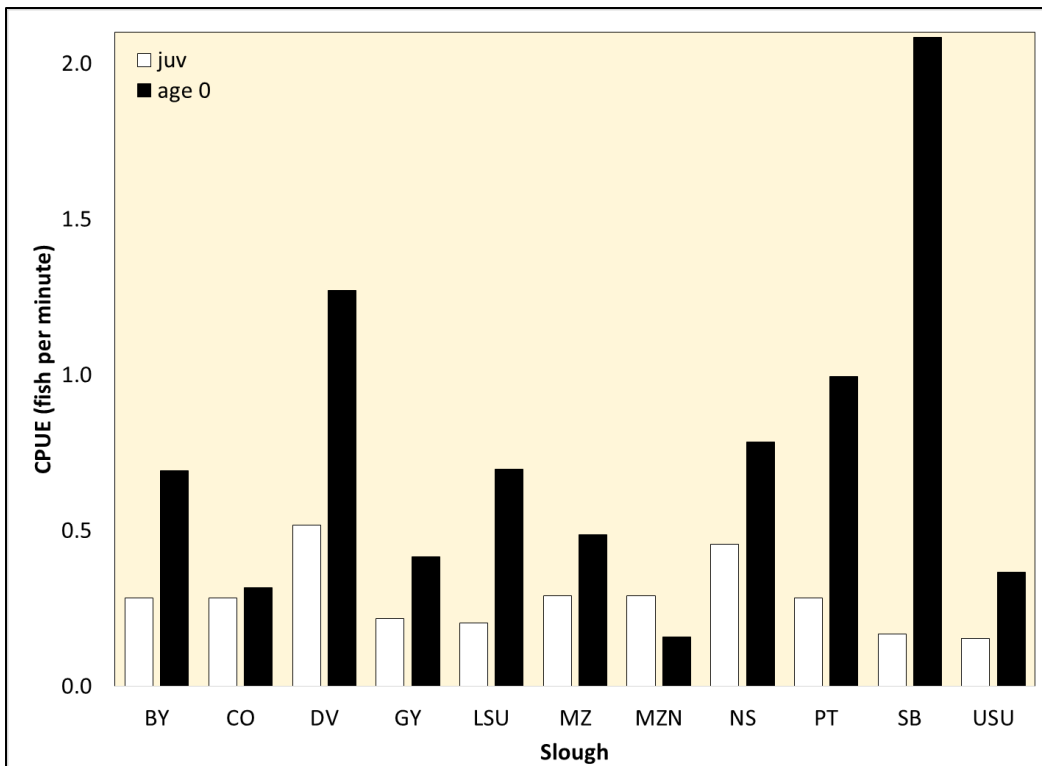


Figure 19. Average otter trawl CPUE of age classes of striped bass in 2016 (“BY” = Boynton Slough, “CO” = Cutoff Slough, “DV” = Denverton Slough, “GY” = Goodyear Slough, “LSU” = lower Suisun Slough, “MZ” = Montezuma Slough, “MZN” = Montezuma new, “NS” = Nurse Slough, “PT” = Peytonia Slough, “SB” = First Mallard Slough, and “USU” = upper Suisun Slough).

Sacramento Splittail

Sacramento splittail in 2016 were the most abundant they had ever been in the entire study history (Figure 20). Annual otter trawl CPUE in 2016 was 14% higher than 2015's CPUE and more than double the average value for all years of the study. The increase from 2015 to 2016 was mainly due to substantially more age-0 fish (0.4 and 4.0 fish per trawl, respectively; Figure 20), with only 1982 and 1986 posting higher annual age-0 CPUE values than 2016 (Figure 20). The annual beach seine CPUE also showed a large influx of age-0 fish, with 2016's CPUE value, comprised of 94% age-0 fish, being the highest in the study's history. However, age-2+ fish were also more abundant in 2016 than in any other study year, likely due in part to high survival of the 2014 year class (Figure 20). Such high recruitment of age-0 fish in 2016, given Yolo Bypass inundation during the prime spawning period, was similar to that seen in other years of spring flooding (Moyle *et al.* 2004, Sommer *et al.* 1997). The banner year Sacramento splittail displayed in Suisun Marsh in 2016 was especially striking given an index value of 0 for the FMWT in 2016 (CDFW 2017) and the previous concordance among the FMWT index, Yolo Bypass flooding, and Suisun Marsh Fish Study indices (Feyrer *et al.* 2006, Sommer *et al.* 1997).

