Title

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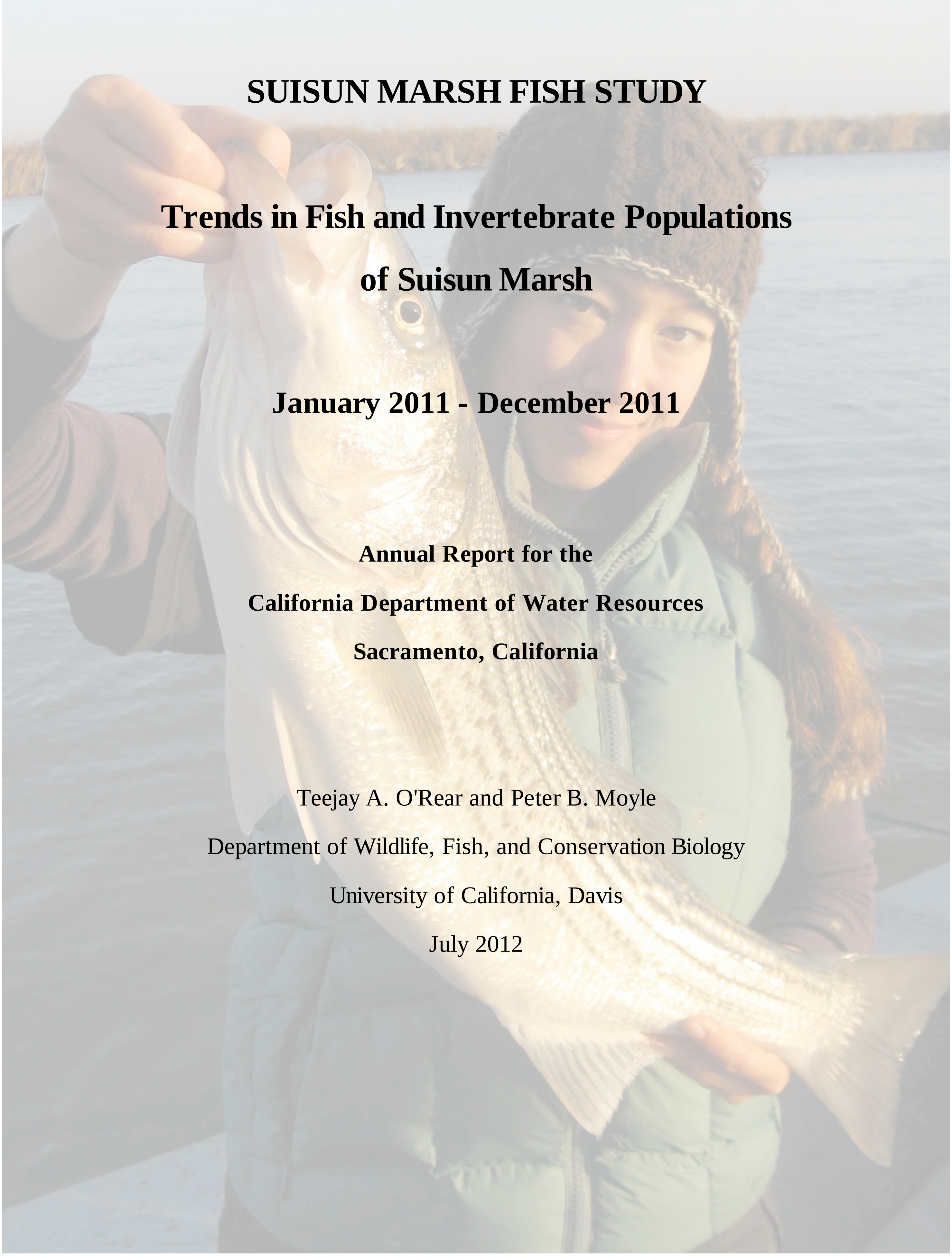

SUISUN MARSH FISH STUDY

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2011 - December 2011

Annual Report for the

California Department of Water Resources

Sacramento, California

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SUMMARY

Suisun Marsh, at the geographic center of the San Francisco Estuary, is important habitat for introduced and native fishes. With funding from the California Department of Water Resources (DWR), the University of California, Davis, Suisun Marsh Fish Study has systematically monitored the marsh's fish populations since 1980. The purpose of the study has been to determine the environmental factors affecting fish abundance and distribution within the context of evolving water management.

In 2011, we conducted 259 otter trawls and 74 beach seines. Our catches of plankton-feeding macroinvertebrates and fishes were strongly influenced by the interaction of high Delta outflows, low salinities, and the cold winter and spring. The prolonged low salinities severely reduced the population of overbite clams (*Potamocorbula amurensis*) in the southwest marsh, in addition to delaying the appearance of Black Sea jellyfish (*Maeotias marginata*) medusae until very late in the year. Species that ultimately benefit from high flows for spawning, due to either increased floodplain inundation [*e.g*., Sacramento splittail (*Pogonichthys macrolepidotus*)] or reduced salinities [*e.g*., white catfish (*Ameiurus catus*)], recruited to the marsh in high numbers. Additionally, delta smelt (*Hypomesus transpacificus*) reached their highest abundance in the marsh since 2001, which was likely due to the combination of (1) high flows both reducing entrainment and promoting plankton blooms, (2) colder water during spring creating more favorable spawning conditions, and (3) appropriate temperatures and salinities occurring in the marsh during autumn. Cold temperatures in the first part of the year delayed reproductive development of introduced fishes such as striped bass (*Morone saxatilis*) and Mississippi silverside (*Menidia audens*). In the case of striped bass, young-of-year fish arrived in the marsh later than in average years and after mysids, their primary prey, had already declined to low levels; consequently, there was a mismatch in timing between predator and prey. This mismatch probably increased mortality of young striped bass, leading to their reduced abundance in our otter trawls, and forced a greater proportion of these fish inshore, which was reflected in an increase in their numbers in our beach seines. As in 2010, cold temperatures truncated the spawning period and increased mortality of Mississippi silverside, with the effect that they reached their lowest abundance since 1998. The end result was that native species comprised a greater proportion of the macroinvertebrate and fish assemblages in 2011 relative to recent years.

We were also able to sample two areas during spring to which we previously have not had access: the upper Cordelia Slough complex and a duck-club ditch. The Cordelia Slough sampling reflected a fish community primarily structured by a salinity gradient, with salt-intolerant species more abundant in reaches influenced by freshwater flows. Sampling in the duck club ditch showed high abundances of small fish, reflecting the high productivity of these habitats. However, the fish assemblages in different parts of the ditch revealed that a water control structure was limiting larger, older fish to just part of the ditch.

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INTRODUCTION

Suisun Marsh is a brackish-water marsh bordering the northern edge 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.* 1986). Most of the marsh area is diked wetlands managed for waterfowl, with the rest of the acreage consisting of tidal sloughs and marsh plain (DWR 2001). The marsh's central location in the San Francisco Estuary makes it an important nursery for salt-tolerant-freshwater, estuarine, and marine fishes.

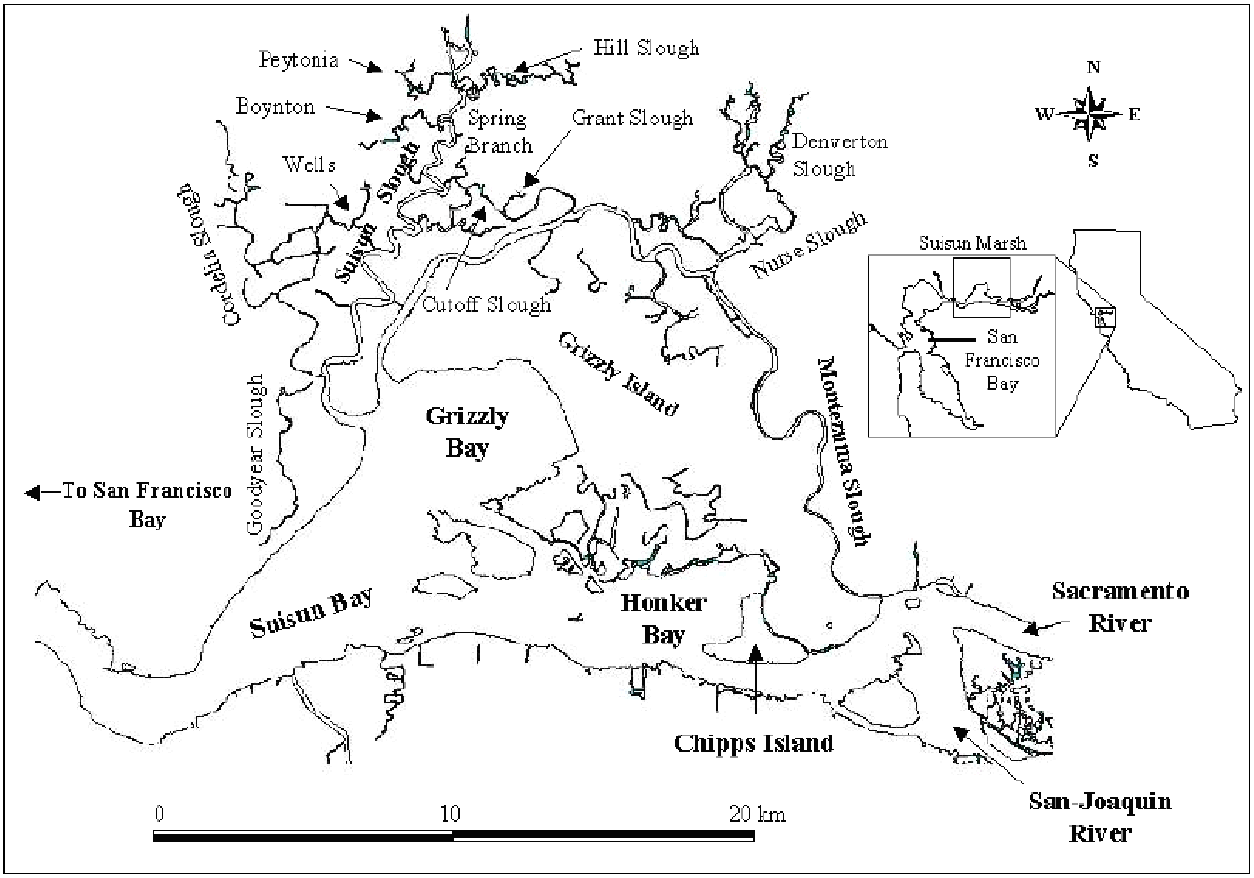

Figure 1. Suisun Marsh and Bay (from Schroeter *et al.* 2006).

In January 1979, DWR contracted with UC Davis to monitor fish populations in Suisun Marsh. Since 1979, 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 used two primary 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 in the marsh (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; and (3) enhancing understanding of the life history and ecology of key species in the marsh. Secondary objectives have included supporting research by other investigators through special collections; providing background information for in-depth studies of other aspects of the Suisun Marsh aquatic ecosystem (*e.g.*, studies of jellyfish biology); contributing to the general understanding of estuarine systems through publication of peer-reviewed papers; training undergraduate and graduate students in estuarine studies and fish sampling; and providing a venue for managers and biologists interested in the marsh to experience it firsthand. The project also collected fish for studies on (1) documenting predation on delta smelt by Mississippi silverside and striped bass via DNA techniques, (2) American shad (*Alosa sapidissima*) life history and distribution using genetic analyses, (3) sexual behavior of tule perch (*Hysterocarpus traski*), (4) longfin smelt (*Spirinchus thaleichthys*) ecology through otolith chemistry, (5) food-web structure using stable isotopes, and (6) fatty-acid composition of key zooplankton species. Additionally, the long-term dataset is currently being used to (1) model delta and longfin smelt population dynamics, (2) study trends in near-shore fish assemblages along the San Francisco Estuary's longitudinal axis, (3) inform wetland restoration in the western marsh, and (4) compare the biomass of marsh fishes to those in the bays. Data collected by the study has also been used to inform future management of the San Francisco Estuary for the benefit of native fishes (Moyle *et al.* 2012*a*) and to compare fish assemblages along the estuary's salinity gradient (Moyle *et al.* 2012*b*).

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 recruitment. The structure of the fish community was relatively constant through time; however, total fish abundance declined over the five years. The decline was partly due to strong cohorts early in the study period, which was 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, possibly as a result of drought and high exports allowing increased salinities in the marsh and depressing reproductive success of native fishes. Like Moyle *et al.* (1986), Meng *et al*. (1994) found a general decline in total fish abundance (particularly in the native fishes) through time. 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 decrease.

In recent years, O'Rear and Moyle (2010, 2009, 2008) have bolstered the findings of previous studies and documented changes that appear to be happening in other parts of the estuary. For instance, the timing, variability, and magnitude of Delta outflow continue to be important factors affecting the abundance of fishes recruiting into the marsh from upstream or downstream areas [*e.g.*, striped bass, yellowfin goby (*Acanthogobius flavimanus*), respectively]. Additionally, Delta outflow, through its influence on marsh salinities, has also affected fishes produced in the marsh [*e.g.*, white catfish and black crappie (*Pomoxis nigromaculatus*)]. Perhaps most notably, there appears to be a limitation of pelagic food supplies sometime in summer that results in an inshore movement of fishes. Finally, the marsh still provides vital habitat for at-risk native species (*e.g.*, Sacramento splittail, longfin smelt) that is largely and increasingly absent from the Delta. 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.

Several recent studies have been conducted assessing the threat of three increasingly numerous introduced species on native fishes. Of particular concern have been two species of pelagic jellyfish from the Black Sea region that have been extraordinarily abundant during summer and early autumn in some years (Wintzer *et al.* 2011*a*, Schroeter 2008). Wintzer *et al.* (2011*b*) found that Black Sea jellyfish (*Maeotias marginata*) and an undescribed species of *Moerisia* fed heavily on calanoid copepods, which are important food items of declining pelagic fishes such as delta smelt. They compared the diets of the jellyfish to those of young striped bass and threadfin shad (*Dorosoma petenense*) and found little potential for competition between striped bass and jellyfish, while the likelihood of competition between threadfin shad and jellyfish was much higher. Given that diets between threadfin shad and delta smelt have been very similar (Feyrer *et al.* 2003), while those of striped bass have been more akin to those of longfin smelt (Feyrer *et al.* 2003), jellyfish could be harming delta smelt by reducing calanoid abundance. O'Rear (2012) explored the diet of white catfish, a fish that has fed on delta smelt, striped bass, and threadfin shad (Miller 1966), throughout a year in all areas of the marsh where the catfish was abundant. He found that they subsisted largely on food supplied by managed wetlands from autumn to spring, while much of their diet consisted of slough-produced or bay-produced items during summer. Notably, white catfish never ate at-risk fishes such as striped bass or delta smelt, and their most common food item - amphipods - was not likely to be a limiting food resource. Thus, these studies have more finely resolved the effects of these introduced species on native fishes, with white catfish appearing relatively innocuous and the jellyfish seemingly much more pernicious, both findings of which will inform better management of the system.

The purpose of this report is to (1) update the results of the previous Suisun Marsh Fish Study report (O'Rear and Moyle 2011), which explored the composition of fish assemblages in inshore and channel habitats, macroinvertebrate ecology in channels, patterns in catch of life-history stages of important fishes, and findings of a pilot study undertaken to more finely resolve the effects of low DO and other abiotic factors on fish during early autumn; and (2) report the findings of two ancillary sampling events in the Cordelia Slough complex and in the Tule Red Duck Club.

METHODS

Study Area

Suisun Marsh is a tidal brackish-water marsh covering about 34,000 hectares (DWR 2001). Roughly two-thirds of the marsh area is diked wetlands managed for waterfowl; the remainder consists of sloughs that separate and deliver water to the wetland areas and to marsh plain that is inundated by high tides throughout the year (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). There are two major tidal 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, Boynton, 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, 3-7 m deep, and partially riprapped (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.). Substrates in all sloughs are generally fine organics, although a few sloughs also have bottoms partially comprised of coarser materials (*e.g.*, Denverton Slough), 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. The major source of fresh water in the marsh comes from the Sacramento River through Montezuma Slough, although small creeks, particularly on the northwest and west-central sides of the marsh, also contribute fresh water. As a result, salinities are generally lower in the eastern, northwestern, and west-central portions of the marsh. Freshwater inflows are highest in winter and spring due to rainfall runoff and snowmelt; 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 primarily on water surface elevation and not salinity throughout much of the year (Matern *et al.* 2002). During extreme tides, water depths can change as much as 1.8 m over a tidal cycle, often dewatering more than 50% of the smaller sloughs at low tide and overtopping dikes at high tide.

A number of water management facilities influence the hydrology and water quality of the marsh. State Water Project and Central Valley Project water export facilities in the southern Delta affect the timing and magnitude of freshwater inflow into Suisun Marsh. The Suisun Marsh Salinity Control Gates, located in Montezuma Slough just downstream of the confluence of the Sacramento and San Joaquin rivers, are operated to inhibit saltwater intrusion into the marsh during flood tides, which provides fresher water for diked wetlands (DWR 2001). Numerous water control structures, most of which are unscreened for fish, are located throughout the marsh; they are most commonly opened in early autumn for flooding wetlands to attract wintering waterfowl and in late winter and spring to leach salts from wetland soils and to set seeds of desired plants. The amount of water diverted by managed wetlands is restricted to varying extents in different areas of the marsh from autumn through spring for protecting listed fishes (*e.g*., delta smelt; Table 1). Wetlands are usually drained in late spring, with drainage water being discharged directly into numerous sloughs within the marsh, and remain dry throughout summer. Goodyear Slough is now connected to Suisun Bay by a channel that was built to depress salinities in the slough for water diverters in the western portion of the marsh.

Table 1. Managed wetlands diversion restrictions in Suisun Marsh (% opening for delta smelt dependent on catches in Montezuma Slough by the California Department of Fish and Wildlife's 20-mm survey).

Species	Restriction Period	Affected Sloughs	Maximum Intake Opening
Chinook salmon	Nov 1 - Feb 1	Cutoff, Denverton, Montezuma, Nurse, Suisun north to Goat Island	0%
Chinook salmon	Feb 20 - Mar 31	Cutoff, Denverton, Montezuma, Nurse, Suisun north to Goat Island	25%
delta smelt	Apr 1 - May 31	Denverton, Goodyear, Montezuma, Nurse, Suisun north to Goat Island	20-35%

Sampling

Since 1980, monthly juvenile and adult fish sampling has been conducted at standard sites within Suisun Marsh. Prior to 1994, a total of 12 sloughs and 27 sites were sampled. Several of these historic sites were sampled only in 1980 and 1981, with 17 sites 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 (Figure 2). [Latitude and longitude coordinates for current, regularly sampled sites were obtained (± 100 m) using a Global Positioning System receiver and are found in Schroeter *et al.* (2006)].

In 2011, we sampled two regions to which we previously had no access. To understand the aquatic community in the west-central marsh inaccessible because of Union Pacific railroad bridges, we trawled several sloughs in the Cordelia Slough complex (Figure 2) on April 18, 2011 (Figure 3). On May 13, 2011, we sampled a small ditch above and below a water control structure within a duck club - Tule Red (Figure 2 and 4) - to assess the aquatic community within a managed wetland, a type of habitat we previously had not sampled.

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 millimeters (mm) stretch in the body and 6 mm stretch in the cod end. The otter trawl was towed at 4 kilometers per hour (km/hr) for 5 minutes in small sloughs and, to compensate for small catches, 10 minutes in large sloughs. Because the ditch we sampled in Tule Red was much too small for the boat and net we use for our standard sampling, we used a smaller otter trawl (opening: 0.9 m X 2.4 m; length: 3.7 m; stretched body mesh: 32 mm; stretched cod-end mesh: 6 mm) pulled at 3.5 km/hr. In upper Suisun and Denverton sloughs, inshore fishes were sampled with a 10-m beach seine having a stretched mesh size of 6 mm; we also used the same seine for sampling at the Tule Red Duck Club and for sampling on Montezuma Slough in May at the historic MZ6 site (the Montezuma seines were performed to increase the sample size of Mississippi silversides for a delta-smelt predators study conducted by DWR's Division of Environmental Services). 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 (SL), and returned to the water. Sensitive native species were processed first and immediately released. Numbers of Siberian prawn (*Exopalaemon modestus*), Black Sea jellyfish, Oriental shrimp (*Palaemon macrodactylus*), California bay shrimp (*Crangon franciscorum*), Harris mud crab (*Rhithropanopeus harrissii*), overbite clam, clams from the genus *Macoma*, and Asian clam (*Corbicula fluminea*) were also recorded. Siberian prawn were first positively identified in February 2002, although they were probably present in 2001. Siberian prawn likely comprised a large percentage of the 2001 and early 2002 shrimp catch that was recorded as Oriental shrimp; abundances of Siberian prawn are herein reported separately. 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. The index was necessary because most mysids pass through the trawl, and those that remain in the net are difficult to accurately count.

