Title
Trends in fish populations of Suisun Marsh January 2006 - December 2007.

Authors
O'Rear, Teejay Alexander
Moyle, Peter B

Publication Date
2008

Trends in Fish Populations of Suisun Marsh
January 2006 - December 2007

Annual Report For
Contract
SAP 4600001965
California Department of Water Resources
Sacramento, California

Teejay A. O'Rear and Peter B. Moyle

Department of Wildlife, Fish, and Conservation Biology,
University of California, Davis
December 2008

ABSTRACT

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 began in 1979 and has systematically monitored 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 operation of the Suisun Marsh Salinity Control Gates. Otter trawl catches of native fishes declined considerably from the study's beginning until about 1995; since then, it has stabilized somewhat at relatively low levels. Although the trend was less severe, otter trawl catches of introduced fish also declined until the early 1990s. Since the study's inception, otter trawl catch of introduced fish has been highly variable, primarily due to erratic recruitment. Beach seine catch has gradually increased over the study's history, as the result of rising Mississippi silverside numbers. In 2006, 253 otter trawls and 84 beach seines were conducted; fish per trawl was somewhat above the average for all years, while fish per seine was the highest recorded in the study's history. In 2007, 282 otter trawls and 80 beach seines were conducted; beach seine and otter trawl catches were relatively low. High catches of a few introduced species in 2006 and their subsequent decline in numbers in 2007 were the primary determinants of otter and beach seine catch per unit effort values for both years. Most fishes peaked in abundance in the warmer months, mainly due to influxes of young-of-year; recruitment appeared much higher in 2006 than in 2007. Catch of many species plummeted in late summer concurrent with increasing numbers of Black Sea jellyfish (*Maeotias marginata*).

INTRODUCTION

Suisun Marsh is a brackish-water marsh bordering the northern edge of Suisun Bay in the San Francisco Estuary; it is the largest contiguous estuarine marsh remaining in the 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 latitudinal location in the San Francisco Estuary makes it an important rearing area for euryhaline freshwater, estuarine, and marine fishes.

Peter B. Moyle initiated the University of California, Davis Suisun Marsh Fish Study in 1979 to monitor the fish community in the context of anthropogenic changes in estuary hydrology (e.g., water exports). In 1980, the study became systematic with monthly samples at fixed locations around the marsh. Since its inception, the study has focused on the abundance and distribution of fishes in relation to each other and environmental variables through time. Additionally, a major purpose has been to evaluate the effects on fishes of the Suisun Marsh Salinity Control Gates installed in Montezuma Slough, 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 assemblage was relatively constant through time; however, total fish abundance declined over the five years. The decline was partly the result of strong year classes early in the study period followed by both extremely high river discharges and drought. 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 fish 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.

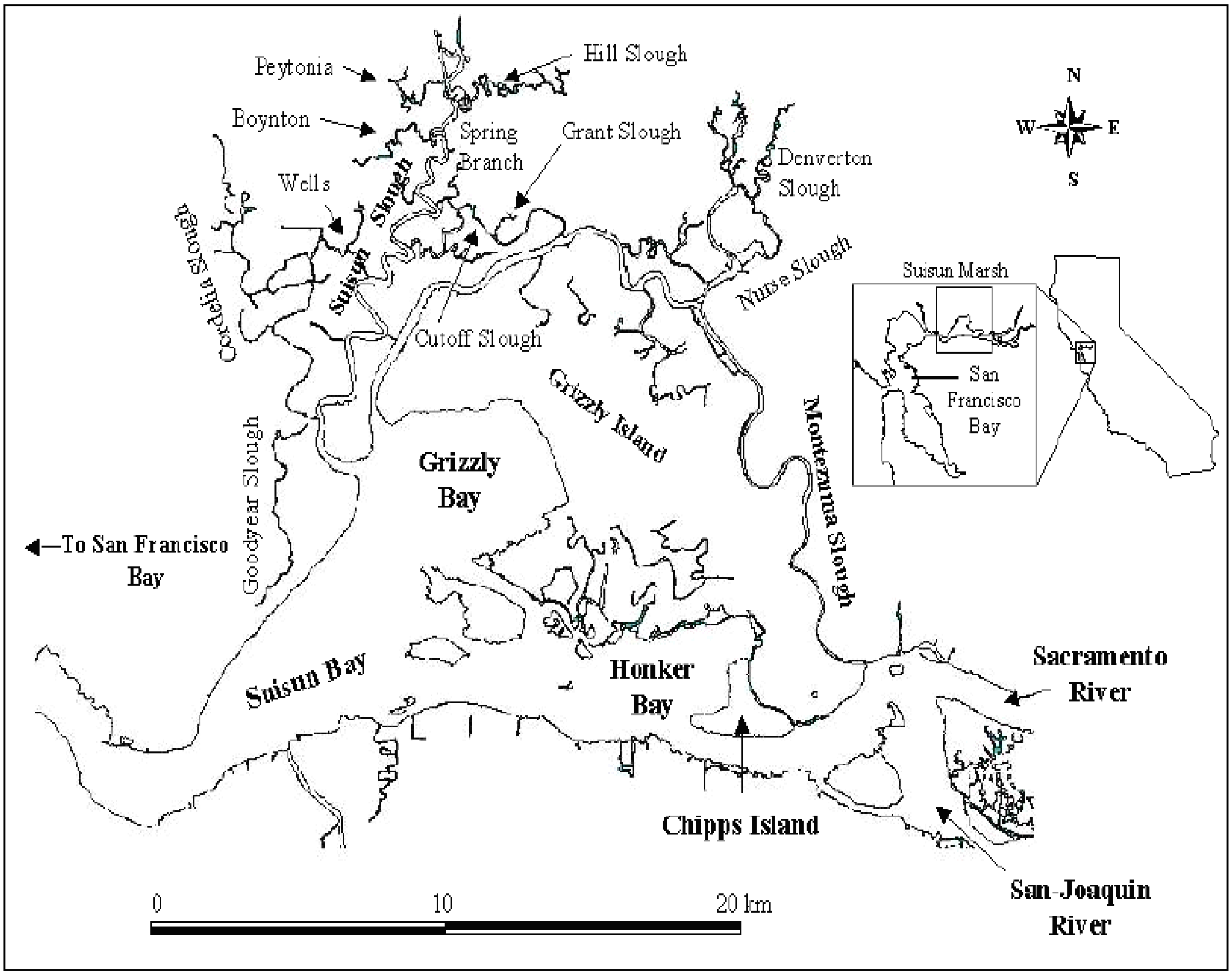

Figure 1. Suisun Marsh and Bay (from Schroeter et al. 2006).

This report updates the results of the Suisun Marsh fish study (Schreoter et al. 2006) through 2007, reporting further on the trends in the fish and macroinvertebrate populations and focusing on 2006 and 2007.

OBJECTIVES

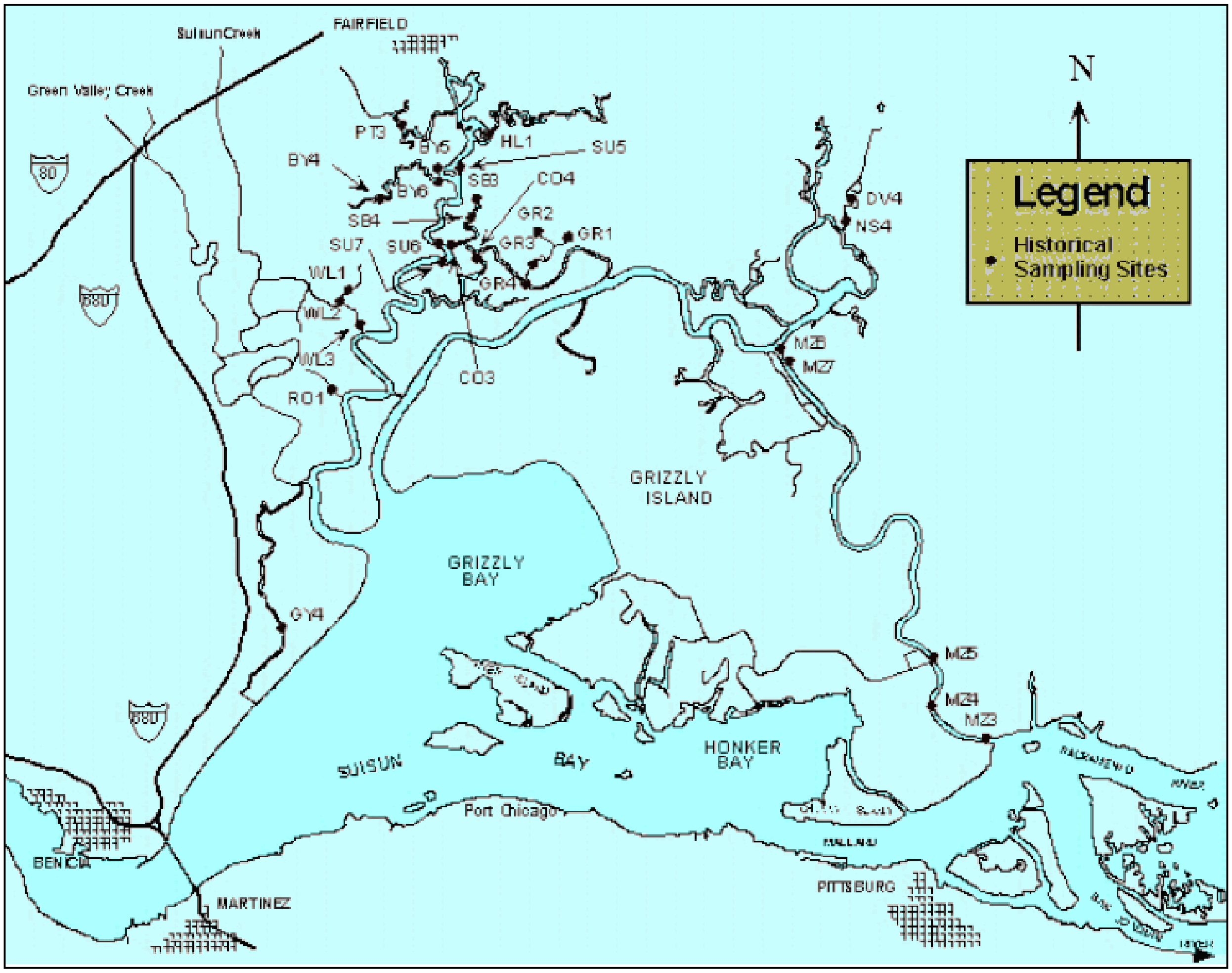

Figure 2. Map of historic Suisun Marsh sampling sites (from Schroeter et al. 2006).

The objectives of the Suisun Marsh fish study are (1) to understand factors determining the abundance, distribution, and assemblage structure of introduced and native fishes, especially in relation to environmental variables; (2) to 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., 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 first hand; 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.

STUDY AREA

Suisun Marsh is a tidally influenced brackish-water marsh covering about 34,000 hectares (California Department of Water Resources 2001). Roughly two-thirds of the marsh

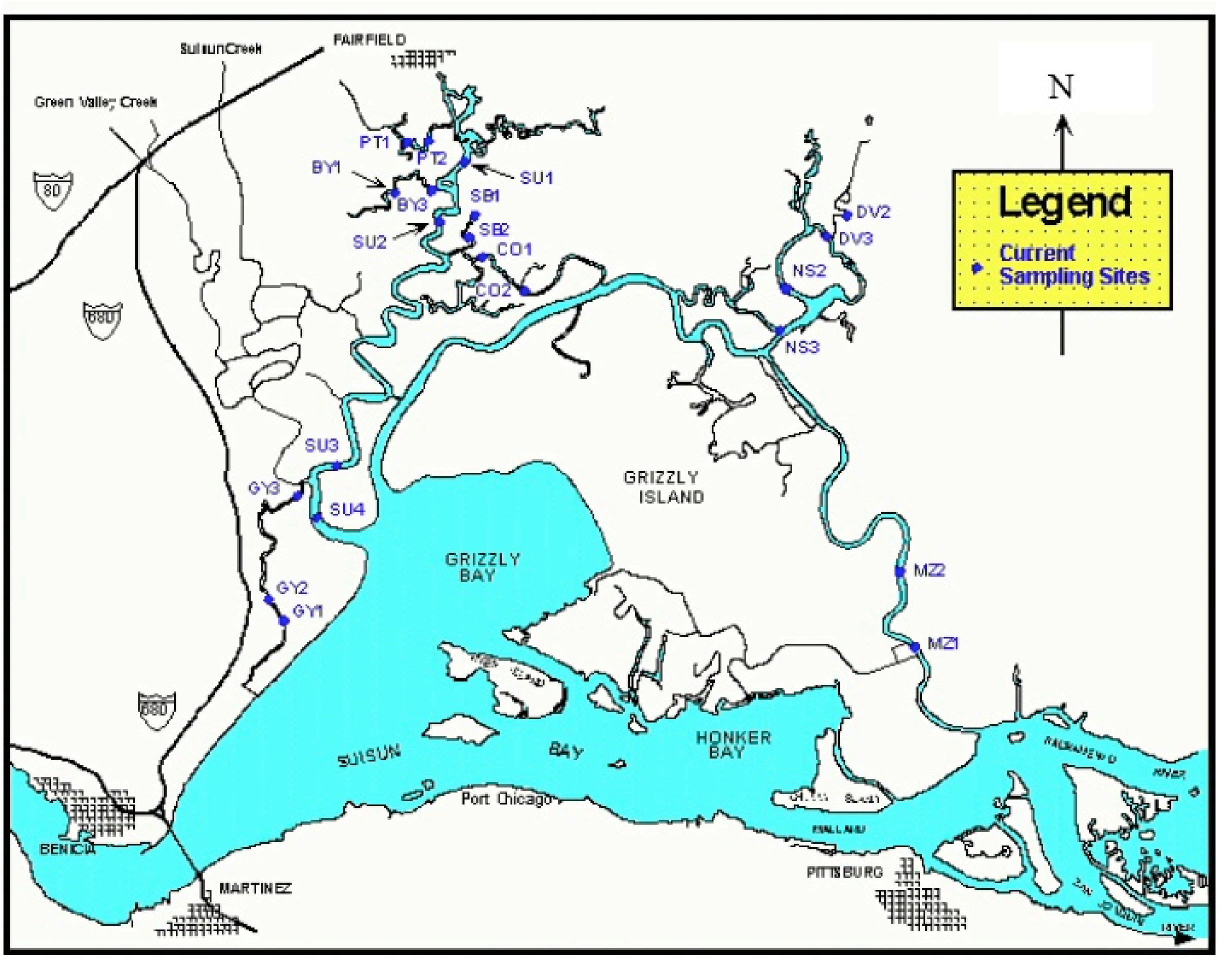

Figure 3. Map of current Suisun Marsh sampling sites (from Schroeter et al. 2006).

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).

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, and Goodyear sloughs (Figure 1). First and Second Mallard sloughs are tributary to Cutoff Slough and are part of the 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 m wide, 2-4 m deep, and partially rip-rapped (Meng et al. 1994). Tributary sloughs are usually 7-10 m wide, 1-2 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 composed of coarser materials (e.g., Denverton Slough).

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 northwest sides of the marsh, also contribute fresh water. As a result, salinities are generally lower in the eastern and northern 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. 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 effect the timing and magnitude of freshwater inflow into Suisun Marsh. 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 at high tides and provide fresh water primarily for diked wetlands (California Department of Water Resources 2001; Figure 1). Numerous diversion intakes are located throughout the marsh; they are most commonly operated in early fall for flooding wetlands to

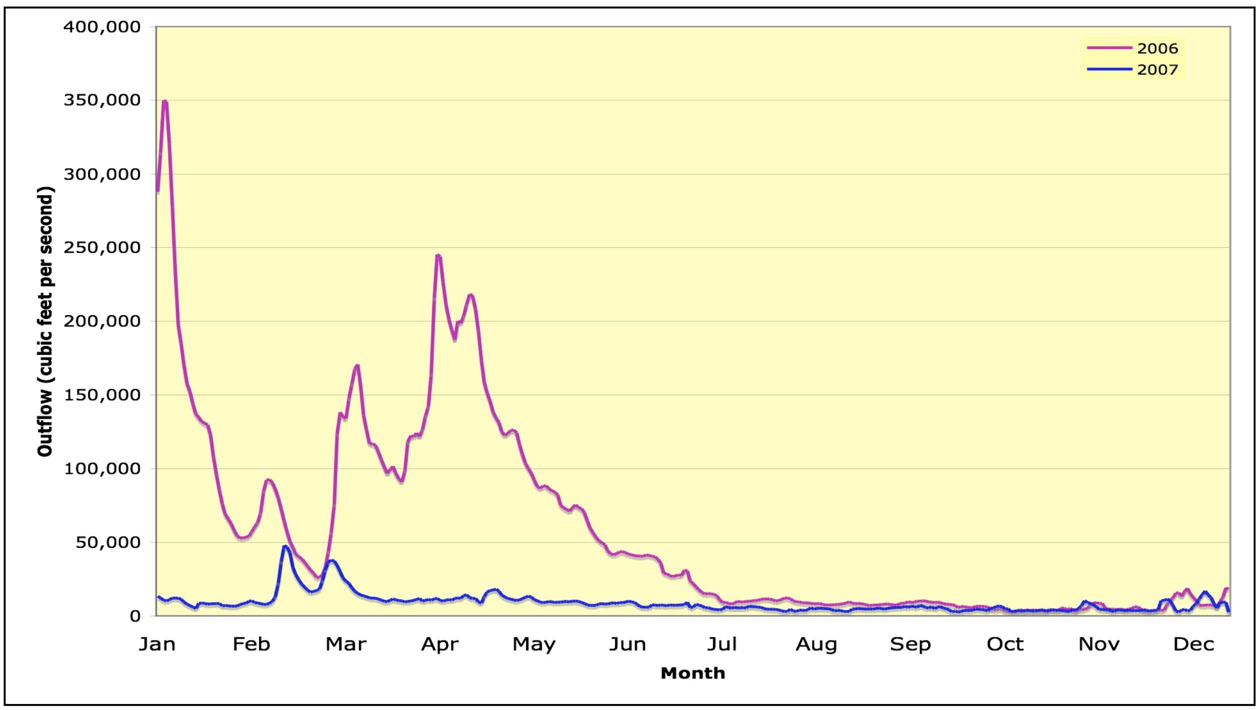

Figure 4. Daily Delta outflow for 2006 and 2007 (http://www.usbr.gov/mp/cvo/vungvari/doutdly.prn).

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 (Figure 2). Several of these historic sites were sampled only in 1980 and 1981, with 17 sites being sampled consistently until 1994. From 1994 to the present, 21 sites in 9 sloughs have been regularly sampled (Figure 3). Latitude and longitude coordinates for currently sampled sites were obtained (± 100 m) using a Global Positioning System receiver (adjustments made by Alan Kilgore of the California Department of Fish and Game's Technical Services Branch GIS) and are found in Schroeter et al. (2006). Data from all years and sites are included in this report to facilitate comparisons.

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. In 2007, midwater trawling was conducted from late spring through autumn in Montezuma, Suisun, and Nurse sloughs with the same net as that used for otter trawling; horizontal plates were placed on top of the doors in order to elevate the net. 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; midwater trawls were towed for 5 minutes. In 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 tidal stage (incoming, high, outgoing, low), temperature (degrees Celsius, °C), salinity (parts per thousand, ppt), specific conductance (microsiemens, µS), and water transparency (Secchi depth, cm) were recorded. Dissolved oxygen parameters (mg/l and % saturation), first sampled in 2000, were also recorded.

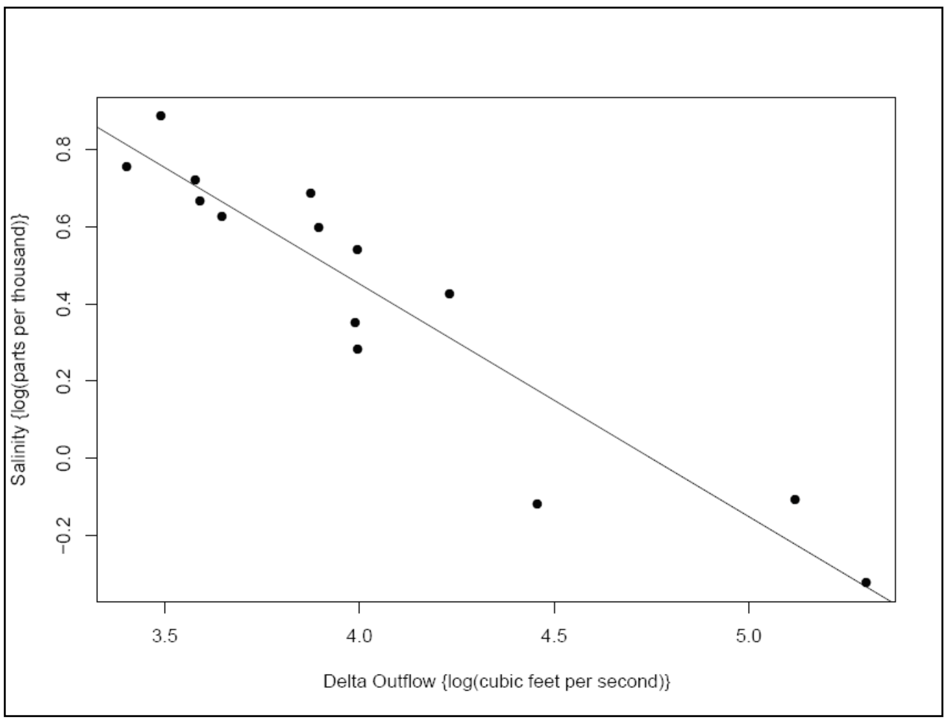

Figure 5. Relationship between Delta outflow and salinity for randomly selected days in 2006 and 2007 {log(parts per thousand) = 2.86 - 0.60log(cubic feet per second); $R^2 = 0.87$; $p < 0.01$; $n = 13$}.

Contents of each trawl or seine were placed into large containers of water. Fishes were identified, measured to the nearest mm standard length, and returned to the water. When possible, 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*), Chinese mitten crab (*Eriocheir sinensis*), 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 and Oriental shrimp 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. Mitten crab were sexed and measured to the nearest mm maximum carapace width.

All data collected by the study is available on the Bay Delta and Tributaries website (http://bdat.ca.gov/).

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

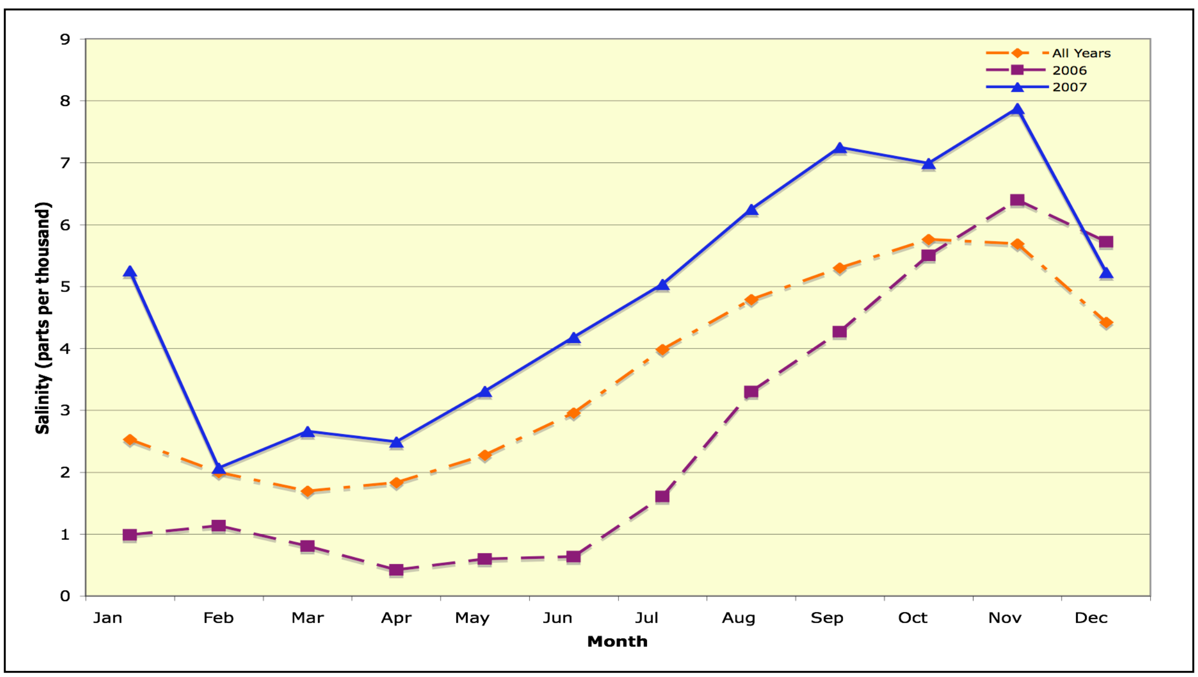

Figure 6. Average monthly salinities in Suisun Marsh for 2006, 2007, and all years (1980-2007).

Suisun Marsh.

Delta outflow in 2006 was relatively large, reflecting the wet year (Figure 4). A series of warm, wet storms pounded Northern California at the end of December 2005, leading to a high Delta runoff with a short lag time and steep receding limb in early January 2006. Twice the average monthly precipitation in the northern part of the state in March increased Delta outflow, although with cooler than average temperatures much of the precipitation was stored in the snowpack. However, heavy precipitation continued into April; high river discharges, especially in the San Joaquin River, resulted in substantial Delta outflows. Unseasonably warm temperatures in May led to melting of the large snowpack and high Delta outflows that lasted into July. Delta outflows then declined gradually until storms in mid- and late December both elevated outflow to a peak of about 18,000 cubic feet per second (cfs).

2007 was considerably drier than 2006, resulting in comparatively low Delta outflow for much of the year. Only in February did outflows increase substantially: once in the early part of the month, when a low-pressure system poured rain on Northern California; and at the end of the month, when cold storms dumped snow in the mountains and rain in the valleys. A few storms at the beginning and end of December elevated Delta outflow, although much less than the February storms and for shorter periods.

Salinity

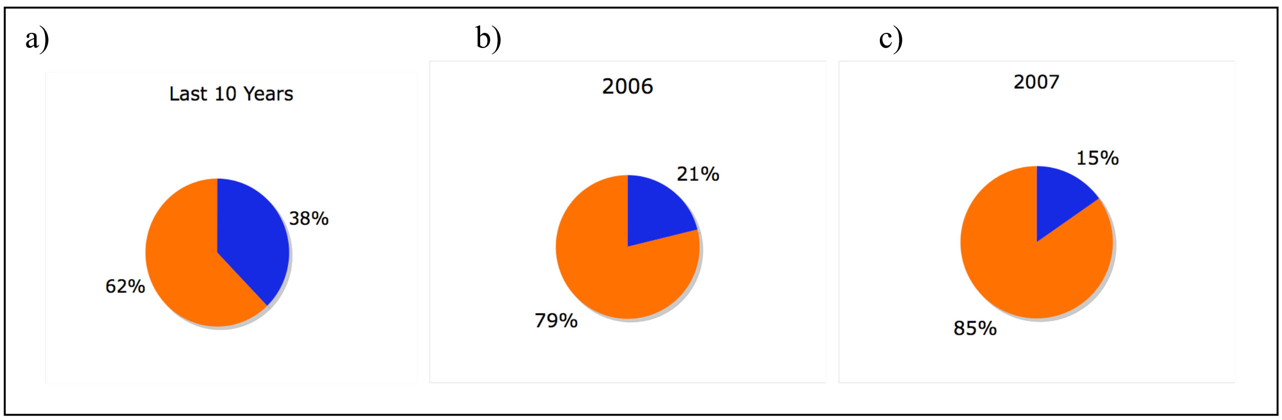

Figure 7. Percentage of days (in blue) X2 was within Suisun Bay for a) the last 10 years (i.e., 1997 to 2007), b) 2006, and c) 2007.

Salinities in Suisun Marsh are strongly inversely correlated with Delta outflow (Figure 5). Consistent with the wet year, monthly average salinities in 2006 were generally lower than the 27-year mean monthly salinities (Figure 6). However, average salinities in November and December 2006 were greater than that of the 27-year averages, likely a result of low Delta inflows and high exports at the State Water Project and Central Valley Project pumping facilities in the South Delta.