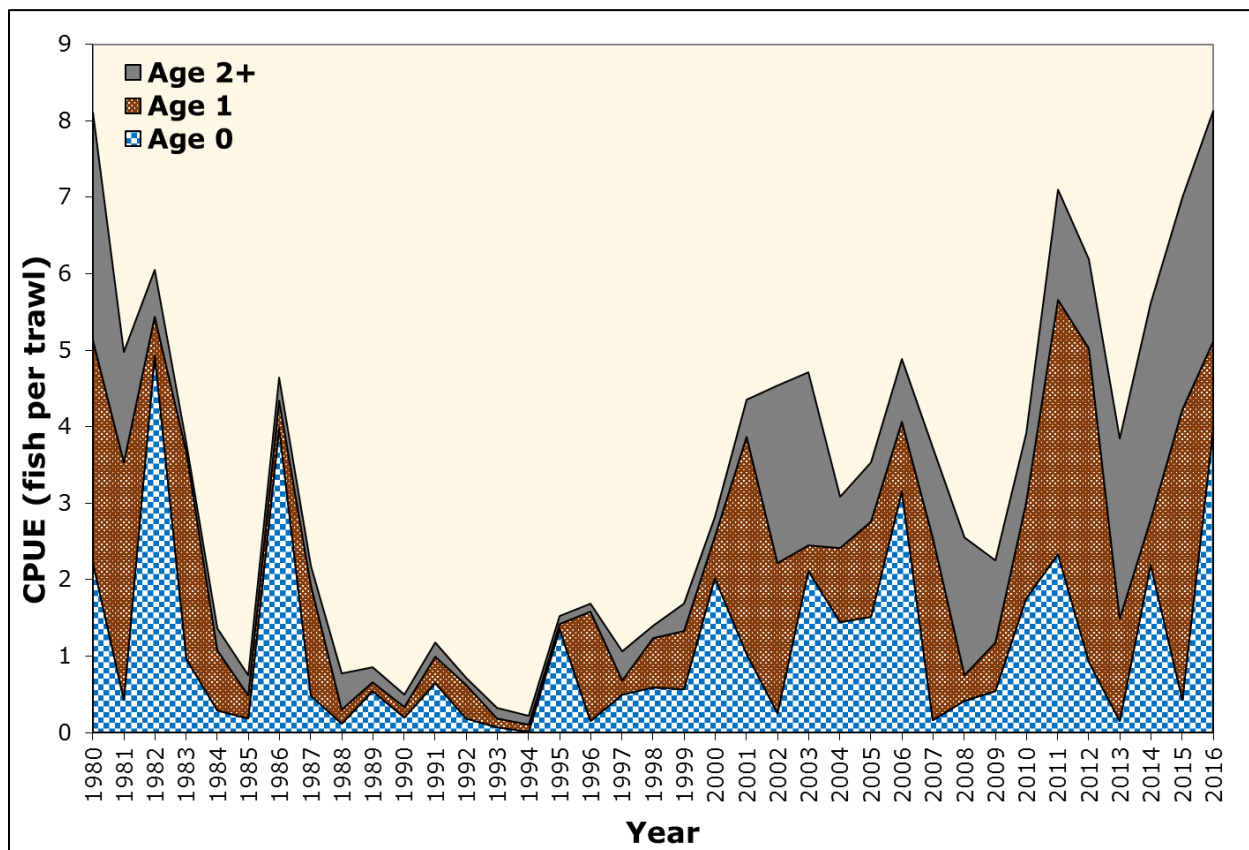


Figure 20. Annual otter trawl CPUE of three age classes of Sacramento splittail.

In 2016, Denverton Slough hosted more age-2+ and age-1 Sacramento splittail than any other trawled slough, with age-0 fish very abundant, too (Figure 21). All three age classes were also abundant in Nurse, Peytonia, and First Mallard sloughs; Cutoff Slough had the highest age-0 CPUE

of any slough trawled. Conversely, numbers of all three age classes of Sacramento splittail were low in both eastern Montezuma and lower Suisun sloughs (Figure 21). Nevertheless, beach seine CPUE among the three beaches was highest in eastern Montezuma Slough, reflecting usage of shorelines of Montezuma Slough by age-0 fish (Appendix B).