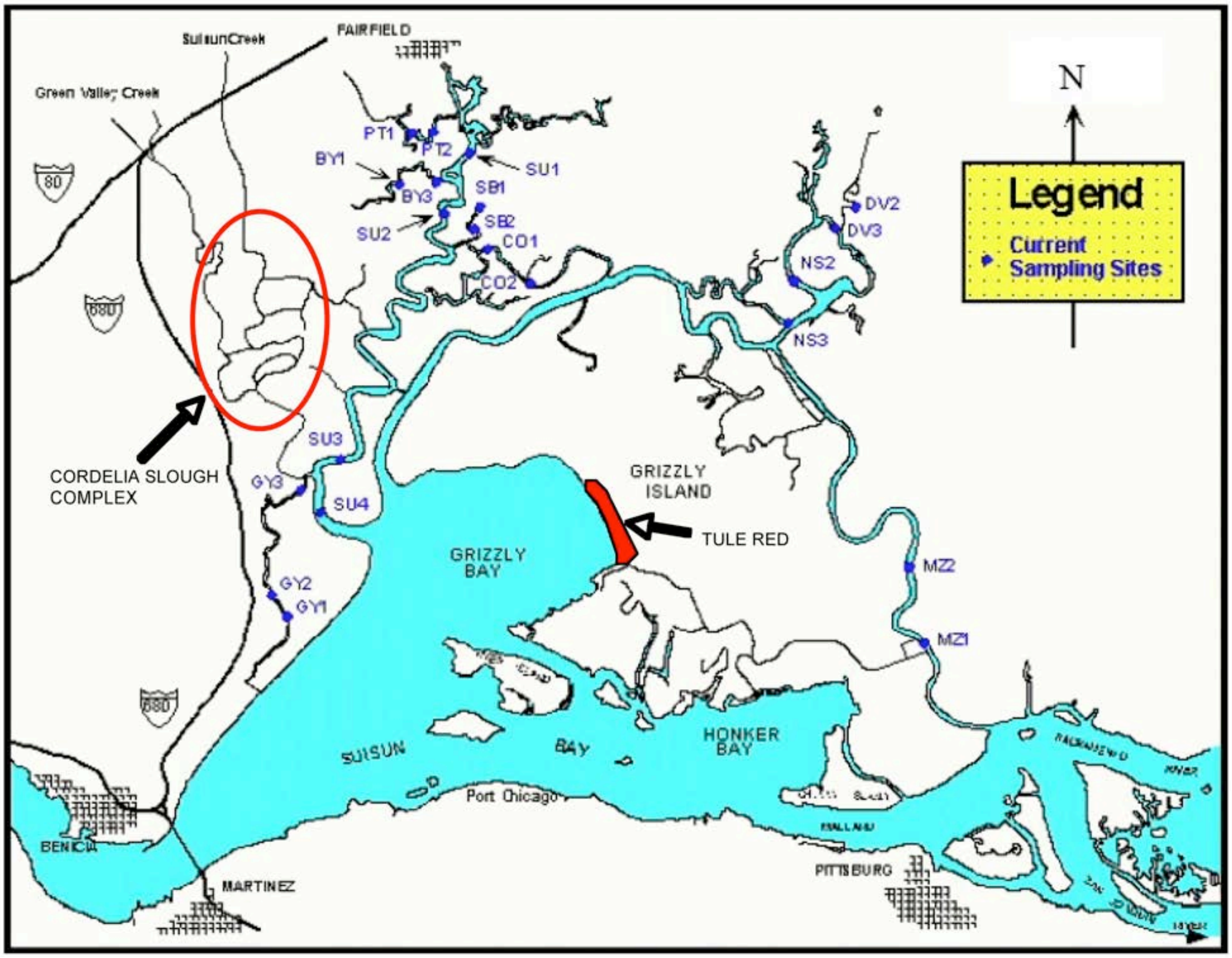

Figure 2. Map of current Suisun Marsh standard sampling sites (from Schroeter *et al*. 2006) and locations of the Tule Red Duck Club and the Cordelia Slough complex (both denoted in red).

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 otter trawls was calculated as

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

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." Beach seine CPUE values for

Figure 3. Sampling sites within the Cordelia Slough complex ("CRD" = Cordelia Slough; "IBI" = Ibis Cut; "FH" = Frank Horan Slough; and "CHA" = Chadbourne Slough; numbers denote unique sample sites within the sloughs, with the larger numbers closer to the slough mouths).

annual comparisons were calculated as for otter trawls, with number of fish caught in the seines in the numerator and number of seines pulled as the denominator. For slough-to-slough comparisons made for young-of-year and juvenile striped bass, the CPUE denominator was "number of minutes" rather than "number of trawls" to account for differential time spent trawling (*e.g.*, 10 minutes in Montezuma Slough, 5 minutes in Denverton Slough). For monthly comparisons, in order to account for unequal effort among sloughs, CPUE values for otter trawls were calculated as

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

where i = slough, j =month, and n is the number of sloughs; once again, CPUE values for invertebrates were calculated likewise. The same method was used for calculating monthly beach seine CPUE values. Monthly water-quality averages for 2011 were calculated as for monthly 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." X2, the distance in kilometers from Golden Gate Bridge along the thalweg to the near-bed water with salinity of 2 ppt, was calculated following Jassby *et al.* (1995). The location of X2 is associated with the historically productive low-salinity zone and high abundances of phytoplankton, macroinvertebrates, and several fishes (Jassby *et al*. 1995). Consequently, when X2 is located in Suisun Bay, the abundance of fishes in Suisun Marsh is often relatively high. The Net Delta Outflow Index ("Delta outflow"), a proxy for water exiting the Sacramento-San Joaquin 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 DWR's Dayflow website (2012). Results were then graphed and compared.

Age classes for fishes except Sacramento splittail and striped bass were determined by observing peaks in length-frequency graphs. Sacramento splittail age classes were determined following Matern and Sommer (unpublished data). Striped bass young-of-year 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."

Catches of all fishes and by each method from 1979 to 2011 are found in "Appendix A"; annual catches for each slough in 2011, and trawl and seine effort for each slough in 2011, are found in "Appendix B" and "Appendix C," respectively; and catches for all fishes and macroinvertebrates from the Cordelia Slough complex and Tule Red sampling events are found in "Appendix D."

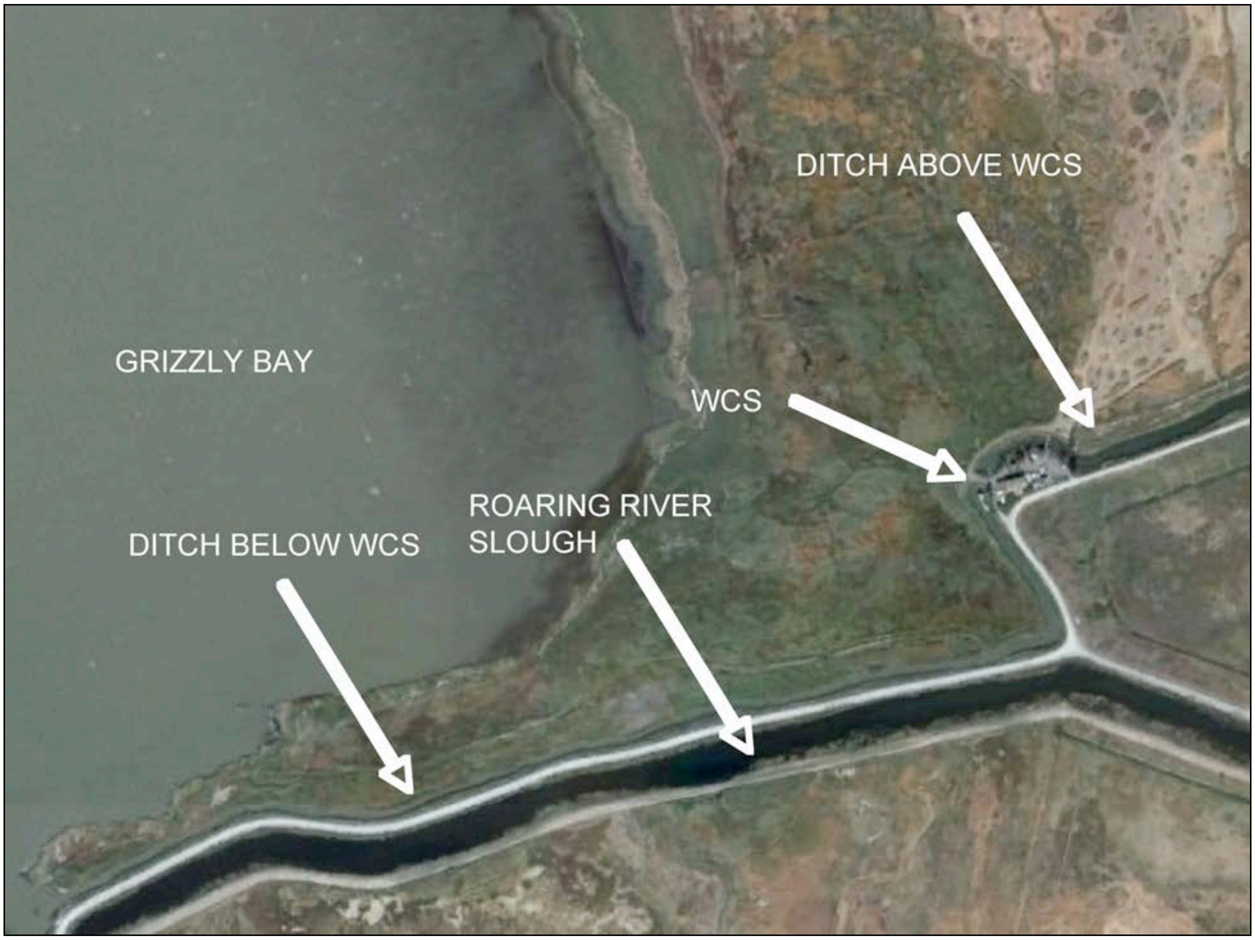

Figure 4. Map showing major features of Tule Red Duck Club ditch and adjacent waterways (WCS = water control structure).

RESULTS AND DISCUSSION

Abiotic Conditions

Delta Outflow

2011 was classified as a wet year by DWR; concomitantly, Delta outflow was generally much higher through most of the year in 2011 relative to the drier year of 2010 (Figure 5). A very wet March in 2011 resulted in Delta outflow that was the highest recorded since 2006 and that was more than double the highest value recorded in 2010. Relatively wet conditions in May and June contributed to higher summertime Delta outflows in 2011 than in 2010. The higher outflows of 2011 appeared to greatly affect fishes of the marsh, including delta and longfin smelt.

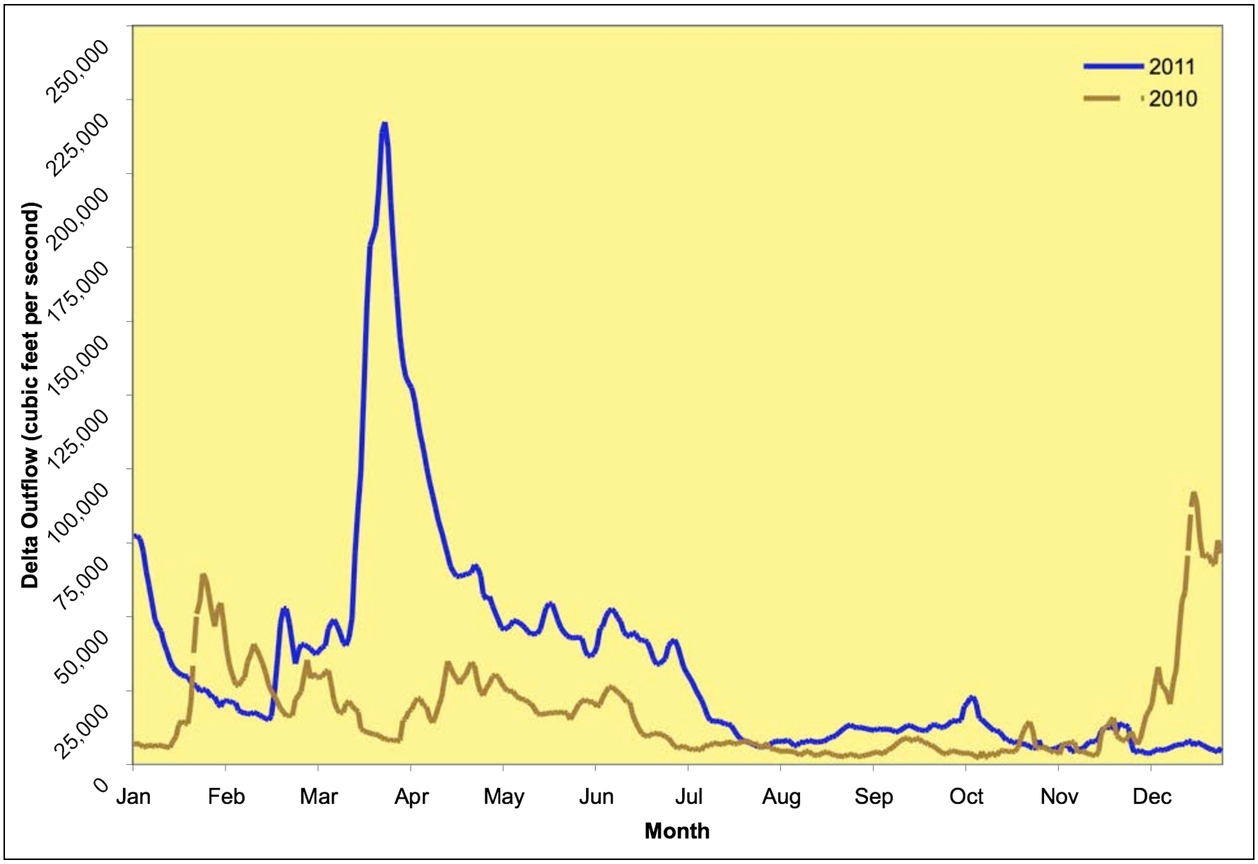

Figure 5. Daily Delta outflow for 2010 and 2011.

Salinity

Following the high Delta outflows, salinities in Suisun Marsh during 2011 were substantially lower than during an average year (Figure 6). Salinities were comparatively low during winter and spring, which is the usual pattern. However, summer salinities, especially during June and July, were very low relative to the average, and they did not begin appreciably increasing until August. From August until the end of the year, salinity gradually increased, although the absolute values were lower than the average in all months except December (Figure 6). These low salinities precluded the need to operate the Suisun Marsh Salinity Control Gates for the entire year. Concomitant with lower salinities, X2 was within Suisun Bay for 57% of 2011, which was the greatest amount of time X2 has been in the bay over the last five years. Notably, X2 was within Suisun Bay during summer and autumn (Figure 6), a key period for listed species such as delta smelt (Nobriga *et al*. 2008, Feyrer *et al*. 2007).

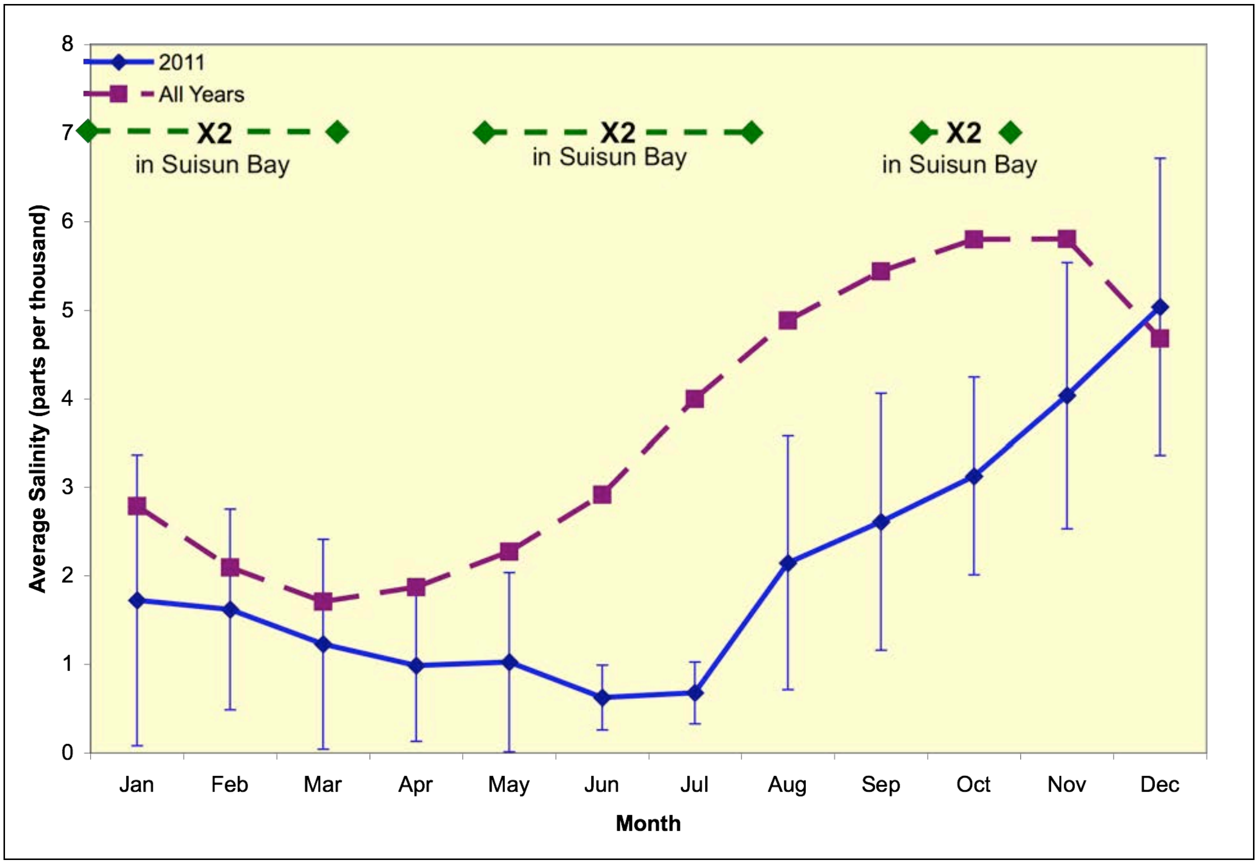

Figure 6. Average monthly salinities for 2011 and from 1980 to 2011 ("all years"); error bars are standard deviations for 2011. "X2" and accompanying dashed lines indicate when X2 was within Suisun Bay (*i.e.*, between 55 and 75 km from Golden Gate Bridge).

Dissolved Oxygen

Dissolved oxygen (DO) concentrations in the marsh are affected by decomposition of organic material, temperature, salinity, wind, 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. Because oxygen solubility decreases with higher salinities and temperatures, DO values are frequently lower in summer and autumn than in winter. Hypoxic water can be discharged into some sloughs from some managed wetlands during autumn, further lowering DO (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. Because of all the factors listed above, marsh DO is usually high in winter, lower in spring and summer, and lowest in autumn.

