## Title
Trends in fish and invertebrate populations of Suisun Marsh January 2009 - December 2009.



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# Trends in Fish and Invertebrate Populations of Suisun Marsh
## January 2009 - December 2009

**Annual Report for the**
**California Department of Water Resources**
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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 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, especially in relation to water management activities.

In 2009, 256 otter trawls and 75 beach seines were conducted. Relative to 2008, three of four plankton-feeding macroinvertebrates increased in otter trawls. Fishes were more abundant in otter trawls yet less abundant in beach seines from 2008 to 2009; these differences were mainly due to abundance changes in introduced fishes that have pelagic larvae during late spring [e.g., striped bass (*Morone saxatilis*), yellowfin goby (*Acanthogobius flavimanus*)]. However, annual otter trawl catch per unit effort was below the average for the entire study period (16.5 and 25.5 fish per trawl, respectively). Otter trawl catch of threadfin shad (*Dorosoma petenense*), Delta smelt (*Hypomesus transpacificus*), and longfin smelt (*Spirinchus thaleichthyes*) was low, which was consistent with the dry year and low numbers recorded in other regions of the estuary (Fish et al. 2009). These catch patterns are consistent with greater recruitment due to larger and more variable Delta outflows in spring, coupled with somewhat more abundant pelagic food supplies compared to 2008.

In October 2009, anoxic conditions in Goodyear Slough likely killed several species of fish including splittail (*Pogonichthys macrolepidotus*), striped bass, and threespine stickleback (*Gasterosteus aculeatus*). This fish kill further highlights the importance of dissolved oxygen in the ecology of fishes in the marsh.

The key findings of 2009 include the following:

- Higher and more variable Delta outflows during late spring increased recruitment of fishes with pelagic larvae into the marsh.
- Greater otter trawl catches of both fish and plankton-feeding invertebrates, coupled with lower beach seine catches, suggest that pelagic food supplies were higher (albeit still low) in 2009 than in 2008.
- Anoxic events can render regions of the marsh fishless through direct mortality.
- The marsh continues to be an important habitat in the San Francisco Estuary for desirable fishes such as splittail, striped bass, and tule perch (*Hysterocarpus traski*).

# INTRODUCTION

Suisun Marsh is a brackish-water marsh bordering the northern edge of Suisun Bay in the San Francisco Estuary; 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 tidally influenced sloughs (California Department of Water Resources 2001). The marsh's central location in the San Francisco Estuary makes it an important rearing area for euryhaline freshwater, estuarine, and marine fishes.

The University of California, Davis, Suisun Marsh Fish Study was initiated in 1979 to monitor the abundance and distribution of fishes in relation to each other, to environmental variables, and to water management activities (e.g., water exports). Additionally, a major purpose has been to evaluate the effects on fishes of the Suisun Marsh Salinity Control Gates, which began operating in 1988 (California Department of Water Resources 2001). The study has used two primary methods for sampling fishes: beach seines and otter trawls. Juveniles and adults of all species have been surveyed since the beginning of the study; between 1994 and 2002, larval fishes were also surveyed to better understand their ecology in the marsh.

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 year-classes early in the study period, which was followed by both extremely high river discharges 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.

This report updates the results of the previous Suisun Marsh Fish Study report (O'Rear and Moyle 2009), which explored the composition of the fish community in four regions of the marsh through the year and the ecology of important fishes and invertebrates.

# OBJECTIVES

The objectives of the Suisun Marsh fish study are to (1) understand factors determining the abundance, distribution, and community structure of introduced and native fishes, especially in relation to environmental variables; (2) examine long-term changes in the Suisun Marsh ecosystem in relation to other changes in the San Francisco Estuary; (3) monitor the effects of water management operations and associated infrastructure (e.g., the Suisun Marsh Salinity Control Gates) on marsh fishes; and (4) contribute to understanding of the life history and ecology of key species in the marsh. Secondary goals of the project include training undergraduate and graduate students in estuarine studies and fish sampling; providing a venue for managers and biologists interested in the marsh to experience it firsthand; supporting studies by other investigators through special collections; providing background information for in-depth studies of other aspects of the Suisun Marsh aquatic system (e.g., studies of jellyfish biology); and contributing to the general understanding of estuarine systems through publication of peer-reviewed papers. In 2009, 16 undergraduate students, five graduate students, three environmental management workers, and one principal investigator assisted in trawling and seining for fishes.

## STUDY AREA

Suisun Marsh is a tidal brackish-water marsh covering about 34,000 hectares (California Department of Water Resources 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 (California Department of Water Resources 2001). The marsh is contiguous with the northern boundary of Suisun Bay and is central to the San Francisco Estuary (Figure 1).

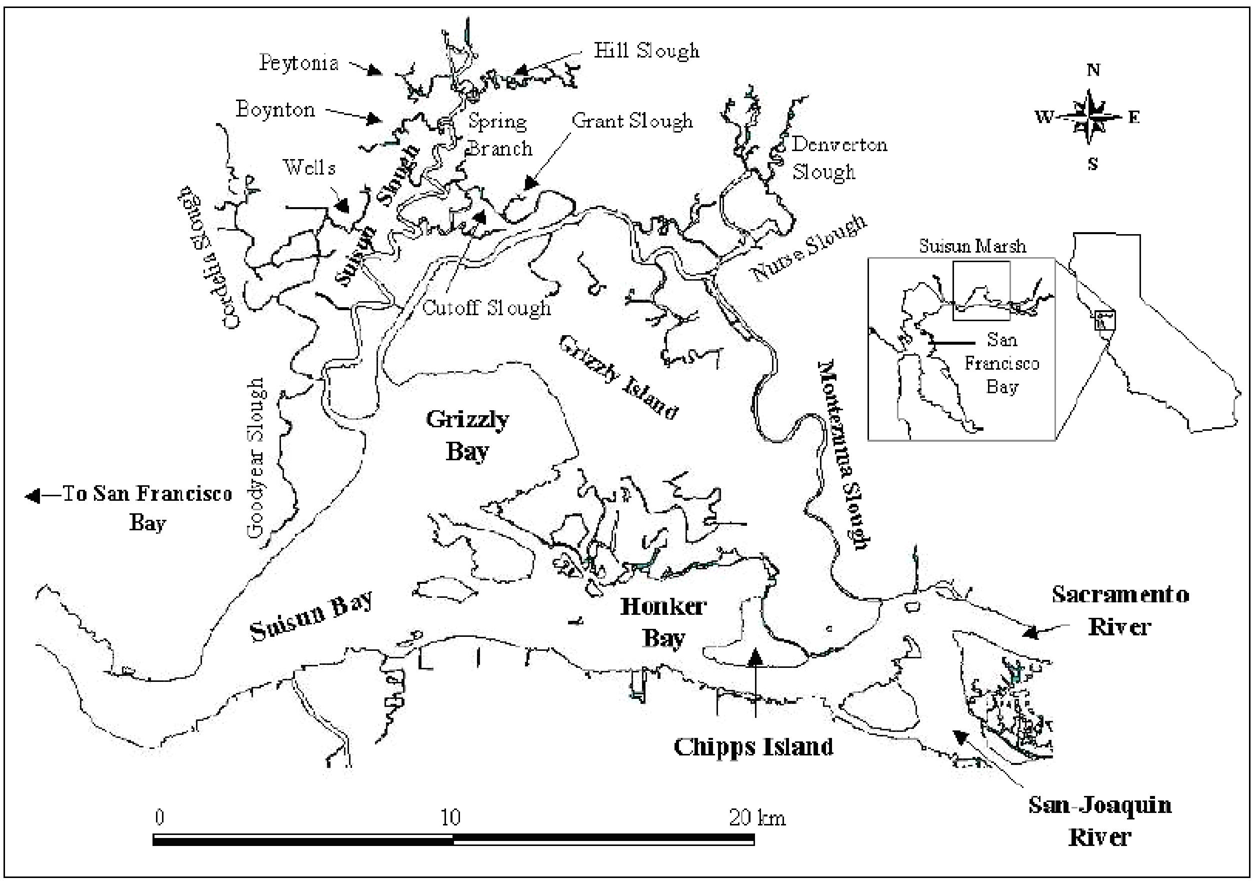


**Figure 1.** Suisun Marsh and Bay (from Schroeter et al. 2006).

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 Hunters Cut connect Suisun and Montezuma sloughs (Figure 1). Suisun Slough begins near Suisun City and trends 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.nerrs.noaa.gov/SanFrancisco/welcome.html).

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 communis*) 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. Fresh water enters the marsh primarily from the Sacramento River through Montezuma Slough, although small creeks, particularly on the north and west sides 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 runoff and snowmelt in the Sacramento and San Joaquin hydrologic regions; consequently, marsh salinities are often lowest in these seasons. Salt water enters the marsh through lower Suisun and 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 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, which are 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 (California Department of Water Resources 2001; Figure 1). Numerous diversion intakes, most of which are unscreened for fish, are located throughout the marsh; they are most commonly operated in early autumn for flooding wetlands to attract wintering waterfowl. Wetlands are usually drained in early spring, with drainage water being discharged directly into numerous sloughs within the marsh. 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.

## METHODS

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 ($\pm$ 100 m) using a Global Positioning System receiver and are found in Schroeter et al. (2006).

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 mm stretch in the body and 6 mm stretch in the cod end.

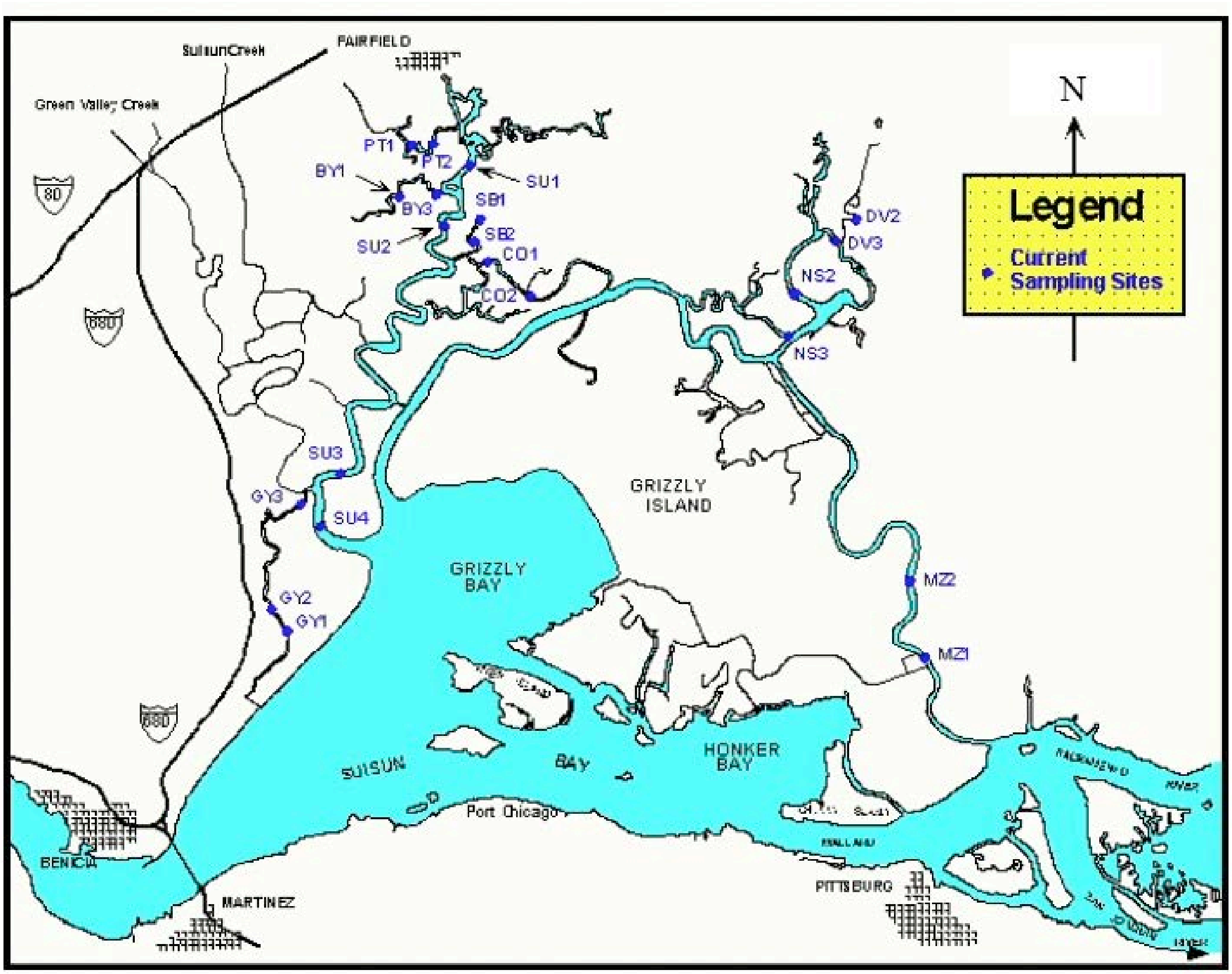


**Figure 2.** Map of current Suisun Marsh sampling sites (from Schroeter et al. 2006).

The otter trawl was towed at approximately 4 km/hr for 5 minutes in small sloughs and 10 minutes in large sloughs to compensate for small catches. In upper Suisun and Denverton sloughs, monthly sampling was augmented 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 either a Yellow Springs Instruments (YSI) 85 or 95 meter. Dissolved oxygen parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also measured with the YSI 95. 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 millimeter 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 (*Maeotias marginata)*, Oriental shrimp (*Palaemon macrodactylus*), California bay shrimp (*Crangon franciscorum*), overbite clam (*Corbula amurensis*), 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. Shrimp from the family Mysidae were pooled into one category, "mysids," and given an abundance ranking: 1 = 1-3 shrimp, 2 = 3-50 shrimp, 3 = 51-200 shrimp, 4 = 201-500 shrimp, and 5 = >500 shrimp. The index was necessary because most mysids pass through the trawl, and those that remain in the net are difficult to accurately count.

All data collected by the study is available upon request from Teejay O'Rear (taorear@ucdavis.edu). Catch values for all fishes and by each method from 1979 to 2009 are found in Appendix A; annual catch and amount of effort for each slough and method for 2009 are found in appendices B and C.

## ENVIRONMENTAL CONDITIONS

### Net Delta Outflow

The Net Delta Outflow Index, a proxy for water exiting the Sacramento-San Joaquin Delta, is 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 substantially affects myriad physical, chemical, and biological aspects of Suisun Marsh.

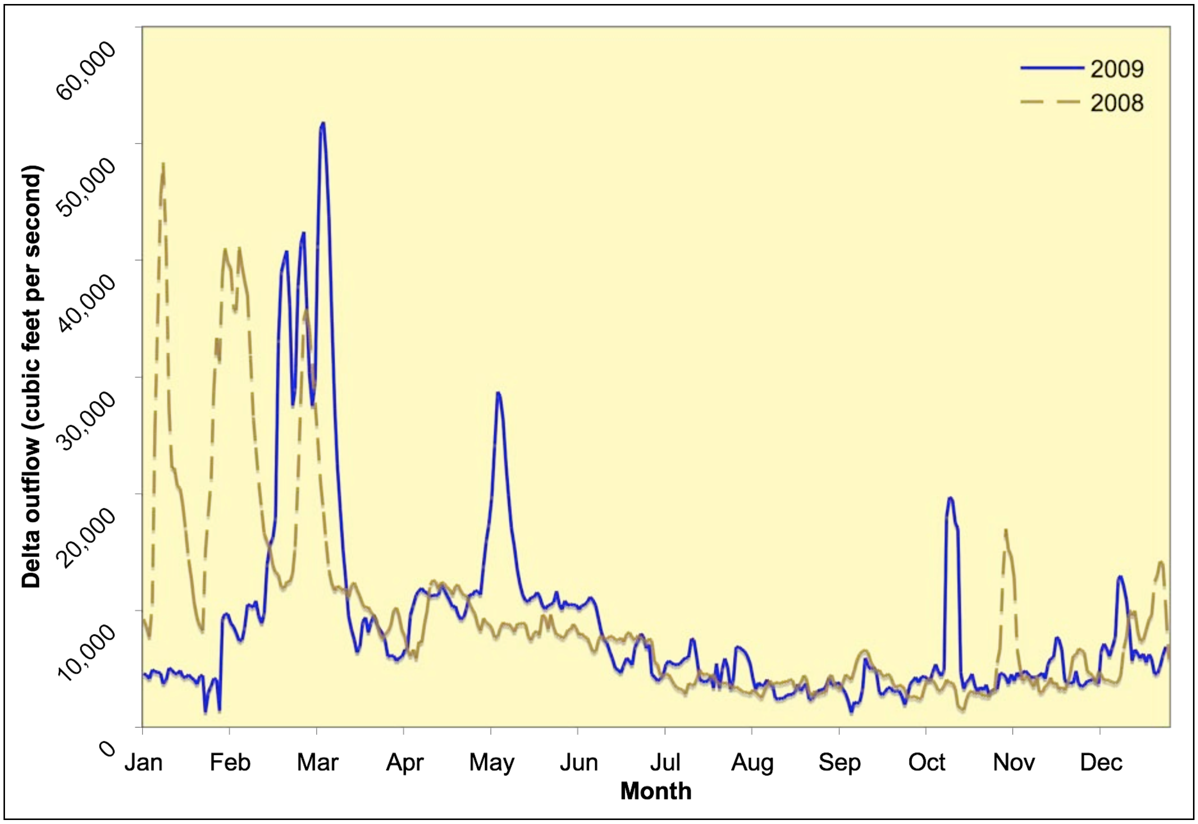


**Figure 3.** Daily Delta outflow for 2008 and 2009 (http://www.usbr.gov/mp/cvo/vungvari/doutdly.prn).

2009 started off with a very dry January; consequently, Delta outflow remained low while marsh salinities stayed high (figures 3 and 4). However, a series of storms hit the state throughout February and into March, elevating Delta outflow. Outflows generally subsided through the latter part of March and most of April, during which precipitation was weak (Figure 3). The final storm of spring occurred in early May, raising Delta outflow to nearly 30,000 cubic feet per second (cfs). Following this storm, Delta outflow subsided until spiking dramatically in the middle of October when the remnants of Typhoon Melor made land and caused heavy precipitation. Relatively small storms in November and December mildly increased Delta outflow to close out the year.