As expected with the dry year, 2007 salinities in Suisun Marsh were generally greater than the 27-year average and 2006 values (Figure 6). However, salinity in December 2007 was less than in December 2006, which is surprising since the average Delta outflow in December 2006 was over 2,000 cfs greater than in December 2007 (9,317 versus 7,249). This discrepancy is best explained by operation of the Suisun Marsh Salinity Control Gates. The gates were tidally operated from December 1 to December 17, while our sampling occurred from December

17-19. Conversely, the Suisun Marsh Salinity Control Gates were open for the entire month of December 2006. Thus, our lower salinity measurements in December 2007 probably reflected low saline marsh water artificially induced by gate operations.

Salinities in Suisun Marsh generally increase from east to west and north to south, with the highest salinities consequently found in the southwestern portion of the marsh (i.e., lower Suisun and Goodyear sloughs). This pattern was followed in both 2006 and 2007, with the highest yearly average salinities measured in lower Suisun and Goodyear sloughs (Table 1). As expected, salinities were higher for all sloughs in 2007 than in 2006 (Table 1).

Table 1. Average yearly salinities (sample sizes in parentheses) for sampled sloughs in 2006 and 2007 (MZ = Montezuma, NS = Nurse, DV = Denverton, CO = Cutoff, SB = First Mallard, PT = Peytonia, BY = Boynton, GY = Goodyear, SU1+2 = Upper Suisun, and SU3+4 = Lower Suisun; see Figure 3 for slough locations).

Slough	MZ	NS	DV	CO	SB	PT	BY	GY	SU1+2	SU3+4
Mean 2006 Salinity	1.69 (25)	2.59 (24)	2.55 (24)	2.54 (24)	2.31 (24)	1.57 (24)	1.88 (24)	4.36 (36)	2.13 (24)	3.64 (24)
Mean 2007 Salinity	3.88 (32)	4.54 (23)	5.27 (24)	4.99 (25)	4.59 (26)	3.02 (31)	3.40 (29)	8.30 (35)	4.49 (30)	6.93 (24)

Salinity extremes in 2006 and 2007 were typical for Suisun Marsh and correspond to the commonly observed horizontal salinity gradient discussed above. Salinity maxima occurred in lower Suisun (10.0 ppt) and Goodyear (13.1 ppt) sloughs in autumn of 2006 and 2007, respectively. The freshest water for both years was measured in Montezuma Slough in winter and spring concomitant with high Delta outflows.

The location of X2, the distance in kilometers from Golden Gate Bridge along the

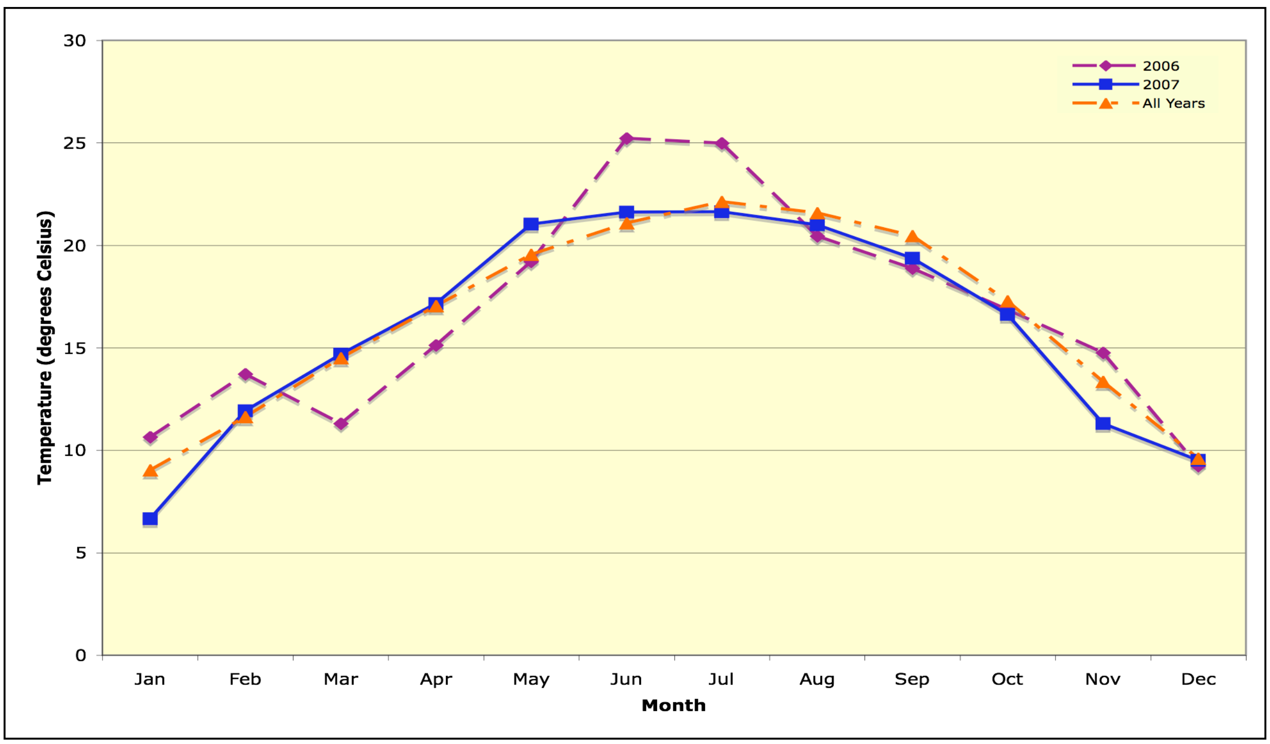

Figure 8. Monthly average temperatures in Suisun Marsh for 2006, 2007, and all years (1980-2007).

thalweg to the near-bed water with a salinity of 2 ppt, is associated with the 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.

The average percentage of days X2 has been located each year in Suisun Bay for the last ten years has been 38% (Figure 7). In 2006 and 2007, the number of days X2 was in Suisun Bay was lower than the 10-year average. In 2006, very high Delta outflow early in the year moved X2 seaward out of Suisun Bay; low outflow in late summer and autumn allowed X2 to move upstream past Suisun Bay into the lower Sacramento and San Joaquin rivers. In 2007, lack of high outflow events and generally low outflow kept X2 upstream of Suisun Bay for much of the year.

Temperature

Water temperatures in Suisun Marsh are primarily a function of solar radiation and, to a lesser extent, water volume. Generally, average monthly temperatures follow a pattern typical of temperate regions in the Northern Hemisphere: coldest temperatures occur in winter (December and January) and warmest temperatures occur in summer (July and August).

Average monthly temperatures in 2006 were similar to those for all study years (Figure 8), with the exception of June and July: water temperatures in those two months were above

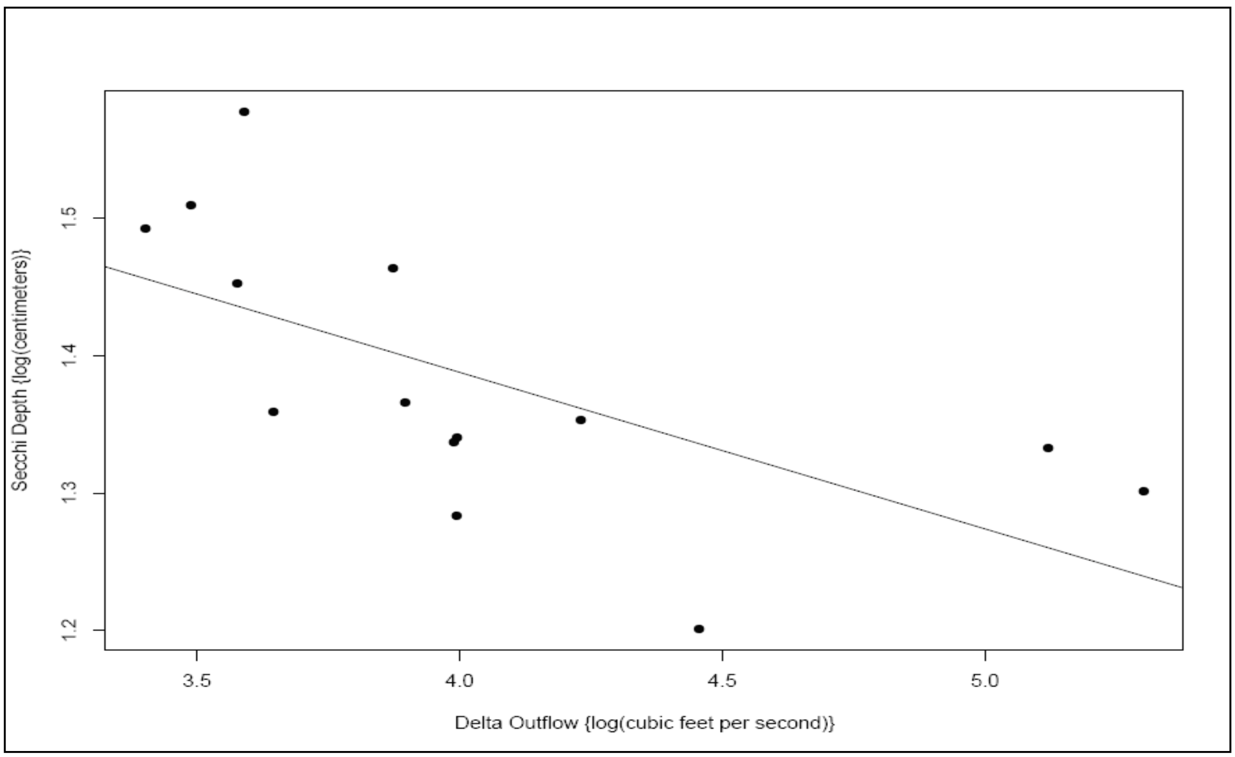

Figure 9. Relationship between Delta outflow and transparency in Suisun Marsh for randomly selected days in 2006 and 2007 {log(centimeters) = 1.84 - 0.11log(cubic feet per second); $R^2 = 0.41$; $p = 0.01$; $n = 12$}.

average, reflecting a heat wave in early summer. Maximum and minimum temperatures in 2006 occurred during the months with the highest and lowest average monthly temperatures (June and

December), respectively: the maximum was recorded on June 22 in First Mallard Slough (32.1°C), while the minimum was recorded on December 19 in Peytonia Slough (7°C).

Average monthly temperatures in 2007 strongly mirrored the average regime (Figure 8). Minimum (4.6°C) and the maximum (23.9°C) temperatures were measured on January 18 in Denverton Slough and on June 18 in Cutoff Slough, respectively. Temperature extremes, as in 2006, occurred in the months with the average highest and lowest temperatures.

Water Transparency

The magnitude of freshwater inflow (mainly from the Sacramento River) is the primary determinant of water transparency in Suisun Marsh (Figure 9). 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. 2006 varied little from this pattern, with the exception of late fall and early winter when Delta outflow was particularly low and transparency was substantially above the November and December averages for all study years (Figure 10).

Although average transparencies in 2007 were slightly higher for most months due to the

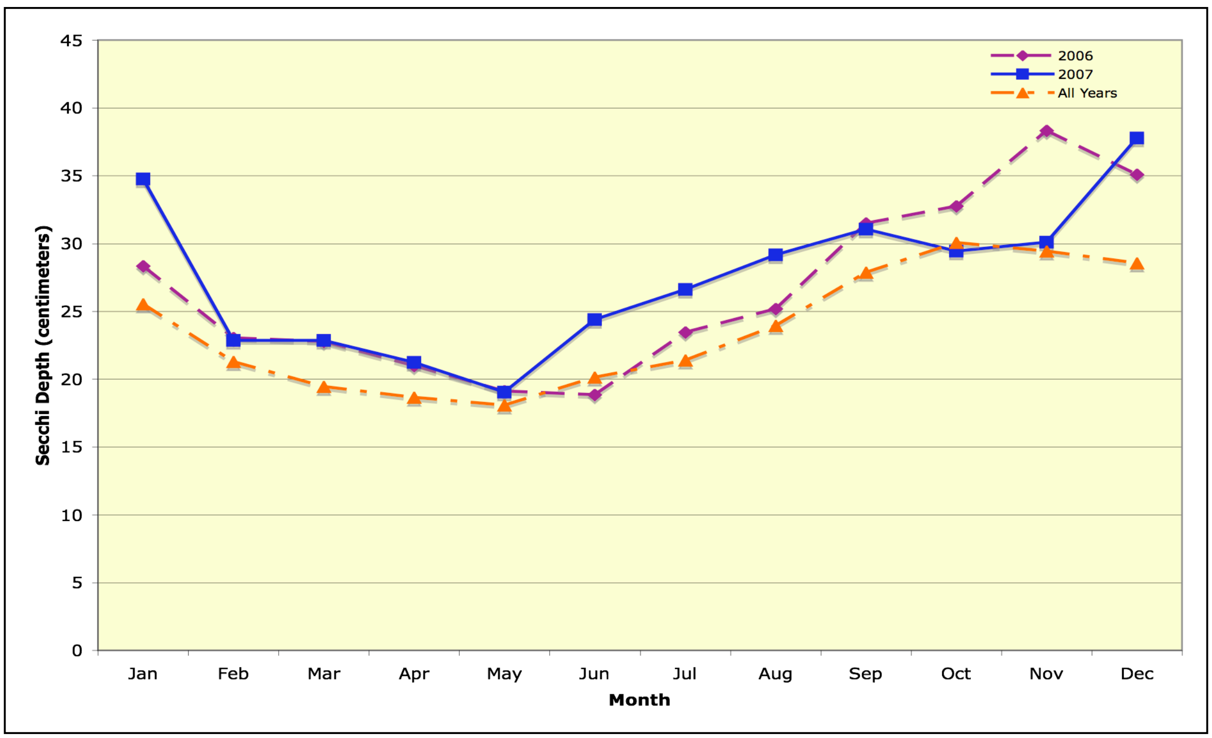

Figure 10. Average monthly transparencies in Suisun Marsh for 2006, 2007, and all years (1980-2007).

dry year, the pattern followed the common annual trend (i.e., transparency was at a minimum in spring and a maximum in autumn; Figure 10). However, transparency was particularly high in December 2007, which somewhat contradicts the salinity data. Transparency and salinity are both negatively correlated to Delta outflow (Figures 5 & 9); thus, closure of the Suisun Marsh Salinity Control Gates may change conditions sufficiently to result in both low salinities and transparencies. However, it is possible that the low, freshwater Delta outflow captured by the gates also had lost most of its sediment load, resulting in high transparency concurrent with low salinity.

Dissolved Oxygen

Dissolved oxygen concentrations in the marsh appear substantially affected by in-marsh duck club operations. Generally, hypoxic water is discharged into sloughs from duck ponds during autumn, lowering oxygen concentrations in the sloughs. Likewise, draining ponds in spring by discharging to the sloughs also depresses marsh oxygen concentrations (R. E. Schroeter, unpublished). Thus, the yearly pattern of marsh oxygen concentrations exhibits sags in spring and autumn (Figure 11).

A pattern similar to the general trend was seen in 2006, in which monthly average oxygen concentrations were lowest in June and November (Figure 11). However, the monthly averages for June and November were substantially lower than June and November monthly averages for the entire study period. It is possible that the very low June value was influenced by above average water temperatures (Figure 8), which lowers dissolved oxygen concentrations by decreasing the solubility of atmospheric oxygen. Low dissolved oxygen in November may have

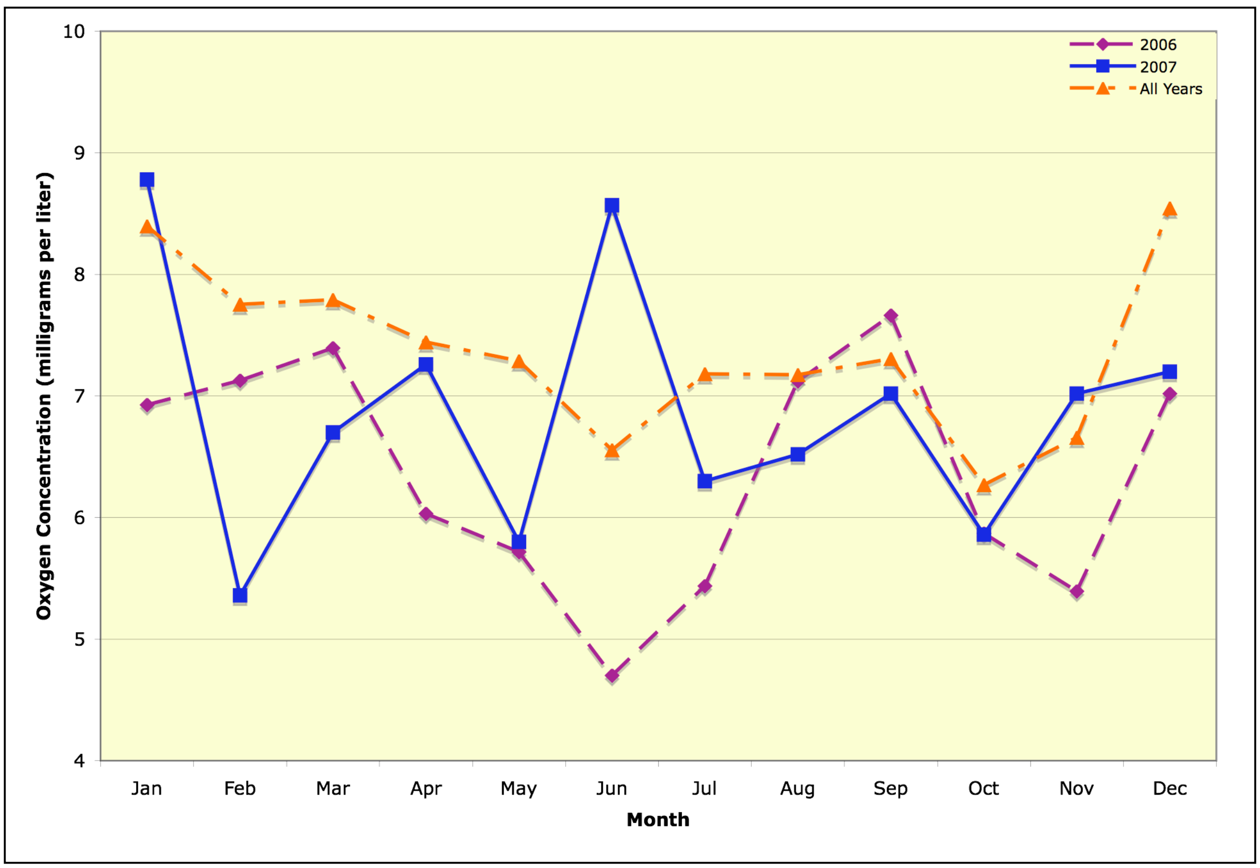

Figure 11. Monthly average dissolved oxygen concentrations in Suisun Marsh for 2006, 2007, and all years (2000 - 2007).

been a result of an inability of the marsh to buffer hypoxic duck pond discharge due to low Delta outflow.

Monthly average oxygen concentrations in 2007 varied from the general trend in two major ways: oxygen concentration was much lower than the average for all years in February and in June it was appreciably higher than that for all years. The initiation of duck pond discharging into the marsh and low Delta outflow could have converged to give rise to the low February value. The high June value could have been due to a phytoplankton bloom that occurred over the sampling period; because our measurements took place during the day, they would have coincided with the daily maximum photosynthetic oxygen production. This explanation is bolstered by several measurements indicating supersaturation taken over the same time period; however, data from a concurrent study does not show any evidence of a phytoplankton bloom in June (A. Parker, San Francisco State University, pers. comm.).

Oxygen concentration dropped below 3 mg/L in 2006 five times; four of the measurements were taken in Goodyear Slough in June or autumn. The minimum oxygen concentration (0.8 mg/L) in 2006 was also recorded in Goodyear Slough. In 2007, oxygen concentration dipped below 3 mg/L six times, with the majority of those measurements recorded in Peytonia Slough during October. The minimum oxygen concentration (0.10 mg/L) in 2007 was measured in Denverton Slough on May 25.

TRENDS IN FISH ABUNDANCE AND DISTRIBUTION

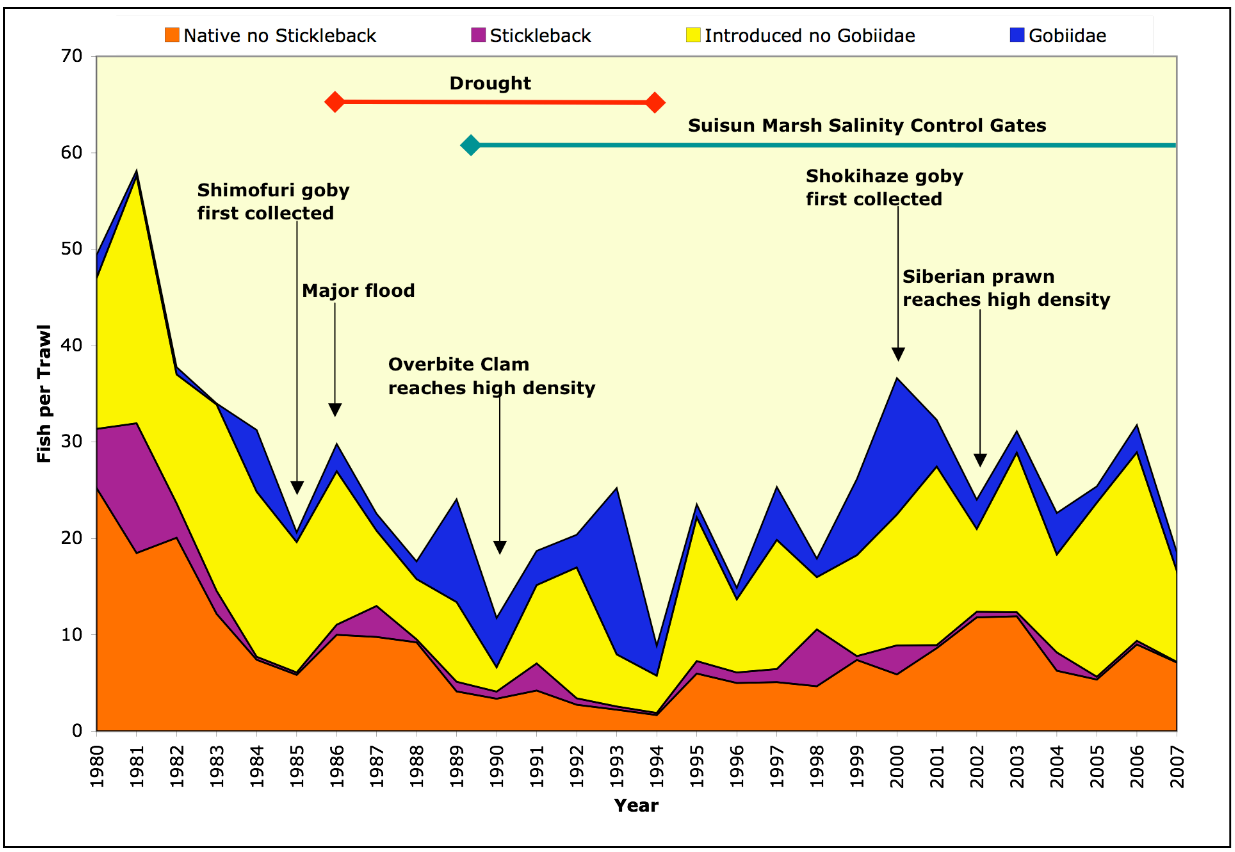

Figure 12. Annual catch per unit effort for native fish without threespine stickleback, threespine stickleback, introduced fish without gobies, and gobies captured by otter trawl in Suisun Marsh from 1980 to 2007, with timing of important marsh events.

Otter Trawls

Yearly total fish catch per trawl has declined from the study's inception to relatively consistent, cyclic catches over the last twenty years (Figure 12). The decrease in native fish catch has been more precipitous and less variable than that for introduced fishes (Figure 13); introduced fish catch has remained highly variable over the entire study period (Figure 14).

Total fish caught per trawl in 2006 was high relative to the last 20 years (Figure 12), although was only slightly above the 28-year average (31.8 versus 29.2 fish per trawl). Introduced fishes were a little more than two-times as abundant as native fishes; however, both increased in numbers compared to 2005. The greater abundance of introduced fishes was primarily due to dramatic increases in five species: black crappie (*Pomoxis nigromaculatus*), black bullhead (*Ameiurus melas*), shimofuri goby (*Tridentiger bifasciatus*), threadfin shad (*Dorosoma petenense*), and white catfish (*Ameiurus catus*; Figure 14). The jump in 2006 native fish numbers was almost solely due to the highest catch of prickly sculpin (*Cottus asper*; Figure 13) seen in the last ten years.

Total catch per trawl in 2007 was substantially lower than both 2006 and the 28-year mean (18.2, 31.8, and 29.2, respectively). The decline in catch from 2006 to 2007 was most severe for introduced species (Figures 12 and 14); with the exception of black bullhead, the catch of all introduced fishes that contributed to 2006's high value decreased considerably (Figure 14).

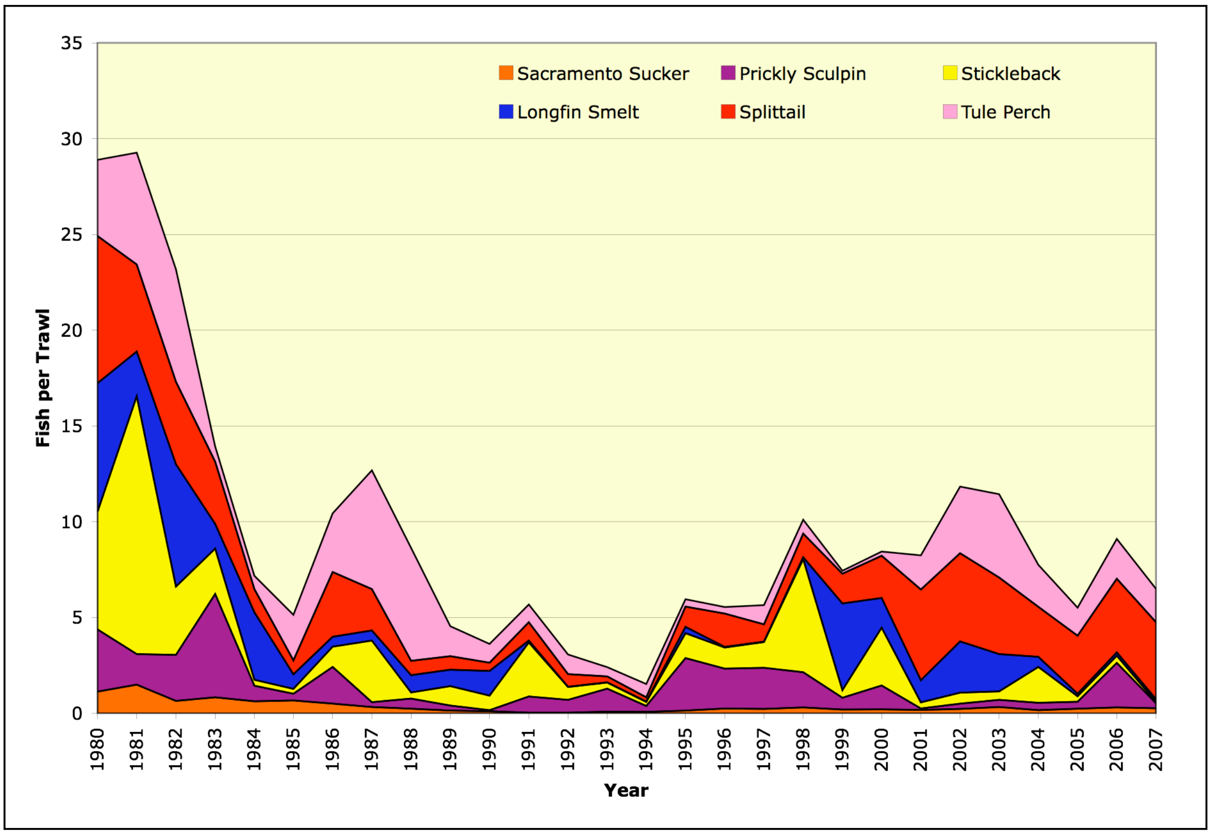

Figure 13. Annual catch per unit effort for the six most commonly caught native fishes captured by otter trawl in Suisun Marsh from 1980 to 2007.

Additionally, catch of striped bass (*Morone saxatilis*) in 2007 was the lowest seen in nine years and thus also contributed to the steep drop in introduced fish catch. The decline in native fish catch from 2006 to 2007 was mainly due to a return of the low catch of prickly sculpin, which has commonly occurred in the last decade.