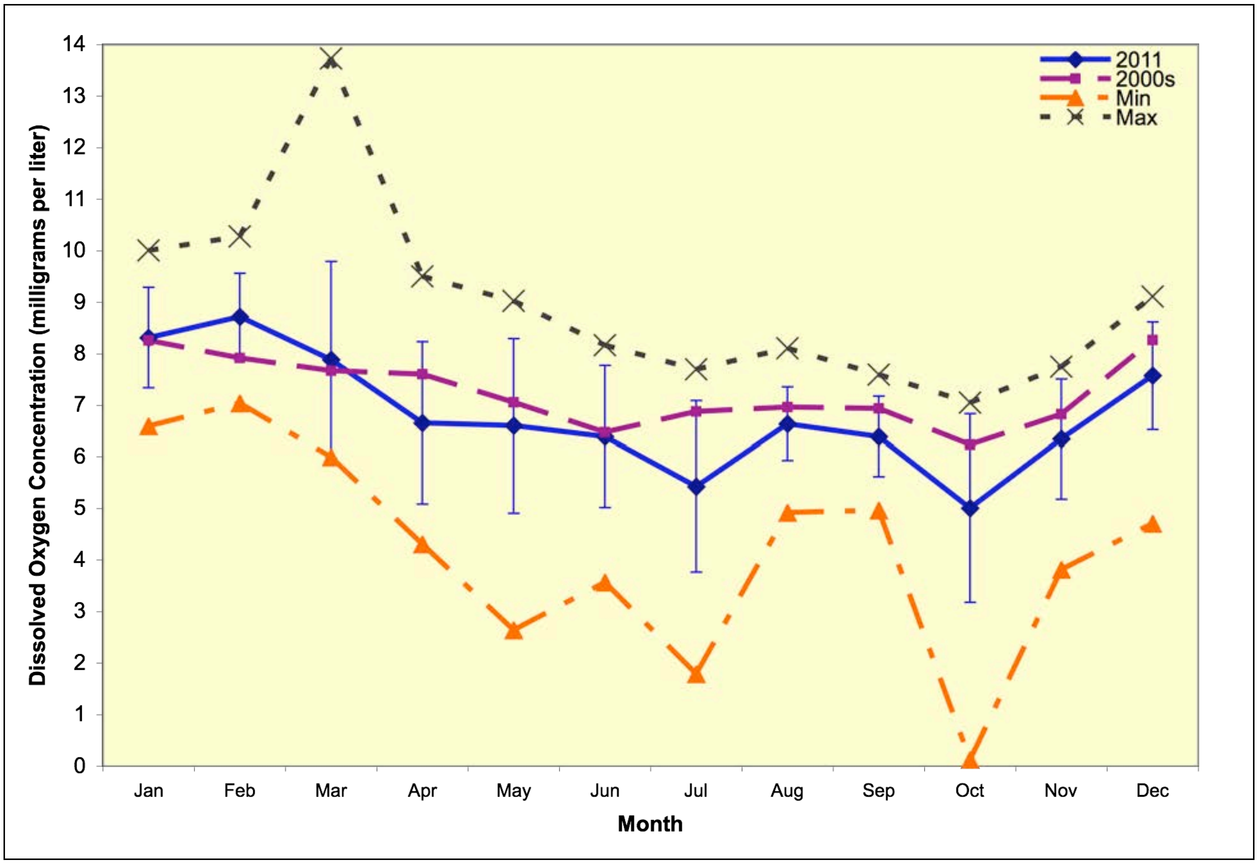

Figure 7. Monthly average DO concentrations for 2011 and from 2000 to 2011 ("2000s"), and the monthly minimum/maximum DO concentration ("min" and "max") for 2011; error bars are standard deviations for 2011.

The pattern in 2011 followed that of previous years, with DO very high in winter, comparatively low in autumn, and at moderate levels during spring and summer (Figure 7). Notably, DO was substantially lower in July 2011 as compared to the average for all years (Figure 7), though this was likely due to our sampling coinciding with a very hot day that found temperatures abnormally high in dead-end sloughs of the northeast and central regions of the marsh; these were also the areas where the lowest DO values of the month were recorded. DO levels from 1.1 mg/L to 0.1 mg/L were measured in upper Goodyear Slough and upper Peytonia Slough on October 14 and in upper Peytonia on October 20. By October 26, DO had substantially improved in both upper Goodyear and upper Peytonia sloughs, reaching 3.65 and 3.59 mg/L, respectively. The increase in DO in upper Peytonia Slough occurred concurrent with a decline in DO of upper Suisun Slough from 5.58 mg/L on October 20 to 3.79 mg/L on October 26. By November, DO in Peytonia and upper Suisun sloughs was above 5 mg/L. These patterns during October suggest discharge of low-DO managed wetlands water into upper Peytonia Slough that was retained within the slough when combined with weak tides, warm temperatures, and net upstream flows (Siegel *et al*. 2011). After the return of stronger tides during the week of October 23, the anoxic water in upper Peytonia appeared to flush into upper Suisun Slough.

Dilution of the discharge water was apparently complete by mid-November, which was probably facilitated by decreasing water temperatures over that period.

Water Temperature and Transparency

Water Temperature

Water temperatures in Suisun Marsh are primarily a function of solar radiation and, to a lesser extent, water volume. Generally, average monthly temperatures follow a pattern typical of temperate regions in the Northern Hemisphere: coldest temperatures occur in winter (December and January) and warmest temperatures occur in summer (July and August). Monthly water temperatures in 2011 followed that pattern (Figure 8). However, a major difference between 2011 and the average for all years of the study was that water temperatures were considerably cooler for the first half of 2011. This likely had a substantial impact on our catches of several species of fish and invertebrates, as discussed below.

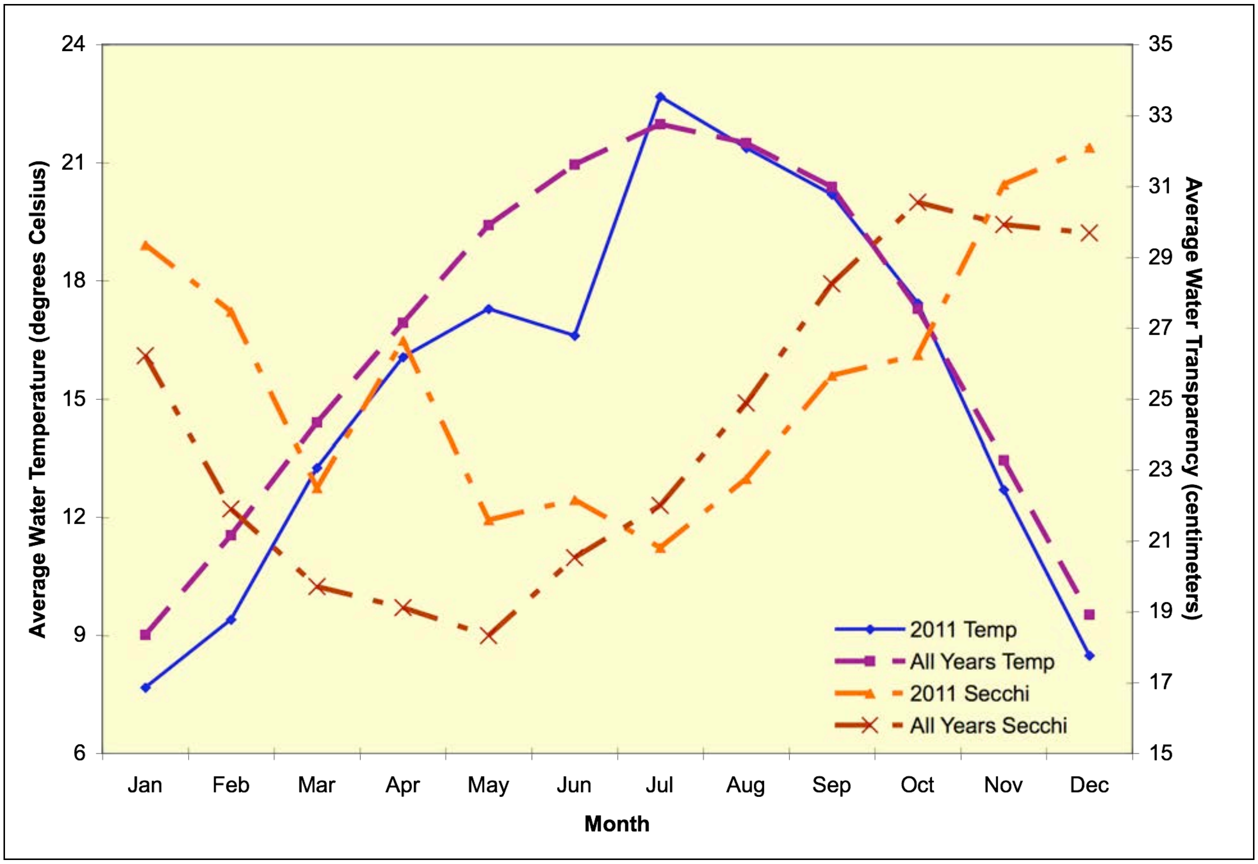

Figure 8. Monthly average temperatures and transparencies for 2011 and from 1980 to 2011 ("all years").

Water Transparency

The magnitude of freshwater inflow (mainly from the Sacramento River) is the primary determinant of water transparency in Suisun Marsh (O'Rear and Moyle 2008). Transparencies in the marsh are usually lowest in spring when river flows are highest; likewise, transparency generally reaches a maximum in October when river flows are at their annual minimum. As a result, the trends in transparency often mirror those for salinity. The pattern during 2011 was no exception (Figure 8); nevertheless, transparencies during the first half of 2011 were higher than the average for all years of the study despite the relatively high Delta outflows. This could be a result of declining sediment supplies in the Sacramento-San Joaquin watershed due to factors such as dams and bank stabilization (Wright and Schoelhamer 2004) and/or increased trapping of sediment by invasive macrophytes in the Delta. Conversely, transparencies were notably lower in the latter half of 2011 relative to that for all years of the study except for November and December.

Trends in Invertebrate Abundance and Distribution

Four plankton-feeding macroinvertebrates - California bay shrimp (native), Siberian prawn (introduced), Black Sea jellyfish (introduced), and overbite clam (introduced) - that are important to the food web (*e.g.*, Black Sea jellyfish: Wintzer *et al.* 2011*b*; California bay shrimp: Hatfield 1985; overbite clam: Kimmerer and Orsi 1996; Siberian prawn: Nobriga and Feyrer 2008) are commonly captured by otter trawl in Suisun Marsh. Annual catch of California bay shrimp has been highly variable, although decreasing trends in abundance were evident in the early 1980s and early 2000s (Figure 9). While catch of Siberian prawn has also been variable, it mirrored the catch for California bay shrimp from 2004 to 2010 (Figure 9). Black Sea jellyfish were first captured in 1981 and have been present in trawls during most years of the study's history, while overbite clam was not recorded until 1990 (Figure 9). Both the clams and the jellyfish exhibited increasing trends in the early 2000s and are now commonly captured relative to the 1980s and 1990s (Figure 9). The abundance for Black Sea jellyfish in 2011 remained similar to that in 2010, while Siberian prawn noticeably increased with a concomitant decline in the California bay shrimp catch from 2010 to 2011. Most importantly, overbite clam numbers crashed in 2011 after reaching their highest-ever abundance in the marsh during 2010.

California Bay Shrimp

California bay shrimp dropped by about 44% from 2010 to 2011, although the annual CPUE value was the second highest recorded since 2001 (Figure 9). In most years, monthly California bay shrimp catch in the marsh generally exhibits a single peak that occurs sometime between spring and late summer, the ascending limb of which coincides with a decline in Delta outflow and intrusion of more-saline water into the marsh. This pattern is consistent with the known spawning of California bay shrimp in downstream saltier water during autumn and winter followed by an upstream flux of juveniles during spring and summer for rearing (Hatfield 1985). Given these previously documented patterns, plus the relatively high Delta outflows in 2011 that persisted deep into summer, our catch of bay shrimp did not begin to noticeably increase until late in the year (*i.e.*, September; Figure 10). However, unlike most previous years, the catch of California bay shrimp stayed high throughout the remainder of 2011, suggesting either/both a continuing influx of juveniles into the marsh from downstream bays or/and high survival within the marsh. The first explanation seems likely given that bay shrimp were only captured in lower

Suisun Slough in July; reached high numbers in lower Suisun Slough in August, concurrent with appearing in other larger sloughs (*i.e.*, those sloughs exposed to greater tidal excursion) and Goodyear Slough; and were captured in all areas of the marsh except upper First Mallard Slough in September while still being abundant in lower Suisun Slough (O'Rear, unpublished data). Concomitantly high mysid numbers would bolster the latter explanation given the dominance of mysids in the bay shrimp's diet (Siegfried 1982); however, mysids were very rare in the marsh after July (see the "Striped Bass" section for further discussion). Nevertheless, California bay shrimp have been known to prey on amphipods [such as the bottom-dwelling *Americorophium spinicorne* (Siegfried 1982)], crustaceans that are common and frequently abundant in the marsh and for which we do not have accurate population indices. Thus, our relatively stable catches of California bay shrimp in the latter part of 2011 could still be partly attributable to high survival if they were feeding on an large amphipod population.

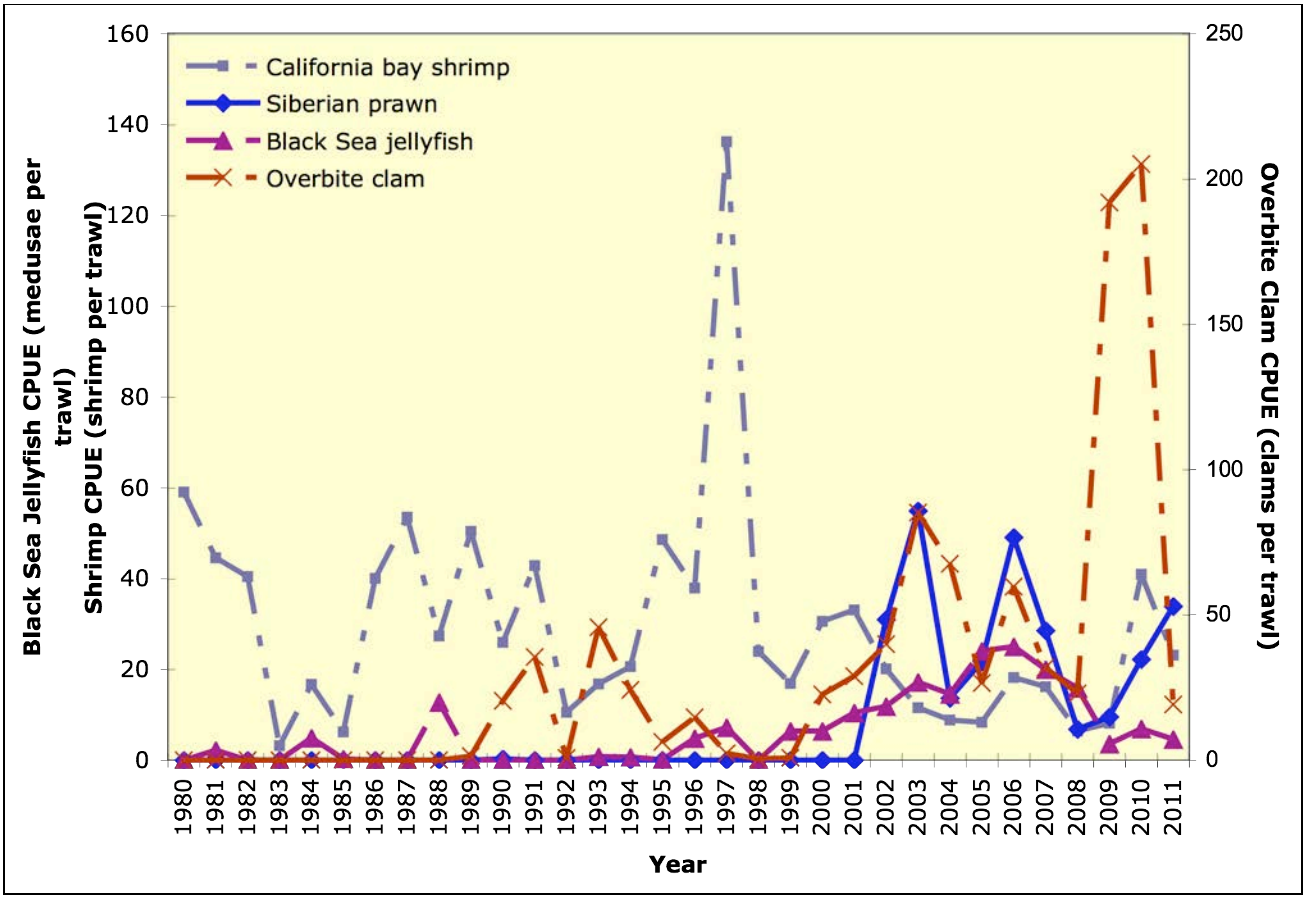

Figure 9. Annual otter trawl CPUE for four common invertebrates in Suisun Marsh from 1980 to 2011.

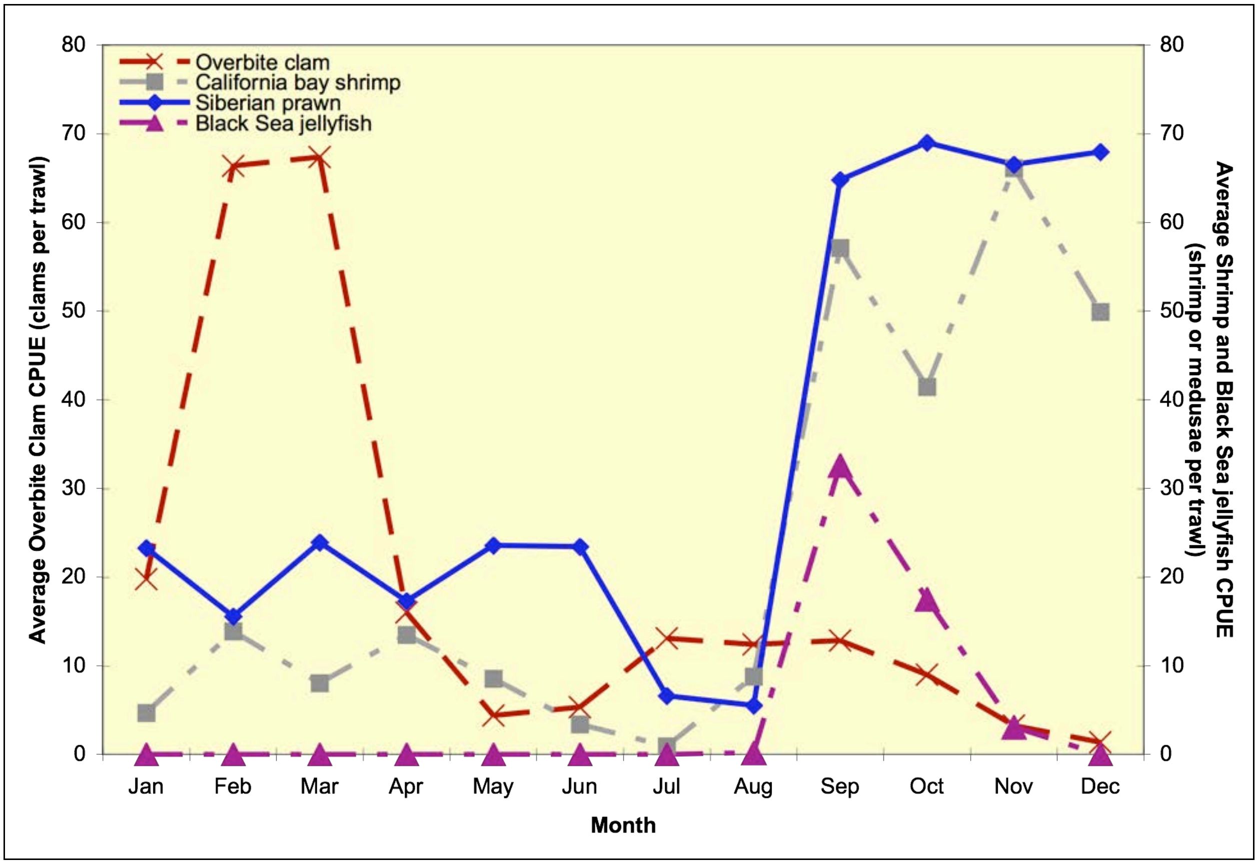

Figure 10. Average monthly otter trawl CPUE during 2011 for four common invertebrates in Suisun Marsh.

Siberian Prawn

Siberian prawn differ from California bay shrimp in several respects: (1) the prawn spawns in late spring and summer rather than in autumn and winter (Oh *et al.* 2002); (2) they are associated with lower salinities (Emmett *et al.* 2002) and, unlike California bay shrimp, can complete their life cycle in fresh water (Xu *et al.* 2008); and Siberian prawn appear to derive more of their food from the benthic rather than the pelagic food web (Xu *et al.* 2008, Siegfried 1982). Consequently, Siberian prawn are generally most abundant in the marsh during late summer and early autumn (*i.e.*, after recruitment of newly spawned juveniles) in the fresher sloughs of the northwestern and eastern marsh. This was basically the case in 2011, with nearly half of the year's catch (44%) occurring in Denverton and Nurse sloughs in the eastern marsh and two-thirds of the catch occurring in just the last four months of the year (Figure 10). The monthly catch of Siberian prawn, similar to the monthly catch of California bay shrimp, remained remarkably consistent and high from September to December (Figure 10), suggesting that factors affecting the bay shrimp were similar to those affecting the prawns, despite peak abundances of the two shrimps occurring in different areas of the marsh (*i.e.*, Denverton Slough for Siberian prawn and lower Suisun Slough for California bay shrimp).

Black Sea Jellyfish

The appearance of Black Sea jellyfish medusae is contingent upon both salinity and temperature, with the medusae most abundant in moderately brackish, warm water (*e.g*., salinity = 3-7 ppt, water temperature > 19°C; Schroeter 2008). These conditions usually occur in summer; in 2011, however, the co-occurrence of appropriate salinity and temperature for a medusa bloom did not happen until September, and then only in lower Suisun and lower Goodyear sloughs. This was followed by decline in temperatures during October below that favorable for medusae. As a result, the prolonged higher Delta outflows and lower salinities appeared to delay and thus shorten the bloom, and they also restricted it to the southwest marsh's sloughs.