Like 2008, 2009 received below-average precipitation. However, the precipitation pattern and the resultant Delta outflow differed between the two years. First, Delta outflow in 2009 did not increase substantially until February, a month later than the previous year (Figure 3). Second, the storm during May 2009 contributed to Delta outflow remaining above 10,000 cfs for a month and a half later than in 2008. Finally, the first large Delta outflows of autumn in 2009 hit the marsh a month earlier than in 2008. These differences in hydrology likely affected, both directly and indirectly, our catches of fish.

## Salinity

Salinities in Suisun Marsh are strongly inversely correlated with Delta outflow (O'Rear and Moyle 2008) and thus are usually lowest in late winter and highest in early autumn (Figure 4). Reflecting the generally low outflow, the average monthly salinities in 2009 were higher

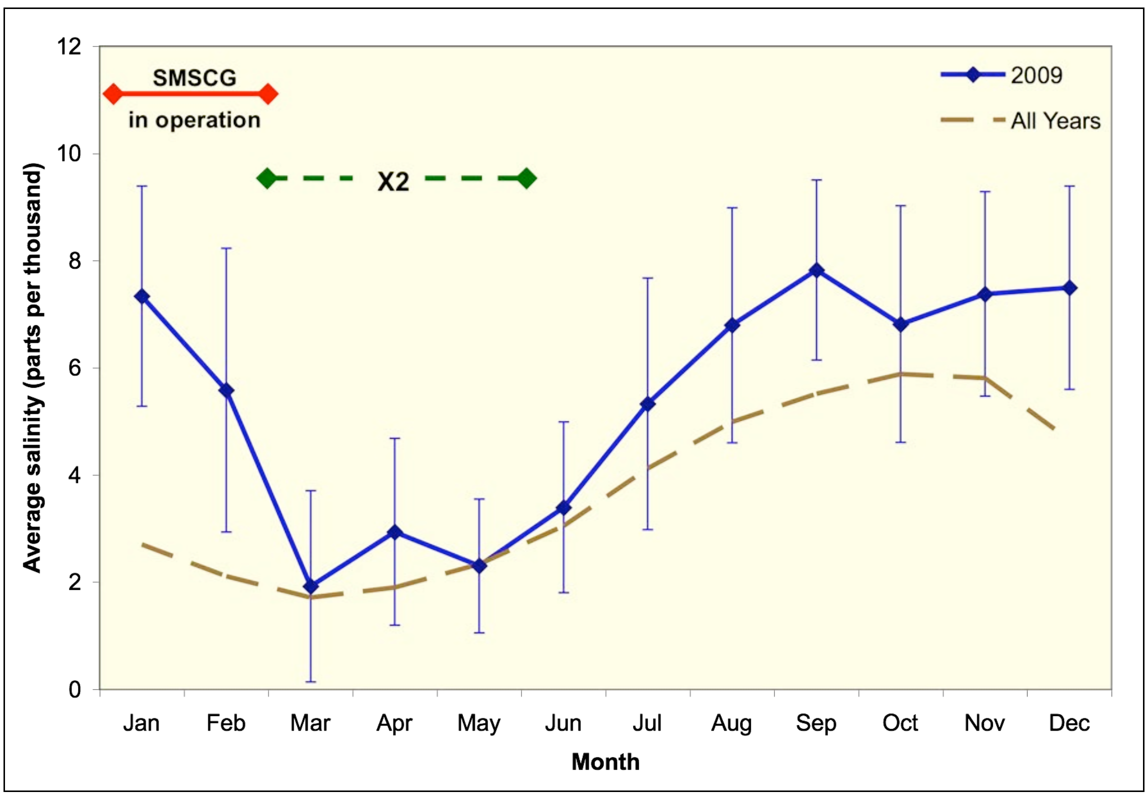


**Figure 4.** Average monthly salinities for 2008, 2009, and from 1980 to 2009 ("all years"); error bars are standard deviations for 2009 (SMSCG = Suisun Marsh Salinity Control Gates). Line around "X2" denotes time X2 was within Suisun Marsh.

than the average for all years (1980-2009) except in March and May (Figure 4). However, salinities in 2009 remained lower than in 2008 from May through December. Coupled with the intense rainfall of October 2009, these lower salinities allowed the marsh to remain fresh enough to negate the need to operate the Suisun Marsh Salinity Control Gates.

A distinct geographical salinity gradient generally sets up in late spring as Delta outflow subsides, with salinities highest in the southwest part of the marsh and lowest in the eastern and northern portions. However, this gradient was present throughout 2009, even during the wetter months of February and March. For the most part, the disparity in salinities was driven by very high values in our two upper Goodyear Slough sites; during March, for example, the salinity of the two upper Goodyear sites averaged 7.2 ppt, while the next highest salinity recorded was 2.1 ppt in Denverton Slough. Circulation in upper Goodyear Slough is often poor due to both water operations and tidal flows (Culberson et al. 2004), which probably contributed to the omnipresent gradient observed in 2009.

The location of X2, the distance in kilometers from Golden Gate Bridge along the thalweg to the near-bed water with salinity of 2 ppt, is associated with the historically productive entrapment 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. It also follows that the longer X2 is within Suisun Bay, the abundance of fishes in Suisun Marsh should be greater over a longer time span.

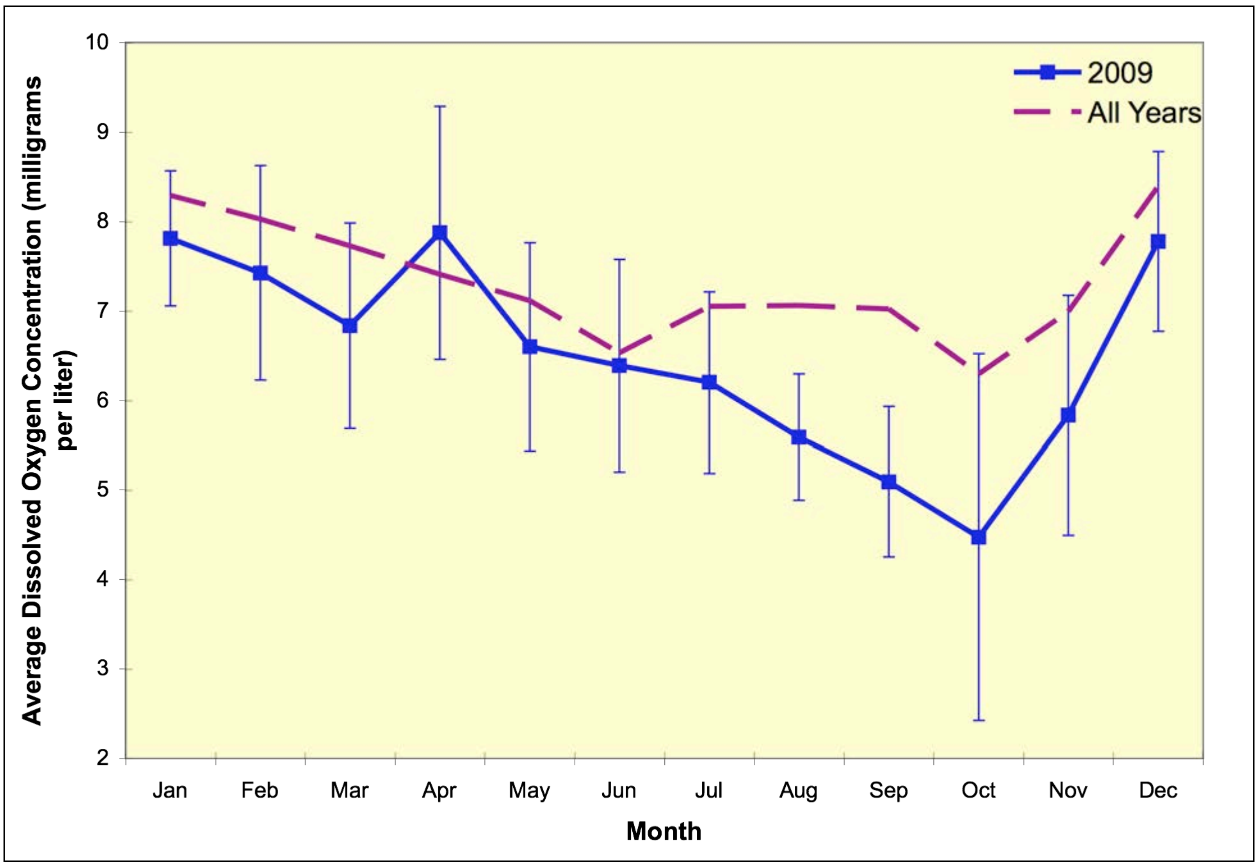


**Figure 5.** Monthly average dissolved oxygen concentrations for 2009 and from 2000 to 2009 ("all years"); error bars are standard deviations for 2009.

X2 was located in Suisun Marsh for 21% of 2009, with most of those days occurring in March, May, and the first third of June (Figure 4). Since the young of many fishes are spawned in or migrate to the marsh during late spring, then X2 was within Suisun Marsh when many of these fishes began to recruit. Consequently, high catches of some fishes in the marsh during May and June (e.g., striped bass) could have been at least partially attributed to X2 position.

## Dissolved Oxygen

Dissolved oxygen concentrations in the marsh are affected respiration, photosynthesis, temperature, salinity, flow magnitudes, and in-marsh duck club operations. Because oxygen solubility decreases with higher salinities and temperatures, oxygen concentrations are frequently lower in summer and autumn than in winter. Hypoxic water is frequently discharged into sloughs from some duck ponds during autumn, further lowering oxygen concentrations (Siegel et al. 2011, Schroeter and Moyle 2004). Likewise, draining of some ponds in spring by discharging to the sloughs can also depress marsh oxygen concentrations (Siegel et al. 2011, Schroeter and Moyle 2004).

**Figure 6.** Dead splittail and bluegill netted in upper Goodyear Slough during the anoxia event in October 2009 (photo by Adam Clause).

The overall monthly pattern for dissolved oxygen followed the pattern for all years, with concentrations highest in winter, lower in spring and summer, and at a minimum in autumn (Figure 5). Dissolved oxygen was notably high in April, which was probably due to high wind speeds during the first day of sampling. Dissolved oxygen concentrations were especially low in October, particularly in upper Goodyear Slough and sloughs of the northwest marsh (i.e., Peytonia, Boynton, and upper Suisun sloughs). In fact, upper Goodyear Slough was anoxic when sampled in October and probably resulted in the deaths of bluegill (*Lepomis macrochirus*), splittail (Figure 6), adult striped bass, threespine stickleback, and Mississippi silversides (*Menidia audens*) since several of these species (e.g., splittail, striped bass) were also captured alive and healthy at our lower Goodyear Slough site (GY3) where DO concentration was above 5.0 mg/L. In total, we observed at least 30 dead splittail (mostly adults), three adult striped bass (i.e., striped bass longer than 423 mm SL), one bluegill, a few Mississippi silversides, and a few threespine stickleback. While the water in the northwest marsh was not anoxic when sampled, it still averaged just 3.10 mg/L, with measurements below 3.0 mg/L in both Peytonia and Boynton sloughs. These low concentrations coincided with both a large storm and duck club water operations. The storm could have washed large amounts of organic material into the sloughs; with the water still relatively warm, decomposition rates would have been very high. Additionally, some duck clubs probably discharged hypoxic water into the sloughs as part of autumn flood-up and pond recirculation (Siegel et al. 2011). Consequently, for upper Goodyear Slough (which receives very little flushing flows), what little oxygen remained was likely used up by bacterial decomposition of organic material. Conversely, oxygen concentrations were much higher (mean = 6.4 mg/L) in the sloughs of the eastern marsh (i.e., Denverton, Nurse, and Montezuma sloughs), which have both less duck club outfalls per river-kilometer (Matern et al. 2002) and better circulation.

## Water Temperature and Transparency

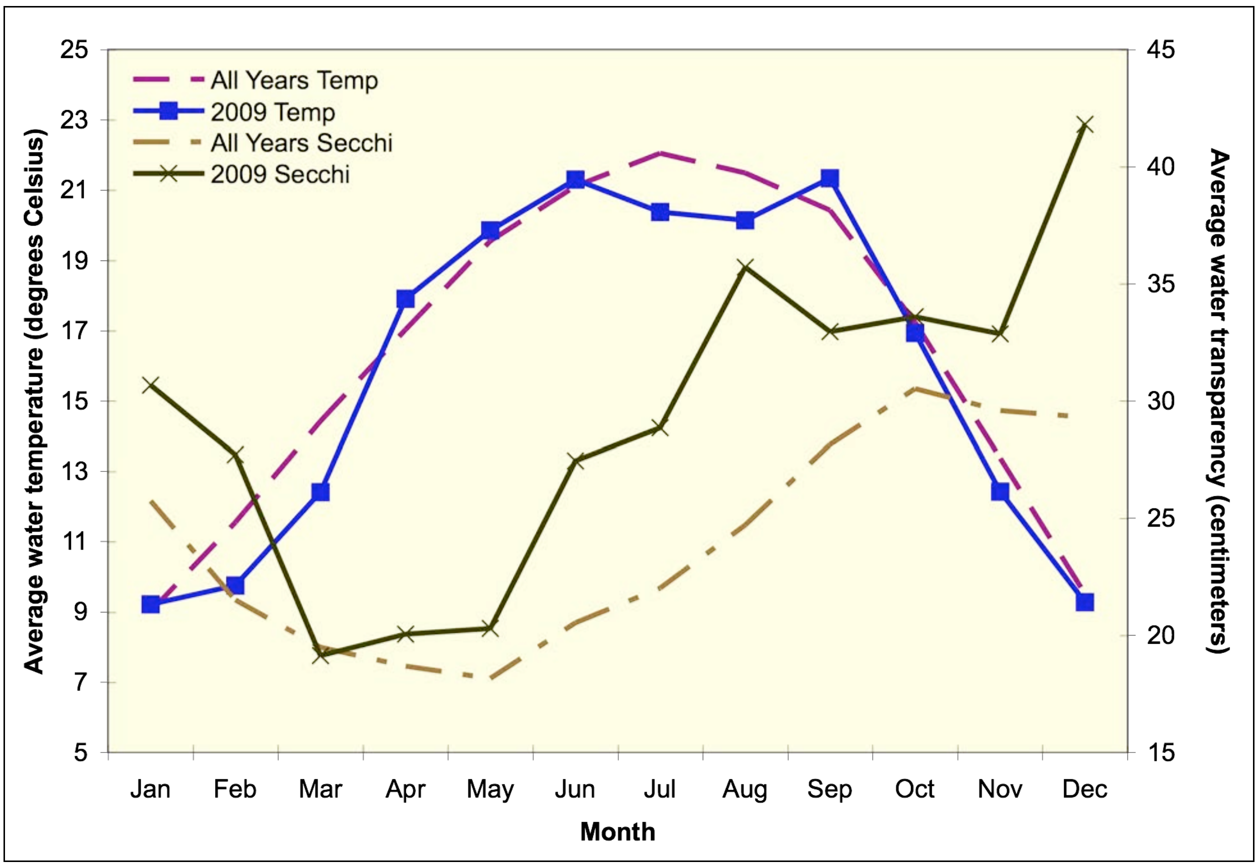


**Figure 7.** Monthly average temperatures and transparencies for 2009 and from 1980 to 2009 ("all years").

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 2009 followed the usual pattern, with temperatures highest in summer and lowest in winter (Figure 7). Water temperatures were notably above average in September, although that was because our sampling coincided with a strong high-pressure system and exceptionally warm weather at the end of the month.

