Title
Trends in fish populations of Suisun Marsh January 2008 - December 2008.

Authors
O'Rear, Teejay Alexander
Moyle, Peter B

Publication Date
2009

Data Availability
The data associated with this publication are available upon request.

Trends in Fish Populations of Suisun Marsh
January 2008 - December 2008

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 2009

EXECUTIVE SUMMARY

Suisun Marsh, at the geographic center of the San Francisco Estuary, is important habitat for introduced and native fishes. The University of California, Davis Suisun Marsh Fish Study has systematically monitored the marsh's fish populations since 1980. The purpose of the study has been to determine the environmental factors affecting fish abundance and distribution, especially in relation to water management activities.

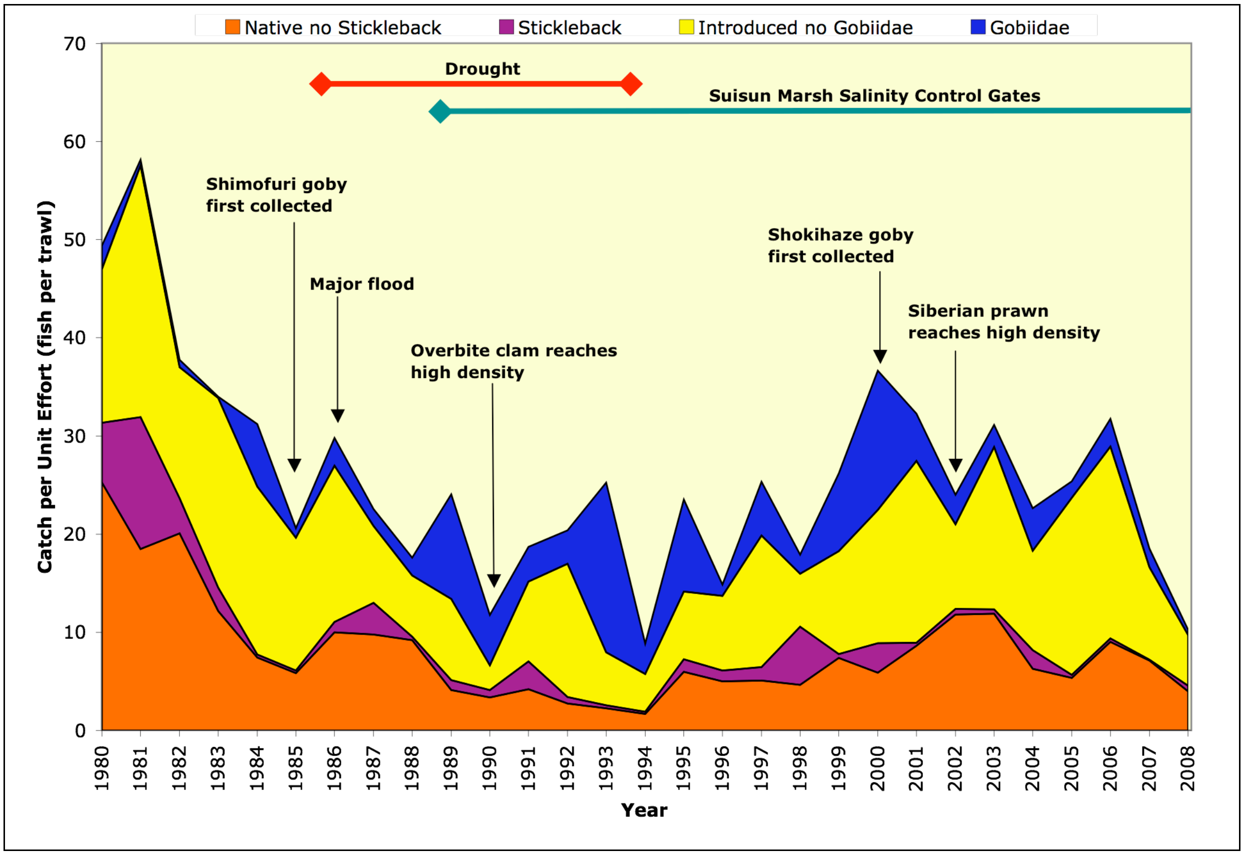

Figure A. Annual otter trawl catch per unit effort from 1980 to 2008 for native fish without threespine stickleback, threespine stickleback, introduced fish without gobies, and gobies from 1980 to 2008, with timing of important events.

