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SUISUN MARSH FISH STUDY

Trends in Fish and Invertebrate Populations of Suisun Marsh

January 2012 - December 2012

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. The University of California, Davis, Suisun Marsh Fish Study, in partnership with the California Department of Water Resources (DWR) has systematically monitored the marsh's fish populations since 1980. The primary purpose of the study has been to determine environmental and anthropogenic factors affecting fish abundance and distribution.

2012 was a dry, relatively warm year. Delta outflow was generally below average throughout the year except in December; as a result, salinities were higher than usual during 2012, particularly in summer and autumn. Water clarity was also substantially greater during summer and autumn. Dissolved oxygen levels were sufficient for most fish species, although somewhat low values were recorded in small sloughs of the western marsh during spring. Water temperatures were notably warmer than average in January and April.

In 2012, 256 otter trawls and 77 beach seines were conducted; catches were dominated by introduced species associated with either warmer temperatures or saltier water. Black Sea jellyfish (*Maeotias marginata*) and Mississippi silverside (*Menidia audens*) both returned to relatively abundant levels in 2012 after the low numbers recorded in 2011. Striped bass (*Morone saxatilis*) numbers in both beach seines and otter trawls during 2012 were higher than average, which appeared due in part to earlier recruitment in the marsh coinciding with abundant mysids. In contrast, native fish numbers were lower than normal. Recruitment of young-of-year Sacramento splittail (*Pogonichthys macrolepidotus*) during 2012 was low, likely because of lack of floodplain inundation for spawning and rearing. Numbers of tule perch (*Hysterocarpus traski*), threespine stickleback (*Gasterosteus aculeatus*), and prickly sculpin (*Cottus asper*) were also down. Longfin smelt (*Spirinchus thaleichthys*) and delta smelt (*Hypomesus transpacificus*) catches were very low during 2012, especially for delta smelt when compared to 2011's relatively high catch. In sum, catches during 2012 were quite typical for a dry, warm, salty year.

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INTRODUCTION

Suisun Marsh is a brackish-water marsh bordering the northern edges of Suisun, Grizzly, and Honker bays in the San Francisco Estuary (Figure 1); it is the largest uninterrupted expanse of estuarine marsh remaining on the western coast of the contiguous United States (Moyle *et al.* 1986). Much of the marsh area is diked wetlands managed for waterfowl, with the rest of the acreage consisting of tidal sloughs, marsh plains, and grasslands (DWR 2001). The marsh's central location in the San Francisco Estuary makes it an important nursery for salt-tolerant-freshwater, estuarine, and marine fishes; the marsh is also a migratory corridor for anadromous fishes such as Chinook salmon (*Oncorhynchus tshawytscha* Vincik 2002).

The University of California, Davis, Suisun Marsh Fish Study was begun with DWR in 1979 to monitor and to understand the abundance and distribution of fishes in relation to each other, to abiotic and biotic variables, and to water management (*e.g.*, water exports). DWR has continually partnered with UC Davis to monitor Suisun Marsh fishes to comply with regulatory permits. These permits have required monitoring of the aquatic environment to assess impacts on fish and related aquatic life (San Francisco Bay Conservation and Development Commission 4-84 (M) Special Condition B and US Army Corps of Engineers 16223E58B Special Condition 1). The monitoring is further supported by the Revised Suisun Marsh Monitoring Agreement (Agreement Number 4600000634).

The study has consistently used two methods for sampling fishes: beach seines and otter trawls. Juveniles and adults of all species have been surveyed systematically since 1980; between 1994 and 1999, larval fishes were also surveyed to better understand their ecology 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 (*e.g.*, Rosenfield and Baxter 2007); and (3) enhancing understanding of the life history and ecology of key species in the marsh (*e.g.*, O'Rear 2012). Secondary objectives have included supporting research by other investigators through special collections (*e.g.*, Liu *et al.*2012); providing background information for in-depth studies of other aspects of the Suisun Marsh aquatic ecosystem (*e.g.*, studies of jellyfish biology; Meek *et al.* 2012, Wintzer *et al.* 2011*a*, *b*, *c*); contributing to the general understanding of estuarine systems through publication of peer-reviewed papers (*e.g.*, Matern *et al.* 2002); training undergraduate and graduate students in estuarine studies and fish sampling; and providing a venue for managers, biologists, and others interested in the marsh to experience it firsthand.

Moyle *et al.* (1986) evaluated the first five years of data collected by the study and found three groups of species that exhibited seasonal trends in abundance, primarily due to differences in recruitment timing. The structure of the fish assemblage was relatively constant through time; however, total fish abundance declined over the five years. The decline was partly due to strong year classes early in the study period followed by both extremely high river flows and drought that resulted in poor recruitment. The authors also found that native fishes tended to be more prevalent in small, shallow sloughs, while introduced species were more prominent in large sloughs.

Meng *et al.* (1994) incorporated eight more years into their study, which revealed that the fish assemblage structure was less constant over the longer time period than the earlier study indicated. Additionally, introduced fishes had become more common in small, shallow sloughs. Like Moyle *et al.* (1986), Meng *et al.* (1994) found a general decline in total fish abundance through time, partly because of the negative effects of drought and high salinity on native fishes. Matern *et al.* (2002) found results similar to Meng *et al.* (1994): fish diversity was highest in small sloughs, and native fish abundances continued to fall.

In recent years, O'Rear and Moyle (2013*b*, 2012, 2010, 2009) have bolstered 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 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 partially in the marsh [*e.g.*, white catfish (*Ameiurus catus*) 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 (O'Rear and Moyle 2013*a*). 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 assessed 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 and *Moerisia lyonsi* 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 of 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 been recorded as feeding on delta smelt, striped bass, and threadfin shad (Miller 1966). O'Rear collected catfish stomach contents throughout a year in all areas of Suisun Marsh where the catfish was abundant. O'Rear (2012) found that the catfish subsisted largely on food supplied by managed wetlands such as the amphipod *Eogammrus confervicolus* from autumn to spring, while much of their diet consisted of slough-produced or bay-produced foods during summer. Notably, white catfish never ate at-risk fishes such as striped bass or delta smelt, and their most common food - amphipods - was unlikely 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 potentially more pernicious.

METHODS

Study Area

Suisun Marsh is a mosaic of landscape types totaling about 38,000 hectares, with about 9% of the acreage comprised of tidal sloughs (M. Young, UC Davis, personal communication, DWR 2001). The marsh is contiguous with the northern boundary of Suisun, Grizzly, and Honker bays and is central to the San Francisco Estuary (Figure 1), with San Pablo Bay to the west and the Sacramento-San Joaquin Delta ("Delta") to the east. There are two major subtidal channels in the marsh: Montezuma and Suisun sloughs (Figure 1). Montezuma Slough generally arcs northwest from the confluence of the Sacramento and San Joaquin rivers, then curves southwest and terminates at Grizzly Bay (the major embayment of Suisun Bay). Major tributary sloughs to Montezuma are Denverton and Nurse; Cutoff Slough and Hunter Cut connect Suisun and Montezuma sloughs (Figure 1). Suisun Slough begins near Suisun City and meanders south until emptying into Grizzly Bay southwest of the mouth of Montezuma Slough. Major tributaries to Suisun Slough, from north to south, are Peytonia, 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 and 3-7 m deep, with banks consisting of a mix of riprap and fringing marsh (Meng *et al.* 1994). Tributary sloughs are usually 10-20 m wide, 2-4 m deep, and fringed with common reed (*Phragmites communis*) and tules (*Schoenoplectus* spp.). Most sloughs in the marsh are diked to some extent, although small sloughs (*e.g.,* First Mallard) within the Rush Ranch preserve are undiked and thus have marsh plains regularly inundated by high tides. Substrates in all sloughs are generally fine organics, although a few sloughs also have bottoms partially comprised of coarser materials (*e.g.*, Denverton Slough; Matern *et al.* 2002), and the larger, deeper sloughs (*e.g.,* Montezuma Slough) can have sandy channel beds.

The amount of fresh water flowing into Suisun Marsh is the major determinant of its salinity. Fresh water enters the marsh primarily from the western Delta through Montezuma Slough, although small creeks, particularly on the northwest and west edges of the marsh, also contribute fresh water. As a result, salinities are generally lower in the eastern and northwestern portions of the marsh. Freshwater inflows are highest in winter and spring due to rainfall and snowmelt runoff; consequently, marsh salinities are lowest in these seasons. Salt water enters the marsh through lower Suisun and lower Montezuma sloughs from Grizzly Bay via tidal action, although the effect of the tides is more pronounced on water-surface elevation and less so on salinity throughout much of the year (Matern *et al.* 2002). During extreme tides, water depths can change as much as 2 m over a tidal cycle, often dewatering much of the smaller sloughs at low tide and overtopping dikes at high tide.

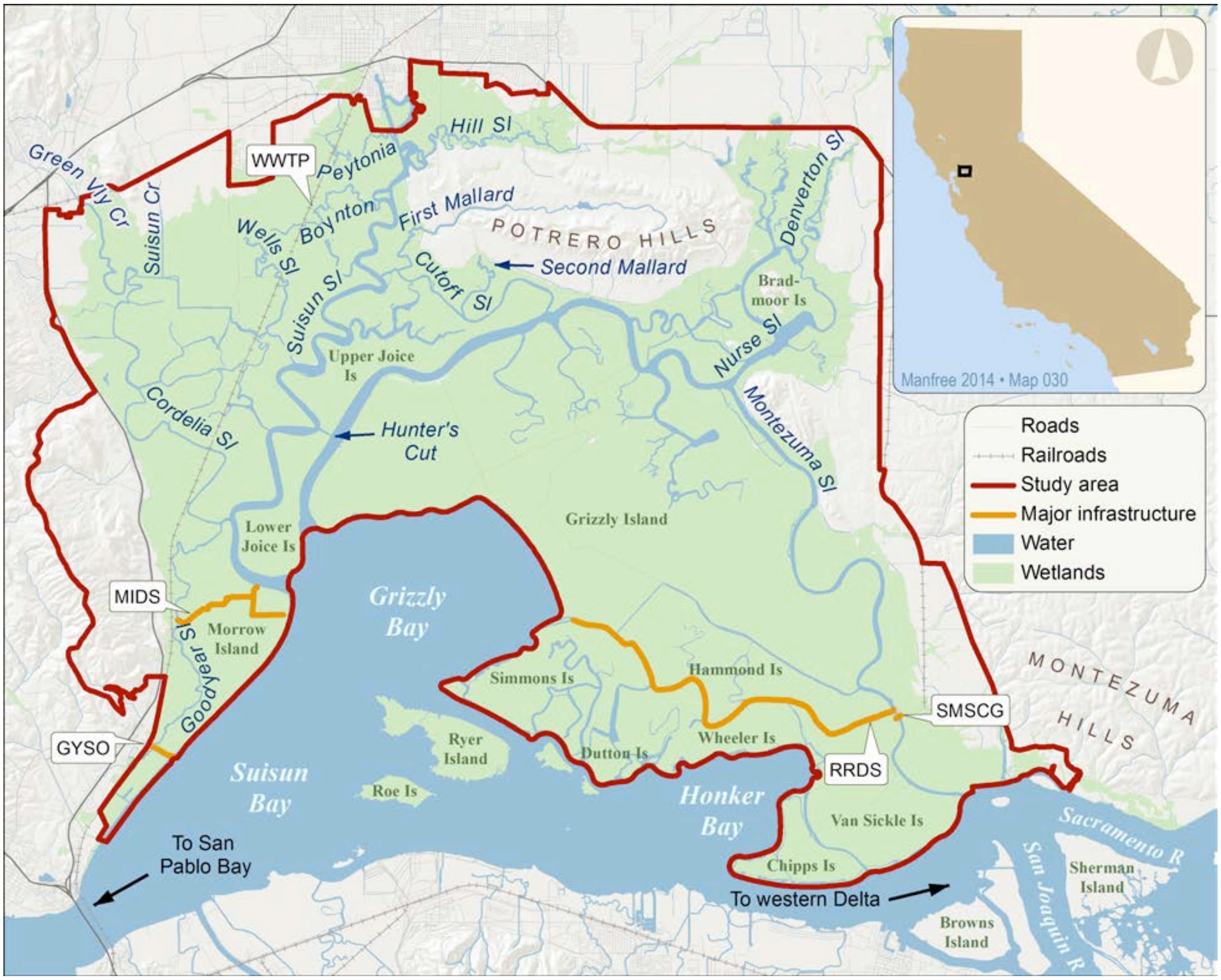

Figure 1. Suisun Marsh study area ("GYSO" = Goodyear Slough Outfall, "MIDS" = Morrow Island Distribution System, "RRDS" = Roaring River Distribution System, "SMSCG" = Suisun Marsh Salinity Control Gates, and "WWTP" = the Fairfield-Suisun Sanitation District's wastewater treatment plant discharge point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

A number of water management facilities alter the hydrology and water quality of the marsh. State Water Project and Central Valley Project water export facilities in the southern Delta affect the timing and magnitude of freshwater flow into Suisun Marsh (DWR 1984). The Suisun Marsh Salinity Control Gates, located in Montezuma Slough just downstream of the confluence of the Sacramento and San Joaquin rivers, are operated to inhibit saltwater intrusion into the marsh during flood tides, which provides fresher water for diked wetlands (DWR 2001; Figure 1). Numerous water control structures, most of which are unscreened for fish, are located throughout the marsh; they are opened in early autumn for flooding wetlands to attract wintering waterfowl, with water diverted from adjacent subtidal sloughs. Most water control structures remain open to some extent (or are reopened) during winter and spring, mainly to maintain water elevations in the wetlands, to leach salts from wetland soils, and to promote growth of desired waterfowl plants (DWR 1984). Diversions are restricted in some sloughs of the marsh during winter and spring to reduce entrainment of endangered fishes. Most wetlands are drained in late spring, with drainage water being discharged directly into sloughs within the marsh, and remain dry throughout summer. Several canal systems - the Roaring River Distribution System, the Morrow Island Distribution System, and the Goodyear Slough Outfall - redirect water in the marsh, with goal of providing lower-salinity water for managed wetlands (Figure 1; DWR 2001). The Fairfield-Suisun Sewer District discharges tertiary-treated wastewater into Boynton Slough; the wastewater's salinity and the DO are often low and high, respectively (Figure 1; Siegel *et al.* 2011).

Sampling

Since 1980, monthly juvenile and adult fish sampling has been conducted at standard sites within subtidal sloughs of Suisun Marsh. Originally, 47 sites in 13 sloughs were sampled; however, several of these sites were sampled only in 1980 and 1981, with 17 sites in seven sloughs being sampled consistently until 1994 (see O'Rear and Moyle 2008). From 1994 to the present, 21 sites in nine sloughs have been regularly sampled by otter trawl (Figure 2).