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; conversely, transparency generally reaches a maximum in October when river flows are at their annual minimum. As a result, average monthly transparencies often mirror those for salinity. 2009 was no exception, with monthly average transparencies higher than the averages for all years during all months except March (Figure 7).

## TRENDS IN INVERTEBRATE ABUNDANCE AND DISTRIBUTION

Four plankton-feeding macroinvertebrates are commonly captured by otter trawl in Suisun Marsh: California bay shrimp, Siberian prawn, Black Sea jellyfish, and overbite clam. 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 8). While catch of Siberian prawn, first captured in the marsh during 2002 (Schroeter et al. 2006), has also been variable, it has mirrored the catch for California bay shrimp from 2004 to 2009 (Figure 8). 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 8). 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 8).

Otter trawl annual catch per unit effort for California bay shrimp and Siberian prawn increased slightly from 2008 to 2009 (Table 1). However, overbite clam and Black Sea jellyfish increased and decreased dramatically, respectively, from 2008 to 2009 (Table 1). In fact, the highest annual catch per unit effort for overbite clam ever in the study's history was recorded in 2009, while Black Sea jellyfish medusae were at their lowest level since 1998. The low abundance of Black Sea jellyfish medusae is especially noteworthy given the favorable abiotic environment (i.e., salinity = 3-7 ppt, water temperature > 19°C; Schroeter 2008) present during the summer of 2009.

**Table 1.** Annual catch per unit effort (CPUE) for four common invertebrate species in Suisun Marsh during 2008 and 2009.

| Species | California Bay Shrimp | Siberian prawn | overbite clam | Black Sea jellyfish |
|---|---|---|---|---|
| 2008 CPUE | 6.4 | 6.8 | 22.9 | 15.9 |
| 2009 CPUE | 8.1 | 9.5 | 192.1 | 3.7 |

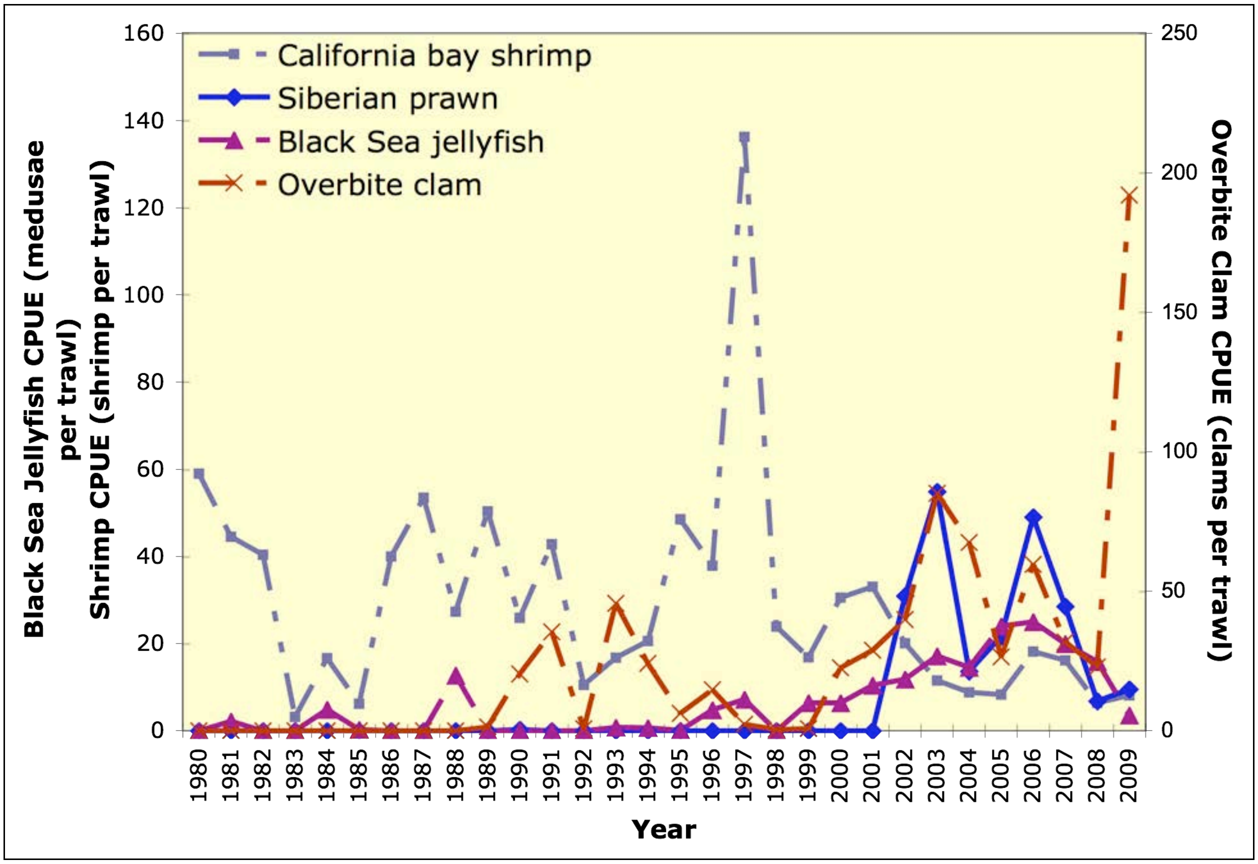


**Figure 8.** Annual otter trawl catch per unit effort for four common invertebrates in Suisun Marsh.

The monthly pattern of catch for California bay shrimp was typical: highest catches were made in late spring in the southwest marsh (Figure 9). This was probably due to the recruitment into the marsh of young produced downstream in Grizzly and San Pablo bays just as salinities began to increase, which occurred in lower Suisun and lower Goodyear sloughs in April (Gewant and Bollens 2005). While California bay shrimp were geographically ubiquitous, they were always most abundant in the southwest marsh.

The monthly catch pattern of Siberian prawn in 2006, 2007, and 2008 reached its maximum in autumn; in 2009, however, the trend in catch closely mirrored that for California bay shrimp (Figure 9), although high Siberian prawn catches were made in September and October. Like California bay shrimp, Siberian prawn were found throughout the marsh; conversely, they were most abundant where California bay shrimp were rare. In particular, high catches were made in fresher regions of the marsh (e.g., 45% of the total catch was from Denverton and upper Suisun sloughs), while much lower numbers were found in the saltier southwest marsh (e.g., only 12% of the catch came from lower Suisun and Goodyear sloughs). Thus, like in previous years, it appears that Siberian prawns prefer lower salinities than California bay shrimp (O'Rear and Moyle 2008, Emmett et al. 2002).

The monthly catch of overbite clam in 2009 was typical, with most caught during summer and very few captured early and late in the year (Figure 9; O'Rear and Moyle 2009, O'Rear and Moyle 2008). While the annual catch per unit effort for 2009 was the highest ever recorded, almost the entire catch (99%) came from the slough that has historically hosted high densities of overbite clams: lower Suisun. Overbite clams were never as abundant in any of the other sloughs, and they were completely absent from sloughs in the eastern marsh (i.e., Denverton, Nurse, and Montezuma). Thus, it appears that overbite clams have become denser in regions of the marsh where they had already been established rather than invading new areas.

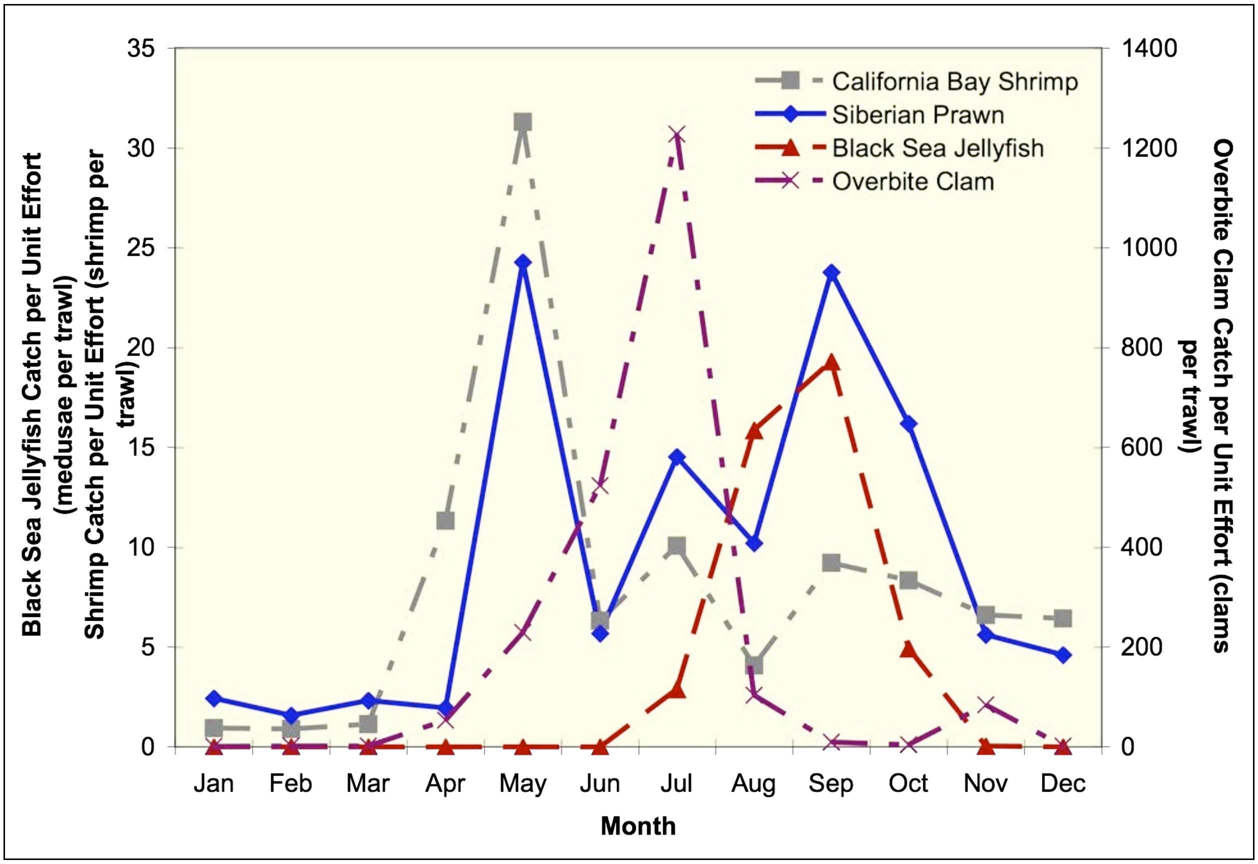


**Figure 9.** Monthly otter trawl catch per unit effort during 2009 for four common invertebrates in Suisun Marsh.

Similar to overbite clam, the monthly catch pattern for Black Sea jellyfish was typical, with medusae first appearing in summer, reaching their peak in late summer, and rapidly declining in early autumn (O'Rear and Moyle 2009, O'Rear and Moyle 2008). Medusae were found throughout the marsh, although they were never abundant in lower Suisun or Goodyear sloughs (Figure 9). As mentioned previously, the low catch of medusae is surprising given the favorable abiotic environment.

## 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 (figures 10 and 11; O'Rear and Moyle 2008). From 2006 to 2008, however, catch declined substantially, concurrent with lower Delta outflows and higher marsh salinities. The decrease in the annual catch per unit effort for native fish has been more precipitous and less variable than that for introduced fishes (Figure

10).  Catch per unit effort for introduced fishes has been highly variable over the study's history (Figure 11).

Relative to 2008, annual otter trawl catch per unit effort increased (10.3 fish per trawl to 16.6 fish per trawl) in 2009, although the year still had the fifth-lowest catch per unit effort in the study's 30-year history.  The increase was mostly due to higher catches of introduced species, the catch per unit effort of which nearly doubled from 2008 to 2009 (5.7 to 11.3 fish per trawl). Conversely, the annual otter trawl catch per unit effort for native species barely increased from 4.6 to 5.3 fish per trawl and thus only weakly contributed to the change in the total catch from 2008 to 2009.

The higher annual otter trawl catch for introduced fishes in 2009 was mostly due to striped bass, the catch per unit effort of which more than tripled from 2008 to 2009 (Table 2). Three other species were also more abundant in 2009 and contributed to the higher catch: yellowfin goby, shimofuri goby (*Tridentiger bifasciatus*), and American shad (*Alosa sapidissima*; Table 2).  Young-of-year fish comprised the bulk of the catch for all four species (Table 3).  Conversely, black bullhead continued the decline began in 2008 and were nearly

**Table 2.** Percent change in annual otter trawl catch per unit effort (fish per trawl) for five of the most common introduced species caught in Suisun Marsh (% increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled).

| Species | Striped Bass | Yellowfin Goby | Shimofuri Goby | American Shad | Black Bullhead |
|---|---|---|---|---|---|
| 2008 CPUE | 2.53 | 0.18 | 0.25 | 0.23 | 0.53 |
| 2009 CPUE | 7.79 | 0.36 | 0.80 | 0.41 | 0.02 |
| % Change | 208% | 99% | 217% | 78% | -96% |

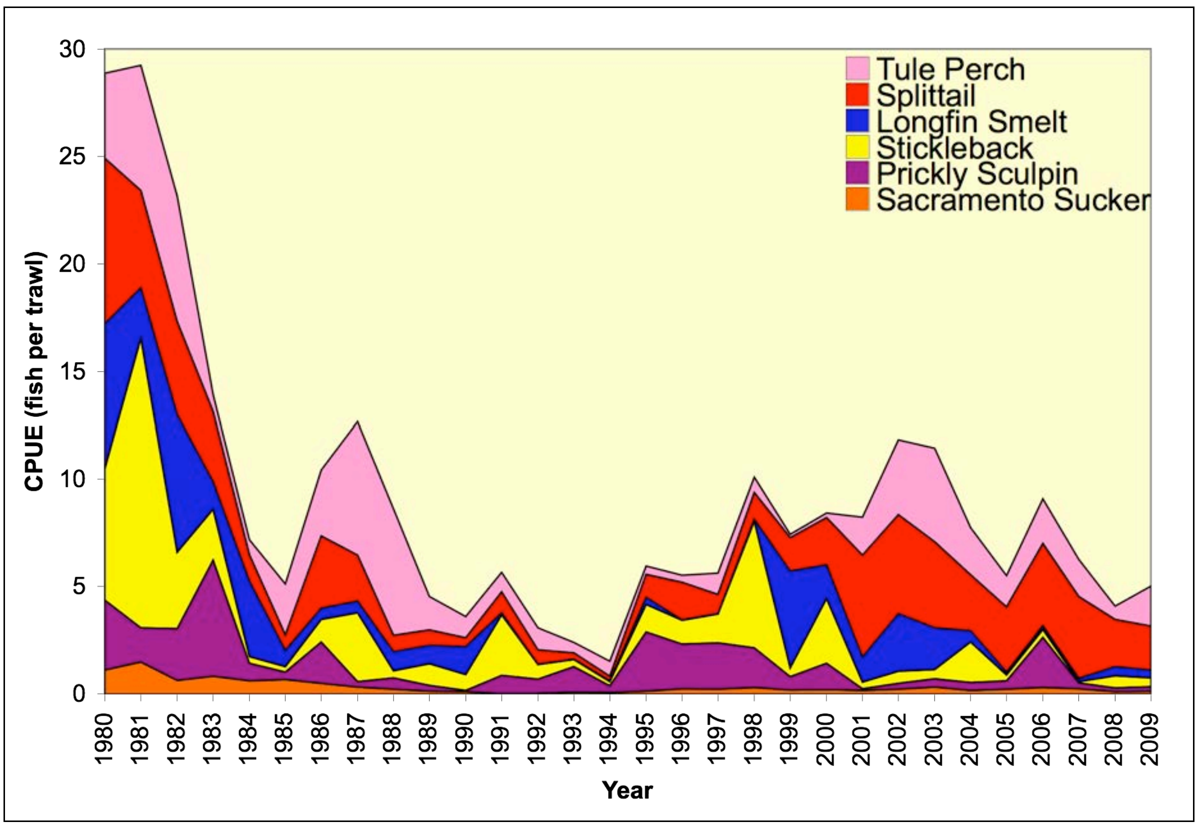


**Figure 10.**  Annual otter trawl catch per unit effort from 1980 to 2009 for the six native fishes most commonly captured in Suisun Marsh.