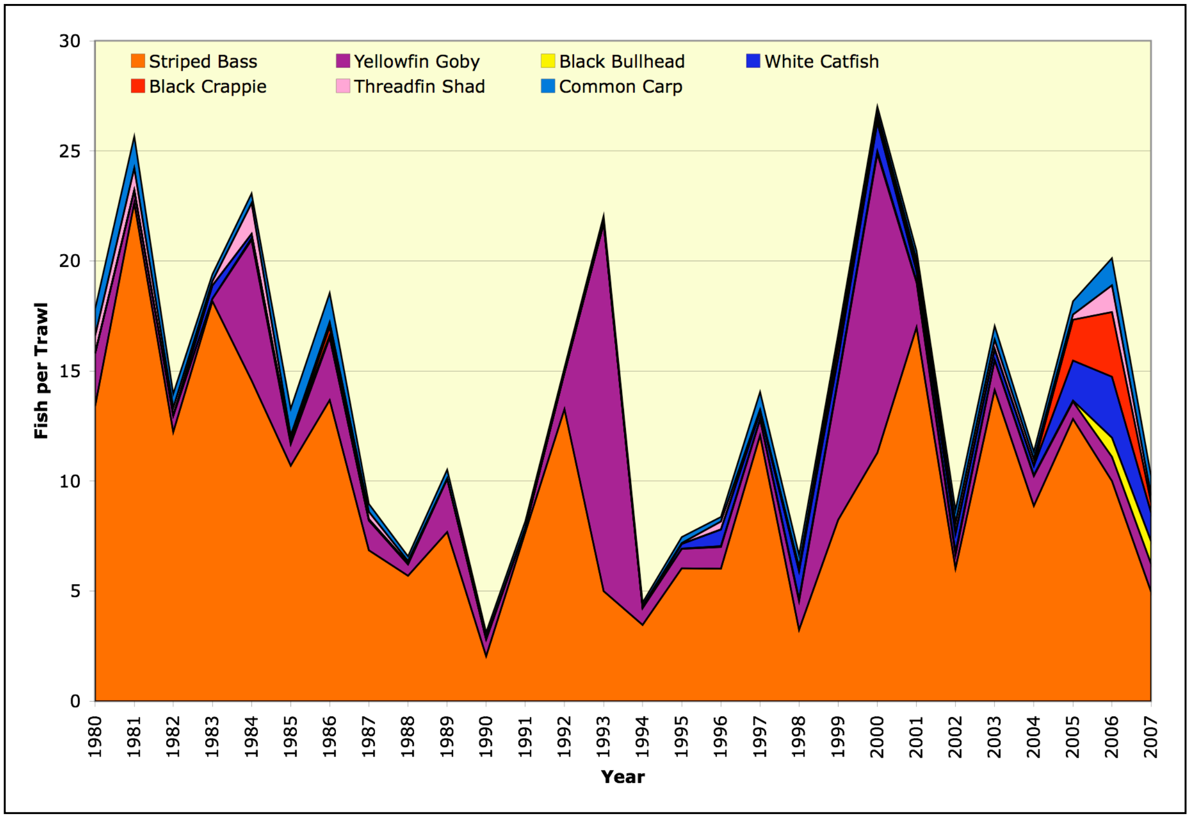

Figure 14. Annual catch per unit effort for the seven most commonly caught introduced fishes captured by otter trawl in Suisun Marsh from 1980 to 2007.

Beach Seines

Unlike otter trawl catches, beach seine catches have increased since the study's inception (Figure 15). Similar to otter trawl catches, variability in native fish catch between years was much less than that for introduced fishes (Figure 15). 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 (*Menidia audens*), have dominated the catch.

The highest catches of Mississippi silverside and threadfin shad ever in the study's history were made in 2006; consequently, the highest total catch per seine haul ever was also recorded in 2006 (Figure 15). The 2006 striped bass catch was also substantial: only three other years had higher values (1981, 1997, and 2005). Consistent with the previous decade, native fish catch was relatively low.

Total beach seine catch per unit effort in 2007 fell substantially compared to 2006, and was below the 28-year average annual total catch per seine haul (43.61 versus 56.33). Threadfin shad, Mississippi silverside, striped bass, and splittail (*Pogonichthys macrolepidotus*) were the primary drivers for the low 2007 value: catch for all species decreased severely. Consistent with the dry year and generally more saline water, only one species - yellowfin goby (*Acanthogobius flavimanus*) - increased noticeably from 2006 to 2007 (1.92 versus 4.84 fish per seine haul)

.

Midwater Trawls

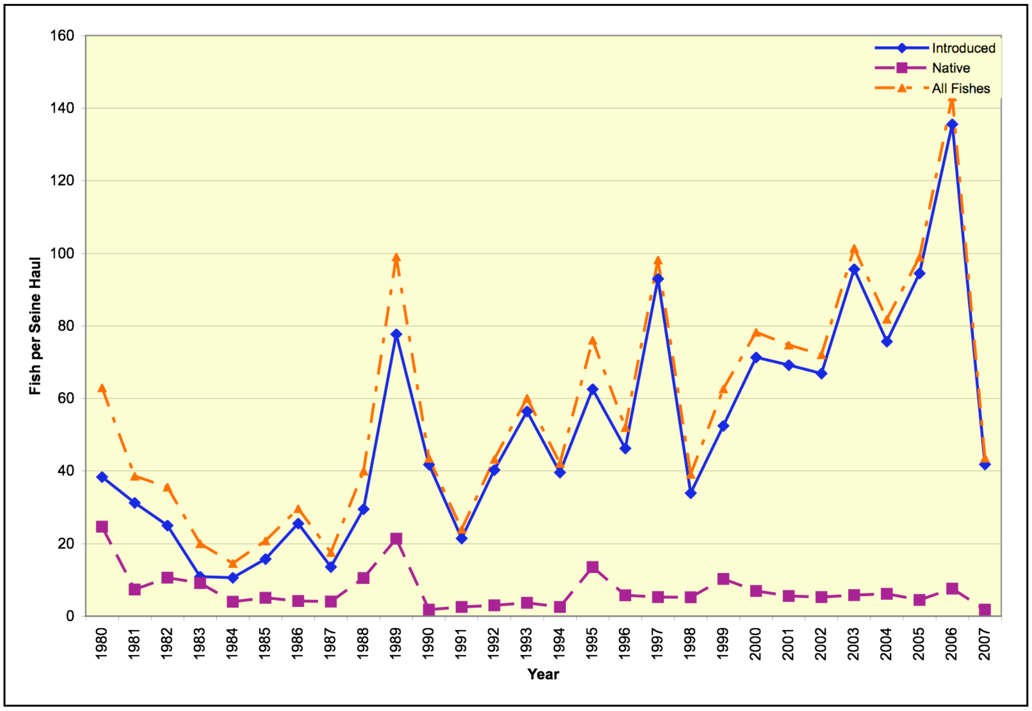

Figure 15. Annual catch per unit effort for introduced, native, and all fishes captured by beach seine in Suisun Marsh from 1980 to 2007.

Very few fishes were captured in the 2007 midwater trawls; of 31 midwater trawls deployed, only 17 captured fish. The most frequently caught fish was striped bass, of which only 12 were captured during the entire year - eight of those fish were captured in one trawl in upper Suisun Slough in July. Only two other noteworthy catches were made: 11 white catfish caught in three trawls, all of which were probably netted on the bottom at the beginning of the trawls as the net rose into the water column; and two subadult Delta smelt (*Hypomesus transpacificus*), which were captured in late November in lower Suisun Slough.

Species Accounts

Clupeidae

Threadfin Shad

Otter trawl catches of threadfin shad were relatively high in the first five years of the study, declined to very low levels during the dry late 1980s and early 1990s, and generally increased from 1996 to the present (Figure 16). Threadfin shad captured by otter trawls have usually been larger than those caught by beach seine (Table 2), perhaps due to a lower capture efficiency of small young-of-year by the otter trawl.

The 2006 otter trawl catch per unit effort for threadfin shad was the second highest ever recorded (Figure 16). Most of the shad were captured in three sloughs: First Mallard, Peytonia, and Cutoff (5.0, 3.0, and 1.8 fish per trawl, respectively). The majority of fish caught by otter trawling occurred in autumn and early winter after the high late summer beach seine catches

(Figure 17). Additionally, otter trawl-caught threadfin shad were larger than fish caught with beach seines in both 2006 and 2007 (Table 2). Consequently, it is possible that threadfin shad moved from near-shore areas to deeper channel habitats as summer progressed to autumn.

The 2007 otter trawl catch of threadfin shad declined and essentially returned to the 27-year average (0.3 per trawl; Figure 16). The spatiotemporal pattern of threadfin shad catch in 2007 was similar to that of 2006: most fish were captured in early winter and autumn in First Mallard, Peytonia, and Cutoff sloughs (although the second highest catch was recorded in Nurse Slough); and threadfin shad captured in otter trawls were considerably larger than those seined in 2007 (Table 2).

Table 2. Mean standard lengths in mm (sample sizes in parentheses) of threadfin shad captured by beach seine and otter trawl for 2006, 2007, and all years (1979 to 2007).

Beach Seine			Otter Trawl		
2006	2007	All Years	2006	2007	All Years
44 (847)	56 (95)	51 (3969)	62 (275)	75 (97)	70 (2427)

Beach seine catches of threadfin shad have generally been larger than otter trawl catches, possibly due in part to the smaller mesh size of the seine and its greater capture efficiency of young-of-year shad. Like 2006 and 2007, threadfin shad captured by beach seine were smaller

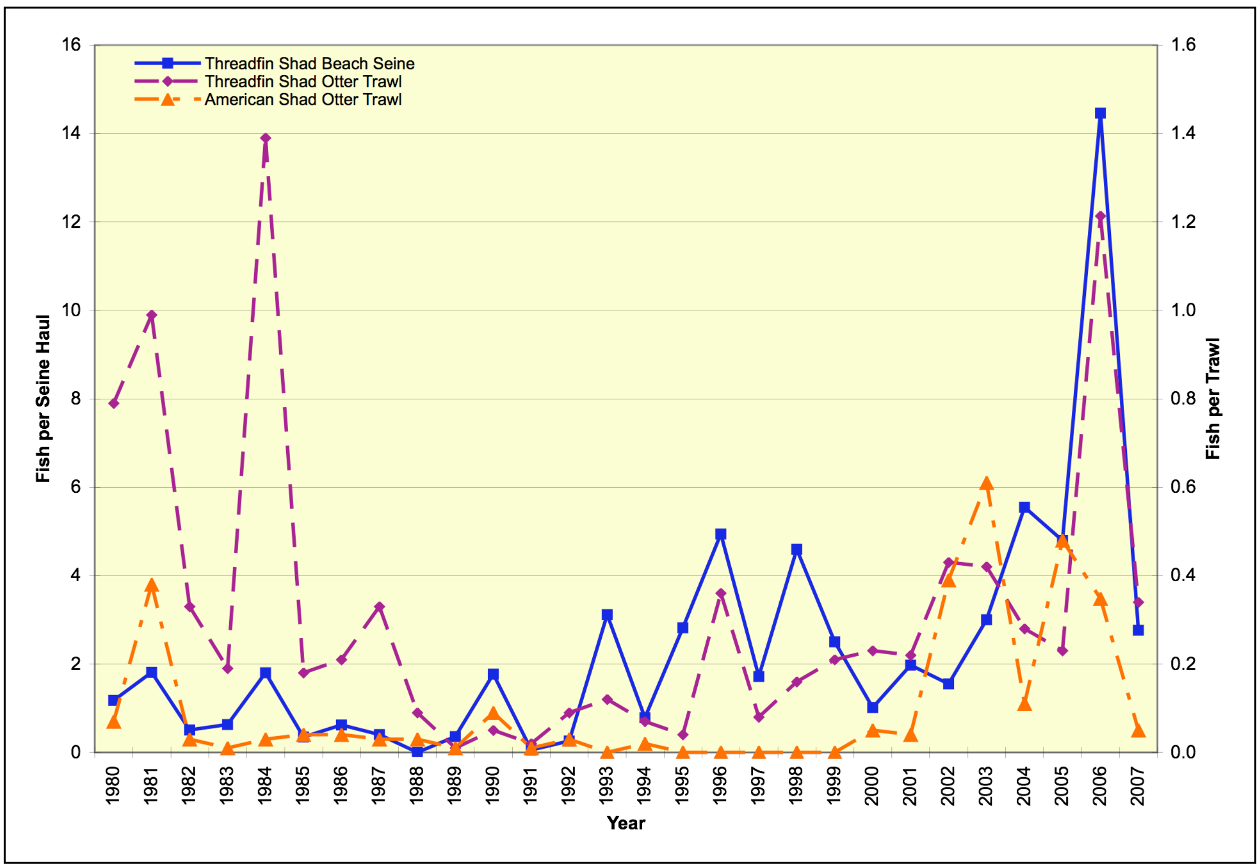

Figure 16. Annual otter trawl catch per unit effort of threadfin shad and American shad and annual beach seine catch per unit effort for threadfin shad in Suisun Marsh from 1980 to 2007.

than those caught by otter trawling over the entire study period (Table 2). Annual beach seine

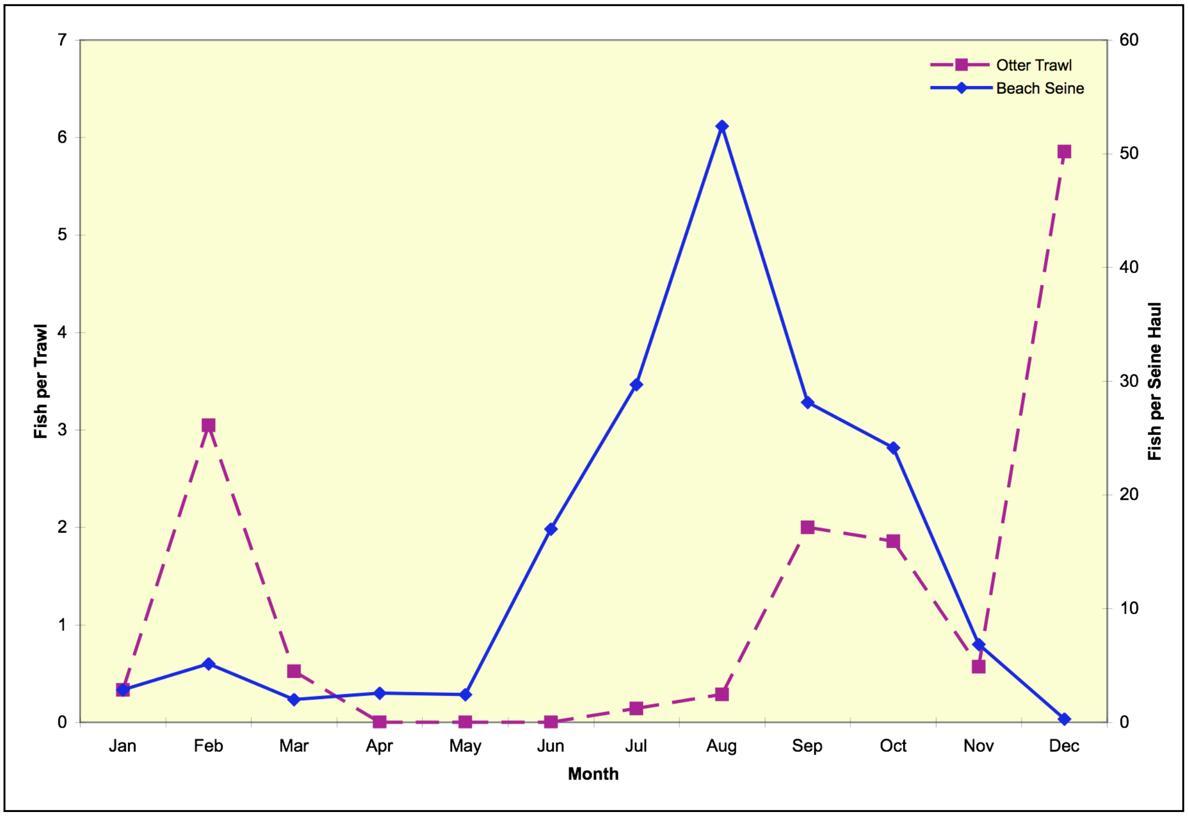

Figure 17. Monthly catch per unit effort for threadfin shad captured by beach seining and otter trawling in Suisun Marsh during 2006.

catch of threadfin shad has generally increased over the duration of the study, with recent local maxima in 1996, 1998, 2004, and 2006 (Figure 16). Consistent with the intolerance of threadfin shad to temperatures below 9°C (Griffith 1978), none of the eight years with the highest beach seine catches of threadfin shad have had temperatures dip below 8°C for more than a few days.

The 2006 beach seine catch per unit effort was the highest in the study's history and almost three times higher than the second highest value (14 versus 6 fish per seine haul; Figure 17). The catch remained relatively low until June, after which it rose rapidly, reached a peak in August, then declined steadily over the remainder of the year (Figure 17). The mean standard length of the fish captured decreased concurrent with a greater catch in June, implying the recruitment of young-of-year fish (Figure 18). Average length of shad steadily increased from June until the end of the year, as expected if sampling the same cohort.

It is unknown whether the high 2006 catch was due to downstream emigration of larvae from the Delta to the marsh or higher in-marsh spawning success; regardless, many factors probably coincided to provide favorable conditions for recruitment within the marsh. Below-normal salinities in the marsh and Suisun Bay in spring may have resulted in greater reproductive success of resident adult threadfin shad (Wang 1986, Turner 1966). From the beginning of June to the middle of August X2 was located within Suisun Bay, which likely co-occurred with the peak abundance of larvae. Finally, water temperature was above average for the months of June and July, spanning the period when larvae transform into juveniles. In sum, favorable temperatures for growth complemented by greater production of young-of-year shad could have led to the high 2006 catch.

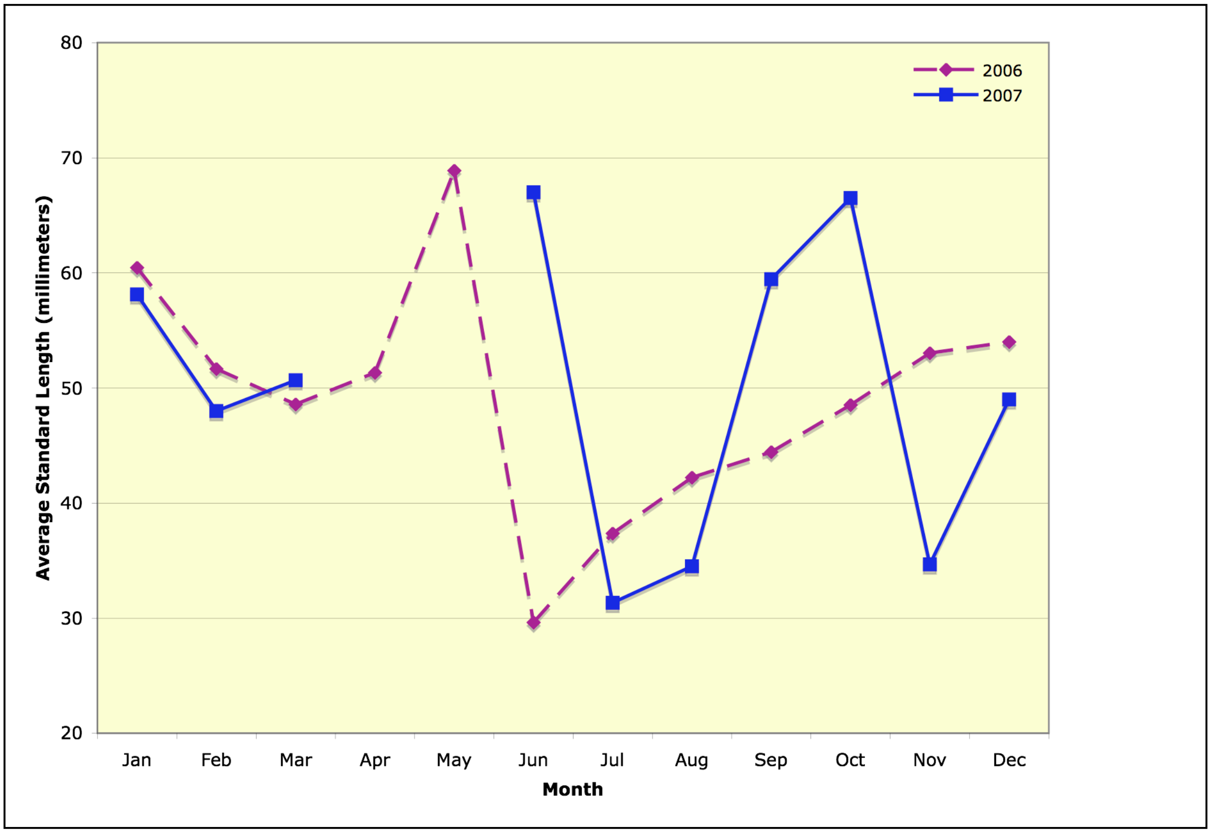

Figure 18. Monthly average standard length for threadfin shad captured by beach seine in Suisun Marsh during 2006 and 2007.

Substantially more threadfin shad were seined in Denverton Slough than in Suisun Slough (26 and 10 fish per seine haul, respectively) in 2006. Curiously, in 2006 threadfin shad were captured much more frequently in trawls in Suisun Slough than in Denverton Slough (1.0 and 0.1 fish per trawl, respectively).

Beach seine catch per unit effort in 2007 dropped off precipitously relative to 2006 and like the otter trawl catch returned to the mean catch for the entire study period (3 and 2 fish per seine haul, respectively). The conditions that likely contributed to 2006's high catch did not exist in 2007: spring salinities were much higher, June and July temperatures were lower, and X2 was only within Suisun Bay in March. The only substantial catch made was in Denverton Slough in September; these fish were generally larger than those captured in 2006, perhaps reflecting a smaller proportion of the catch made up of young-of-year due to poor 2007 recruitment.

<u>American Shad</u>

American shad (*Alosa sapidissima*) were infrequently caught (0.1 American shad per trawl for all years compared to an average of 0.5 fish per trawl for all years and species) in otter trawls. Their ability to tolerate rapid salinity increases when larger than 25 mm total length and their anadromy suggests that American shad move rapidly through the estuary, including the marsh. Despite that possibility, otter trawl catches of American shad roughly paralleled those for threadfin shad in 2006 and 2007 (i.e., they were relatively high in 2006 and low in 2007; Figure

16). Because both shads have similar feeding ecologies (e.g., pelagic planktivores), then X2 position and water temperature probably contributed to the American shad catch as for the threadfin shad catch.

With the exception of one year (2005), American shad beach seine catches have been routinely very low. 2006 and 2007 were no exception, with only 14 and 9 fish captured, respectively. These low catches, concomitant with commonly marginal otter trawl catches and frequently substantial beach seine catches of threadfin shad, suggest that American shad rarely inhabit the marsh in numbers.

Splittail

Splittail are consistently one of the most abundant fish in Suisun Marsh. A major limiting factor for their population is apparently the amount of flooded terrestrial vegetation in spring available for spawning and rearing (Moyle et al. 2004, Moyle 2002, Sommer et al. 1997). As a result, splittail abundance often spikes after major spring flow events. Annual splittail otter trawl catch per unit effort in the marsh has generally mirrored the magnitude of spring Delta outflows, with catch declining from the study's inception through the relatively dry 1980s (with the exception of relatively high catches in 1986 and 1987 following the high outflow in spring of 1986) and early 1990s (Figure 19). However, generally high springtime flows from the mid-1990s to the present (e.g., 1995, 1998, and 2006) have coincided with a steadily increasing splittail catch. Additionally, a strong year class from 1999 appeared to dominate the catch for the following four years, as evidenced by (1) the large beach seine catch in 1999, (2) the increasing average standard length of fish captured by otter trawl from 2000 to 2002 (103, 131,

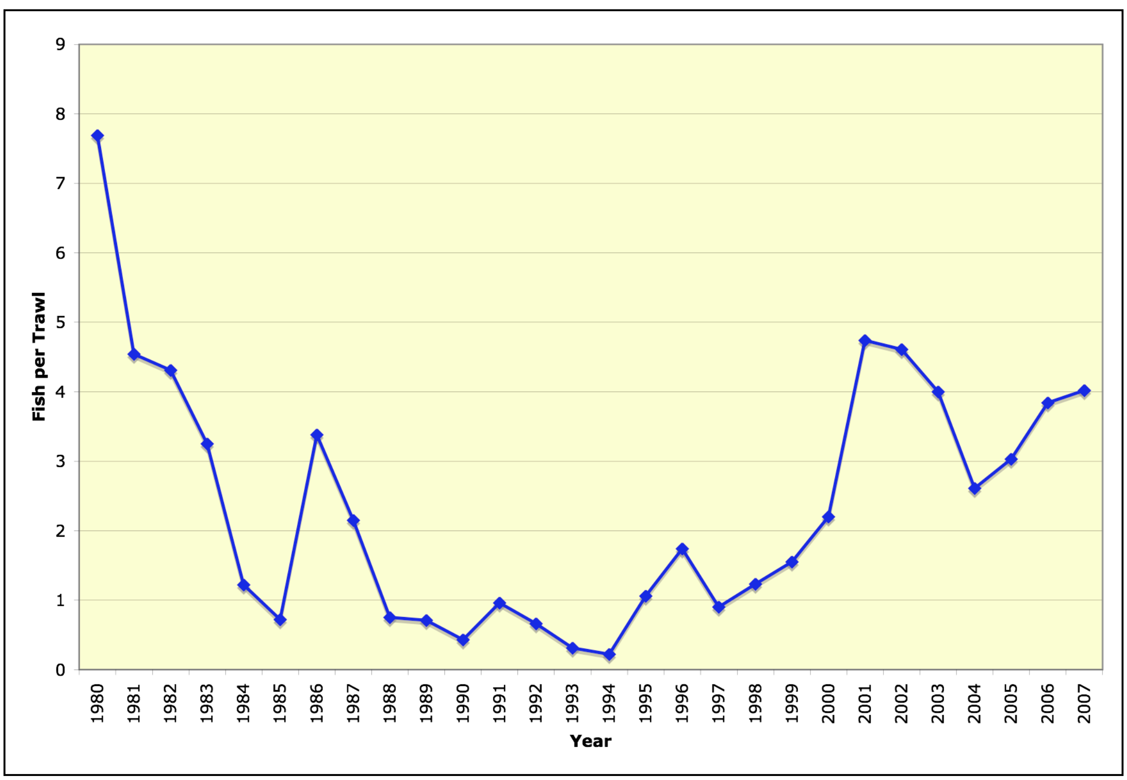

Figure 19. Annual splittail catch per trawl in Suisun Marsh from 1980 to 2007.

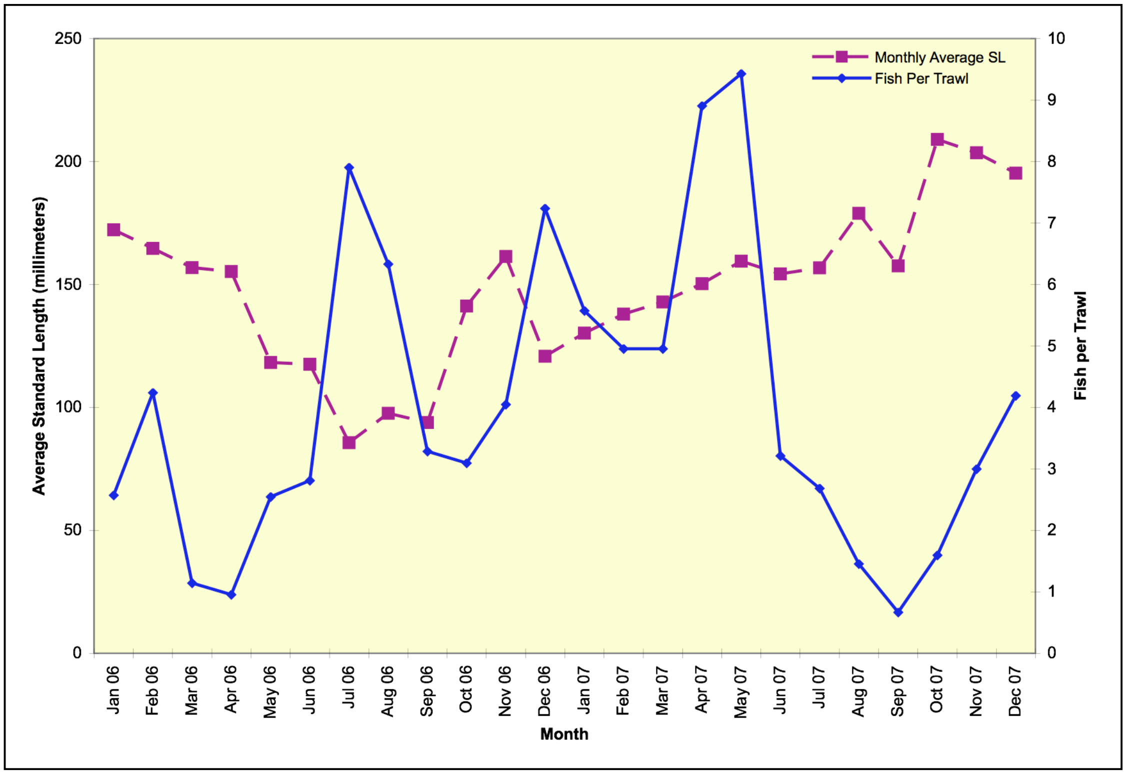

Figure 20. Monthly average standard length and catch per unit effort for splittail captured by otter trawling in Suisun Marsh during 2006 and 2007.

and 165 mm for 2000, 2001, and 2002, respectively) and (3) the high otter trawl catch in 2001 followed by substantial but slowly decreasing catches in 2002 and 2003 (Figure 19).