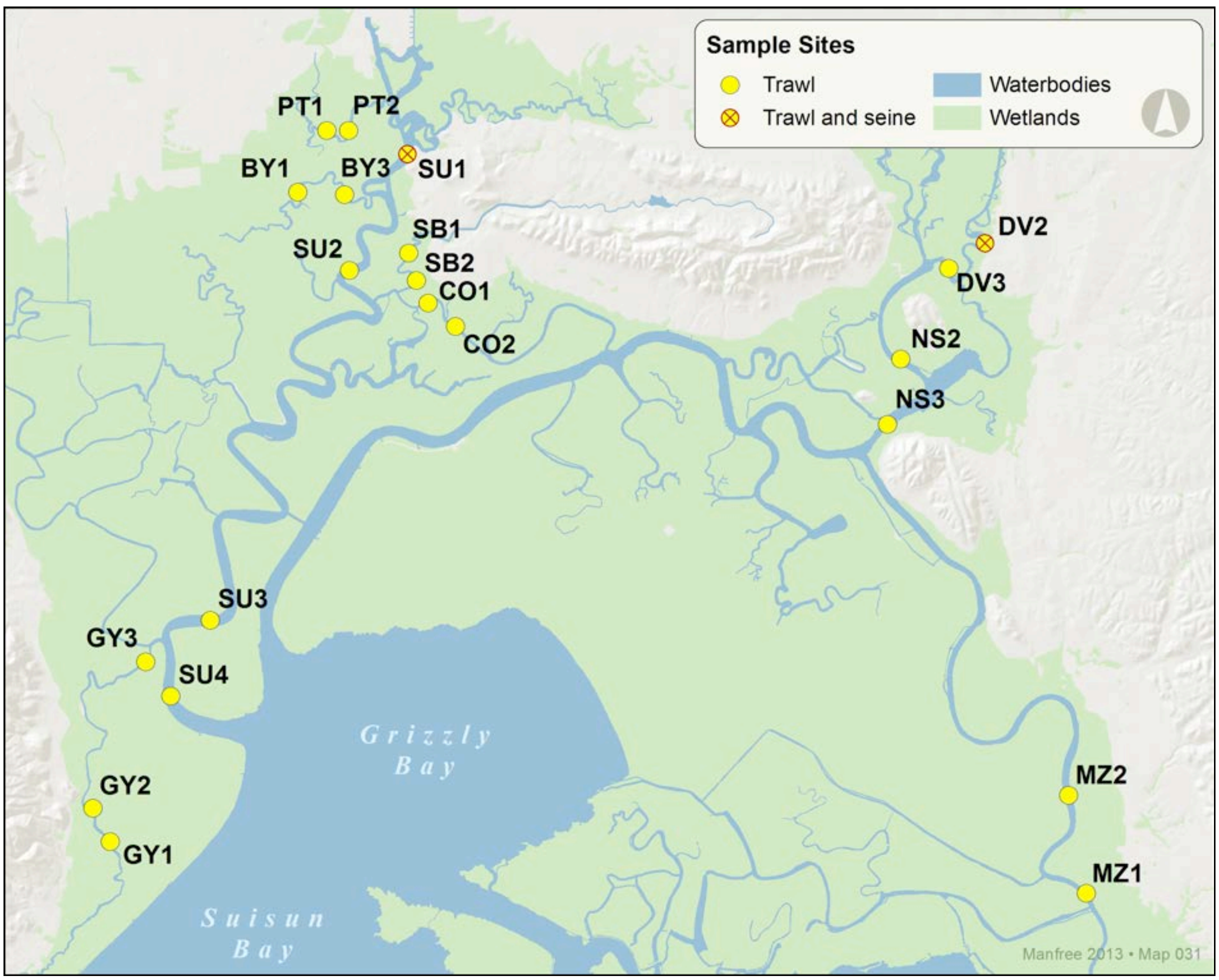

Figure 2. Current Suisun Marsh Fish Study sampling sites (map by Amber Manfree).

Trawling was conducted using a four-seam otter trawl with a 1.5-m X 4.3-m opening, a length of 5.3 m, and mesh sizes of 35-millimeter (mm) stretch in the body and 6-mm stretch in the cod end. The otter trawl was towed at 4 km/hr for 5 minutes in small sloughs and at the same speed for 10 minutes in large sloughs. In Denverton and upper Suisun sloughs, inshore fishes were sampled with a 10-m beach seine having a stretched mesh size of 6 mm. For each site, temperature (degrees Celsius, °C), salinity (parts per thousand, ppt), and specific conductance (microsiemens, µS) were recorded with a Yellow Springs Instruments (YSI) 85 meter. Dissolved oxygen parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also measured with the YSI 85. Water transparency (Secchi depth, cm), tidal stage (ebb, flood, high, low), and water depths (m) were also recorded.

Contents of each trawl or seine were placed into large containers of water. Fishes were identified, measured to the nearest mm standard length (mm SL), and returned to the water. Sensitive native species were processed first and immediately released. Numbers of Siberian prawn (*Exopalaemon modestus*), Black Sea jellyfish, oriental shrimp (*Palaemon macrodactylus*), California bay shrimp (*Crangon franciscorum*), overbite clam (*Potamocorbula amurensis*), and Asian clam (*Corbicula fluminea*) were also recorded. Siberian prawn were first positively identified in February 2002, although they likely comprised a large percentage of the 2001 and early 2002 shrimp catch that was recorded as oriental shrimp. However, abundances of Siberian prawn for this report are only considered from 2002 onward. Crustaceans from the order Mysida were pooled into one category, "mysids," and given an abundance ranking: 1 = 1-3 mysids, 2 = 4-50 mysids, 3 = 51-100 mysids, 4 = 101-500 mysids, and 5 = >500 mysids.

Data analysis

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

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

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

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

where *i* = slough, *j* =month, and *n* is the number of sloughs; once again, CPUE values for invertebrates were calculated likewise. Monthly water-quality averages for 2012 were calculated as for CPUE values, with the sum of the measurements of the water-quality parameter of interest (*e.g.*, Secchi depth, water temperature) substituting for "number of fish." X2, the distance in kilometers from the Golden Gate Bridge along the thalweg to the near-bed water with salinity of 2 ppt, was calculated following Jassby (1995). The Net Delta Outflow Index ("Delta outflow"), a proxy for water leaving the Delta, was calculated by summing river flows entering the Delta, channel depletions, in-Delta diversions, and State Water Project, Central Valley Project, and Contra Costa Water District exports. Delta outflow was obtained from the California Department of Water Resource's Dayflow website (2013*a*).

Age classes of fishes except Sacramento splittail and striped bass were determined from peaks and valleys in length-frequency graphs. Sacramento splittail age classes were determined following Matern and Sommer (unpublished data). Young-of-year (YOY) striped bass were classified as those fish belonging to the length-frequency-graph peak corresponding to the smallest size classes after April, adults were considered fish larger than 423 mm SL, and all others were classified as "juveniles." Catch of all fishes and by each method from 1979 to 2012 are found in Appendix A; annual catch of each slough and number of trawls/seines in each slough in 2012 are found in appendices B and C.

Results of 2012 were then graphed and compared to those of 2011 and averages for all years of the study.

RESULTS AND DISCUSSION

Abiotic Conditions

Delta Outflow

2012 was a relatively dry year, with concomitantly below-average Delta outflow for most months (Figure 3). Outflows were moderate and varying from mid-March to early May but were generally less than the average over the study's period and far below outflows seen in 2011.

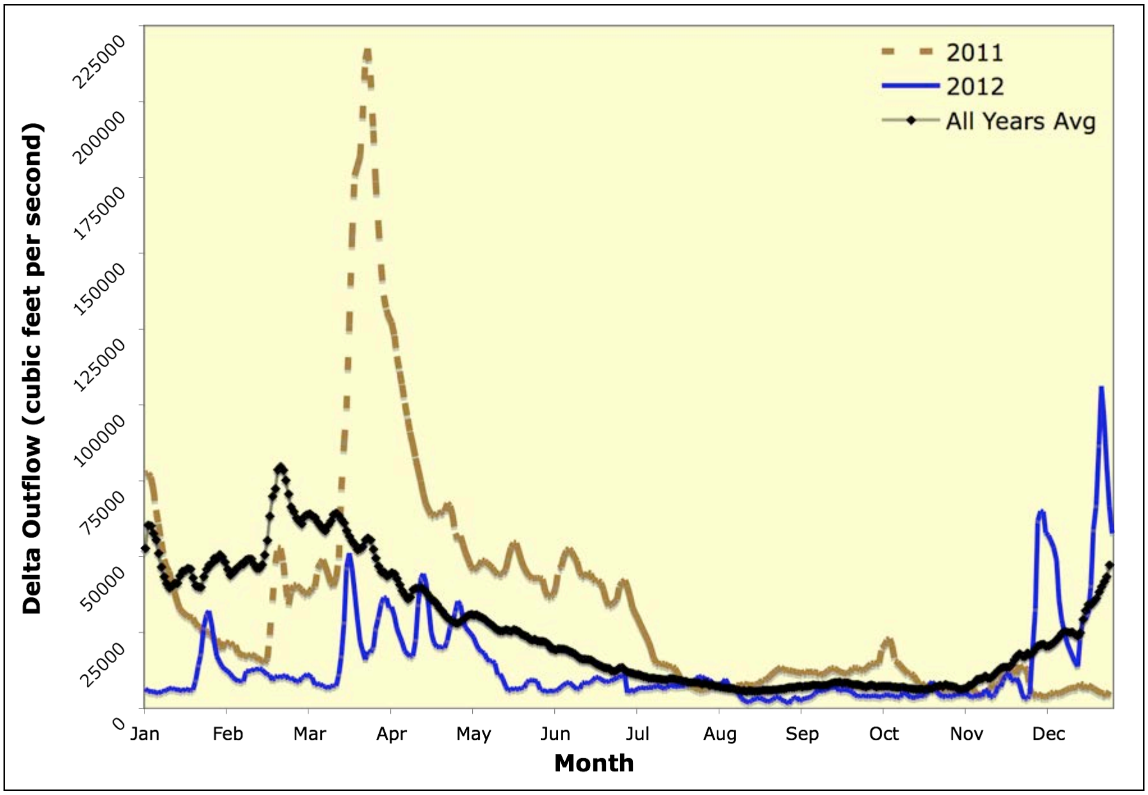

Figure 3. Daily Delta outflow in 2012, 2011, and the average for all years of the study (1980 - 2012).

From mid-May until mid-November, outflows were relatively low and constant. Large storms in late November and in December raised Delta outflow substantially, the only period during 2012 when outflows were considerably larger than the average for the last 32 years.

Salinity

Inverse to low Delta outflows, salinities in 2012 were generally higher than the average for the study's entire period, particularly when compared to the wet year of 2011 (Figure 4). The lowest values recorded in 2012 occurred during spring, with X2 within Suisun Bay during most of that time. Summer and autumn salinities were higher than the all-years average, which required operation of the salinity control gates during October and November. High Delta outflows in

December 2012 freshened the marsh and thus negated the need to operate the salinity control gates in that month. The highest monthly salinities were always recorded in the southwest marsh (*i.e.*, Goodyear and lower Suisun sloughs), the region of the marsh closest to Grizzly Bay (Figure 1). The lowest monthly salinities were always found in either Boynton Slough or eastern Montezuma Slough, due to those locations' proximities to freshwater sources (*i.e.*, a wastewater treatment plant discharge point and the western Delta, respectively; Figure 1).

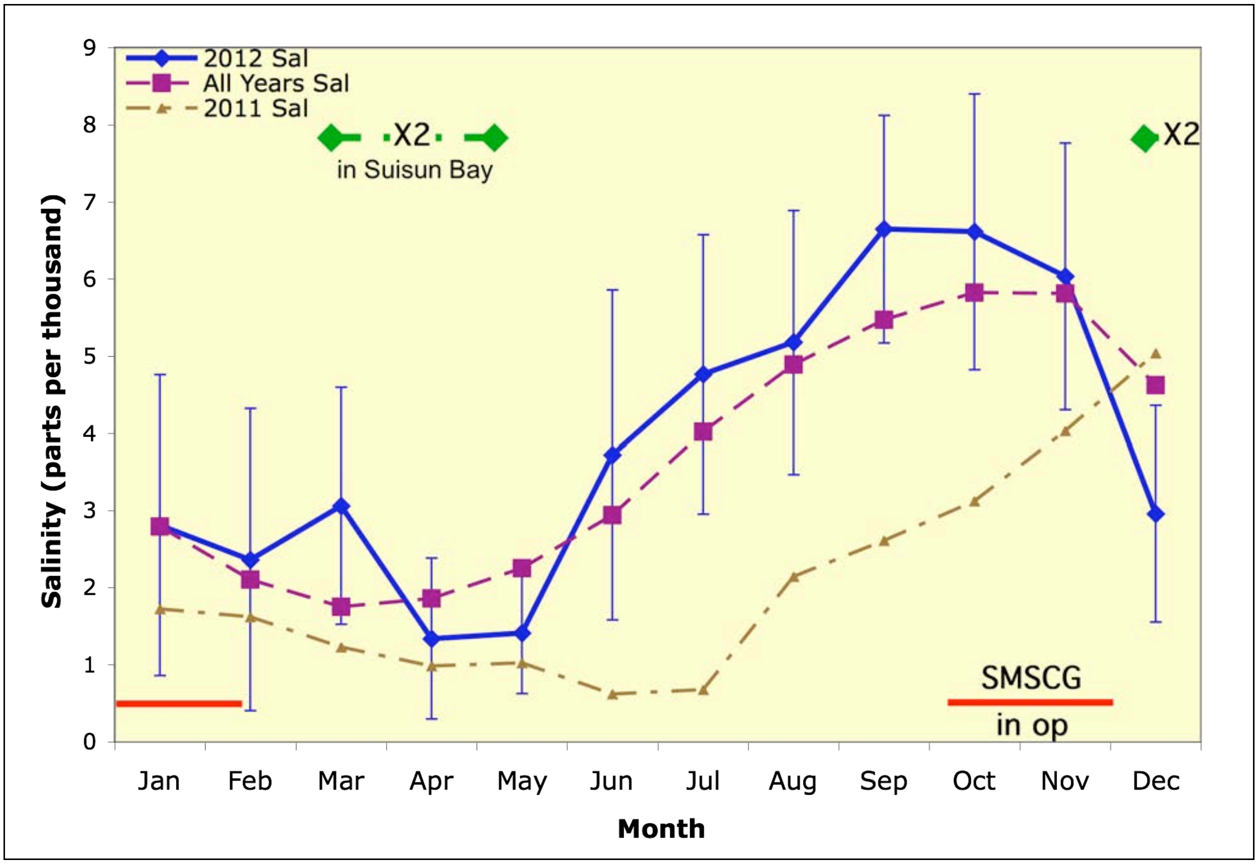

Figure 4. Monthly average salinity in 2012, 2011, and for all years of the study (1980 - 2012); error bars are standard deviations in 2012. Red bars show when the SMSCG were operating. X2 and the surrounding green, dashed bars show when X2 was within Suisun Bay (*i.e.*, between 55 and 75 km from Golden Gate Bridge).

Dissolved Oxygen (DO)

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, likely due to enhanced mixing of surface and subsurface water layers. Because oxygen solubility decreases with higher salinities and temperatures, DO concentrations are frequently lower in summer and autumn than in winter. Water discharged into sloughs from duck ponds during autumn has been occasionally observed to contain low DO concentrations and may compound regional low DO concentrations in some areas of the marsh (Siegel *et al.* 2011). Likewise, draining wetlands in spring by discharging to the sloughs can also depress marsh DO levels (Siegel *et al*. 2011), though not nearly to the extent of that which occurs in autumn. Consequently, marsh DO is usually high in winter, lower in spring and summer, and lowest in autumn.

The pattern of monthly DO in 2012 was somewhat different than for previous years. The lowest values occurred in April and May, while most years, such as 2011, have had the lowest values recorded in October (O'Rear and Moyle 2012, 2010, Siegel *et al.* 2011; Figure 5). The low DO values in April and May were likely due in part to above-average water temperatures (see Figure 6 in the next section). All measurements below 5 mg/L in April and May occurred in small, dead-end sloughs adjoining managed wetlands (Goodyear Slough, Peytonia Slough, Boynton Slough, and Denverton Slough), while values higher than 5 mg/L occurred in either larger sloughs (*e.g.*, Montezuma and Suisun sloughs) or a small, undiked slough (First Mallard). Notably, values less than about 4 mg/L during April and May were only recorded in upper Goodyear Slough. DO levels thereafter increased through summer and into early autumn (Figure 5). While DO levels did decline in October (Figure 4), the drop was not accompanied by the extremely low values that have been recorded in previous years (O'Rear and Moyle 2013*b*, 2012, 2010, Siegel *et al.* 2011, Schroeter and Moyle 2004). This was likely due in part to staggered, coordinated flood-drain events among managed-wetlands owners (S. Chappell, Suisun Resource Conservation District, personal communication).

