

UC Davis

UC Davis Previously Published Works

Title

Suisun Marsh Fish Study trends in fish and invertebrate populations of Suisun Marsh January 2013 - December 2013.

Permalink

<https://escholarship.org/uc/item/09q0x2qt>

Authors

O'Rear, Teejay Alexander
Moyle, Peter B

Publication Date

2015

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 2013 - December 2013

**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

University of California, Davis

December 2015

SUMMARY

Suisun Marsh, at the geographic center of the San Francisco Estuary, is important habitat for introduced and 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 main purpose of the study has been to determine environmental and anthropogenic factors affecting fish distribution and abundance.

2013 was a dry year, with lower-than-average Delta outflow and, concomitantly, higher-than-average salinities throughout most of the year. Except for notably cold temperatures in January and February, water temperatures were relatively normal. Dissolved-oxygen concentrations were at sufficient levels for most fishes throughout the year, while water transparencies were higher than usual during summer and autumn.

In 2013, 275 otter trawls and 101 beach seines were conducted. Catches of invertebrates and fishes reflected in part the dry, saltier year. Numbers of Siberian prawn (*Exopalaemon modestus*) and California bay shrimp (*Crangon franciscorum*) were both down, while overbite clam (*Potamocorbula amurensis*) abundance increased dramatically. Low recruitment of fishes spawned primarily upstream of the marsh [*e.g.*, Sacramento splittail (*Pogonichthys macrolepidotus*), white catfish (*Ameiurus catus*), striped bass (*Morone saxatilis*)] resulted in lower-than-average otter trawl catches for both introduced and native fishes in 2013. Conversely, high numbers of age-0 longfin smelt (*Spirinchus thaleichthys*) were caught, which was surprising given the positive relationship between longfin smelt and Delta outflow. Beach seine catches were about average, with declines in some native and introduced fishes matched by increases in other species. Mississippi silverside (*Menidia audens*) were relatively abundant, likely due to favorable water temperatures extending the spawning period.

TABLE OF CONTENTS

Introduction.....	4
Methods.....	6
Results and Discussion.....	12
Abiotic Conditions.....	12
Trends in Invertebrate Distribution and Abundance.....	19
Trends in Fish Distribution and Abundance.....	21
Conclusion.....	31
Acknowledgements.....	32
References.....	33
Appendices.....	37

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 expanse of 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 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 to better understand their ecology (Matern and Meng 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.*, O'Rear 2012). 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); contributing to the general understanding of estuarine systems through publication of peer-reviewed papers (*e.g.*, Matern *et al.* 2002); 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 species 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 tended to be more prevalent in small, shallow sloughs, while introduced 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, introduced 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 negative effects of drought and high salinity on 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 both bolstered previous findings and enhanced understanding of the aquatic ecosystem's food web. O'Rear and Moyle (2014*a, b*, 2009) found that the timing, variability, and magnitude of Delta outflow continued to be important factors affecting abundance of fishes recruiting into the marsh from upstream and downstream areas [*e.g.*, striped bass, yellowfin goby (*Acanthogobius flavimanus*), respectively]. Additionally, a limitation in pelagic food appeared to occur sometime in summer that resulted in an inshore movement of fishes (O'Rear and Moyle 2013*a*). Studies on introduced jellyfish found a high likelihood of competition for food between the jellyfish and two pelagic fishes [threadfin shad (*Dorosoma petenense*) and delta smelt (*Hypomesus transpacificus*); Wintzer *et al.* 2011*b*]. O'Rear (2012) discovered that white catfish mostly ate food from managed wetlands from autumn through spring while subsisting on bay-produced or slough-produced food during summer; unlike previous studies in the Sacramento-San Joaquin Delta (Turner 1966), white catfish in Suisun Marsh never ate at-risk fishes. 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. Finally, data from an ongoing companion study (the "Arc Project") sampling the North Delta, Sherman Lake, and Suisun Marsh have been revealing that the marsh provides increasingly vital habitat for at-risk native species. For example, Sacramento splittail have been far less abundant in the North Delta and Sherman Lake, two regions considered good native-fish habitat, relative to Suisun Marsh (M. Young, UC Davis, unpublished data). 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).

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 (Moyle *et al.* 2014, M. Young, UC Davis, personal communication, 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. There are two major subtidal channels in the marsh: Montezuma and Suisun sloughs (Figure 1). Montezuma Slough generally arcs northwest from the confluence of the Sacramento and San Joaquin rivers, then curves southwest and terminates at Grizzly Bay (the major embayment of Suisun Bay). Major tributary sloughs to Montezuma are Denverton and Nurse; Cutoff Slough and Hunter Cut connect Suisun and Montezuma sloughs (Figure 1). Suisun Slough begins near Suisun City and meanders south until emptying into Grizzly Bay southwest of the mouth of Montezuma Slough. Major 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>).

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 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.*, Denverton Slough; Matern *et al.* 2002), and the larger, deeper sloughs (*e.g.*, Montezuma Slough) can have sandy channel beds.

The amount of fresh water flowing into Suisun Marsh is the major determinant of its salinity. Fresh water enters the marsh primarily from the western Delta through Montezuma Slough, although small creeks, particularly on the northwest 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. 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 through lower Suisun and lower Montezuma sloughs from Grizzly Bay via tidal action, although the effect of the tides is more pronounced on water-surface elevation and less so 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.

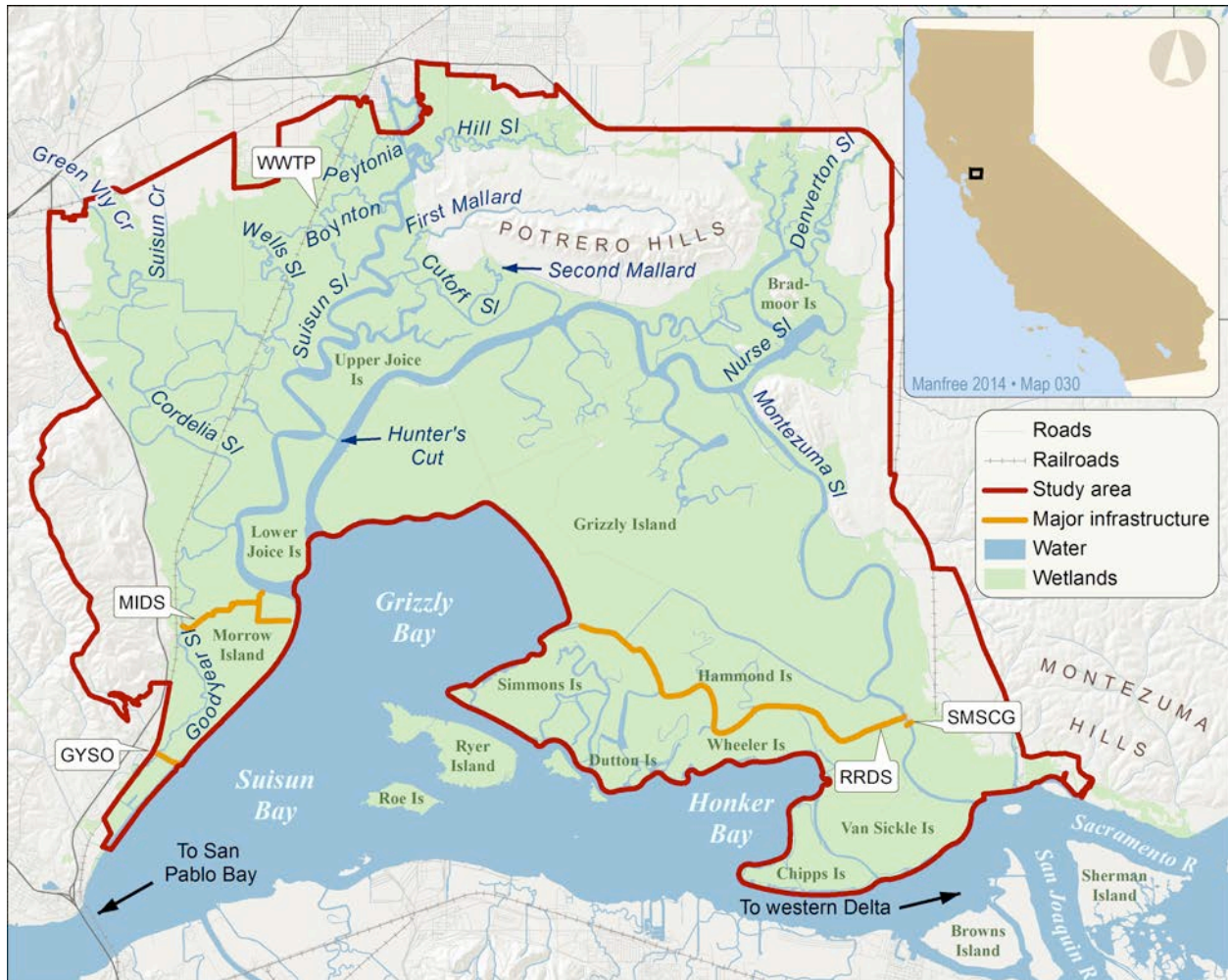


Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point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

A number of 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 endangered fishes. 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; the wastewater's salinity and the DO are often low and high, respectively (Figure 1; Siegel *et al.* 2011).

Sampling

Since 1980, monthly juvenile and adult fish sampling has been conducted 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 (see O'Rear and Moyle 2008). From 1994 to the present, 21 sites in nine sloughs have been regularly sampled by otter trawl (Figure 2). Exploratory sampling in the North Delta and Sherman Lake regions in 2011 revealed relatively high native-fish abundances (DeCarion *et al.* 2012) and spurred the Arc Project, a study being conducted by researchers at the UC Davis Center for Watershed Sciences (<https://watershed.ucdavis.edu/project/north-delta-arc-native-fishes-0>). The Arc Project has used, in part, identical sampling techniques as the Suisun Marsh Fish Study. In November 2012, two additional sites - one historical (MZ6) and one new (MZN3; Figure 2) - were added to the monthly Suisun Marsh Fish Study sampling for the Arc Project. Because the MZ6 and MZN3 sites were sampled throughout 2013, their otter trawl data are included in this report (grouped together under "MZN"). Several additional sites were sampled intermittently in 2013 for other projects, but their data are not included in monthly or slough-to-slough comparisons due to the infrequent sampling. Because of personnel injuries, endangered-species take issues, and equipment failure, otter trawl sampling in 2013 was incomplete in May and August (see Appendix C for un-sampled sites); no DO data are available for July 2013. Beach seining in Denverton and upper Suisun sloughs, however, was conducted for all months of 2013.

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, μS) were recorded with a Yellow Springs Instruments (YSI) 85 meter. Dissolved oxygen parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also measured with the YSI 85. Water transparency (Secchi depth, cm), tidal stage (ebb, flood, high, low), and water depths (m) were also recorded.

Contents of each trawl or seine were placed into large containers of water. Fishes were identified, measured to the nearest mm standard length (mm SL), and 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 rare Suisun Marsh clam 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. However, 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.

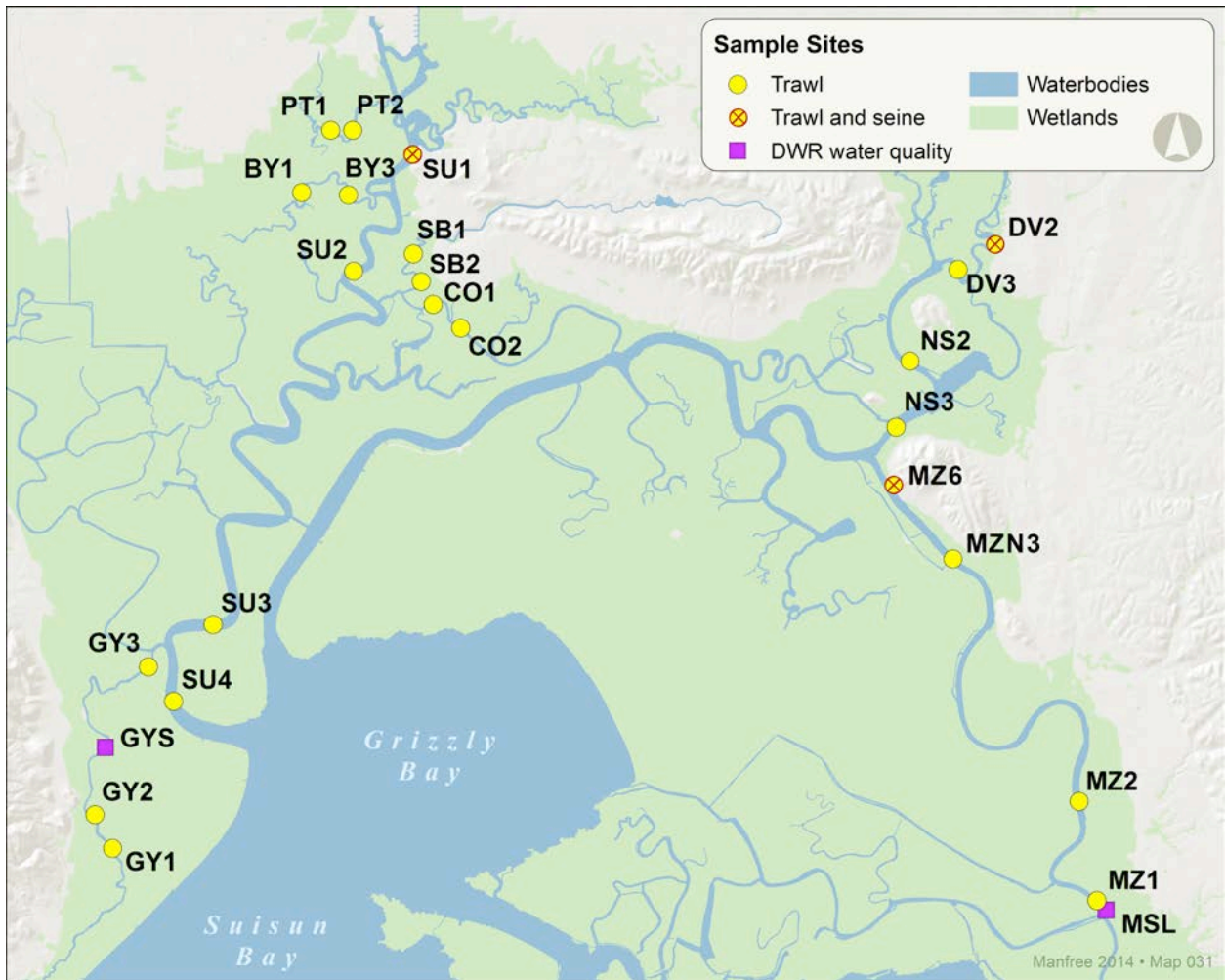


Figure 2. Current Suisun Marsh Fish Study sampling sites and DWR water-quality monitoring stations used in this report (map by Amber Manfree).