Otter trawl catch per unit effort in 2006 was greater than in 2004 and 2005 (4, 3, and 3, respectively). Catches in the first four months of the year were relatively low (Figure 20), possibly due to adult spawning movements upstream or into flooded vegetation in the marsh - habitats our otter trawl does not sample. Beginning in May, catch increased dramatically with a concurrent decrease in mean monthly standard length; coupled with high spring Delta outflow, this was probably a result of high reproductive success and recruitment of young-of-year into the fishery. As summer progressed into autumn, otter trawl catches generally declined while standard length increased, likely reflecting the prominence of the 2006 year class in our sampling. Catch of splittail in November and December was similar to that in summer: catch was relatively high and standard lengths low, suggesting recruitment of a second 2006 cohort into the fishery with prespawning movements of adults out of the marsh. Alternatively, our high November and December catches may have been due to young-of-year moving into deeper wintering areas; a concomitant decrease in beach seine catch bolsters this possibility.

The annual pattern of otter trawl catch per unit effort of splittail in 2007 was similar to 2006 in that it was low in early spring, declined through late summer and autumn, and once again increased at the end of the year (Figure 20). However, catch in 2007 differed from 2006 in three major ways: the dip in the 2007 spring catch was not as severe as in 2006; peak catch was shifted to earlier in the year (April and May in 2007 rather than June and July in 2006); and late summer and autumn catches were considerably less than in 2006 (Figure 20). The higher spring catch of splittail in 2007 was not accompanied by a decrease in average standard length - in fact, standard length generally increased linearly throughout the entire year. Coupled with low Delta outflow in early 2007, the greater 2007 spring catch is likely due to limited spawning success. Unlike in 2006, peak catch in 2007 did not coincide with a drop in standard length, indicating that the large catch was the result of sampling fish primarily from the 2006 year class and low recruitment of 2007 young-of-year. The substantial catches in April and May might have been due to the predominance of the 2006 year class in the population, in addition to return of post-

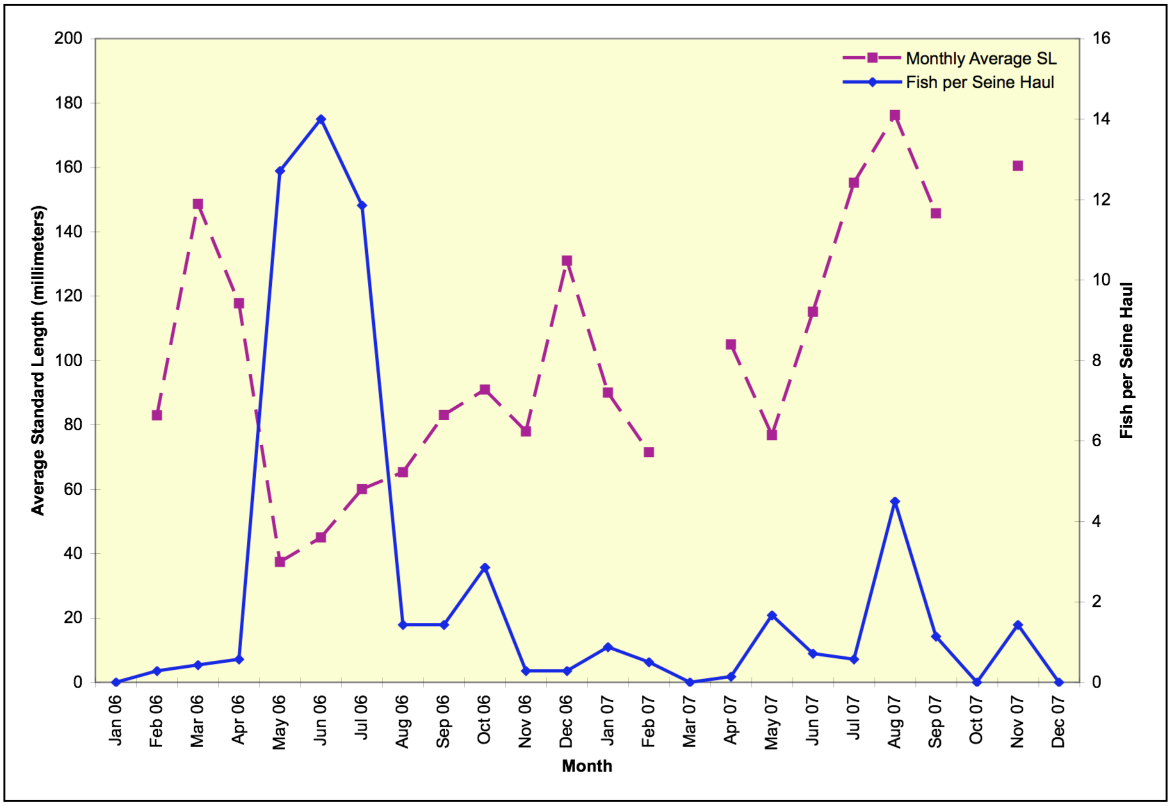

Figure 21. Monthly average standard length and catch per unit effort of splittail from beach seines in 2006 and 2007.

spawn adults (albeit less than in 2006). Poor reproductive success in 2007 resulting in fewer young-of-year recruiting into the catches was probably the primary reason for the low late summer and autumn catches.

Otter trawl catch per unit effort from 1995 to 2007 has roughly followed beach seine catch per unit effort by a one-year time lag, intimating recruitment of young-of-year captured in beach seines into the otter trawl fishery the following year. This is supported by the smaller average standard length of splittail captured by beach seine compared to otter trawl (81 mm versus 139 mm) over the same period.

Beach seine catch of splittail in 2006 was the second highest in the last 12 years. Consistent with a large influx of young-of-year, catch per unit effort was highest in May, June, and July while average standard length plummeted over the same period (Figure 21). A steep decline in catch occurred in August concurrent with high otter trawl catches and increasing standard length, possibly due young-of-year shifting from foraging on zooplankton common in near-shore areas to benthic invertebrates of the channel bed (Sommer et al. 1997). Thereafter beach seine catch remained low while average standard length increased, suggesting that, like our otter trawl catch, we continued to sample primarily the 2006 cohort.

The low total beach seine catch per unit effort (less than one fish per seine haul) in 2007 reflected poor reproductive success. While there was a slight drop in average standard length of splittail captured by beach seine in May along with an increase in catch, the changes were minor and nowhere near as pronounced as in 2006 (Figure 21). Consistent with the otter trawl data, standard length of splittail generally increased linearly throughout the year, reflecting the dominance of the 2006 year class in our 2007 beach seine catch. With the exception of an anomalously high catch of mostly yearling fish in August at our Suisun Slough site, monthly beach seine catch per unit effort throughout 2007 was routinely low.

It has been noted previously that a substantial proportion of the total splittail otter trawl catch comes from a few sloughs (Schroeter et al. 2006). Specifically, Goodyear, First Mallard, and lower Suisun sloughs consistently contribute a disproportionately large percentage of the total catch. 2006 and 2007 were no exception: 61% of the splittail catch in 2006 and 50% of the catch in 2007 was from the three sloughs. It is unlikely that water quality variables contributed significantly to this spatial distribution because temperatures are generally equal in all sloughs at a given time; Goodyear and First Mallard sloughs often have very low oxygen concentrations while other sloughs usually have higher dissolved oxygen levels (e.g., Suisun Slough). Average salinities in Goodyear, First Mallard, and lower Suisun Sloughs are quite different (Table 1) despite all three sloughs yielding high splittail catches.

Ictaluridae

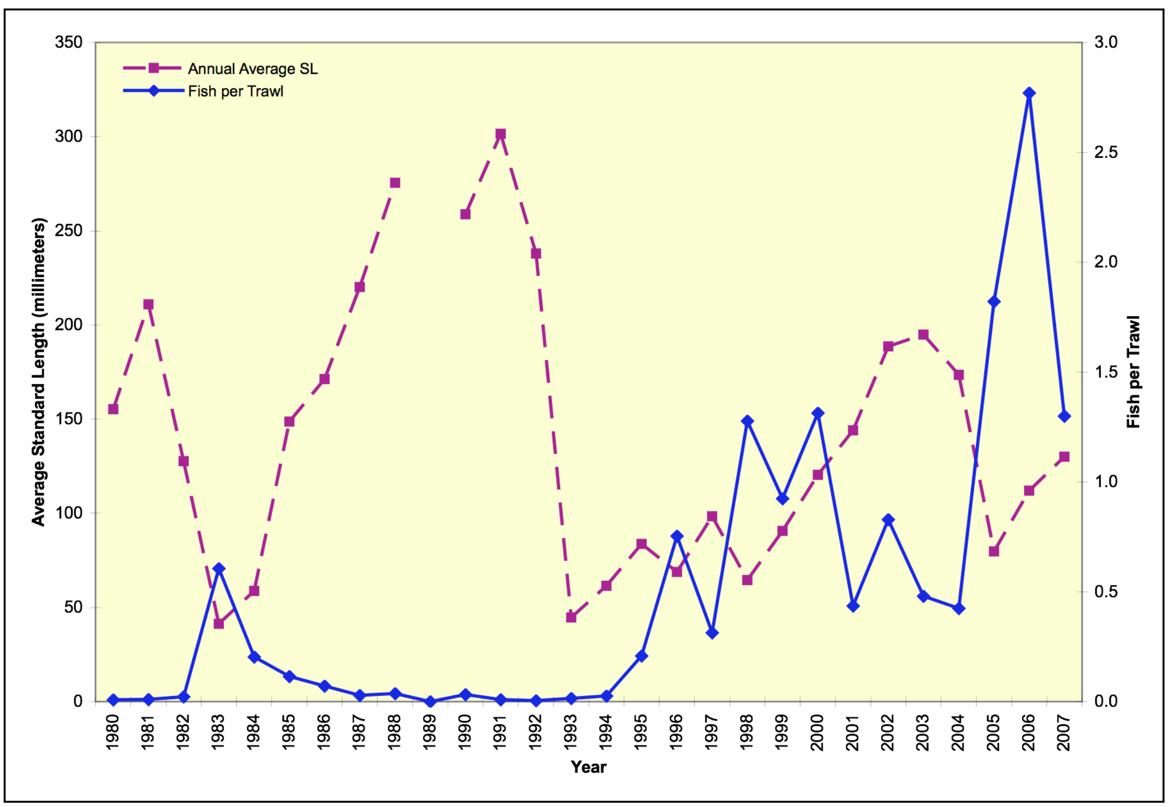

Figure 22. Annual catch per unit effort and average standard length of white catfish captured by otter trawl in Suisun Marsh from 1980 to 2007.

White Catfish

With the exception of a fairly strong year class in 1983 that dominated the catch for the remainder of the 1980s, white catfish were uncommonly caught in otter trawls from the study's inception until 1995. Beginning in 1995, catch of white catfish has fluctuated but overall has grown roughly linearly (Figure 22). The late 1990s were comparatively wet years, thus the substantial increase in the white catfish catch may be due in part to either greater Delta outflows or decreased salinities. Salinity - or some factor correlated with it - appears to be a major factor determining geographic distribution because over two-thirds of all white catfish caught in otter trawls from 1980 to 2007 came from just three sloughs in the fresher eastern marsh (i.e., Montezuma, Denverton, and Nurse sloughs), while only three percent were captured in the saltiest sloughs (i.e., Goodyear and lower Suisun Sloughs; Table 1). When white catfish are caught in the western marsh, they almost invariably come from the fresher sloughs (e.g., Peytonia and Boynton; Table 1). This distribution is somewhat surprising given the species' native range (i.e., Atlantic coastal watersheds) and its ability to survive and feed in water up to 14 ppt (Allen and Avault 1971). Interestingly, beach seine catch of Mississippi silverside has increased concurrent with larger catches of white catfish through time, and white catfish are known to feed on silversides (Moyle 2002); however, no diet studies have been performed on the marsh's white catfish so the relationship between the two species remains unknown.

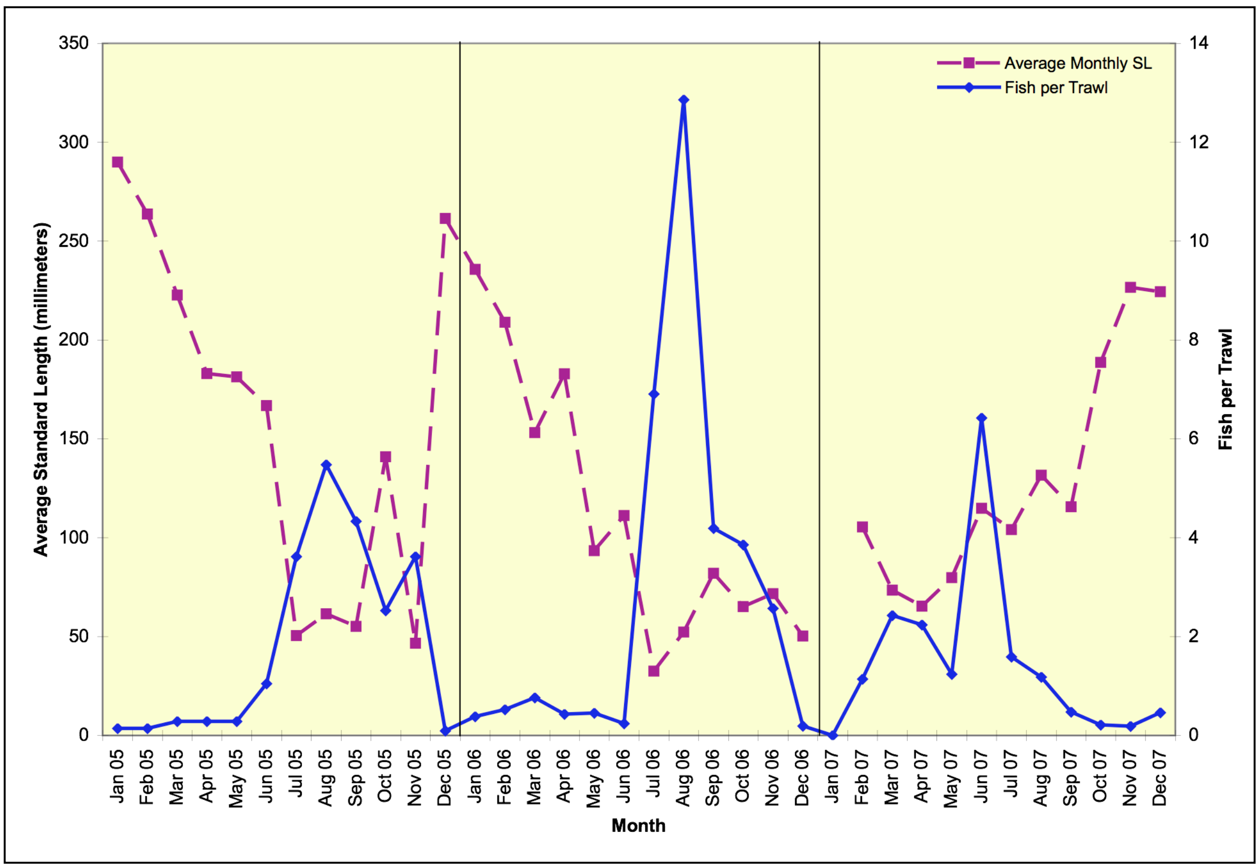

Figure 23. Monthly average standard length and catch per unit effort for white catfish captured in Suisun Marsh by otter trawl from 2005 to 2007.

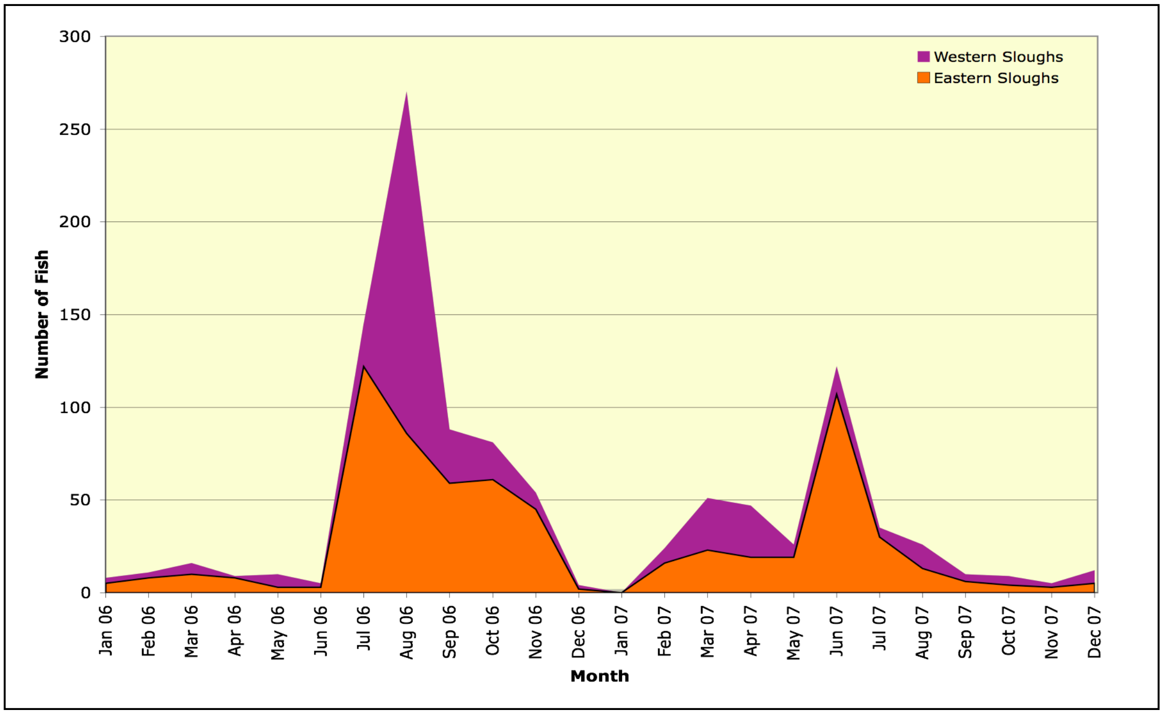

Figure 24. Number of white catfish captured by otter trawl in eastern (Denverton, Nurse, and Montezuma) and western (Suisun, Peytonia, Boynton, Goodyear, First Mallard, and Cutoff) sloughs of Suisun Marsh in 2006 and 2007.

The 2006 otter trawl catch of white catfish is the highest recorded in the study's history, primarily due to the large influx of young-of-year into the catches in July and August (Figure 23). The fresher marsh in spring and summer (the period of white catfish spawning and hatching; Hughes and Carlson 1986), in addition to other factors previously discussed (i.e., X2 position, water temperature), may have provided more favorable conditions for early life-history stages.

The decreasing average standard length concurrent with a relatively constant catch in the first five months of both 2005 and 2006 (Figure 23) is hard to explain; a roughly similar pattern exists for two other high-catch years, 1998 and 2000. Figure 23 implies an equal exchange early in the year of juvenile and adult white catfish into and out of the catches, respectively. White catfish do make seasonal movements (Hughes and Carlson 1986), with fish moving downstream in winter and back upstream in spring and summer, but there is no sign of the geographic distribution of our catch varying with season. In fact, the majority of white catfish in 2006 were captured in eastern marsh (Figure 24) and the fresher sloughs of the western marsh (especially Peytonia Slough), which is consistent with data for all years of the study.

The pattern of otter trawl catch per unit effort of white catfish in 2007 somewhat resembled that of 2006, with high catches in summer and lower catches at the beginning and end of the year (Figure 23). However, there are a number of noticeable differences: in 2007, the spring catch increased concomitant with declining average standard length; the peak catch did not coincide with a precipitous drop in average standard length; and the pattern of catch seemed shifted earlier relative to the 2006 catch. The higher catch in early spring intimates recruitment of young-of-year, although water temperature in the marsh in that period was probably too low for spawning. When considered in the context of the average standard length in both the first half of 2007 and the latter half of 2006, the high catch in June 2007 likely consisted primarily of yearlings and not young-of-year. If moderate salinities do repress some aspect of reproduction or an early life history stage, then this is an expected observation. The apparent shift in the 2007 catch pattern to earlier in the year agrees with the marsh warming sooner in 2007 relative to 2006.

<u>Black Bullhead</u>

Prior to 2006, black bullheads were very rarely caught in Suisun Marsh otter trawls (less than 8 fish per year from 1979 to 2005), with about a quarter of those fish captured in Denverton Slough. However, otter trawl catch increased in 2006 (n = 220) and continued to climb in 2007 (n = 289).

The seasonal catch pattern of black bullheads in 2006 and 2007 is quite different from that of white catfish. Peak catch of black bullhead in both years occurred in autumn (Figure 25), not in summer as for white catfish (Figure 23). Additionally, the relatively constant monthly average standard length of black bullheads through both years implies little reproduction and recruitment of young-of-year (Figure 25). The geographical distribution between the two species is somewhat disparate as well: 81% and 84% of the black bullheads captured in 2006 and 2007, respectively, came from Peytonia, Boynton, and Denverton sloughs. No black bullheads were caught in Nurse Slough, only one in Montezuma Slough, and seven in Suisun Slough over the two years.

The high catch of black bullheads in autumn of both years and spring of 2007 coincides

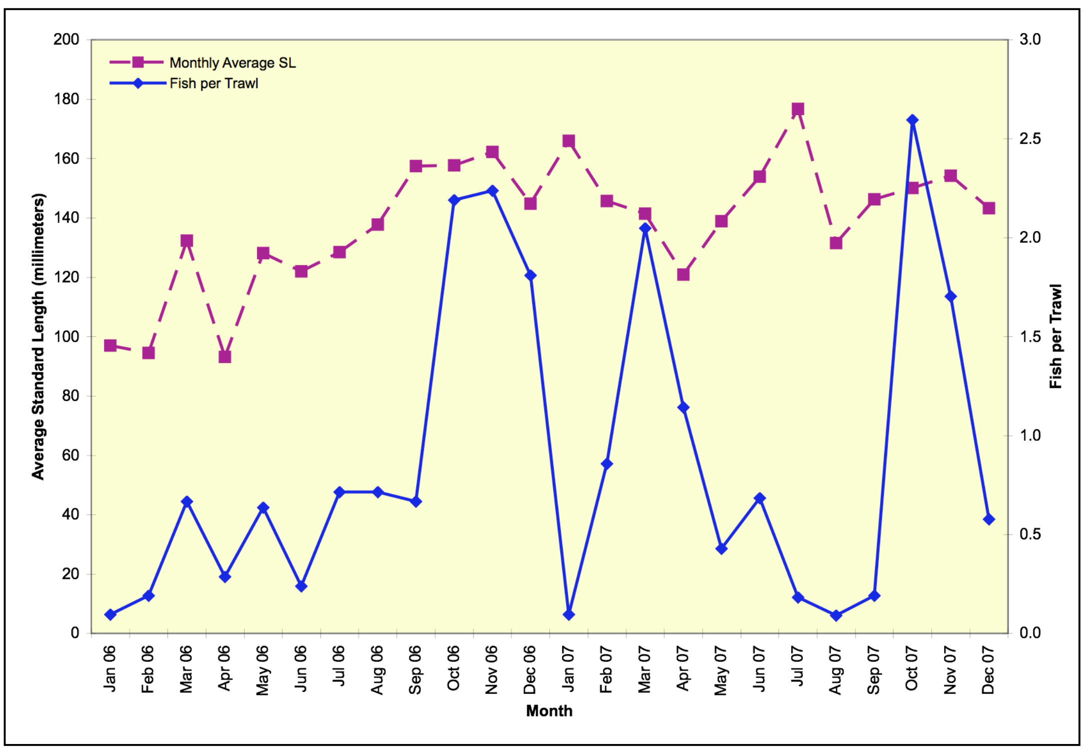

Figure 25. Monthly average standard length and otter trawl catch per unit effort of black bullhead in Suisun Marsh for 2006 and 2007.

with duck club water recirculation and pond draining. Additionally, the sites we sample in

Denverton, Peytonia, and Boynton sloughs are close to duck pond outfalls. It is possible that black bullheads reside upstream of our sampling sites in late spring and summer and move into nutrient-rich, food-laden plumes of pond water in the cooler months. Threespine sticklebacks (*Gasterosteus aculeatus*) have been discharged with duck pond water into the sloughs (Matern et al. 2002); black bullheads are known to feed on fish in late summer and autumn (Repsys et al. 1976), so they could be moving downstream to duck pond outfalls to feed on threespine sticklebacks. Alternatively, black bullheads might be present in the duck ponds and consequently introduced into the sloughs with discharge water. Black bullheads are physiologically tolerant and thus would be likely to endure the low oxygen concentrations and high temperatures of duck ponds through summer and fall. In a French marsh, black bullheads preferentially inhabited conditions similar to those in the duck ponds, possibly due to the rich food supply (Cucherousset et al. 2006).

Osmeridae

Delta Smelt

Since 1984, otter trawl catch of Delta smelt has been routinely low (less than 7 fish per year; Figure 26), tracking the estuary-wide decline in smelt numbers (California Department of Water Resources and Department of Fish and Game 2007, Bennett 2005, Moyle 2002). Although we have conducted just 47 midwater trawls over the study's history, it is still somewhat surprising that we have only captured three Delta smelt from the water column of the large sloughs.

In 2006, only two Delta smelt were caught by otter trawl: both were captured in late

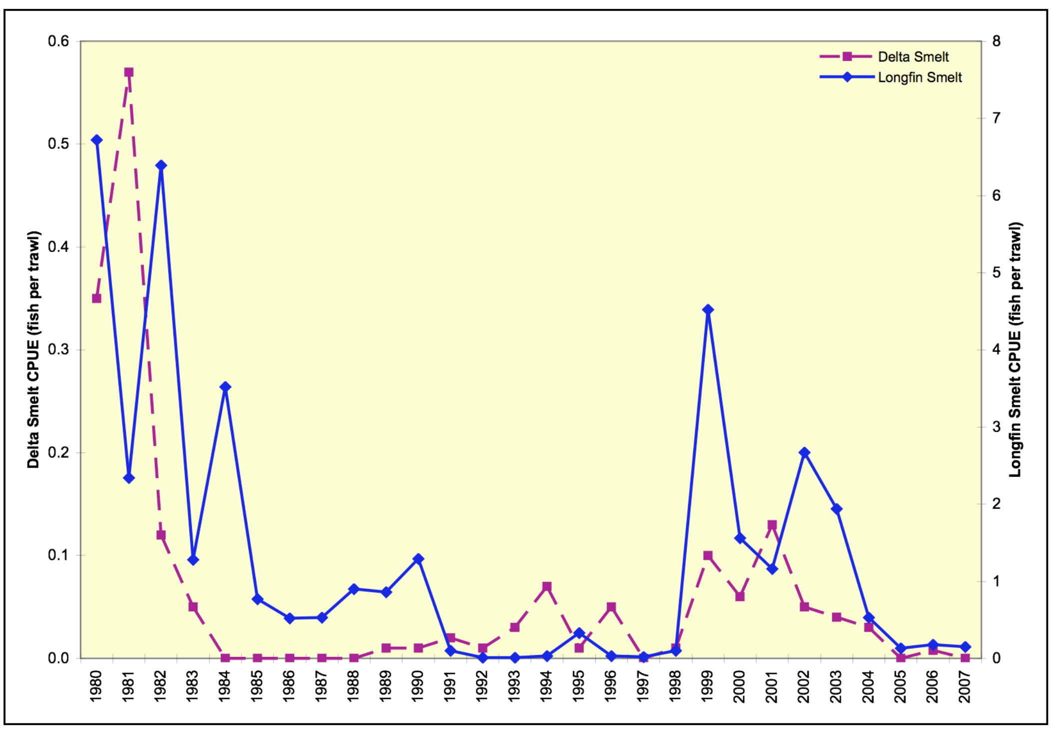

Figure 26. Annual otter trawl catch per unit effort (CPUE) of Delta and longfin smelt from 1980 to 2007.

autumn in lower Suisun Slough. Catch in 2007 consisted of just one captured by otter trawl in

First Mallard Slough and two by midwater trawl in lower Suisun Slough; all were captured in autumn. All Delta smelt captured were 50-69 mm SL; when coupled with timing of capture, these were subadult fish.