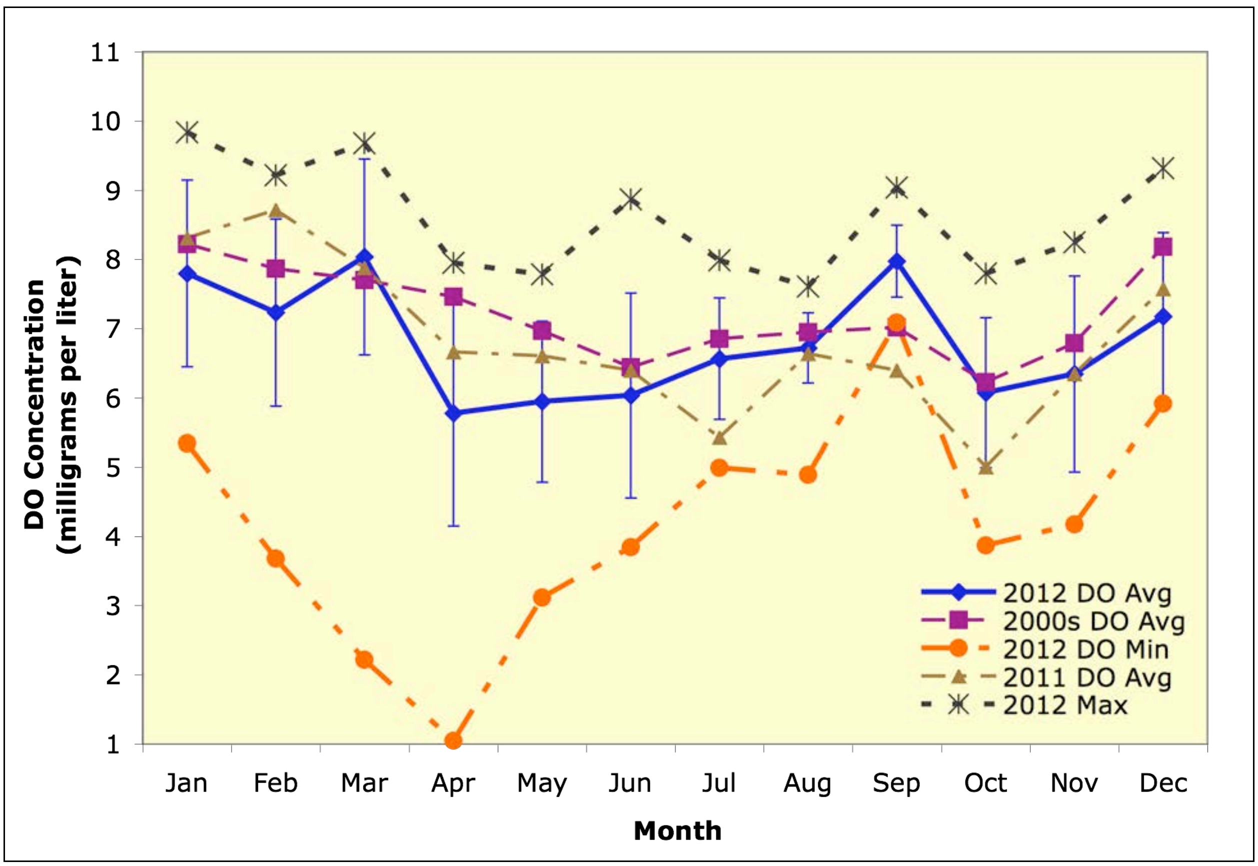

Figure 5. Monthly average DO concentration in 2012, 2011, and for the 2000s (2000 - 2012); maximum DO concentration in 2012, and minimum DO concentration in 2012. Error bars are standard deviations in 2012.

Water Temperature

Water temperatures in 2012 differed from the average in several ways. Both January and April exhibited warmer-than-usual water temperatures, consistent with the trends in air temperatures for those months (DWR 2012*b*, 2012*c*; Figure 6). The March 2012 average and standard deviation were both relatively low, primarily due to our sampling spanning a large storm. Water temperatures were cooler than average in August and September; those values were mainly due to our sampling both co-occurring with low-pressure systems and occurring towards the ends of both months. Late spring through mid-summer and autumn both found water temperatures in the marsh similar to previous years (Figure 6). Water temperature differences among the sloughs in the marsh appeared minimal (Figure 6).

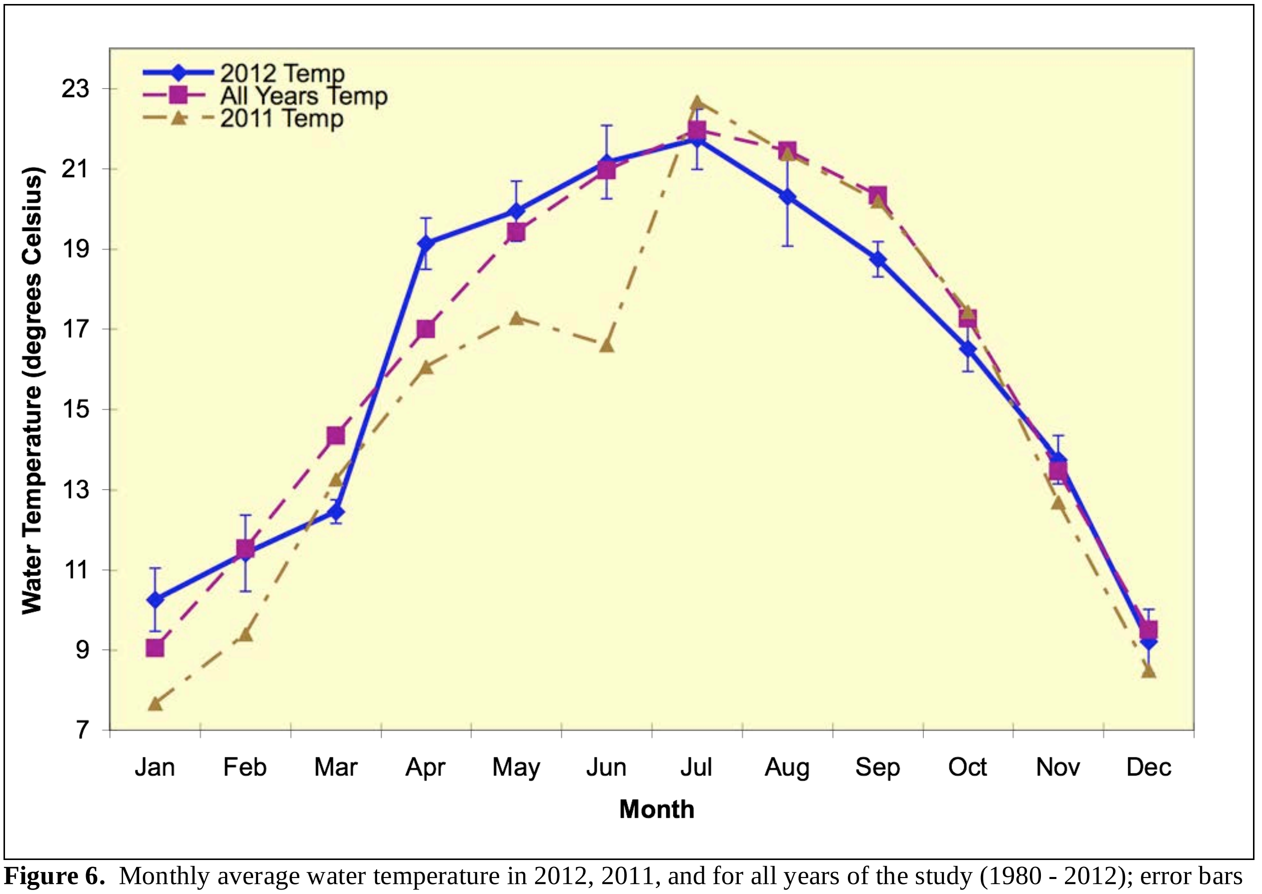

Figure 6. Monthly average water temperature in 2012, 2011, and for all years of the study (1980 - 2012); error bars are standard deviations in 2012.

Water Transparency

Water transparency is partially a function of Delta outflow, with lower outflows corresponding to higher transparencies in the marsh (O'Rear and Moyle 2012, O'Rear and Moyle 2008, Moyle *et al.* 1986). The dry year of 2012 followed this trend, with nine of the 12 months having higher average Secchi depth readings than normal (Figure 7). While Secchi depths were slightly greater for early spring, they were much higher than both the all-years average and 2011 for most of summer and all of autumn (Figure 7). Uncommonly high Delta outflows in December (Figure 3) were accompanied by a lowering of average Secchi depth below the value for all years. With the exception of December, the lowest monthly Secchi depths were always located in sloughs far away from Grizzly Bay and the western Delta (Denverton, upper Suisun, and First Mallard sloughs), with most of the highest monthly Secchi depths occurring in eastern Montezuma Slough. The deviation of Secchi depths was relatively large from June through November (Figure 7), months of low and constant Delta outflow; months with elevated outflows generally had lower Secchi depth deviations.

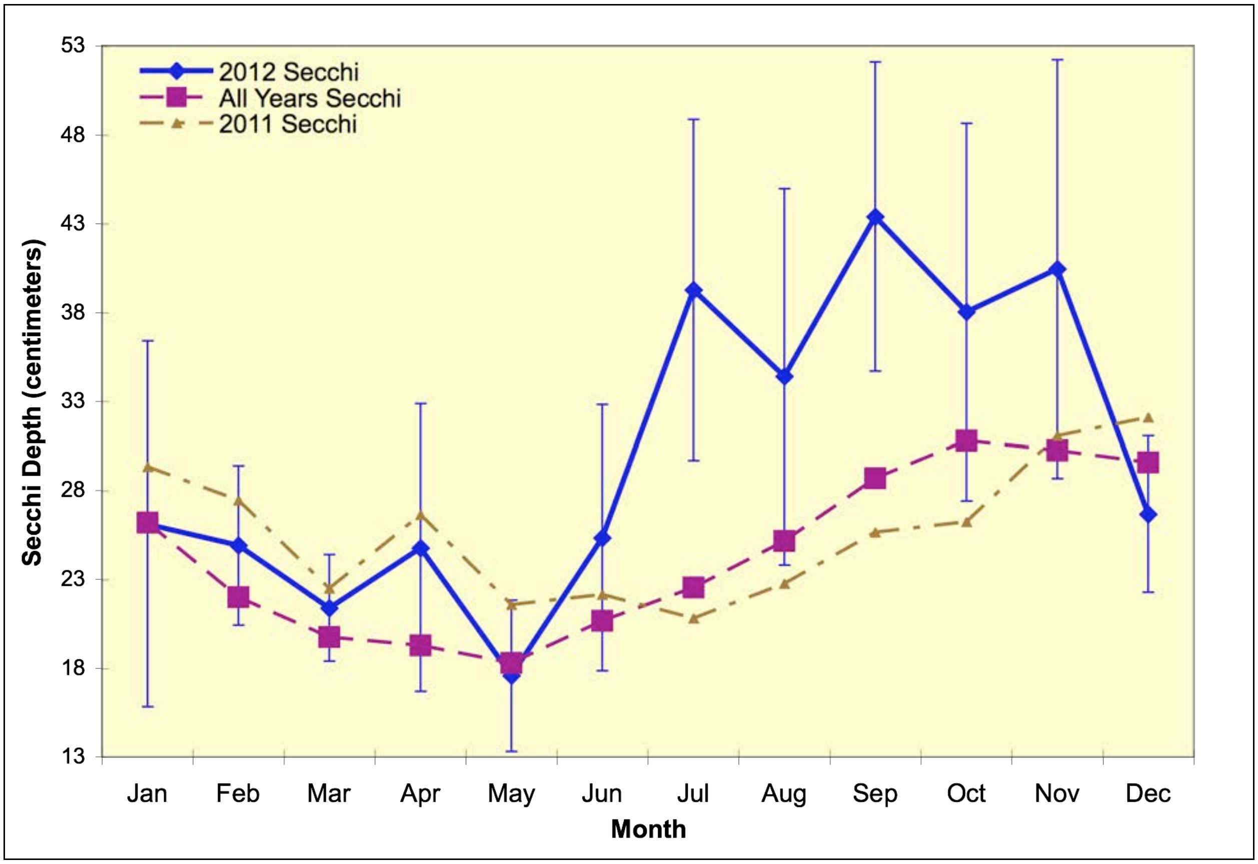

Figure 7. Monthly average water transparency in 2012, 2011, and for all years of the study (1980 - 2012); error bars are standard deviations in 2012.

Trends in Invertebrate Distribution and Abundance

Four plankton-feeding macroinvertebrates are commonly captured by otter trawl in Suisun Marsh: California bay shrimp, Siberian prawn, Black Sea jellyfish, and overbite clam, of which only California bay shrimp is native. These invertebrates are important components of the food web, either as competitors [*e.g.*, Black Sea jellyfish (Wintzer *et al.* 2011), overbite clam (Feyrer *et al.* 2003)] or as food sources [*e.g.*, California bay shrimp and Siberian prawn (Nobriga and Feyrer 2008)] for fishes of the marsh.

Black Sea Jellyfish

Black Sea jellyfish annual CPUE rebounded from the low point in 2011 to the highest ever recorded in 2012 (Figure 8). The monthly trend in CPUE was quite typical, with medusae first appearing in mid-summer, reaching a peak in late summer, and then declining through autumn (O'Rear and Moyle 2012, 2013*b*; Figure 9). Black Sea jellyfish were extraordinarily abundant in upper Suisun (*i.e.*, the SU1 and SU2 sites; Figure 2) and Nurse sloughs during the bloom period, with nearly two-thirds (62%) of 2012's catch coming from just those two sloughs. Nevertheless, Black Sea jellyfish were common throughout the rest of the marsh except in Denverton Slough, where only 11 of the 6,725 medusae were captured. Water temperatures and salinities in Denverton Slough during late summer were within ranges favorable for medusae (salinity = 3 - 7 ppt, water temperature >19℃; Schroeter 2008), suggesting that other factors, such as hydrodynamics, were not appropriate for a bloom in that slough.

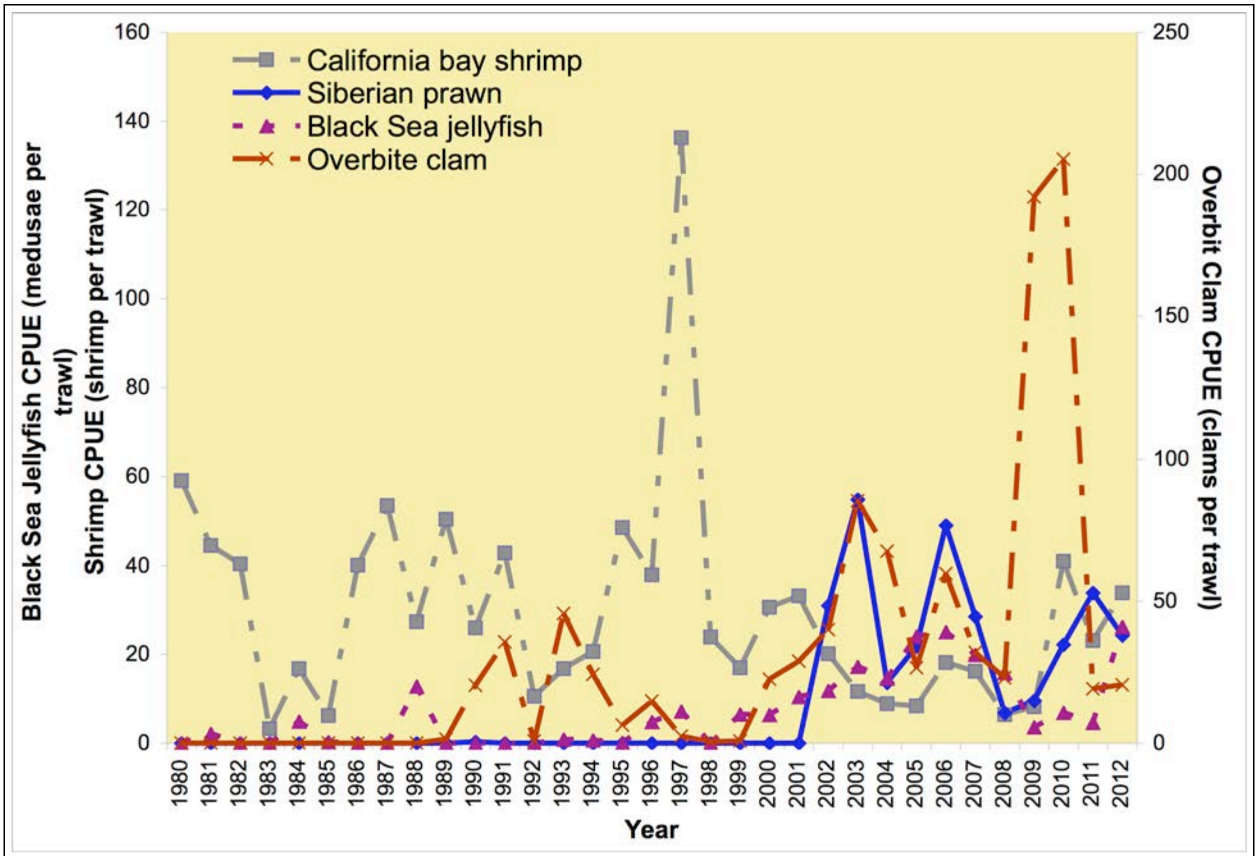

Figure 8. Annual otter trawl CPUE of four common macroinvertebrates.