Data analysis

For this report, catch-per-unit-effort (CPUE) values were calculated differently depending on the type of comparison. For comparisons made among calendar years, CPUE for

beach seines and otter trawls was calculated as

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

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

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

where i = slough, j = month, and n is the number of sloughs; once again, CPUE values for invertebrates were calculated likewise. To describe geographic distribution, proportion of the 2013 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 2013 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." Fifteen-minute salinity and water-temperature data from DWR fixed stations - GYS and MSL (Figure 2) - were graphed with the water-quality data collected with the fish sampling to provide additional context. These two were chosen because (1) they are the DWR stations closest to our fish-sampling sites and (2) they are in sloughs that exhibit opposing extremes of habitat conditions (*e.g.*, slough cross section, geographical position) and so serve as useful bookends. X2, the distance in kilometers from the Golden Gate Bridge along the thalweg to the near-bed water with salinity of 2 ppt, was calculated following Jassby *et al.* (1995). X2 location has historically been associated with high abundances of phytoplankton, macroinvertebrates, and several fishes (Jassby *et al.* 1995). When X2 has been within Suisun Bay, abundance of some fishes in Suisun Marsh has been relatively high (*e.g.*, longfin smelt; Rosenfield and Baxter 2007). 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 California Department of Water Resource's Dayflow website (2014).

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 Matern and Sommer (unpublished data). 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." Catch of all fishes and by each method from 1979 to 2013 are found in Appendix A; annual catch of each slough and number of trawls/seines in each slough in 2013 are found in appendices B and C.

Monthly water-quality results of 2013 were then graphed and compared to averages for all years of the study. Annual CPUE values for otter trawls and beach seines were graphed, as were monthly CPUE values for dominant invertebrate and fish species.

RESULTS AND DISCUSSION

Abiotic Conditions

Delta Outflow

Delta outflow in 2013 was below the all-years (*i.e.*, 1980 - 2013) average for nearly the entire year (Figure 3), consistent with DWR's "Dry" classification for the Sacramento River. Delta outflow was relatively high in the first half of January but then only rose notably once more - in early April - for the remainder of the year (Figure 3). Delta outflow from May to the end of the year generally declined mildly and steadily.



Figure 3. Daily Delta outflow in 2013 and the average for all years of the study (1980 - 2013; DWR 2014).

Salinity

Consistent with low Delta outflow in 2013, salinities in the marsh were higher than the average for all months except January (Figure 4). Average Suisun Marsh Fish Study salinities were always within bounds of the two fixed stations, although the study's average salinities tended to be closer to the MSL gauge's salinities except in September and October (Figure 5). The disparity in average salinity between 2013 and all years increased from April to October, after which the monthly salinities paralleled each other. Highest monthly salinities were always in the southwest marsh in either Goodyear Slough or, in October, lower Suisun Slough (*i.e.*, the SU3 and SU4 stations; Figure 2). Lowest salinities were in eastern Montezuma from January to May, in Boynton Slough during summer, and then Peytonia, Nurse, and eastern Montezuma in the last three months of the year, respectively. The relatively high salinities resulted in operation of the Suisun Marsh Salinity Control Gates throughout much of the control season (October - May); X2 was within Suisun Bay from mid-January to mid-March (Figure 4).

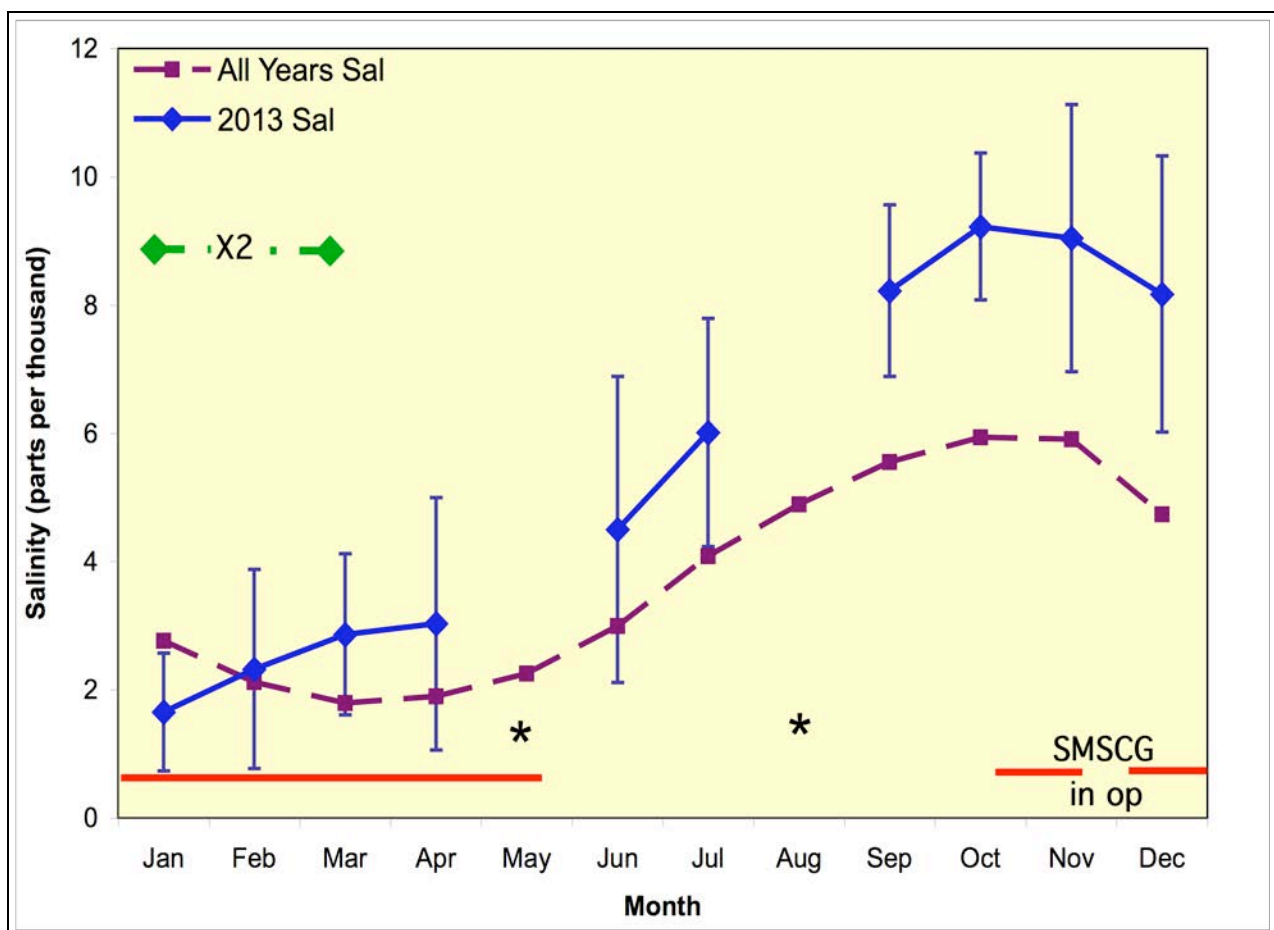


Figure 4. Monthly average salinity in 2013 and for all years of the study (1980 - 2013); error bars are standard deviations in 2013. Red bars show when the SMSCG were operating. X2 and the surrounding green, dashed bars show when X2 was within Suisun Bay (*i.e.*, between 55 and 75 km from Golden Gate Bridge). Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

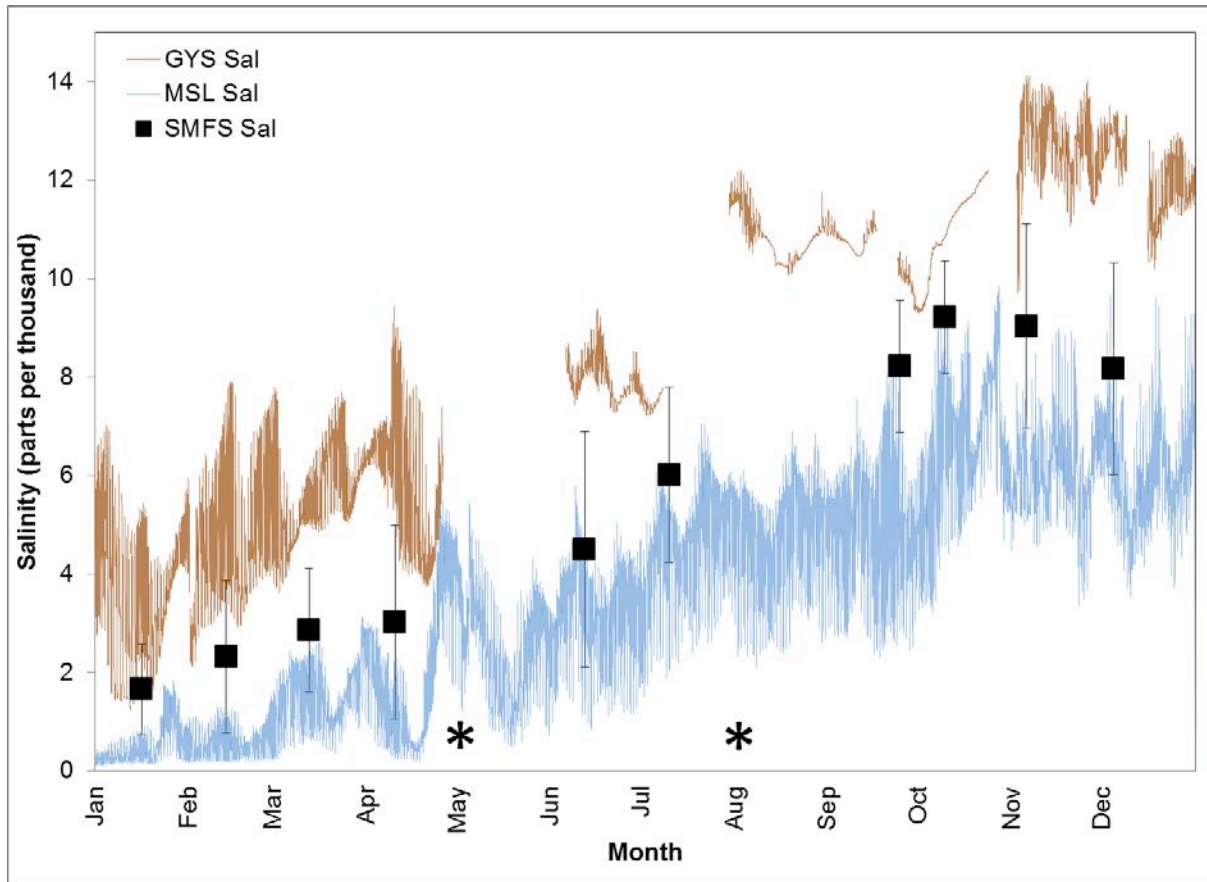


Figure 5. Fifteen-minute salinity from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average salinities and standard deviations from the Suisun Marsh Fish Study ("SMFS"). Asterisks denote months in 2013 with incomplete data for the Suisun Marsh Fish Study due to personnel injuries, endangered-species take issues, and equipment failure.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) concentrations in the marsh are affected by decomposition of organic material, temperature, salinity, wind, Delta outflow, and diverting and draining of duck ponds. 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. High Delta outflow can elevate DO levels via increased water mixing. Water discharged into sloughs from duck ponds 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. Thus because of managed-wetlands operations and environmental drivers, such as temperature, marsh DO is usually high in winter, lower in spring and summer, and lowest in autumn.

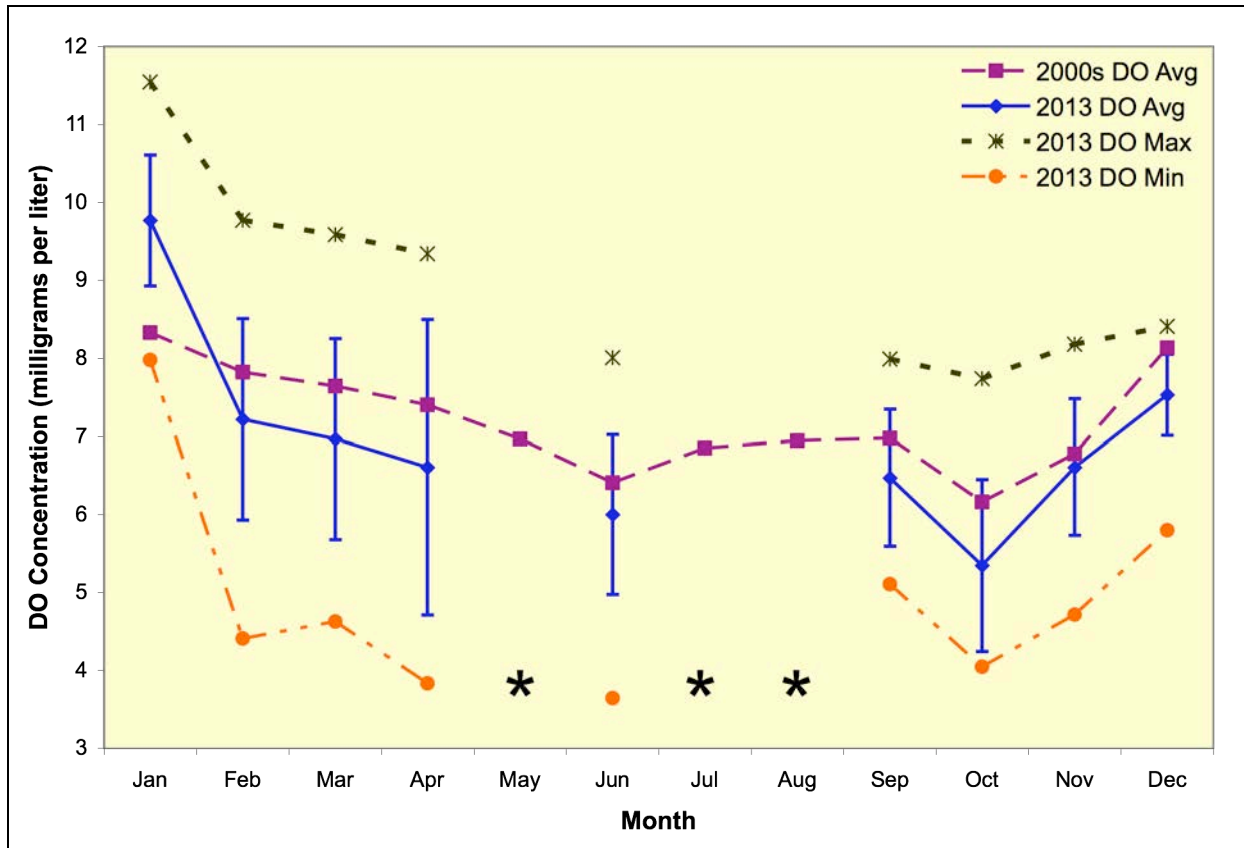


Figure 6. Monthly average DO concentration in 2013 and for the 2000s (2000 - 2013), maximum DO concentration in 2013, and minimum DO concentration in 2013. Error bars are standard deviations in 2012. Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

DO concentrations in 2013 followed the average trend for all months except in January 2013, when it was unusually high and coincided with a cold snap (Figure 6). For all months but January, DO was slightly lower in 2013 than the average for the 2000s. Trends in minimum and maximum DO paralleled well 2013's averages (Figure 6). Highest DO concentrations were always in eastern Montezuma Slough; lowest concentrations were always in small, diked sloughs (*i.e.*, Denverton, Boynton, Peytonia, and upper Goodyear sloughs).