Overbite Clam

Abundance of overbite clam declined precipitously from 2010 to 2011. Given the clam's sensitivity to prolonged fresh water (Schroeter 2011, Nicolini and Penry 2000), the reduction in overbite clam abundance in the marsh was likely due to relatively high and prolonged Delta outflow during 2011. Although there was a slight increase in numbers during the summer recruitment period (Figure 8), the increase and absolute numbers were much less than in previous drier years (*e.g.*, 2009, 2010; O'Rear and Moyle 2011). As in prior years, the bulk of the catch (82%) occurred in the southwest marsh in lower Suisun and lower Goodyear sloughs, and, despite the high flows of 2011, small numbers were still present in upper Suisun Slough near the west end of Cutoff Slough.

Trends in Fish Abundance and Distribution

Otter Trawls

Annual fish per trawl generally declined in the first 15 years of the study (1980-1995); from then until 2006, it vacillated around a relatively stable mean (Figure 11; O'Rear and Moyle 2009). From 2006 to 2008, however, catch declined substantially, concurrent with lower Delta outflows and higher marsh salinities. The last three years have seen a mild increase in catch. The decrease in the annual CPUE for native fish has been more precipitous and less variable than that for introduced fishes (Figure 11). CPUE for introduced fishes has been highly variable over the study's history (Figure 11).

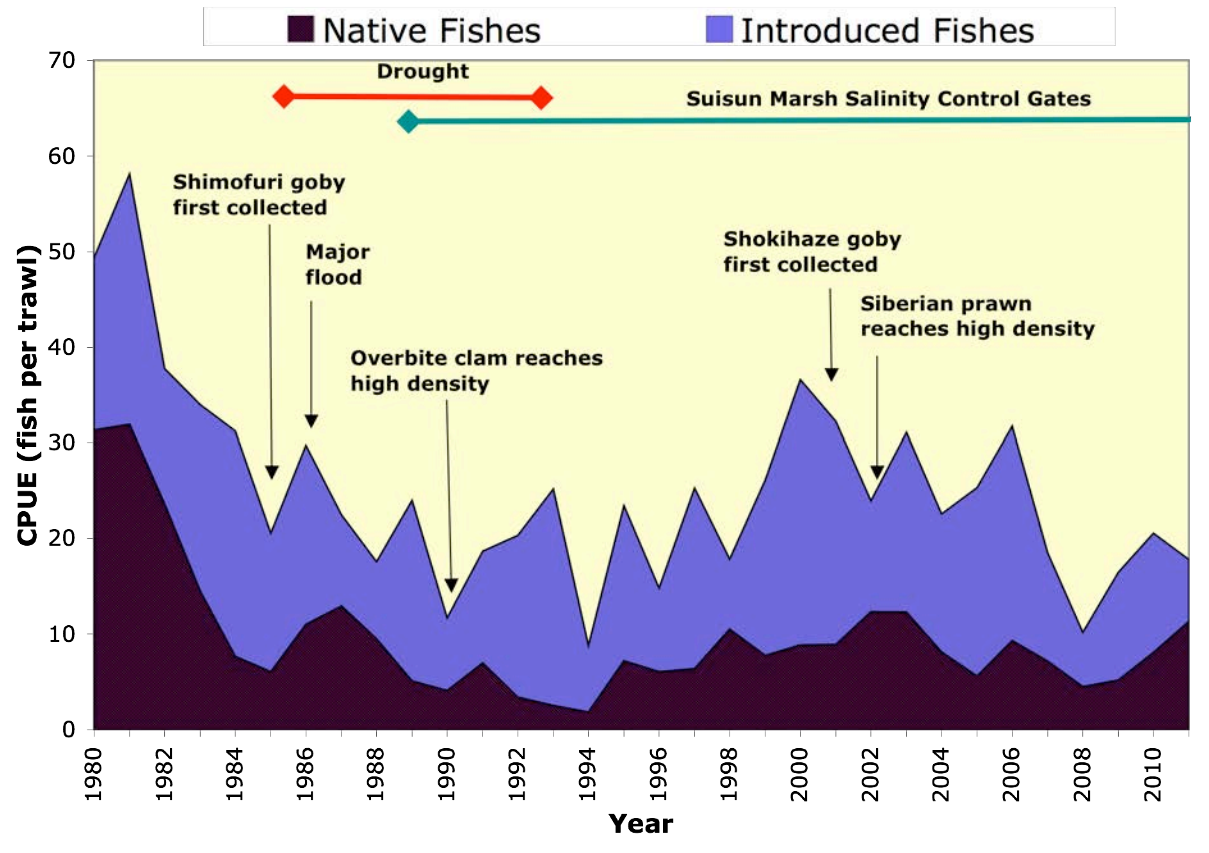

Figure 11. Annual otter trawl CPUE from 1980 to 2011 for native and introduced fishes, with timing of important events noted.

Annual otter trawl CPUE declined slightly from 20.6 fish per trawl in 2010 to 18.9 in 2011. The drop in catch was mainly due to reduction in numbers of four introduced species: striped bass, shimofuri goby (*Tridentiger bifasciatus*), yellowfin goby, and white catfish (Table 2). The decline in the catch of striped bass appeared mainly due to delayed recruitment of young-of-year striped bass into the marsh from a later spawn as a result of relatively cold water temperatures during winter and spring. In addition, once young-of-year striped bass began entering the marsh in numbers during July, mysid abundances had already dropped to very low levels, possibly reducing the survival of this year class of fish and thus our catch. This appeared compensated in part by increased numbers of young-of-year striped bass in near-shore areas, which was reflected in a larger beach seine catch. The juvenile striped bass probably moved inshore to feed on prey abundant on vegetation, sediments, and rocks, especially amphipods. This greater use of near-shore habitats by young striped bass has been observed at a larger scale throughout the estuary (Sommer *et al*. 2011, Schroeter 2008). The drop in white catfish numbers during 2011 was almost solely due to lower numbers of adults; this decrease was partially compensated by a pulse of young-of-year fish, which had not occurred since 2006. These changes in the white catfish population are consistent with high mortality of adult fish. Based on the 1983 cohort (O'Rear and Moyle 2011), white catfish in the marsh have a lifespan of about six years. The last large catches of young-of-year white catfish before 2011 occurred in 2005 and 2006; these fish made up a large proportion of the white catfish catch thereafter. Consequently, most white catfish that dominated the catch in the late 2000s were close to the end of their lives in 2011.

` **Table 2.** Percent decline in otter trawl catch between 2010 and 2011 of four abundant introduced fishes in Suisun Marsh.

Species	2010 CPUE	2011 CPUE	% Decline
white catfish	1.92	1.34	30%
striped bass	6.07	2.96	51%
shimofuri goby	1.63	0.38	77%
yellowfin goby	1.65	0.77	53%

Factors affecting the 2011 yellowfin and shimofuri goby catch in the marsh appear more obscure than for white catfish and striped bass. Delayed reproduction because of the cold winter and spring is likely partly responsible for the reduced shimofuri goby catch. Young-of-year shimofuri gobies are usually very abundant in our catches by July (*e.g*., O'Rear and Moyle 2008); during 2011, however, young-of-year fish did not appear in the catches until August, and they were never abundant in beach seines or otter trawls in any part of the marsh. Young-of-year yellowfin gobies generally reach peak abundance in beach seines during June, thereafter reaching peak abundance in otter trawls a month later in July. Although the timing of the highest catch in otter trawls during 2011 occurred in July, the maximum in beach seine catch was not reached until August and was very low relative to the previous four years (O'Rear and Moyle 2011, 2010, 2009). Additionally, the beach seine annual CPUE for 2011 was the lowest recorded since 1992, and the annual otter trawl CPUE for 2011 was considerably below the average for all years (0.8 fish per trawl and 2.6 fish per trawl, respectively). These patterns are consistent with both (1) lower recruitment of yellowfin gobies from downstream into the marsh and (2) appropriate conditions (*e.g.*, food abundance) within the channels of the sloughs.

The only native fish that contributed substantially to the otter trawl catch was Sacramento splittail. Annual otter trawl CPUE for 2011 was nearly double that of 2010 (6.3 fish per trawl and 3.3 fish per trawl, respectively). This increase in catch was due in part to high recruitment of young-of-year fish from upstream, a common pattern observed in years (such as 2011) when floodplains are inundated during spring (Sommer *et al*. 2008, Moyle *et al*. 2004, Sommer *et al*. 1997). However, a larger proportion of the catch of Sacramento splittail during 2011 was comprised of the 2010 year class, suggesting either high survival of this cohort or an influx of additional 2010 year-class fish into the marsh from other areas (*e.g*., the western Delta).

Beach Seines

Unlike the trend for annual otter trawl CPUE, annual beach seine CPUE has generally increased since the study's inception (Figure 12); however, since reaching a high point in 2006, beach seine catches have been decreasing. Similar to otter trawl catches, variability in native fish CPUE among years has been much less than that for introduced fishes (Figure 12). With the exception of a few early years (*e.g.*, 1980 and 1983), catch of native fishes has been consistently low and contributed very little to the total catch. Introduced fishes, particularly Mississippi silverside, have dominated the beach seine hauls.

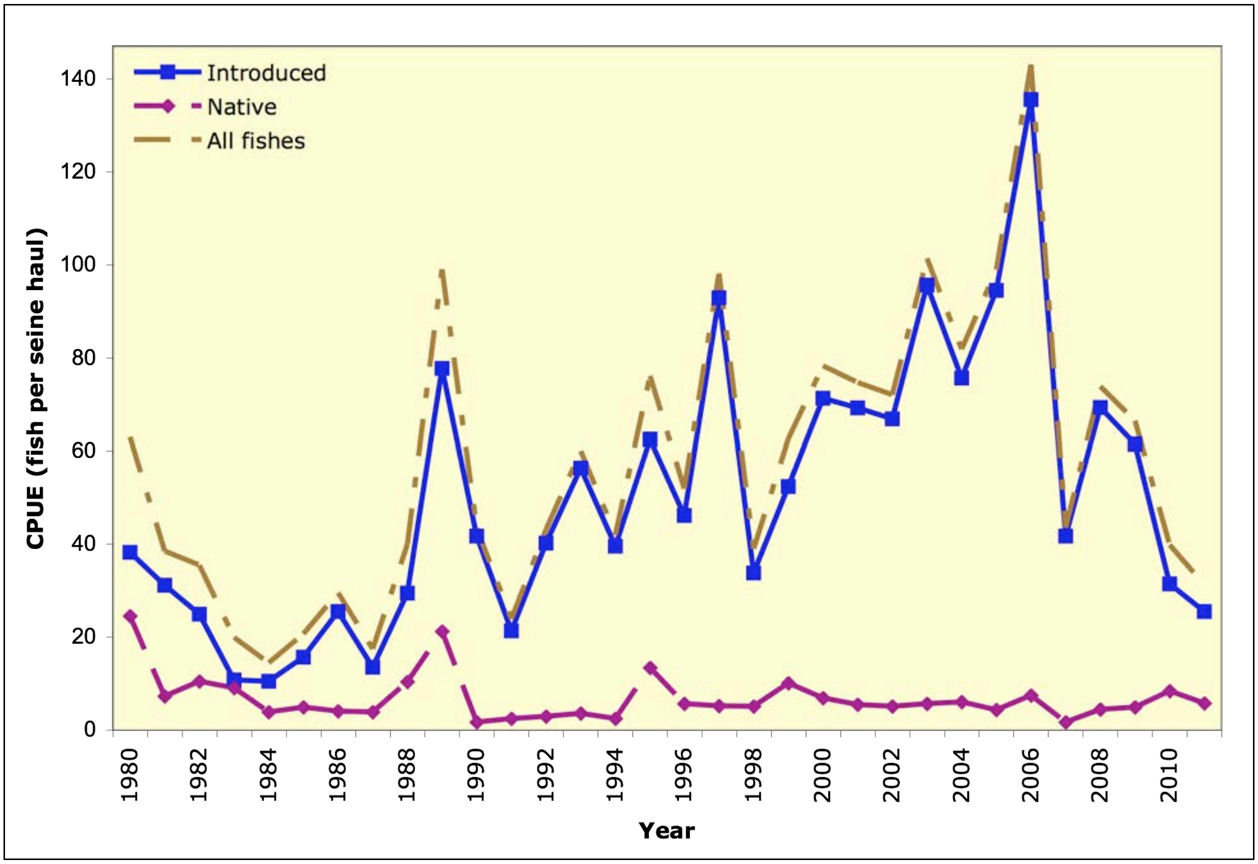

Figure 12. Annual beach seine CPUE from 1980 to 2011 for introduced, native, and all fishes.

Annual beach seine CPUE dropped from 2010 to 2011 and reached its lowest point since 1998. This was due to declines in three fishes: threespine stickleback (*Gasterosteus aculeatus*), yellowfin goby, and Mississippi silverside. The decline in the catch of threespine stickleback was primarily due to the timing of sampling in 2010, which co-occurred with the flushing of a duck pond during April in Denverton Slough. As in 2010, cool temperatures in 2011 likely increased mortality of eggs and decreased fecundity/growth of adults of Mississippi silverside (Stoeckel and Heidinger 1988, Hubbs *et al.* 1971), hence continuing the decline in the species' catch that began in 2009 (Figure 12). Conversely, the striped bass catch nearly tripled (150 fish in 2010 and 434 fish in 2011), while Sacramento splittail catch in 2011 was almost 3.5 times the size of 2010's value (230 fish and 66 fish, respectively). As previously discussed, the higher beach seine catch of striped bass was possibly due to lower mysid abundance in the channels. Increased numbers of Sacramento splittail in the beach seine catch was due to greater reproductive success upstream since the vast majority of the catch (87%) was comprised of young-of-year fish.

Fish Species of Interest

Fishes of the Pelagic Organism Decline

THREADFIN SHAD

Otter trawl catches of threadfin shad were relatively high in the first five years of the study, declined to very low levels during the dry late 1980s and early 1990s, and generally increased through the late 1990s to 2006 (Figure 13). From 2006 to 2008, both otter trawl catch and beach seine catch dropped precipitously with declines in Delta outflows and increased salinities, with the annual beach seine CPUE reaching its lowest value in 2009 since 1992 (O'Rear and Moyle 2010). Otter trawl catch increased from 2008 to 2011, while beach seine catch rose from 2009 to 2011 (Figure 13), coincident with years generally wetter than 2007 and 2008.

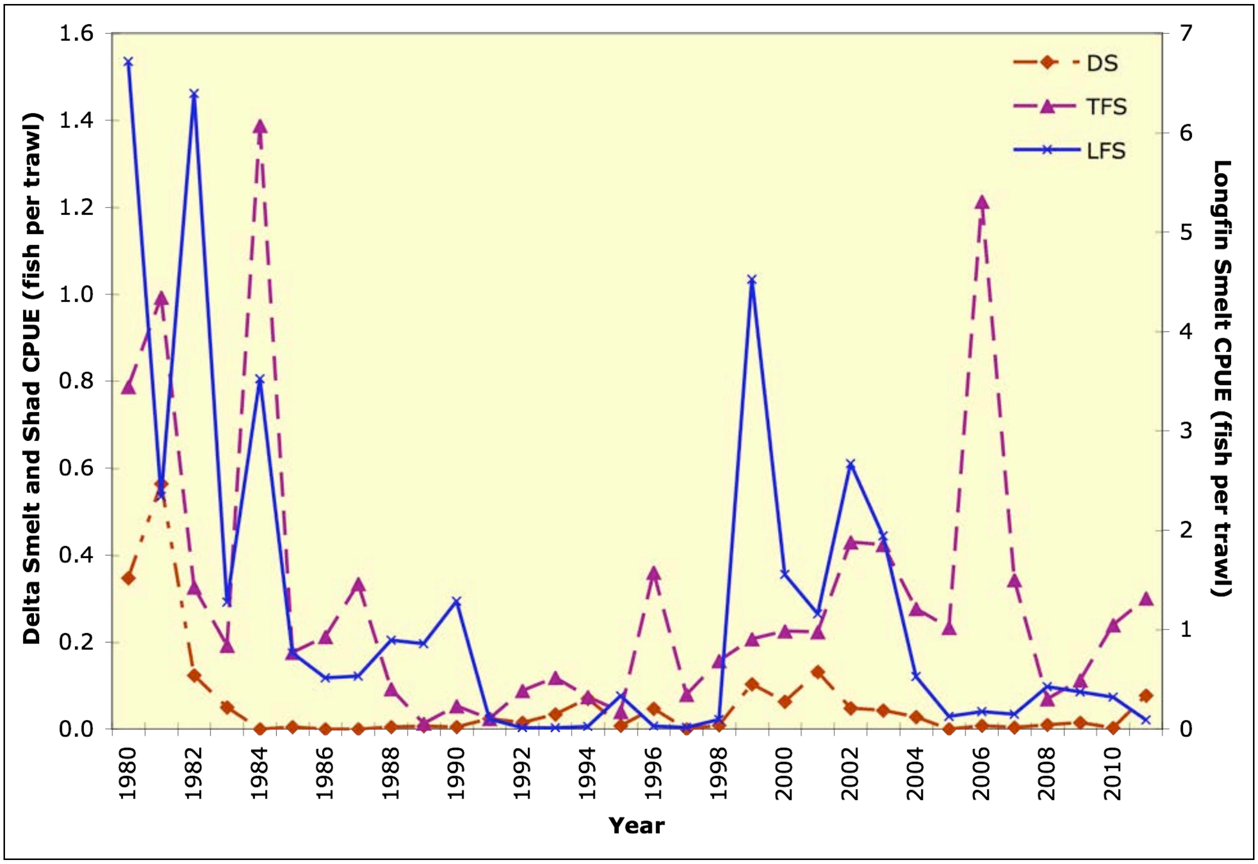

Figure 13. Annual otter trawl CPUE for threadfin shad ("TFS"), delta smelt ("DS"), and longfin smelt ("LFS") from 1980 to 2011.

Recruitment of young-of-year fish into the marsh during 2011 continued the increase that began in 2009 concomitant with fresher water co-occurring with the spawning period - generally June - of threadfin shad. For instance, salinity in Denverton Slough (where the bulk of the beach seine catch is made in each year) in 2009 was 3.1 ppt in June 2009, 1.8 ppt in June 2010, and 1.0 ppt in June 2011. While some of the recruitment was likely from fish spawned upstream in the Delta that subsequently washed into the marsh, reproduction within the marsh probably also contributed to the increased 2011 catches: adult-sized fish (*i.e.*, those larger than 60 mm SL; Gerdes and McConnell 1963) were present throughout much of the year, and fish less than two months old (*i.e.*, those less than 40 mm SL; Moyle 2002; Figure 14) continued to occur well after Delta outflow declined and saltier water began intruding into the marsh.

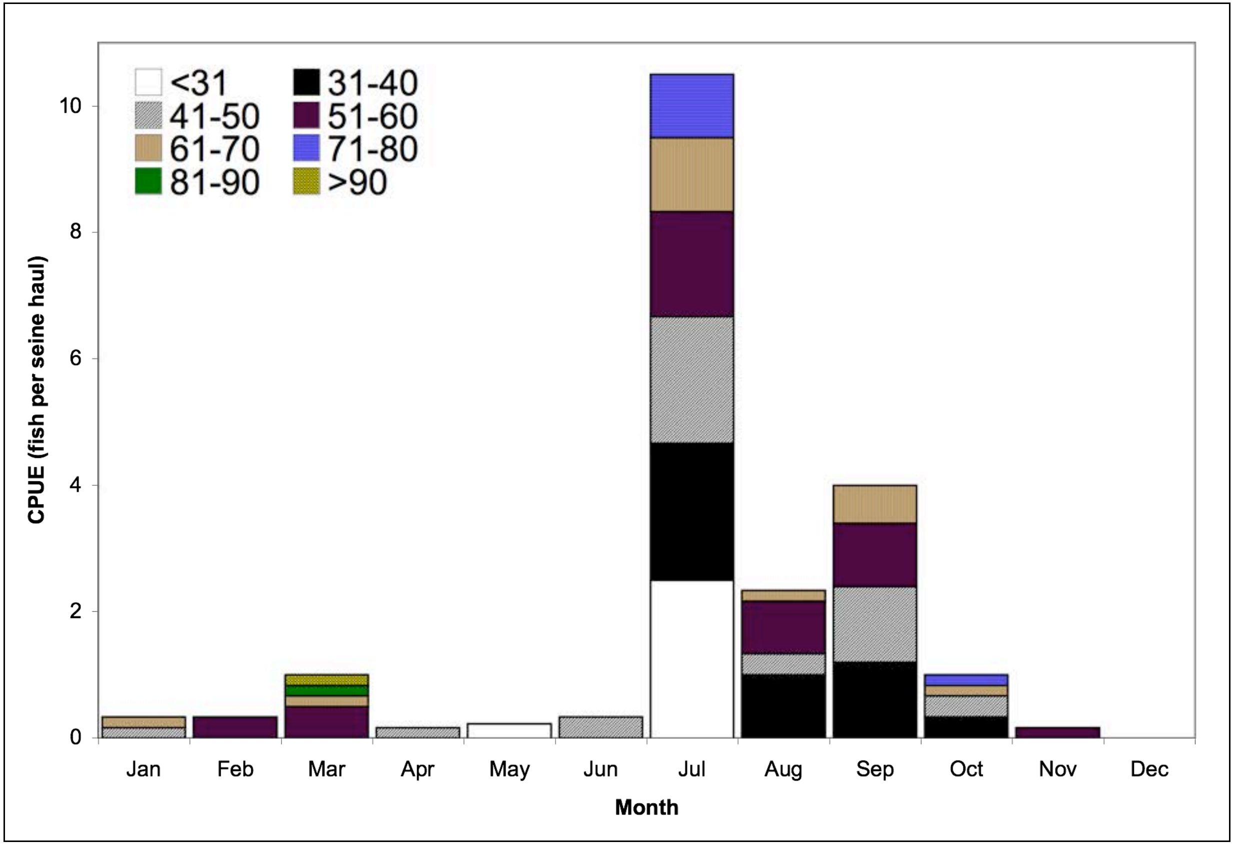

Figure 14. Monthly seine CPUE during 2011 for size classes of threadfin shad.