In 2008, 286 otter trawls, 19 midwater trawls, and 76 beach seine hauls were conducted. Four macroinvertebrates commonly captured in otter trawls declined in abundance from 2007 to 2008. Fish per otter trawl was the second lowest recorded in the study's history (Figure A), mainly due to a lack of young-of-year fish, and only 14 fish were caught in the midwater trawls. Conversely, many fishes that declined in otter trawls [e.g., striped bass (*Morone saxitilis*), shimofuri goby (*Tridentiger bifasciatus*), yellowfin goby (*Acanthogobius flavimanus*); Table A] became more abundant in beach seine catches. These results suggest that our lower trawl catches were the result of poor recruitment of young-of-year fish and movement of fish from channel habitats to shoreline areas, which may have been caused by low river flows and limited pelagic food supplies.

Table A. % change in beach seine and otter trawl annual catch per unit effort from 2007 to 2008 for common marsh fishes.

Species	Beach Seine % Change	Otter Trawl % Change
common carp	184%	-36%
Mississippi silverside	158%	-21%
striped bass	364%	-49%
prickly sculpin	358%	-41%
shimofuri goby	365%	-35%
tule perch	225%	-63%
yellowfin goby	159%	-86%

The otter trawl catch of fishes of the Pelagic Organism Decline [POD; threadfin shad (*Dorosoma petenense*), American shad (*Alosa sapidissima*), Delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthyes*) and striped bass] was low (Figure B). With the exception of striped bass, most POD fishes were captured in spring or autumn in sloughs that generally provide good water quality and abundant food. These patterns imply that both little recruitment due to low river inflows and less favorable conditions within the marsh were responsible for the low catch of POD species during 2008.

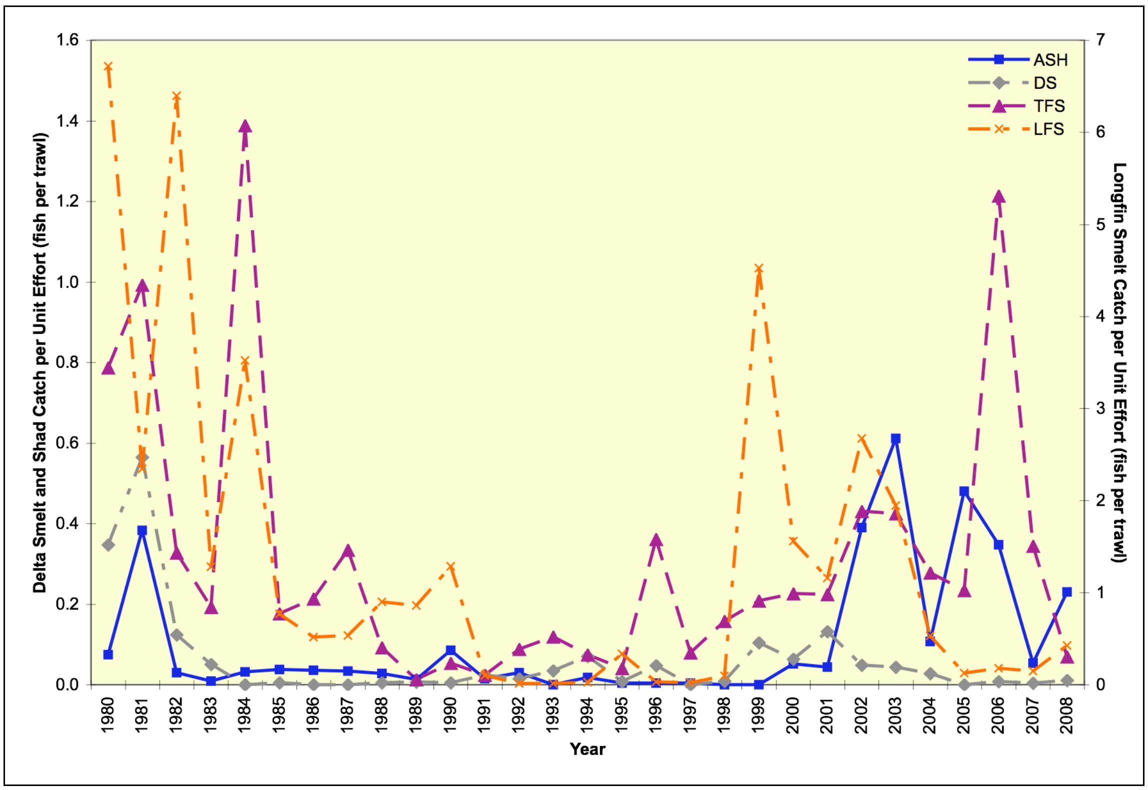

Figure B. Annual otter trawl catch per unit effort for fishes of the Pelagic Organism Decline (ASH = American shad, DS = Delta smelt, TFS = threadfin shad, and LFS = longfin smelt).