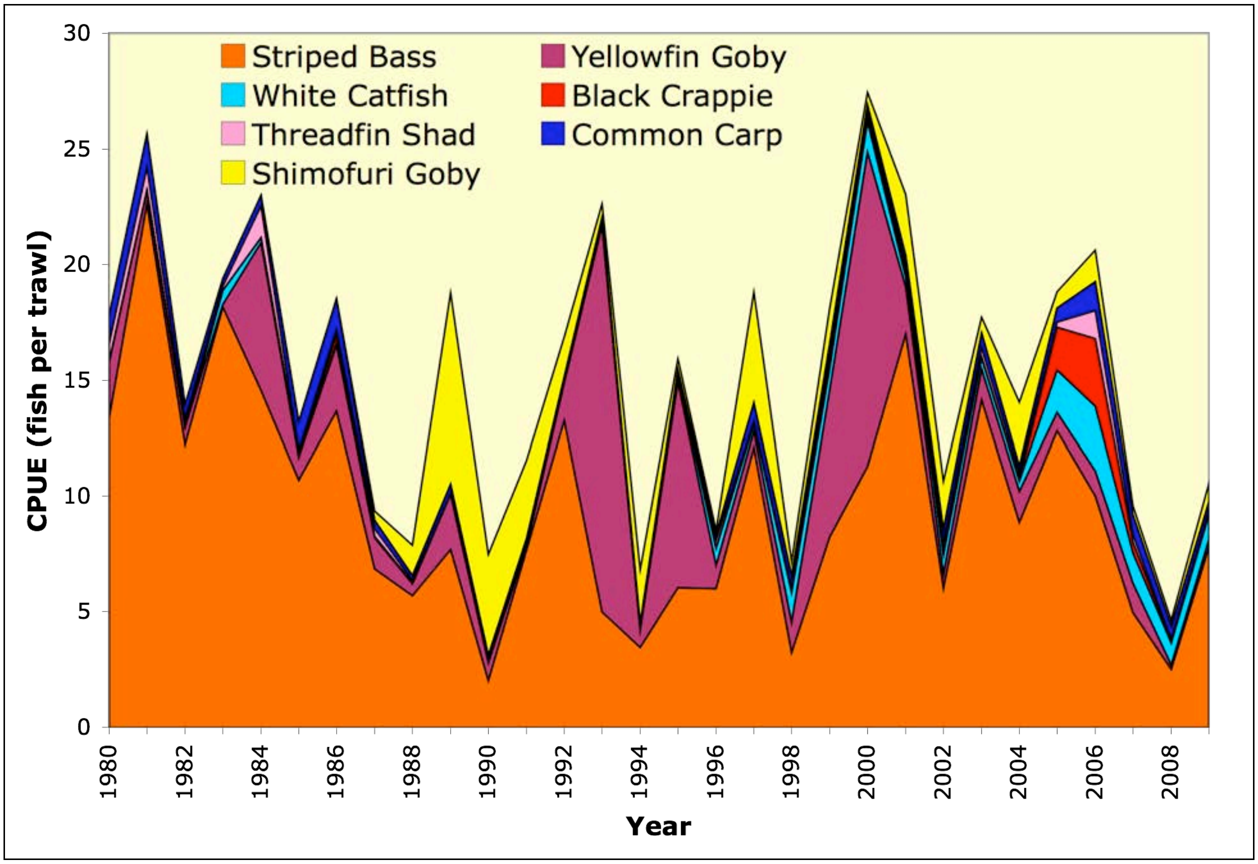


**Figure 11.** Annual otter trawl catch per unit effort from 1980 to 2009 for the seven introduced fishes most commonly captured in Suisun Marsh.

nonexistent in 2009 (Table 2).

Compared to 2008, annual otter trawl catch-per-unit-effort values for native fishes in 2009 either remained constant [e.g., Sacramento sucker (*Catostomus occidentalis*)] or slightly declined (e.g., longfin smelt). A notable exception was tule perch, the catch per unit effort of which tripled from 0.6 to 1.9 fish per trawl.

**Table 3.** Percent of 2009 otter trawl catch comprised of young-of-year (YOY) fish for four introduced species in Suisun Marsh. (YOY striped bass = fish less than 109 mm SL captured after April, YOY yellowfin goby = fish captured after May smaller than 140 mm SL, YOY shimofuri goby = all fish captured after June, YOY American shad = all fish captured after June smaller than 120 mm SL; Moyle 2002).

| Species | Striped Bass | Yellowfin Goby | Shimofuri Goby | American Shad |
|---|---|---|---|---|
| %YOY | 75% | 85% | 96% | 95% |

The increase in the total otter trawl catch from 2008 to 2009 was mainly due to higher catches of striped bass, yellowfin and shimofuri gobies, and American shad (Table 3). All four of these species have pelagic larvae that are often produced in late spring, with striped bass and American shad recruiting from upstream, yellowfin gobies recruiting from downstream bays, and shimofuri gobies resulting from both in-marsh and upstream reproduction (Moyle 2002, Wang 1986). Thus, our higher 2009 catches may have been due to high Delta outflow in May and saltwater intrusion in June, which spanned the recruitment period for all four species. However, opposite of 2008, catches of yellowfin gobies, American shad, and striped bass all declined in beach seines (discussed below) while increasing in otter trawls. As a result, our higher otter trawl catches were likely more strongly the result of young-of-year fish residing in open-water habitat rather than moving inshore, implying that pelagic food sources were more abundant in 2009 than in 2008. That X2 was positioned in the marsh during much of May and part of June (Figure 4) bolsters this possibility.

**Beach Seines**

Unlike the annual otter trawl catch per unit effort, annual beach seine catch per unit effort has increased since the study's inception (Figure 12). Similar to otter trawl catches, variability in native fish catch per unit effort 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.

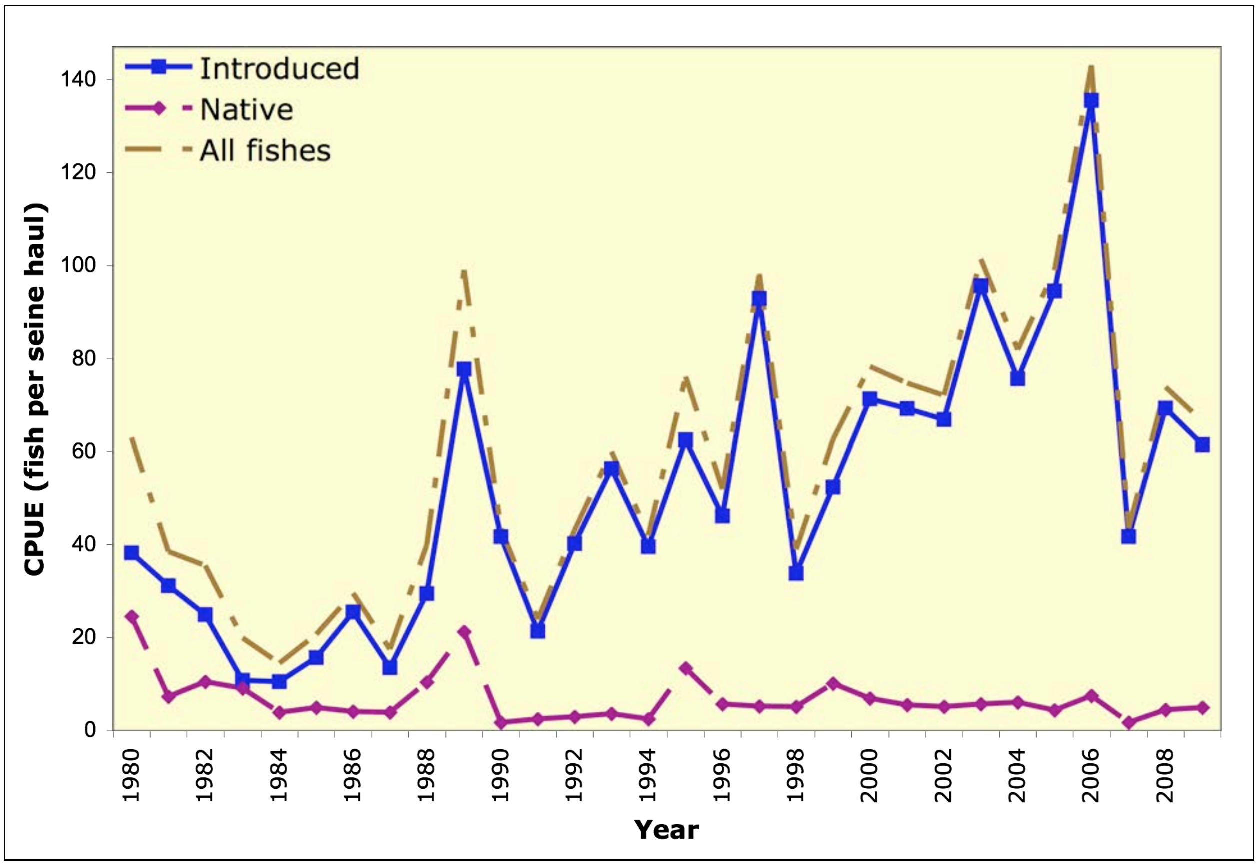


**Figure 12.** Annual beach seine catch per unit effort from 1980 to 2009 for introduced, native, and all fishes.

Annual beach seine catch per unit effort from 2008 to 2009 decreased from 73.9 to 66.5 fish per haul. The lower 2009 catch was almost solely due to a reduction in numbers of introduced fishes, which declined by nearly 8 fish per seine haul (Figure 12). This drop was mainly due to smaller catches of striped bass and yellowfin goby, which decreased by 64% and

48%, respectively, from 2008 to 2009. Additionally, American shad, while never very abundant in seine hauls, also decreased from 2008 to 2009 (28 to 10 fish per year, respectively). These changes are consistent with greater food supplies in thalweg habitats. Conversely, annual catch per unit effort for native fishes in 2009 (4.97) was about the same as in 2008 (4.49). This lack of change from 2008 to 2009 was mainly due to a drop in the staghorn sculpin catch (91 less fish per year in 2009) being nearly equaled by a greater threespine stickleback catch (95 more fish per year in 2009).

**Fish Species of Interest**

*Fishes of the Pelagic Organism Decline*

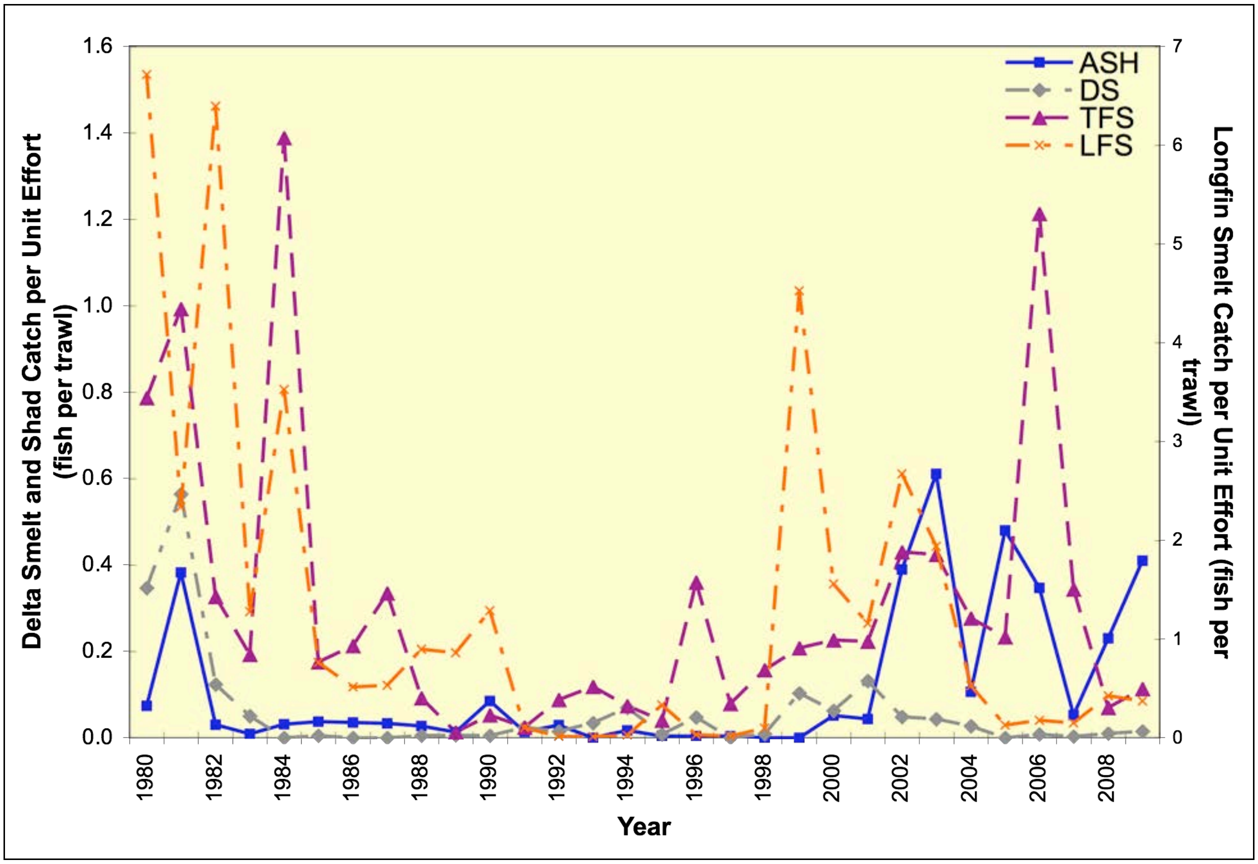


**Figure 13.** Annual otter trawl catch for threadfin shad (TFS), American shad (ASH), Delta smelt (DS), and longfin smelt (LFS) from 1980 to 2009.

<u>Threadfin Shad</u>

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 from 1996 to 2006 (Figure 13). For the most part, this pattern has been paralleled by the beach seine catch. Since 2006, both otter trawl and beach seine catches have declined precipitously concomitant with higher marsh salinities and lower Delta outflow. From 2008 to 2009, annual catch per unit effort for otter trawls increased very mildly (0.07 to 0.11 fish per trawl), while the beach seine catch-per-unit-effort value was the lowest recorded since 1992 (0.28 and 0.26 fish per seine haul for 2009 and 1992, respectively).

The monthly catch patterns in 2009 for both beach seines and otter trawls (figures 14 and 15) were similar to those of 2008 (O'Rear and Moyle 2009) and reflect little recruitment. Very few fish were captured during spring or early summer by either sampling method; for the latter half of the year, threadfin shad were present but in low numbers. Beach seine catch was highest in August (with 86% of the catch from Denverton Slough) and declined thereafter concurrent with the otter trawl catch generally increasing (figures 14 and 15). Similar to previous years (O'Rear and Moyle 2009, O'Rear and Moyle 2008, Matern et al. 2002, Moyle et al. 1986), threadfin shad were most abundant in otter trawls during autumn and winter (Figure 14) in First Mallard Slough, which is the smallest slough in the marsh we sample.