DELTA SMELT

Since 1984, otter trawl catch of delta smelt has been routinely low (less than 7 fish per year), tracking the estuary-wide decline in smelt numbers (Figure 13; Feyrer *et al*. 2007, Bennett 2005, Moyle 2002). Although we have conducted just 66 midwater trawls over the study's history, we have only captured four delta smelt from the water column of the large sloughs.

Annual otter trawl CPUE in 2011 was the highest recorded since 2001, with a total of 20 fish captured in trawls. One of these fish was a subadult from the 2010 year class captured in upper Suisun Slough during January; additionally, the only delta smelt caught in a beach seine was a subadult fish also of the 2010 year class that was captured in upper Suisun Slough during January 2011. The rest (19 fish) were subadults (size range: 46-70 mm SL) of the 2011 year class captured during autumn, with 16 of those caught in lower Suisun Slough during November and December. These catches were likely due to the interaction of several factors mostly occurring outside Suisun Marsh: (1) cool water available during the spawning period; (2) high springtime Delta outflow that both reduced entrainment at the south Delta pumps and sped larval fish to the western Delta and Suisun Bay and Marsh; (3) relatively high Delta outflow during summer and autumn that both diluted ammonium and promoted high phytoplankton abundances; and (4) favorable water temperatures and salinities in lower Suisun Slough during autumn, particularly November.

LONGFIN SMELT

The annual otter trawl CPUE for longfin smelt in Suisun Marsh has paralleled that seen in other parts of the estuary (*e.g.*, the Delta): catches were high in the early 1980s, were low throughout the dry years of the late 1980s and early 1990s, increased somewhat in the wetter years of the late 1990s and early 2000s, and declined to low levels again beginning in 2005 (Figure 13). Our catch pattern has been influenced by Delta outflow (Rosenfield and Baxter 2007), which, when large, transports larvae to more productive regions of the estuary (*e.g.*, Suisun Bay; Bay Institute *et al.* 2007, Moyle 2002) and reduces entrainment mortality (Bay Institute *et al.* 2007).

Annual otter trawl CPUE for longfin smelt in 2011 was the lowest seen since 1997, although the annual beach seine CPUE was the second highest recorded since the study's inception. In the previous four dry years (2007 - 2010), two pulses of longfin smelt were observed: (1) post-larval fish that appeared in the southwest marsh during spring when salinities had begun to increase and were around 4 ppt (O'Rear and Moyle 2011, 2010, 2009, 2008) and (2) pre-spawning adults, again captured primarily in the southwest marsh (*i.e.*, lower Suisun and lower Goodyear sloughs), during autumn once water temperatures had begun to decline. Both of these pulses reflected movement of longfin smelt from Grizzly Bay into the marsh via lower Suisun and lower Montezuma sloughs. The pattern in catch of adults in 2011 was very similar to previous years, with all of the adult-sized fish caught in autumn (Figure 15) and about half of those fish captured in the southwest marsh. However, catch of young-of-year fish during 2011 was distinctly different from the previous four years: (1) young-of-year were first captured in Cutoff Slough, far into the interior of the marsh (Figure 15); (2) the largest catch of young-of-year fish did not occur in the southwest region of the marsh in lower Suisun Slough but in the far northeastern side of the marsh in Denverton Slough; (3) salinity during the large catch in Denverton Slough was 1 ppt rather than around 4 ppt; and (4) young-of-year fish were, despite some variability in the catch (Figure 15), generally present in the marsh from April through December. These differences in the 2011 young-of-year catch are likely the result of both (1) higher Delta outflow through much of the year and (2) cooler-than-average water temperatures (Figure 5 and 6). That larger catches of young-of-year longfin smelt occurred in Cutoff and Denverton sloughs suggests that they entered the marsh through eastern Montezuma Slough rather than through the southwest marsh, which could reflect differences in spawning location between wet and dry years. Additionally, the comparatively large catch of young-of-year fish in Denverton Slough despite a salinity less than 4 ppt presumably reflects food abundance: Denverton Slough often has the highest plankton abundances of any slough in the marsh, and plankton abundances generally increase from Montezuma Slough, through Nurse Slough, and into Denverton Slough (Schroeter 2011, A. Wintzer, personnel communication). The persistence of young-of-year longfin smelt in the marsh from April to December was likely due to cooler water temperatures (Rosenfield and Baxter 2007). Notable, however, was their absence in July, during which water temperatures were very high in some parts of the marsh.

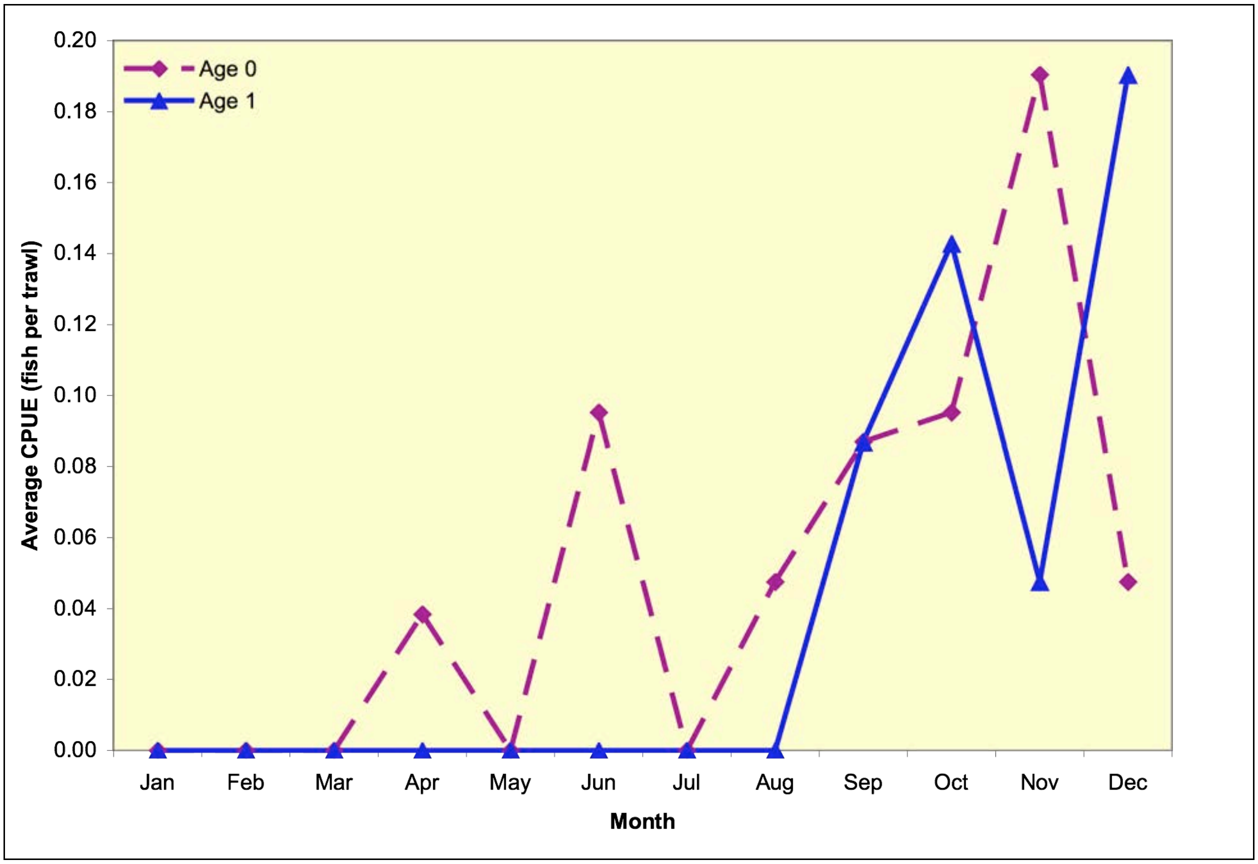

Figure 15. Monthly average otter trawl CPUE for age classes of longfin smelt during 2011.

STRIPED BASS

Striped bass is consistently one of the most abundant fishes in trawl catches. Although highly variable, annual otter trawl CPUE of striped bass has been in long-term decline since the study's inception (Figure 16). The strongest decline in the catch occurred in the first 10 years of the study, which was followed by highly variable catches through much of the 1990s (Figure 16). Moderately high catches were common during the relatively wet early 2000s, although the catch dropped off sharply beginning in 2005 and, despite mild increases in numbers during 2009 and 2010, fell to the third-lowest level recorded in the study's history in 2011. While the drought period that began in the mid-1980s likely influenced the decline in catch seen from 1980 to 1990, this alone cannot fully explain the pattern because large catches have been made in dry years (*e.g.*, 1991, 2001; Figure 16). A plethora of other factors, such as increased water exports, altered food webs, and lower egg production, also have no doubt contributed to the pattern of the otter trawl catch (Sommer *et al.* 2011, Kimmerer *et al.* 2009, DWR and California Department of Fish and Game 2007, Moyle 2002).

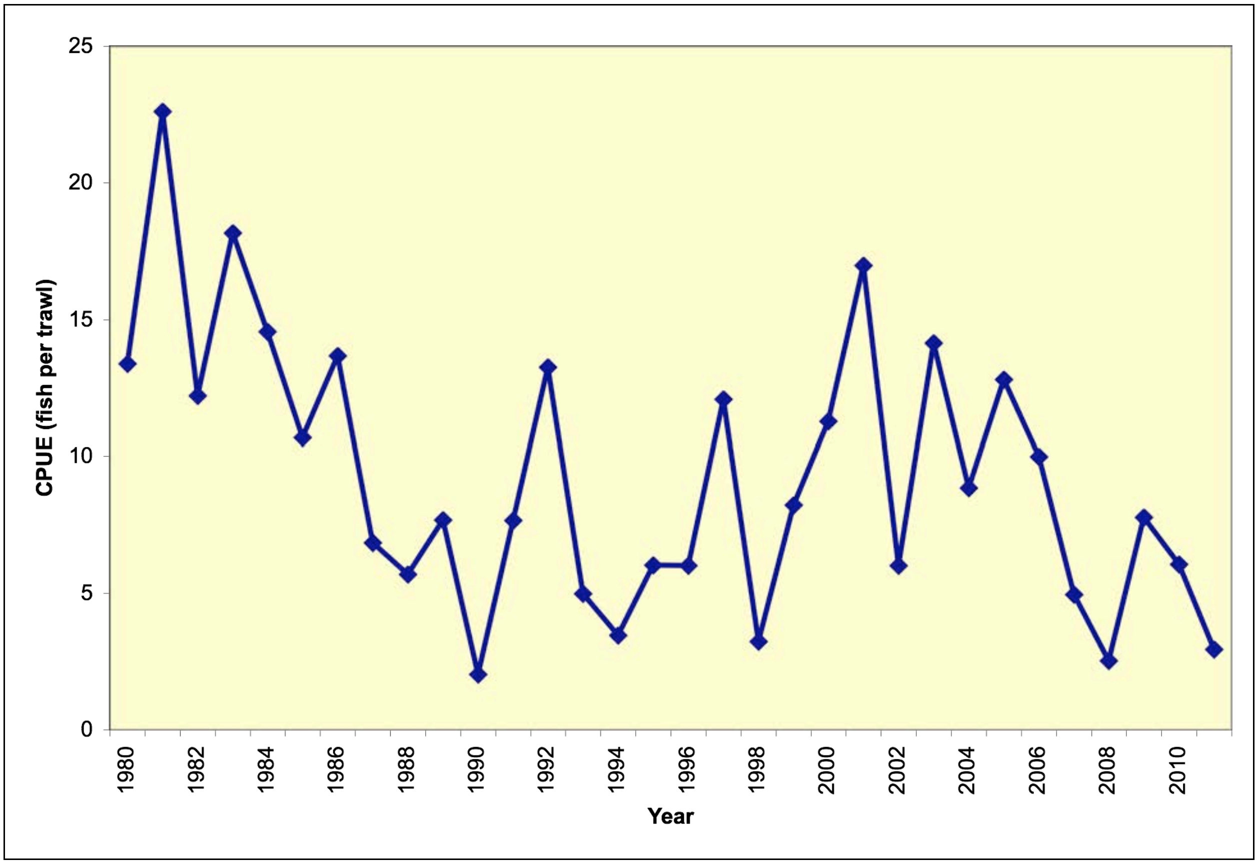

Figure 16. Annual otter trawl CPUE from 1980 to 2011 for striped bass.

The monthly pattern in catch for adult striped bass in the marsh was typical, while catches of young-of-year and juvenile fish were slightly different than previous years in both timing and numbers. Adults were present during fall and winter prior to their upstream spawning migration in spring (Figure 17). More importantly, we captured adult striped bass via hook-and-line in the first five months of the year yet did not catch a ripe fish until May (O'Rear, unpublished data), in contrast to 2010 when ripe fish were first caught in March. As previously intimated, this was likely due to the cold winter and spring slowing reproductive development, leading to a later spawn than in most years. The consequent affect appeared to be a delay in the arrival of young-of-year fish into the marsh - in most previous recent years (*e.g.*, 2006, 2007, 2009, 2010), the first high catches of young-of-year fish occurred in June, while in 2011 it did not occur until July (Figure 18). After July in 2011, unlike in 2010, both the beach seine and the otter trawl catches of young-of-year fish crashed (Figure 17 and 18), suggesting high mortality. A major difference between 2010 and 2011 was the co-occurrence of mysids (a major food item of young striped bass; Feyrer *et al.* 2003) with young-of-year striped bass. In 2010, the pulse of young-of-year fish coincided with a high abundance of mysids, after which the slow decline in mysid numbers was paralleled by a similar drop in young-of-year numbers (O'Rear and Moyle 2011). However, when young-of-year fish first arrived in the marsh in 2011, mysid numbers had already bottomed out (Figure 17), although mysids increased mildly (probably due to recruitment of *Hyperacanthomysis longirostris*; Orsi 1997) through late summer and were tracked by a similar pattern in the young-of-year catch. *Neomysis mercedis* and *N. kadiakensis*, both native species, make up a substantial proportion of the mysid community of the marsh during spring and early summer (Carlson and Matern 2000). *Neomysis mercedis* is known to be sensitive to warm water temperatures, with abundances falling rapidly once water temperature exceeds 22°C (Heubach 1969). Temperatures during the summer of 2010 were mild and did not frequently rise above 22°C (O'Rear and Moyle 2011), while temperatures as high as 27°C were attained in July 2011. Consequently, catch of young-of-year striped bass in the marsh during 2011 appeared to be the result of a mismatch between a predator (young-of-year striped bass) and its major prey (mysids), mediated by cold water affecting reproductive development of adult striped bass and warm water affecting mysid numbers.

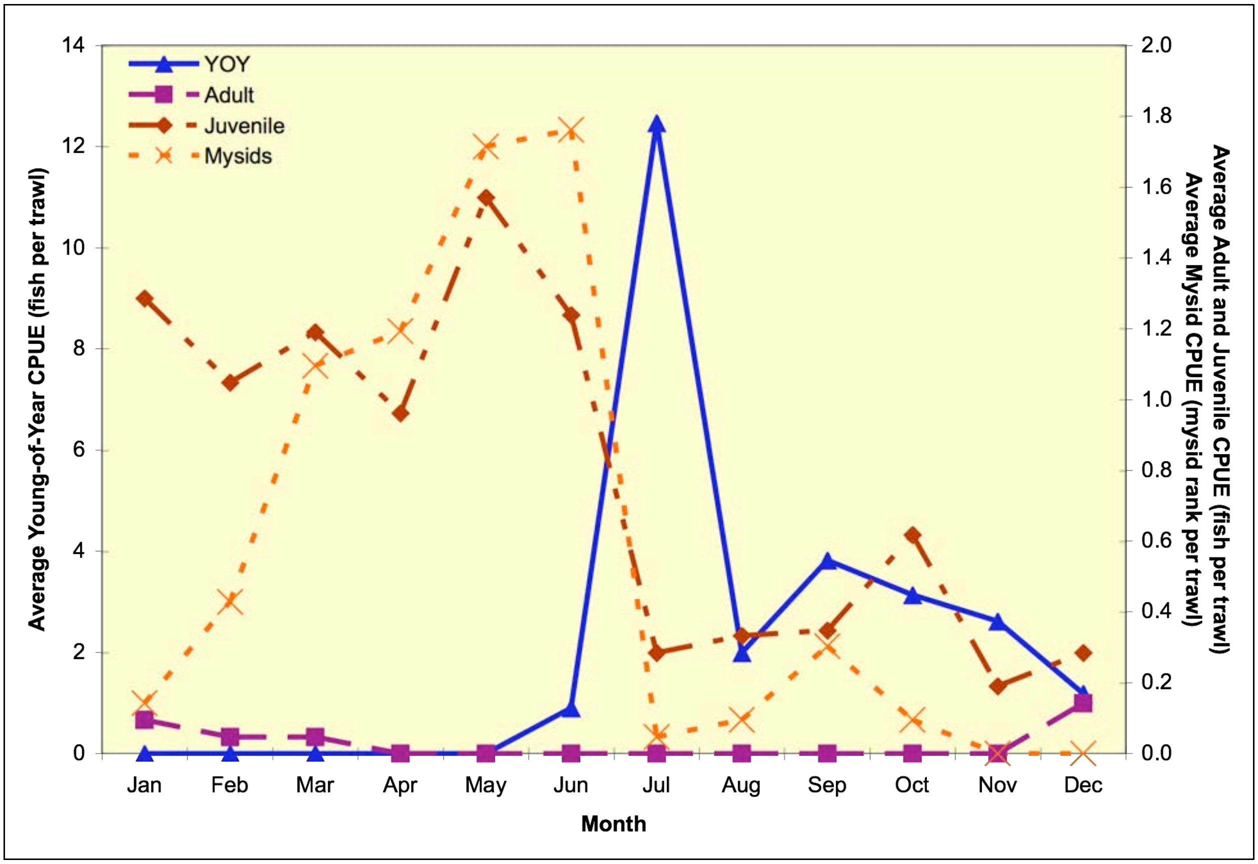

Figure 17. Average monthly otter trawl CPUE for mysids and for young-of-year (YOY), juvenile, and adult striped bass during 2011.

Juvenile striped bass, too, had a different pattern of catch in 2011 as compared to 2010. In 2010, both juvenile striped bass and California bay shrimp exhibited similar patterns in catch: they were low in abundance during winter, increased during spring, reached highest abundances in summer, and then declined to low levels in autumn (O'Rear and Moyle 2011). This was likely due to juvenile striped bass following and feeding on the bay shrimp, as their abundances were positively correlated that year and gut contents of juvenile striped bass contained bay shrimp (O'Rear, personal observation). In 2011, however, juvenile striped bass were only abundant from January to May while California bay shrimp were only abundant from September to December. Similar to the relationship between young-of-year fish and mysids, there was a mismatch in timing between juvenile striped bass and California bay shrimp, which may have caused our poor catches after June by either (1) increasing mortality of juvenile fish through lack of food, or (2) forcing juvenile striped bass to move outside the marsh in search of prey.