Water Temperature

Water temperatures in 2013 were relatively normal except for the two first months when the water in 2013 was considerably cooler than usual, following the trends in air temperature for those months (Figure 7; DWR 2013a, b). Average water temperatures from the fish study in 2013 were within the ranges of the two fixed monitoring stations (Figure 8). The most extreme water temperatures from the fish study were always recorded in the smaller sloughs, with, for example, highest and lowest annual temperatures found in Denverton Slough (Figure 9). This was consistent with water temperature varying more in Goodyear Slough than in Montezuma Slough, with Goodyear attaining higher summer temperatures and lower winter temperatures than Montezuma (Figure 8).

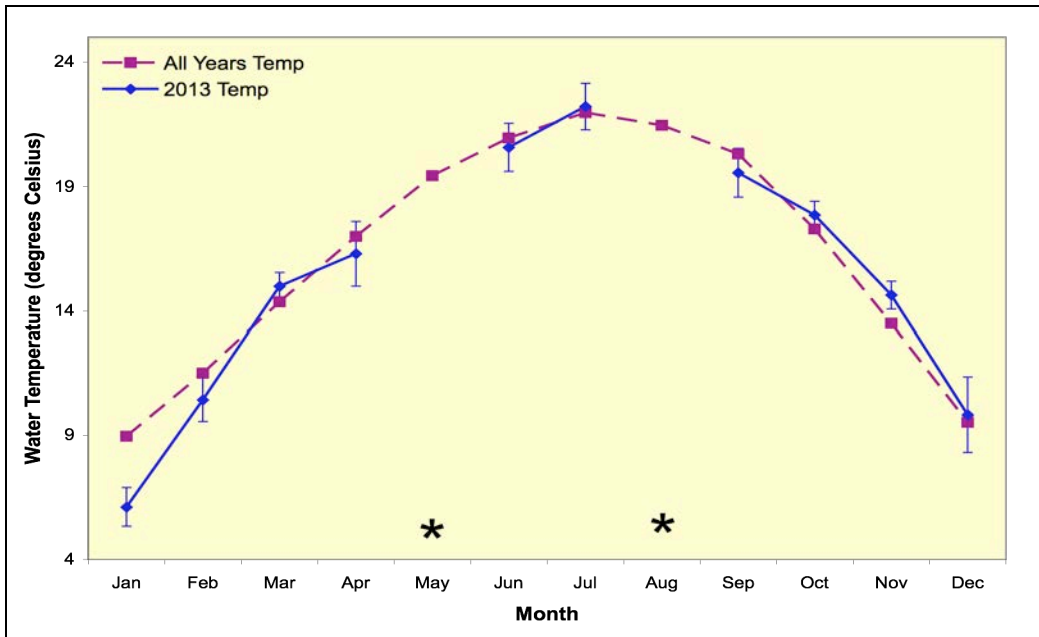


Figure 7. Monthly average water temperature in 2013 and for all years of the study (1980 - 2013); error bars are standard deviations in 2013. Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

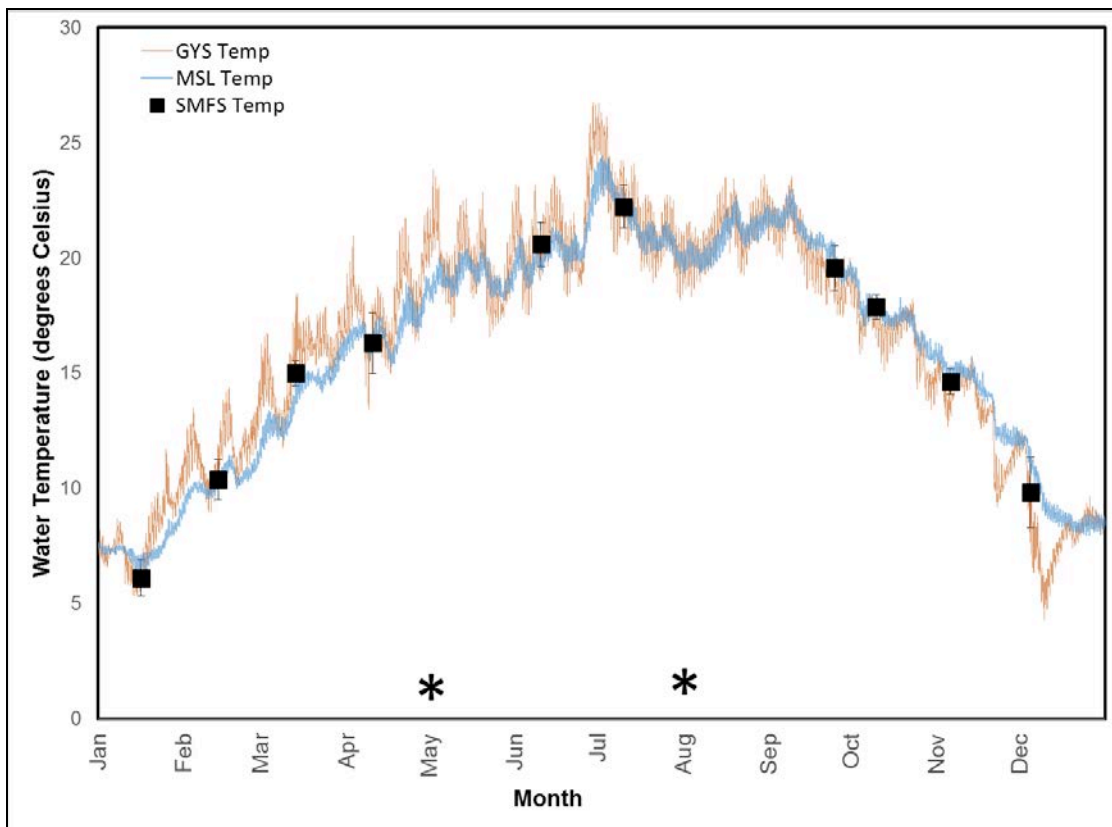


Figure 8. Fifteen-minute water temperatures from fixed stations in Goodyear Slough (GYS) and Montezuma Slough (MSL), with average temperatures and standard deviations from the Suisun Marsh Fish Study ("SMFS"). Asterisks denote months in 2013 with incomplete data for the Suisun Marsh Fish Study data due to personnel injuries, endangered-species take issues, and equipment failure.

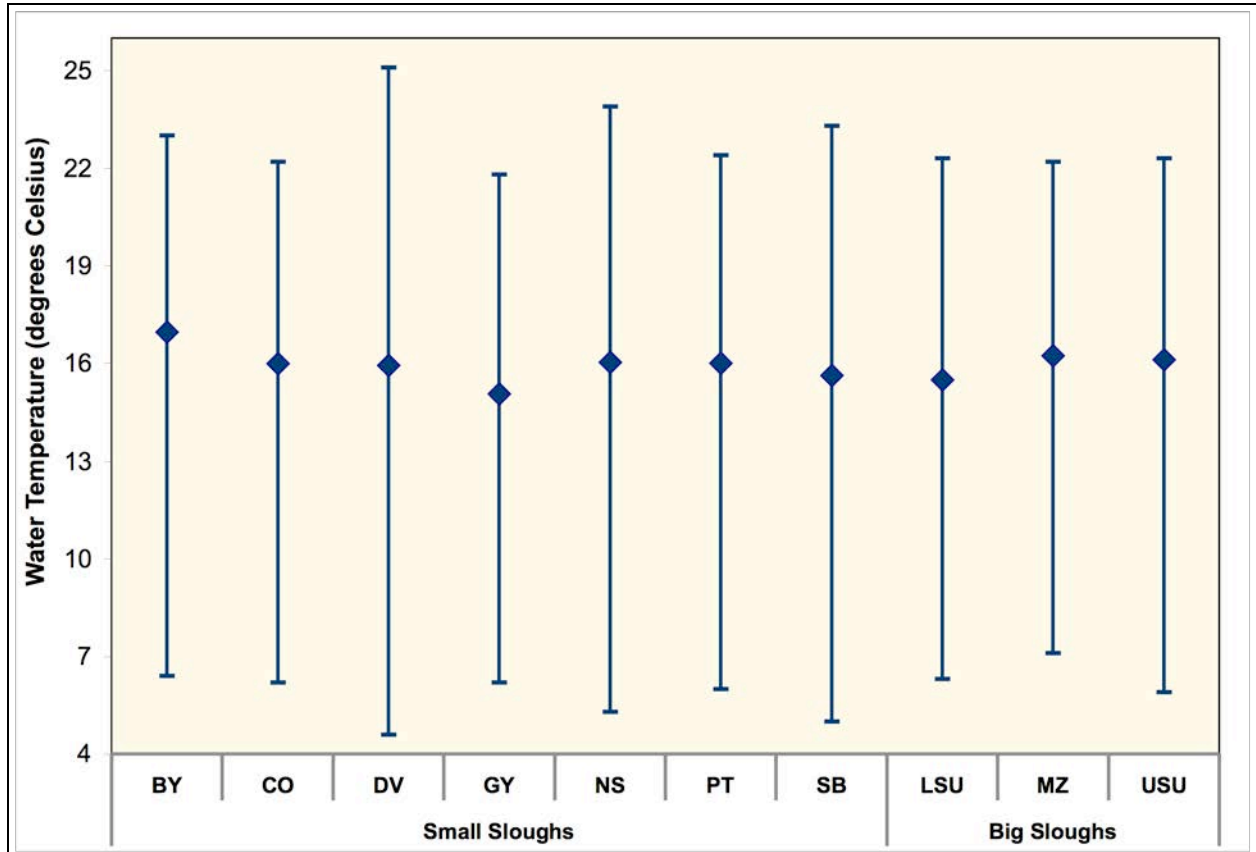


Figure 9. Annual average water temperatures and ranges for sloughs in 2013 ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "LSU" = lower Suisun Slough, "MZ" = Montezuma Slough, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "USU" = upper Suisun Slough).

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 2014*d*, 2008, Moyle *et al.* 1986). The dry year of 2013 followed this trend, with 6 of the 10 months of complete sampling exhibiting higher-than-average transparencies. Notably, transparencies in the first four months of 2013 were about the same as that for all years of the study, while they were considerably higher than average during summer and autumn (Figure 10). Lower transparencies were generally in small sloughs (*e.g.*, Denverton, First Mallard sloughs) distant from the western Delta and Grizzly Bay; eastern Montezuma, on average, had the clearest water of the sites sampled (Figure 11). Variability in transparency was similar among months except in April, when transparencies were generally lower and more even among the sloughs (Figure 10).

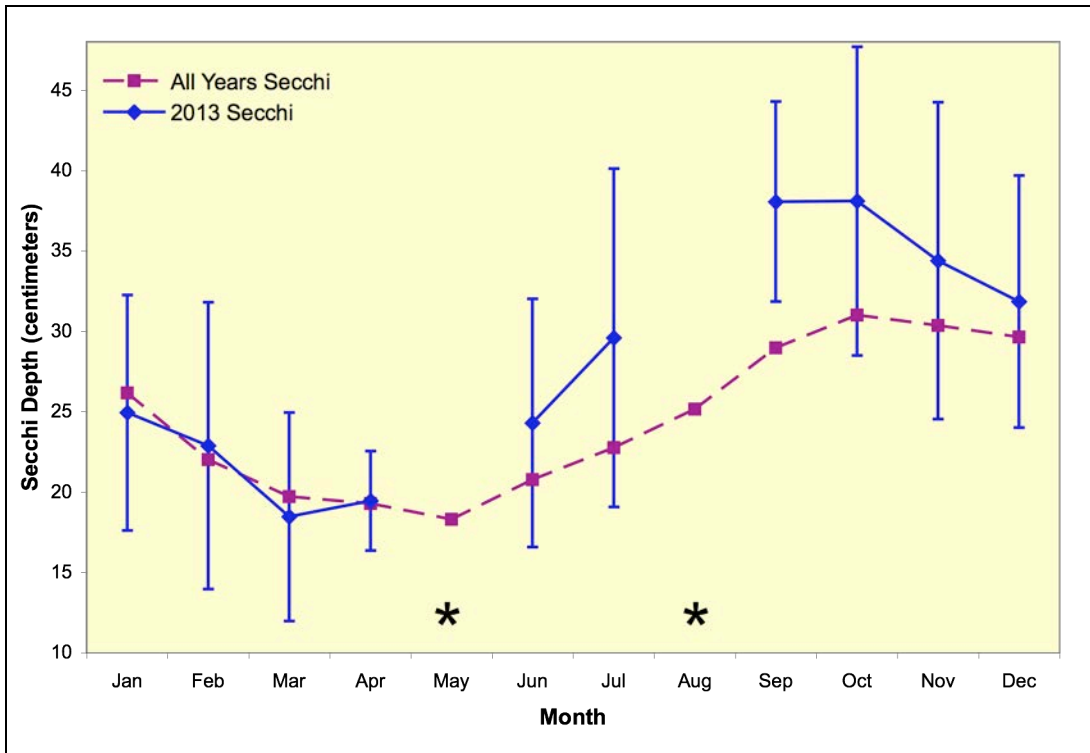


Figure 10. Monthly average water transparency in 2013 and for all years of the study (1980 - 2013); error bars are standard deviations in 2013. Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