Overbite Clam

Annual CPUE of overbite clam in 2012 increased only slightly relative to 2011 (20.5 to 19.2 clams per trawl, respectively; Figure 8) and was well below the average CPUE (39 clams per trawl) since its first appearance in the marsh (1988). Unlike in 2011, when numbers of overbite clam rose only very mildly during the summer recruitment period, the pattern of monthly CPUE during 2012 returned to the typical trend from late spring into early autumn of a rapid rise and then decline. This is likely due in part to relatively high salinities in the marsh during 2012 favoring recruitment of early life-history stages (Miller and Stillman 2013, Schroeter 2011, Nicolini and Penry 2000). Similar to 2010, a large proportion (52%) of the 2012 catch was captured in upper Suisun Slough, with nearly the rest of the catch coming from lower Goodyear and lower Suisun sloughs. Despite high abundances in upper Suisun Slough, overbite clams were either extremely rare or absent in nearby small sloughs (*e.g.,* First Mallard Slough and Boynton Slough, respectively), suggesting that smaller sloughs in the interior of the marsh are inhospitable to the clam (Schroeter 2011). The overbite clam was neither common nor abundant in any slough sampled in the eastern marsh (Denverton, Nurse, and eastern Montezuma).

California Bay Shrimp

Annual California bay shrimp CPUE increased from 2011 to 2012 (Figure 8), with 2012 having the second-highest CPUE since 2002. Catch in 2012 was relatively low in January and generally declined through April (Figure 9), corresponding to movement of adults out of the marsh and downstream into saltier waters needed for reproduction (Hatfield 1985, Siegfried 1980, Krygier and Horton 1975). Recruitment of YOY shrimp in the marsh began in May, reached its peak in June, and declined from July to December. The peak CPUE was attained much earlier in 2012 (June) than in 2011 (October), due in part to appropriate salinities within the marsh for the shrimp occurring earlier in 2012. This shifting of the peak catch to earlier in the year for dry years has been seen before in both Suisun Marsh (*e.g.,* 2007, 2009, 2010) and in other parts of the estuary (Hatfield 1985, Siegfried 1980). Consistent with both recruitment from downstream saltier areas of the estuary (*e.g.,* the Pacific Ocean just outside of Golden Gate; Hatfield 1985) and the need of the shrimp for relatively saline water, over two-thirds of 2012 catch came from just three of the 21 sites sampled in the marsh: the lower Suisun Slough sites and the lower Goodyear Slough site, the three sampling locations closest to Grizzly Bay (Figure 2).

Siberian Prawn

Annual CPUE of Siberian prawn in 2012 was about average, with five years having higher values and five years having lower values (Figure 8). Monthly CPUE generally declined from January to December, with just a slight increase in August during the period of recruitment (Oh *et al.* 2002; Figure 9). The lack of a substantial increase in catch during late summer or early autumn in 2012 suggests reduced reproductive success, which is likely due in part to higher-than-average salinities (Xu *et al.* 2008, Emmett *et al.* 2002). The bulk of the Siberian prawn population within the marsh is generally in the northeastern and northwestern regions, reflecting the association of the species with fresher water (Emmett *et al.* 2002). This pattern was basically followed in 2012, with 52% of the catch made in just three sloughs in the northwest and northeast marsh: upper Suisun, Boynton, and Denverton (Figure 2). Nevertheless, moderate catches were made in Goodyear Slough and lower Suisun Slough, with each slough hosting 10% of the annual catch.

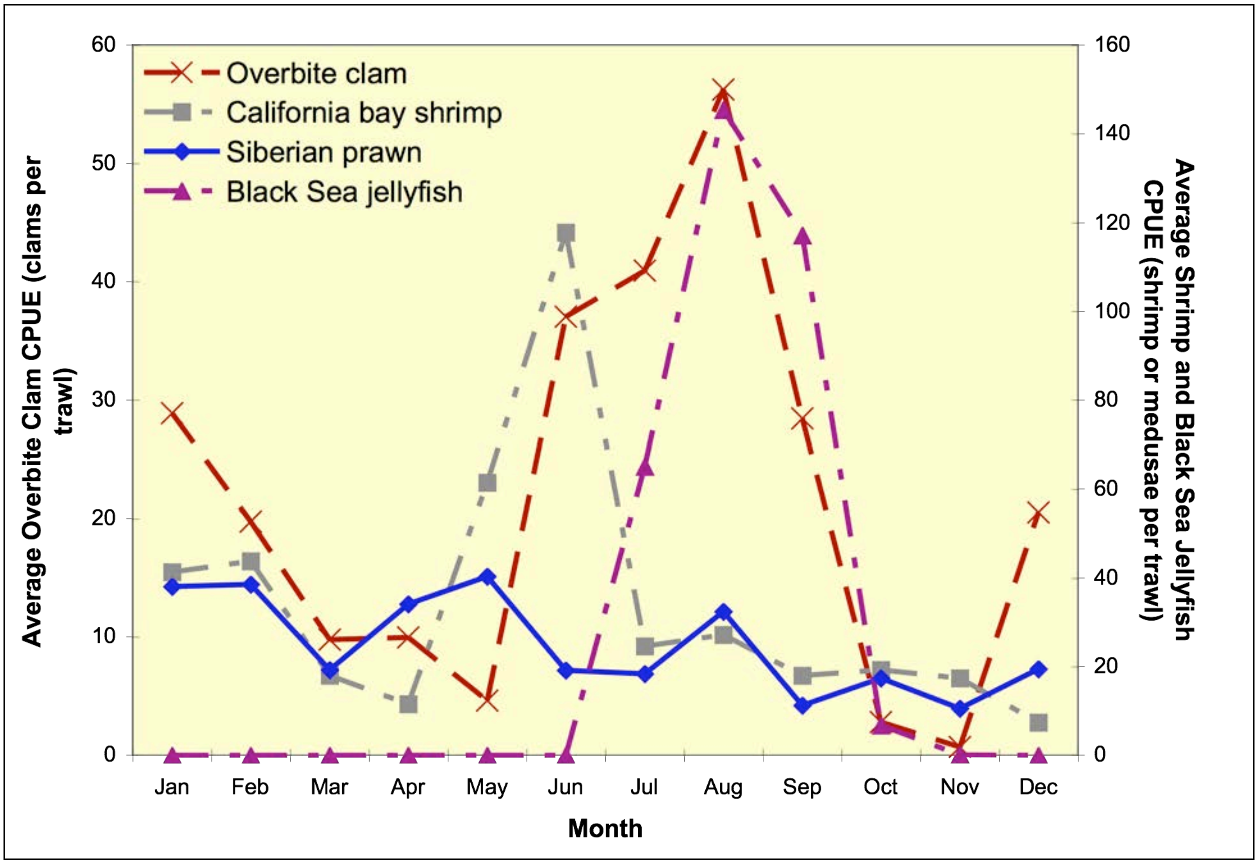

Figure 9. Monthly average CPUE of four common macroinvertebrates in Suisun Marsh in 2012.

Trends in Fish Distribution and Abundance

Otter Trawls

Annual otter trawl CPUE increased from 17.9 fish per trawl in 2011 to 23.7 fish per trawl in 2012 (Figure 10), with the 2012 CPUE slightly below the average for all years (23.7 versus 25.3 fish per trawl). The increase in total CPUE was solely due to large jumps in numbers of introduced species, mainly striped bass but also common carp (*Cyprinus carpio)*, shimofuri goby (*Tridentiger bifasciatus*), and shokihaze goby (*Tridentiger barbatus;* Table 1). Conversely, numbers for four abundant native fishes dropped from 2011 to 2012: Sacramento splittail, threespine stickleback, prickly sculpin, and, in particular, tule perch (Table 1).

The decline in native fishes from 2011 to 2012 appears due partially to the effects of the dry year in 2012 on Sacramento splittail. Sacramento splittail recruitment in the estuary rises with increasing floodplain inundation in Yolo Bypass (Feyrer *et al.* 2006, Sommer *et al.* 1997) during the spawning period (February - May; Sommer *et al.* 2008, Feyrer *et al.* 2006, Moyle *et al.* 2004), the flooding of which generally happens more frequently and to a larger spatial extent in wet years (Sommer *et al.* 2004). There was little floodplain inundation of Yolo Bypass during 2012 (DWR 2013*b*) concomitant with a 61% decline in otter trawl CPUE of YOY Sacramento splittail from 2011 to 2012 (see "Sacramento Splittail" section for further discussion).

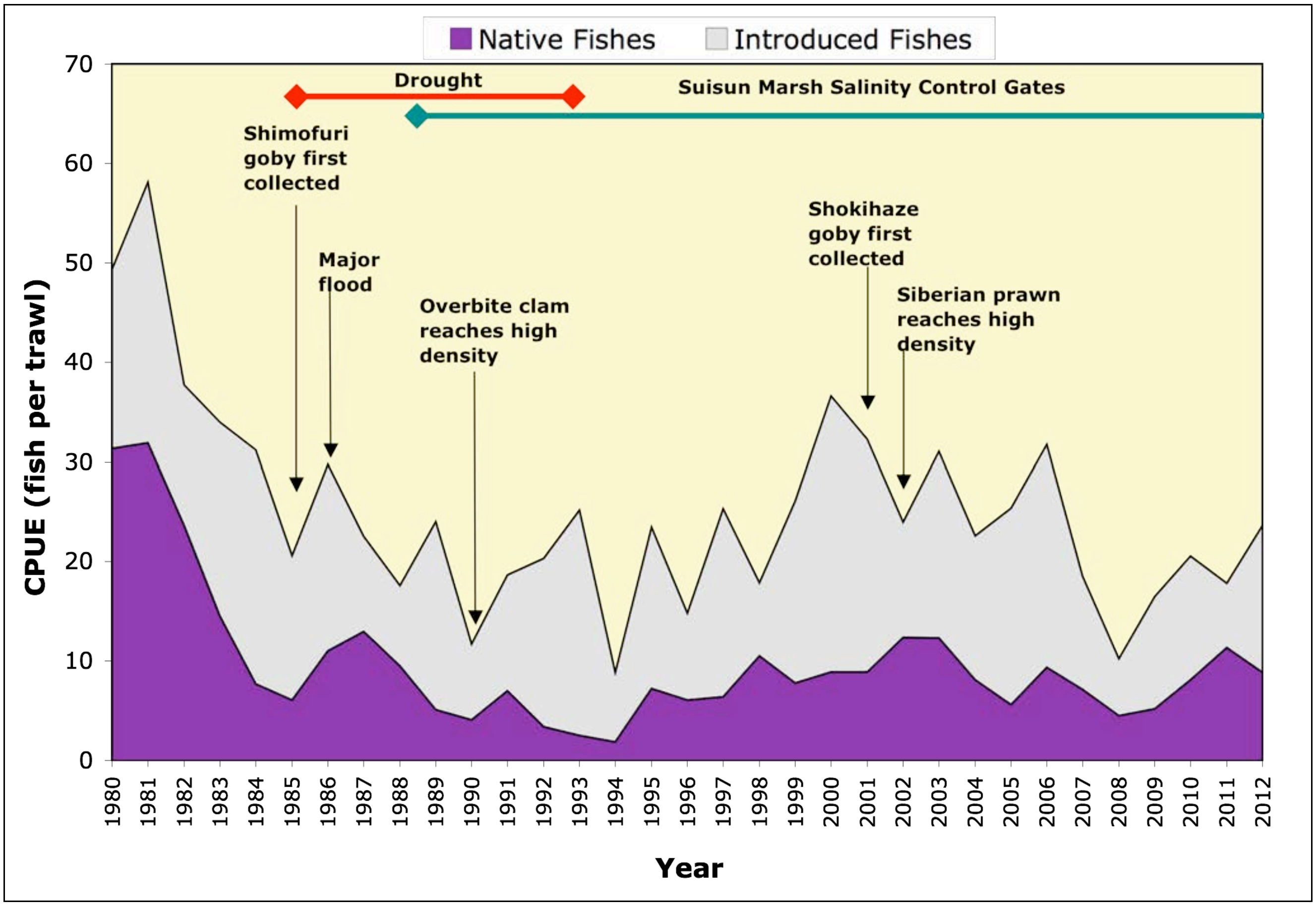

Figure 10. Annual otter trawl CPUE of native and introduced fishes, with important events highlighted.

Table 1. Percent change in annual otter trawl CPUE of eight common marsh fishes [(% increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled; species in bold are native; "all years" is the average for 1980 - 2012 for all species except shimofuri goby and shokihaze goby, for which "all years" begins with the year of their respective introductions (1985 and 1999)].

Species	All Years CPUE	2011 CPUE	2012 CPUE	2011-2012 % Change
Sacramento splittail	**2.6**	**6.3**	**5.9**	**-6%**
threespine stickleback	**1.7**	**0.9**	**0.2**	**-73%**
prickly sculpin	**1.2**	**1.3**	**1.0**	**-24%**
tule perch	**2.0**	**1.9**	**0.9**	**-53%**
common carp	0.5	0.2	0.5	+131%
striped bass	9.3	3.0	10.8	+264%
shimofuri goby	1.6	0.4	0.6	+58%
shokihaze goby	0.2	0.2	0.4	+81%

The reasons for the drop in the CPUE of the other three native fishes from 2011 to 2012 are more obscure. Annual otter trawl CPUE of both threespine stickleback and prickly sculpin has previously been found to be a function of sampling during draining of managed wetlands in late winter and spring (O'Rear and Moyle 2013*a*, Matern *et al*. 2002); our lower numbers of these two species in 2012 likely reflect the mismatch in timing between our sampling and large drainage events, rather than actual abundances of the species in the marsh. Of the four native species, the decline in CPUE from 2011 to 2012 was greatest for tule perch (Table 1). While part of this decline was, as for splittail, due to lower recruitment [the proportion (33%) of the 2012 catch comprised of YOY was the fourth lowest in the study's 32-year history; O'Rear, unpublished data], the 2012 CPUE of fish older than one year was also low compared to the study's average (0.7 and 1.1 fish per trawl, respectively). Thus the decline in tule perch appears to be associated with factors acting on both life-history stages.

The substantial increase in the striped bass CPUE from 2011 to 2012, and hence the CPUE of all introduced fishes, was primarily due to two months of very high abundance of YOY striped bass in 2012 (Figure 11). This pattern is unusual in two ways: (1) most years have just one month of very high abundance of YOY striped bass followed by a rapid, exponential decline in CPUE, and (2) the peak CPUE is usually in June (O'Rear and Moyle 2013*a*, 2013*b*, 2008). In 2012, the peak CPUE was in May and was followed by a CPUE that was nearly as high in June (Figure 11). This could have been due to an expanded spawning season and hence a longer recruitment season in the marsh; however, this was not the case since the increase in mean length of YOY fish from May to June in 2012 (15 and 28 mm SL, respectively) corresponds well with values reported in the literature for a one-month growth of a single cohort of post-larval fish [Conover *et al.* 1997, Boynton *et al.* 1977 (as cited in Hill *et al.* 1989), Mihursky *et al.* 1976 (as cited in Hill *et al.* 1989)]. Instead, the high YOY CPUE persisting into June 2012 was likely due to high survival from feeding on abundant, co-occurring mysids (Figure 11), which is an important food item for YOY striped bass (Wintzer *et al.* 2011*b*, Feyrer *et al.* 2003). The earlier peak catch in 2012 may have been due to an earlier onset of spawning: we observed the first ripe adult striped bass in the marsh in 2012 in February (the first ripe fish observed in 2011 and 2010 were in May and March, respectively; O'Rear, unpublished data); additionally, the minimum temperature necessary for spawning (14℃; Moyle 2002) was reached in mid-April and was maintained above that value throughout the rest of spring in the Sacramento River - the primary spawning area for striped bass (Moyle 2002) - in 2012 (DWR 2013*c*). While 14℃ was also first reached in mid-April in 2010, it dipped below that value several times in the following three weeks; 14℃ was not attained in 2011 until early May (DWR 2013*c*).