Similar to previous years, lower Suisun, First Mallard, and Nurse sloughs had among the highest CPUE values for striped bass (Figure 19), which Schroeter *et al.* (2006) attributed to shallow depths that provide high food concentrations. A notable disparity was the very high catch of young-of-year fish in Boynton Slough, which has typically exhibited among the lowest abundance of fish (Matern *et al.* 2002). This distribution was primarily due to young-of-year fish. Conversely, juvenile striped bass were generally much more evenly spread throughout the marsh than young-of-year (Figure 19).

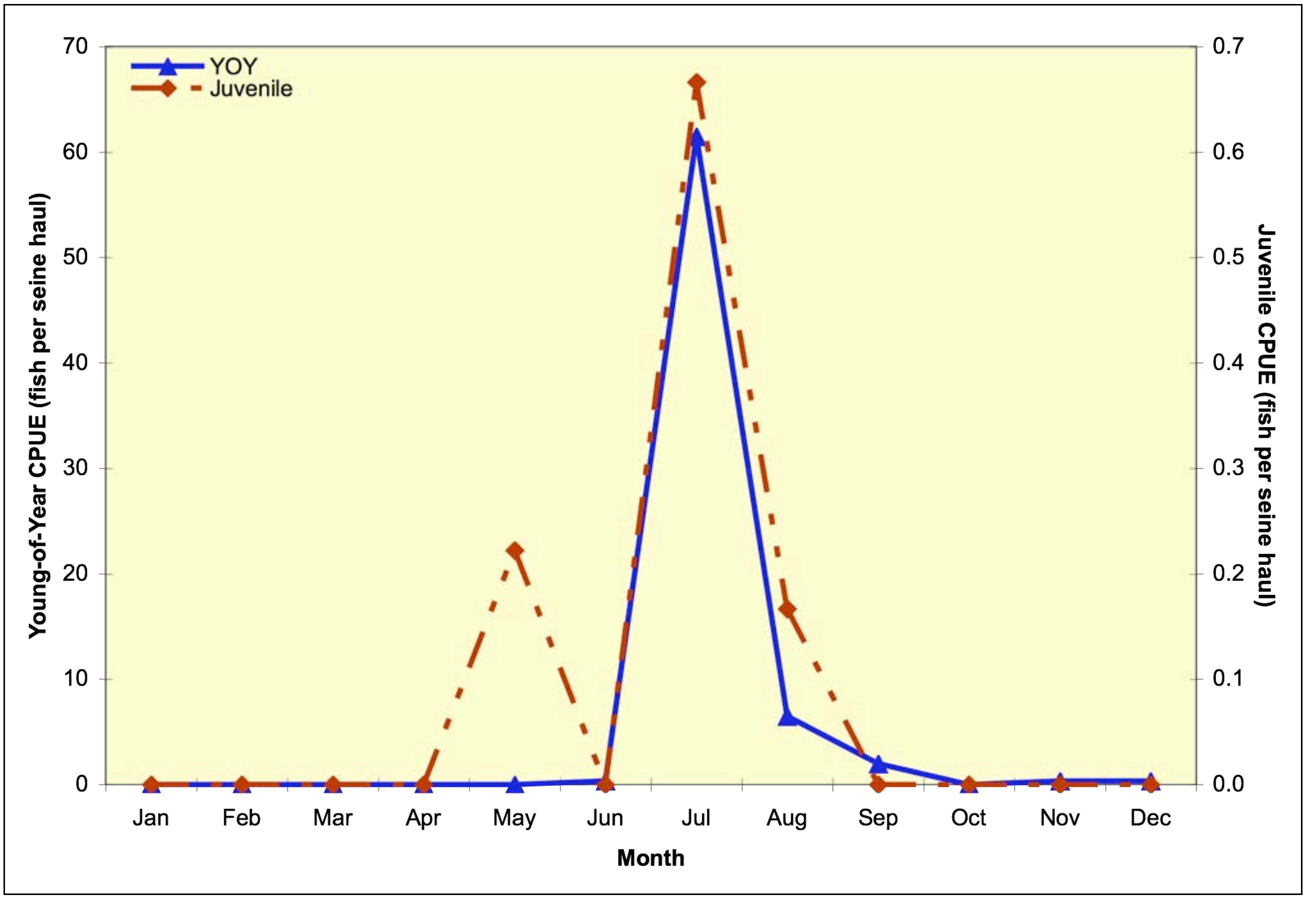

Figure 18. Beach seine catch of age classes of striped bass during 2011.

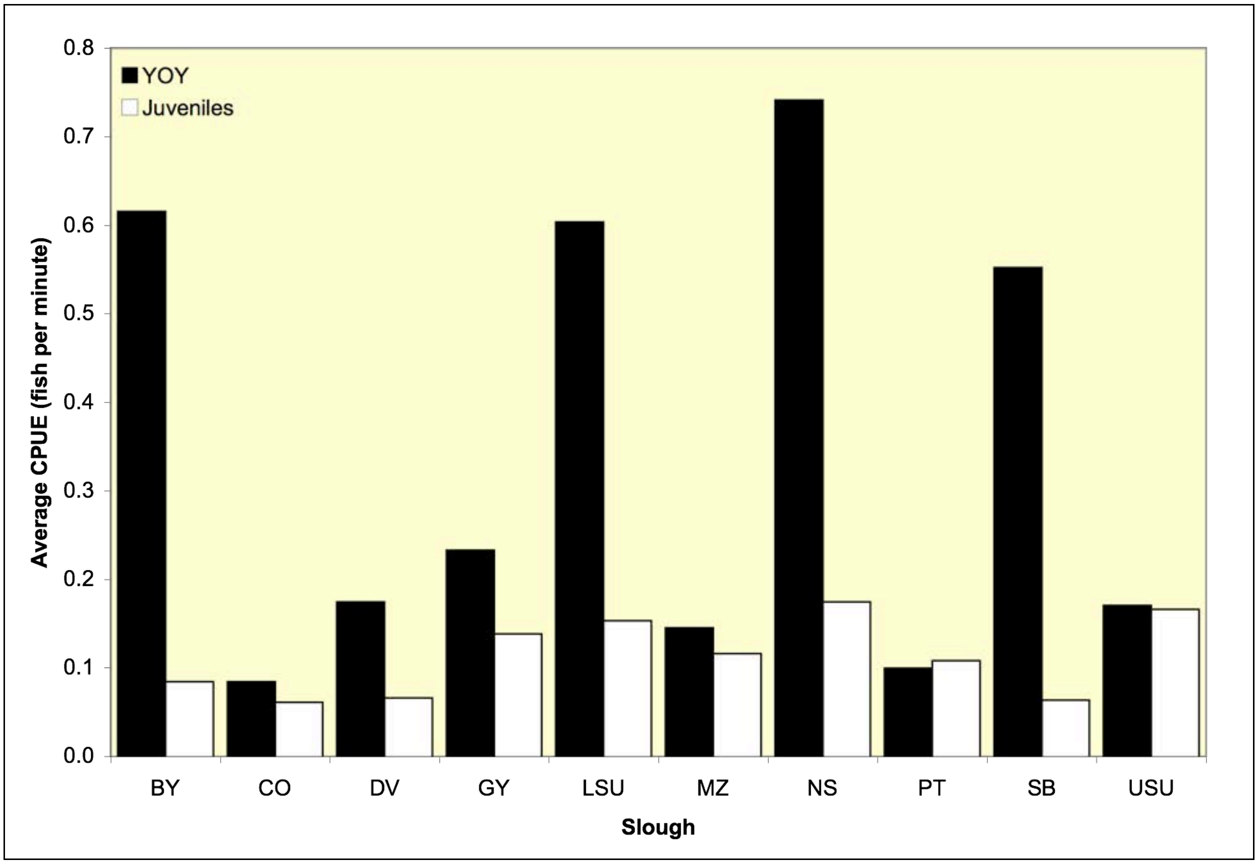

Figure 19. Average otter trawl CPUE for young-of-year and juvenile striped bass in sloughs of Suisun Marsh during 2011 ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "LSU" = lower Suisun Slough, "MZ" = Montezuma Slough, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "USU" = upper Suisun Slough).

Sacramento Splittail

Sacramento splittail have been the most commonly captured native fish in Suisun Marsh. Not including 1986 and 1987, Sacramento splittail annual otter trawl CPUE declined considerably from 1980 to 1994; this was mirrored fairly well by the beach seine CPUE, which was more variable over that period (Figure 20 and 21). From 1995 to 2006, otter trawl CPUE generally increased and was accompanied by large beach seine catches in years of high springtime Delta outflow (*e.g.,* 1995, 2006). Otter trawl catches once again declined from 2006 to 2009 but have been on the rise since then. The otter trawl and beach seine CPUE patterns are influenced by the amount of floodplain available for spawning and rearing during the spring (Moyle *et al.* 2004, Sommer *et al.* 1997), hence our higher catches during and just following wet years.

Annual CPUE for Sacramento splittail in both otter trawls and beach seines increased dramatically from 2010 to 2011, with otter trawl CPUE nearly doubling (3.3 fish per trawl to 6.3 fish per trawl) and beach seine CPUE more than tripling (0.9 fish per seine haul to 3.1 fish per seine haul). Although an increase in young-of-year fish contributed to the high otter trawl value, the major driver in the large 2011 catch was yearling fish (Figure 20). This influence of the previous year's cohort on the catch was also seen in 2010 (O'Rear and Moyle 2011), suggesting that either survival is very high in the marsh or that there is a prolonged movement of Sacramento splittail to the marsh from other areas (*e.g.*, the western Delta). Conversely, the large beach seine catch was almost exclusively due to young-of-year fish, with 87% of the total catch comprised of the 2011 cohort. Clearly, the high catches of Sacramento splittail in both gear types is in part due to high reproductive success as a result of high Delta outflow and, consequently, inundation of floodplains spanning the spawning period of Sacramento splittail (*i.e.*, March and April).

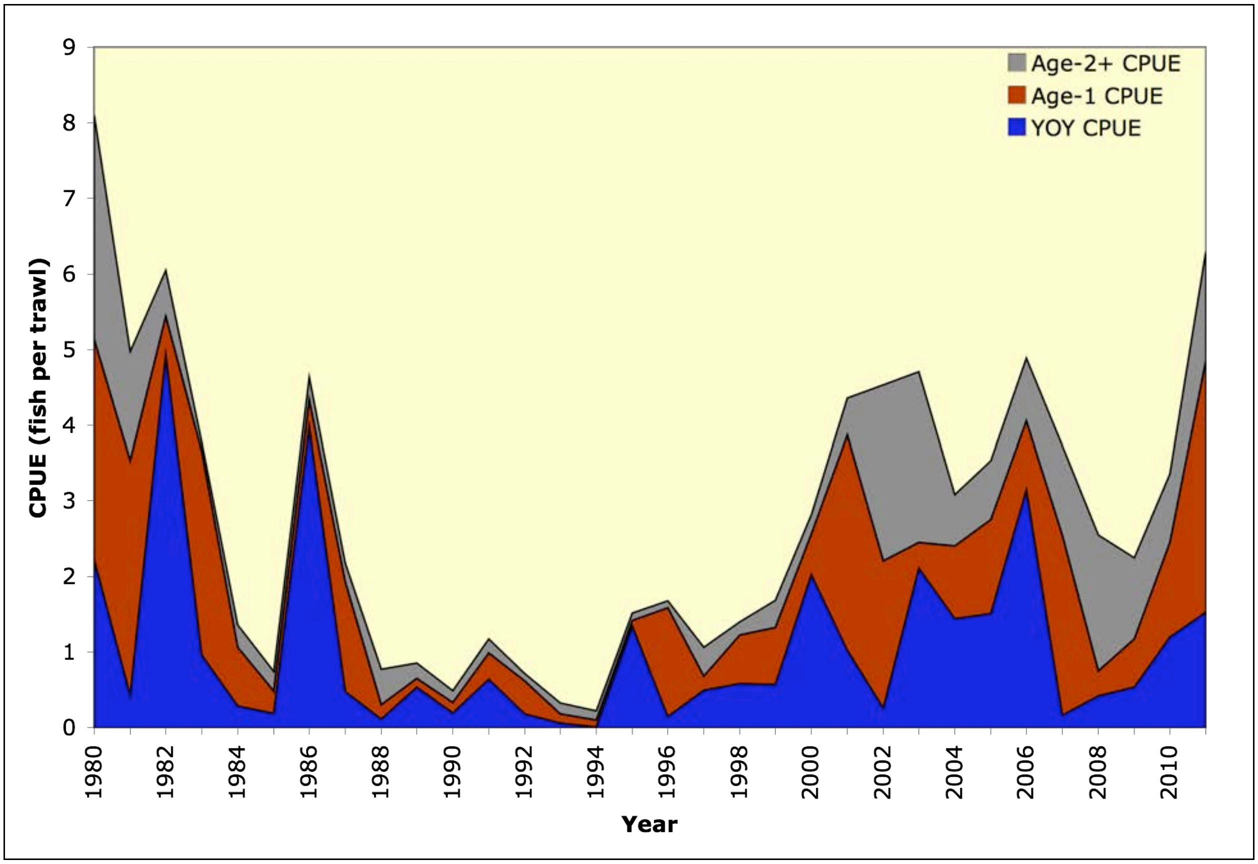

Figure 20. Annual otter trawl CPUE from 1980 to 2011 for age classes of Sacramento splittail.

In most years, there is a notable decline in the adult Sacramento splittail catch from about February to June, corresponding to spawning activities upstream of the marsh, and a rise in the catch sometime in mid-summer, suggesting a return of those fish to Suisun Marsh (*e.g.*, O'Rear and Moyle 2011). In 2011, however, there was only a very mild decrease in the adult (*i.e.*, "age 2+") catch that started in March, and it was not followed by a jump in adult numbers sometime during summer (Figure 22). This could be explained by Sacramento splittail spawning within the marsh, which has been documented previously during very wet years such as 1995 (Meng and Matern 2001), although this seems unlikely for 2011. Given that Sacramento splittail most commonly spawn during March or April (Moyle *et al.* 2004), young-of-year fish should have appeared earlier than in June had adults spawned within the marsh, which was the month that young-of-year were first caught by both types of nets. Additionally, had Sacramento splittail spawned within the marsh, the pattern in catch should have been more similar to species that annually spawn within the marsh such as shimofuri goby, which explodes in numbers and then declines through the rest of the year (O'Rear and Moyle 2010). However, the young-of-year Sacramento splittail catch in the otter trawl continually increased after June, while the monthly pattern in the beach seine catch of young-of-year fish increased from June to July, remained high in August, and then began to decline. These patterns are more consistent with a rather prolonged movement of Sacramento splittail from upstream areas into the marsh, coupled with a movement off of the banks and into deeper habitats as the fish grow, rather than spawning within the marsh.

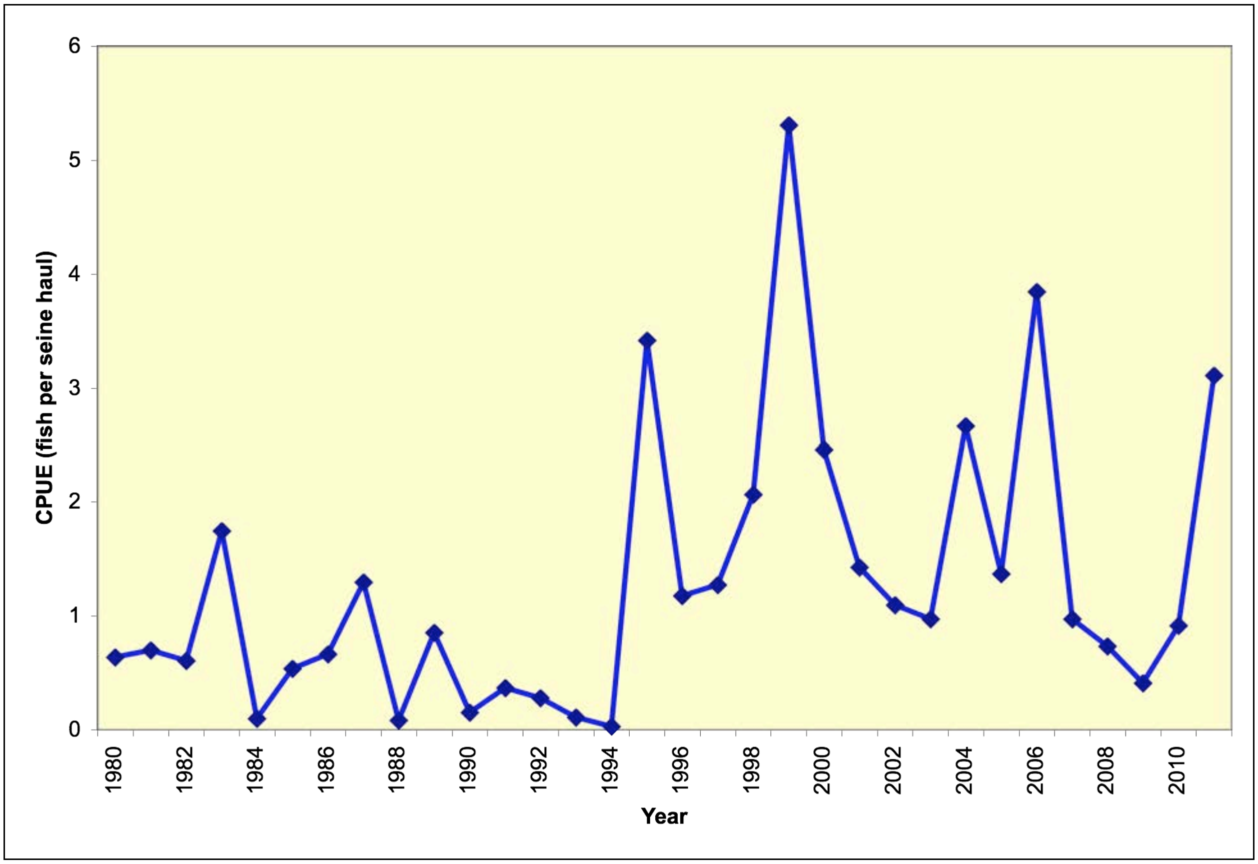

Figure 21. Annual beach seine CPUE from 1980 to 2011 for Sacramento splittail.

A decline occurred in the catch of age-1 fish in otter trawls that began in May and reached a minimum in October, along with considerably lower numbers of adults captured in September and October. A drop in adult numbers during September and October has been noted previously (N. Ross, personal communication) in years when DO reached particularly low levels and fish kills were observed (*e.g.*, 2004; Schroeter and Moyle 2004). Additionally, more frequent sampling during autumn of 2010 showed that Sacramento splittail will vacate smaller sloughs when DO levels drop (O'Rear and Moyle 2011) and enter larger sloughs, where they are less susceptible to capture by our trawls. While DO may partially account for the low numbers of adults and age-1 fish in October 2011 given the low-DO conditions in Peytonia and upper Goodyear sloughs, it cannot explain the changes that occurred in previous months, especially during August and September when DO levels were relatively high (Figure 7). Passive integrated transponder tagging coupled with fixed arrays and continuous water-quality measurements associated with another project our lab is undertaking should yield insight on the drivers of this phenomenon.

Distribution of the age classes of Sacramento splittail was disparate. The southwest marsh - Goodyear and lower Suisun sloughs - had the highest abundances (3.4 and 3.5 fish per trawl, respectively) of young-of-year fish (Figure 23). Age-1 fish were also very abundant in Goodyear Slough but even more so in Montezuma Slough (5.2 and 6.3 fish per trawl, respectively). Sloughs of the northeast marsh (Denverton and Nurse sloughs) hosted the highest densities of adults (4.5 and 2.1 fish per trawl, respectively; Figure 23).