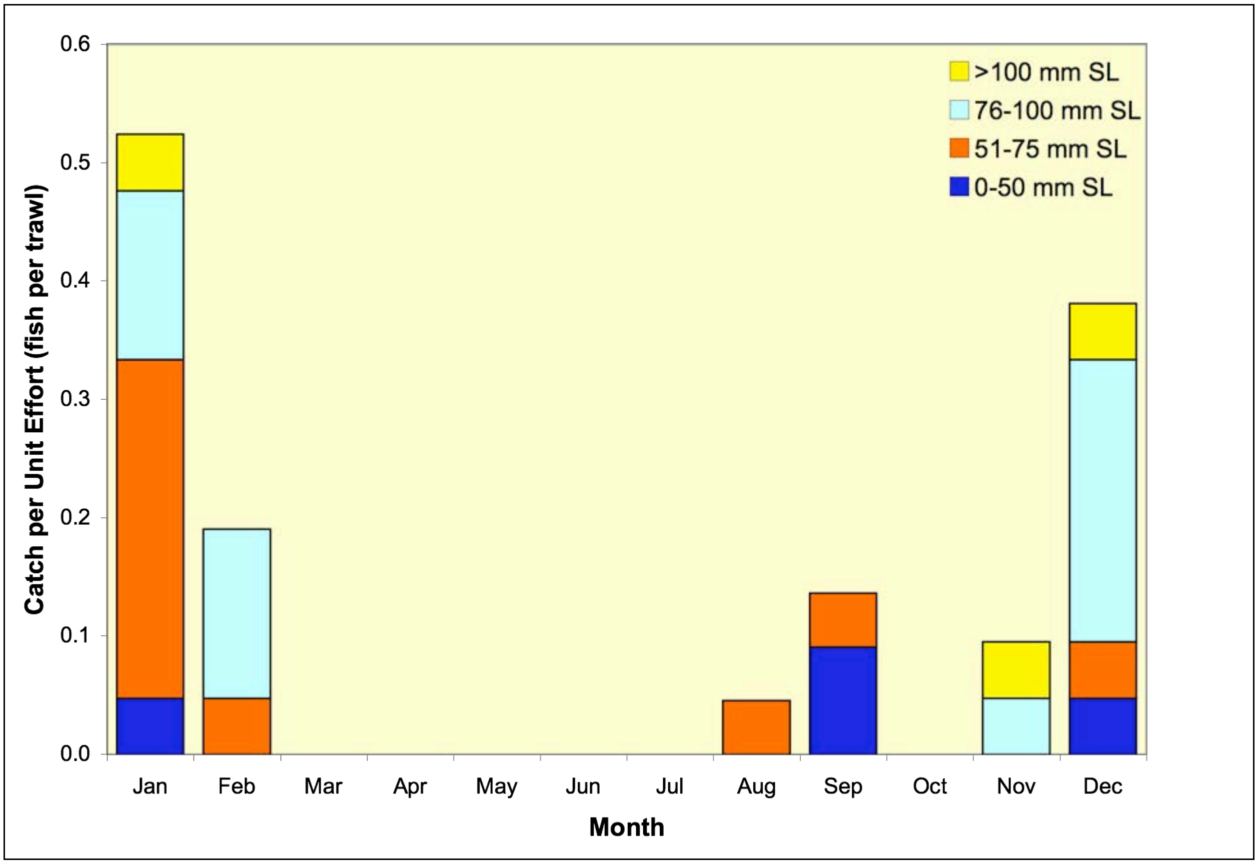


**Figure 14.** Monthly otter trawl catch per unit effort during 2009 for size-classes of threadfin shad.

The ecology of threadfin shad in the marsh is intriguing, particularly their consistent appearance in otter trawls towed in smaller sloughs during late autumn and winter. It appears that abiotic reasons are insufficient to explain these patterns. First, threadfin shad are very sensitive to both absolute and rapid changes in temperatures when the water is cold (Moyle 2002, Griffith 1978), both of which are most extreme in the smaller sloughs during the colder months (O'Rear, unpublished data). Second, while increasing salinity seems a plausible explanation because threadfin shad are rarely captured in Goodyear Slough and enter otter trawls in autumn when salinities are highest, three lines of evidence reject this conjecture: (1) threadfin shad always show up in otter trawls in early autumn, regardless of the salinity; (2) if salinity were the major factor, then threadfin shad catches in otter trawls should decline when higher Delta outflows freshen the marsh, which has not been observed; and (3) threadfin shad are usually most abundant in beach seines during late summer and early autumn when salinities are near their annual maxima. It is likely that dissolved oxygen is not driving these patterns, either, since dissolved oxygen concentrations are nearly always higher in the larger sloughs. Instead, it appears that the threat of predation by adult striped bass is largely responsible for the distribution of threadfin shad in Suisun Marsh. First, adult striped bass are most abundant in the marsh from October to March, spanning the period when we make our greatest otter trawl catches of threadfin shad. Second, adult striped bass can be especially dense in Denverton Slough while they are usually much less abundant in upper Suisun Slough (O'Rear, unpublished data); assuming that shallow water provides a refuge from predation, then this would explain why threadfin shad have been captured more commonly in beach seines in Denverton Slough yet are much rarer in otter trawls, while the opposite pattern has been seen in upper Suisun Slough. Third, First Mallard Slough is very close to the confluence of Cutoff and upper Suisun sloughs, the junction of which often hosts aggregations of adult striped bass. First Mallard is the shallowest slough we sample in the marsh; additionally, other fishes on which striped bass are known to prey (e.g., Mississippi silversides, spittail; Nobriga and Feyrer 2008, Moyle 2002, Stevens 1966) usually co-occur with threadfin shad in this slough during the cold months. Finally, adult striped bass have been seen attacking threadfin shad shoals during autumn (R.E. Schroeter, University of California, Davis, personal communication).

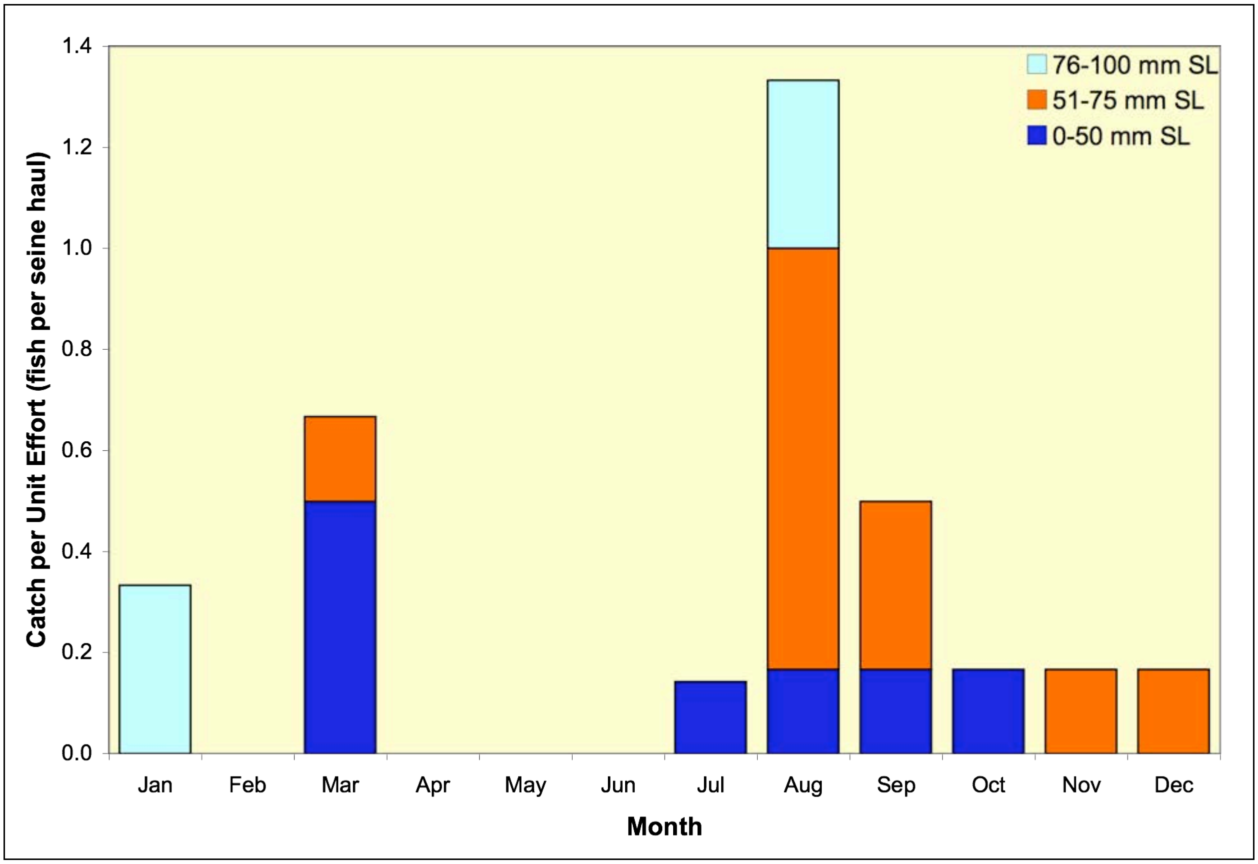


**Figure 15.** Monthly beach seine catch per unit effort during 2009 for size-classes of threadfin shad.

American Shad

American shad have been infrequently caught in otter trawls. Their ability to tolerate rapid salinity increases when larger than 25 mm total length (Zydlewski and McCormick 1997) and their anadromy suggests that American shad move rapidly through the estuary, including the marsh. Still, the third-highest otter trawl catch of the study's history was recorded in 2009 (Figure 13).

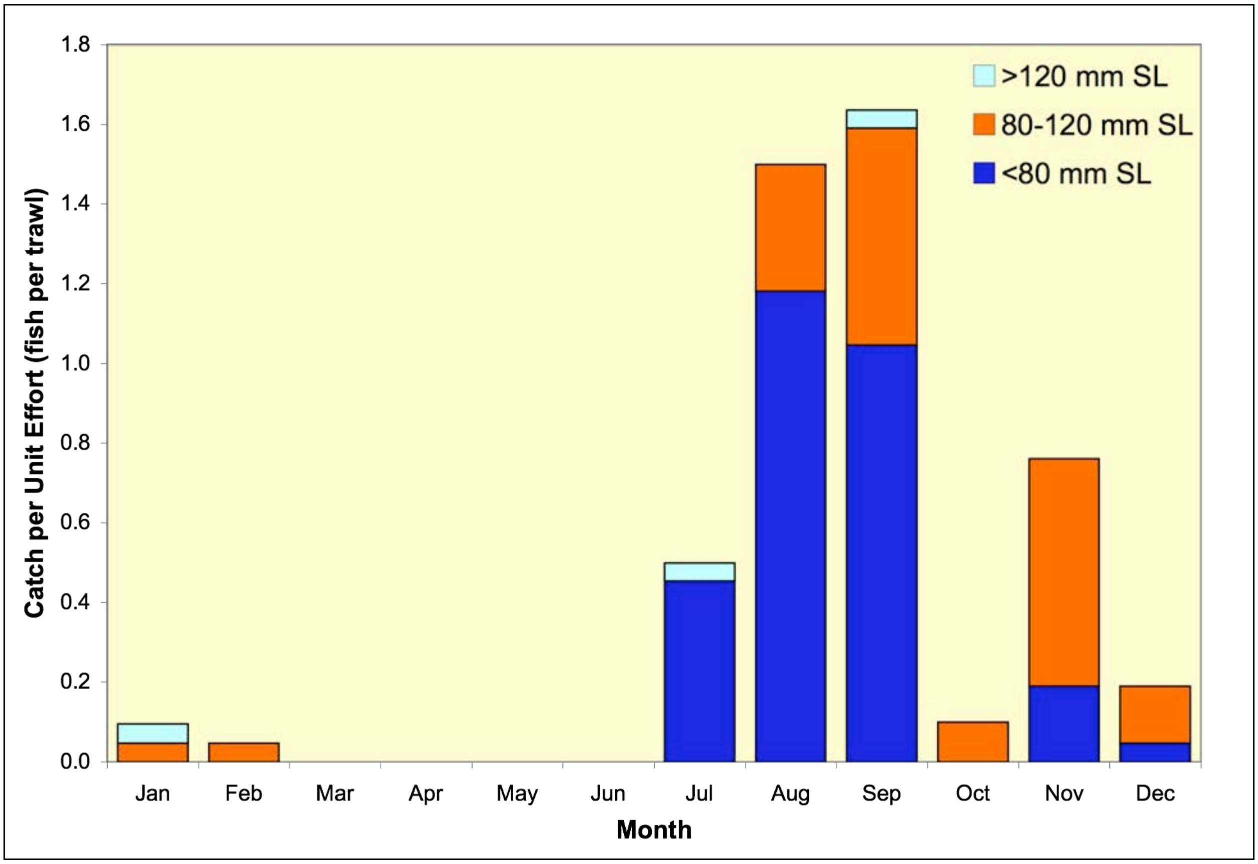


**Figure 16.** Monthly otter trawl catch per unit effort during 2009 for size-classes of American shad.

American shad appeared unusually early in 2008, when relatively large catches were made of very small fish during April in Suisun Slough (O'Rear and Moyle 2009). In contrast, young-of-year American shad did not appear in our catches during 2009 until July (Figure 16), and these fish were substantially larger than those captured in April 2008 (61 mm SL and 30 mm SL, respectively). However, the timing of the 2009 catch is more consistent with both the spawning period (i.e., late spring; Moyle 2002) and the historical monthly trend seen in the marsh (O'Rear, unpublished data).

Consistent with previous years, American shad were most prevalent in the southwest marsh: 77% of the otter trawl catch came from the lower Suisun and lower Goodyear Slough sites. Other pelagic fishes (e.g., longfin smelt, American shad, striped bass) were also often abundant in these sites (O'Rear and Moyle 2009) while being rare in upper Goodyear Slough.

This implies that sloughs in the southwest marsh with favorable water quality (e.g., high dissolved oxygen concentrations) may provide relatively dense planktonic food sources and thus good habitat for American 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; California Department of Water Resources and Department of Fish and Game 2007, Bennett 2005, Moyle 2002). Although we have conducted just 66 midwater trawls over the study's history, it is still somewhat surprising that we have only captured four Delta smelt from the water column of the large sloughs.

We caught only four Delta smelt with otter trawls in 2009; we never caught more than one Delta smelt in any trawl. At least three of the four fish were adults (Table 4). All Delta smelt were captured in December or January from the western marsh when water temperatures were low, salinities were moderate, and oxygen concentrations were high (Table 4).

**Table 4.** Standard length, sampling timing, and environmental data for Delta smelt captured by otter trawl in 2009.

| Slough | Standard Length (mm) | Sampling Date | Sampling Time | Water Temperature (°C) | Salinity (ppt) | Oxygen Concentration (mg/L) | Secchi Depth (cm) | Tide |
|---|---|---|---|---|---|---|---|---|
| Lower Suisun | 70 | 14-Jan-09 | 10:00 | 8.7 | 9.4 | 8.20 | 30 | ebb |
| Peytonia | 70 | 14-Jan-09 | 14:54 | 9.6 | 5.3 | 8.10 | 31 | flood |
| First Mallard | 80 | 15-Jan-09 | 8:00 | 8.1 | 6.2 | 8.16 | 30 | ebb |
| Upper Suisun | 50 | 15-Dec-09 | 7:10 | 8.5 | 5.6 | 7.97 | 32 | ebb |

The most common fish captured in trawls containing Delta smelt was splittail, which occurred in three of the four trawls (Figure 17). Striped bass and tule perch were present in half of the trawls that captured Delta smelt. Several other species, most of which were introduced, were caught in one of the Delta smelt trawls (Figure 17). In general, the assemblages of the four trawls were disparate.

In summary, catch of Delta smelt in Suisun Marsh during 2009 was very low, consisting of only four fish. These fish did not appear until water temperatures reached their annual minima and water quality was good. Delta smelt were captured only in the western marsh and were accompanied by different fish assemblages in each trawl. Consequently, water quality parameters appeared to be more strongly associated with the presence of Delta smelt than the makeup of the fish assemblage.

Longfin Smelt

The annual otter trawl catch per unit effort for longfin smelt in Suisun Marsh parallels that seen in other parts of the estuary (e.g., the Delta): catches were high in the early eighties,

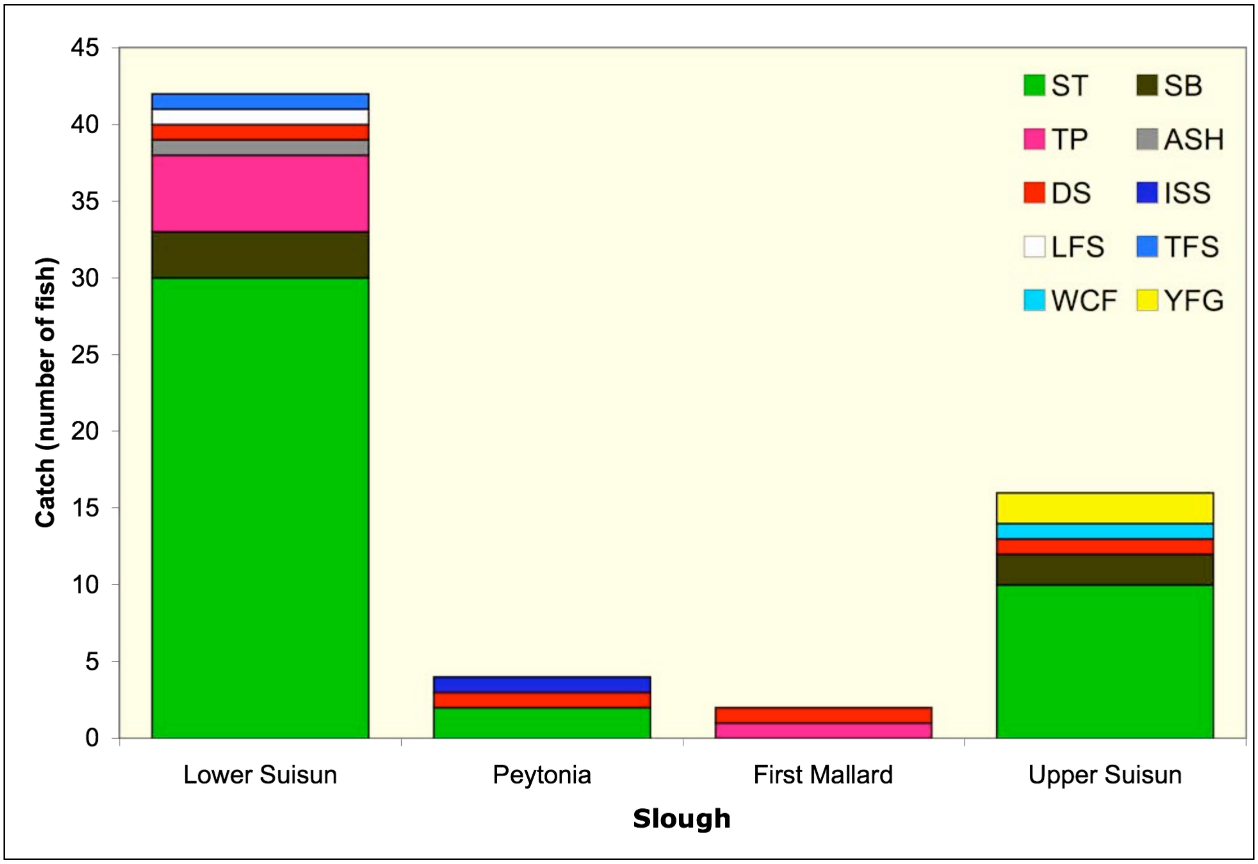


**Figure 17.** Fishes captured in trawls containing Delta smelt in 2009 (WCF = white catfish, ISS = Mississippi silverside, YFG = yellowfin goby, TP = tule perch, SB = striped bass, and ST = splittail; other acronyms as in Figure 13).