Different regions of the marsh provided distinct habitats and thus hosted distinct fish assemblages. The factors driving the composition of the fish assemblages differed among regions. Water quality appeared important in the southwest and northwest regions of the marsh, while undisturbed shallow-water habitat contributed to the fish assemblage in the central marsh.

Factors structuring the eastern marsh's fish assemblage, where abiotic conditions are generally milder, were more ambiguous.

The key findings of 2008 include the following:

1. Most fish species declined in the otter trawl catches while increasing in beach seine catches; additionally, midwater trawls captured very few fishes. Four of the most common macroinvertebrates were also less abundant in otter trawls. These results are consistent with limited pelagic food supplies.
2. The decrease in the abundance of several species (e.g., splittail, white catfish, black crappie) can be partially attributed to the effects of low river flows on spawning, which resulted in fewer young-of-year recruiting to the marsh.
3. The composition of fish communities in sloughs of the western and central marsh appeared to be partly determined by water-quality parameters (e.g., salinity, dissolved oxygen concentration); however, the factors structuring the communities of the eastern marsh were less clear.
4. The monthly catch pattern for several species appeared to be synchronized in different areas of the marsh, indicating that these fishes were affected by factors that were similar throughout space for a given time.

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 location in the San Francisco Estuary makes it an important rearing area for euryhaline freshwater, estuarine, and marine fishes.

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

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

Meng et al. (1994) incorporated eight more years into their study, which revealed that the fish assemblage structure was less constant over the longer time period than the earlier study indicated. Additionally, introduced fishes had become more common in small, shallow sloughs, possibly as a result of drought and high exports allowing increased salinities in the marsh and depressing reproductive success of native fishes. Like Moyle et al. (1986), Meng et al. (1994) found a general decline in total fish abundance (particularly in the native fishes) through time. Matern et al. (2002) found results similar to Meng et al. (1994): fish diversity was highest in small sloughs, and native fish abundances continued to decrease.

This report updates the results of the previous Suisun Marsh Fish Study report (O'Rear and Moyle 2008), which explored in depth the ecology of many of the marsh's fishes and invertebrates.

OBJECTIVES

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

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 area is diked wetlands managed for waterfowl; the remainder consists of sloughs that separate and deliver water to the wetland areas (California Department of Water Resources 2001). The marsh is contiguous with the northern boundary of Suisun Bay and is central to the San Francisco Estuary (Figure 1).