Beach seine catches of Delta smelt have consistently been low - only 59 fish have been captured since 1983. Invariably, seined Delta smelt have been subadults or adults captured in autumn or winter. No Delta smelt were caught in seine hauls in 2006 or 2007.

Longfin Smelt

Longfin smelt (*Spirinchus thaleichthys*) have been captured in otter trawls much more frequently than Delta smelt; however, drought and high exports in the mid-1980s and early 1990s likely contributed to the crash in our catches over that period (Figure 26; Bay Institute et al. 2007, Moyle 2002). Longfin smelt catch somewhat rebounded with relatively high outflows in 1999 and the early 2000s, although catch in the last three years has been substantially lower (Figure 26).

We captured 45 longfin smelt by otter trawling in 2006; 64% of these fish were caught in lower Suisun Slough, with the remainder coming from Nurse, Goodyear, Boynton, and Montezuma sloughs. All longfin smelt were captured from late August to December; monthly average standard length generally increased in that period (Table 3). Standard deviation of standard length jumped appreciably due to capture of one large fish (88 mm) in November and two (82 and 92 mm) in December (Table 3), possibly representing yearling fish migrating toward the Delta for spawning.

Table 3. Standard deviation and average of standard length (number of fish in parentheses) of longfin smelt captured by otter trawl in 2006.

Month	Aug	Sep	Oct	Nov	Dec
Average SL (mm)	39 (8)	46 (12)	46 (13)	70 (6)	65 (6)
Standard Dev. of SL	2.97	8.30	4.79	10.28	17.44

All 35 longfin smelt caught in otter trawls in 2007 came from lower Suisun Slough; 26 of those fish were young-of-year (average standard length = 28 mm, standard deviation = 2.1) captured on May 18. Longfin smelt from the 2006 year class were caught in March, October, and November (two, one, and one fish, respectively), and young-of-year were captured in August and December (two and three fish, respectively). The low catches are expected for the dry year and low Delta outflow since longfin smelt abundance is positively correlated to large spring outflows (Bay Institute et al. 2007, Moyle 2002); our poor catches of longfin smelt were mirrored elsewhere in the estuary by the California Department of Fish and Game's summer tow-net survey and fall midwater trawl.

Salmonidae

Although water quality (e.g., temperature) of the marsh is generally unsuitable for salmonids, Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) are occasionally captured in otter trawls. With the exception of two fish caught in autumn that were probably jacks, all Chinook salmon captured by otter trawl were young-of-year taken in late winter and early spring, coinciding with emigration of fall-run juveniles. Only seven steelhead have been caught by otter trawl in the marsh during the entire study: five of these fish were between 320 and 380 mm standard length. All steelhead were captured in late autumn or early winter when marsh temperatures were lowest. No steelhead and only three Chinook salmon were captured by otter trawl in 2006; the salmon were taken in First Mallard (two fish) and Nurse (1 fish) sloughs in winter. In 2007, no salmonids were caught in otter trawls.

Beach seine catch of Chinook salmon has always been higher over the study's history compared to the otter trawl catch (389 versus 75 fish). While the larger seine catch is partially due to the net's smaller mesh size, the penchant of young-of-year Chinook salmon to rear in shallow areas (such as our seining sites) is also likely responsible (Sommer et al. 2001). Average standard length of Chinook salmon taken in seine hauls was almost identical to that of fish from otter trawls (45 mm and 46 mm, respectively). Given the timing of capture and their size, Chinook salmon caught in seines were probably all fall-run fish. The majority of seined salmon have been taken in Denverton Slough reflecting the closer proximity of Denverton Slough to the Sacramento River.

Eight and six Chinook salmon were captured in beach seines in 2006 and 2007, respectively. Congruent to the entire study period, all salmon were young-of-year, caught in late winter, and all but two taken in Denverton Slough. No steelhead were seined in 2006 or 2007.

Mississippi Silverside

Due to their small size and penchant for shallow, inshore waters, Mississippi silversides are caught in far fewer numbers and less frequently in otter trawls than in beach seine hauls (Figure 27). Still, a few patterns in the otter trawl catch data are discernible. First, the largest otter trawl catches are made in winter: 50% of all Mississippi silversides were taken in December and January. Second, they disproportionately (44%) were caught in First Mallard

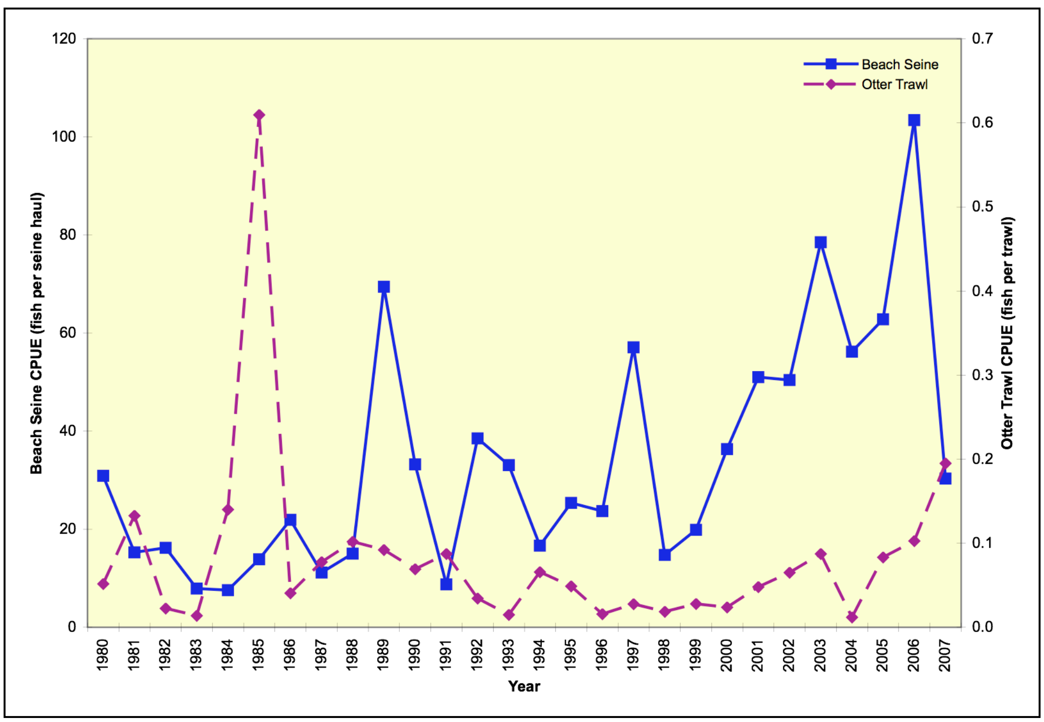

Figure 27. Annual otter trawl and beach seine catch per unit effort (CPUE) for Mississippi silverside captured in Suisun Marsh from 1980 to 2007.

Slough; this slough has the lowest mean depth of any sampled. The appearance of silversides in the thalweg (i.e., the general sampling location of our otter trawl) in the coldest months may be due to wintering behavior (discussed below). Third, the average standard length of silversides captured by otter trawl has been the same as that by beach seine (52 mm), which implies that the probability of capture by the two methods for all standard lengths is about the same.

Consistent with the pattern for all years of the study, timing of peak otter trawl catch of Mississippi silverside occurred in December and January in 2006 and 2007, respectively. Although double the number of fish was captured in 2007 compared to 2006 (54 versus 26), catch for both years was still quite low. While most fish were captured in First Mallard Slough in 2007, the majority of fish caught in 2006 came from lower Suisun and Peytonia sloughs.

Annual beach seine catch per unit effort for Mississippi silverside has been consistently larger than the otter trawl catch per unit effort (Figure 27). In the first nine years of the study catch per unit effort tended to vary around 15 fish per seine haul. However, from 1988 to 1997, annual catch per unit effort appeared to vary with greater amplitude around a higher average but without any noticeable upward or downward trajectories. Although the beginning of this period coincided with the initiation of Suisun Marsh Salinity Control Gates operations, how and whether the gates played a role in the change in catch is unknown. From 1998 to 2007, catch per unit effort has grown roughly linearly, with that period containing the two years with the highest catches recorded in the study's history (2003 and 2006; Figure 27). This pattern is consistent with silverside catch in the Unites States Fish and Wildlife Service beach seine survey catch

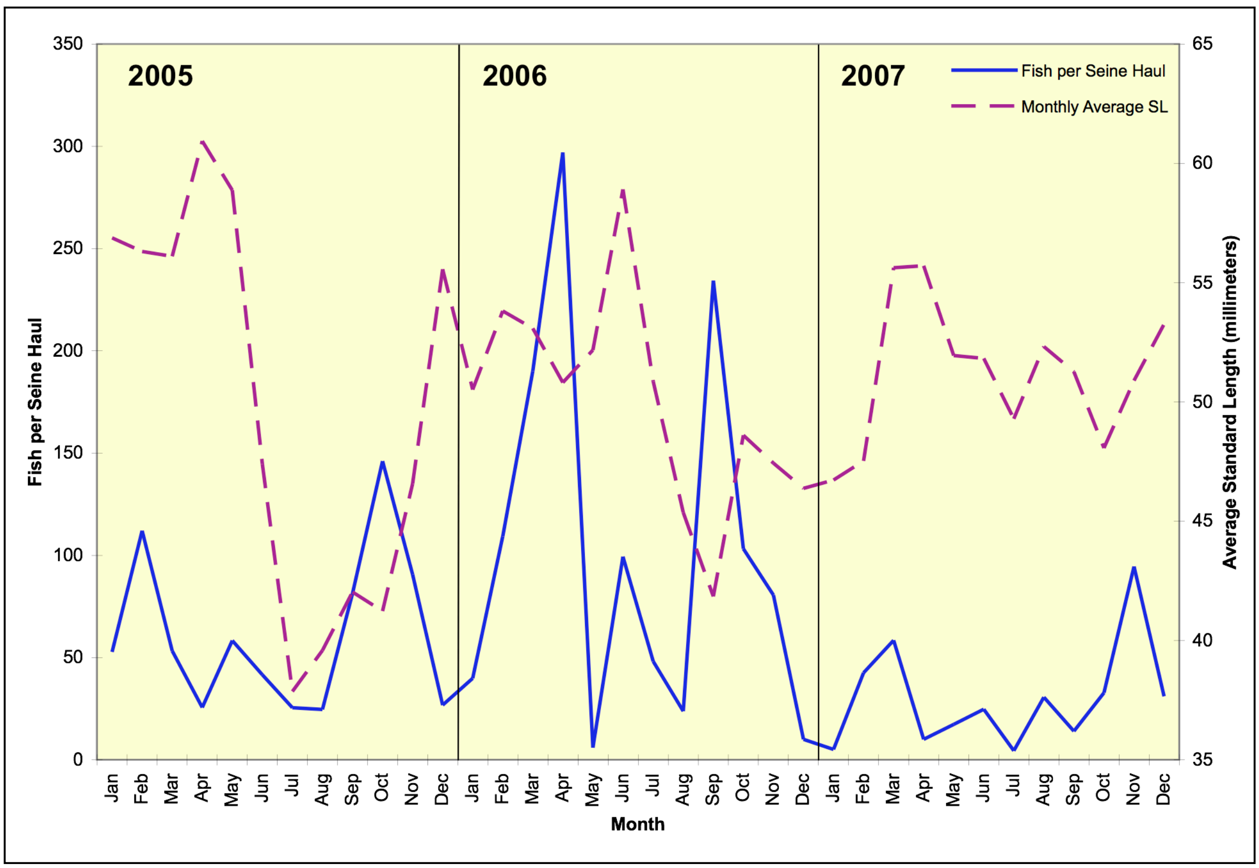

Figure 28. Monthly average standard length and beach seine catch per unit effort for Mississippi silverside from 2005 to 2007.

(Moyle and Bennett 2008).

As mentioned previously, the highest annual beach seine catch ever was recorded in 2006; catch peaked in April and again in September. The 2007 beach seine catch, while considerably lower, exhibited a similar pattern: maxima were reached in spring (March) and autumn (November). Like 2006 and 2007, 2005 beach seine catch also had peaks early in the year and in autumn (Figure 28).

In other regions, Mississippi silversides frequently spawn twice a year: yearling fish spawn in spring, while the resultant young-of-year spawn in late summer (Moyle 2002, Middaugh and Hemmer 1992). Consequently, bimodal length distributions for late spring and early autumn reflect the influx of young-of-year from the two spawning events (Moyle 2002, Middaugh and Hemmer 1992). An attending effect would be spring and autumn average standard length minima concurrent with two catch maxima. 2005, 2006, and 2007 beach seine catch per unit effort for Mississippi silverside in Suisun Marsh is congruent with two groups of young-of-year entering the fishery (Figure 28); however, the high spring catches of all years did not coincide with low average standard lengths. Additionally, silverside generally do not spawn until water temperature has reached at least 15°C (Middaugh and Hemmer 1992, Hubbs 1982), which was not reached in either Suisun or Denverton sloughs until April in both years. The smallest fish captured by beach seine from the two years was 18 mm SL, the minimum age of which would be probably around four weeks (Gleason and Bengston 1996, Hubbs 1982). Thus, the large spring catches occurred at least a month earlier than would be expected if they consisted primarily of recently spawned young-of-year. In other words, high spring catches presumably consist mainly of yearling fish.

The decline in beach seine catch in winter coincides with a increase in otter trawl catch, which could be the result of silversides moving into deeper waters for refuge; little feeding occurs below 15°C and high mortality is common in very cold weather (Stoeckel and Heidinger 1988).

The steep decline in average standard length in summer, coupled with high autumn catches concurrent with low average standard lengths, suggests that most yearling fish die after reproducing in spring and the resultant young-of-year produce the second cohort in late summer. However, catch of the first cohort in summer for both years was quite low, implying high mortality rates. Gleason and Bengston (1996) found evidence of predation on larger young-of-year silversides; striped bass larger than 150 mm SL (i.e., the marsh's main piscivorous fish) were fairly common in the marsh in August 2006 and the summer of 2007, so predation could have contributed to the low summer catches. Additionally, Castellanos and Rozas (2001) found Mississippi silversides were most abundant in a backwater thickly vegetated with tules in summer. Consequently, it is possible that silversides moved from our bare seining beaches to the copious emergent macrophytes that fringe the marsh's sloughs, perhaps to evade predation by striped bass and white catfish or to exploit high food densities. Such movements would have resulted in our relatively low beach seine catches during summer.

The conditions (X2 position) that may have led to high catches of threadfin shad in 2006 might also have been a boon for the second cohort of Mississippi silverside because the two species are both planktivores and probably have highest spawning success in low-salinity water (Moyle 2002).

In 2005, 2006, and 2007, monthly beach seine catch per unit effort declined severely in late autumn and remained low until mid-winter (Figure 28); a similar pattern has been observed elsewhere (Middaugh and Hemmer 1992). As previously discussed, this may be the result of wintering behavior. While it is tempting to ascribe the low cold-water catches to temperature-induced mortality as commonly occurs with threadfin shad (Turner 1966) and Mississippi silverside (Stoeckel and Heidinger 1988), this is likely not the case since high spring catches of yearlings imply low mortality through the winter.

Many more Mississippi silversides are captured by beach seine in Denverton Slough than in Suisun Slough: 85% and 65% of all Mississippi silversides caught in 2006 and 2007, respectively, came from Denverton Slough.

Cottidae

Clearly, freshwater inflow affects abundance of prickly sculpin in the marsh: high annual catch per unit effort has occurred concurrent with relatively high Delta outflow in 1986, 1995, 1998, 2000, and 2006 (Figure 29). Conversely, many years of low Delta outflow (i.e., the late 1980s, early 1990s, 2001) are attended by small catches of prickly sculpin. It is likely that high outflow in spring results in greater reproductive success and more favorable rearing conditions (Meng and Matern 2001). Alternatively, larval prickly sculpin are pelagic (Moyle 2002), and thus could have been washed into the marsh from upstream spawning sites.

Consistent with the wet year and prolonged spring Delta outflow, 2006 otter trawl catch per unit effort for prickly sculpin reached its highest point since 1995 (Figure 29). Monthly catch per unit effort peaked with a declining average standard length in spring, intimating recruitment of high numbers of young-of-year (Figure 30). Catch declined as standard length

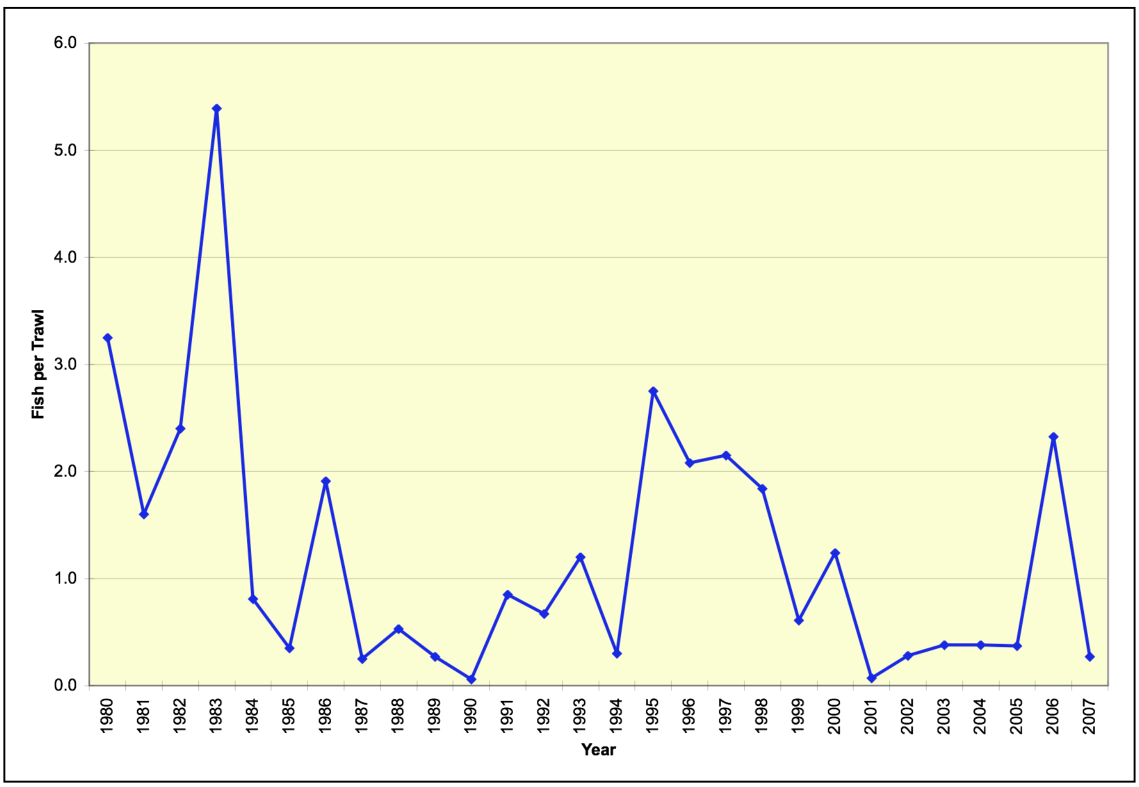

Figure 29. Annual otter trawl catch per unit effort for prickly sculpin caught in Suisun Marsh from 1980 to 2007.

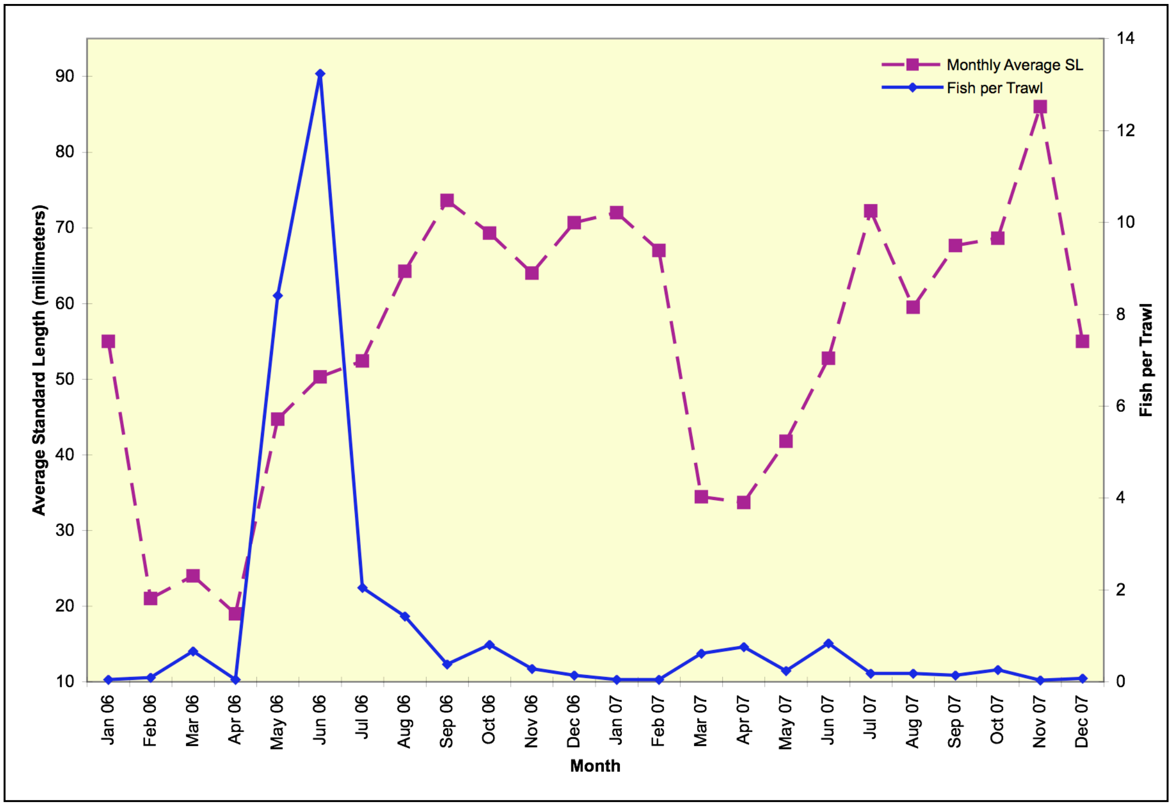

Figure 30. Monthly average standard length and catch per unit effort for prickly sculpin captured by otter trawl in Suisun Marsh during 2006 and 2007.

increased from midsummer through the end of the year, likely the result of both growth and higher mortality of young-of-year fish relative to older age classes.

The pattern of 2007 monthly otter trawl catch per unit effort mirrored that of 2006 though, as expected of a dry year, considerably fewer fish were captured (Figure 30). Catch peaked in spring concomitant with minima in average standard length; however, neither of the peaks was as pronounced as in 2006, suggesting poorer reproductive success or recruitment. Catch from summer to the year's end was similar to 2006, with decreasing catches attended by increasing size (Figure 30).

Prickly sculpin are captured in beach seines in fewer numbers than in otter trawls - 2006 and 2007 did not vary from this pattern, with only 49 and five fish caught, respectively. Despite the low numbers, beach seine catch for both years exhibited patterns similar to the otter trawl catch: most fish were young-of-year and captured in spring, and average standard length reached minima in spring and then generally increased until the end of the year.

More than a third of prickly sculpin captured in 2006 came from Peytonia Slough. Conversely, only 31% of the total fish was taken from sloughs in the middle and east of the marsh (i.e., First Mallard, Cutoff, Montezuma, Nurse, and Denverton sloughs) even though 48% of our sampling sites are located in those regions. Following the trend in absolute numbers, otter trawl catch per unit effort declined from the western to eastern marsh (Table 4). In 2007, geographic distribution in catch shifted somewhat, with the highest catch per unit effort recorded

Table 4. Annual catch per trawl of prickly sculpin from the western (Peytonia, Boynton, Goodyear, and Suisun sloughs), middle (First Mallard and Cutoff sloughs), and eastern (Denverton, Nurse, and Montezuma sloughs) regions of Suisun Marsh.

Year	Fish per Trawl		
	Western Marsh	Middle Marsh	Eastern Marsh
2006	3.0	2.1	1.0
2007	0.3	0.6	0.1

in the mid-marsh sloughs (Table 4). At first glance it appears salinity could be a factor controlling the distribution of prickly sculpin, with the fish choosing more saline water; however, prickly sculpin are abundant in myriad lotic and lentic freshwater environments (Moyle 2002) and Peytonia Slough was the freshest slough sampled in 2006.

Staghorn sculpin (*Leptocottus armatus*), with the exception of high catches in the first three years of the study, are seldom caught in large numbers by otter trawl. Presumably, the trawl does a poor job of sampling small young-of-year fish. The high salinity requirements of their life history (Moyle 2002) generally reduces occurrence in Suisun Marsh during high Delta outflow years; this was reflected in the 2006 catch, in which only five fish were captured, all in the southwest portion of the marsh and four of the five in late August. Catch increased somewhat in 2007, with 16 fish taken mainly from the southwestern marsh in spring.

The beach seine catch of staghorn sculpin was the inverse of otter trawl catch: beach seine catch was higher in 2006 than in 2007 and all fish in both years were captured in spring. Fish captured by beach seine were significantly smaller than those caught in otter trawls (Student's t-test, $p < 0.0001$), possibly reflecting young-of-year recruiting to the otter trawl fishery later in the year. Although young-of-year moving upstream into estuaries is an acknowledged phenomenon, the mechanism for these movements remains unknown.

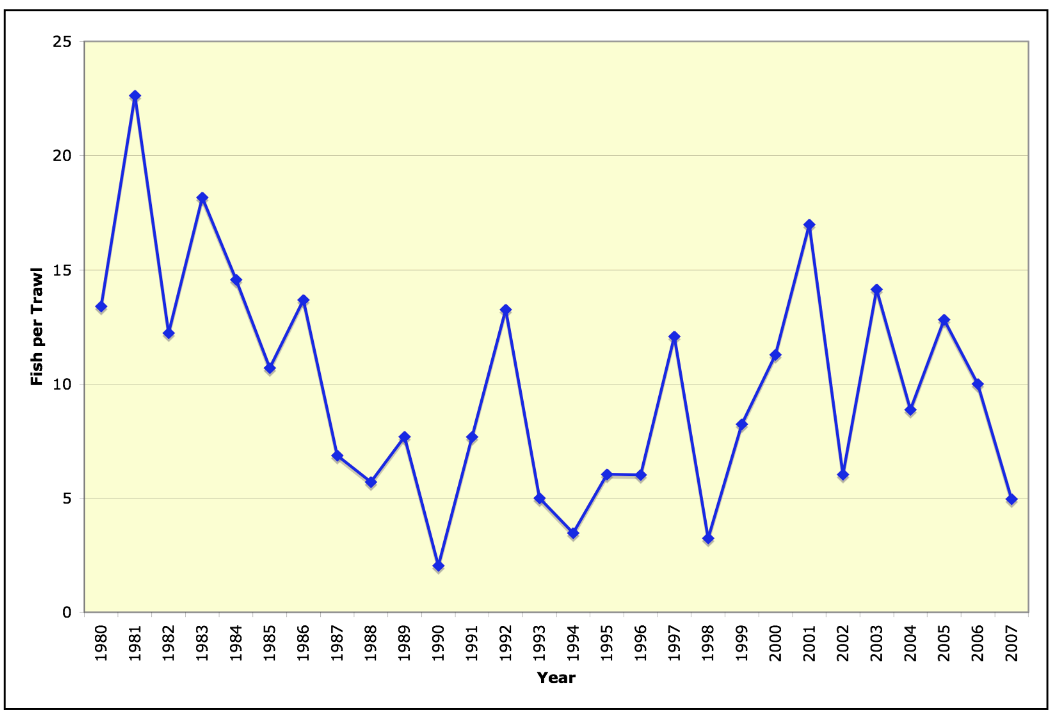

Figure 31. Annual catch per unit effort for striped bass captured by otter trawl in Suisun Marsh from 1980 to 2007.

Striped Bass

Striped bass are consistently one of the most abundant fishes in trawl catches. Although somewhat variable, annual catch per unit effort of striped bass decreased significantly from 1980 to 1990 (annual fish per trawl = 18.86 - 1.45 (year); R^2 = 0.67; p = 0.002; n = 11; Figure 31). From 1991 to 2007, catch per unit effort had no significant increasing or decreasing trends (fish per trawl = 7.27 + 0.20 (year); R^2 = 0.06; p = 0.35; n = 17). 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 otter trawl catch (California Department of Water Resources and Department of Fish and Game 2007, Moyle 2002).