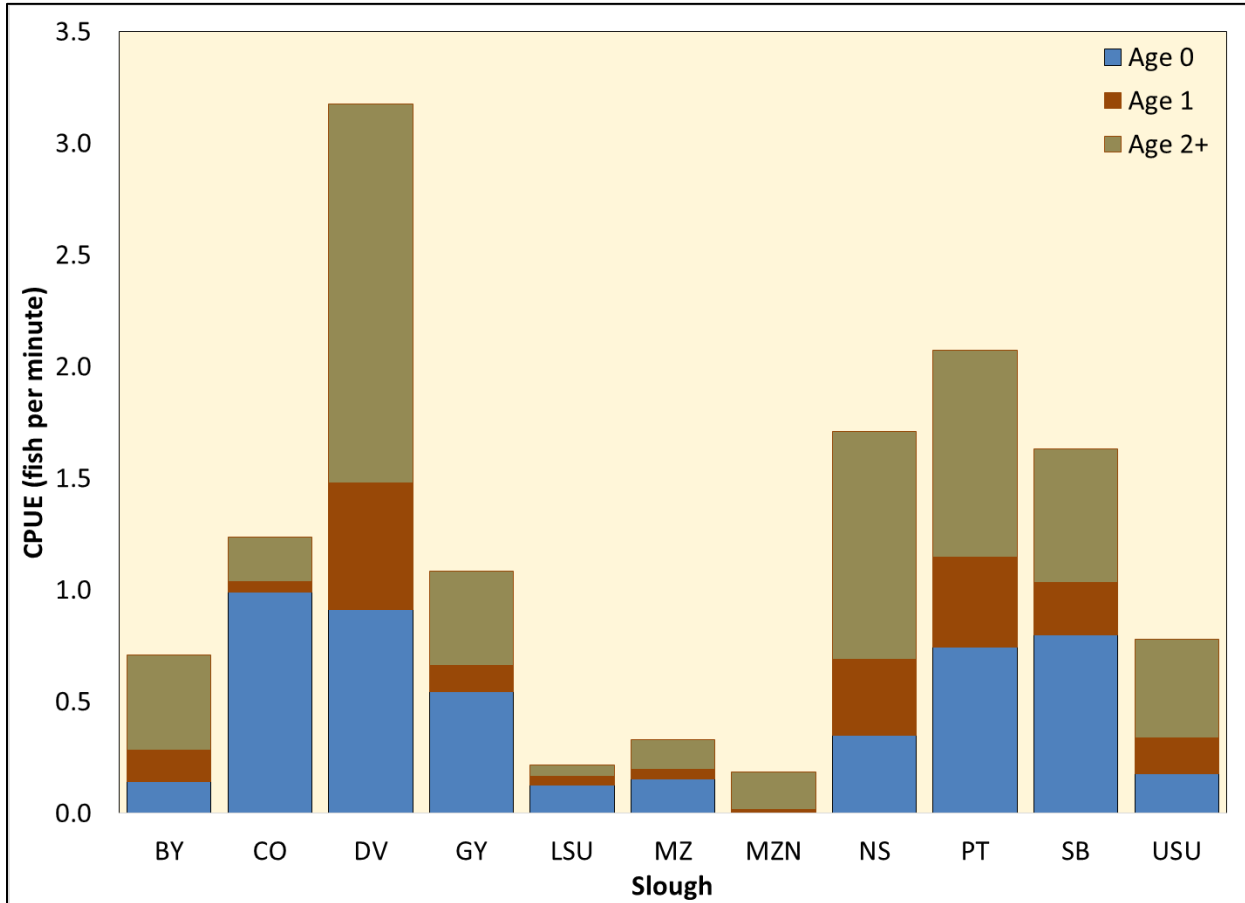


Figure 21. Average otter trawl CPUE of age classes of splittail in 2016 (codes as in Figure 19).

White Catfish

White catfish were nearly absent in 2016 relative to much of the last two decades (Figure 22). Annual CPUE in 2016 continued the steep decline that occurred during the latest drought, reaching the lowest level recorded since 1994 (Table 1; Figure 22). Only 22 white catfish were caught in 2016 as compared to an average of 255 per year from 1995 to 2016. No age-0 white catfish (*i.e.*, those smaller than 76 mm SL) were captured in 2016. None of the white catfish caught in 2016 came from the saltier sloughs of the southwest marsh (*i.e.*, Goodyear and lower Suisun). The low numbers and distribution of white catfish in 2016 were consistent with (1) poor survival and nonexistent reproduction/recruitment due to higher-than-average salinities during the drought (Markle 1976, Allen and Avault, Jr. 1971, Kendall and Schwartz 1968), and (2) insufficient outflows during early summer that prohibited recruitment of upper-estuary age-0 fish into the marsh, in contrast to 1983 and 1998 (O’Rear and Moyle 2014b).