The large increase in the carp CPUE from 2011 to 2012 was primarily due to a very large catch of YOY fish in May 2012. The bulk of the May 2012 YOY catch (73%) occurred in the southwest marsh close to the mouth of Cordelia Slough (*i.e.*, the GY3, SU3, and SU4 sites; Figure 2) while the upper Goodyear Slough sites contributed only 3% to the catch. These geographical patterns in the YOY catch, coupled with salinities (range: 7.6 - 5.0 ppt) harmful to carp egg-hatching success (Lam and Sharma 1985) in upper Goodyear Slough in March and April, suggest that the YOY carp were spawned within the Cordelia Slough watershed. Because carp require both still-water conditions and submerged/emergent aquatic vegetation for spawning (Smith and Walker 2004, Lam and Sharma 1985), the only appropriate habitats within the Cordelia Slough watershed for spawning would have been (1) a managed wetland or (2) the lower reaches of Suisun and Green Valley creeks.

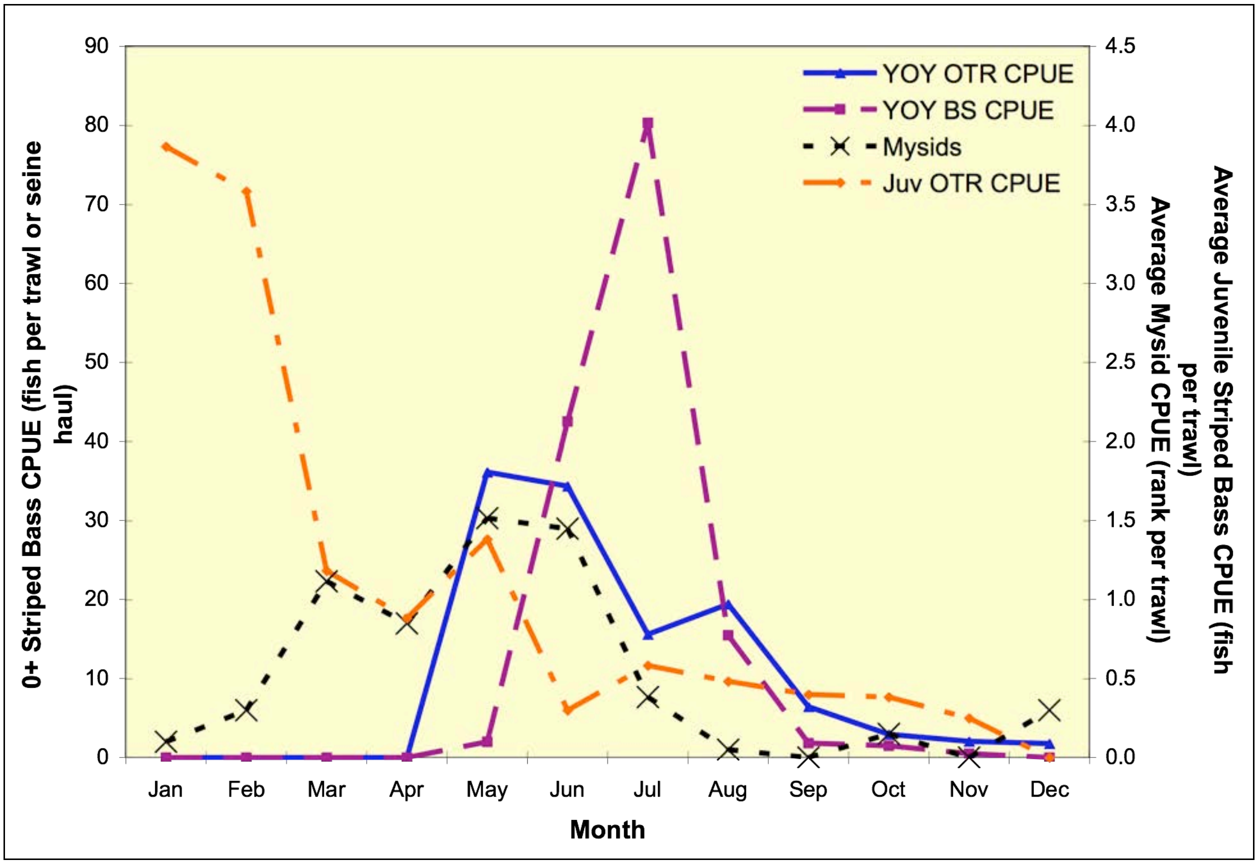

Figure 11. Monthly average CPUE of striped bass age classes and mysids ("OTR" = otter trawl, "BS" = beach seine) in 2012.

As for the other introduced fishes, increases in otter trawl CPUE from 2011 to 2012 of shimofuri and shokihaze gobies was due to elevated recruitment of YOY fish. In the case of shimofuri goby, however, the improved recruitment was apparently followed by high mortality: monthly otter trawl CPUE rapidly rose to a peak of 2.7 fish per trawl in July, remained fairly high at 2.0 fish per trawl in August, but then plummeted to 0.2 fish per trawl in September. This pattern has been seen in previous years (*e.g.*, 2009), the likely culprit of which has been limited food supplies (O'Rear and Moyle 2010). The pattern in monthly CPUE of shokihaze goby was similar to that of shimofuri goby, with a peak CPUE of 2.1 fish per trawl in August followed by a much lower CPUE of 0.3 fish per trawl in September. However, very little is known about the biology of shokihaze goby in the estuary, and thus reasons for the increase from 2011 to 2012 remain unknown.

Beach Seines

Annual beach seine CPUE increased 88% from 2011 to 2012 (31.4 to 59.1 fish per seine haul, respectively; Figure 12), although the 2012 value was about the same as the average for all years of the study (57.1 fish per seine haul). While striped bass were an important factor in the higher 2012 CPUE relative to 2011, the main reason for the increase was due to a strong rebound in Mississippi silverside numbers (Table 2). Native fish beach seine CPUE dropped 34% from

2011 to 2012 (5.8 to 3.8 fish per seine haul, respectively), and the 2012 value was only 55% of the value for all years of the study (6.8 fish per seine haul). The decline in native fish was primarily due to Sacramento splittail and threespine stickleback (Table 2).

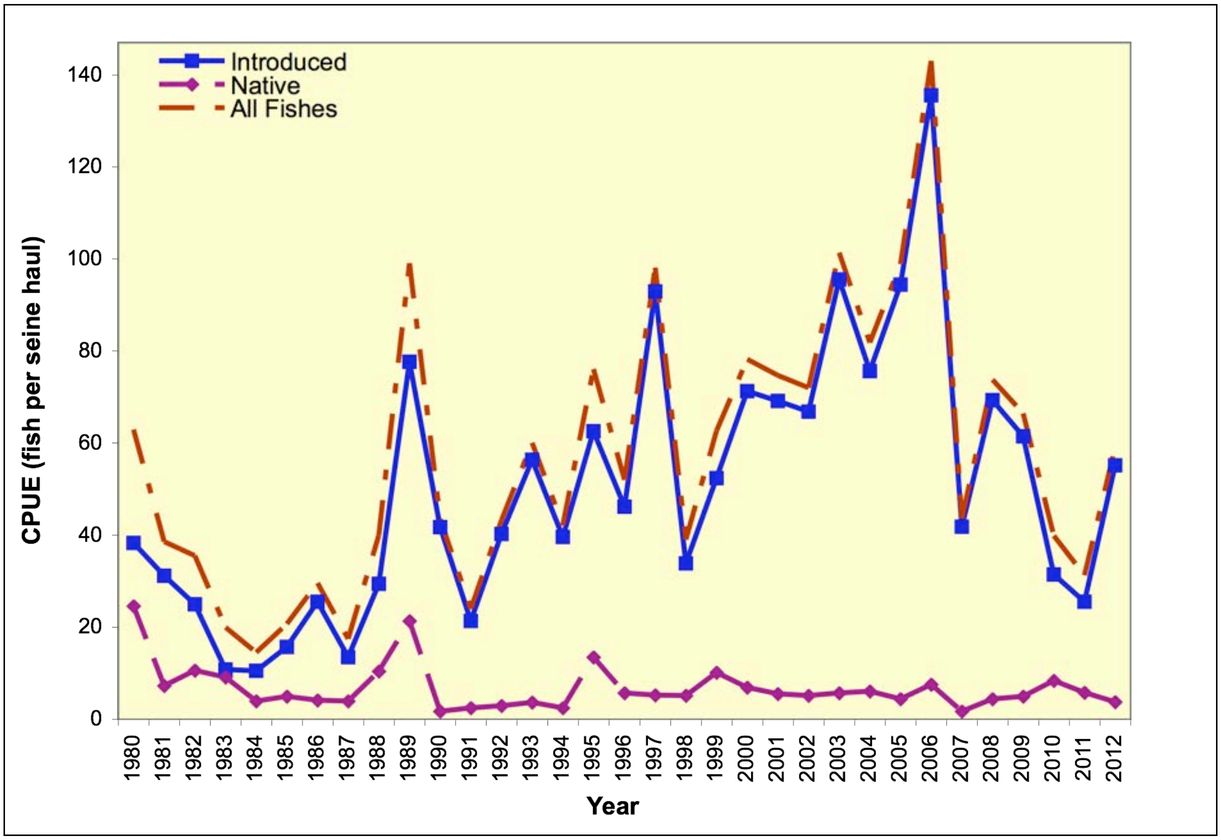

Figure 12. Annual beach seine CPUE of introduced, native, and both categories of fishes combined.

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

Species	All Years CPUE	2011 CPUE	2012 CPUE	2011-2012 %Change
Sacramento splittail	**1.3**	**3.1**	**2.2**	**-29%**
threespine stickleback	**1.9**	**1.0**	**0.3**	**-72%**
Mississippi silverside	34.1	15.7	40.1	155%
striped bass	5.9	5.9	11.3	93%

The rise of introduced fishes in beach seines from 2011 to 2012 appears due to two factors. In the case of Mississippi silverside, the generally warm year of 2012 was partially responsible for the improved recruitment over 2011. Warmer water promotes Mississippi silverside populations through (1) increasing over-winter survival of adults (Stoekel and Heideinger 1988), (2) earlier initiation of spawning (Middaugh and Hemmer 1992), (3) improved egg survival (Hubbs *et al.* 1971), and (4) a faster time-to-hatch (Hubbs *et al.* 1971). For striped bass, peak beach seine catch occurred in July after the high May and June otter trawl catches and concurrent with a decline in mysid numbers in otter trawls (Figure 11). Lengths of striped bass in beach seines averaged about the same as those in the otter trawls and so the beach seine fish were not from a later spawn, suggesting that food limitation in the channels of the marsh resulted in a shift of YOY striped bass into near-shore areas. This shift has been previously observed at different scales in the estuary (Sommer *et al.* 2011, O'Rear and Moyle 2010).

Reasons for the drop in beach seine CPUE of native fishes appear similar to that for the otter trawls. Nearly all Sacramento splittail caught in beach seines are YOY fish (O'Rear and Moyle 2012), and thus the decline in beach seine CPUE from 2011 to 2012 reflects reduced recruitment (Table 2). Threespine stickleback numbers are likely due in part to our springtime beach seine hauls not occurring during large drainage events of managed wetlands, which was not the case in April 2010 when sampling coincided with large managed-wetlands outflows and very large beach seine catches of stickleback (O'Rear and Moyle 2013*a*).

Fish Species of Interest

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

LONGFIN SMELT

Otter trawl CPUE in 2012 fell by more than half in comparison to 2011 and was far below the average for all years of the study (0.04, 0.09, and 1.21 fish per trawl, respectively; Figure 13), with only seven YOY and five adult fish captured in 2012. These low catches were not wholly unexpected given both (1) the positive relationship between Delta outflow and longfin smelt abundance and (2) the low Delta outflow in 2012 (Rosenfield and Baxter 2007, Matern *et al.* 2002). Similar to other dry years (*e.g.*, 2009; O'Rear and Moyle 2010), YOY fish peaked in spring and declined through summer; pre-spawning adult fish were present in the marsh during autumn and winter (Figure 14). Four of the five adult fish were captured in lower Suisun and lower Goodyear sloughs; YOY fish were scattered throughout the marsh.

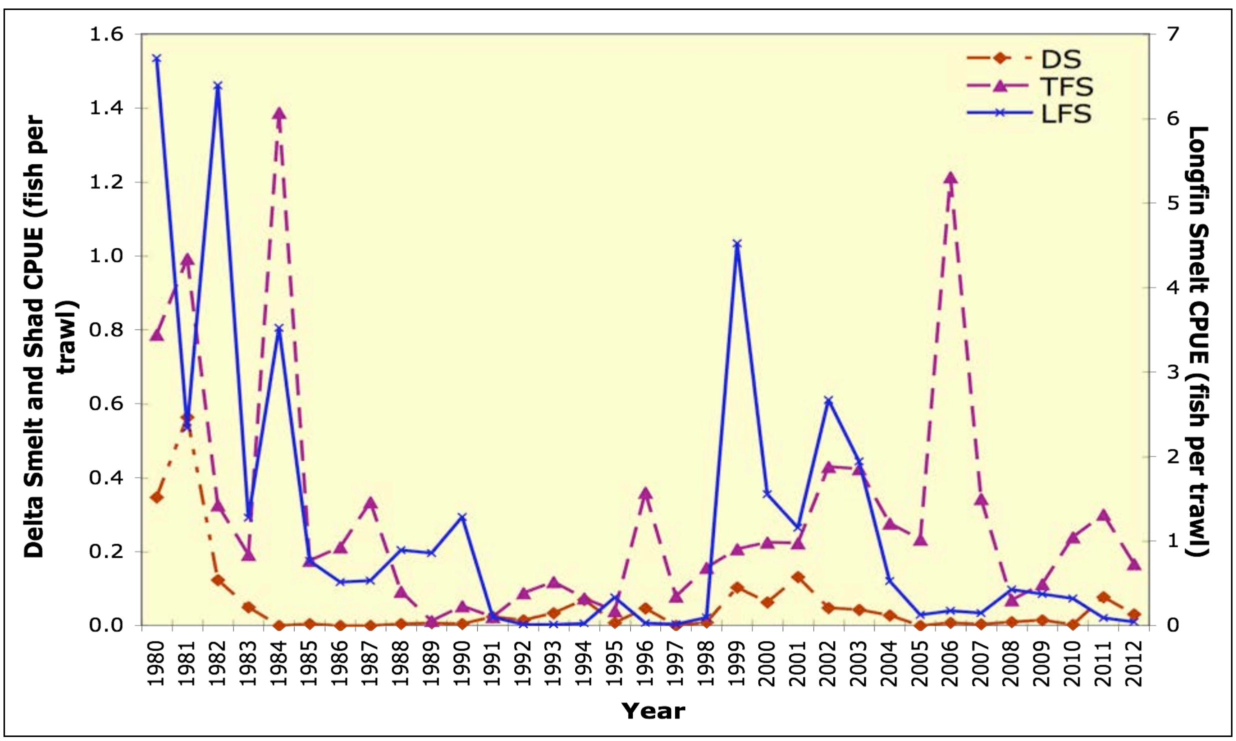

Figure 13. Annual otter trawl CPUE of three fishes of the Pelagic Organism Decline ("DS" = delta smelt, "TFS" = threadfin shad, and "LFS" = longfin smelt).