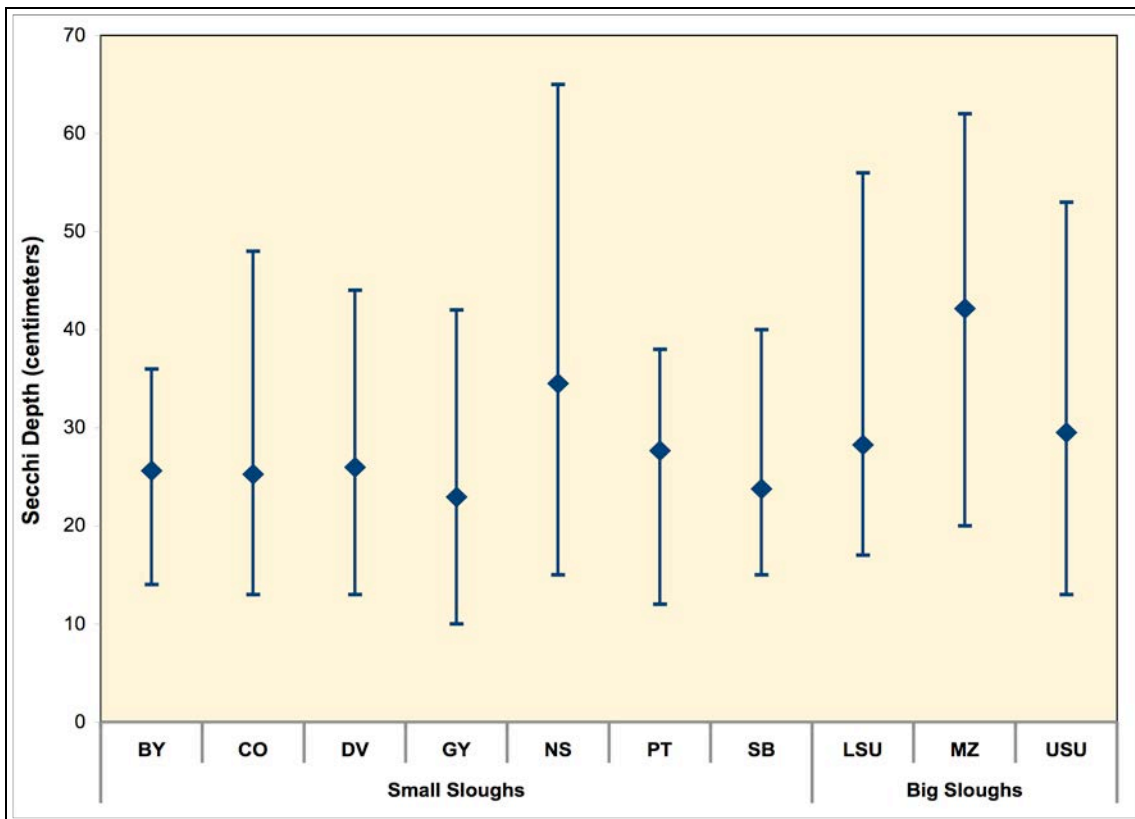


Figure 11. Annual average water transparencies and ranges for sloughs in 2013 (slough codes as in Figure 9).

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 food [*e.g.*, California bay shrimp and Siberian prawn (Nobriga and Feyrer 2008)] for fishes of the marsh.

Black Sea Jellyfish

Black Sea jellyfish annual CPUE declined by 71% from 2012 to 2013 (26 to 8 medusae per trawl; Figure 12), with the 2013 CPUE close to the average for the entire study period (8 and 7 medusae per trawl, respectively). However, Black Sea jellyfish are generally very abundant in August (Schroeter 2008), so the low CPUE in 2013 is due in part to no August data. Monthly CPUE was typical, with catches first occurring in July, reaching a maximum in September, and then steeply declining to November. Black Sea jellyfish were especially abundant in Montezuma and upper Suisun sloughs (35% and 21% of the 2013 catch, respectively) while being very rare in Denverton and Goodyear sloughs, with only 5 and 9 medusae caught in each smaller slough, respectively, in 2013.

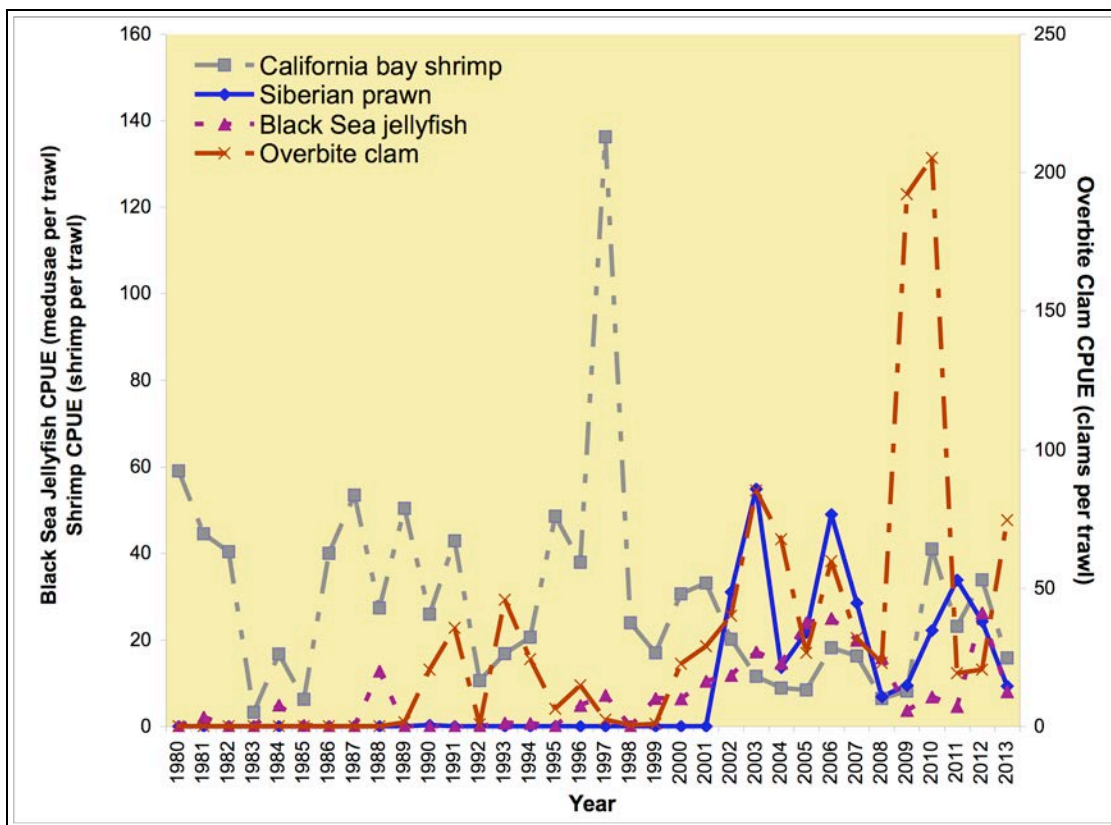


Figure 12. Annual otter trawl CPUE of four common macroinvertebrates.

Overbite Clam

Annual overbite-clam CPUE in 2013 increased tremendously from 2012 (75 and 21 clams per trawl, respectively) and was well above the average (40 clams per trawl) since 1988, the first year overbite clams were captured in the marsh. Overbite clams were especially abundant during summer and early autumn, likely due to relatively high salinities favoring recruitment of early life-history stages (Miller and Stillman 2013, Schroeter 2011, Nicolini and Penry 2000). Only 110 of the 19,682 overbite clams captured in 2013 were not from Suisun Slough, with the catch in Suisun Slough split nearly evenly between the upper (*i.e.*, SU1 and SU2; Figure 2) and lower reaches (48.7% and 50.7% of the annual catch, respectively). This is the fourth year in a row in which a substantial proportion of the overbite clam catch has been made in upper Suisun Slough. No overbite clams were captured in Denverton, Peytonia, or First Mallard sloughs, further supporting previous patterns that smaller sloughs in the marsh are inhospitable to the clam (O'Rear and Moyle 2014*d*, Schroeter 2011).

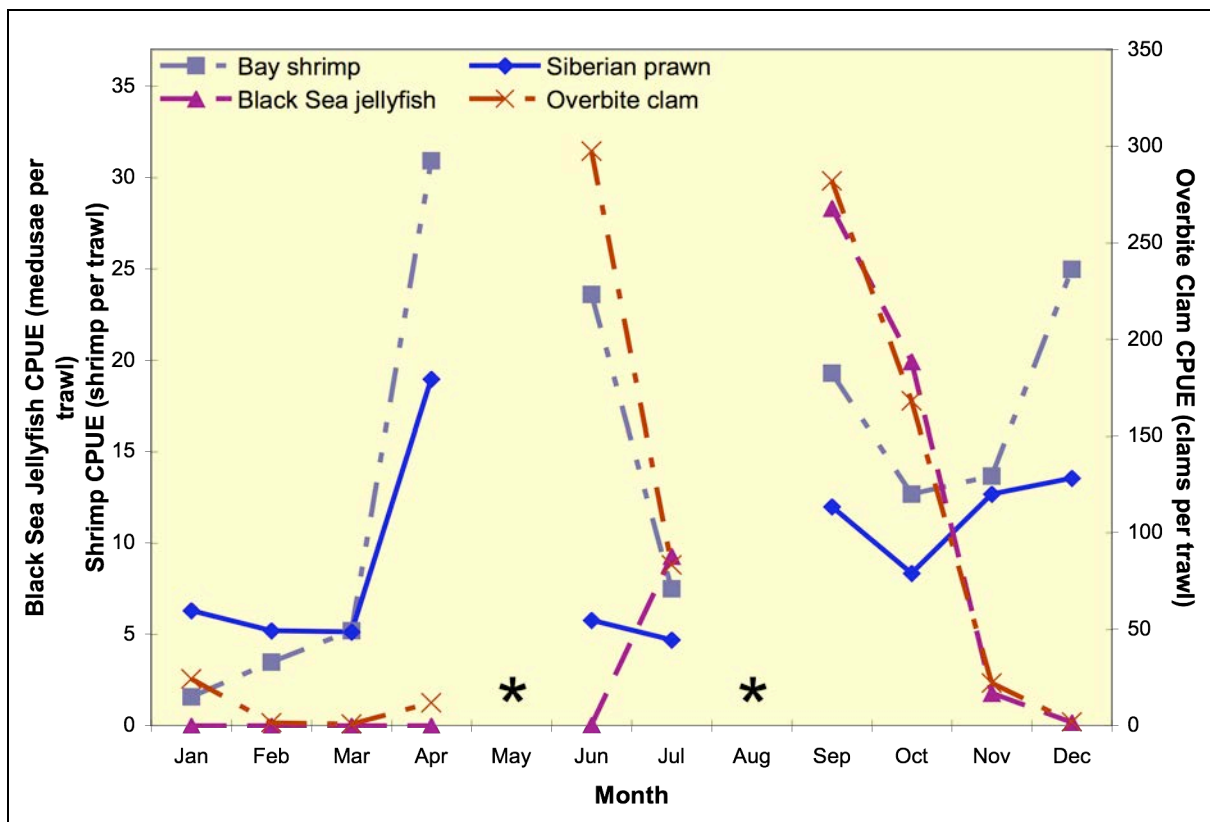


Figure 13. Monthly average CPUE of four common macroinvertebrates in Suisun Marsh in 2013. Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

California Bay Shrimp

California bay shrimp annual CPUE dropped by nearly half from 2012 to 2013 (34 and 16 shrimp per trawl, respectively) and was well below the average for the entire study period (29

shrimp per trawl; Figure 12). Monthly CPUE was low in the first three months of 2013, increased dramatically starting in April, and was relatively variable for the rest of the year. (Figure 13). The first high catch so early in 2013 (*i.e.*, April) was likely due to the dry, salty year; earlier recruitment in dry years has been observed throughout the estuary (O'Rear and Moyle 2014c, d, Hatfield 1985, Siegfried 1980). Most of the bay shrimp in 2013 were caught in the large sloughs, with Suisun and Montezuma sloughs comprising 50% and 23% of the annual catch, while four of the fresher, smaller interior sloughs - Denverton, First Mallard, Boynton, and Peytonia - together only comprised 7% of the catch. These patterns are consistent with both the bay shrimp's requirement for higher salinities (Krygier and Horton 1975) and the preference for deeper water as they grow (Israel 1936).

Siberian Prawn

Annual CPUE of Siberian prawn reached its second-lowest point in 2013 (9 shrimp per trawl) since its invasion around 2002, with only 2008 having a lower value (Figure 12). Monthly CPUE was relatively low during winter and summer and elevated somewhat in autumn (Figure 13). The highest monthly CPUE occurred in April concurrent with the freshening of the marsh, which likely transported more prawns from upstream areas into Suisun Marsh (Brown and Hieb 2014). Surprisingly, a large proportion - 35 % - of the catch in 2013 came from the saltier southwest marsh despite the prawn's association with fresher water (Brown and Hieb 2014, Emmett *et al.* 2002).

Trends in Fish Distribution and Abundance

Otter Trawls

Annual otter trawl CPUE declined from 23.7 fish per trawl in 2012 to 13.3 fish per trawl in 2013 (Figure 14). The 2013 CPUE was well below the average for the whole study (24.9 fish per trawl) and was the third-lowest value recorded in the study's history. The decline was more severe for introduced fishes, the CPUE for which dropped by 62% from 2012 to 2013 while native fishes only dropped by 13%. Striped bass and white catfish were the major introduced species responsible for the low 2013 CPUE (Table 1). Of native fishes, Sacramento splittail and prickly sculpin (*Cottus asper*) were also caught in lower numbers in 2013, although their contribution to the native annual CPUE was mitigated by increases in both tule perch (*Hysterocarpus traski*) and longfin smelt (Table 1). These CPUE values are likely biased low, however, since otter trawl sampling in May and August - two months of generally high fish abundance (O'Rear and Moyle 2008, Moyle *et al.* 1986) - in 2013 was incomplete. Nevertheless, low CPUE values for striped bass in other surveys in 2013 (*e.g.*, Fall Midwater Trawl, Summer Towntown Survey; Osborn *et al.* 2015), plus our beach seine data, which were complete (see below for discussion), intimate that fish abundances in 2013 were well below average.

Table 1. Percent change in annual otter trawl CPUE of six 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 - 2013 for all species except shimofuri goby, for which "all years" begins with the year of introduction (1985)].