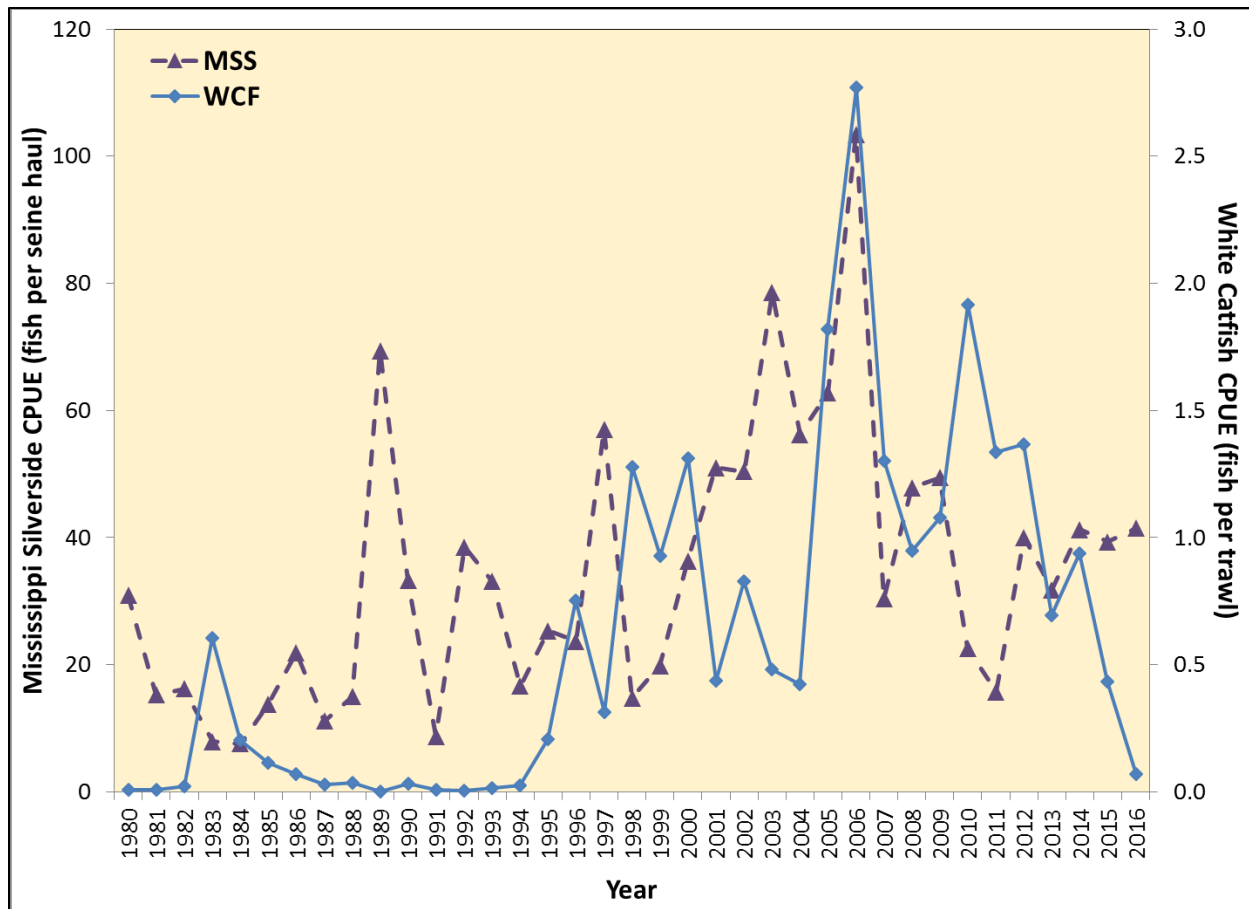


Figure 22. Annual CPUE of white catfish ("WCF") and Mississippi silverside ("MSS").

Mississippi Silverside

Mississippi silversides were moderately abundant in 2016, with similar CPUE values for 2016, 2015, and the average for all years (41, 39, and 35 fish per seine, respectively; Figure 22). The stability of the annual CPUE during the drought and into 2016 was striking (Figure 22). Monthly CPUE was high from January to March, thereafter declined to lower levels through summer, and then roughly increased through late summer and early autumn until peaking during November (Figure 23). Fish smaller than 30 mm SL, which are likely two months old and younger (Gleason and Bengston 1996, Hubbs 1982), were present from June through August (Figure 24), suggesting a unimodal spawning period in 2016 rather than the more typical mildly bimodal period seen in warm years (*e.g.*, 2015; O'Rear and Moyle 2017).

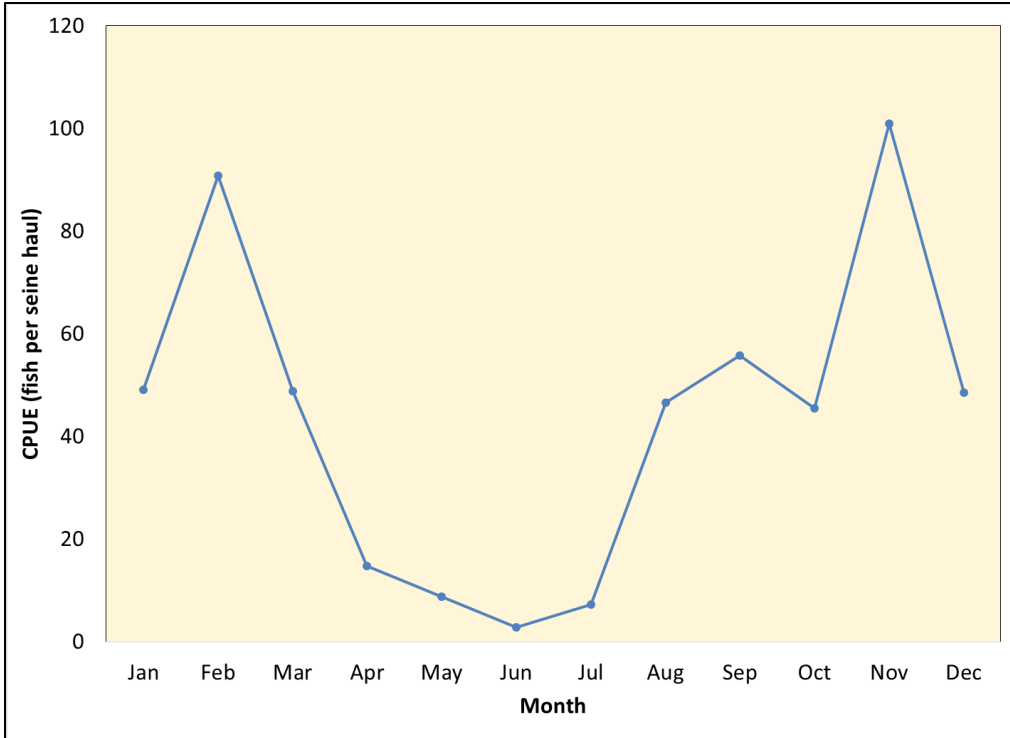


Figure 23. Monthly average beach seine CPUE of Mississippi silverside in 2016.