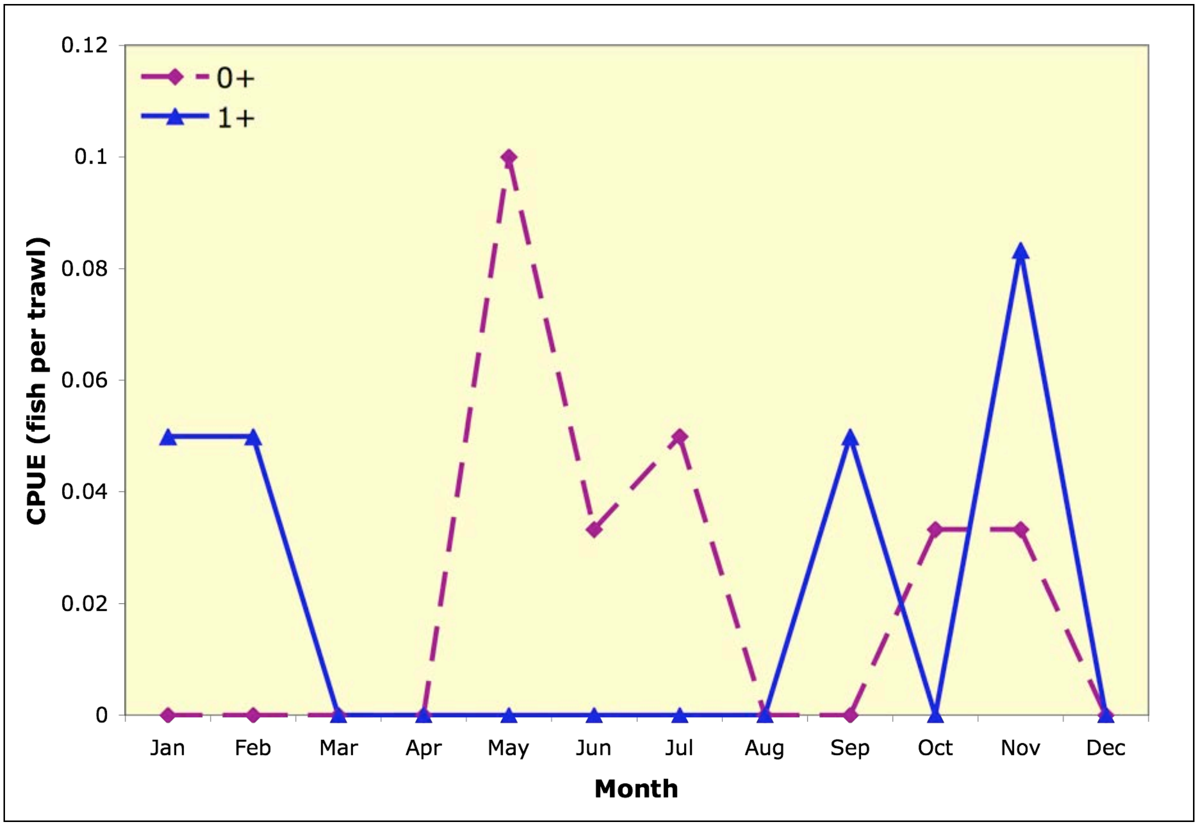

Figure 14. Monthly average otter trawl CPUE of two age classes of longfin smelt in 2012.

DELTA SMELT

Otter trawl CPUE in 2012 declined to a lower level that has been more commonly seen over the last decade than the rather high 2011 value (Figure 13). We caught seven delta smelt in the marsh during 2012, with six of the seven fish from the 2011 cohort. All of the 2011 year-class fish were caught during winter in Suisun, Nurse, and First Mallard sloughs. The one fish from the 2012 cohort was captured in December in lower Goodyear Slough.

THREADFIN SHAD

Threadfin shad numbers in 2012 were low. Both beach seine and otter trawl catches fell from 2011 to 2012, with annual CPUE values for both gear types in 2012 being well below averages for all years of the study (Table 3). All but one of the fish captured by beach seine in 2012 came from Denverton Slough, while only one fish from an otter trawl came from the saltier southwest region of the marsh. Low Delta outflow and above-average salinities in 2012 were the factors most likely responsible for the year's CPUE values. Larval abundance is higher during wetter years in the marsh (Meng and Matern 2001); beach seine CPUE is generally greater during wet years (O'Rear and Moyle 2009) and is often accompanied by a higher otter trawl CPUE (*e.g.*, 2006, 2011; Figure 13). These patterns in Suisun Marsh are consistent with those in the Delta, where both YOY and older threadfin shad are more abundant in fresher water (Feyrer *et al.* 2009, Feyrer *et al.* 2007).

Table 3. CPUE values for threadfin shad; "all years" is the average annual CPUE for 1980 - 2012.

Gear	2011	2012	All Years
otter trawl	0.3	0.2	0.3
beach seine	1.6	0.5	2.1

STRIPED BASS

Striped bass were relatively abundant in 2012, with annual beach seine and otter trawl CPUE values both above averages for all years of the study (Figure 15, Table 1 and 2). YOY striped bass were found at all sites of the marsh, but they were particularly abundant in First Mallard Slough while being sparse in Cutoff and eastern Montezuma sloughs (Figure 16). Juvenile striped bass were fairly evenly distributed throughout the marsh (Figure 16). Factors responsible for the elevated 2012 numbers include earlier recruitment coinciding with abundant food supplies, as discussed in previous sections.

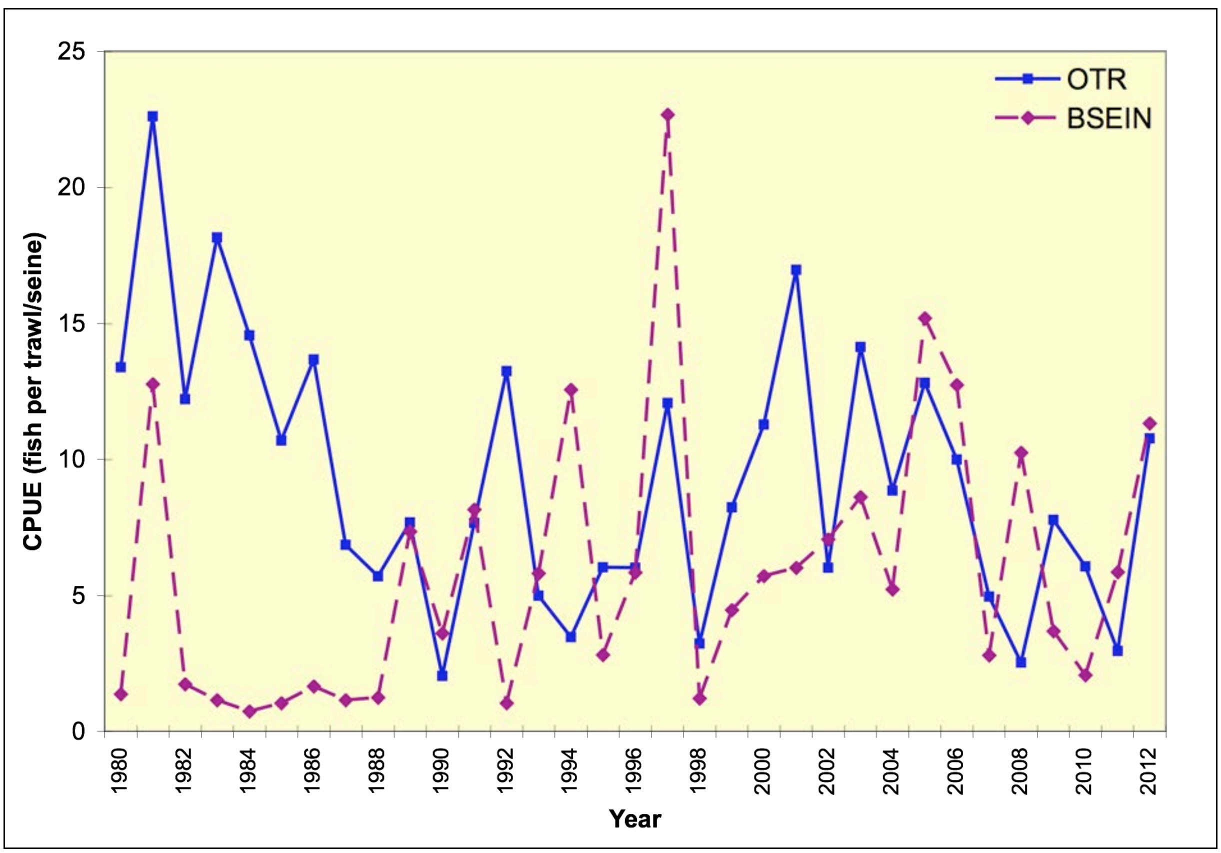

Figure 15. Annual otter trawl and beach seine CPUE of striped bass (codes as in Figure 11).

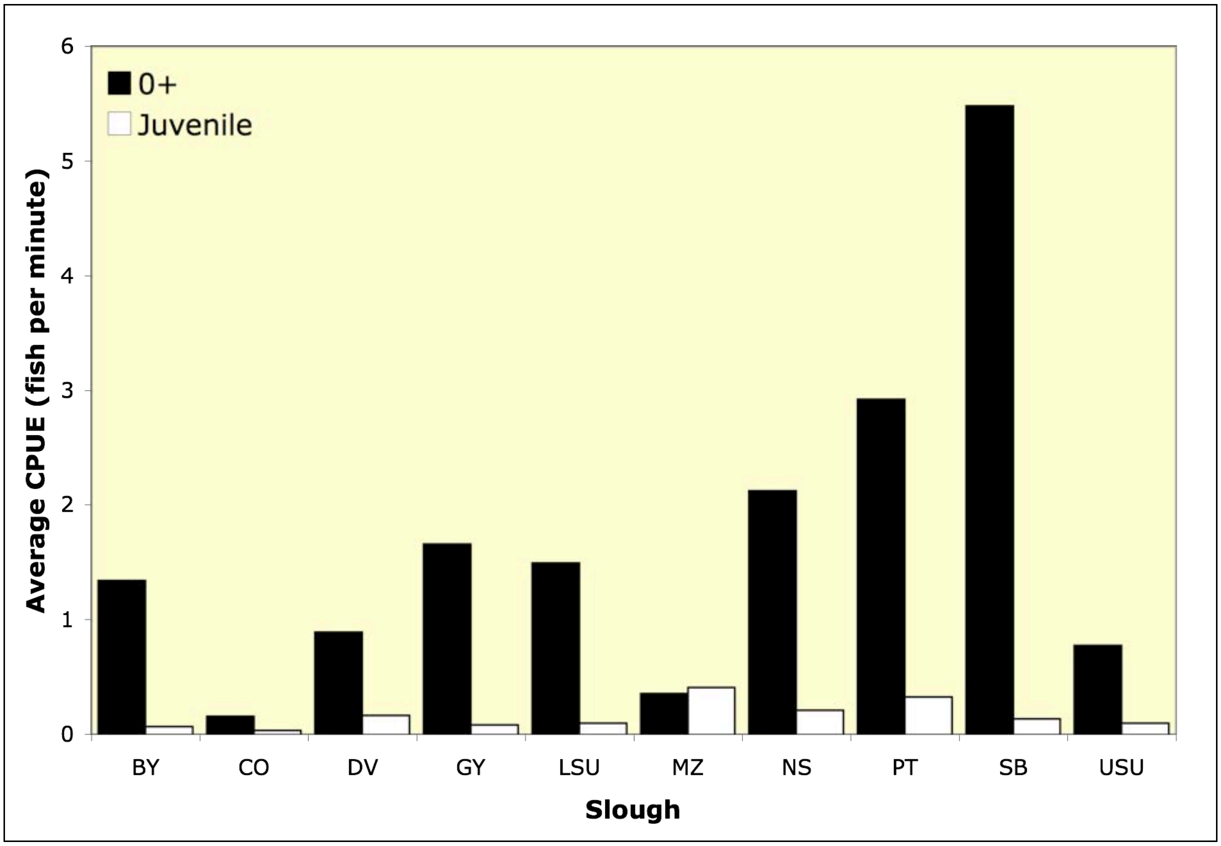

Figure 16. Average otter trawl CPUE of age classes of striped bass in 2012 ("BY" = Boynton Slough, "CO" = Cutoff Slough, "DV" = Denverton Slough, "GY" = Goodyear Slough, "LSU" = lower Suisun Slough, "MZ" = Montezuma Slough, "NS" = Nurse Slough, "PT" = Peytonia Slough, "SB" = First Mallard Slough, and "USU" = upper Suisun Slough).

Sacramento Splittail

Although recruitment of YOY Sacramento splittail in 2012 was low relative to both 2011 and the average for all years of the study (0.9, 2.3, and 1.1 fish per trawl, respectively), otter trawl CPUE of all splittail was the third highest recorded in the study's history (Figure 17). The high abundance of Sacramento splittail in 2012 was because of large numbers of fish from the 2011 year class - 2012 had the highest ever annual CPUE of 1+ fish (Figure 17). The record CPUE of 1+ fish was attributable in part to very successful reproduction and recruitment during the wet year of 2011 (Contreras *et al.* 2012, O'Rear and Moyle 2012).

Similar to previous years (*e.g.*, 2011), geographic distribution of the age classes was not uniform. YOY CPUE was highest in First Mallard Slough; decent catches were also made in Goodyear, lower Suisun, and Peytonia sloughs. Age-1+ fish were especially abundant in Peytonia Slough, although they were common throughout the marsh (Figure 18). Adult Sacramento splittail were notably more abundant in Denverton Slough than elsewhere.

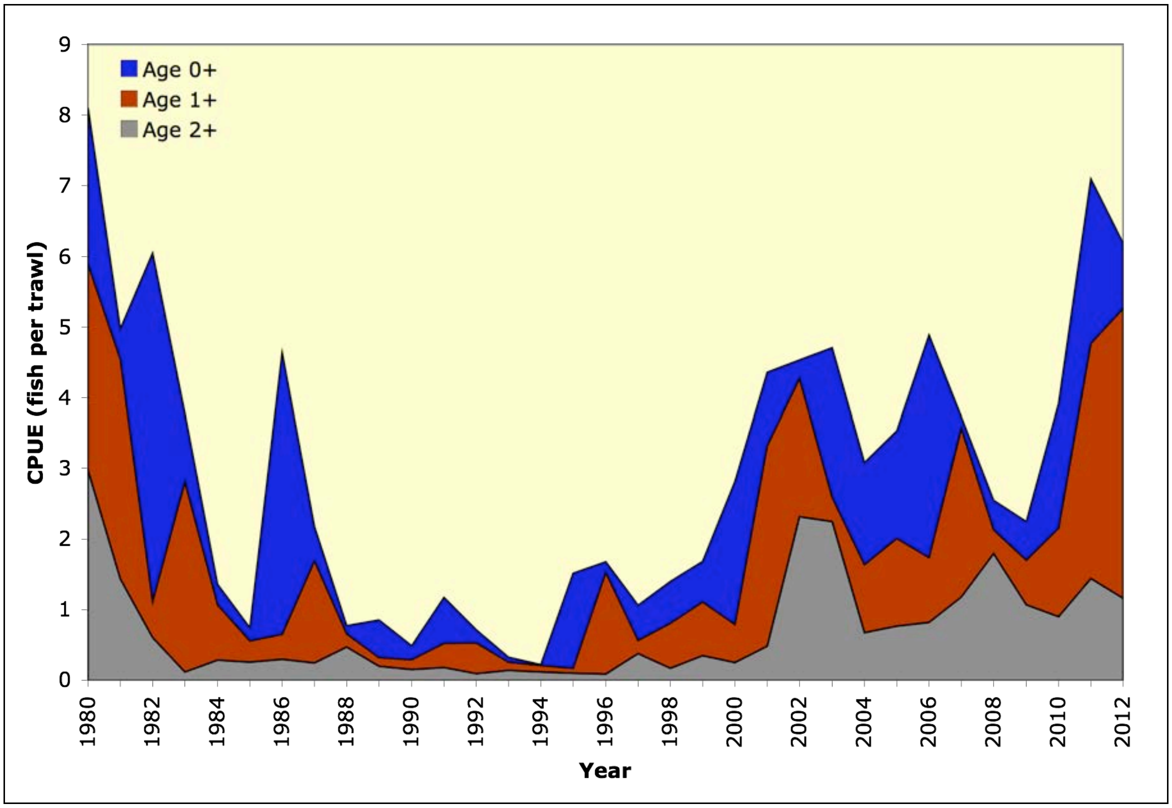

Figure 17. Annual otter trawl CPUE of three age classes of Sacramento splittail.