Schroeter et al. (2006) reported that young-of-year striped bass make up an overwhelming proportion of their otter trawl catch and thus suggested that catch size is a function of reproductive success and recruitment. Otter trawl catch per unit effort in both 2006 and 2007 reflect this trend: catch per unit effort in 2006 was double that in 2007 (10.0 and 5.0 fish per trawl, respectively), while annual average standard length in 2007 was considerably larger than in 2006 (113 mm SL and 69 mm SL, respectively). Monthly catch per unit effort pattern also reflects a greater influx of young-of-year into the catches in 2006, with a greater catch in early summer concomitant with a much lower average standard length (Figure 32).

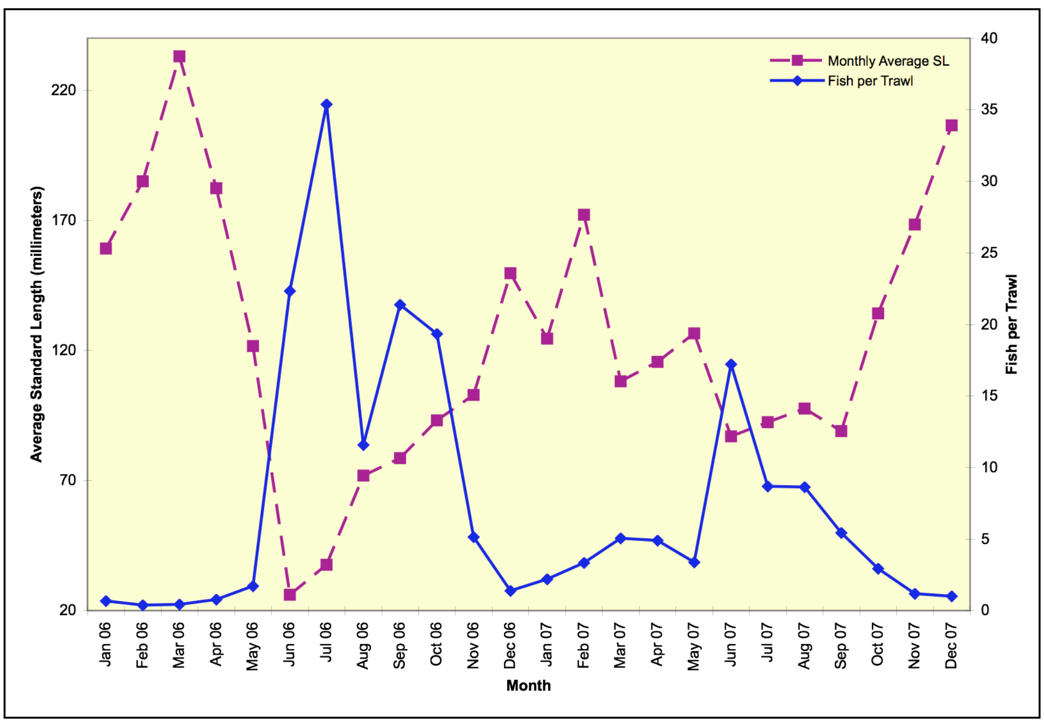

Figure 32. Monthly average standard length and catch per unit effort for striped bass captured by otter trawl in Suisun Marsh during 2006 and 2007.

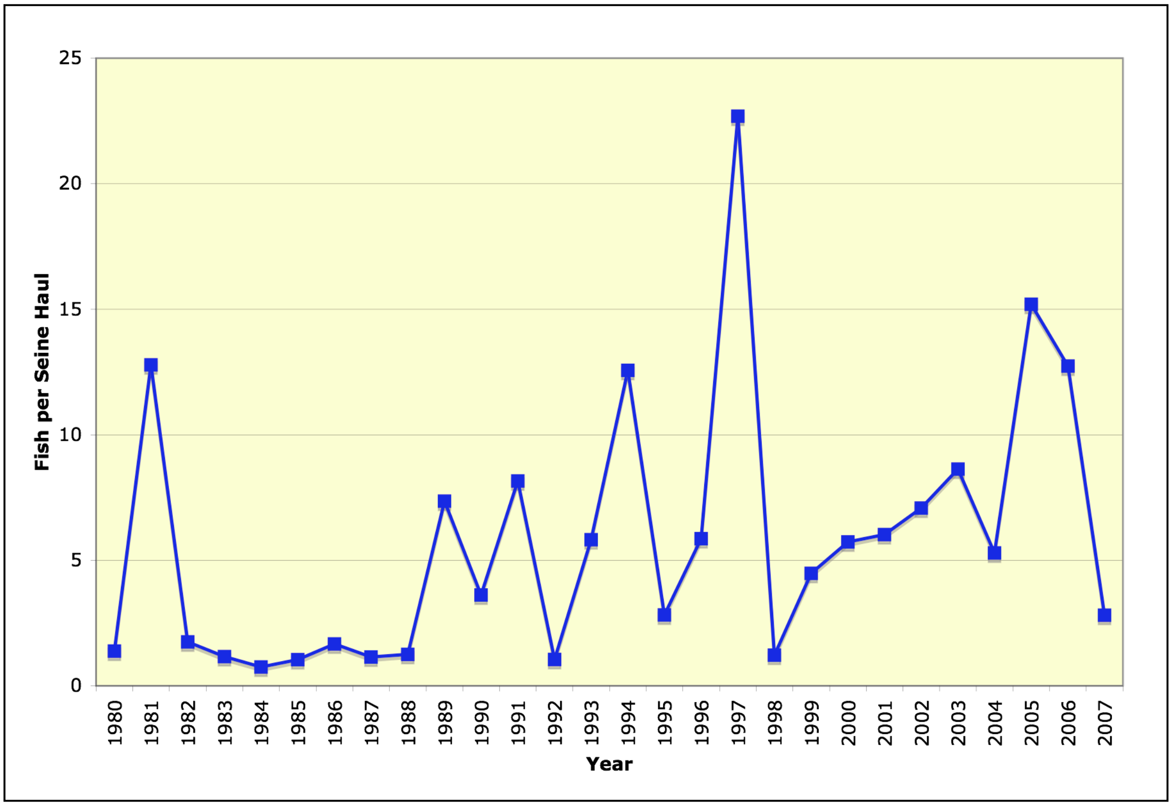

Figure 33. Annual catch per unit effort for striped bass captured by beach seine in Suisun Marsh from 1980 to 2007.

Schroeter et al. (2006) reported catching the majority of striped bass in lower Suisun, Goodyear, and First Mallard sloughs. Additionally, they found that catch per unit effort was lower in Goodyear Slough in 2004, and posited that low oxygen concentrations may have been the culprit. The geographic distribution of catch in 2006 and 2007 was similar to past years, with catch per unit effort highest in lower Suisun, First Mallard, and Nurse sloughs (Table 5). While catch of striped bass in Goodyear Slough was quite high in 2006, all but two fish were taken when dissolved oxygen concentration was above 4.90 mg/l. However, the catch per unit effort rank of Goodyear Slough declined noticeably in 2007 (Table 5), while dissolved oxygen concentrations were generally higher than in 2006; additionally, substantial catches were made in First Mallard Slough in both 2006 and 2007 when dissolved oxygen concentrations dipped below 4.0 mg/l. Thus, dissolved

Table 5. Striped bass annual otter trawl catch per unit effort (CPUE) and CPUE rank (1 being highest CPUE, 10 being lowest) for sloughs in Suisun Marsh during 2006 and 2007.

Slough	2006		2007	
	CPUE	Rank	CPUE	Rank
Montezuma	6.16	5	3.18	5
Nurse	24.63	2	8.13	3
Denverton	3.50	9	1.46	10
First Mallard	9.75	3	13.50	1
Cutoff	4.96	6	4.19	4
Boynton	1.08	10	2.10	8
Peytonia	4.71	7	2.94	6
Goodyear	7.36	4	2.51	7
Upper Suisun	4.33	8	1.84	9
Lower Suisun	35.04	1	13.13	2

oxygen concentration alone likely does not explain the lower Goodyear Slough catches of recent years.

Schroeter et al. (2006) speculated that sloughs close to large, shallow bays host the bulk

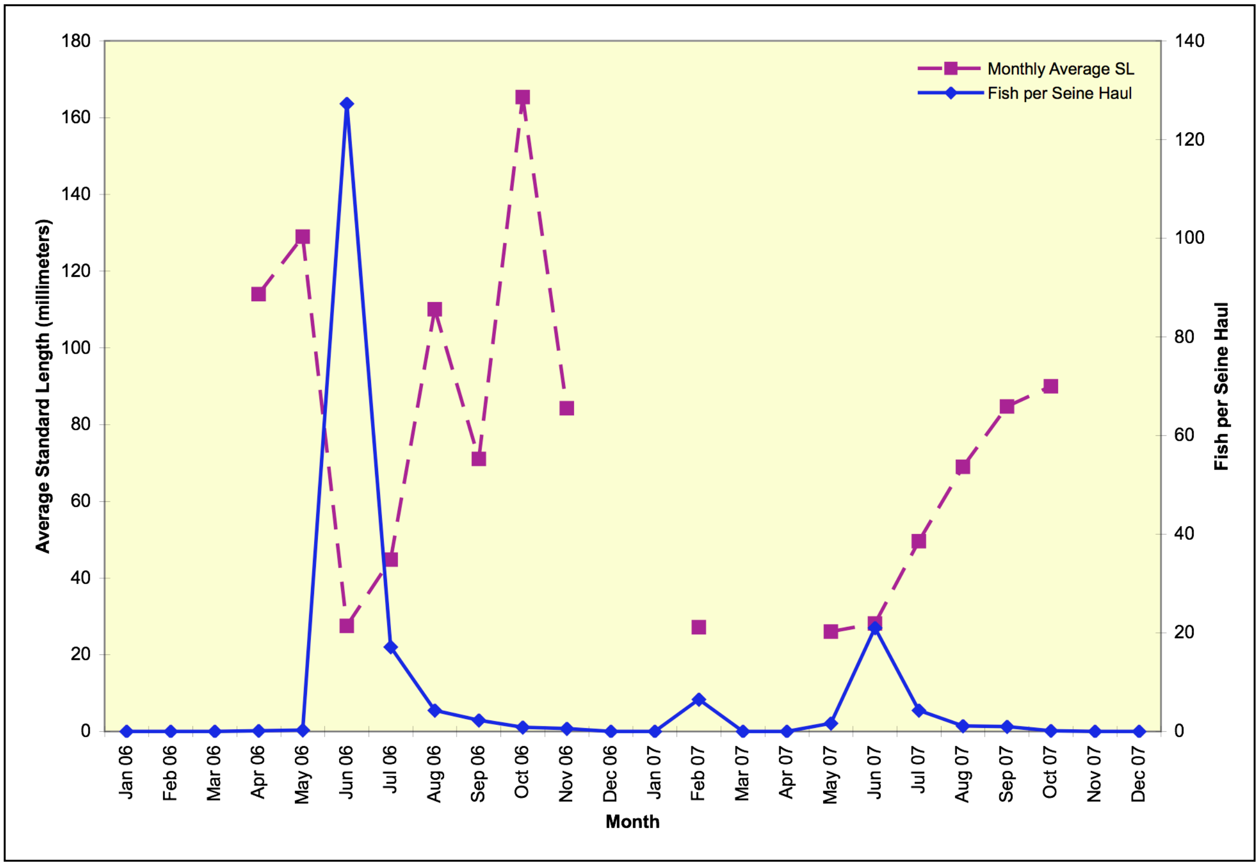

Figure 34. Monthly average standard length and catch per unit effort for striped bass caught by beach seine in Suisun Marsh during 2006 and 2007.

of the juvenile striped bass population, primarily due to high zooplankton densities. This explanation is consistent with the high 2006 and 2007 catches in Nurse Slough (Table 5). Nurse Slough is adjacent to Little Honker Bay, a very wide, shallow embayment that receives a substantial westerly fetch in the warm months. Our lower Suisun Slough sites are roughly within one river-kilometer of Grizzly Bay. While First Mallard Slough is distant from a large embayment, it is the shallowest slough that we sample. Thus, shallow water habitats with favorable hydraulics and presumed resultant high food densities (Thackeray 2004, Moyle 2002) may at least partially explain the observed striped bass distribution.

Annual beach seine catch per unit effort has roughly followed that of otter trawl catch per unit effort: it generally decreased and remained low through the 1980s, then began to vary around a higher average from 1989 to 2007 (Figure 33). Peak beach seine catches have frequently coincided with peak otter trawl catches (e.g., 1989, 1997, 2003, 2005), implying that both methods are primarily sampling the same cohort.

Monthly beach seine catch per unit effort in 2006 was negligible until June, when it skyrocketed and reached its yearly maximum (Figure 34); catch thereafter declined roughly exponentially until reaching zero in December. Catch per unit effort was inversely related to average standard length, indicative of a large influx of young-of-year. Otter trawl catch lagged behind beach seine catch by about a month, which is consistent with data for all years of the study.

The pattern of beach seine catch per unit effort in 2007 was very similar to that in 2006: virtually no striped bass were captured in winter and early spring; catch peaked in June concomitant with low average standard length; and catch decreased through the remainder of the year while size increased (Figure 34).

Geographic distribution of beach seine catches, like for otter trawl catches, was disparate: more fish were captured in Suisun Slough than Denverton Slough. This distribution is opposite that of the beach seine catches of threadfin shad and Mississippi silverside, which share similar food resources with young-of-year striped bass (Moyle 2002). However, the timing of peak monthly catch per unit effort for all three species is different: catch of Mississippi silverside attains its maximum in spring, striped bass in early summer, and threadfin shad in late summer. Striped bass have very high metabolic rates (Moyle 2002) and thus may need a greater area per fish than other species, which Suisun Slough might provide.

Black Crappie

Black crappie, the most frequently captured centrarchid in Suisun Marsh, were (excepting 1986) very rarely caught in otter trawls until a relatively large catch was made in 1999

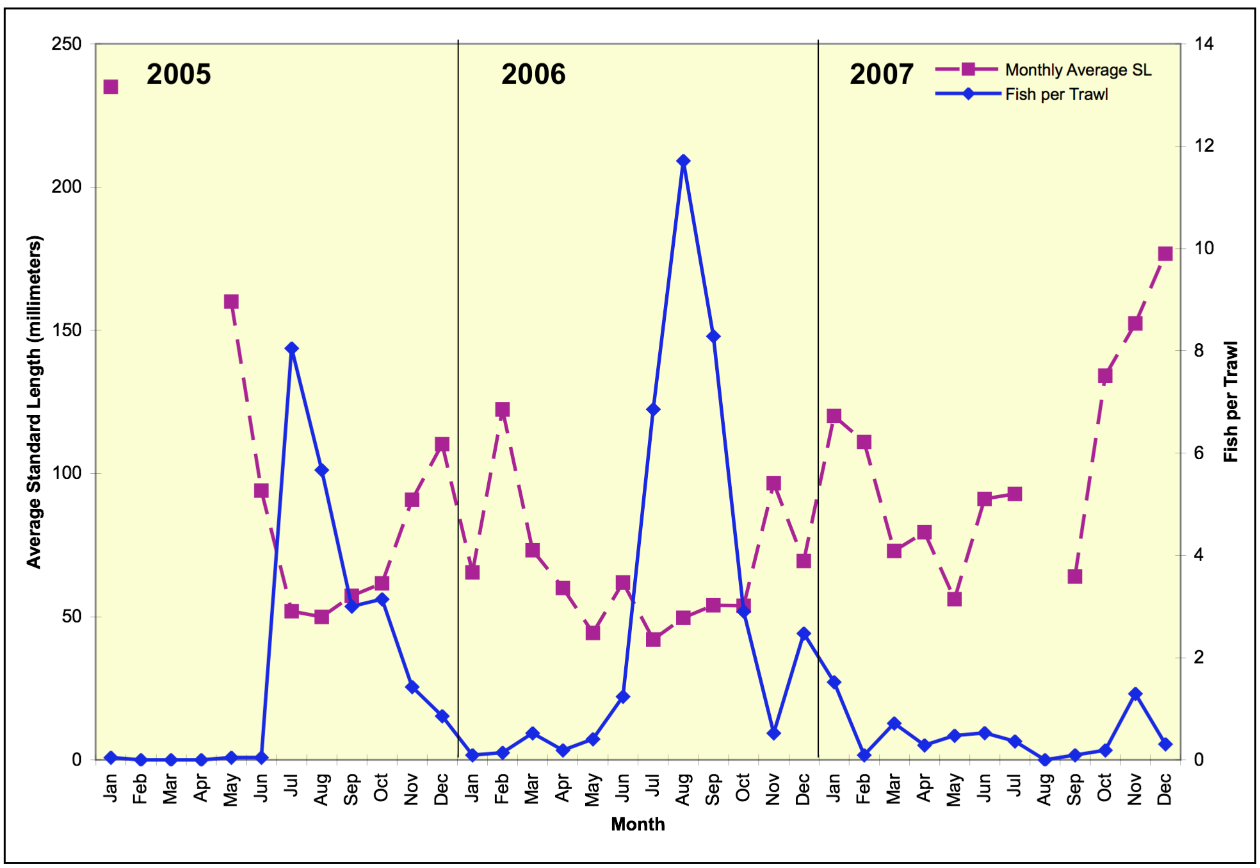

Figure 35. Monthly average standard length and catch per unit effort for black crappie captured by otter trawl in Suisun Marsh from 2005 to 2007.

concurrent with moderate Delta outflow. Catch then declined from 1999 until 2005, when it jumped to more than three times the 1999 value. The highest annual catch of black crappie was recorded in 2006, when they were the third most frequently captured fish in otter trawls. In 2007, catch decreased dramatically and returned to the 1999 level.

Catch in 2005 was defined by a large influx of young-of-year entering the catches in summer, with monthly catch per unit effort then declining while the average standard length of the fish increased through the remainder of the year (Figure 35). The pattern was similarly followed in 2006, with the exception that peak catches were substantially higher than in 2005 (Figure 35). 2007 differed from the previous two years in that there was no noticeable drop in average standard length; catch per unit effort remained consistently low through summer and early autumn; and a relatively high catch was made in November (Figure 35).

The geographic distribution of black crappie is striking: 80% of the fish came from First Mallard and Denverton sloughs in 2005; 88% came from Cutoff and First Mallard sloughs in 2006; and 50% came from Denverton and First Mallard sloughs in 2007, with somewhat lesser catches made in Peytonia and Boynton sloughs. Additionally, out of the 1,340 black crappie caught from 2005 through 2007, none were taken in the larger sloughs (i.e., Suisun and Montezuma sloughs). Further, only 11 of the 1,340 black crappie were captured in Goodyear Slough. Though far fewer black crappie were caught in beach seines, those that were came from Denverton Slough.

It appears that black crappie are associated with small sloughs of low salinity (and consequently Delta outflow; Figure 5). This inference is bolstered by a study that found white crappie (*Pomoxis annularis*) associated with salinities less than 5 ppt in a Gulf Coast watershed (Gelwick et al. 2001). Unfortunately, there are no known laboratory experiments testing the salinity tolerances of either crappie species. However, it appears that either the egg, larval, or young juvenile stage is susceptible to moderate-to-high salinities. Young-of-year dominated the catch in 2005 and 2006, which both had below-average salinities during the spring spawning and

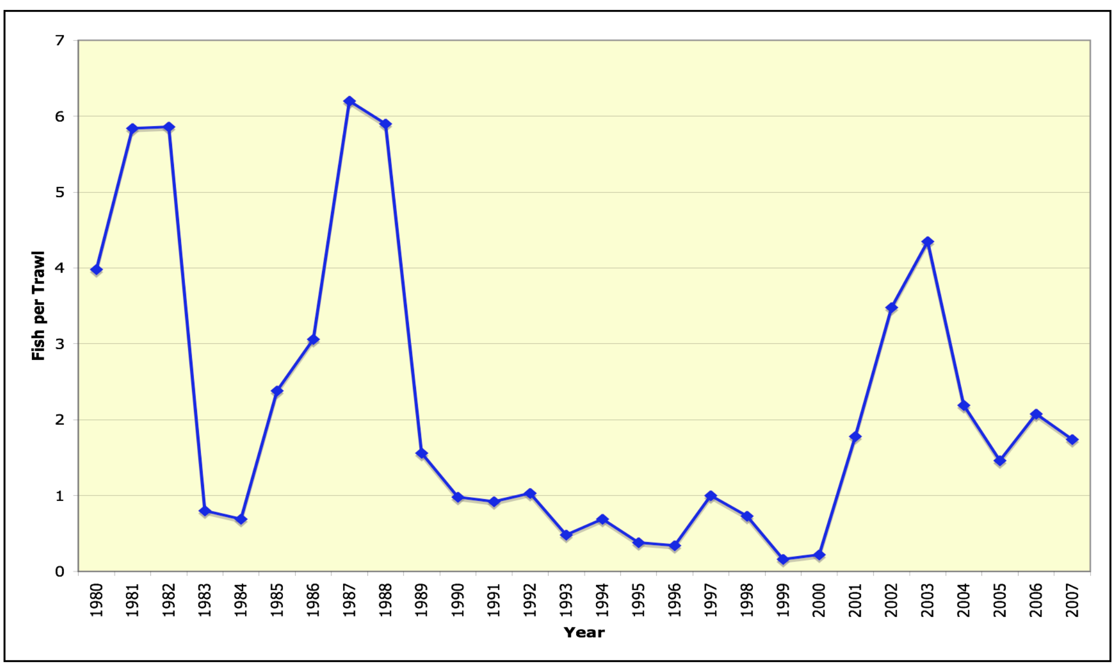

Figure 36. Annual otter trawl catch per unit effort for tule perch in Suisun Marsh from 1980 to 2007.

summer rearing periods. Conversely, salinities in 2007 were considerably higher and far fewer young-of-year entered the catches; consequently, black crappie in 2007 were larger than those in 2005 or 2006 (annual average standard lengths: 117, 61, and 54 mm, respectively). Additionally, although more and larger ripe black crappie (J. Durand, University of California, Davis, pers. comm.) were captured in 2007 than in 2006, the expected strong influx of young-of-year did not occur.

It is likely that catches of black crappie reflect recruitment from suitable areas for spawning. Black crappie prefer to spawn in shallow, hard-bottomed, cover-laden areas well protected from wind (Pope and Willis 1997). The small sloughs - particularly Denverton and First Mallard sloughs - have more of this habitat than the large sloughs (i.e., Montezuma and Suisun sloughs; Meng and Matern 2001). Assuming low larval dispersion rates, our high catches of young-of-year in Denverton, First Mallard, and Cutoff sloughs may be due the combination of low salinity and presence of appropriate spawning habitat.

Tule Perch

Otter trawl catch per unit effort for tule perch was highly variable in the 1980s, dropped to low levels in the 1990s, and increased again in the 2000s (Figure 36). Unlike many species in the marsh (e.g., splittail, prickly sculpin), tule perch density is not related to Delta outflow: large otter trawl catches have been made in low (1987, 1988, 2001), moderate (2003, 2004), and high outflow years (1986; Figure 36). As the only freshwater member of the family Embiotocidae,

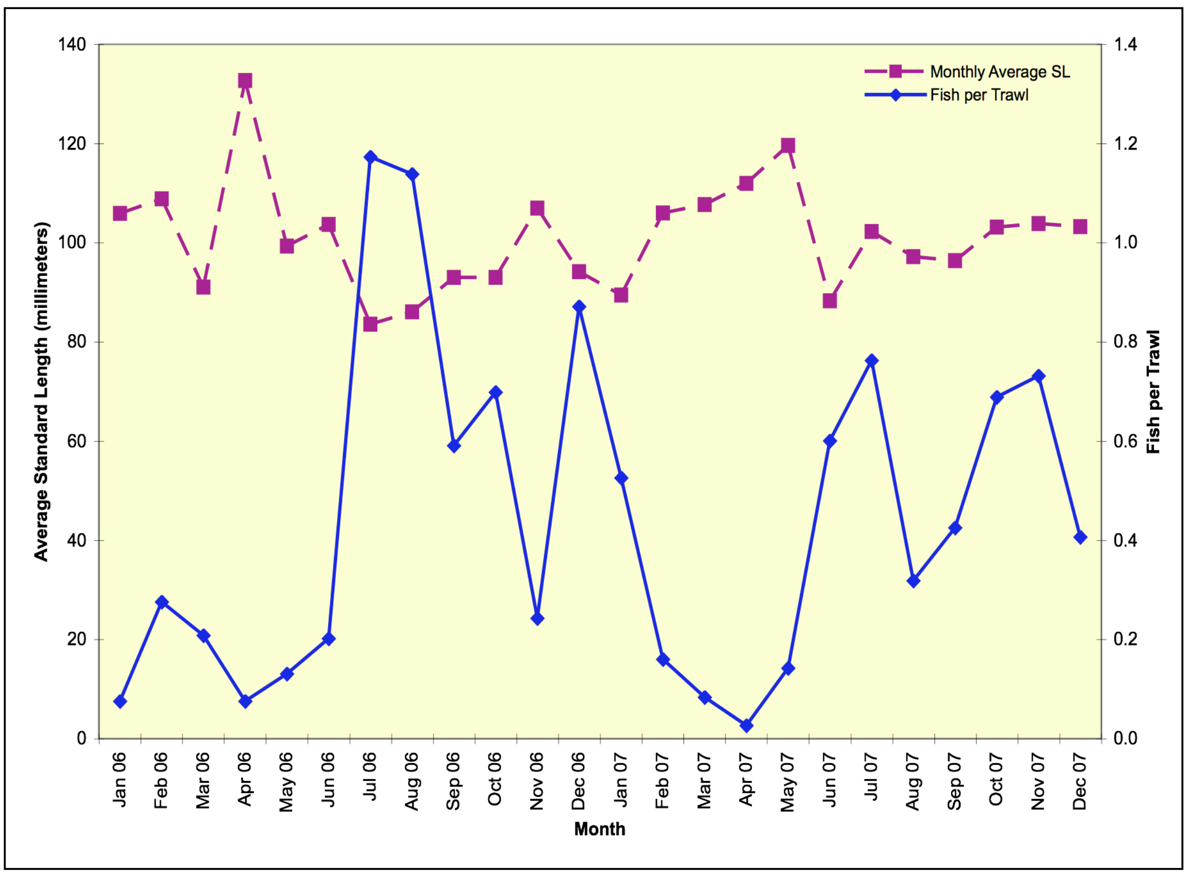

Figure 37. Monthly average standard length and catch per unit effort for tule perch captured by otter trawl in Suisun Marsh during 2006 and 2007.

tule perch are euryhaline (Moyle 2002) and are likely not to suffer from high salinities in dry years.

Annual otter trawl catch per unit effort of tule perch in 2006 was about the average for all years of the study (2.1 and 2.2 fish per trawl, respectively). Monthly catch per unit effort was relatively low until July, when it reached its annual maximum (Figure 37). This high catch was attended by only a slight dip in average standard length; however, because tule perch are viviparous, their large young reduce average standard length less than young of oviparous fish. Catch per unit effort then declined until December, when the third highest value was recorded (Figure 37).

2007 annual otter trawl catch per unit effort was lower than in both 2006 and the average for all years of the study (1.7, 2.2, and 2.1 fish per trawl, respectively). Like 2006, peak catches were made in summer and late autumn; however, the pattern appeared to shift to earlier in the year, perhaps due to higher spring temperatures (Figure 37).

Schroeter et al. (2006) found tule perch most abundant in Cutoff and First Mallard sloughs. This pattern persisted into 2006, when 37% and 21% of the total tule perch captured were taken from Cutoff and First Mallard sloughs, respectively. In 2007, 37% of the tule perch were again taken in Cutoff Slough; however, they were generally distributed more evenly than in the previous year. Interestingly, while moderate numbers of tule perch were captured in Peytonia Slough, in both years none were taken from upper Suisun Slough and few were caught in Boynton Slough. Consistent with Schroeter et al. (2006), few tule perch were taken from Goodyear Slough in 2006 and 2007.