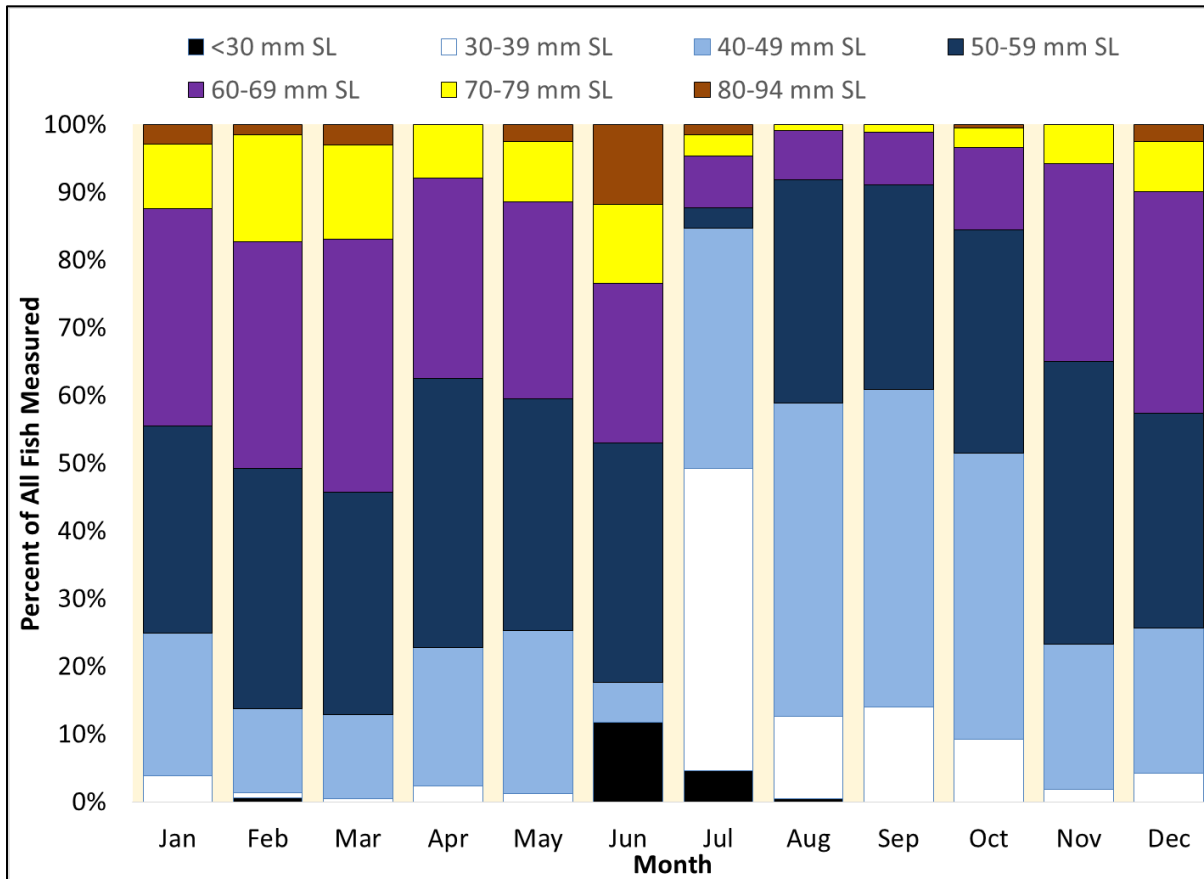


Figure 24. Monthly average beach seine CPUE of size classes (mm SL) of Mississippi silverside in 2016.

CONCLUSION

Calendar year 2016 was the first year since 2011 to have prolonged higher-than-average outflows, which affected Suisun Marsh substantially. Salinities and water transparencies dropped considerably with the high outflows during spring, although a return to lower-than-normal outflows in late spring and early summer corresponded to salinities and especially transparencies rising above averages for most of summer and well into autumn. Water temperatures were notably warm during winter and again in November. DO concentrations were generally satisfactory in Suisun Marsh in all months and areas except for fairly low values recorded in localized areas in April and in autumn, with the latter due in part to the abnormally high November temperatures.

Fish and invertebrate abundances in 2016 appeared to respond substantially to the elevated flows and to the warmer, fresher conditions. Overbite clam numbers crashed in 2016 after attaining their highest abundance in the study's history in 2015, a pattern that also occurred when wet conditions returned in 2011 following a four-year drought. The elevated spring outflows in 2016 likely contributed to higher numbers of Siberian prawn, threadfin shad, and striped bass by both increasing transport of upper-estuary individuals into Suisun Marsh and improving spawning conditions for all three species. Sacramento splittail responded strongly to the wetter conditions, posting their highest abundance ever in 2016. However, without high outflow conditions extending into early summer, the decline in white catfish abundance that began with the drought continued its steep decline, with only negligible numbers of a once very abundant Suisun Marsh fish captured in 2016. Native species associated with cool water fared poorly: California bay shrimp, delta smelt, and longfin smelt were all at some of their lowest-ever abundances. While such low numbers of cool-water native species were recorded in other surveys in the estuary as well, species that were notably abundant in Suisun Marsh during 2016 (*e.g.*, Sacramento splittail and threadfin shad) were also low in abundance in the greater estuary, highlighting the increasing importance of Suisun Marsh for desirable fishes and invertebrates.

ACKNOWLEDGEMENTS

Sampling in Suisun Marsh has been the responsibility of many graduate students and others over the years, including Donald Baltz, Robert Daniels, Bruce Herbold, Lesa Meng, Scott Matern, Robert Schroeter, Patrick Crain, John Durand, Alpa Wintzer, and Sabra Purdy. They have been assisted by literally hundreds of volunteers and student assistants. Special thanks to Phil Antipa, Kathleen Berridge, Scotty McDonald, Chris Jasper, Jacob Montgomery, Joshua Porter, Paul Takemoto, Mike Wigginton, and Brian Williamson, all of who helped out tremendously during the 2016 sampling year. Special thanks also to Amber Manfree for the maps in this report. Special thanks to Laura Bermudez of DWR for providing the 15-minute water-quality data. We appreciate the continued support of the sampling program over the years by DWR. Randall Brown of DWR kept the program going during its early uncertain years. The views expressed in this report are those of the authors and do not reflect the official policy or position of DWR.