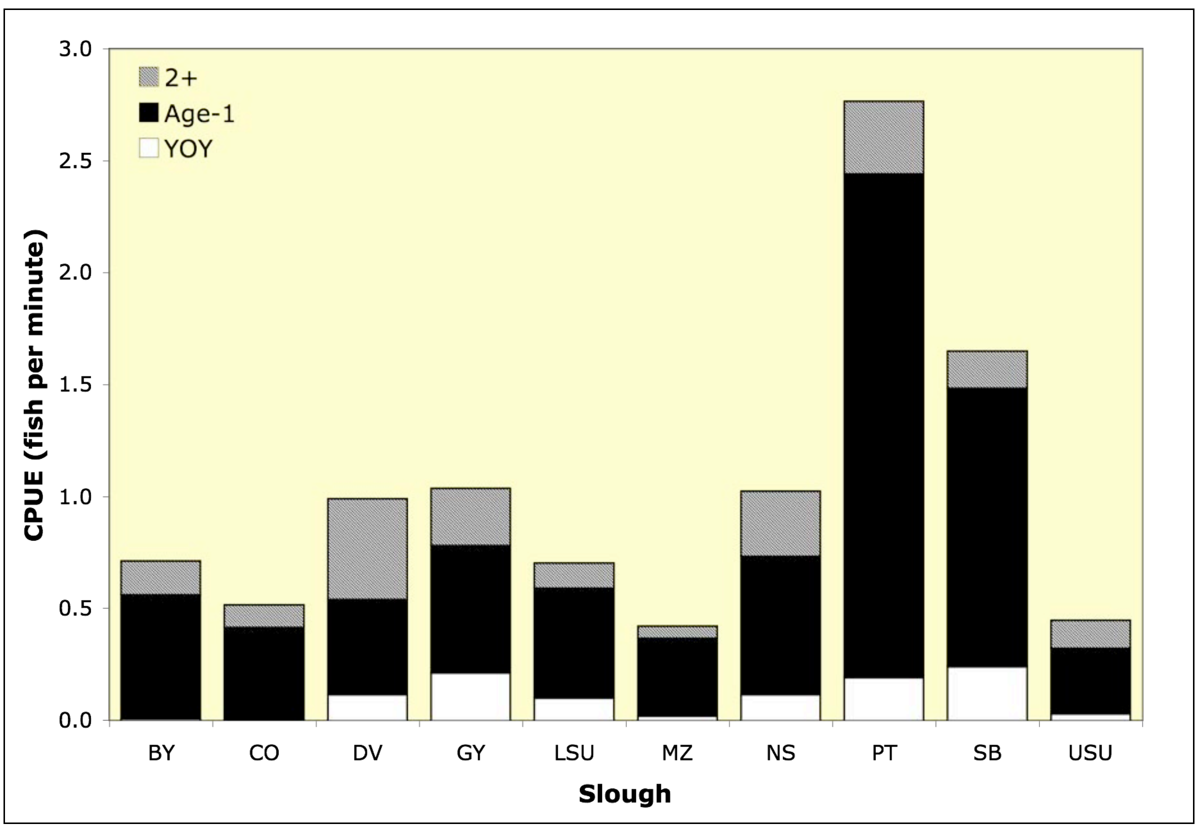

Figure 18. Average otter trawl CPUE of age classes of splittail in 2012 (codes as in Figure 16).

Other Fish Species

WHITE CATFISH

White catfish were abundant in 2012, with 2012's otter trawl CPUE the fourth highest recorded in the study's history (Figure 19). As for Sacramento splittail, the 2011 year class dominated the catch - 86% of the 2012 catch was comprised of age-1+ fish (O'Rear, unpublished data). Similar to other dry years (*e.g.*, 2008, 2010), no YOY white catfish were caught. These patterns are consistent with the white catfish's intolerance of moderate and high salinities (Allen and Avault, Jr. 1971, Kendall and Schwartz 1968).

The geographic distribution of white catfish in 2012 also reflects, in part, the effect of salinity. Only 3% of all white catfish were caught in the saltier southwestern marsh (*i.e.*, Goodyear and lower Suisun sloughs), while 63% of the year's catch came from Denverton Slough. The fresher northwestern marsh also hosted relatively high catches: 15% of the total catch came from upper Suisun Slough and 36% of the fish older than two years were caught in Boynton Slough.

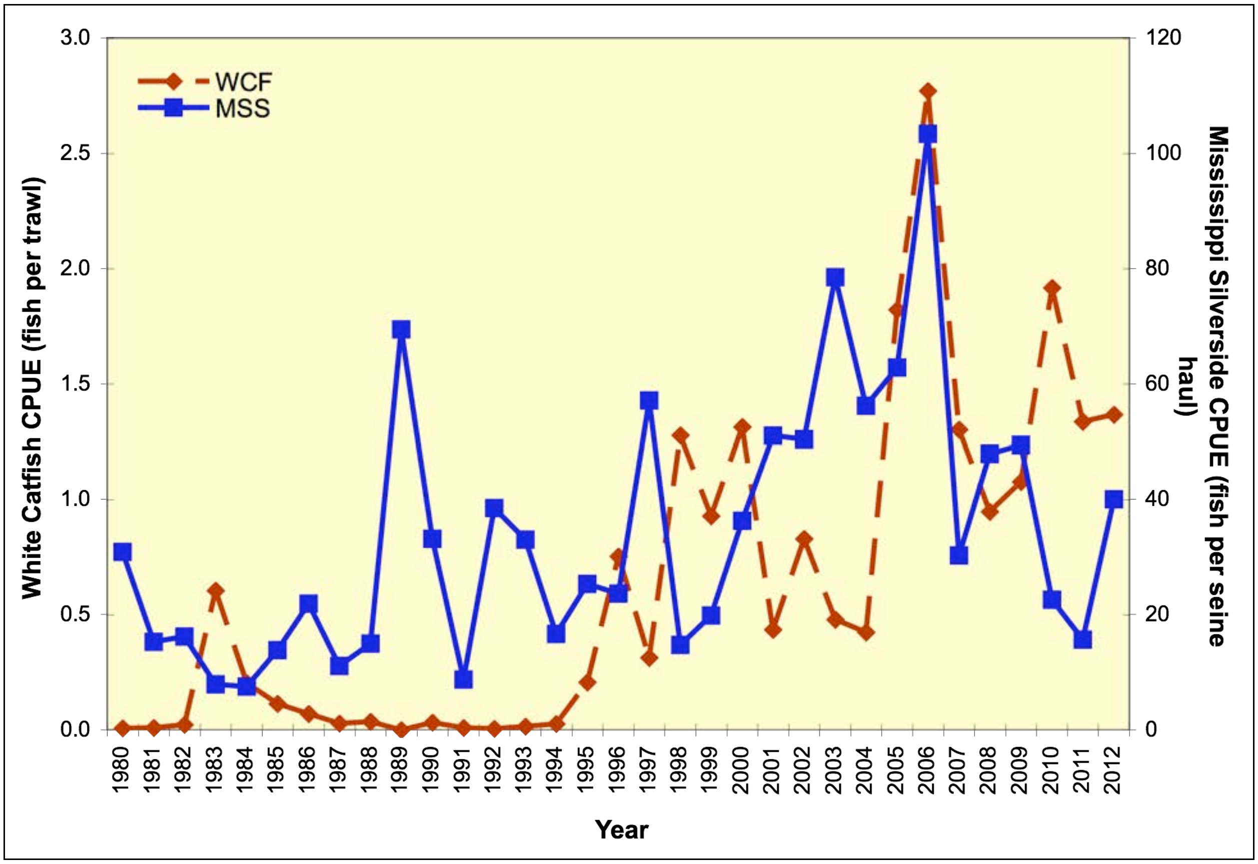

Figure 19. Annual CPUE of white catfish ("WCF") and Mississippi silverside ("MSS").

MISSISSIPPI SIVERSIDE

Mississippi silverside increased dramatically from 2011 to 2012 (Table 2), although 2012's annual beach seine CPUE was comparable to the average for all years of the study (40.1 and 34.1 fish per seine haul, respectively; Figure 19). The trend in monthly CPUE was fairly typical, with moderate catches from January to March, very low numbers during the spring months, and then much higher catches in summer and autumn (Figure 20). However, CPUE during 2012 was generally more than twice that of 2011's values for most months (O'Rear and Moyle 2012). Notably, fish about two months old (*i.e.*, fish smaller than 31 mm SL; Gleason and Bengston 1996, Hubbs 1982) were only present from July to September in 2011 (O'Rear and Moyle 2012) while being present from June to October in 2012 (Figure 20), suggesting a longer reproductive period in 2012. As previously discussed, warmer water temperatures in 2012 were likely the major reason for the increased numbers in 2012, although other factors may have also played a role. For example, endocrine-disrupting compounds have been implicated in damage to gonads of Mississippi silversides in Suisun Marsh and hence reduced reproductive output, with possible effects on population dynamics.

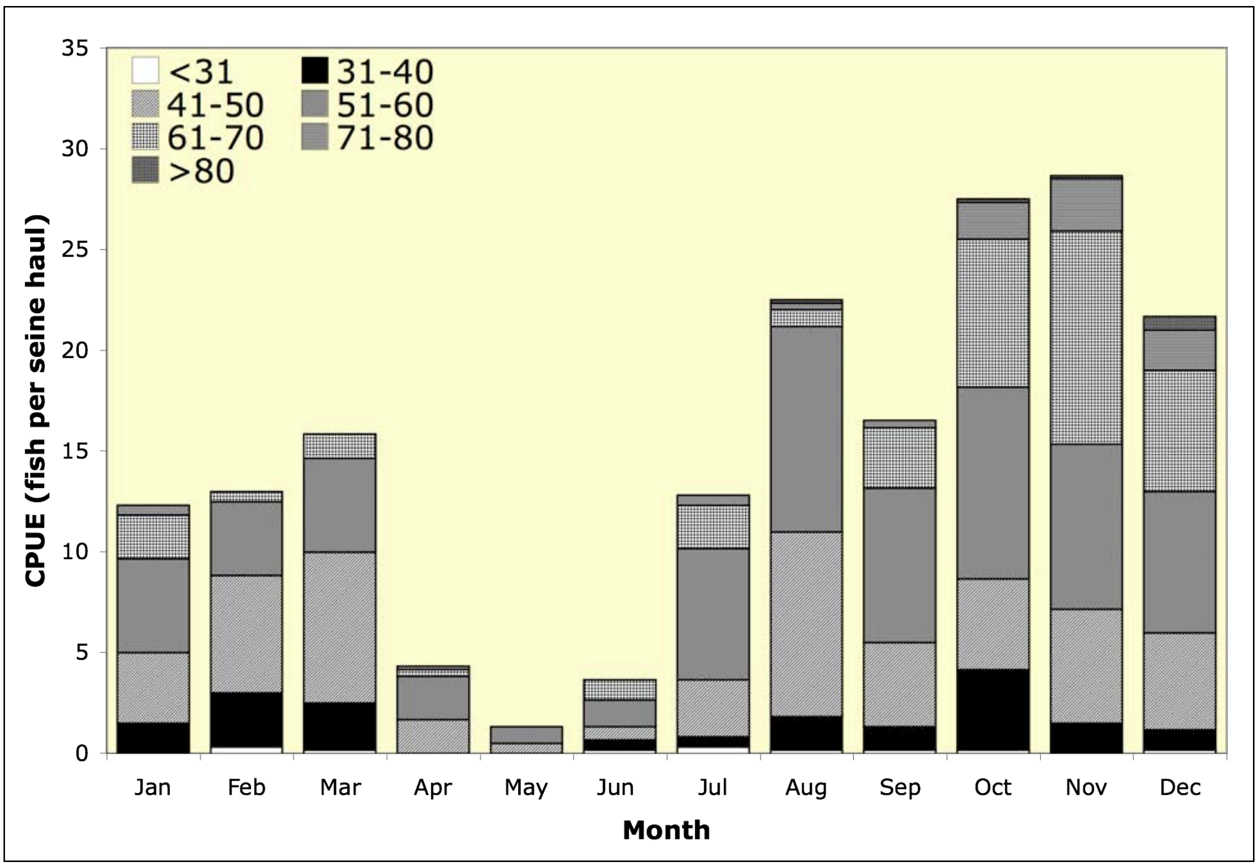

Figure 20. Monthly average beach seine CPUE of size classes (mm SL) of Mississippi silverside in 2012.

CONCLUSION

2012 was a dry year with low Delta outflow that resulted in above-average salinities in the marsh. The marsh's water was also often clearer and warmer than usual. Consequently, catches were dominated by introduced fishes and invertebrates associated with warm and/or salty conditions. Striped bass and Mississippi silverside both had a good year, and Black Sea jellyfish reached an all-time high in 2012. Conversely, native fish numbers were down, especially compared to their resurgence in 2011. The low catch of natives in 2012 was partly attributable to little recruitment of Sacramento splittail; decreased numbers of tule perch also contributed substantially to the decline of native fishes.

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REFERENCES

Allen, K. O. and J. W. Avault. 1971. Notes on the relative salinity tolerance of channel and blue catfish. Progressive Fish Culturist 33(3): 135-137.

Brander, S. M., R. E. Connon, G. He, J. A. Hobbs, K. L. Smalling, S. J. Teh, J. W. White, I. Werner, M. Denison, and G. N. Cherr. 2013. From 'omics to otoliths: responses of an estuarine fish to endocrine disrupting compounds across biological scales. Plos One 8(9): 1-15.

Conover, D. O., J.J. Brown, and A. Ehtisham. 1997. Countergradient variation in growth of young striped bass (*Morone saxatilis*) from different latitudes. Canadian Journal of Fisheries and Aquatic Sciences 54: 2401-2409.

Contreras, D., K. Osborn, R. Baxter, and S. Slater. 2012. 2011 status and trends report for pelagic fishes of the upper San Francisco Estuary. Interagency Ecological Program Newsletter 25: 22-35.

DWR. 2013*a*. Interagency ecological program. Available: www.iep.water.ca.gov (January 2013).

DWR. 2013*b*. California Data Exchange Center. Available: http://cdec.water.ca.gov/cgiprogs/stationInfo?station_id=LIS (March 2013).

DWR. 2013*c*. California Data Exchange Center. Available: http://cdec.water.ca.gov/cgiprogs/stationInfo?station_id=FPT (March 2013).

DWR. 2012*a*. California monthly climate summary January 2012. California, California Department of Water Resources.

DWR. 2012*b*. California monthly climate summary April 2012. California, California Department of Water Resources.

DWR. 2001. Comprehensive Review Suisun Marsh Monitoring Data 1985-1995. California, California Department of Water Resources.

Emmett, R. L., S. A. Hinton, D. J. Logan, and G. T. McCabe, Jr. 2002. Introduction of a Siberian freshwater shrimp to western North America. Biological Invasions 4: 447-450.

Feyrer, F., B. Herbold, S. A. Matern, and P. B. Moyle. 2003. Dietary shifts in a stressed fish assemblage: consequences of a bivalve invasion in the San Francisco Estuary. Environmental Biology of Fishes 67: 277-288.

Feyrer, F., M. L. Nobriga, and T. R. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734.

Feyrer, F. T. Sommer, and S. B. Slater. 2009. Old school vs. new school: status of threadfin shad (*Dorosoma petenense*) five decades after its introduction to the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 7(1).

Feyrer, F., T. Sommer, and W. Harrell. 2006. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. Hydrobiologia 573: 213-226.

Gleason, T. R., and D. A. Bengston. 1996. Size-selective mortality in inland silversides: evidence from otolith microstructure. Transactions of the American Fisheries Society 125: 860-873.

Hatfield, S. 1985. Seasonal and interannual variation in distribution and population abundance of the shrimp *Crangon franciscorum* in San Francisco Bay. Hydrobiologia 129: 199-210.

Hill, J., J.W. Evans, and M.J. Van Den Avyle. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)-- striped bass. U.S. Fish Wildl. Sew. Biol. Rep. 82 (11.118). U.S. Army Corps of Engineers TR EL-82-4. 35 pp.

Hubbs, C. 1982. Life history dynamics of *Menidia beryllina* from Lake Texoma. American Midland Naturalist 107(1): 1-12.

Hubbs, C., H. Sharp, and J. F. Schneider. 1971. Developmental rates of *Menidia audens* with notes on salinity tolerance. Transactions of the American Fisheries Society 100: 603-610.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinksi. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5: 272-289.

Kendall, A. W., and F. J. Schwatz. 1968. Lethal temperature and salinity tolerances of the white catfish, *Ictalurus catus*, from the Patuxent River, Maryland. Chesapeake Science 9: 103-108.