Species	All Years CPUE	2012 CPUE	2013 CPUE	2013/2012 % Change
Sacramento splittail	2.7	5.9	3.5	-41%
longfin smelt	1.2	0.0	1.5	+275%
prickly sculpin	1.1	1.0	0.4	-60%
tule perch	2.0	0.9	1.7	+89%
white catfish	0.6	1.4	0.7	-50%
striped bass	9.5	10.8	3.1	-71%

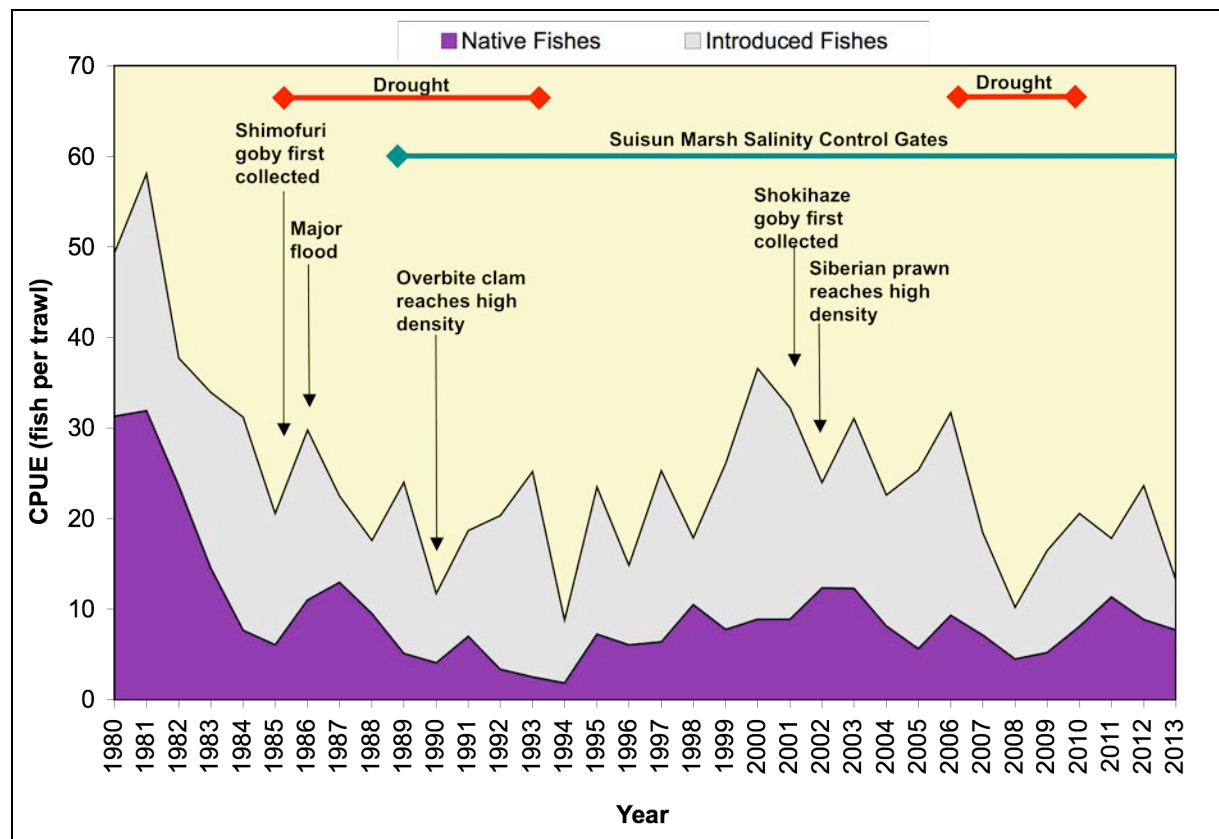


Figure 14. Annual otter trawl CPUE of native and introduced fishes, with important events highlighted.

Beach Seines

Annual beach seine CPUE in 2013 was slightly lower than in 2012 (46.4 and 59.1 fish per seine, respectively), with 2013's value also a little below that for the average from 1980 to 2013 (56.8 fish per seine; Figure 15). Change in CPUE for both introduced and native fishes from 2012 to 2013 was about 12 and less than one fish per seine haul, respectively (Figure 15). The relative stability of the CPUE from 2012 to 2013 was due to increases in some fishes and

declines in others, with the variation greater in the introduced fishes. For native fishes, Sacramento splittail CPUE declined mildly between the two years, while a drop in staghorn sculpin (*Leptocottus armatus*) was accompanied by an increase in both threespine stickleback (*Gasterosteus aculeatus*) and tule perch (Table 2). For introduced fishes, striped bass CPUE plummeted from 2012 to 2013, similar to their otter trawl CPUE, while shimofuri goby (*Tridentiger bifasciatus*) and especially yellowfin goby increased dramatically (Table 2). Notably, most fishes exhibiting lower beach seine and otter trawl CPUE values in 2013 - striped bass, Sacramento splittail, and white catfish - are fishes that primarily recruit from upstream areas into Suisun Marsh during spring and summer.

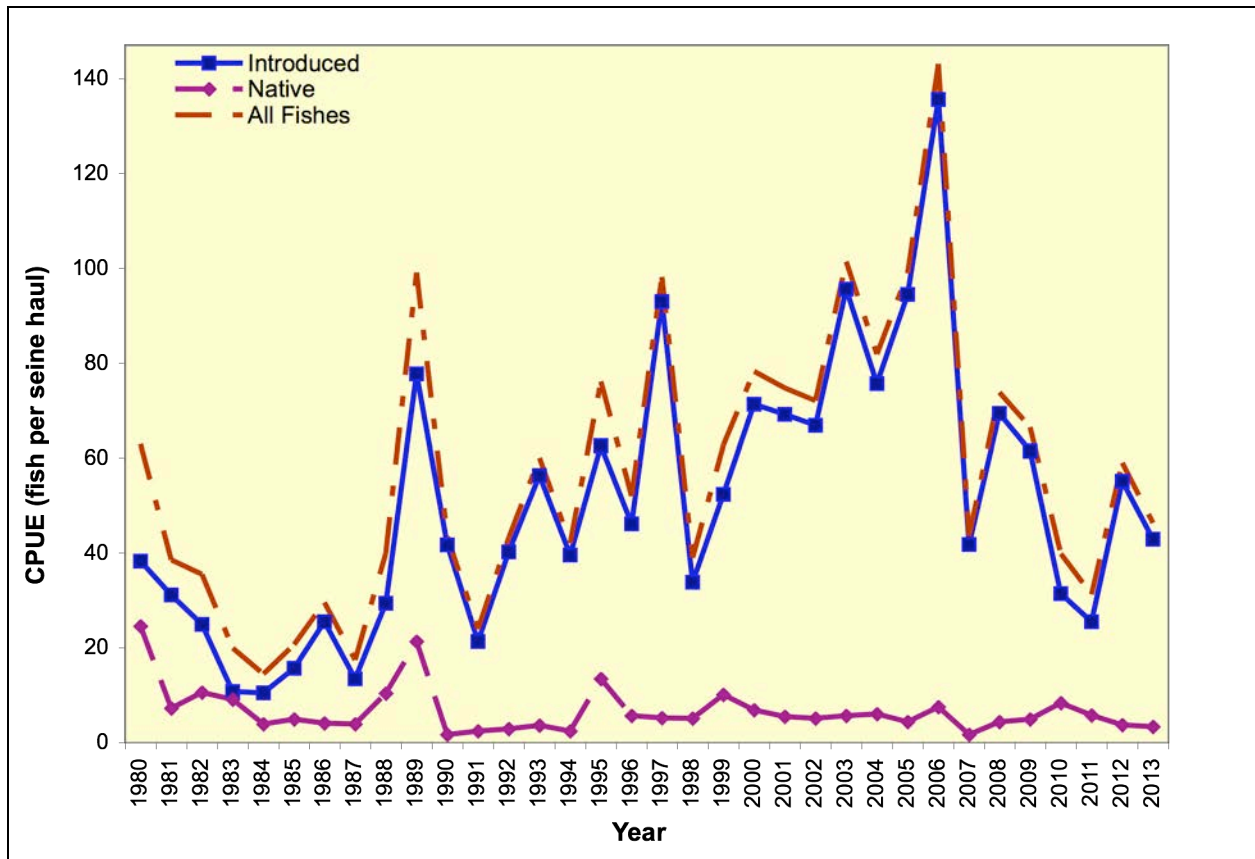


Figure 15. Annual beach seine CPUE of introduced, native, and both categories of fishes combined.

Table 2. Percent change in annual beach seine 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).

Species	All Years CPUE	2012 CPUE	2013 CPUE	2013/2012 % Change
Sacramento splittail	1.4	2.2	1.6	-26%
threespine stickleback	1.8	0.3	0.7	+158%
staghorn sculpin	1.9	0.7	0.2	-76%
tule perch	0.8	0.4	0.7	+62%
striped bass	5.9	11.4	3.2	-72%
shimofuri goby	1.0	0.2	0.9	+281%
yellowfin goby	6.7	2.1	5.2	+152%

Fishes of the Pelagic Organism Decline

LONGFIN SMELT

Otter trawl CPUE in 2013 rose by almost 300% relative to 2012 (Figure 16; Table 1) and was similar to the average for all years of the study (1.5 and 1.2 fish per trawl for 2013 and all years, respectively). Of the 397 longfin smelt captured by otter trawl, all but eight individuals were age-0 fish. Eighty-five percent of the age-0 fish were caught in May; given that sampling in this month did not include lower Suisun and lower Goodyear sloughs, generally the location with the highest longfin smelt densities during dry years (O'Rear and Moyle 2014b), CPUE for May was likely biased low. Despite the very high numbers of age-0 longfin smelt, the pattern in monthly CPUE was similar to previous patterns: age-0 CPUE increased rapidly and peaked in spring, then declined to negligible numbers during summer; and adult, 1+ fish first appeared in autumn, with their maximum CPUE occurring late in the season (Figure 17). Five of the 8 adult fish were captured in lower Suisun Slough; age-0 longfin smelt were especially abundant in Cutoff and Montezuma sloughs, with those two sloughs hosting 42% and 43%, respectively, of the total May catch. The high number of age-0 fish in the dry year of 2013 was anomalous given the positive relationship between Delta outflow and abundance (Rosenfield and Baxter 2007), especially since age-0 fish were also more abundant throughout the rest of the estuary (K. Souza, personal communication, 2013).

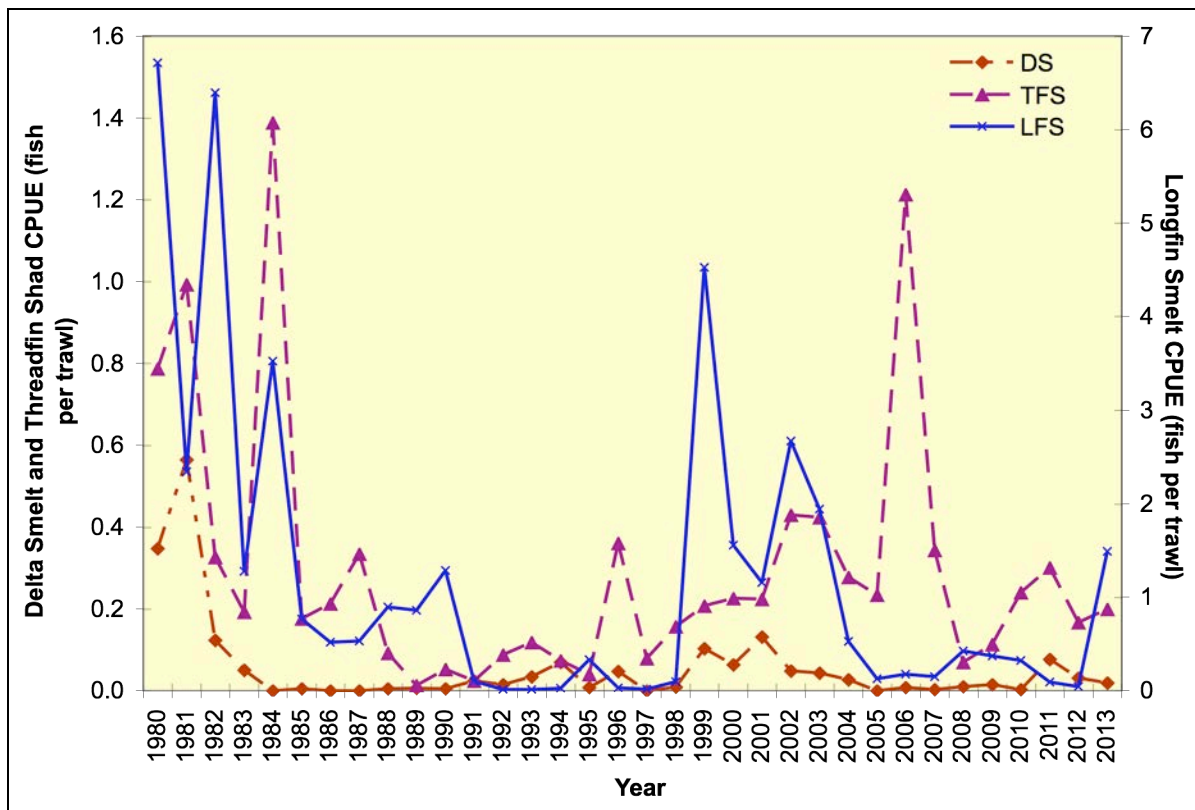


Figure 16. Annual otter trawl CPUE of three fishes of the Pelagic Organism Decline ("DS" = delta smelt, "TFS" = threadfin shad, and "LFS" = longfin smelt).