REFERENCES

- Allen, K. O. and J. W. Avault. 1971. Notes on the relative salinity tolerance of channel and blue catfish. *Progressive Fish Culturist* 33(3): 135-137.
- Baumsteiger, J., R. Schroeter, T. O'Rear, J. Cook, and P. Moyle. 2017. Long-term surveys show invasive overbite clams (*Potamocorbula amurensis*) are spatially limited in Suisun Marsh, California. *San Francisco Estuary and Watershed Science* (in press).
- Brown, T. and K. A. Hieb. 2014. Status of the Siberian prawn, *Exopalaemon modestus*, in the San Francisco Estuary. *San Francisco Estuary and Watershed Science* 12(1).
- CDFW. 2017. Trends in abundance of selected species. Available: <http://www.dfg.ca.gov/delta/data/fmwt/Indices/index.asp> (March 2017).
- Cloern, J. E., K. A. Hieb, T. Jacobson, B. Sanso, E. Di Lorenzo, M. T. Stacey, J. L. Largier, W. Meiring, W. T. Peterson, T. M. Powell, M. Winder, and A. D. Jassby. 2010. Biological communities in San Francisco Bay track large-scale climate forcing over the North Pacific. *Geophysical Research Letters* 37: 1-6.
- DWR. 2017a. Interagency ecological program. Available: www.iep.water.ca.gov (March 2017).
- DWR. 2017b. Monthly climate summaries. Available: http://www.water.ca.gov/floodmgmt/hafoo/csc/climate_data/# (March 2017).
- DWR. 2001. Comprehensive Review Suisun Marsh Monitoring Data 1985-1995. California, California Department of Water Resources.
- DWR. 1984. Plan of Protection for the Suisun Marsh. California, California Department of Water Resources.
- Feyrer, F., J. E. Cloern, L. R. Brown, M. A. Fish, K. A. Hieb, and R. Baxter. 2015. Estuarine fish communities respond to climate variability over both river and ocean basins. *Global Change Biology* 21: 3608-3619.
- Feyrer, F., B. Herbold, S. A. Matern, and P. B. Moyle. 2003. Dietary shifts in a stressed fish assemblage: consequences of a bivalve invasion in the San Francisco Estuary. *Environmental Biology of Fishes* 67: 277-288.
- Feyrer, F., M. L. Nobriga, and T. R. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 64:723-734.
- Feyrer, F., T. Sommer, and B. Harrell. 2006. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. *Hydrobiologia* 573: 213-226.
- Feyrer, F. T. Sommer, and S. B. Slater. 2009. Old school vs. new school: status of threadfin shad (*Dorosoma petenense*) five decades after its introduction to the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science* 7(1).
- Gleason, T. R., and D. A. Bengtson. 1996. Size-selective mortality in inland silversides: evidence from otolith microstructure. *Transactions of the American Fisheries Society* 125: 860-873.
- Hatfield, S. 1985. Seasonal and interannual variation in distribution and population abundance of the shrimp *Crangon franciscorum* in San Francisco Bay. *Hydrobiologia* 129: 199-210.
- Hubbs, C. 1982. Life history dynamics of *Menidia beryllina* from Lake Texoma. *American Midland Naturalist* 107(1): 1-12.
- Kendall, A. W., and F. J. Schwatz. 1968. Lethal temperature and salinity tolerances of the white catfish, *Ictalurus catus*, from the Patuxent River, Maryland. *Chesapeake Science* 9: 103-108.
- Krygier, E. E., and H. F. Horton. 1975. Distribution, reproduction, and growth of *Crangon nigricauda* and *Crangon franciscorum* in Yaquina Bay, Oregon. *Northwest Science* 49: 216-240.
- Manfree, A. D. 2017. Suisun Marsh Fish Study sampling sites 2016 [map]. (ca. 1:88990). Davis, CA.
- Markle, D. F. 1976. The seasonality of availability and movements of fishes in the channel of the York River, Virginia. *Chesapeake Science* 17: 50-55.

- Matern, S. A., P. B. Moyle, and L. C. Pierce. 2002. Native and alien fishes in a California estuarine marsh: twenty-one years of changing assemblages. *Transactions of the American Fisheries Society* 131: 797-816.
- Meek, M., A. Wintzer, N. Sheperd, and B. May. 2012. Genetic diversity and reproductive mode in two non-native hydromedusae, *Maotias marginata* and *Moerisia* sp., in the Upper San Francisco Estuary, California. *Biological Invasions*. 15(1): 199-212.
- Meng, L., and S. A. Matern. 2001. Native and alien larval fishes of Suisun Marsh, California: the effects of freshwater flow. *Transactions of the American Fisheries Society* 130: 750-765.
- Meng, L., P. B. Moyle, and B. Herbold. 1994. Changes in abundance and distribution of native and alien fishes of Suisun Marsh. *Transactions of the American Fisheries Society* 123: 498-507.
- Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and population dynamics of Sacramento splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: a review. *San Francisco Estuary and Watershed Science* 2(2): Article 3.
- Moyle, P. B., R. A. Daniels, B. Herbold, and D. M. Baltz. 1986. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. *U. S. National Marine Fisheries Service Fishery Bulletin* 84(1): 105-117.
- Moyle, P. B., A. D. Manfree, and P. L. Fielder. 2014. *Suisun Marsh: ecological history and possible futures*. United States, University of California Press.
- Nicolini, M. H., and D. L. Penry. 2000. Spawning, fertilization, and larval development of *Potamocorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. *Pacific Science* 54: 377-388.
- Nobriga, M. L., and F. V. Feyrer. 2008. Diet composition in San Francisco Estuary striped bass: does trophic adaptability have its limits? *Environmental Biology of Fishes* 83: 495-503.
- O'Rear, T. A., and P. B. Moyle. 2017. *Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2015 - December 2015*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2016. *Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2014 - December 2014*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2015. *Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2013 - December 2013*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2014a. *Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2012 - December 2012*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2014b. *Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2011 - December 2011*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2014c. *Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2010 - December 2010*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2014d. *Trends in fish and invertebrate populations of Suisun Marsh January 2009 - December 2009*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2009. *Trends in Fish Populations of Suisun Marsh January 2008 - December 2008*. California, California Department of Water Resources.
- O'Rear, T. A., and P. B. Moyle. 2008. *Trends in Fish Populations of Suisun Marsh January 2006 - December 2007*. California, California Department of Water Resources.
- Rosenfield, J. A., and R. D. Baxter. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. *Transactions of the American Fisheries Society* 136: 1577-1592.