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 the amount of fresh water exiting the Delta, 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).

The monthly catch pattern of post-larval longfin smelt in 2009 was very similar to that in 2008, albeit events occurred a month later in 2009: fish were first captured in April, reached their maximum density in May, declined to low levels thereafter, and were almost all captured in lower Suisun and lower Goodyear sloughs (Figure 18). Additionally, salinity in lower Suisun Slough (4.6 pt) when the peak catch of post-larval smelt was made (i.e., May) was very similar to salinities when peak catches were made in 2007 and 2008 (4.4 and 3.7, respectively). Consequently, it appears that post-larval smelt were once again transported into the marsh with saltier water from Grizzly and San Pablo bays, with the shift in the timing of events between 2008 and 2009 due to the differences in Delta outflow.

Like in previous years, catch of longfin smelt increased through autumn (Figure 18). Most of these fish were probably adults migrating upstream to spawn. Just as in 2008, about two-thirds of the autumn catch came from lower Suisun Slough, although the total number in 2009 was lower than in 2008 (eight and 23 fish, respectively). However, four longfin smelt (70-105 mm SL) were seined in autumn of 2009 while none were in 2008.

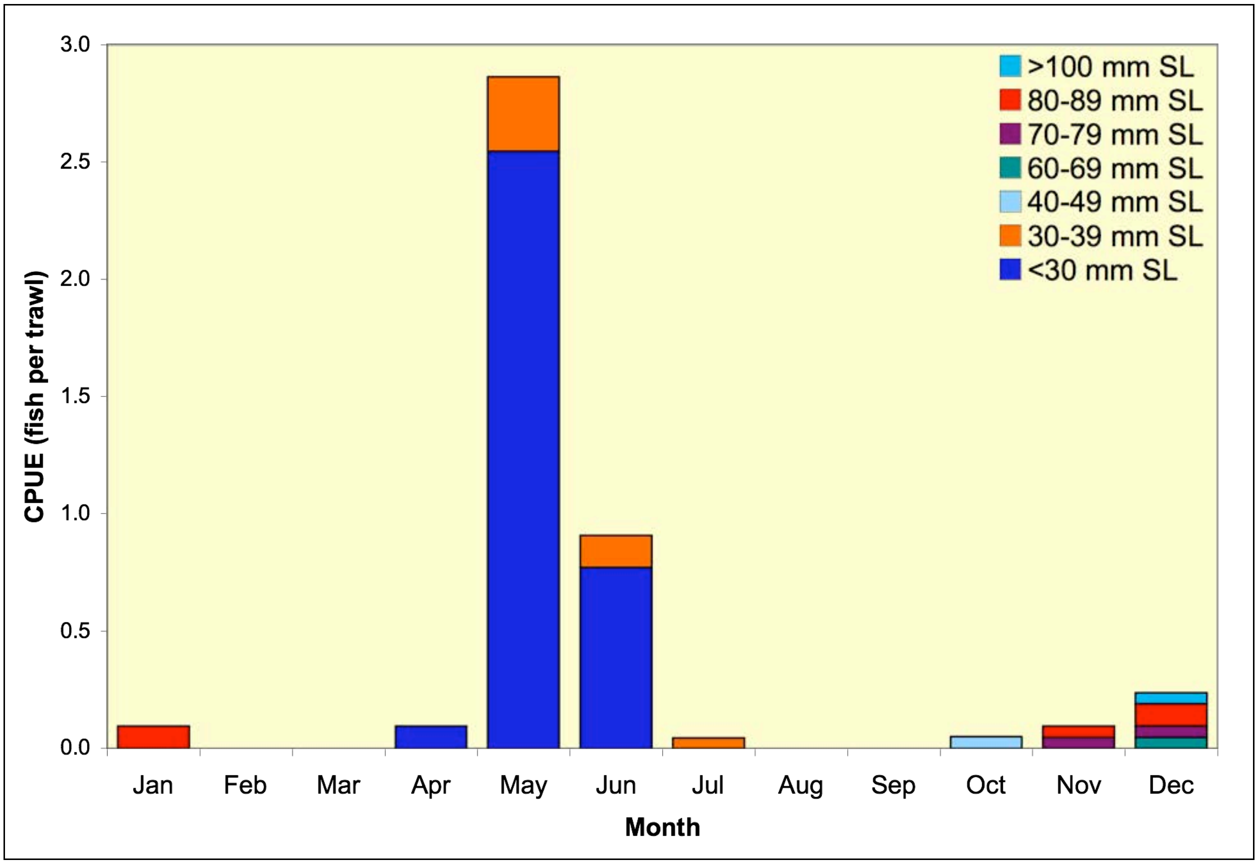


**Figure 18.** Monthly otter trawl catch per unit effort during 2009 for size-classes of longfin smelt.

<u>Striped Bass</u>

Striped bass are consistently one of the most abundant fishes in trawl catches. Although somewhat variable, annual otter trawl catch per unit effort of striped bass decreased significantly from 1980 to 1990 (Figure 19). From 1991 to 2008, catch per unit effort had no significant increasing or decreasing trends (Figure 19). While the drought period that began in the mid-1980s likely influenced the decline in catch seen in the first 10 years of the study period, this alone cannot fully explain the pattern because large catches have been made in dry years (e.g., 1991, 2001). A plethora of other factors, such as increased water exports and altered food webs, also have no doubt contributed to the pattern of the otter trawl catch (California Department of Water Resources and Department of Fish and Game 2007, Moyle 2002).

As previously discussed, the annual catch per unit effort in 2009 increased for otter trawls while decreasing in beach seines, implying that food supplies in open water were more abundant than in 2008. This may have been the case in June, when otter trawl catch of young-of-year fish was at its peak and X2 was within the marsh (Figure 20). After June, however, monthly otter trawl catches of young-of-year striped bass began to rapidly decrease, especially compared to the averages for all years (Figure 21). Additionally, both Black Sea jellyfish medusae and young-of-year shimofuri goby began to recruit to the otter trawls in July (Figure 20). While the specific species of zooplankton that striped bass, shiomfuri gobies, and Black Sea jellyfish consume have been different, all three species have been shown to feed on crustaceans in the plankton (J. Moore, California Department of Water Resources, personal communication, Grimaldo et al.

2009, Schroeter et al. 2008, Feyrer et al. 2003). In August, otter trawl catch of shimofuri gobies plummeted concomitant with both a higher Black Sea jellyfish otter trawl catch and a higher shimofuri goby beach seine catch. In fact, the parallel trends between the monthly shimofuri goby beach seine catch and the monthly Black Sea jellyfish otter trawl catch are striking, especially in light of predation by Black Sea jellyfish medusae on goby larvae (Schroeter 2008). In September, the beach seine catch for striped bass increased while the otter trawl catch continued to decline (Figure 20). These patterns suggest that while pelagic food supplies may have been abundant in June, they quickly became limiting and forced the young-of-year of both striped bass and shimofuri gobies inshore. While the aforementioned is plausible, it should be held very cautiously: two extremely large catches of young-of-year striped bass were made in First Mallard and Montezuma sloughs in June and July, respectively, and thus could have biased high the average otter trawl catches in those months.

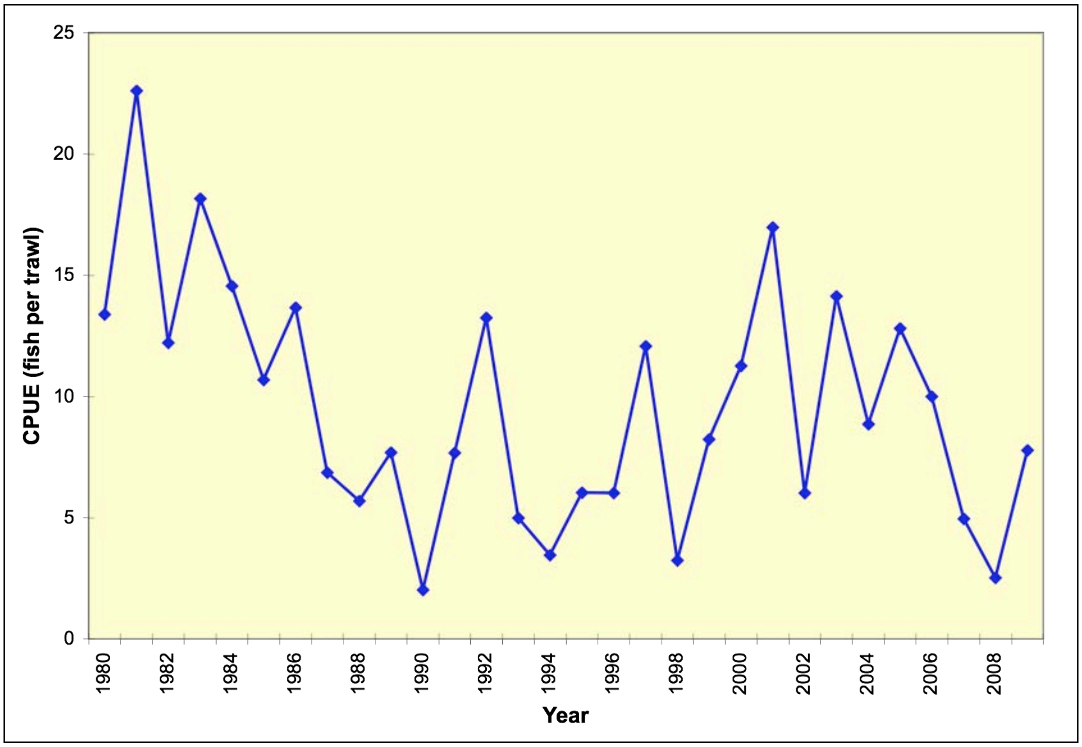


**Figure 19.** Annual otter trawl catch per unit effort from 1980 to 2009 for striped bass.

Similar to previous years, lower Suisun and First Mallard sloughs had higher otter trawl catch-per-unit-effort values (10.1 and 24.7 fish per trawl, respectively) than most of the other sloughs, which has been attributed to shallow depths (Schroeter et al. 2006). Conversely, Montezuma Slough had the second-highest catch per unit effort among all sloughs in 2009, mainly due to very high catches in June and July (51 and 196 fish, respectively). However, 94% of the striped bass caught in Montezuma Slough during those two months came from the downstream site (i.e., MZ2; Figure 2); this site has a shallow shoal on the river-left bank. In July, we observed small fish surfacing on this shoal while being pursued by larger fish just before we trawled through it. The abundance of small yearling and young-of-year striped bass in that trawl, coupled with the cannibalistic habits of striped bass (Moyle 2002), suggests that the bulk of those striped bass were captured on that shoal. Thus, despite Montezuma Slough being

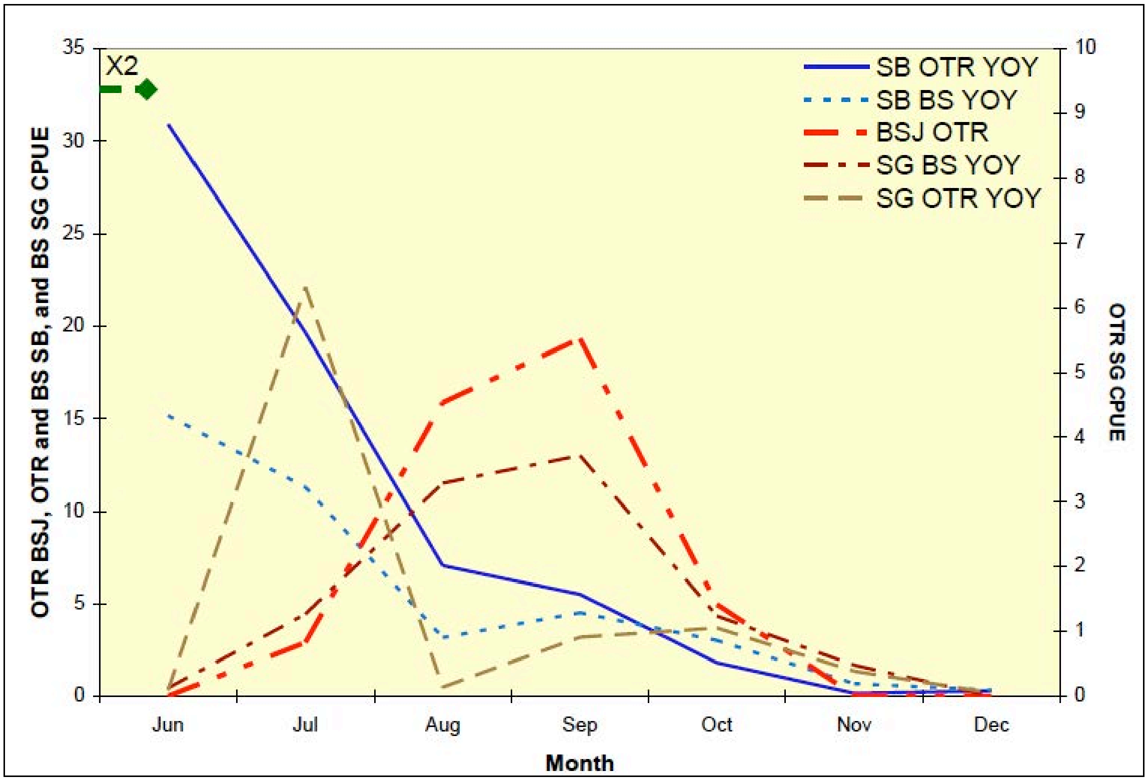


**Figure 20.** Monthly otter trawl (OTR) and beach seine (BS) catch per unit effort for young-of-year striped bass and shimofuri gobies and monthly otter trawl catch per unit effort for Black Sea jellyfish during the last seven months of 2009. (SG= shimofuri goby, BSJ=Black Sea jellyfish; all other acronyms as in tables 1 and 3 and Figure 17.) Line below "X2" denotes time when X2 was within Suisun Marsh.

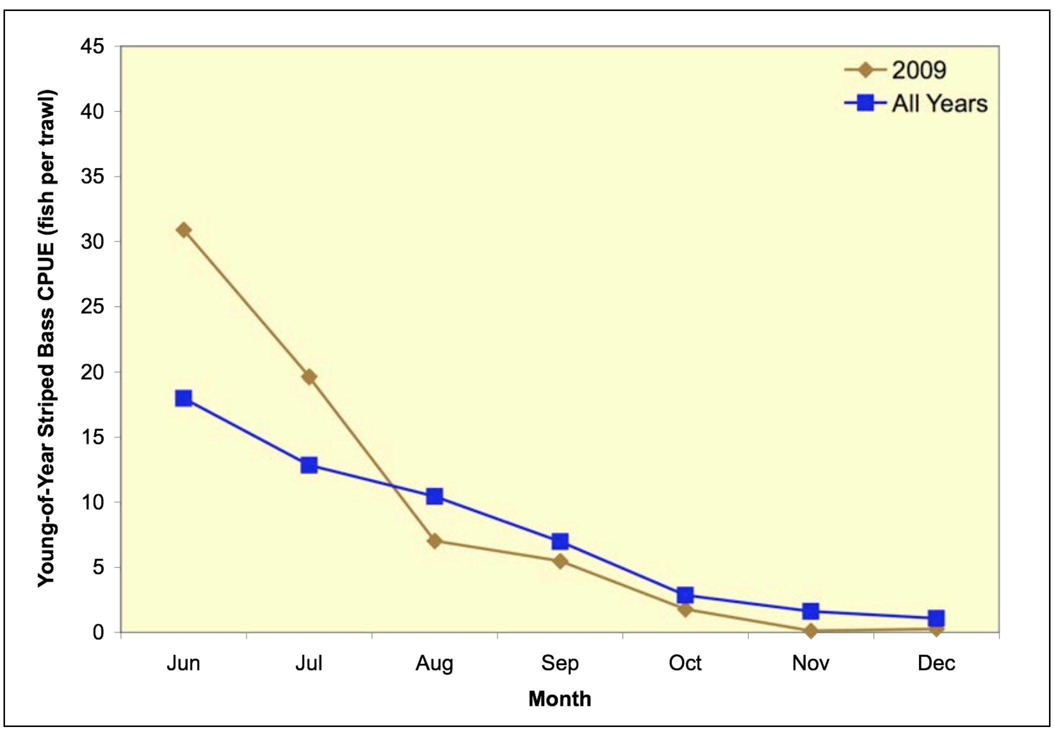


**Figure 21.** Otter trawl catch per unit effort for young-of-year striped bass from June to December during 2009 and from 1980 to 2009 ("all years").

the deepest slough we sample, it still seems that striped bass were most abundant near or in shallow water.