Lam, T. J., and R. Sharma. 1985. Effects of salinity and thyroxine on larval survival, growth, and development in the carp, *Cyprinus carpio*. Aquaculture 44: 201-212.

Liu, J., A. Tatarenkov, T. A. O'Rear, P. B. Moyle, and J. C. Avise. 2012. Molecular evidence for multiple paternity in a population of the viviparous tule perch *Hysterocarpus traski*. Journal of Heredity 104: 217-222.

Matern, S. A., P. B. Moyle, and L. C. Pierce. 2002. Native and alien fishes in a California estuarine marsh: twenty-one years of changing assemblages. Transactions of the American Fisheries Society 131: 797-816.

Meek, M., A. Wintzer, N. Sheperd, and B. May. 2012. Genetic diversity and reproductive mode in two non-native hydromedusae, *Maeotias marginata* and *Moerisia* sp., in the Upper San Francisco Estuary, California. Biological Invasions. 15(1): 199-212.

Meng, L., and S. A. Matern. 2001. Native and alien larval fishes of Suisun Marsh, California: the effects of freshwater flow. Transactions of the American Fisheries Society 130: 750-765.

Meng, L., P. B. Moyle, and B. Herbold. 1994. Changes in abundance and distribution of native and alien fishes of Suisun Marsh. Transactions of the American Fisheries Society 123: 498-507.

Middaugh, D. P., and M. J. Hemmer. 1992. Reproductive ecology of the inland silverside, *Menidia beryllina*, (Pisces: Atherinidae) from Blackwater Bay, Florida. Copeia 1:53-61.

Miller, E. E. 1966. White catfish. Pages 430-440 *in* A. Calhoun, ed. Inland fisheries management. Sacramento, California Department of Fish and Game.

Moyle, P. B. 2002. Inland Fishes of California. California, University of California Press.

Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and population dynamics of Sacramento splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science 2(2): Article 3.

Moyle, P. B., R. A. Daniels, B. Herbold, and D. M. Baltz. 1986. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. U. S. National Marine Fisheries Service Fishery Bulletin 84(1): 105-117.

Nicolini, M. H., and D. L. Penry. 2000. Spawning, fertilization, and larval development of *Potamocorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. Pacific Science 54: 377-388.

Nobriga, M. L., T. R. Sommer, F. Feyrer, and K. Fleming. 2008. Long-term trends in summertime habitat suitability for delta smelt (*Hypomesus transpacificus*). San Francisco Estuary and Watershed Science 6(1): Article 1.

Oh, C., H. Suh, K. Park, C. Ma, and H. Lim. 2002. Growth and reproductive biology of the freshwater shrimp *Exopalaemon modestus* in a lake of Korea. Journal of Crustacean Biology 22: 357-366.

O'Rear, T. A. 2012. Diet of an introduced estuarine population of white catfish in California. Master's thesis. University of California, Davis.

O'Rear, T. A., and P. B. Moyle. 2012. Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2011 - December 2011. California, California Department of Water Resources.

O'Rear, T. A., and P. B. Moyle. 2013*a*. Suisun Marsh Fish Study: trends in fish and invertebrate populations of Suisun Marsh January 2010 - December 2010. California, California Department of Water Resources.

O'Rear, T. A., and P. B. Moyle. 2013*b*. Trends in fish and invertebrate populations of Suisun Marsh January 2009 - December 2009. California, California Department of Water Resources.

O'Rear, T. A., and P. B. Moyle. 2010. Long term and recent trends of fishes and invertebrates in Suisun Marsh. Interagency Ecological Program Newsletter 23(2): 26-48

O'Rear, T. A., and P. B. Moyle. 2009. Trends in Fish Populations of Suisun Marsh January 2008 - December 2008. California, California Department of Water Resources.

O'Rear, T. A., and P. B. Moyle. 2008. Trends in Fish Populations of Suisun Marsh January 2006 - December 2007. California, California Department of Water Resources.

Rosenfield, J. A., and R. D. Baxter. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. Transactions of the American Fisheries Society 136: 1577-1592.

Schroeter, R. E. 2011. The temporal and spatial trends, biological constraints, and impacts of an invasive clam, *Corbula amurensis*, in Suisun Marsh, San Francisco Estuary. California, University of California.

Schroeter, R. E. 2008. Biology and long-term trends of alien hydromedusae and striped bass in a brackish tidal marsh in the San Francisco Estuary. Doctoral dissertation. University of California, Davis.

Schroeter, R. E., and P. B. Moyle. 2004. Dissolved oxygen sags in Suisun Marsh, 2004. California, University of California, Davis.

Schroeter, R., A. Stover, and P. B. Moyle. 2006. Trends in Fish Populations of Suisun Marsh January 2005 - December 2005. California, California Department of Water Resources.

Siegel, S., P. Bachand, D. Gillenwater, S. Chappel, B. Wickland, O. Rocha, M. Stephenson, W. Heim, C. Enright, P. Moyle, P. Crain, B. Downing, and B. Bergamaschi. 2011. Final evaluation memorandum, strategies for reducing low dissolved oxygen and methylmercury events in northern Suisun Marsh. Prepared for the State Water Resources Control Board, Sacramento, California. SWRCB Project Number 06-283-552-0.

Siegfried, C. A. 1980. Seasonal abundance and distribution of *Crangon franciscorum* and *Palaemon macrodactylus* (Decapoda, Caridea) in the San Francisco Bay-Delta. Biological Bulletin 159: 177-192.

Smith, B. B., and K. F. Walker. 2004. Spawning dynamics of common carp in the River Murray, South Australia, shown by macroscopic and histological staging of gonads. Journal of Fish Biology 64: 336-354.

Sommer, T., R. Baxter, and B. Herbold. 1997. Resilience of splittail in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 126: 961-976.

Sommer, T. R., W. C. Harrell, Z. Matica, and F. Feyrer. 2008. Habitat associations and behavior of adult and juvenile splittail (Cyprinidae: *Pogonichthys macrolepidotus*) in a managed seasonal floodplain wetland. San Francisco Estuary and Watershed Science 6(2): Article 3.

Sommer, T. R., W. C. Harrell, A. Mueller-Solger, B. Tom, and W. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 14: 247-261.

Sommer, T. R., F. Mejia, K. Hieb, R. Baxter, E. Loboschefsky, and F. Loge. 2011. Long-term shifts in the lateral distribution of age-0 striped bass in the San Francisco Estuary. Transactions of the American Fisheries Society 140: 1451-1459.

Stoeckel, J. N., and R. C. Heidinger. 1988. Overwintering of the inland silverside in southern Illinois. North American Journal of Fisheries Management 8: 127-131.

Vincik, R. F. 2002. Adult Chinook salmon migration monitoring at the Suisun Marsh Salinity Control Gates, Sept. - Nov. 2001. Interagency Ecological Program Newsletter 15(2): 45-48.

Wintzer, A.P., M. H. Meek, and P. B. Moyle. 2011*a*. Life history and population dynamics of *Moerisia* sp., a non-native hydrozoan, in the upper San Francisco Estuary (U.S.A.). Estuarine and Coastal Shelf Science 94: 48-55.

Wintzer, A.P., M.H. Meek, and P. B. Moyle. 2011*b*. Trophic ecology of two non-native hydrozoan medusae in the upper San Francisco Estuary. Marine and Freshwater Research 62: 952–961.

Wintzer, A., M. Meek, P. Moyle, and B. May. 2011*c*. Ecological insights into the polyp stage of non-native hydrozoans in the San Francisco Estuary. Aquatic Ecology 5(2): 151-161.

Xu, J., M. Zhang, and P. Xie. 2008. Stable isotope changes in freshwater shrimps (*Exopalaemon modestus* and *Macrobrachium nipponensis*): trophic pattern implications. Hydrobiologia 605: 45-54.

APPENDIX A

Total number of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all methods from 1979 to 2012 (native species in bold).

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
American shad	*Alosa sapidissima*	1126	246		1372
bay pipefish	***Sygnathus leptorhynchus***	**2**			**2**
bigscale logperch	*Percina macrolepida*	17	2		19
black bullhead	*Ameiurus melas*	875	3		878
black crappie	*Pomoxis nigromaculatus*	1816	90	1	1907
bluegill	*Lepomis macrochirus*	19	18		37
brown bullhead	*Ameiurus nebulosus*	28			28
California halibut	***Paralichthys californicus***	**5**			**5**
channel catfish	*Ictalurus punctatus*	174	7		181
Chinook salmon	***Oncorhynchus tshawytscha***	**72**	**388**	**1**	**461**
common carp	*Cyprinus carpio*	4951	448	1	5400
delta smelt	***Hypomesus transpacificus***	**654**	**138**	**4**	**796**
fathead minnow	*Pimephales promelas*	36	38		74
golden shiner	*Notemigonus crysoleucas*	6	4		10
goldfish	*Carassius auratus*	297	47		344
green sturgeon	***Acipenser medirostris***	**3**			**3**
green sunfish	*Lepomis cyanellus*	5	3		8
hardhead	***Mylopharadon conocephalus***	**1**			**1**
hitch	***Lavinia exilicauda***	**120**	**16**		**136**
largemouth bass	*Micropterus salmoides*		1		1
longfin smelt	***Spirinchus thaleichthys***	**11394**	**51**	**5**	**11450**
longjaw mudsucker	***Gillichthys mirabilis***	**1**			**1**
Mississippi silverside	*Menidia audens*	665	77651		78316
northern anchovy	***Engraulis mordax***	**258**		**37**	**295**
Pacific herring	***Clupea harengeus***	**467**	**116**		**583**
Pacific lamprey	***Lampetra tridentata***	**43**			**43**
Pacific sanddab	***Citharichthys sordidas***	**3**	**2**		**5**
plainfin midshipman	***Porichthys notatus***	**11**			**11**
prickly sculpin	***Cottus asper***	**10447**	**914**	**1**	**11362**
rainbow trout	***Oncorhynchus mykiss***	**8**	**4**		**12**
rainwater killifish	*Lucania parva*	32	94		126
redear sunfish	*Lepomis microlophus*	2	1		3
river lamprey	***Lampetra ayresi***	**3**			**3**
Sacramento blackfish	***Orthodon macrolepidotus***	**24**	**116**		**140**
Sacramento pikeminnow	***Ptychocheilus grandis***	**147**	**227**		**374**
Sacramento splittail	***Pogonichthys macrolepidotus***	**25890**	**3225**	**14**	**29129**
Sacramento sucker	***Catostomus occidentalis***	**3280**	**112**	**5**	**3397**

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	Total
shimofuri goby	*Tridentiger bifasciatus*	9827	2186	1	12014
shiner perch	***Cymatogaster aggregata***	**17**			**17**
shokihaze goby	*Tridentiger barbatus*	709	2	6	717
speckled sanddab	***Citharichthys stigmaeus***	**3**			**3**
staghorn sculpin	***Leptocottus armatus***	**2516**	**3314**		**5830**
starry flounder	***Platichthys stellatus***	**1984**	**260**	**4**	**2248**
striped bass	*Morone saxatilis*	82972	13362	30	96364
surf smelt	***Hypomesus pretiosus***	**5**			**5**
threadfin shad	*Dorosoma petenense*	2715	5147	1	7863
threespine stickleback	***Gasterosteus aculeatus***	**17177**	**5379**	**6**	**22562**
tule perch	***Hysterocarpus traski***	**18684**	**1987**	**6**	**20677**
wakasagi	*Hypomesus nipponensis*	10	6		16
warmouth	*Lepomis gulosus*	1			1
western mosquitofish	*Gambusia affinis*	18	338		356
white catfish	*Ameiurus catus*	5276	163	13	5452
white crappie	*Pomoxis annularis*	112			112
white croaker	***Genyonemus lineatus***	**1**			**1**
white sturgeon	***Acipenser transmontanus***	**113**		**2**	**115**
yellowfin goby	*Acanthogobius flavimanus*	19439	15812		35251
Total		224461	131918	138	356517

APPENDIX B

Total 2012 otter trawl catch of each fish species in each slough of Suisun Marsh (native species in bold).

Species	Slough										Total
	Boynton	Cutoff	Denverton	Goodyear	lower Suisun	Montezuma	Nurse	Peytonia	First Mallard	upper Suisun	
American shad	1			5	4	18	1	7	3	2	41
black bullhead	4		2					4			10
black crappie			18				3	1			22
channel catfish			2			3				2	7
common carp	13	6	27	29	33	11	5	1	6	6	137
delta smelt				**1**	**3**		**3**		**1**		**8**
golden shiner								1			1
goldfish				1				1			2
hitch							**1**				**1**
longfin smelt	**2**			**1**	**6**	**2**					**11**
Mississippi silverside							1				1
northern anchovy									**1**		**1**
Pacific herring					**1**		**1**				**2**
prickly sculpin	**23**	**16**	**43**	**89**	**27**	**7**	**7**	**23**	**8**	**4**	**247**
rainwater killifish				1							1
Sacramento pikeminnow								**1**			**1**
Sacramento splittail	**85**	**62**	**119**	**186**	**169**	**117**	**123**	**351**	**198**	**107**	**1517**
Sacramento sucker	**6**	**4**	**5**	**4**	**1**		**1**	**32**	**8**		**61**
shimofuri goby	9	7	47	4	2	42	9	9	7	17	153
shokihaze goby	3		3		16	7	17	1		46	93
speckled sanddab					**1**						**1**
staghorn sculpin	**3**	**5**	**3**	**23**	**37**	**6**	**1**	**4**	**8**	**11**	**101**
starry flounder			**4**	**1**	**15**	**5**	**5**			**5**	**35**
striped bass	168	23	127	313	382	193	281	390	674	208	2759
threadfin shad		1			1	15	10	15	1		43

Species	Slough										Total
	Boynton	Cutoff	Denverton	Goodyear	lower Suisun	Montezuma	Nurse	Peytonia	First Mallard	upper Suisun	
threespine stickleback	**1**		**4**	**41**	**2**	**1**	**4**	**3**	**3**	**2**	**61**
tule perch	**25**	**12**	**40**	**4**	**50**	**11**	**43**	**24**	**9**	**9**	**227**
white catfish	19	7	220	7	3	23	8	9	1	53	350
white sturgeon					**1**					**4**	**5**
yellowfin goby	7	10	4	17	49	19	6	8	14	28	162
Total	369	153	668	727	803	480	530	885	942	504	6061

Total 2012 beach seine catch of each fish species in Denverton, Montezuma, and upper Suisun sloughs (native species are in bold).

Species	Slough			Total
	Denverton	Montezuma	upper Suisun	
American shad	2			3
black crappie	8			8
channel catfish	1			1
Chinook salmon	**1**			**1**
common carp	14		2	16
delta smelt			**1**	**1**
golden shiner			1	1
goldfish	4			4
longfin smelt	**1**			**1**
Mississippi silverside	1644	813	628	3085
prickly sculpin	**3**		**3**	**6**
Sacramento splittail	**88**		**83**	**171**
Sacramento sucker	**1**	**4**	**2**	**7**
shimofuri goby	14		4	18
staghorn sculpin	**6**		**48**	**54**
striped bass	502		371	873
threadfin shad	16	18	1	35
threespine stickleback	**15**		**6**	**21**
tule perch	**5**		**27**	**32**
western mosquitofish	1		2	3
white catfish	47			47
yellowfin goby	18	4	137	159
Total	2391	839	1316	4547

APPENDIX C

Number of otter trawls in each slough and each month in 2012.

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Boynton	2	2	2	2	2	2	2	2	2	2	2	2	24
Cutoff	2	2	2	2	2	2	2	2	2	2	2	2	24
Denverton	2	2	2	2	2	2	2	2	2	2	2	2	24
First Mallard	2	2	2	2	2	2	2	2	2	2	2	2	24
Goodyear	3	3	3	3	3	3	3	3	3	3	3	3	36
lower Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma	2	2	2	2	2	2	2	2	2	2	4	4	28
Nurse	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
upper Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Total	21	21	21	21	21	21	21	21	21	21	23	23	256

Number of beach seines in each slough and each month in 2012.

Slough	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Denverton	3	3	3	3	3	3	3	3	3	3	2	3	35
Montezuma											3	3	6
upper Suisun	3	3	3	3	3	3	3	3	3	3	3	3	36
Total	6	6	6	6	6	6	6	6	6	6	8	9	77