- Schoelhamer, D. H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. *Estuaries and Coasts* 34: 885-899.
- Schroeter, R., A. Stover, and P. B. Moyle. 2006. Trends in Fish Populations of Suisun Marsh January 2005 - December 2005. California, California Department of Water Resources.
- Siegel, S., P. Bachand, D. Gillenwater, S. Chappel, B. Wickland, O. Rocha, M. Stephenson, W. Heim, C. Enright, P. Moyle, P. Crain, B. Downing, and B. Bergamaschi. 2011. Final evaluation memorandum, strategies for reducing low dissolved oxygen and methylmercury events in northern Suisun Marsh. Prepared for the State Water Resources Control Board, Sacramento, California. SWRCB Project Number 06-283-552-0.
- Sommer, T., R. Baxter, and B. Herbold. 1997. Resilience of splittail in the Sacramento-San Joaquin Estuary. *Transactions of the American Fisheries Society* 126: 961-976.
- Vincik, R. F. 2002. Adult Chinook salmon migration monitoring at the Suisun Marsh Salinity Control Gates, Sept. - Nov. 2001. *Interagency Ecological Program Newsletter* 15(2): 45-48.
- Wintzer, A.P., M. H. Meek, and P. B. Moyle. 2011a. Life history and population dynamics of *Moerisia* sp., a non-native hydrozoan, in the upper San Francisco Estuary (U.S.A.). *Estuarine and Coastal Shelf Science* 94: 48-55.
- Wintzer, A.P., M.H. Meek, and P. B. Moyle. 2011b. Trophic ecology of two non-native hydrozoan medusae in the upper San Francisco Estuary. *Marine and Freshwater Research* 62: 952-961.
- Wintzer, A., M. Meek, P. Moyle, and B. May. 2011c. Ecological insights into the polyp stage of non-native hydrozoans in the San Francisco Estuary. *Aquatic Ecology* 5(2): 151-161.

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 2016 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
American shad	<i>Alosa sapidissima</i>	1591	306		1897
bay pipefish	<i>Sygnathus leptorhynchus</i>	2			2
bigscale logperch	<i>Percina macrolepida</i>	17	2		19
black bullhead	<i>Ameiurus melas</i>	882	3		885
black crappie	<i>Pomoxis nigromaculatus</i>	2092	116	1	2209
bluegill	<i>Lepomis macrochirus</i>	20	18		38
brown bullhead	<i>Ameiurus nebulosus</i>	29			29
California halibut	<i>Paralichthys californicus</i>	9	3		12
channel catfish	<i>Ictalurus punctatus</i>	175	7		182
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	73	405	1	479
common carp	<i>Cyprinus carpio</i>	5316	521	1	5838
delta smelt	<i>Hypomesus transpacificus</i>	664	144	4	812
fathead minnow	<i>Pimephales promelas</i>	36	38		74
golden shiner	<i>Notemigonus crysoleucas</i>	9	12		21
goldfish	<i>Carassius auratus</i>	305	49		354
green sturgeon	<i>Acipenser medirostris</i>	3			3
green sunfish	<i>Lepomis cyanellus</i>	5	3		8
hardhead	<i>Mylopharadon conocephalus</i>	1			1
hitch	<i>Lavinia exilicauda</i>	123	16		139
largemouth bass	<i>Micropterus salmoides</i>		3		3
longfin smelt	<i>Spirinchus thaleichthys</i>	11867	53	5	11925
longjaw mudsucker	<i>Gillichthys mirabilis</i>	1			1
Mississippi silverside	<i>Menidia audens</i>	1284	93523		94807
northern anchovy	<i>Engraulis mordax</i>	329		37	366
Pacific herring	<i>Clupea harengus</i>	483	136		619
Pacific lamprey	<i>Lampetra tridentata</i>	48			48
Pacific sanddab	<i>Citharichthys sordidas</i>	3	2		5
plainfin midshipman	<i>Porichthys notatus</i>	20			20
prickly sculpin	<i>Cottus asper</i>	11003	1009	1	12013
rainbow trout	<i>Oncorhynchus mykiss</i>	9	4		13
rainwater killifish	<i>Lucania parva</i>	35	137		172
redeer sunfish	<i>Lepomis microlophus</i>	2	1		3
river lamprey	<i>Lampetra ayresi</i>	3			3
Sacramento blackfish	<i>Orthodon macrolepidotus</i>	26	116		142