*Splittail*

Splittail have been the most commonly captured native fish in Suisun Marsh. Not including 1986 and 1987, splittail annual otter trawl catch per unit effort declined considerably from 1980 to 1994; this was mirrored fairly well by the beach seine catch per unit effort, which was more variable over that period (Figure 22). From 1995 to 2006, otter trawl catch per unit effort generally increased and was accompanied by large beach seine catches in years of high springtime Delta outflow (e.g., 1995, 2006). However, otter trawl catches have declined severely since 2006, concurrent with decreasing beach seine catches beginning in 2007 (Figure 22). The otter trawl and beach seine catch patterns are likely 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 years of high flows.

In 2009, annual otter trawl catch per unit effort reached its lowest point (2.0 fish per trawl) in the last 10 years; the 2009 annual beach seine catch per unit effort was the lowest recorded (0.4 fish per seine haul) since 1994 (Figure 22). As in 2008, this was primarily due to a lack of recruitment: young-of-year fish comprised only 13% of the otter trawl catch, and the beach seine catch, the bulk of which consists of young-of-year, was similarly low. Consequently, lack of considerable floodplain inundation during spring of 2009 probably resulted in poor conditions for reproductive success and thus our low catches.

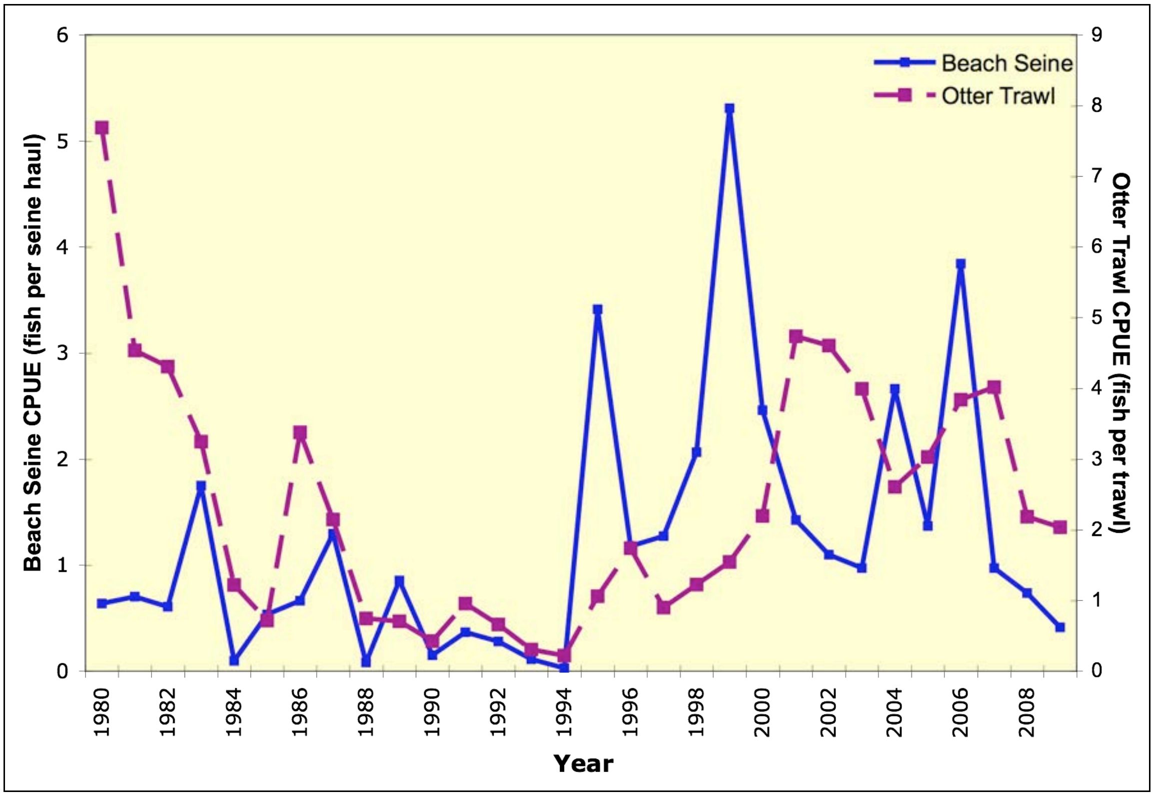


**Figure 22.** Annual otter trawl and beach seine catch per unit effort from 1980 to 2009 for splittail.

As in 2008, fish spawned in 2006 made up a substantial portion (22%) of the total otter trawl catch (O'Rear and Moyle 2009). However, one-third of the otter trawl catch in 2009 was comprised of fish measuring 111-170 mm SL. Most of these fish were spawned in 2008 and, considering the low recruitment for that year, intimate that survival for this cohort was high.

The trend in the monthly otter trawl catch in 2009 was typical. Catch of adult fish (i.e., those measuring more than 215 mm SL; Moyle 2002) declined in March and April (Figure 23), reflecting movement of these fish either upstream or inshore to spawn. Adult catches thereafter increased and were followed by recruitment of young-of-year fish. Young-of-year reached their peak abundance in otter trawls during July and August and in beach seines during June and July, implying movement of fish from inshore areas to thalweg habitats (O'Rear and Moyle 2008, Sommer et al. 1997). The total otter trawl catch reached its minimum in October, increasing thereafter to close out the year (Figure 23).

As seen in previous years (O'Rear and Moyle 2009, O'Rear and Moyle 2008, Schroeter et al. 2006), a disproportionate amount of the total otter trawl catch (23%) came from lower Suisun Slough. In contrast to previous years, First Mallard Slough did not host an abundance of splittail, contributing only 7% to the total catch; given the lower numbers of young-of-year fish and the importance of First Mallard Slough as a nursery and refuge for small fishes (O'Rear and Moyle 2009), this is not a surprising result. However, First Mallard Slough had the highest

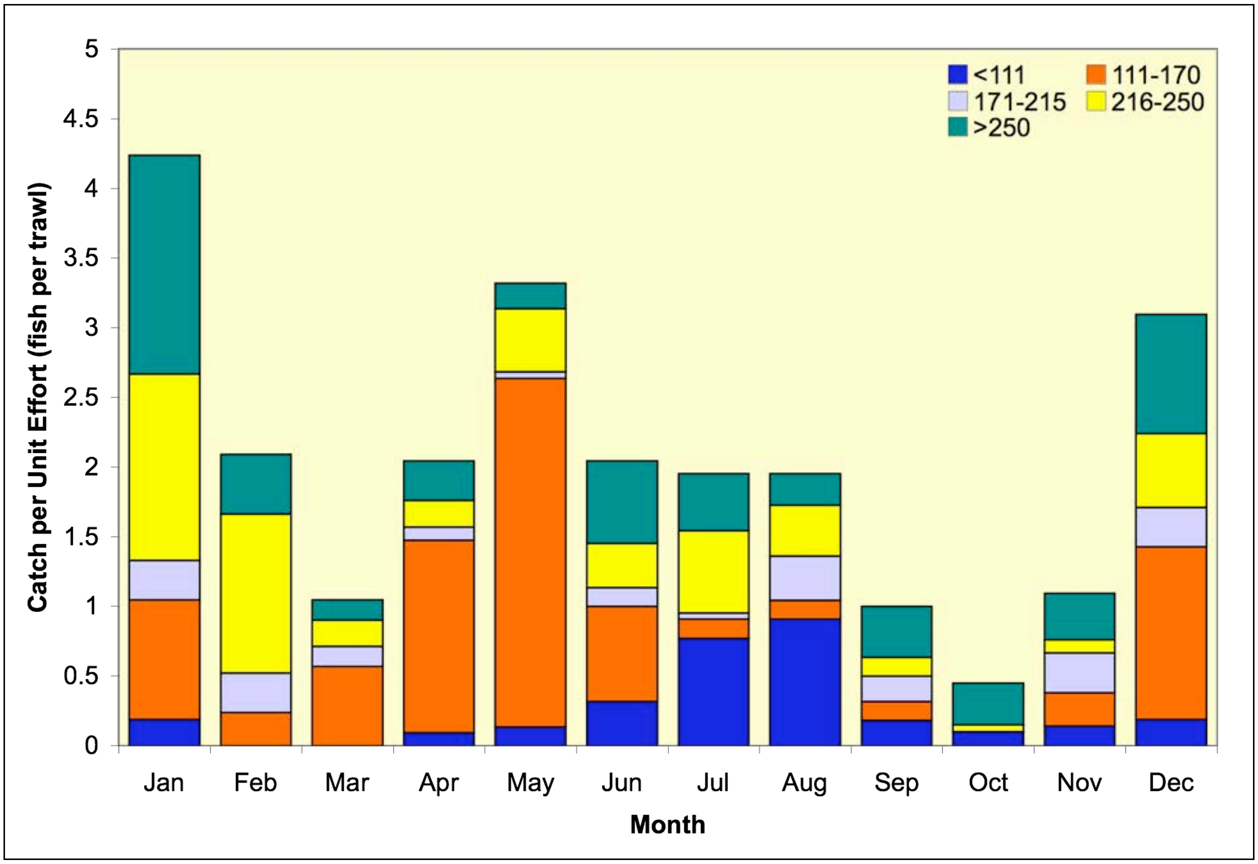


**Figure 23.** Monthly otter trawl catch per unit effort during 2009 for size-classes of splittail.

young-of-year catch per unit effort (2.6 fish per trawl) of any we sample in the marsh, so it remains an important habitat for splittail.

*White Catfish and Mississippi Silverside*

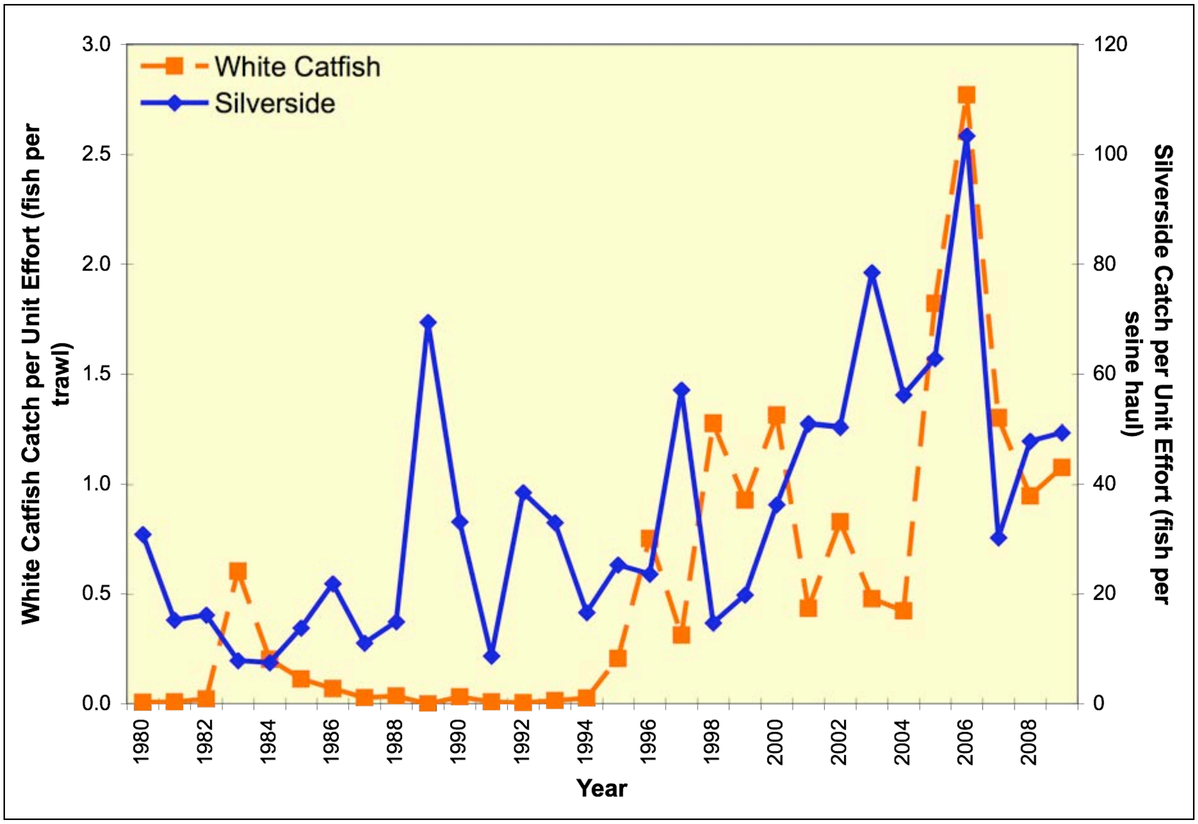


**Figure 24.** Annual catch per unit effort for white catfish and Mississippi silverside from 1980 to 2009.

Of all the introduced fish species in the marsh, 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 2009, however, white catfish have been increasingly abundant, which appears tied to lower salinities that span the late-spring/early-summer spawning period during wetter years (see O'Rear and Moyle 2009). Beach seine catch of Mississippi silversides was relatively constant from 1980 to 1988; however, from 1989 to 1997, catch began to vary more around a higher mean (Figure 24). From 1998 to 2006, Mississippi silversides became increasingly more abundant, but numbers have been lower from 2007 to 2009.

The otter trawl catch per unit effort for white catfish in 2009 was about the same as in 2008 (1.08 and 0.95 fish per trawl, respectively). Of 276 white catfish caught in otter trawls, only three were young-of-year fish (i.e., those smaller than 144 mm SL captured after June); additionally, only two white catfish were captured from the southwest marsh, while the sloughs with the highest catch-per-unit-effort values were Peytonia and Denverton. With the exception of two relatively large catches made in Boynton and Cutoff sloughs during October, white catfish were most abundant in late spring and early summer (Figure 25) in the fresher sloughs of the marsh.  All of these patterns are consistent with the preference of white catfish for low salinities and warm water temperatures.

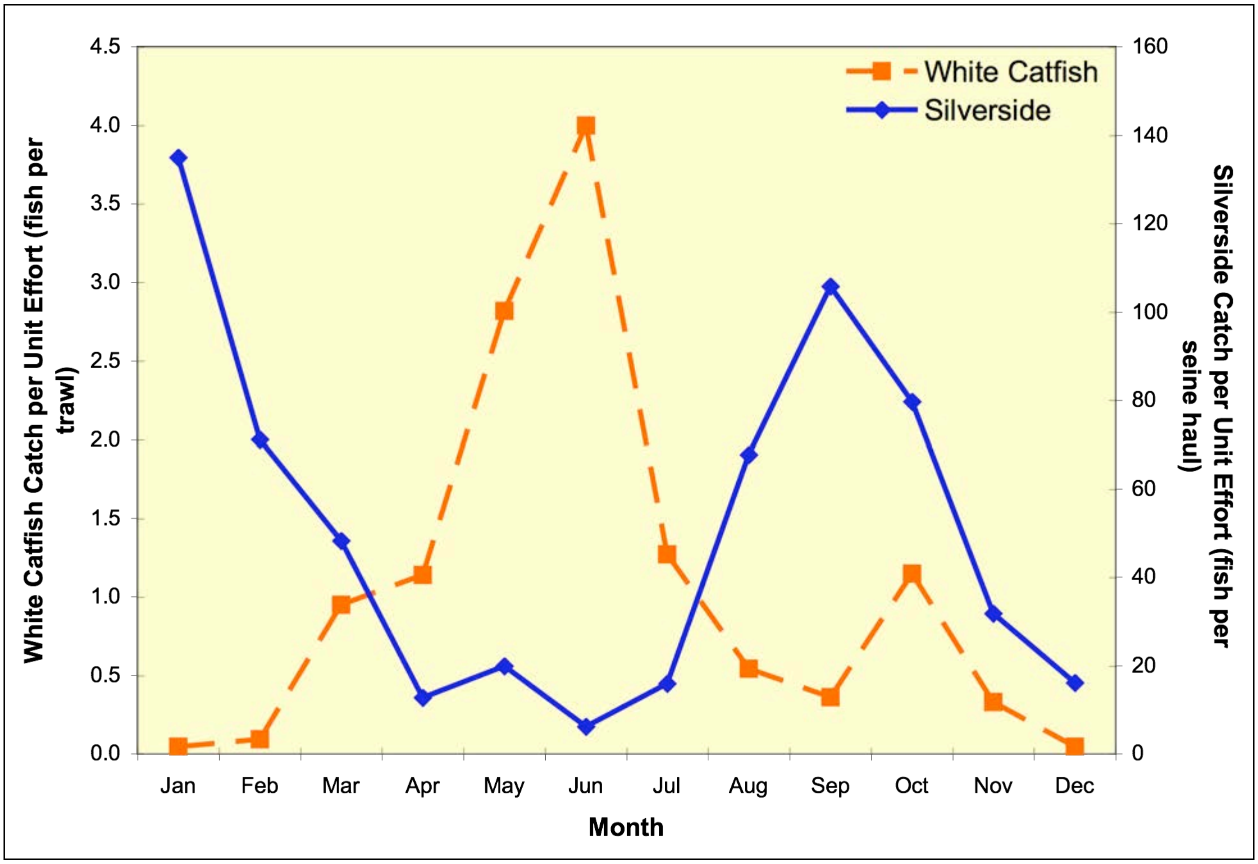


**Figure 25.** Monthly catch per unit effort for Mississippi silversides and white catfish during 2009.

Previous studies in other water-bodies 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.  The pattern in beach seine catches suggests that there are also two major spawning peaks in the marsh (O'Rear and Moyle 2009).  2009 appeared to follow this trend, with substantial catches of mature fish (i.e., larger than 50 mm SL; Middaugh and Hemmer 1992, Hubbs 1982) in April, May, September, and October; and the appearance of young-of-year fish in June and December (Figure 26).  Unlike in 2008, life-history events in Denverton and upper Suisun sloughs occurred simultaneously (e.g., young-of-year were first caught in June in both sloughs; O'Rear and Moyle 2009).  As in 2008, Denverton Slough during 2009 was substantially warmer than upper Suisun Slough in April (19.9°C and 17.9°C, respectively); however, the absolute temperatures for both sloughs were well above that required for silverside reproduction (15°C; Hubbs 1982) and thus may have accounted for the synchrony of the two sloughs.  One noticeable anomaly was a giant catch made in upper Suisun during January, a large proportion of which consisted of mature fish (Figure 25).