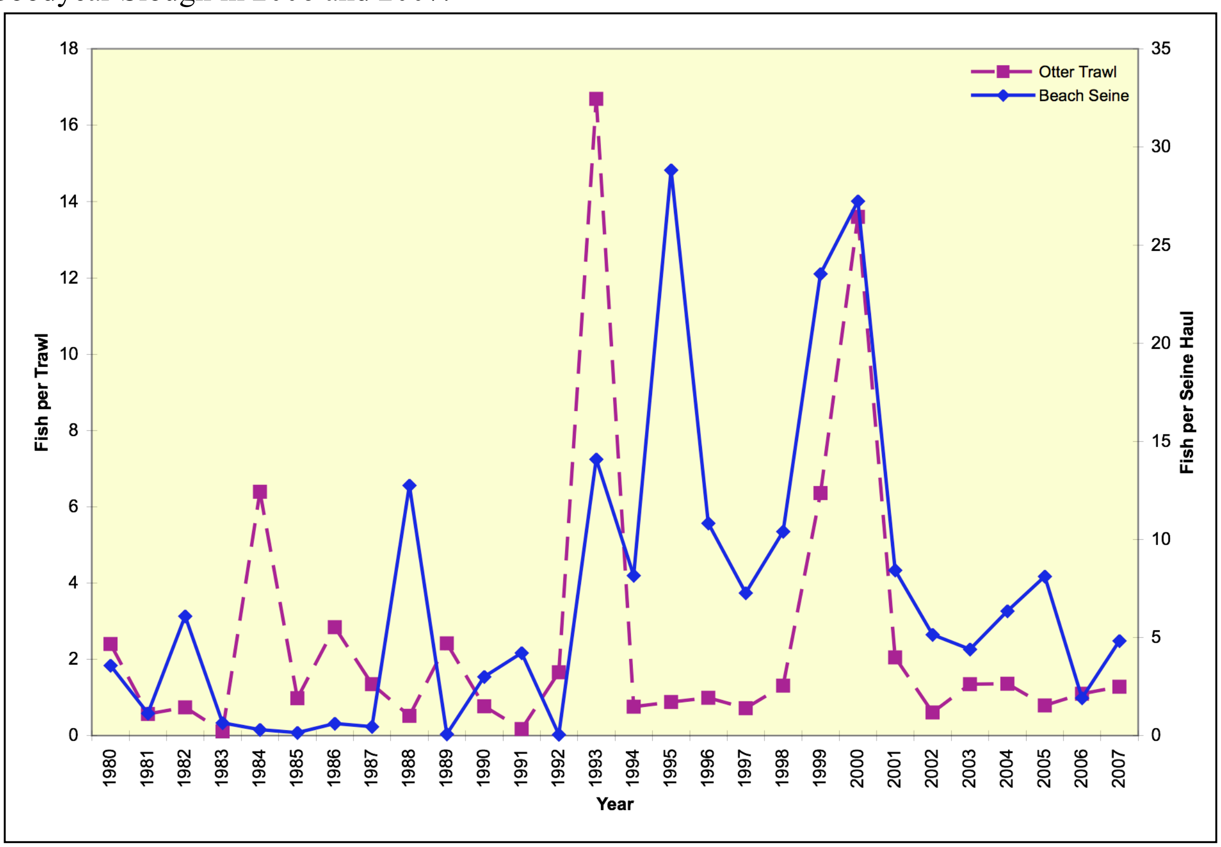

Figure 38. Annual catch per unit effort for yellowfin goby caught by beach seine and otter trawl in Suisun Marsh from 1980 to 2007.

Gobiidae

Yellowfin Goby

Annual otter trawl catch per unit effort for yellowfin goby has been quite variable over the study's history, with peak catches in 1984, 1993, and 2000 - all years of relatively low Delta outflow. Additionally, it appears that a strong year-class may have dominated the catch for three three-year periods starting in 1980, 1986, and 1989 (Figure 38). Otter trawl catch per unit effort was relatively low throughout the mid-1990s and for the last five years (i.e., 2002 - 2007; Figure 38); however, yellowfin gobies are often one of the most abundant fishes captured in otter trawls.

Otter trawl catches in 2006 and 2007 were similar. Monthly catch per unit effort was relatively low in winter and early spring, attended by a relatively large average standard length until May (Figure 39). In both years, catch peaked in July concomitant with low average standard lengths, indicating an influx of young-of-year (Figure 39). Catch per unit effort in 2006 then declined gradually while average standard length increased, probably the result of growth

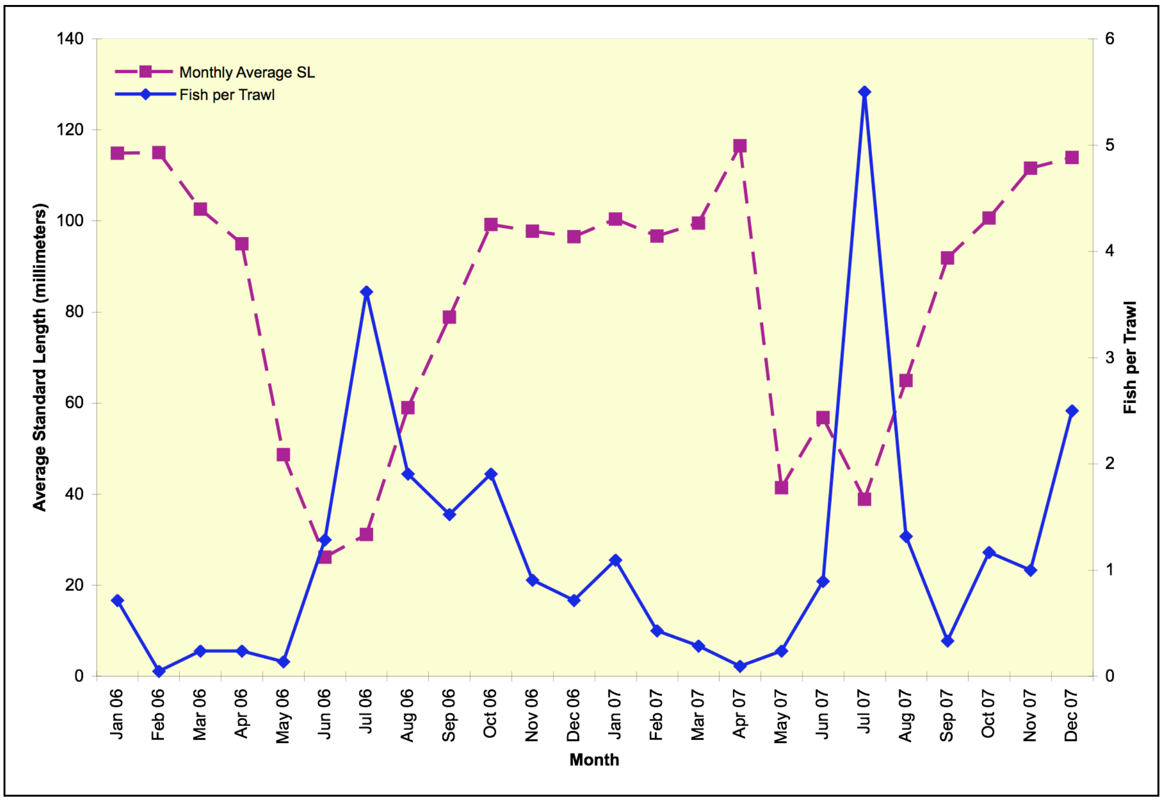

Figure 39. Monthly average standard length and catch per unit effort for yellowfin goby captured by otter trawl in Suisun Marsh during 2006 and 2007.

and mortality of young-of-year. In the latter third of 2007, standard length gradually increased until the end of the year, while catch per unit effort crashed in September and then generally rose through the remainder of the year (Figure 39).

While yellowfin gobies are present throughout the marsh, they are not distributed evenly between the sloughs. In 2006, 35% of all yellowfin gobies caught by otter trawling were taken from lower Suisun Slough. Yellowfin gobies apparently need salinities higher than 5 ppt for successful breeding (Wang 1986); salinities in 2006 did not reach 5 ppt in Suisun Slough until

August, intimating that the high catch of small fish in July was primarily due to young-of-year entering the marsh from other parts of the estuary. Very low springtime catches in the eastern marsh (i.e., Denverton, Montezuma, and Nurse sloughs) and Goodyear Slough imply that most fish were spawned downstream of Suisun Bay.

In 2007, as in 2006, a large percentage (46%) of otter trawl-caught yellowfin gobies came

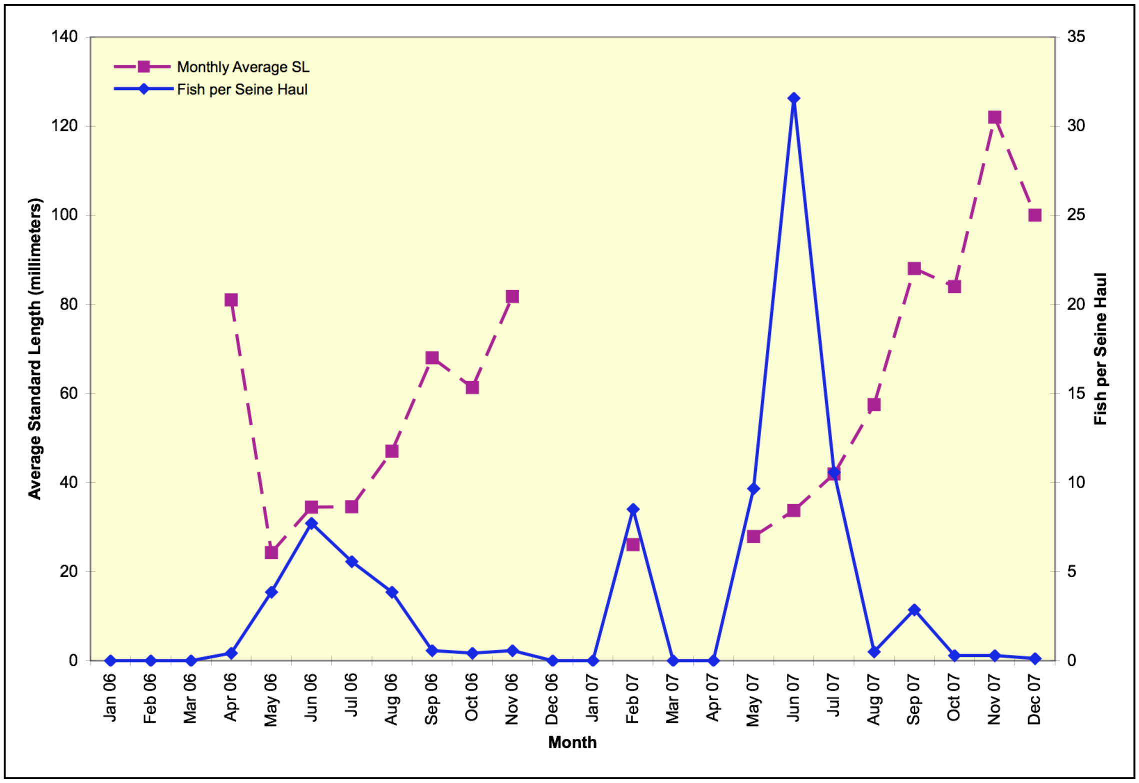

Figure 40. Monthly average standard length and catch per unit effort for yellowfin goby captured by beach seine in Suisun Marsh during 2006 and 2007.

from lower Suisun Slough. However, in 2007 5 ppt was reached in lower Suisun Slough in May, well before the peak catch. Thus, the higher catch in 2007 may have been because of young-of-year entering the marsh from downstream, joined by additional juveniles produced by in-marsh spawning.

Like the otter trawl catch, the annual seine catch per unit effort for yellowfin goby has been highly variable. However, beach seine catch per unit effort has roughly vacillated around a higher average from 1992 to 2007, although a generally decreasing trend is evident from 2001 to 2007 (Figure 38). While high seine catches were made in years with high otter trawl catches (e.g., 1993, 2000), other years of high beach seine catch coincided with low otter trawl catch (e.g., 1988, 1995).

The monthly pattern of beach seine catch per unit effort in 2006 and 2007 somewhat mirrors that of otter trawl catch per unit effort. Except for February 2007, winter and early spring seine catches were exceptionally low: no fish were caught in January, February, and March 2006, or in January, March, and April 2007 (Figure 40). Catch per unit effort then increased in May and peaked in June in both years, a month earlier than otter trawl catch per unit effort peaks and concurrent with low average standard lengths. Sizes of yellowfin gobies caught by the two methods in June and July 2006 were about the same, suggesting an offshore movement of young-of-year. Like otter trawl catch, beach seine catch per unit effort declined through autumn until the end of the year, with the exception of an anomalously high catch of very small fish in February 2007.

Distribution of yellowfin gobies captured by seine, like otter trawl, was uneven. In 2006 and 2007, 83% and 89% of all yellowfin goby captured in beach seines came from Suisun Slough. Yellowfin gobies prefer soft substrates (e.g., mud) for spawning, and thus it is tempting to ascribe the unequal beach seine catches to differential spawning since Denverton Slough frequently has a rocky bottom. However, salinities in both Denverton and upper Suisun sloughs are generally too low for breeding. It is most likely that the higher catches in Suisun Slough were the result of its closer proximity to spawning areas outside the marsh (e.g., San Pablo Bay).

Shimofuri Goby

Shimofuri gobies were extremely rare in otter trawls until 1989, when the annual catch per unit effort peaked. Catch per unit effort then oscillated considerably around a relatively low mean (Figure 41). No clear relationship between Delta outflow and otter trawl catch per unit effort for shimofuri goby is evident: large catches have been made in high (1997), moderate (2004), and low (2001) outflow years (Figure 41). Between 1997 and 2002, it appears otter trawl catches of shimofuri and yellowfin gobies were inversely related (Figures 38 & 41); however, from 2003 until 2007, catch of both species tended to mirror each other.

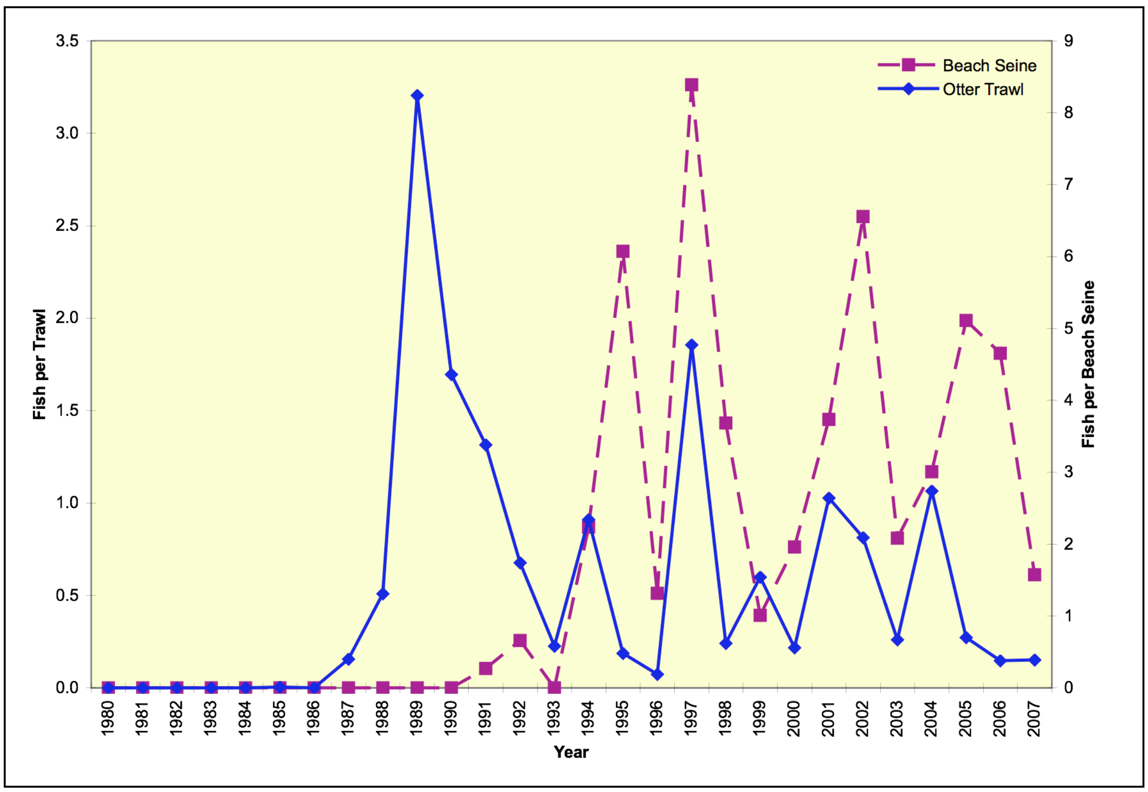

Figure 41. Annual fish per trawl and fish per beach seine for shimofuri goby captured in Suisun Marsh from 1980 to 2007.

The pattern of shimofuri goby monthly otter trawl catch per unit effort in 2006 was fairly similar to that of other species (e.g., white catfish, striped bass, splittail): catch was low in winter and early spring, increased rapidly and reached its peak in summer concomitant with low

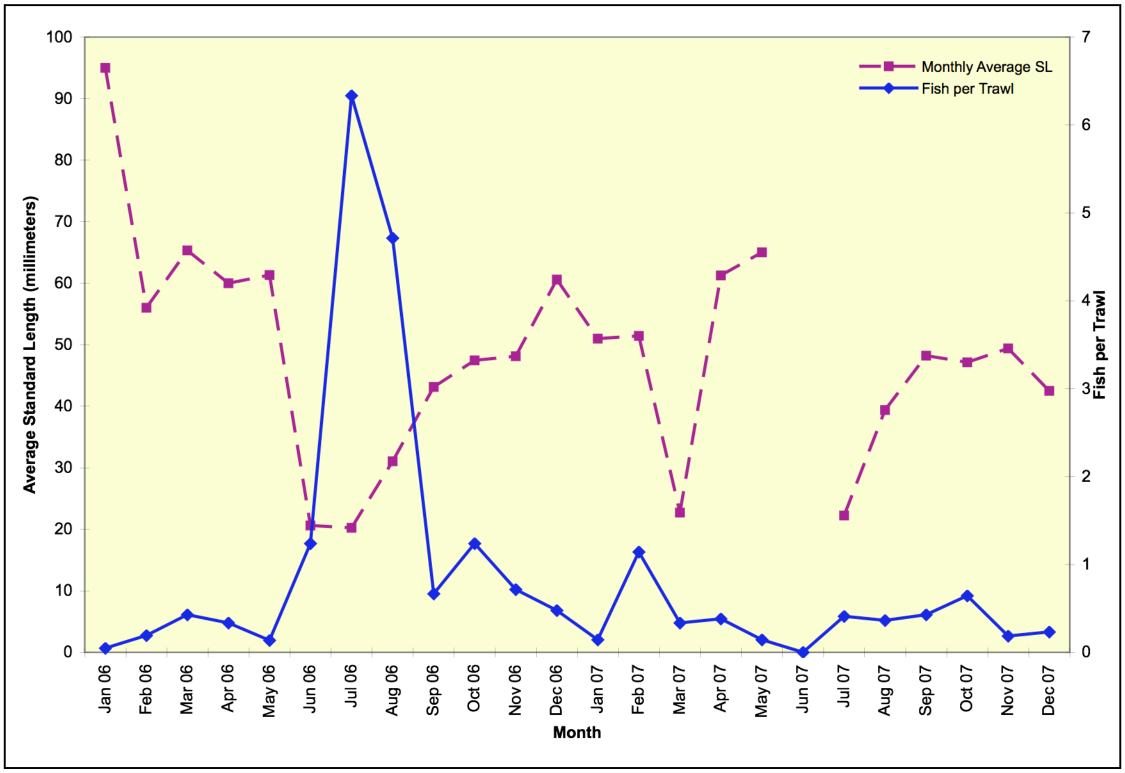

Figure 42. Monthly average standard length and catch per unit effort for shimofuri goby captured by otter trawl from Suisun Marsh during 2006 and 2007.

average standard length, declined precipitously in late summer while size increased, and then decreased less severely through the remainder of the year (Figure 42). As with other marsh fishes, the pattern is consistent with young-of-year entering the catches as they became vulnerable to the otter trawl net, followed by mortality and growth as the year progressed.

Otter trawl catch in 2007 was substantially lower than in 2006. Peak monthly catch per unit effort was highest in February, although still relatively low with only 24 fish captured (Figure 42). Catches in all other months were routinely small (Figure 42). Average standard length declined in March 2007 concurrent with a low catch, possibly due to earlier spawning and lower survival of early life-history stages.

Consistent with the observation that shimofuri gobies prefer shallow-water habitats (Moyle 2002), a small percentage of the otter trawl catch in 2006 and 2007 came from the deeper, larger sloughs (i.e., Montezuma and Suisun sloughs). Except for low catches in Goodyear Slough for both years, shimofuri gobies were distributed fairly evenly between the smaller sloughs. Unlike for yellowfin goby, low catches throughout the year in Montezuma and lower Suisun sloughs of shimofuri goby suggests that in-marsh production contributes substantially to the otter trawl catch.

Shimofuri goby were almost never caught in beach seines until 1994, after which annual catch per unit effort varied considerably around an average higher than that for early years of the study (Figure 41). As for otter trawl catch, no relationship of beach seine catch per unit effort to Delta outflow is evident.

The monthly pattern of beach seine catch per unit effort and average standard length in 2006 and 2007 somewhat resembles that for Mississippi silversides: catch maxima occurred in spring concurrent with high average standard length, and in late summer with low standard length (Figure 43). However, it is unlikely that explanations for the abundance and distribution of silversides are sufficient for shimofuri gobies. Low beach seine catch in winter was not attended by relatively high otter trawl catches, suggesting that shimofuri gobies are not wintering in thalwegs. The small beach seine catch in July 2006 occurred concomitant with a high otter trawl catch; additionally, otter trawl catch declined in August while beach seine catch rose. Also, fish caught in beach seines in July and August 2006 were generally larger than those captured in otter trawls, perhaps due to settling out of larvae in shallow-water habitats (i.e., our seining beaches) and not because of high young-of-year mortality. Conversely, high catch of relatively large fish in spring intimates movement of adult fish into shallow spawning areas. Most shimofuri gobies only live for a year, thus the steep decline of beach seine catch per unit

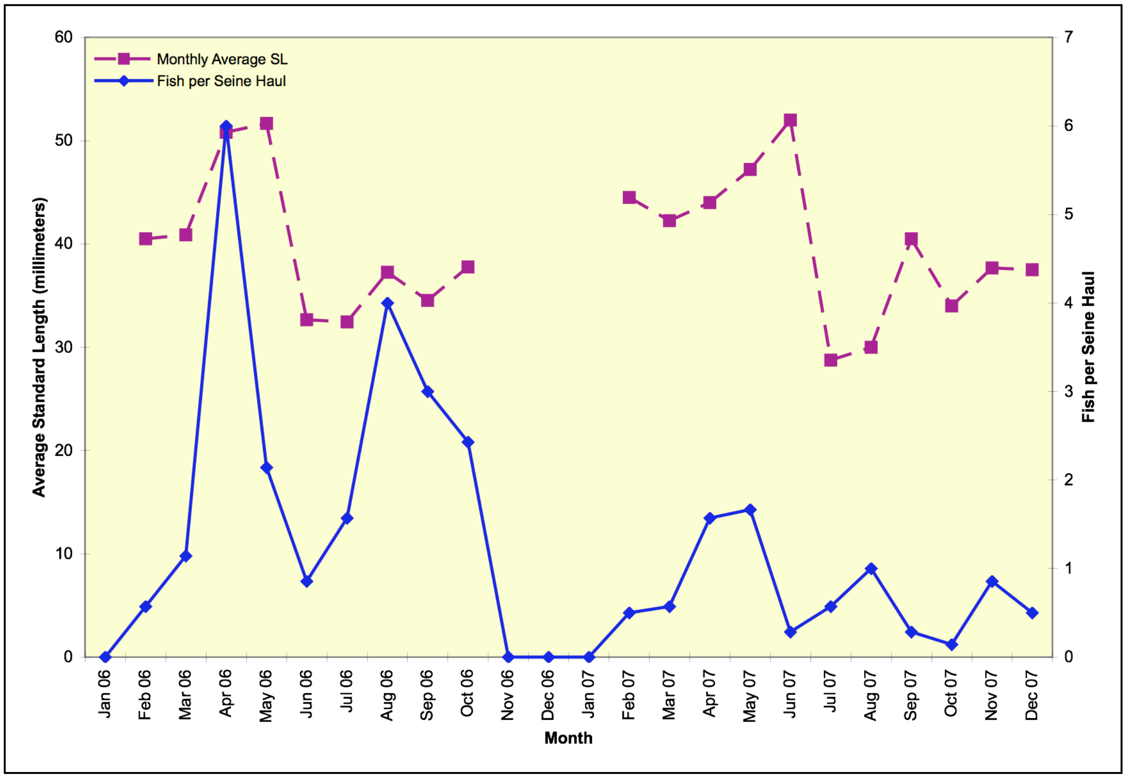

Figure 43. Monthly average standard length and catch per unit effort for shimofuri goby captured by beach seine from Suisun Marsh in 2006 and 2007.

effort in May and June could have been the result of yearling mortality.

Congruent to otter trawl catches, the vast majority of shimofuri gobies captured in beach seines were taken in Denverton Slough (i.e., a small slough) with coarse substrates suitable for nesting. Only four of the 201 fish seined came from Suisun Slough.

Other Fishes

Shokihaze gobies (*Tridentiger barbatus*) were first captured in Suisun Marsh in 1999, reflecting their recent invasion of the system, and have been caught by otter trawling in consistently low numbers from 2001 to 2007. Most shokihaze gobies in 2006 and 2007 were young-of-year fish taken in late summer and autumn from upper Suisun, Montezuma, and Nurse sloughs. None were captured by beach seining in 2006 or 2007, perhaps indicating a preference for deep benthic habitats.

White sturgeon (*Acipenser transmontanus*) were infrequently caught by otter trawling in Suisun Marsh. Although still low, the highest catches of white sturgeon in the study's history were recorded in 2006 and 2007 (16 and 24 fish, respectively). Most fish were captured in Suisun Slough, with catch spread out fairly evenly among months. Average standard length of white sturgeon was 348 mm total length (TL), indicating that most fish were one- to two-years old. However, two white sturgeon about 1000 mm TL were also caught; both came from Suisun Slough.

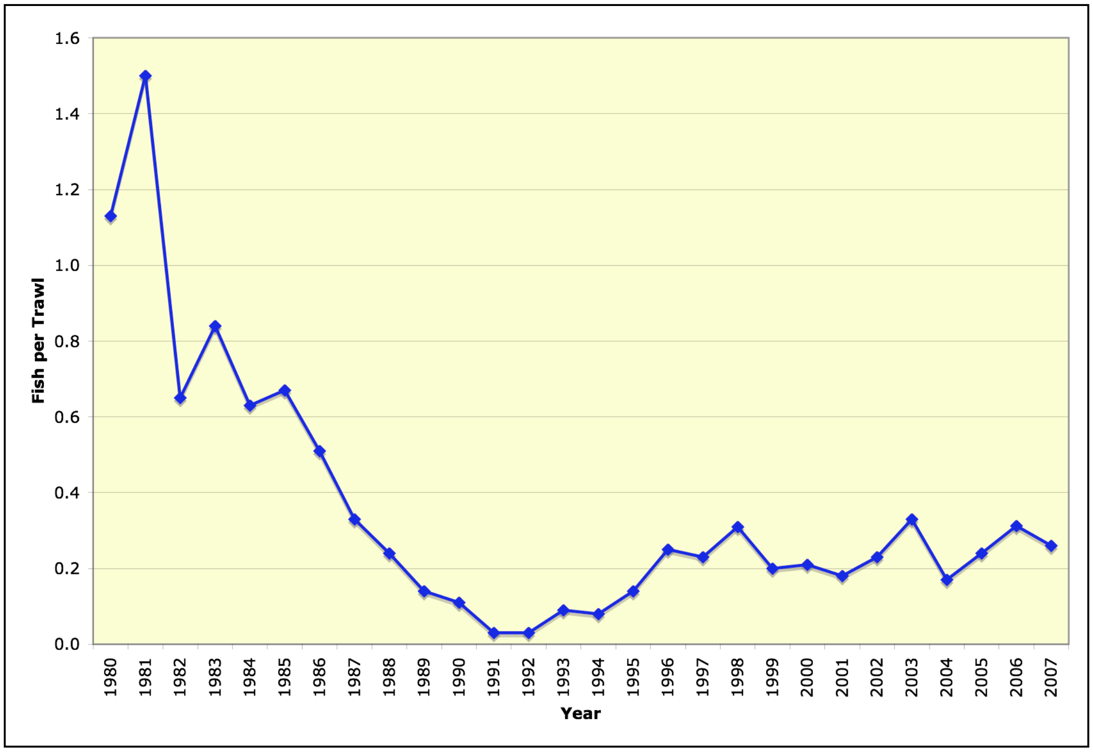

Figure 44. Annual catch per unit effort for Sacramento sucker captured by otter trawling in Suisun Marsh from 1980 to 2007.