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
Sacramento pikeminnow	<i>Ptychocheilus grandis</i>	159	262		421
Sacramento splittail	<i>Pogonichthys macrolepidotus</i>	32584	4608	14	37206
Sacramento sucker	<i>Catostomus occidentalis</i>	3413	119	5	3537
shimofuri goby	<i>Tridentiger bifasciatus</i>	10687	2649	1	13337
shiner perch	<i>Cymatogaster aggregata</i>	17			17
shokihaze goby	<i>Tridentiger barbatus</i>	932	5	6	943
speckled sanddab	<i>Citharichthys stigmaeus</i>	3			3
staghorn sculpin	<i>Leptocottus armatus</i>	2579	3439		6018
starry flounder	<i>Platichthys stellatus</i>	2060	280	4	2344
striped bass	<i>Morone saxatilis</i>	88359	15215	30	103604
striped mullet	<i>Mugil cephalus</i>		1		1
surf smelt	<i>Hypomesus pretiosus</i>	5			5
threadfin shad	<i>Dorosoma petenense</i>	3157	5952	1	9110
threespine stickleback	<i>Gasterosteus aculeatus</i>	17715	6634	6	24355
tule perch	<i>Hysterocarpus traski</i>	21485	2383	6	23874
wakasagi	<i>Hypomesus nipponensis</i>	10	6		16
warmouth	<i>Lepomis gulosus</i>	1			1
western mosquitofish	<i>Gambusia affinis</i>	18	362		380
white catfish	<i>Ameiurus catus</i>	5897	166	13	6076
white crappie	<i>Pomoxis annularis</i>	112			112
white croaker	<i>Genyonemus lineatus</i>	2			2
white sturgeon	<i>Acipenser transmontanus</i>	118		2	120
yellowfin goby	<i>Acanthogobius flavimanus</i>	19862	17450		37312
Total		245640	156158	138	401936

APPENDIX B: 2016 CATCHES

Total 2016 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold).

Species	Slough											Total
	Boyn-ton	Cut-off	Den-vertion	First Mallard	Good-year	lower Suisun	Monte-zuma	Monte-zuma New	Nurse	Peytonia	upper Suisun	
American shad	3	1	44	13	52	40	4		6	13	1	177
black bullhead										1		1
black crappie			20				1		1	1		23
bluegill		1										1
California halibut			1			3						4
common carp	7		4	1	1	1		2	1	10	1	28
goldfish	1											1
longfin smelt			2									2
Mississippi silverside			11	24	7							42
northern anchovy				1	2	4						7
Pacific herring					1							1
plainfin midshipman							1					1
prickly sculpin	19	22	36	10	65	31	9	5	12	22	6	237
rainwater killifish	3											3
Sacramento pikeminnow			1	3			3					7
Sacramento splittail	85	161	572	196	195	52	79	22	308	248	187	2105
Sacramento sucker	4	1	1	4						6		16
shimofuri goby	46	63	113	18	25	9	14	16	110	21	25	460
shokihaze goby	2		1		17	8	12	16	18		22	96
staghorn sculpin					1	1						2
starry flounder			4	2		1	3	13	8	2	2	35
striped bass	119	78	347	280	119	250	187	54	223	153	125	1935
threadfin shad	1		47	10	1		48		73	1	3	184
threespine stickleback	2	8	11	4	25	18	8	8	7	1	7	99
tule perch	43	39	143	30	3	2	3	1	198	125	49	636
white catfish	2		10	2				1		5		20
white sturgeon									1			1
yellowfin goby	5	6	11	7	6	43	18	7	12	8	13	136
Total	342	380	1379	605	520	463	390	145	978	617	441	6260

Total 2016 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	17	5		22
Chinook salmon	6	3		9
goldfish			1	1
Mississippi silverside	1992	1089	941	4022
Pacific herring		2	1	3
prickly sculpin	9	2	11	22
rainwater killifish	3	7	5	15
Sacramento pikeminnow	3	27		30
Sacramento splittail	124	374	54	552
Sacramento sucker		3		3
shimofuri goby	77	19	31	127
staghorn sculpin		2		2
starry flounder	1	3	4	8
striped bass	469	86	172	727
striped mullet	1			1
threadfin shad	197	261	61	519
threespine stickleback	21	30	99	150
tule perch	9	53	39	101
western mosquitofish	2	2	3	7
white catfish	1	1		2
yellowfin goby	24	69	133	226
Total	2956	2038	1555	6549

APPENDIX C: 2016 EFFORT

Number of otter trawls in each slough and each month in 2016.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	2	2	2	2	2	2	2	2	2	2	2	2	24
Cutoff	2	2	2	2	2	2	3	2	2	2	2	2	25
Denverton	3	3	3	3	3	3	3	3	3	3	3	3	36
First Mallard	2	2	2	2	2	2	2	2	2	2	2	2	24
Goodyear	3	3	3	3	3	3	3	3	3	3	3	3	36
lower Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma new	1	1	1	1	1	1	1	1	1	1	1	1	12
Nurse	3	3	3	3	3	3	3	3	3	3	3	3	36
Peytonia	2	2	2	2	2	2	2	2	2	2	2	2	24
upper Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Total	24	24	24	24	24	24	25	24	24	24	24	24	289

Number of beach seines in each slough and each month in 2016.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	2	3		3	2	3	3	3	3	2	2	29
Montezuma new	3	3	3	3	3	3	3	3	2	3	3	3	35
upper Suisun	3	3	3	3	3	2	3	3	3	3	2	2	33
Total	9	8	9	6	9	7	9	9	8	9	7	7	97