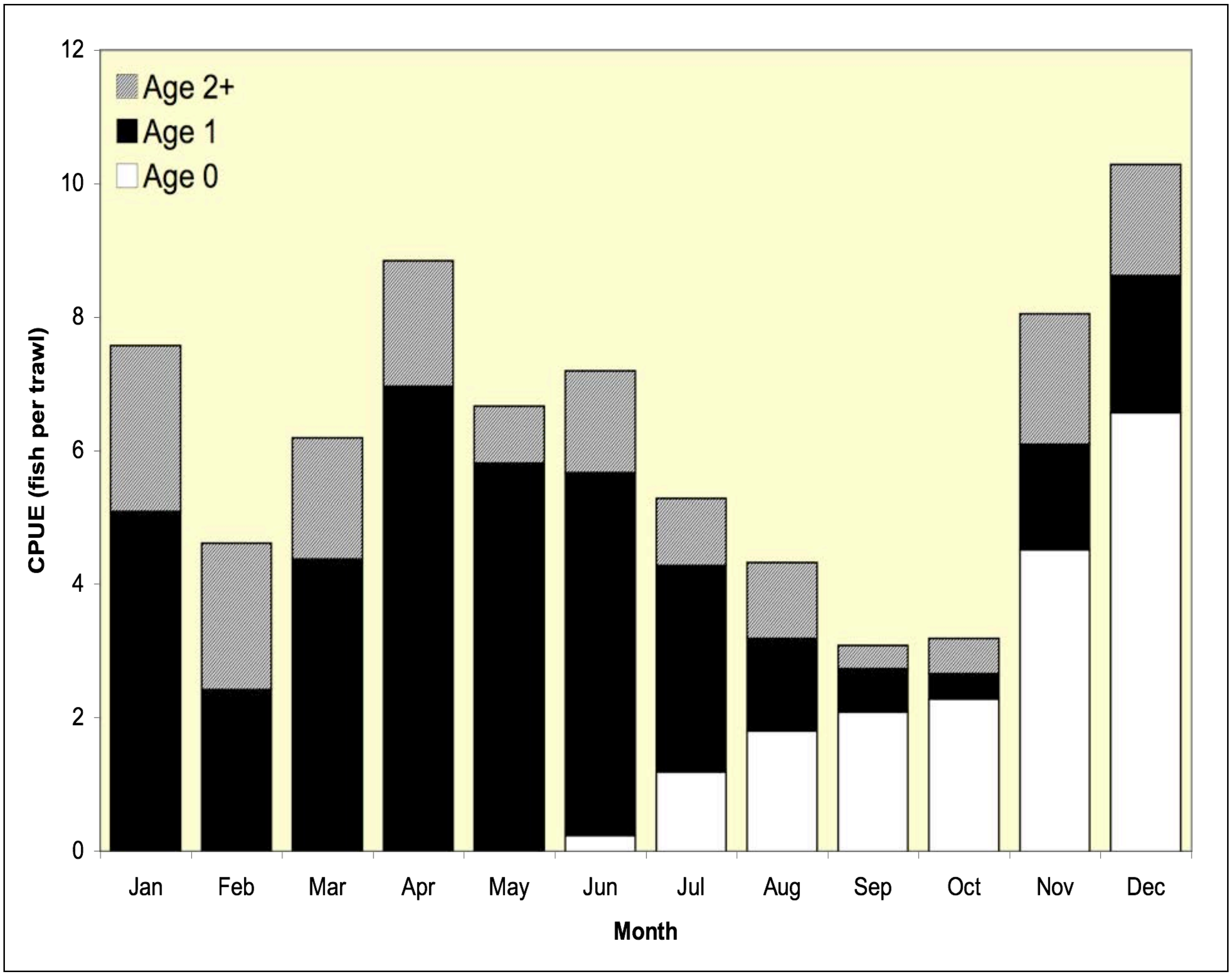

Figure 22. Monthly otter trawl CPUE during 2011 for age classes of Sacramento splittail.

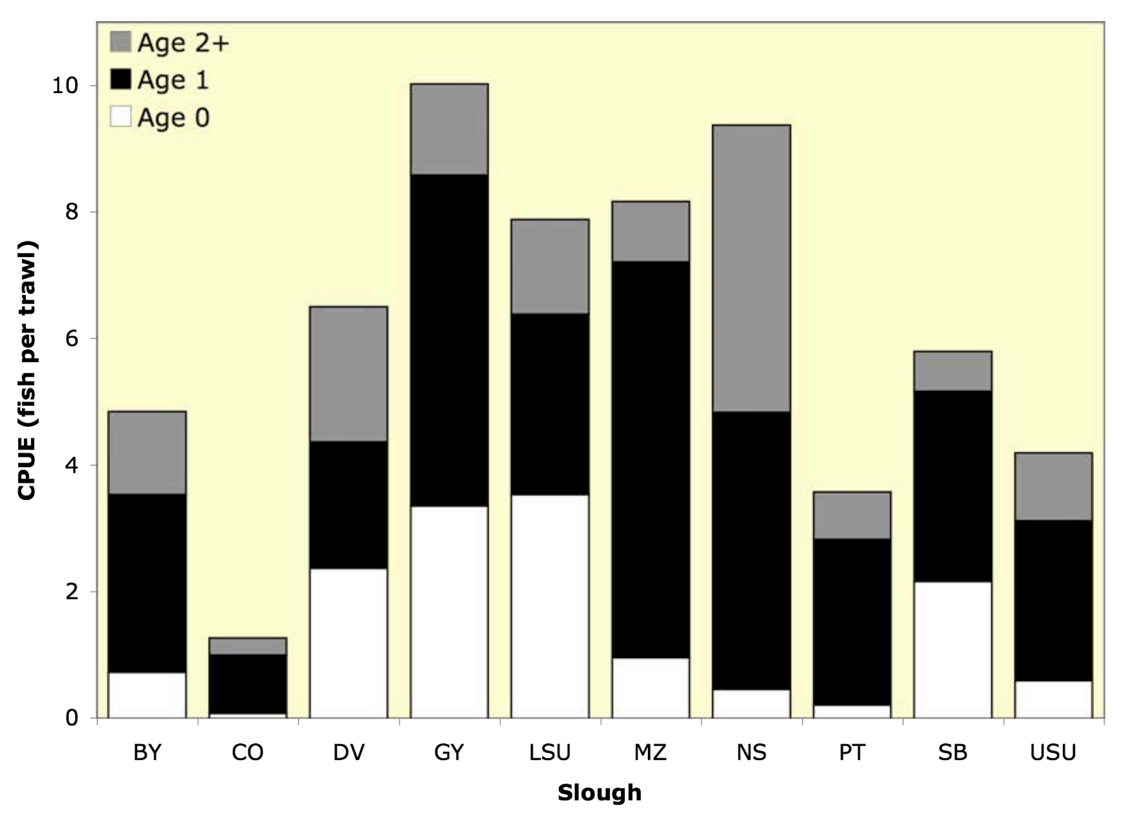

Figure 23. Annual otter trawl CPUE of age classes of Sacramento splittail in sloughs of Suisun Marsh (codes as in Figure 19).

<u>White Catfish and Mississippi Silverside</u>

Of all the introduced fish species in the marsh, only two have exhibited long-term increasing trends: white catfish and Mississippi silverside. With the exception of one strong cohort from 1983, white catfish were present only in low numbers during the 1980s and early 1990s (Figure 24). From 1995 to 2011, however, white catfish became increasingly abundant, which appeared to be tied to lower salinities spanning the late-spring/early-summer spawning period during wetter years (see O'Rear and Moyle 2009). Beach seine catch of Mississippi silverside was relatively constant from 1980 to 1988; however, from 1989 to 1997, catch began to vary more around a higher mean (Figure 24). Although the Suisun Marsh Salinity Control Gates began operating in 1989, whether and how that affected the silverside catch is unknown. From 1998 to 2006, Mississippi silversides became increasingly more abundant, but numbers generally declined from 2007 to 2011 (Figure 24).

Annual otter trawl CPUE for white catfish in 2011 declined by about 30% relative to 2010, which, as previously mentioned, was due to a substantial decline in adult-sized fish partially mitigated by a large catch of young-of-year white catfish (Table 3). White catfish require water that is generally fresher than that found in the marsh for spawning, hence the appearance of young-of-year fish only occurring during wet years (O'Rear and Moyle 2010). As a result, the high recruitment of young-of-year fish during 2011 was probably due to the dual effects of Delta outflow both washing upstream-produced fish into the marsh and allowing reproduction in the marsh by depressing salinities.

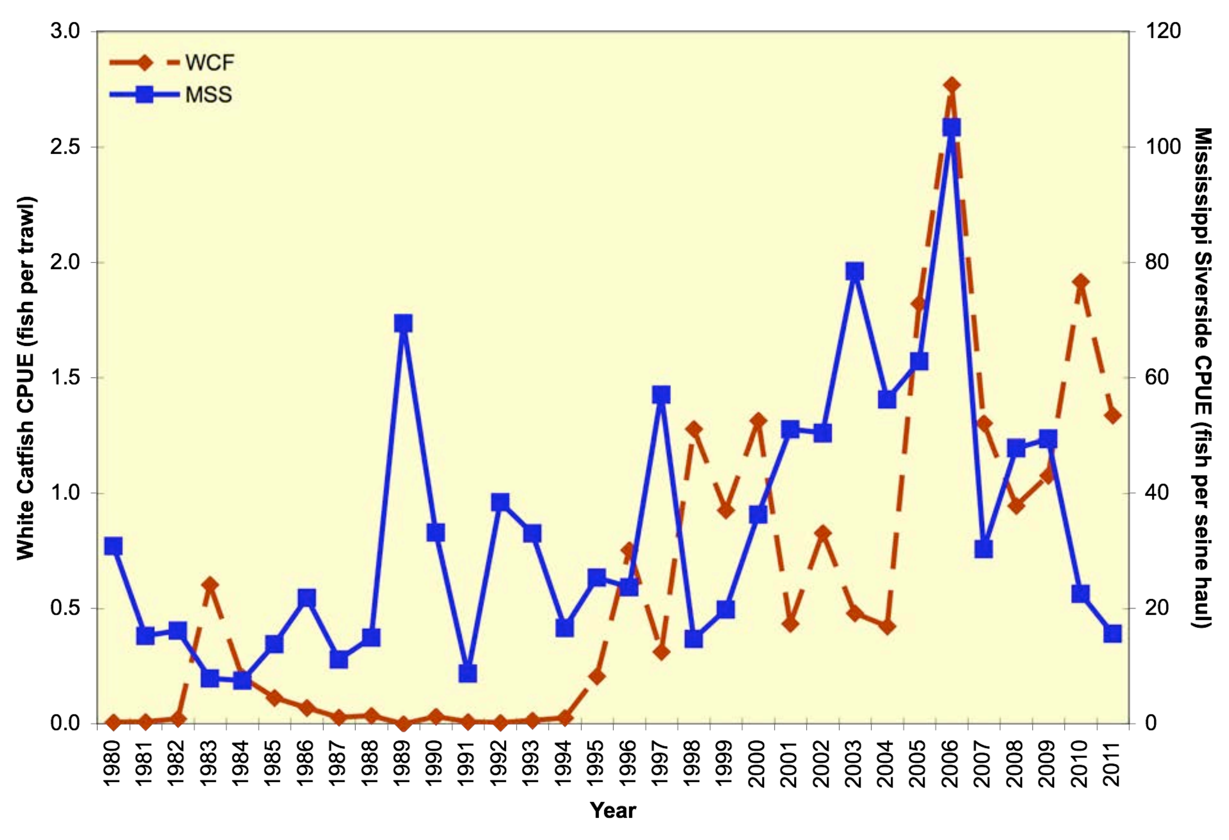

Figure 24. Annual CPUE for white catfish ("WCF") and Mississippi silverside ("MSS") from 1980 to 2011.

Previous studies in other waterways have revealed that silversides frequently have two spawning peaks per year (Moyle 2002, Middaugh and Hemmer 1992), with fish produced the previous year spawning in spring and the resultant young-of-year spawning in late summer. These peaks in spawning are generally followed by pulses of very small fish in late spring and early autumn. The pattern in beach seine catches suggests that there are also generally two major spawning peaks in the marsh (O'Rear and Moyle 2010, 2009). However, 2011, like 2010, did not follow this trend. Appreciable numbers of young-of-year fish were not evident until July (Figure 25), while young-of-year in most years are common by June (O'Rear and Moyle 2010, 2009). Additionally, the late-summer cohort, which usually enters the beach seine catches in autumn (O'Rear and Moyle 2010), was once again completely absent (Figure 25). The cool first half of the year appeared to be the major factor affecting our catches. First, the activity level of Mississippi silversides is reduced when water temperatures dip below 15°C (Stoeckel and Heidinger 1988). Expected effects of this include slower growth, hence greater mortality due to predation and/or slowed reproductive development. Both of these scenarios are consistent with our beach seine catches: catches crashed in spring and the appearance of young-of-year was later than in previous years with more mild temperatures (*e.g.*, 2008). Given that the first young-of-year cohort spawns the second, and that age at maturity is partially a function of size (Middaugh and Hemmer 1992, Hubbs 1982), then the first cohort may not have had enough time to grow large enough to become mature. Consequently, no second cohort would be produced, which is what our data show (Figure 25).

Table 3. Proportion of catch of white catfish in three different life-history stages during 2010 and 2011.

	Year	
Life Stage	2010	2011
Young-of-year	0%	62%
Juvenile	13%	3%
Adult	87%	35%

Cordelia Slough Complex Sampling

Reflecting the wet year, salinities in all sloughs of the Cordelia Slough complex were very low (Table 4) and within the range of those measured at standard sampling sites during April (Figure 6). Notably, the lowest salinities were recorded at the CRD1 station in Cordelia Slough and the CHA1 in Chadbourne Slough (Table 4), which are the sites closest to freshwater inputs from Green Valley and Suisun creeks, respectively (Figure 1). Concomitantly, Secchi depths were likewise low (Table 4), with the exception of the CRD1 measurement that occurred at low tide. DO concentrations were below the average for standard study sites during April (Table 4 and Figure 7), with a particularly low reading in Frank Horan Slough ("FH1"). Given the mild water temperatures, low salinities, and relatively interior position of the sloughs sampled (Figure 3), the low DO readings probably reflected both high organic loads and relatively low circulation, conditions that have been seen in other similar areas of the marsh (*e.g.*, upper Goodyear and upper Peytonia sloughs).

In general, the fish assemblages reflected the influence of salinity and hence the proximity of the sites to sources of fresh water (*e.g.*, Suisun Creek) and salt water (*e.g.*, Grizzly Bay). The upstream sites in Cordelia Slough (CRD1 and CRD2) were distinguished by catches of white catfish and Sacramento sucker (Figure 26), species that are both much more frequently captured in the fresher standard sampling sites and need water that is fresh (or close to it) for reproduction. Additionally, trawls closer to Grizzly Bay (*e.g.*, those in Chadbourne and Frank Horan sloughs) contained staghorn sculpin (*Leptocottus armatus*; Figure 26), which spawns downstream of the marsh and has juveniles that ride upstream currents into the marsh to rear (Moyle 2002). These patterns in catch are consistent with results of a larval fish study conducted in the late 1990s (Meng and Matern 2001), which found larval marine fish [*e.g.*, northern anchovy (*Engraulis mordax*)] more abundant in Cordelia Slough downstream of the railroad bridge relative to sloughs further away from Grizzly Bay (*e.g.*, First Mallard and Denverton sloughs).

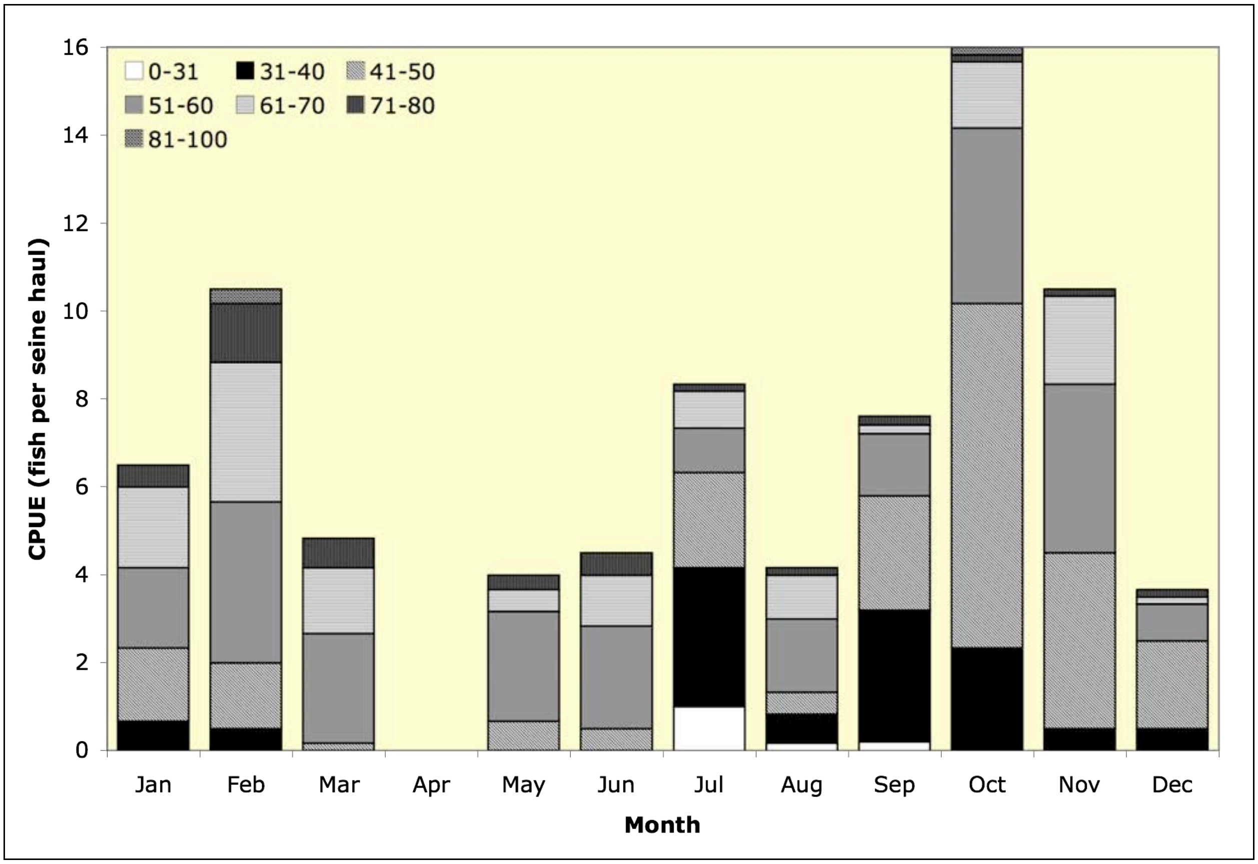

Figure 25. Monthly beach seine catch of size classes of Mississippi silversides during 2011.

Table 4. Average water-quality conditions in sloughs of the Cordelia Slough complex on April 1(see Figure 3 for definitions of codes).

Site	Water Temperature (°C)	Salinity (ppt)	Secchi (cm)	DO (mg/L)
CHA1	16.7	0.8	16.0	7.4
CHA2	17.0	1.1	17.0	6.9
CRD1	16.9	0.5	27.0	6.5
CRD2	17.3	1.2	15.5	5.0
CRD3	17.3	1.4	18.3	4.7
CRD3.5	17.6	1.1	12.0	5.5
CRD4	17.5	1.0	13.0	5.2
FH1	17.2	1.8	14.0	2.9
IBI1	17.6	1.5	14.0	4.9

The most commonly captured fish species were threespine stickleback and prickly sculpin (*Cottus asper*). While this is no doubt partially due to our sampling co-occurring with the recruitment period for these cool-season-spawning fishes (Meng and Matern 2001), it also probably reflects the influence of duck club ponds on the Cordelia Slough complex. The sloughs in the area we sampled are totally diked and heavily managed for waterfowl, with the only tidal marsh consisting of small fringes peppered along Cordelia, Frank Horan, and Chadbourne sloughs (Figure 3). The lentic, highly vegetated conditions of the duck club ponds and their adjacent ditches provide good spawning habitat for both fishes (O'Rear and Moyle 2011, Batzer and Resh 1992); when the ponds are flushed and drained in late winter and spring, both the pond water and the fish are discharged into the sloughs.