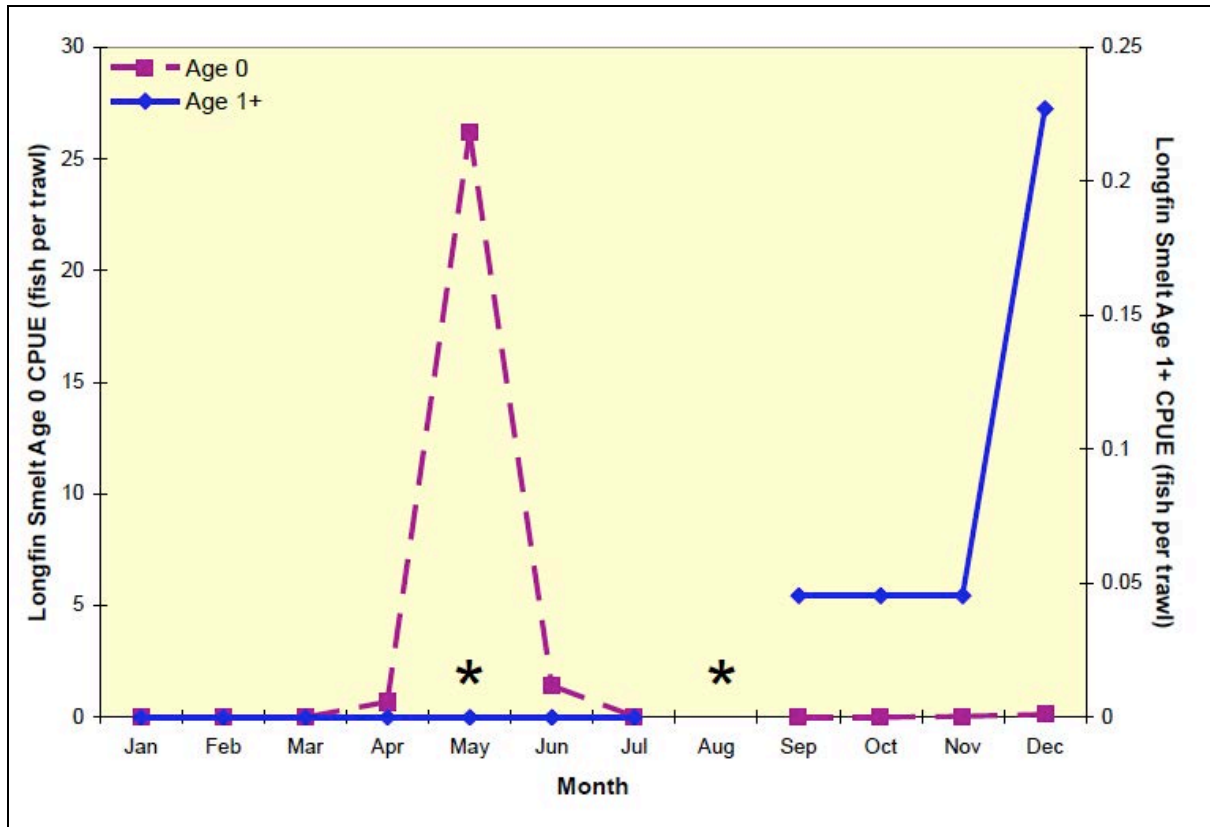


Figure 17. Monthly average otter trawl CPUE of two age classes of longfin smelt in 2013. Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

DELTA SMELT

Delta smelt otter trawl CPUE in 2013 was very low, similar to most years of the 2000s after 2001 (Figure 16) and well below the average for all years (0.02 and 0.06 fish per trawl for 2013 and all years, respectively). We caught 6 delta smelt in 2013: 2 from the 2012 cohort captured in January, and 4 from the 2013 cohort caught in autumn 2013. The January fish were from First Mallard and Montezuma sloughs and measured 70 and 75 mm SL, respectively. Three of the 4 autumn fish were caught in lower Suisun Slough, with the other caught in Montezuma Slough. The autumn fish averaged 57 mm SL and ranged from 50 to 65 mm SL. Notably, the autumn fish from lower Suisun Slough were in waters with salinities around 11.5 ppt.

THREADFIN SHAD

Threadfin shad CPUEs for both beach seines and otter trawls in 2013 were higher than in 2012 but lower than the average for all years of the study (Table 3). Threadfin shad were more abundant in fresher regions of the marsh: none were caught in the saltier southwest marsh, and nearly half (48%) of 2013's otter trawl catch came from eastern Montezuma Slough. These patterns in distribution are consistent with threadfin shad's association with fresher water in the estuary (Feyrer *et al.* 2009, Feyrer *et al.* 2007). The markedly higher beach seine catch in 2013, of which 80% came from Denverton Slough, relative to 2012 is unusual given higher abundances

have more commonly occurred in wetter years (O'Rear and Moyle 2014c, Meng and Matern 2001).

Table 3. CPUE values for threadfin shad; "all years" is the average annual CPUE for 1980 - 2013.

Gear	2012	2013	All Years
otter trawl	0.17	0.20	0.30
beach seine	0.45	1.45	2.08

STRIPED BASS

Striped bass were not as abundant as usual in 2013, with severe drops in both beach seines and otter trawls (Figure 18; Table 1 and 2). While the lower otter trawl CPUE in 2013 is partially attributable to incomplete sampling in August when striped bass are usually very abundant, such is not the case for the beach seines in which sampling was complete, suggesting that striped bass numbers were indeed lower in 2013. Age-0 monthly beach seine CPUE was highest in June and July and co-occurred with a steep decline in abundance of mysids, a major prey of striped bass (Figure 19). Young-of-year striped bass were most abundant in Goodyear and First Mallard sloughs and least abundant in Peytonia and Nurse sloughs (Figure 20). Juvenile striped bass were distributed differently than age-0 fish, being most abundant in the two small northwestern sloughs (Boynton and Peytonia) and Nurse and First Mallard sloughs while being least abundant in eastern Montezuma Slough (Figure 20).

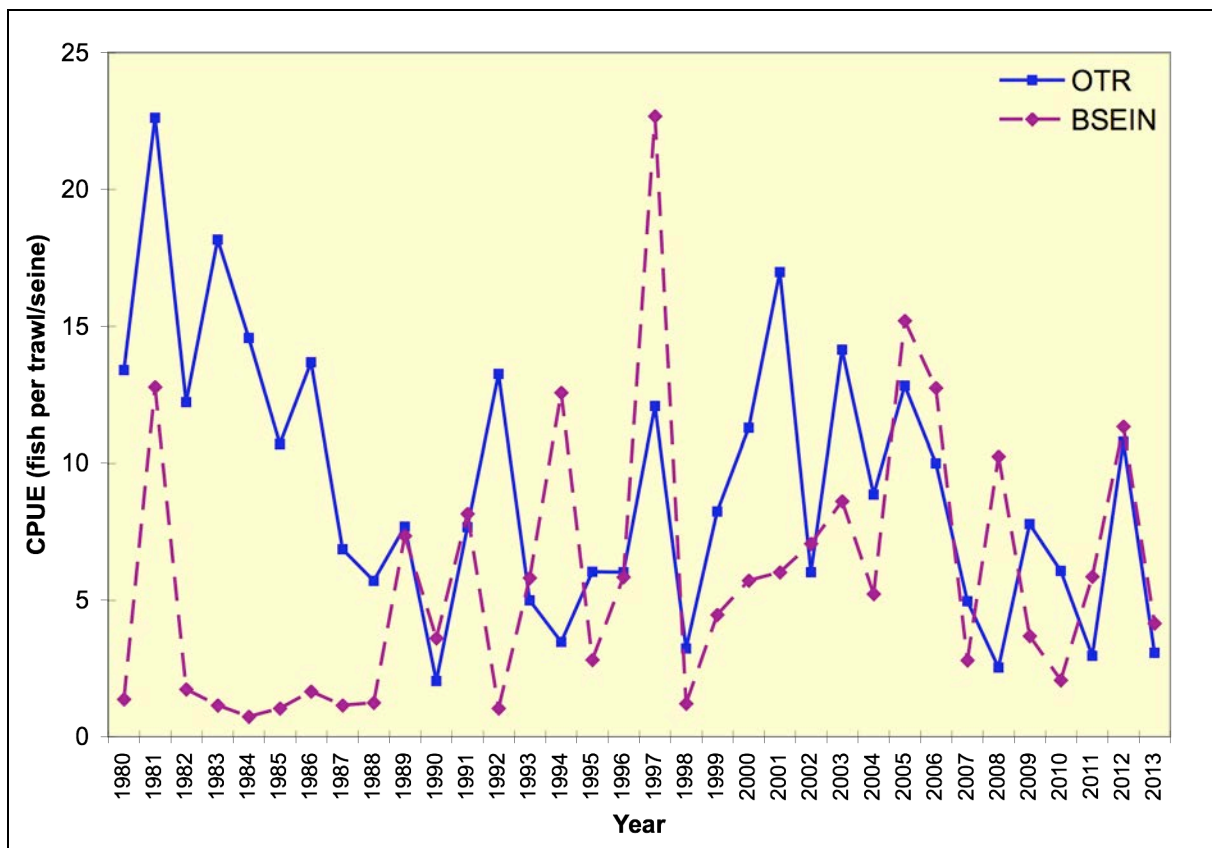


Figure 18. Annual otter trawl and beach seine CPUE of striped bass ("OTR" = otter trawl, "BSEIN" = beach seine).

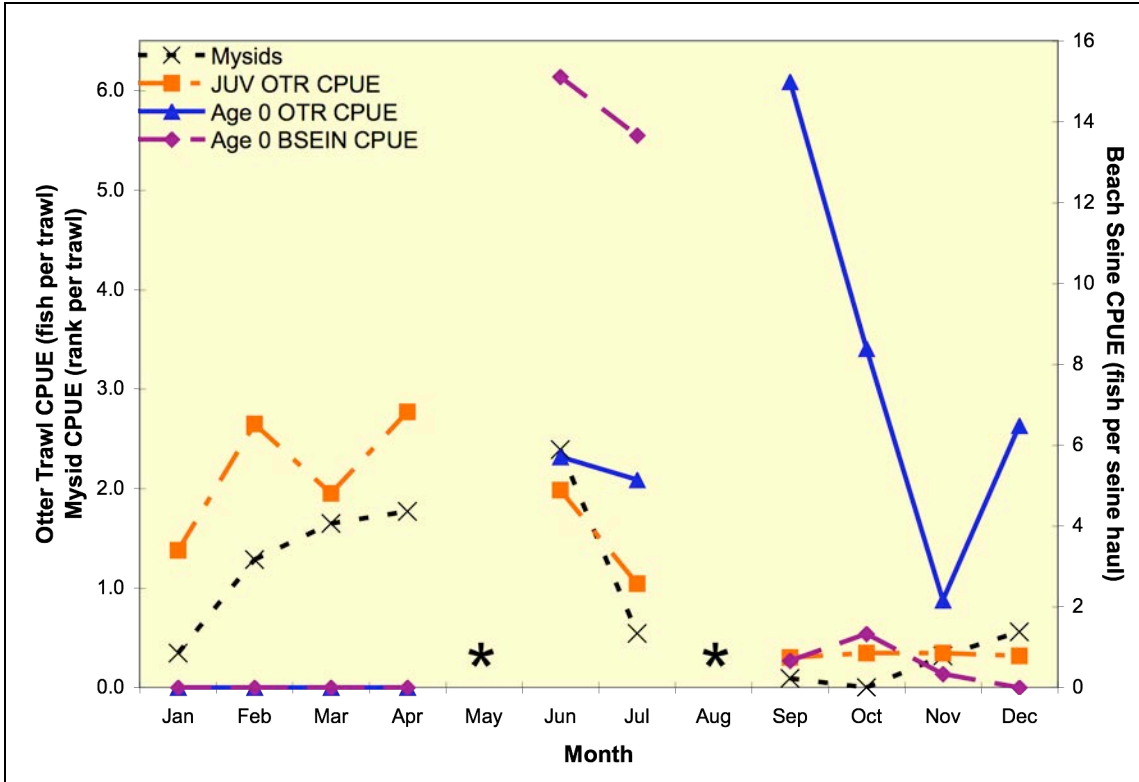


Figure 19. Monthly average CPUE of striped bass age classes and mysids ("OTR" = otter trawl, "BSEIN" = beach seine) in 2013. Asterisks denote months in 2013 with incomplete data due to personnel injuries, endangered-species take issues, and equipment failure.

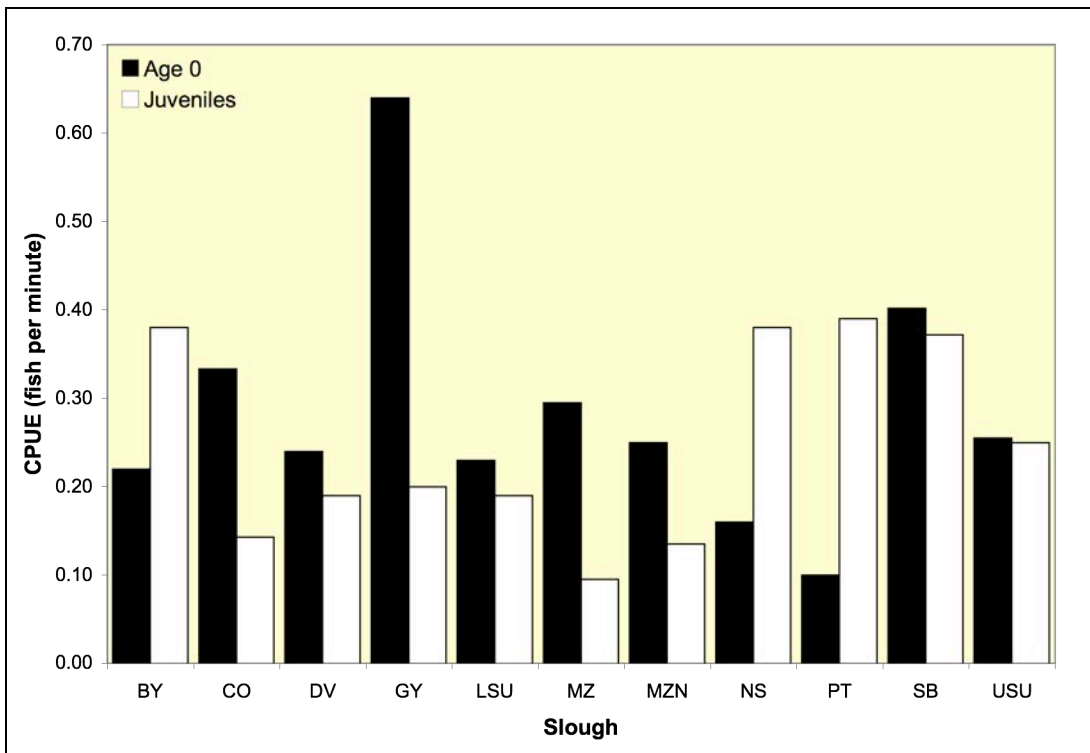


Figure 20. Average otter trawl CPUE of age classes of striped bass in 2013 ("MZN" = Montezuma new; other slough codes as in Figure 9).

Sacramento Splittail

Annual otter trawl CPUE in 2013 was 60% of 2012's CPUE but was well above the average for all years of the study (3.5 and 2.7 fish per trawl in 2013 and for all study years, respectively; Figure 21). The decline from 2012 to 2013 was due to lower numbers of age-0 and age-1 fish; conversely, the age-2+ CPUE in 2013 reached its highest level since 1980 (Figure 21). These patterns are consistent with low reproduction in 2013 because of the dry year (Moyle *et al.* 2004, Sommer *et al.* 1997) coupled with recruitment of the large 2011 cohort to the age-2+ group.