Annual otter trawl catch per unit effort for Sacramento suckers (*Catostomus occidentalis*) very closely mirror that for native fishes: catch per unit effort declined in the early years of the study, then increased somewhat and began modestly varying after the early 1990s (Figure 44). This trend continued into 2006 and 2007: catch per unit effort was relatively low though higher than in the dry early 1990s. Adults made up a considerable part of the catches in 2006 and 2007 (223 and 256 millimeters average standard length, respectively), although several year-classes were also present. Most Sacramento suckers caught in 2006 and 2007 came from the smaller sloughs, particularly Peytonia Slough. This geographic distribution is consistent with the assumption of Schroeter et al. (2006) that Sacramento suckers originate primarily from feeder streams: Peytonia Slough is fed by Ledgewood Creek.

TRENDS IN INVERTEBRATE DISTRIBUTION AND ABUNDANCE

Black Sea Jellyfish (*Maeotias marginata*)

Annual otter trawl catch per unit effort for the introduced Black Sea jellyfish was highly variable until 1999, after which it rose approximately linearly to the present (Figure 45). Otter trawl catch of medusae generally began in summer, peaked in late summer or early autumn, and then declined dramatically through the remainder of the year. Moderate salinities (3 - 10 ppt) and warm temperatures (19 - 24 °C), conditions that prevail in summer and autumn within Suisun Marsh, appear favorable for release of medusae from polyps and their subsequent survival and growth (Schroeter 2008).

The pattern in monthly otter trawl catch per unit effort in 2006 and 2007 was similar to previous years: medusae first appeared in summer, peaked in late summer, then declined severely in autumn (Figure 46). Catch pattern appeared shifted somewhat earlier in 2007, which may be due to favorable salinities occurring earlier. In 2006, high catches began primarily in the southwest marsh, then gradually shifted to the eastern sloughs (e.g., Montezuma and Nurse sloughs); this pattern is consistent with favorable salinities being reached earlier in the southwest part of the marsh.

Overbite Clam (*Potamocorbula amurensis*)

The overbite clam was first discovered in San Francisco Bay in late 1986, and was probably introduced via ballast water jettisoned from Asian ships (Carlton et al. 1990). Three years later, the first overbite clam was captured in Suisun Marsh. Capture of live clams by the trawl reflects high abundance, given that the trawl is not designed for clam capture. From 1989

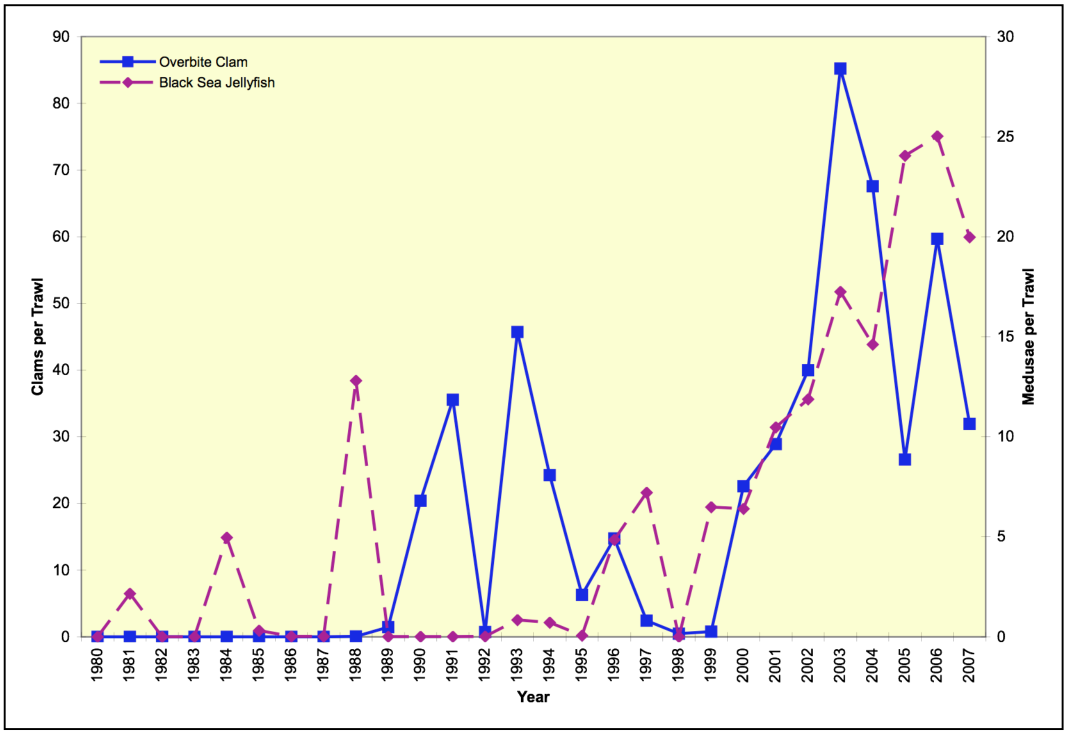

Figure 45. Annual catch per unit effort for Black Sea jellyfish medusae and overbite clam captured by otter trawling in Suisun Marsh from 1980 to 2007.

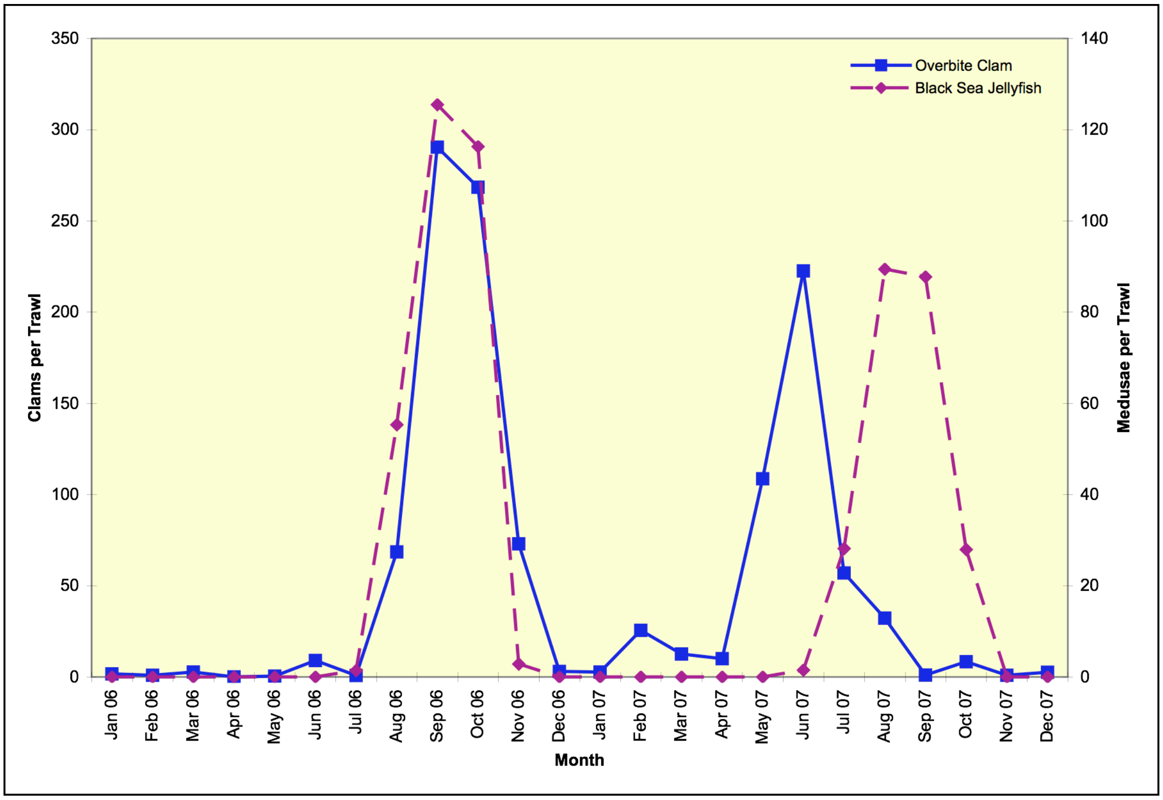

Figure 46. Monthly catch per unit effort for overbite clam and Black Sea jellyfish medusae captured by otter trawl from Suisun Marsh in 2006 and 2007.

to 1994, annual otter trawl catch per unit effort was fairly variable; from 1995 to 1999, catch noticeably declined concurrent with relatively high Delta outflows (Figure 45). Catch per unit effort skyrocketed in the early 2000s, then began varying around a relatively high average from 2004 to 2007. Compared to the entire study period, annual catches in 2006 and 2007 were both relatively high. The large 2006 catch initially seems surprising given that year's low salinities; however, the drier early 2000s and resultant higher salinities may have allowed the overbite clam to gain enough of a foothold to withstand relatively transient increases in freshwater flows.

Monthly otter trawl catch per unit effort of overbite clam in 2006 and 2007 was similar: catches were low in winter and spring, and highest in summer (Figure 46). However, 2007 differed from 2006 in that catch pattern was shifted earlier in the year, and the highest monthly catches were lower than in 2006. Survival, spawning, and fertilization are more successful above 5 ppt (Nicolini and Penry 2000); the distribution of overbite clam in the marsh reflects this constraint, with the vast majority of the otter trawl catch occurring in Goodyear and lower Suisun sloughs.

Shrimp

California Bay Shrimp (Crangon franciscorum)

Annual otter trawl catch per unit effort of California bay shrimp declined through the early 1980s, rebounded after the high Delta outflows of 1986, generally decreased through the dry late 1980s and early 1990s, then increased substantially again in the wet years of 1995 and

1997 (Figure 47). Catch per unit effort was relatively low from 1998 to 2007, with a clear decreasing trend from 2001 to 2005.

California bay shrimp generally spawn in spring downstream of Suisun Bay in more saline water; juveniles then migrate to the rich shallows of northern San Pablo Bay and Suisun Bay (Gewant and Bollens 2005). Monthly catch per unit effort in Suisun Marsh for 2006 may reflect this pattern, with relatively low catches in the first half of the year followed by much higher catches in late summer and early autumn (Figure 48). 2007 was similar, except that peak catches were shifted from summer and autumn to spring, perhaps due to higher, more favorable salinities occurring earlier in the year.

California bay shrimp were caught in all sloughs in both 2006 and 2007. However, of the 23 catches with more than 100 shrimp per trawl, only four did not occur in Montezuma or Suisun sloughs.

Siberian Prawn (Exopalaemon modestus)

Siberian prawn were not positively identified in the marsh until 2002, though were probably first captured in 2001 and identified as Oriental shrimp (*Palaemon macrodactylus*; Schroeter et al. 2006). Since then, Siberian prawn have varied around an average otter trawl catch per unit effort higher than that for California bay shrimp over the same period (Figure 47).

Siberian prawn are primarily freshwater shrimp and have successfully invaded other freshwater habitats in the United States (e.g., the Columbia River; Emmett et al. 2002). The high 2006 monthly otter trawl catch per unit effort from late summer to late autumn and the generally

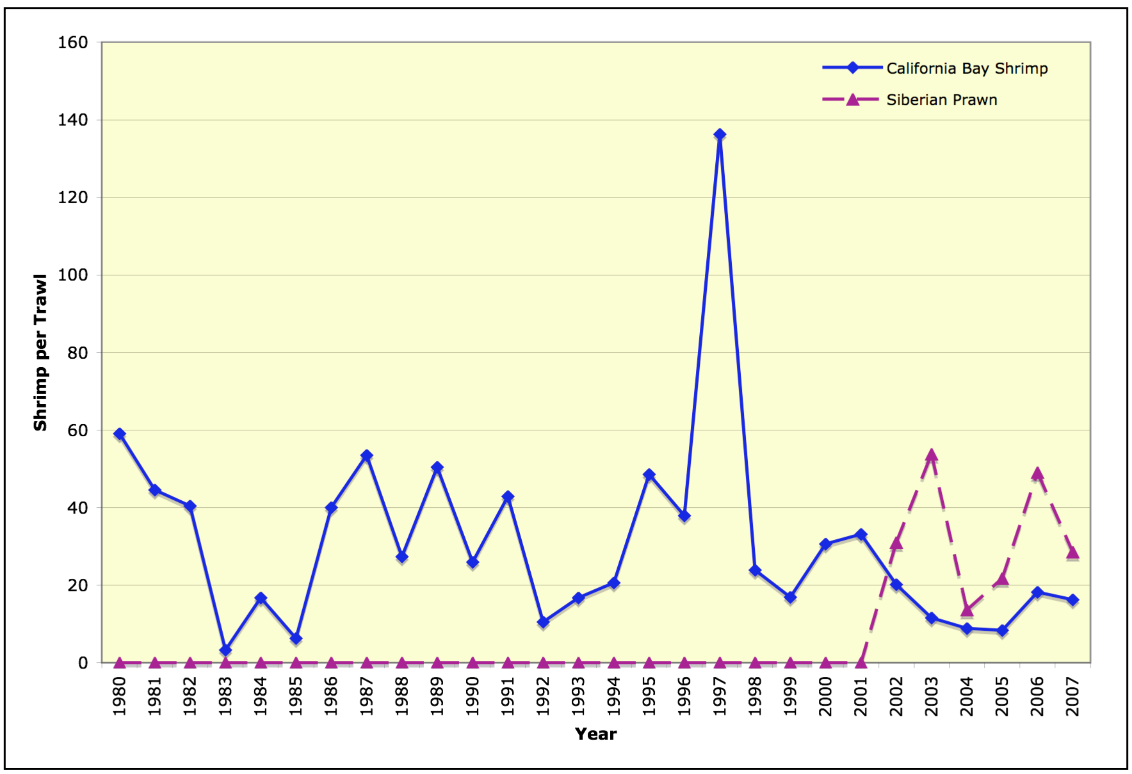

Figure 47. Annual catch per unit effort for California bay shrimp and Siberian prawn captured by otter trawling in Suisun Marsh from 1980 to 2007.

declining catch throughout 2007 (Figure 48) may reflect a sensitivity to elevated salinities. Very low catches in Goodyear and lower Suisun sloughs, particularly in autumn, bolster the possibility that Siberian prawn are intolerant of relatively high salinities.

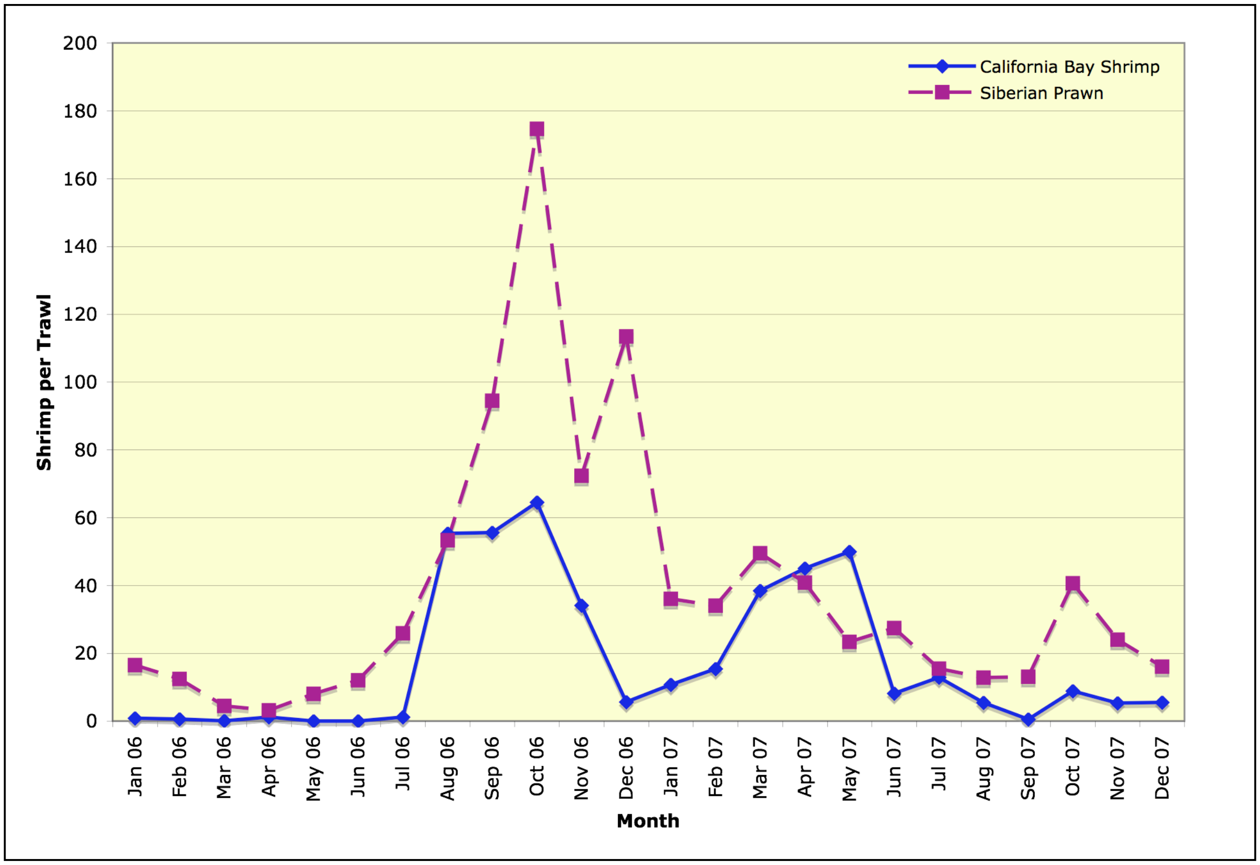

Figure 48. Monthly catch per unit effort for California bay shrimp and Siberian prawn captured by otter trawl from Suisun Marsh in 2006 and 207.

Other Invertebrates

Asian clam (*Corbicula fluminea*) have been frequently captured in otter trawls, albeit in very low numbers (especially compared to overbite clam). They have been captured in all months of the year; most of the higher catches in 2006 and 2007 were made in Montezuma Slough.

Oriental shrimp have been captured by otter trawl throughout the study's history; however, excepting a few early years of the study and 2002, catches have been routinely low. Numbers in 2006 and 2007 were also quite small (23 and 56 shrimp caught, respectively), with most shrimp captured in Suisun Slough. Catch in 2006 was concentrated toward the latter part of the year, while the catch in 2007 was more evenly distributed among months.

Schroeter et al. (2006) reported that catch of mysid shrimp was high in the early part of the study's history, then declined following 1990. In 2006 and 2007, mysids were caught by otter trawl in all months in low numbers. Catch in both years was generally greater in late winter and spring, and was fairly evenly distributed among sloughs. The inability to identify mysids to species under our field conditions precludes our ability to distinguish the proportion of the catch consisting of introduced species (Schroeter et al. 2006).

KEY FINDINGS

1. The UC Davis Suisun Marsh Fish Study is now in its 29th year (30 if the trial year of 1979 is counted); over 6,800 otter trawls and 1,600 beach seines have been conducted, collecting over 310,000 fish (see appendix for species and numbers).

2. Suisun Marsh continues to support a diverse fish fauna (54 species total, with 19 common enough through the years for analysis of trends). The fishes continue to be a mixture of euryhaline marine and freshwater species.

3. Suisun Marsh continues to be an important habitat for native fishes, although numbers and proportion of catch have declined since the 1980s. In the majority of years, the most abundant native fish is splittail.

4. Non-native species dominate the trawl and seine catches in the marsh. Because different species come and go, numbers show wide fluctuations from one year to the next. The most abundant introduced fish in otter trawl catches is usually striped bass, while the beach seine catch is dominated by Mississippi silverside. However, silverside and white catfish both show long-term increasing trends in abundance, suggesting a growing role of these species in the marsh ecosystem. Surges in numbers of black bullhead and black crappie seem to be related to temporary stabilization of freshwater conditions in some sloughs.

5. The abundance of Delta smelt and longfin smelt in Suisun Marsh tracks the Pelagic Organism Decline (POD) noted elsewhere in the estuary, so they are now rarely captured in our samples even when midwater trawls are deployed. The abundance of juvenile striped bass and threadfin shad do not track the POD in the Delta, although numbers of both species were exceptionally low in 2007.

6. Introduced macroinvertebrates, including Black Sea jellyfish and Siberian prawns, have become abundant in the marsh in recent years and are presumably major players in the Suisun Marsh ecosystem.

7. Suisun Marsh is probably the most important rearing area for splittail in the San Francisco Estuary, but splittail numbers depend on strong year classes that are related to years with high outflows (i.e., flooding in the Yolo Bypass and elsewhere).

8. There are strong seasonal changes in the fish and invertebrate fauna that are driven by salinity, temperature, and Delta outflows (freshwater inflow into the marsh).

9. Different regions of the marsh have somewhat different fish faunas that are related to salinity, depth, and water quality.

ACKNOWLEDGEMENTS

Sampling in Suisun Marsh has been the responsibility of many graduate students and others over the years, including Donald Baltz, Robert Daniels, Bruce Herbold, Lesa Meng, Scott Matern, Robert Schroeter, Patrick Crain, John Durand, Alpa Wintzer, and Sabra Purdy. They have been assisted by literally hundreds of volunteers and student assistants. We appreciate the continued support of the sampling program over the years by the California Department of Water Resources. Randall Brown of California Department of Water Resources kept the program going during its early uncertain years. We dedicate this report to his memory; this study would not have happened without him.

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.

The Bay Institute, Center for Biological Diversity, and Natural Resources Defense Council. 2007. Petition to the state of California Fish and Game Commision and supporting information for listing the longfin smelt (*Spirinchus thaleichthys*) as an endangered species under the California Endangered Species Act.

Bennet, W. A. 2005. Critical assessment of the Delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3:

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

California Department of Water Resources and California Department of Fish and Game. 2007. Pelagic Fish Action Plan. California, California Department of Water Resources.

Castellanos, D. L., and L. P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River delta, a Louisiana tidal freshwater ecosystem. Estuaries 24(2): 184-197.

Carlton, J. T., J. K. Thompson, L. E. Schemel, and F. H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. Marine Ecology Progress Series 66: 81-94.

Cucherousset, J., J. M. Paillisson, A. Carpentier, M. C. Eybert, and J. D. Olden. 2006. Habitat use of an artificial wetland by the invasive catfish *Ameiurus melas*. Ecology of Freshwater Fish 15: 589-596.

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.

Gelwick, F. P., S. Akin, D. A. Arrington, and K. O. Winemiller. 2001. Fish assemblage structure in relation to environmental variation in a Texas Gulf Coastal wetland. Estuaries 24(2): 285-296.

Gewant, D. S., and S. M. Bollens. 2005. Macrozooplankton and micronekton of the lower San Francisco Estuary: seasonal, interannual, and regional variation in relation to environmental conditions. Estuaries 28(3): 473-485.

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

Griffith, J. S. 1978. Effects of low temperature on the behavior and survival of threadfin shad, *Dorosoma petenense*. Transactions of the American Fisheries Society 107: 63-70.

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

Hughes, M. J., and D. M. Carlson. 1986. White catfish growth and life history in the Hudson River Estuary, New York. Journal of Freshwater Ecology 3(3): 407-418.

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.

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.

Meng, L., and S. A. Matern. 2001. Native and introduced 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 introduced 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.

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 Esuary: a review. San Francisco Estuary and Watershed Science 2(2): 1-47.

Moyle, P. B., and W. A. Bennett. 2008. Comparing futures for the Sacramento-San Joaquin Delta Technical Appendix D: the future of the Delta ecosystem and its fish. California, Public Policy Institute of California.

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 *Potamcorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. Pacific Science 54(4): 377-388.

Pope, K. L., and D. W. Willis. 1997. Environmental characteristics of black crappie (*Pomoxis nigromaculatus*) nesting sites in two South Dakota waters. Ecology of Freshwater Fish 6(4): 183-189.

Repsys, A. J., R. L. Applegate, and D. C. Hales. 1976. Food and food selectivity of the black bullhead, *Ictalurus melas*, in Lake Poinsett, South Dakota. Journal of the Fisheries Research Board of Canada 33: 768-775.

Schroeter, R. E. 2008. Ph.D. dissertation, University of California, Davis, Davis, California. XX pp.

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

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., M. L. Nobriga, W. C. Harrell, W. Botham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58(2): 325-333.

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.

Thackeray, S. J., D. G. George, R. I. Jones, and I. J. Winfield. 2004. Quantitative analysis of the importance of wind-induced circulation for the spatial structuring of planktonic populations. Freshwater Biology 49: 1091-1102.

Turner, J. L. 1966. Distribution of threadfin shad, *Dorosoma petenense*, tule perch, *Hysterocarpus traski*, and crayfish spp. in the Sacramento-San Joaquin Delta. California Department and Fish and Game Fish Bulletin 136: 160-168.

Wang, J. C. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: a guide to early life histories. Interagency Ecological Program Technical Report 9. 800 pp.

APPENDIX

Total numbers of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all methods from 1979 to 2007.

Common Name	**Scientific Name**	**Otter Trawl**	**Beach Seine**	**Midwater Trawl**	**All Gear Types**
American shad	*Alosa sapidissima*	815	150		965
bay pipefish	*Sygnathus leptorhynchus*	2			2
bigscale logperch	*Percina macrolepida*	17	2		19
black bullhead	*Ameiurus melas*	695	3		698
black crappie	*Pomoxis nigromaculatus*	1744	73	1	1818
bluegill	*Lepomis macrochirus*	19	18		37
brown bullhead	*Ameiurus nebulosus*	28			28
California halibut	*Paralichthys californicus*	5			5
channel catfish	*Ictalurus punctatus*	161	6		167
Chinook salmon	*Oncorhynchus tshawytscha*	72	383	1	456
common carp	*Cyprinus carpio*	4413	365	1	4779
Delta smelt	*Hypomesus transpacificus*	618	135	3	756
fathead minnow	*Pimephales promelas*	26	29		55
golden shiner	*Notemigonus crysoleucas*	4	3		7
goldfish	*Carassius auratus*	270	29		299
green sturgeon	*Acipenser medirostris*	3			3
green sunfish	*Lepomis cyanellus*	5	3		8
hardhead	*Mylopharadon conocephalus*	1			1
hitch	*Lavinia exilicauda*	114	16		130
longfin smelt	*Spirinchus thaleichthys*	11048	32	5	11085
longjaw mudsucker	*Gillichthys mirabilis*	1			1
Mississippi silverside	*Menidia audens*	559	64415		64974
mosquitofish	*Gambusia affinis*	17	268		285
northern anchovy	*Engraulis mordax*	255		37	292
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*	9398	790	1	10189
rainbow trout	*Oncorhynchus mykiss*	7	4		11
rainwater killifish	*Lucania parva*	23	89		112
redear sunfish	*Lepomis microlophus*	2			2
Sacramento blackfish	*Orthodon macrolepidotus*	21	116		137
Sacramento pikeminnow	*Ptychocheilus grandis*	129	211		340
Sacramento sucker	*Catostomus occidentalis*	2982	95	3	3080
shimofuri goby	*Tridentiger bifasciatus*	8829	1615	1	10445
shiner perch	*Cymatogaster aggregata*	17			17
shokihaze goby	*Tridentiger barbatus*	438	2	6	446
speckled sanddab	*Citharichthys stigmaeus*	3			3
splittail	*Pogonichthys*	20641	2671	11	23323

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	All Gear Types
American shad	*Alosa sapidissima*	815	150		965
bay pipefish	*Sygnathus leptorhynchus*	2			2
bigscale logperch	*Percina macrolepida*	17	2		19
black bullhead	*Ameiurus melas*	695	3		698
	macrolepidotus				
staghorn sculpin	*Leptocottus armatus*	2185	2830		5015
starry flounder	*Platichthys stellatus*	1818	258	4	2080
striped bass	*Morone saxatilis*	74985	10849	23	85857
surf smelt	*Hypomesus pretiosus*	5			5
threadfin shad	*Dorosoma petenense*	2476	4860	1	7337
threespine stickleback	*Gasterosteus aculeatus*	16207	4152	6	20365
tule perch	*Hysterocarpus traski*	16771	1787	6	18564
wakasagi	*Hypomesus nipponensis*	10	6		16
warmouth	*Lepomis gulosus*	1			1
white catfish	*Ameiurus catus*	3476	103	12	3591
white crappie	*Pomoxis annularis*	112			112
white croaker	*Genyonemus lineatus*	1			1
white sturgeon	*Acipenser transmontanus*	96		2	98
yellowfin goby	*Acanthogobius flavimanus*	18461	14417		32878
Total		**200499**	**110902**	**124**	**311525**