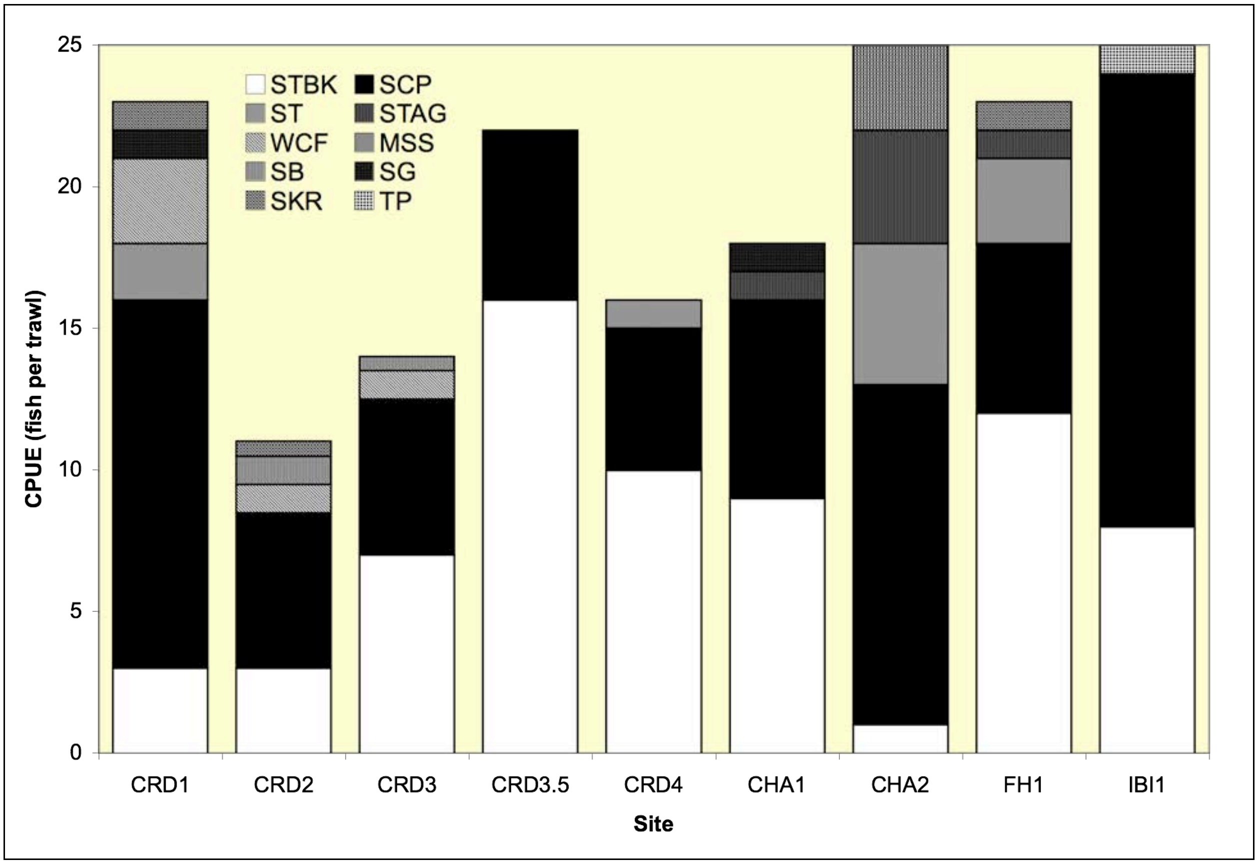

Figure 26. Otter trawl CPUE of fishes at sites in the Cordelia Slough complex from April 2011 (see Figure 3 for definitions of site codes; "STBK" = threespine stickleback, "SCP" = prickly sculpin, "ST" = Sacramento splittail, "STAG" = staghorn sculpin, "SB" = striped bass, "SG" = shimofuri goby, "SKR" = Sacramento sucker, "TP" = tule perch, and all others as in Figure 24).

Tule Red Duck Club Sampling

Like in the Cordelia Slough complex, the Tule Red ditch was obviously affected by the wet year, especially given its proximity to Grizzly Bay (Figure 2 and 3), with salinity averaging only 0.8 ppt (Table 5). The ditch was quite narrow and shallow and contained fairly lush growths of submerged aquatic vegetation. These physical characteristics likely affected the Secchi depth and the water temperature, with both being much higher than at the standard study sites during May (Table 5 and Figure 8). DO levels in the ditch were good and within the range found in the greater marsh (Table 5 and Figure 7). Although we made no counts, we did notice that there were very high numbers of corophiid amphipods in the ditch upstream of the water control structure.

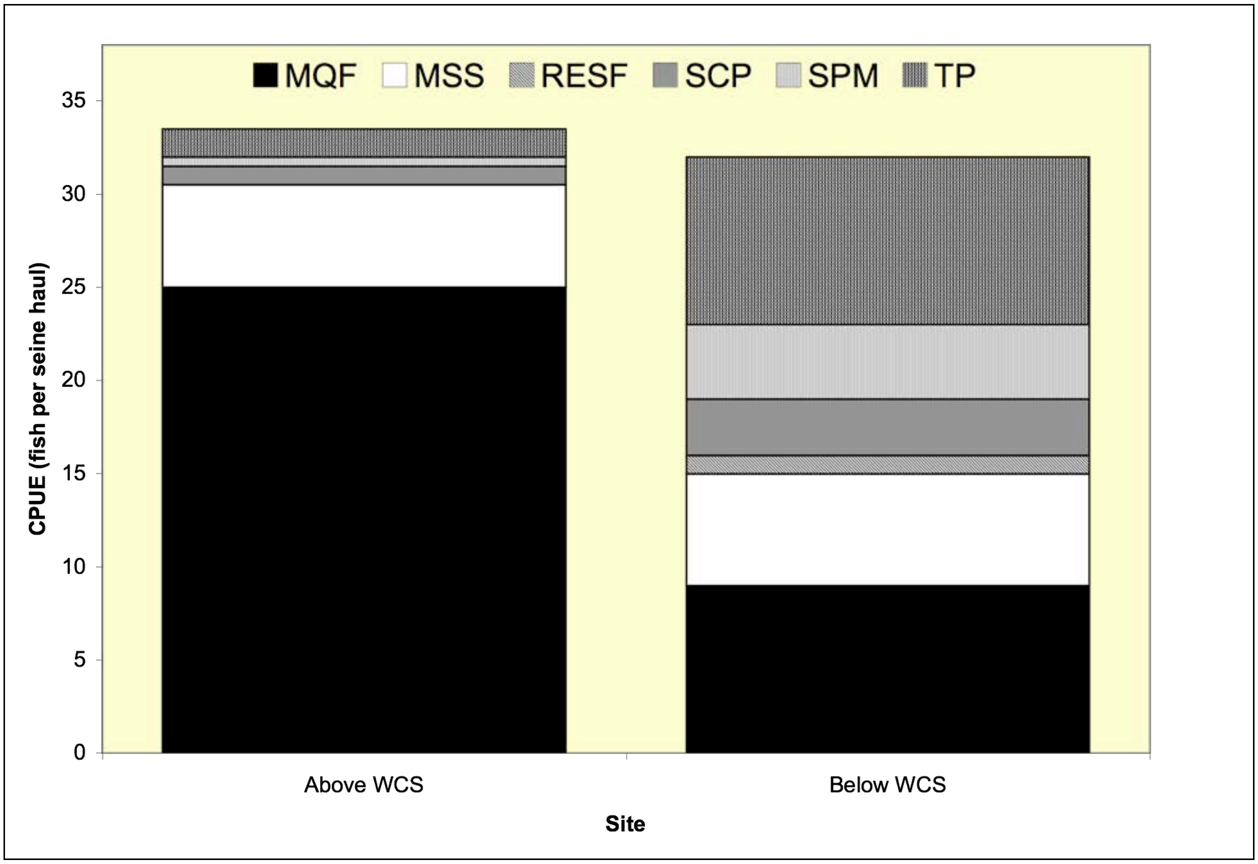

Figure 27. Beach seine CPUE of non-threespine-stickleback fishes above and below the water control structure in the Tule Red Duck Club ditch ["MQF" = western mosquitofish, "RESF" = redear sunfish (*Lepomis microlophus*), "SPM" = Sacramento pikeminnow, and all others as in Figure 26].

Table 5. Average water-quality conditions in the Tule Red Duck Club ditch on May 13.

Parameter	Mean
Water Temperature (°C)	21.5
Salinity (ppt)	0.8
Secchi depth (cm)	31
DO (mg/L)	5.98

Given the amount of vegetation, it comes as no surprise that threespine stickleback was far and above the most abundant fish in both otter trawls and beach seines (see "Appendix D"). However, more notable was the disparity in fish diversity and assemblage in beach seines between the ditch above and below the water control structure (Figure 27) - the fish assemblage below the structure was both more even and more diverse (Figure 27). Western mosquitofish (*Gambusia affinis*) was much more abundant above the structure, comprising 70% of the non-stickleback fish (Figure 27). Below the structure, tule perch were more abundant; additionally, sizes of prickly sculpin and Sacramento pikeminnow (*Ptychocheilus grandis*) below the structure indicated that they were at least one year old, whereas those above the structure were clearly young-of-year fish. Put another way, the assemblage above the structure was dominated by short-lived species and very young individuals of longer-lived species, while the assemblage below the structure consisted of a greater proportion of older, larger, longer-lived species. The dominance of small fishes above the structure was likely due in part to the ditch's main water source: drainage water east of the ditch (R. Capriola, Westerveldt Ecological Services, personal communication) that has to go through numerous water control structures, structures that are easier for small, water-column fishes such as western mosquitofish and threespine stickleback to traverse than larger fishes such as yearling Sacramento pikeminnow. The water control structure is generally used to discharge water towards Grizzly Bay ((R. Capriola, Westerveldt Ecological Services, personal communication; Figure 4) and is elevated above the channel bed (O'Rear, personal observation). Sacramento pikeminnows are not particularly strong swimmers (Myrick and Cech, Jr. 2000), and their deep body shape suggests tule perch are not strong swimmers, either (Moyle and Cech, Jr. 2004). Yearling prickly sculpins are benthic fish (Moyle 2002). Thus the difference in the fish assemblages above and below the control structure is consistent with the structure limiting movement of larger fishes below the structure by (1) serving as a velocity barrier to Sacramento pikeminnows and tule perch and (2) being elevated above the bottom habitat of yearling prickly sculpin. Similar differences in fish assemblages attributable to water control structures have been seen in other studies (*e.g.*, Rozas and Minello 1999, Rogers *et al.* 1994). Alternatively, the larger fishes may have been aggregating below the structure to feed on food delivered by the discharge water, as has been observed for adult striped bass in other areas of the marsh (Moyle 2002).

CONCLUSIONS

Catches in 2011 revealed that cooler temperatures and prolonged high Delta outflows, with concomitant reduced salinities, created conditions within the marsh that were more favorable to native species. In particular, Sacramento splittail and delta smelt had banner years in the marsh, although introduced species dependent on fresh water for reproduction - white catfish and threadfin shad - also had high recruitment of young-of-year in the marsh. The high Delta outflows and cool temperatures reduced the abundances of the plankton-feeding overbite clam and Black Sea jellyfish in both time and space, which could have contributed to the relatively high numbers of delta smelt and California bay shrimp captured during autumn. The cold winter and spring negatively affected two dominant introduced fishes of the marsh - striped bass and Mississippi silverside - by delaying and truncating the spawning periods, respectively. For striped bass, the delayed spawn resulted in the late arrival of young-of-year fish into the marsh, which occurred after mysid abundances had declined to negligible levels. This mismatch in the timing of peak abundance between young-of-year striped bass and their major food source appeared to result in higher mortality in the channels, and hence lower otter trawl catches, and a dispersal of more fish into near-shore habitats, which was reflected in higher beach seine catches of very small striped bass. The cold water of 2011 depressed Mississippi silverside numbers by reducing the portion of the year in which they can spawn and by reducing survival of multiple life-history stages (*e.g.*, eggs, adults). While the sum of all these events resulted in improved conditions of native species at the expense of introduced species, such a year will likely become exceedingly rare in the future due to the projected effects of sea-level rise, more droughts, and warmer water temperatures.

Ancillary surveys in the upper Cordelia Slough complex and the Tule Red Duck Club ditch enhanced our knowledge of the fish assemblages in the marsh. The upper Cordelia complex's fish assemblages followed a salinity gradient, and thus they mirrored the same pattern exhibited along Suisun Slough from Grizzly Bay to Suisun City but at a smaller scale. Sampling in the Tule Red ditch reflected high abundances of small fish, which was no doubt in part due to the high productivity of the shallow, warm, vegetated water. However, the water control structure appeared to limit movement of larger, older native fishes into the ditch above the structure. It is likely that such a phenomenon is common throughout in other similar areas of the marsh, with the highly productive environments only available to short-lived fishes or very young fish.

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APPENDIX A

Total number of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all methods from 1979 to 2011 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
American shad	*Alosa sapidissima*	1085	243		1328
bay pipefish	***Sygnathus leptorhynchus***	**2**			**2**
bigscale logperch	*Percina macrolepida*	17	2		19
black bullhead	*Ameiurus melas*	865	3		868
black crappie	*Pomoxis nigromaculatus*	1794	82	1	1877
bluegill	*Lepomis macrochirus*	19	18		37
brown bullhead	*Ameiurus nebulosus*	28			28
California halibut	***Paralichthys californicus***	**5**			**5**
channel catfish	*Ictalurus punctatus*	167	6		173
Chinook salmon	***Oncorhynchus tshawytscha***	**72**	**387**	**1**	**460**
common carp	*Cyprinus carpio*	4814	432	1	5247
delta smelt	***Hypomesus transpacificus***	**646**	**137**	**4**	**787**
fathead minnow	*Pimephales promelas*	36	38		74
golden shiner	*Notemigonus crysoleucas*	5	3		8
goldfish	*Carassius auratus*	295	43		338
green sturgeon	***Acipenser medirostris***	**3**			**3**
green sunfish	*Lepomis cyanellus*	5	3		8
hardhead	***Mylopharadon conocephalus***	**1**			**1**
hitch	***Lavinia exilicauda***	**119**	**16**		**135**
largemouth bass	*Micropterus salmoides*		1		1
longfin smelt	***Spirinchus thaleichthys***	**11383**	**50**	**5**	**11438**
longjaw mudsucker	***Gillichthys mirabilis***	**1**			**1**
Mississippi silverside	*Menidia audens*	664	74566		75230
northern anchovy	***Engraulis mordax***	**257**		**37**	**294**
Pacific herring	***Clupea harengeus***	**465**	**116**		**581**
Pacific lamprey	***Lampetra tridentata***	**43**			**43**
Pacific sanddab	***Citharichthys sordidas***	**2**	**2**		**4**
plainfin midshipman	***Porichthys notatus***	**11**			**11**
prickly sculpin	***Cottus asper***	**10200**	**908**	**1**	**11109**
rainbow trout	***Oncorhynchus mykiss***	**8**	**4**		**12**
rainwater killifish	*Lucania parva*	31	94		125
redear sunfish	*Lepomis microlophus*	2	1		3
river lamprey	***Lampetra ayresi***	**2**			**2**
Sacramento blackfish	***Orthodon macrolepidotus***	**24**	**116**		**140**
Sacramento pikeminnow	***Ptychocheilus grandis***	**146**	**227**		**373**
Sacramento splittail	***Pogonichthys macrolepidotus***	**24373**	**3054**	**14**	**27441**
Sacramento sucker	***Catostomus occidentalis***	**3219**	**105**	**5**	**3329**
shimofuri goby	*Tridentiger bifasciatus*	9674	2168	1	11843
shiner perch	***Cymatogaster aggregata***	**17**			**17**
shokihaze goby	*Tridentiger barbatus*	616	2	6	624
speckled sanddab	***Citharichthys stigmaeus***	**3**			**3**
staghorn sculpin	***Leptocottus armatus***	**2415**	**3260**		**5675**

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
starry flounder	***Platichthys stellatus***	**1949**	**260**	**4**	**2213**
striped bass	*Morone saxatilis*	80213	12489	30	92732
surf smelt	***Hypomesus pretiosus***	**5**			**5**
threadfin shad	*Dorosoma petenense*	2672	5112	1	7785
threespine stickleback	***Gasterosteus aculeatus***	**17116**	**5358**	**6**	**22480**
tule perch	***Hysterocarpus traski***	**18457**	**1955**	**6**	**20418**
wakasagi	*Hypomesus nipponensis*	10	6		16
warmouth	*Lepomis gulosus*	1			1
western mosquitofish	*Gambusia affinis*	18	335		353
white catfish	*Ameiurus catus*	4926	116	13	5055
white crappie	*Pomoxis annularis*	112			112
white croaker	***Genyonemus lineatus***	**1**			**1**
white sturgeon	***Acipenser transmontanus***	**108**		**2**	**110**
yellowfin goby	*Acanthogobius flavimanus*	19277	15653		34930
Total		218399	127371	138	345908

APPENDIX B

Total 2011 otter trawl catch of each fish species in each slough of Suisun Marsh (codes as in Figure 19).

	Slough										Total
Species	BY	CO	DV	GY	LSU	MZ	NS	PT	SB	USU	
American shad				9	6	2	1	1	10	5	34
black bullhead	1		3					1			5
black crappie			3							2	5
common carp	18	4	15	9	1		4	6	1	2	60
delta smelt					16				1	3	20
fathead minnow	1							2			3
goldfish								1	1		2
hitch	1	1		1		2					5
longfin smelt		2	2	1	8	4	3		1	3	24
Mississippi silverside			1	8			1		8		18
prickly sculpin	24	8	21	138	43	4	8	49	17	18	330
rainbow trout		1									1
rainwater killifish				1							1
Sacramento pikeminnow	2	1		1	2	3	1		1		11
Sacramento splittail	126	33	156	361	205	196	225	86	139	105	1632
Sacramento sucker	30	7	7	13	1		1	25	3	4	91
shimofuri goby	13	28	10	1	1	5	2	10	4	24	98
shokihaze goby			3		6	3	27			13	52
starry flounder		2	2	4	15	8	2		3	8	44
striped bass	91	19	30	73	197	63	110	25	77	81	766
staghorn sculpin	3	2		21	25	3		5	5	10	74
threadfin shad	18	4	10	1	11	8	9	1	12	4	78
threespine stickleback	13	3	7	133	34	1		19	8	10	228
tule perch	114	33	49	14	38	93	11	82	36	23	493
white catfish	54	18	153	1	1	7	49	30	4	29	346
white sturgeon					1					2	3
yellowfin goby	27	8	13	23	43	15	8	19	7	37	200
Total	536	174	485	813	654	417	462	362	338	383	4624

Total 2011 beach seine catch for each fish species in Denverton, Montezuma, and upper Suisun sloughs.

Species	Denverton Slough	Montezuma Slough	Upper Suisun Slough	Total
American shad	32		21	53
black crappie	1			1
Chinook salmon			1	1
common carp	16	1	1	18
delta smelt			1	1
fathead minnow			2	2
goldfish	1			1
longfin smelt	6		3	9
Mississippi silverside	646	1	515	1162
prickly sculpin	3		5	8
rainwater killifish	1		2	3
Sacramento pikeminnow	6			6
Sacramento splittail	101	4	125	230
Sacramento sucker	5		2	7
shimofuri goby	19	1	6	26
staghorn sculpin	24	1	31	56
starry flounder	1			1
striped bass	131		303	434
threadfin shad	104		15	119
threespine stickleback	33	2	38	73
tule perch	7		38	45
western mosquitofish	1		1	2
white catfish	8			8
yellowfin goby	5		49	54
Total	1151	10	1159	2320

APPENDIX C

Number of otter trawls for each slough and each month in 2011.

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Boynton	2	2	2	4	2	2	2	2	2	2	2	2	26
Cutoff	2	2	2	4	2	2	2	2	2	2	2	2	26
Denverton	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	4	2	2	2	26
Nurse	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
Upper Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Peytonia	2	2	2	2	2	2	2	2	2	2	2	2	24
First Mallard	2	2	2	3	2	2	2	2	2	2	2	2	25
Total	21	21	21	26	21	21	21	21	23	21	21	21	259

Number of beach seines for each slough and each month in 2011.

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Denverton	3	3	3	3	3	3	3	3	2	3	3	3	35
Montezuma					3								3
Upper Suisun	3	3	3	3	3	3	3	3	3	3	3	3	36
Total	6	6	6	6	9	6	6	6	5	6	6	6	74

APPENDIX D

Catch of macroinvertebrates and fishes in the Cordelia Slough complex in April 2011. All sites were trawled only once except for the CRD2 and CRD3 sites, both of which were trawled twice.

	Site									Total
Species	CHA1	CHA2	CRD1	CRD2	CRD3	CRD3.5	CRD4	FH1	IBI1	
overbite clam						1	4			5
California bay shrimp	1						2			3
Siberian prawn	6	9	25	42	49		30	83	7	251
macoma clam							7			7
Oriental shrimp	2		1	5		3	3			14
Mississippi silverside		3								3
prickly sculpin	7	12	13	11	11	6	5	6	16	87
Sacramento splittail		5	2				1	3		11
Sacramento sucker			1	1				1		3
shimofuri goby	1		1							2
staghorn sculpin	1	4						1		6
striped bass				2	1					3
threespine stickleback	9	1	3	6	14	16	10	12	8	79
tule perch									1	1
white catfish			3	2	2					7
Total	27	34	49	69	77	26	62	106	32	482

Catch of macroinvertebrates and fishes in the Tule Red Duck Club ditch in May 2011. Note that one seine was pulled below the structure, two above the structure, and two trawls were towed above the structure.

	Site			Total
Species	Above WCS - Seines	Below WCS - Seine	Above WCS - Trawls	
Siberian prawn	5	7	4	16
Mississippi silverside	11	6		17
western mosquitofish	50	9		59
Oriental shrimp		2		2
redear sunfish		1		1
prickly sculpin	2	3		5
Sacramento pikeminnow	1	4		5
threespine stickleback	455	121	248	824
tule perch	3	9	3	15
Total	527	162	255	944