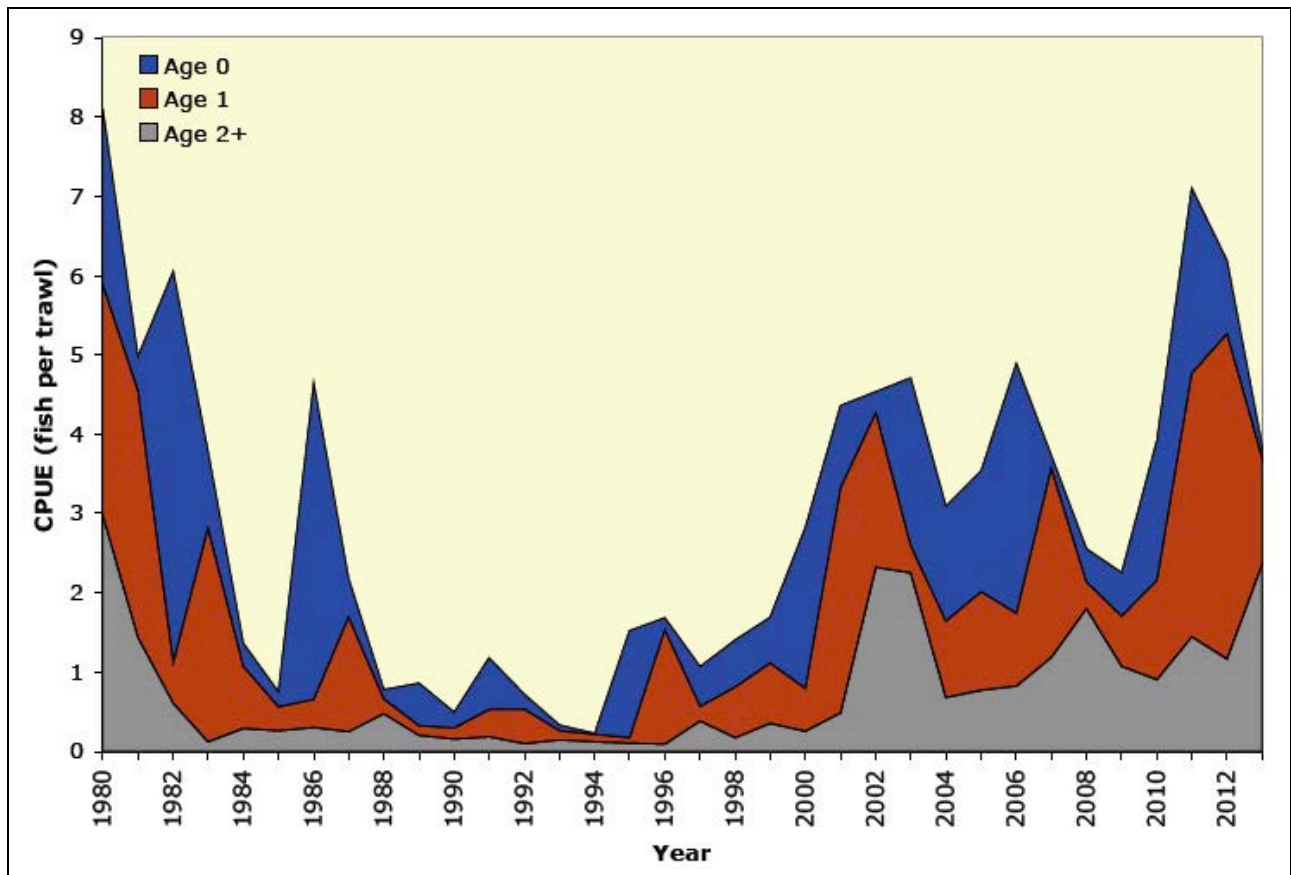


Figure 21. Annual otter trawl CPUE of three age classes of Sacramento splittail.

Geographic distribution of Sacramento splittail differed among age classes. Age-2+ fish were especially abundant in Denverton and Peytonia sloughs while being relatively uncommon in eastern Montezuma Slough (Figure 22). Age-1 fish were distributed similarly to age-2+ fish, with larger numbers of age-1 fish in Denverton, Peytonia, and Nurse sloughs and lower numbers in eastern Montezuma Slough. Age-0 fish were distributed differently than older fish: greatest densities of age-0 splittail were in Denverton and First Mallard sloughs, while none were captured in Peytonia Slough (Figure 22).

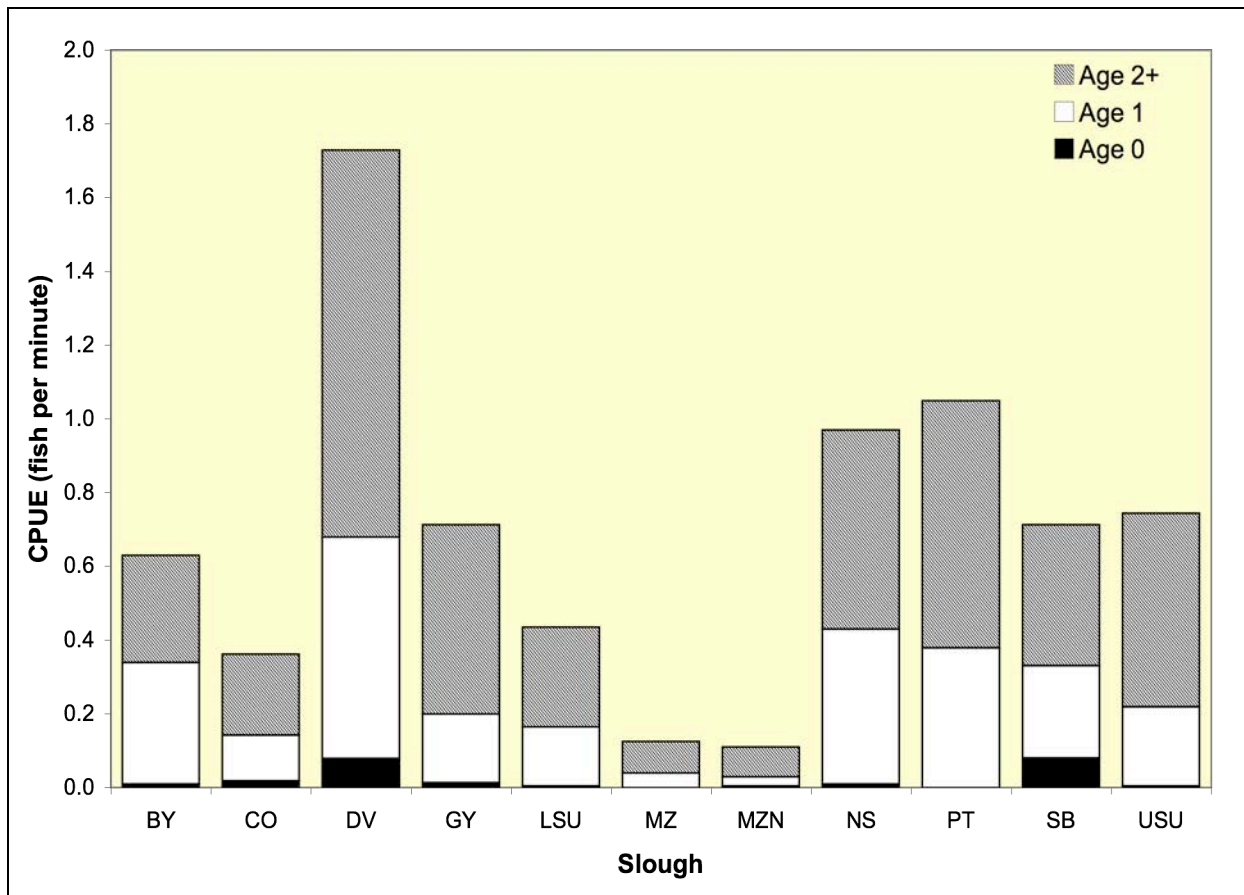


Figure 22. Average otter trawl CPUE of age classes of splittail in 2013 (slough codes as in Figure 9 and 20).

Other Fish Species

WHITE CATFISH

White catfish otter trawl CPUE dropped by nearly 50% from 2012 to 2013, with 2013's value being similar to the all-years average (0.7 and 0.6 fish per trawl for 2013 and all years, respectively; Figure 23). Recruitment of age-0 white catfish is poor in dry years and often results in lower annual otter trawl CPUE values (O'Rear and Moyle 2014*d*). This pattern was followed in 2013, during which no age-0 white catfish were captured.

White catfish are intolerant of moderate and high salinities (Markle 1976, Allen and Avault, Jr. 1971, Kendall and Schwartz 1968) and so are generally less common in the saltier regions of the marsh. This pattern was especially prevalent in 2013, in which 65% of the catch came from just Denver Slough while only one fish (0.5% of the annual catch) was caught in the saltier sloughs of Goodyear and lower Suisun in the southwestern marsh. Fair numbers of white catfish were also taken in Boynton and Cutoff sloughs (12 and 20 fish, respectively).

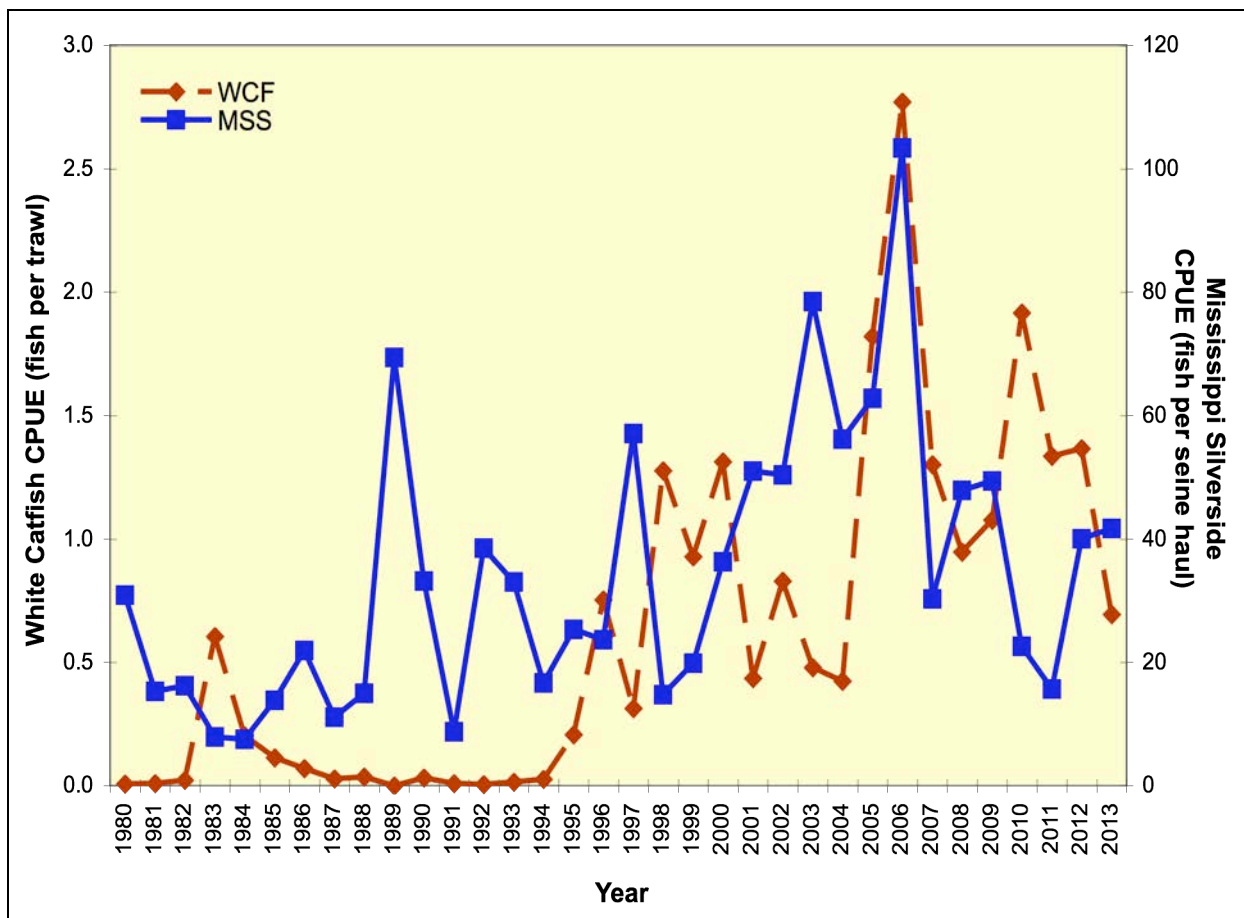


Figure 23. Annual CPUE of white catfish ("WCF") and Mississippi silverside ("MSS").

MISSISSIPPI SILVERSIDES

Mississippi silverside annual beach seine CPUE in 2013 was below the 2012 value and was about the same as the all-years average (40.1, 31.8, and 34.3 fish per seine haul for 2012, 2013, and all years, respectively; Figure 22). Monthly CPUE was moderate during the first three months of the year, declined to lower levels in late spring and early summer, and then peaked during autumn (Figure 24). 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 October and also in December, suggesting reproduction from April through October (Figure 24). This is a longer spawning period than seen in cooler, wetter years such as 2011 (O'Rear and Moyle 2014c).

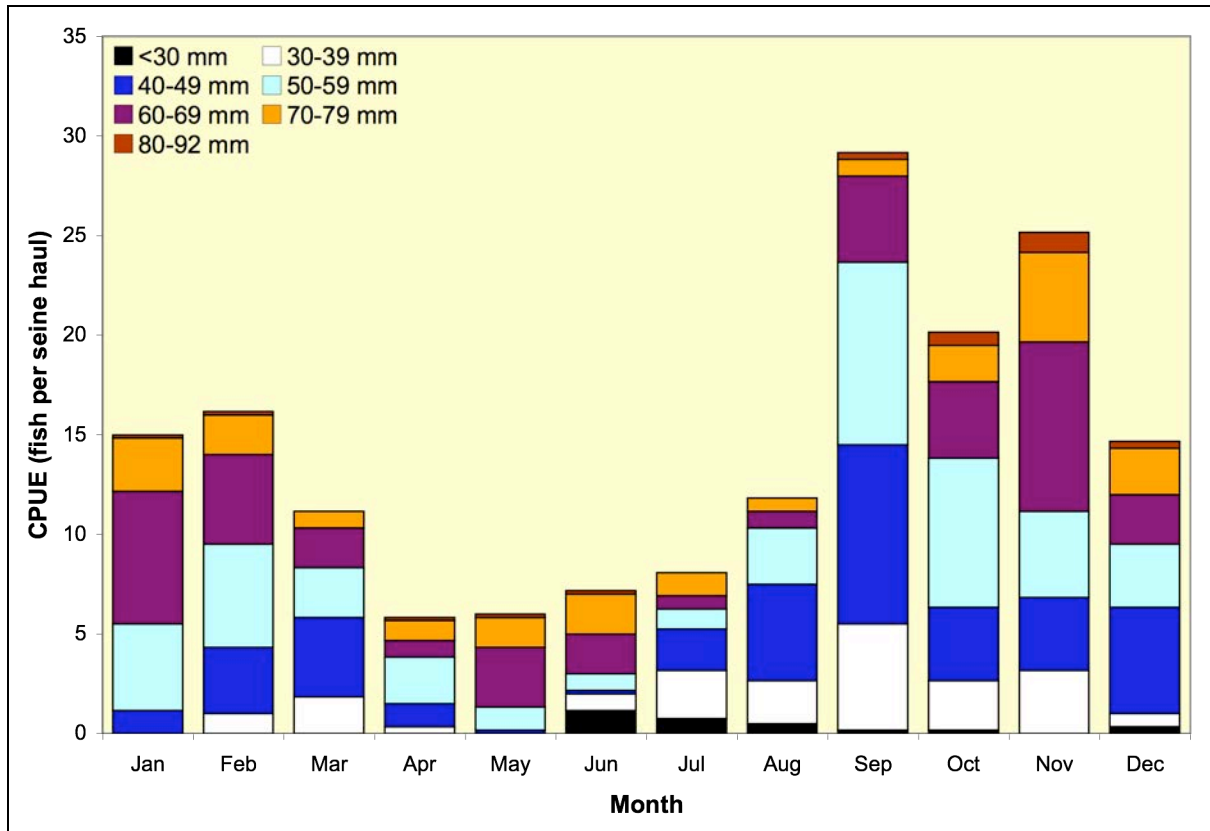


Figure 24. Monthly average beach seine CPUE of size classes (mm SL) of Mississippi silverside in 2013.