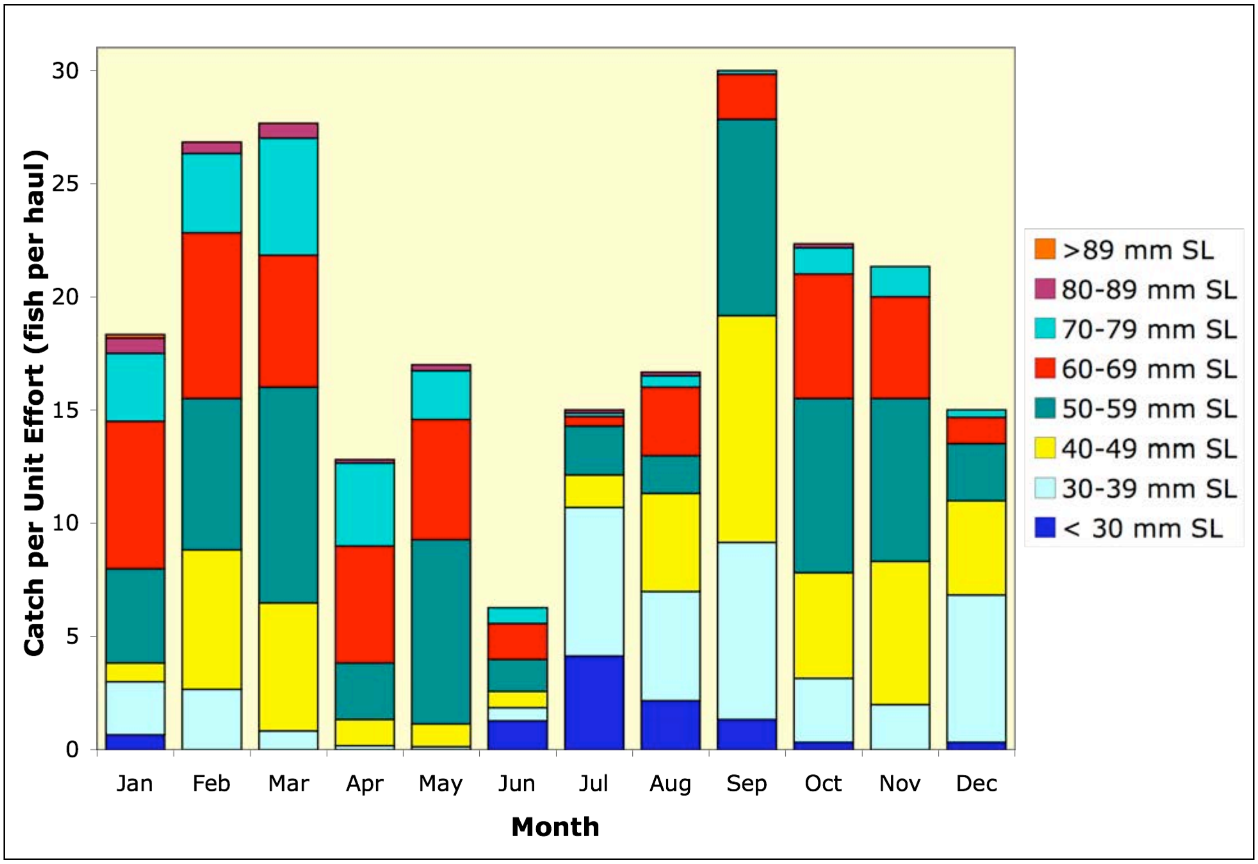


**Figure 26.** Monthly catch per unit effort for size-classes of Mississippi silversides during 2009.

## CONCLUSIONS

Suisun Marsh continues to support a diverse fish and macroinvertebrate fauna, with 27 species of fish captured in 2009. Otter trawl catches increased from 2008 to 2009, mainly due to greater recruitment of fishes with pelagic larvae (i.e., American shad, yellowfin goby, striped bass). Threadfin shad, Delta smelt, and longfin smelt continued to be rare, while striped bass and American shad were relatively more common. Additionally, three of four common macroinvertebrates also became more abundant. However, beach seine catches declined, primarily because of lower numbers of the species that contributed most strongly to the greater otter trawl catches. These catches were most likely due to larger and more variable Delta outflows spanning the recruitment period of fishes with pelagic larvae, coupled with ample pelagic food supplies.

While our monthly sampling schedule yields data that provide valuable insights on seasonal ecological patterns, its frequency and timing generally give information on average, not extreme, conditions. Consequently, extreme events that more negatively affect fishes may not be clearly evident in our data. This was not the case in October, when our sampling coincided with factors leading to anoxic water and thus allowed us to witness a large fish kill in one slough. Fish communities in smaller sloughs with dense duck pond diversions and outfalls are usually dominated by low-oxygen-tolerant fishes (see O'Rear and Moyle 2009), although whether these communities are due to less-tolerant fishes being killed by or moving out of areas with poor water quality remains unknown. However, the fish kill in Goodyear Slough suggests that asphyxia might be important in determining the composition of the fish communities, indicating that the effects of low oxygen concentrations on fishes may be more severe than our data show.

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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 2009.

| Common Name | Scientific Name | Otter Trawl | Beach Seine | Midwater Trawl | All Gear Types |
|---|---|---|---|---|---|
| American shad | *Alosa sapidissima* | 986 | 188 | | 1174 |
| bay pipefish | *Sygnathus leptorhynchus* | 2 | | | 2 |
| bigscale logperch | *Percina macrolepida* | 17 | 2 | | 19 |
| black bullhead | *Ameiurus melas* | 854 | 3 | | 857 |
| black crappie | *Pomoxis nigromaculatus* | 1783 | 81 | 1 | 1865 |
| bluegill | *Lepomis macrochirus* | 19 | 18 | | 37 |
| brown bullhead | *Ameiurus nebulosus* | 28 | | | 28 |
| California halibut | *Paralichthys californicus* | 5 | | | 5 |
| channel catfish | *Ictalurus punctatus* | 164 | 6 | | 17 |
| Chinook salmon | *Oncorhynchus tshawytscha* | 72 | 383 | 1 | 456 |
| common carp | *Cyprinus carpio* | 4674 | 46 | 1 | 581 |
| Delta smelt | *Hypomesus transpacificus* | 625 | 135 | 4 | 764 |
| fathead minnow | *Pimephales promelas* | 28 | 34 | | 62 |
| golden shiner | *Notemigonus crysoleucas* | 5 | 3 | | 8 |
| goldfish | *Carassius auratus* | 289 | 42 | | 331 |
| green sturgeon | *Acipenser medirostris* | 3 | | | 3 |
| green sunfish | *Lepomis cyanellus* | 5 | 3 | | 8 |
| hardhead | *Mylopharadon conocephalus* | 1 | | | 1 |
| hitch | *Lavinia exilicauda* | 114 | 16 | | 13 |
| largemouth bass | *Micropterus salmoides* | | 1 | | 1 |
| longfin smelt | *Spirinchus thaleichthys* | 11266 | 41 | 5 | 11312 |
| longjaw mudsucker | *Gillichthys mirabilis* | 1 | | | 1 |
| Mississippi silverside | *Menidia audens* | 627 | 71761 | | 72388 |
| mosquitofish | *Gambusia affinis* | 18 | 27 | | 288 |
| northern anchovy | *Engraulis mordax* | 257 | | 37 | 294 |
| Pacific herring | *Clupea harengeus* | 457 | 115 | | 572 |
| Pacific lamprey | *Lampetra tridentata* | 43 | | | 43 |
| Pacific sanddab | *Citharichthys sordidas* | 2 | 2 | | 4 |
| plainfin midshipman | *Porichthys notatus* | 11 | | | 11 |
| prickly sculpin | *Cottus asper* | 95 | 848 | 1 | 1349 |
| rainbow trout | *Oncorhynchus mykiss* | 7 | 4 | | 11 |
| rainwater killifish | *Lucania parva* | 27 | 91 | | 118 |
| redear sunfish | *Lepomis microlophus* | 2 | | | 2 |
| Sacramento blackfish | *Orthodon macrolepidotus* | 24 | 116 | | 14 |
| Sacramento pikeminnow | *Ptychocheilus grandis* | 133 | 213 | | 346 |
| Sacramento sucker | *Catostomus occidentalis* | 352 | 96 | 5 | 3153 |
| shimofuri goby | *Tridentiger bifasciatus* | 915 | 236 | 1 | 11142 |
| shiner perch | *Cymatogaster aggregata* | 17 | | | 17 |
| shokihaze goby | *Tridentiger barbatus* | 486 | 2 | 6 | 494 |
| speckled sanddab | *Citharichthys stigmaeus* | 3 | | | 3 |
| splittail | *Pogonichthys macrolepidotus* | 21789 | 2758 | 14 | 24561 |
| staghorn sculpin | *Leptocottus armatus* | 2298 | 3143 | | 5441 |

| Common Name | Scientific Name | Otter Trawl | Beach Seine | Midwater Trawl | All Gear Types |
|---|---|---|---|---|---|
| starry flounder | *Platichthys stellatus* | 1863 | 259 | 4 | 2126 |
| striped bass | *Morone saxatilis* | 7773 | 1195 | 3 | 89638 |
| surf smelt | *Hypomesus pretiosus* | 5 | | | 5 |
| threadfin shad | *Dorosoma petenense* | 2525 | 4915 | 1 | 7441 |
| threespine stickleback | *Gasterosteus aculeatus* | 16473 | 4311 | 6 | 279 |
| tule perch | *Hysterocarpus traski* | 17429 | 1871 | 6 | 1936 |
| wakasagi | *Hypomesus nipponensis* | 1 | 6 | | 16 |
| warmouth | *Lepomis gulosus* | 1 | | | 1 |
| white catfish | *Ameiurus catus* | 423 | 18 | 13 | 4144 |
| white crappie | *Pomoxis annularis* | 112 | | | 112 |
| white croaker | *Genyonemus lineatus* | 1 | | | 1 |
| white sturgeon | *Acipenser transmontanus* | 15 | | 2 | 17 |
| yellowfin goby | *Acanthogobius flavimanus* | 1863 | 1539 | | 33912 |
| Total | | 27652 | 12151 | 138 | 329291 |

# APPENDIX B

Total 2009 otter trawl catch of each fish species in each slough of Suisun Marsh (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).

| Species | Slough | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BY | CO | DV | GY | LSU | MZ | NS | PT | SB | USU | |
| American shad | | | 5 | 29 | 53 | 5 | 7 | 2 | 3 | 1 | 105 |
| black bullhead | 1 | | | | | | | 4 | | 1 | 6 |
| black crappie | | | 6 | | | | 1 | | | | 7 |
| Clupeidae unknown | | 2 | | | 2 | 1 | | | | | 5 |
| common carp | 14 | 1 | 45 | 5 | | | 13 | 14 | 9 | 3 | 104 |
| Delta smelt | | | | | 1 | | | 1 | 1 | 1 | 4 |
| fathead minnow | 1 | | | | | | | | 1 | | 2 |
| goldfish | 7 | | 1 | 1 | | | | 3 | | | 12 |
| longfin smelt | | | | 18 | 66 | | 4 | 4 | 3 | 1 | 96 |
| Mississippi silverside | 1 | | 1 | 4 | | | 1 | 1 | 16 | | 24 |
| northern anchovy | | | | | 2 | | | | | | 2 |
| prickly sculpin | 3 | 6 | 1 | 17 | 2 | 1 | 6 | 16 | 1 | 3 | 56 |
| rainwater killifish | | | | 2 | 1 | | | | | | 3 |
| Sacramento pikeminnow | | | | | | | | | 1 | | 1 |
| Sacramento sucker | 6 | 8 | 4 | 2 | | 2 | | 8 | 5 | | 35 |
| shimofuri goby | 14 | 7 | 90 | 4 | 1 | 1 | 36 | 26 | 3 | 22 | 204 |
| shokihaze goby | 2 | | 2 | | | 2 | 7 | 3 | | 6 | 22 |
| splittail | 30 | 22 | 20 | 65 | 119 | 45 | 67 | 68 | 36 | 49 | 521 |
| staghorn sculpin | | 1 | 1 | 7 | 14 | 1 | | 1 | 2 | 5 | 32 |
| starry flounder | | | 2 | | 1 | 11 | 3 | | | | 17 |
| striped bass | 95 | 74 | 166 | 114 | 242 | 333 | 164 | 172 | 568 | 66 | 1994 |
| threadfin shad | 2 | 1 | 2 | 1 | 2 | 3 | 3 | | 11 | 4 | 29 |
| threespine stickleback | 1 | 3 | 1 | 78 | 11 | | 1 | 2 | 4 | 2 | 103 |
| tule perch | 47 | 72 | 40 | 10 | 69 | 25 | 109 | 72 | 19 | 13 | 476 |
| white catfish | 47 | 14 | 52 | 1 | 1 | 9 | 27 | 75 | 4 | 46 | 276 |
| white sturgeon | | | | | | | 1 | | | | 1 |
| yellowfin goby | 7 | 11 | 6 | 5 | 14 | 8 | 4 | 11 | 8 | 17 | 91 |
| Total | 278 | 222 | 445 | 363 | 601 | 447 | 454 | 483 | 695 | 240 | 4228 |

Total 2009 beach seine catch for each fish species in Denverton and upper Suisun sloughs.

| Species | Denverton Slough | Upper Suisun Slough | Total |
|---|---|---|---|
| American shad | 7 | 3 | 10 |
| black crappie | 2 | | 2 |
| common carp | 8 | 5 | 13 |
| fathead minnow | | 5 | 5 |
| goldfish | 4 | 9 | 13 |
| longfin smelt | 7 | 2 | 9 |
| Mississippi silverside | 993 | 2715 | 3708 |
| prickly sculpin | 39 | 2 | 41 |
| rainwater killifish | | 2 | 2 |
| Sacramento sucker | | 1 | 1 |
| Sacramento pikeminnow | 1 | | 1 |
| shimofuri goby | 224 | 27 | 251 |
| splittail | 14 | 17 | 31 |

| | | | |
|---|---|---|---|
| staghorn sculpin | 4 | 107 | 111 |
| striped bass | 191 | 86 | 277 |
| threadfin shad | 18 | 3 | 21 |
| threespine stickleback | 40 | 87 | 127 |
| tule perch | 16 | 36 | 52 |
| western mosquitofish | | 1 | 1 |
| white catfish | 2 | 2 | 4 |
| yellowfin gby | 50 | 256 | 306 |
| Total | 1620 | 3366 | 4986 |

# APPENDIX C

Number of otter trawls for each slough and each month in 2009.

| Slough | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boynton | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 24 |
| Cutoff | 2 | 2 | 2 | 2 | 2 | 2 | 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 | 1 | 2 | 2 | 23 |
| Goodyear | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 35 |
| Lower Suisun | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 24 |
| Montezuma | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 24 |
| Nurse | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 24 |
| Peytonia | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 29 |
| Upper Suisun | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 25 |
| Total | 21 | 21 | 21 | 21 | 22 | 22 | 22 | 22 | 22 | 20 | 21 | 21 | 256 |

Number of beach seine hauls for each slough and each month in 2009.

| Slough | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Denverton | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 36 |
| Upper Suisun | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 39 |
| Total | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 75 |