Conclusion

2013 was a dry, salty year in Suisun Marsh, with clearer-than-normal water during summer and autumn. Catches of common Suisun Marsh shrimps and overbite clams reflected the abiotic conditions, with lower numbers of shrimp and much higher numbers of the freshwater-intolerant overbite clam (Nicolini and Penry 2000). Numbers of fishes in otter trawls were generally lower than average, in part due to little influx of age-0 fish from fishes that spawn primarily upstream of the marsh (*e.g.*, Sacramento splittail, white catfish, striped bass). Nevertheless, large numbers of age-0 longfin smelt were captured in spring, similar to other areas of the estuary, which is an anomaly given the dry conditions and the positive relationship between Delta outflow and longfin smelt abundance (Rosenfield and Baxter 2007). While otter trawl sampling was incomplete in 2013, other surveys (*e.g.*, Fall Midwater Trawl; Osborn *et al.* 2015) also captured fewer fish, bolstering interpretation of 2013 as a low-recruitment year in Suisun Marsh for freshwater-spawned fishes.

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 Miranda Bell, Amy Chandos, Denise de Carion, Amber Manfree, Jacob Montgomery, Martin Perales, Joshua Porter, Melissa Riley, Mike Wigginton, Brian Williamson, and Matt Young, all of who helped out tremendously during the challenges of the 2013 sampling year. Special thanks also to Amber Manfree for the maps in this report. Special thanks to Erik Loboschefskey of DWR for providing the 15-minute water-quality data; thanks also to Steve Micko for help processing the 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.
- 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).
- DWR. 2014. Interagency ecological program. Available: www.iep.water.ca.gov (March 2014).
- DWR. 2013a. California monthly climate summary January 2013. California, California Department of Water Resources.
- DWR. 2013b. California monthly climate summary February 2013. California, California Department of Water Resources.
- 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.
- De Carion, D. C., B. Schreier, J. L. Conrad, M. Young, J. Frantzych, and A. Sih. 2012. Fish communities of the North Delta. Presentation at the Bay-Delta Conference 17 October 2012.
- Emmett, R. L., S. A. Hinton, D. J. Logan, and G. T. McCabe, Jr. 2002. Introduction of a Siberian freshwater shrimp to western North America. *Biological Invasions* 4: 447-450.
- 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 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. Bengston. 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.
- Israel, H. R. 1936. A contribution toward the life histories of two California shrimps, *Crango franciscorum* (Stimpson) and *Crage nigricauda* (Stimpson). *Fish Bulletin* 46.
- Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinks. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecological Applications* 5: 272-289.
- 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.
- Liu, J., A. Tatarenkov, T. A. O'Rear, P. B. Moyle, and J. C. Avise. 2012. Molecular evidence for multiple paternity in a population of the viviparous tule perch *Hysteroecarpus traski*. Journal of Heredity 104: 217-222.
- 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, *Maeotias 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.
- Miller, N. A., and J. H. Stillman. 2013. Seasonal and spatial variation in the energetics of the invasive clam *Corbula amurensis* in the upper San Francisco Estuary. Marine Ecology Progress Series 476: 129-139.
- Moyle, P. B. 2002. Inland Fishes of California. California, University of California Press.
- 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. 2012. Diet of an introduced estuarine population of white catfish in California. Master's thesis. University of California, Davis.
- O'Rear, T. A., and P. B. Moyle. 2014d. 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. 2014c. 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. 2014^b. 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. 2014^a. 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. 2010. Long term and recent trends of fishes and invertebrates in Suisun Marsh. Interagency Ecological Program Newsletter 23(2): 26-48
- 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.
- Osborn, K., D. Contreras, and R. Baxter. 2014. 2013 status and trends report for pelagic fishes of the upper San Francisco Estuary. Interagency Ecological Program Newsletter 27(2): 3-11.
- 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.
- Schroeter, R. E., T. A. O'Rear, M. J. Young, and P. B. Moyle. 2015. The aquatic trophic ecology of Suisun Marsh, San Francisco Estuary, California, during autumn in a wet year. San Francisco Estuary and Watershed Science 13(3).
- Schroeter, R. E. 2011. The temporal and spatial trends, biological constraints, and impacts of an invasive clam, *Corbula amurensis*, in Suisun Marsh, San Francisco Estuary. California, University of California.
- Schroeter, R. E. 2008. Biology and long-term trends of alien hydromedusae and striped bass in a brackish tidal marsh in the San Francisco Estuary. Doctoral dissertation. University of California, Davis.
- 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.
- Siegfried, C. A. 1980. Seasonal abundance and distribution of *Crangon franciscorum* and *Palaemon macrodactylus* (Decapoda, Caridea) in the San Francisco Bay-Delta. Biological Bulletin 159: 177-192.
- 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.
- Stoeckel, J. N., and R. C. Heidinger. 1988. Overwintering of the inland silverside in southern Illinois. North American Journal of Fisheries Management 8: 127-131.
- Turner, J. L. 1966. Distribution and food habits of ictalurid fishes in the Sacramento-San Joaquin Delta. Pages 130-143 in J. L. Turner and D. W. Kelley, editors. Ecological Studies of the Sacramento-San Joaquin Delta, part 2. California Department of Fish and Game Fish Bulletin 136.

- 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

Total number of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all methods from 1979 to 2013 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
American shad	<i>Alosa sapidissima</i>	1176	255		1431
bay pipefish	<i>Sygnathus leptorhynchus</i>	2			2
bigscale logperch	<i>Percina macrolepida</i>	17	2		19
black bullhead	<i>Ameiurus melas</i>	879	3		882
black crappie	<i>Pomoxis nigromaculatus</i>	1851	98	1	1950
bluegill	<i>Lepomis macrochirus</i>	19	18		37
brown bullhead	<i>Ameiurus nebulosus</i>	28			28
California halibut	<i>Paralichthys californicus</i>	5			5
channel catfish	<i>Ictalurus punctatus</i>	175	7		182
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	73	391	1	465
common carp	<i>Cyprinus carpio</i>	5065	475	1	5541
delta smelt	<i>Hypomesus transpacificus</i>	659	139	4	802
fathead minnow	<i>Pimephales promelas</i>	36	38		74
golden shiner	<i>Notemigonus crysoleucas</i>	6	12		18
goldfish	<i>Carassius auratus</i>	298	48		346
green sturgeon	<i>Acipenser medirostris</i>	3			3
green sunfish	<i>Lepomis cyanellus</i>	5	3		8
hardhead	<i>Mylopharodon conocephalus</i>	1			1
hitch	<i>Lavinia exilicauda</i>	121	16		137
largemouth bass	<i>Micropterus salmoides</i>		3		3
longfin smelt	<i>Spirinchus thaleichthys</i>	11791	52	5	11848
longjaw mudsucker	<i>Gillichthys mirabilis</i>	1			1
Mississippi silverside	<i>Menidia audens</i>	1119	81071		82190
northern anchovy	<i>Engraulis mordax</i>	262		37	299
Pacific herring	<i>Clupea harengus</i>	477	123		600
Pacific lamprey	<i>Lampetra tridentata</i>	43			43
Pacific sanddab	<i>Citharichthys sordidas</i>	3	2		5
plainfin midshipman	<i>Porichthys notatus</i>	11			11
prickly sculpin	<i>Cottus asper</i>	10547	944	1	11492
rainbow trout	<i>Oncorhynchus mykiss</i>	8	4		12
rainwater killifish	<i>Lucania parva</i>	32	110		142
redeer sunfish	<i>Lepomis microlophus</i>	2	1		3
river lamprey	<i>Lampetra ayresi</i>	3			3
Sacramento blackfish	<i>Orthodon macrolepidotus</i>	25	116		141
Sacramento pikeminnow	<i>Ptychocheilus grandis</i>	148	229		377
Sacramento splittail	<i>Pogonichthys macrolepidotus</i>	26875	3390	14	30279
Sacramento sucker	<i>Catostomus occidentalis</i>	3334	113	5	3452
shimofuri goby	<i>Tridentiger bifasciatus</i>	10026	2276	1	12303
shiner perch	<i>Cymatogaster aggregata</i>	17			17
shokihaze goby	<i>Tridentiger barbatus</i>	722	2	6	730
speckled sanddab	<i>Citharichthys stigmaeus</i>	3			3
staghorn sculpin	<i>Leptocottus armatus</i>	2530	3331		5861

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
starry flounder	<i>Platichthys stellatus</i>	2001	262	4	2267
striped bass	<i>Morone saxatilis</i>	83844	13682	30	97556
surf smelt	<i>Hypomesus pretiosus</i>	5			5
threadfin shad	<i>Dorosoma petenense</i>	2782	5293	1	8076
threespine stickleback	<i>Gasterosteus aculeatus</i>	17310	6136	6	23452
tule perch	<i>Hysterothorax traski</i>	19141	2060	6	21207
wakasagi	<i>Hypomesus nipponensis</i>	10	6		16
warmouth	<i>Lepomis gulosus</i>	1			1
western mosquitofish	<i>Gambusia affinis</i>	18	340		358
white catfish	<i>Ameiurus catus</i>	5461	164	13	5638
white crappie	<i>Pomoxis annularis</i>	112			112
white croaker	<i>Genyonemus lineatus</i>	1			1
white sturgeon	<i>Acipenser transmontanus</i>	113		2	115
yellowfin goby	<i>Acanthogobius flavimanus</i>	19505	16479		35984
Total		228702	137694	138	366534

APPENDIX B

Total 2013 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold).

Species	Slough											Total
	Boynton	Cut-off	Denver-ton	First Mallard	Good-year	lower Suisun	Montez-uma	Montezuma New	Nurse	Peytonia	upper Suisun	
American shad	5	5	7	1	3	2	5	4			2	37
black bullhead	1		1		1					1		4
black crappie	2		32									34
channel catfish							1					1
Chinook salmon				1								1
common carp	26	19	25	11	7	2		1	4	4	4	106
delta smelt				1		3		1				5
goldfish			1									1
hitch	1											1
longfin smelt	1	149	1	30		17	114	58	14	3	9	396
Mississippi silverside		3	7	35	1					8		54
northern anchovy						4						4
Pacific herring		3		3					1		3	10
prickly sculpin	6	4	16	3	31	4	16	1	10	5	4	100

Species	Slough											Total
	Boynton	Cutoff	Denver-ton	First Mallard	Good-year	lower Suisun	Montez-uma	Montezuma New	Nurse	Pey-tonia	upper Suisun	
Sacramento blackfish			1									1
Sacramento pikeminnow		1										1
Sacramento splittail	63	38	173	71	107	87	25	22	97	105	149	937
Sacramento sucker	10	9	11	3		1			3	15		54
shimofuri goby	7	12	78	4	3				31	5	9	149
shokihaze goby					2	2	1	4	1		3	13
staghorn sculpin				1	5	5	1				2	14
starry flounder			3		3	6	2	1			2	17
striped bass	60	51	43	77	129	85	78	77	54	49	101	815
threadfin shad	2	1	7	2			32		6		3	53
threespine stickleback	9	4	8	4	55	17	12	8	1	10	5	133
tule perch	26	93	81	59	12	21	25	11	43	20	43	456
white catfish	12	20	119	5	1		9	2	6	6	4	184
yellowfin goby	3	5	2	5	6	11	13	5	4	1	10	65
Total	234	417	616	316	366	267	334	195	275	232	353	3646

Total 2013 beach seine catch of each fish species in Denver-ton, Montezuma, and upper Suisun sloughs (native species are in bold).

Species	Slough			Total
	Denver-ton	Montezuma New	upper Suisun	
American shad	5	2	2	9
black crappie	8			8
Chinook salmon		3		3
common carp	17	7	3	27
delta smelt		1		1
golden shiner		1	1	2
goldfish	1			1
longfin smelt	1			1
Mississippi silverside	792	680	1738	3210
Pacific herring	1	2	4	7
prickly sculpin	7			7
rainwater killifish			1	1
Sacramento pikeminnow	1			1
Sacramento splittail	13	113	39	165

Species	Slough			Total
	Denverton	Montezuma New	upper Suisun	
Sacramento sucker	1			1
shimofuri goby	74	8	8	90
staghorn sculpin	3	2	12	17
starry flounder		1	1	2
striped bass	113	45	162	320
threadfin shad	116	26	4	146
threespine stickleback	24	23	24	71
tule perch	8	34	26	68
western mosquitofish		1	1	2
white catfish	1			1
yellowfin goby	22	193	310	525
Total	1208	1142	2336	4686

APPENDIX C

Number of otter trawls in each slough and each month in 2013.

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Boynton	2	2	2	2	2	2	2	2	2	2	2	2	24
Cutoff	2	2	2	2	1	2	2	2	2	3	2	2	24
Denverton	2	2	2	2	2	2	2	2	2	2	2	2	24
First Mallard	2	2	2	2	2	2	2	2	2	2	2	2	24
Goodyear	3	3	3	3	2	3	3	0	3	3	3	3	32
lower Suisun	2	2	2	2	0	2	2	0	2	2	2	2	20
Montezuma	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma new	2	2	2	2	1	2	2	1	2	2	2	2	22
Nurse	2	2	2	2	2	2	2	2	2	2	2	2	24
Peytonia	2	2	2	2	2	2	2	0	2	2	2	2	22
upper Suisun	2	2	2	2	2	2	2	1	2	2	2	2	23
Total	23	23	23	23	18	23	23	14	23	24	23	23	263

Number of beach seines in each slough and each month in 2013.

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Denverton	3	3	3	3	3	3	3	3	3	3	3	3	36
Montezuma New	3	3	3	0	3	3	3	0	3	3	3	3	30

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
upper Suisun	3	3	3	3	3	3	2	3	3	3	3	3	35
Total	9	9	9	6	9	9	8	6	9	9	9	9	101