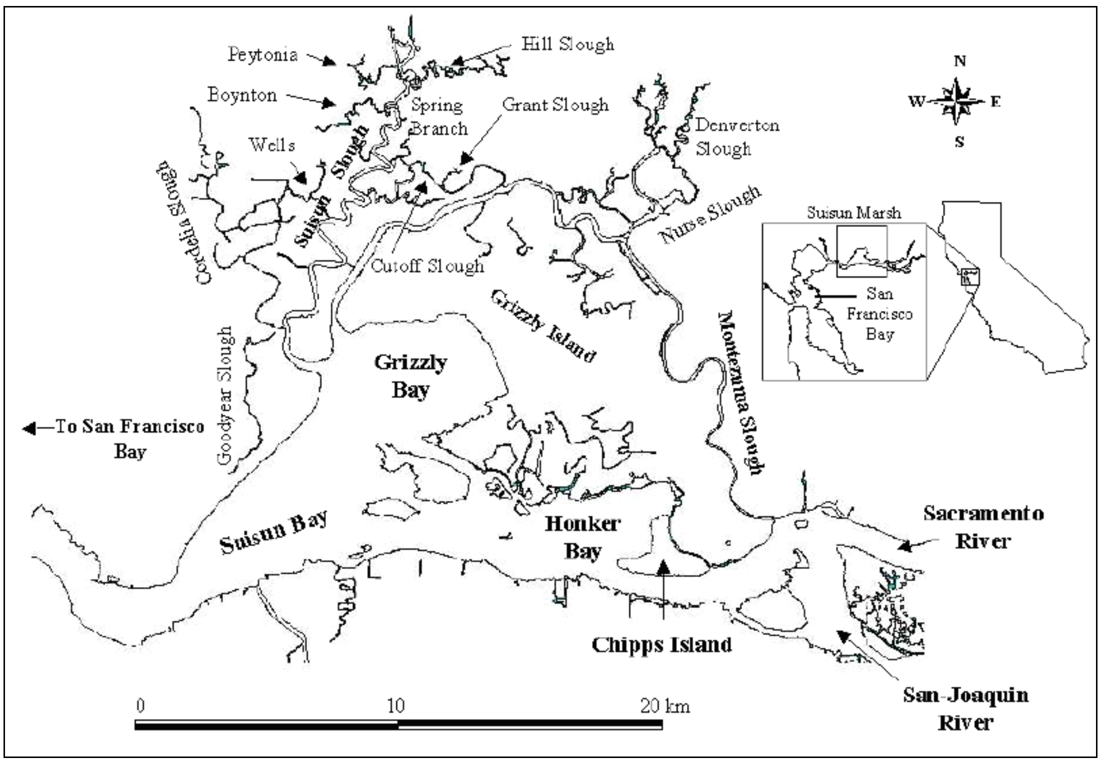

Figure 1. Suisun Marsh and Bay (from Schroeter et al. 2006).

There are two major tidal channels in the marsh: Montezuma and Suisun sloughs (Figure 1). Montezuma Slough generally arcs northwest from the confluence of the Sacramento and San Joaquin rivers, then curves southwest and terminates at Grizzly Bay (the major embayment of Suisun Bay). Major tributary sloughs to Montezuma are Denverton and Nurse; Cutoff Slough and Hunters Cut connect Suisun and Montezuma sloughs (Figure 1). Suisun Slough begins near Suisun City and trends south until emptying into Grizzly Bay southwest of the mouth of Montezuma Slough. Major tributaries to Suisun Slough, from north to south, are Peytonia, Boynton, Cutoff, Wells, 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 riprapped (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 comprised 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 (Matern et al. 2002). During extreme tides, water depths can change as much as 1 m over a tidal cycle, often dewatering more than 50% of the smaller sloughs at low tide and overtopping dikes at high tide.

A number of water management facilities influence the hydrology and water quality of the marsh. State Water Project and Central Valley Project water export facilities in the southern Delta affect the timing and magnitude of freshwater inflow into Suisun Marsh. The Suisun Marsh Salinity Control Gates, which are located in Montezuma Slough just downstream of the confluence of the Sacramento and San Joaquin rivers, are operated to inhibit saltwater intrusion into the marsh at high tides and to provide fresh water 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 attract wintering waterfowl. Wetlands are usually drained in early spring, with drainage water being discharged directly into numerous sloughs within the marsh. Goodyear Slough is now connected to Suisun Bay by a channel that was built to depress salinities in the slough for water diverters in the western portion of the marsh.

METHODS

Since 1980, monthly juvenile and adult fish sampling has been conducted at standard sites within Suisun Marsh. Prior to 1994, a total of 12 sloughs and 27 sites were sampled. Several of these historic sites were sampled only in 1980 and 1981, with 17 sites being sampled consistently until 1994 (see O'Rear and Moyle 2008). From 1994 to the present, 21 sites in nine sloughs have been regularly sampled (Figure 2). In 2008, five additional sites were otter trawled as part of an ancillary project looking at the effects of duck pond discharge water on the marsh's ecology: one in Peytonia Slough just downstream of the PT2 site (Figure 2); one in Boynton Slough between the BY1 and BY3 sites; one in upper Suisun Slough between the SU1 and SU2 sites; and two in Montezuma Slough immediately downstream of the mouth of Nurse Slough. These sites were trawled from January to March and from September to December. Data acquired from the additional upper Suisun, Boynton, and Peytonia sites were included in all calculations in this report since their abiotic data were not different from those of surrounding sites. Because salinities in the added Montezuma Slough sites were higher than in the regularly sampled Montezuma sites, these data were not included in any monthly or water-quality calculations. However, data from the added Montezuma Slough sites were included in the annual otter trawl catch-per-unit-effort values since (1) removing these two sites did not change the results, and (2) adding these sites increased both our sample size and the study's spatial coverage. Latitude and longitude coordinates for current, regularly 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).

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 2008, 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), water transparency (Secchi depth, cm), and water depths (meters, m) were recorded. Dissolved oxygen parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also recorded.

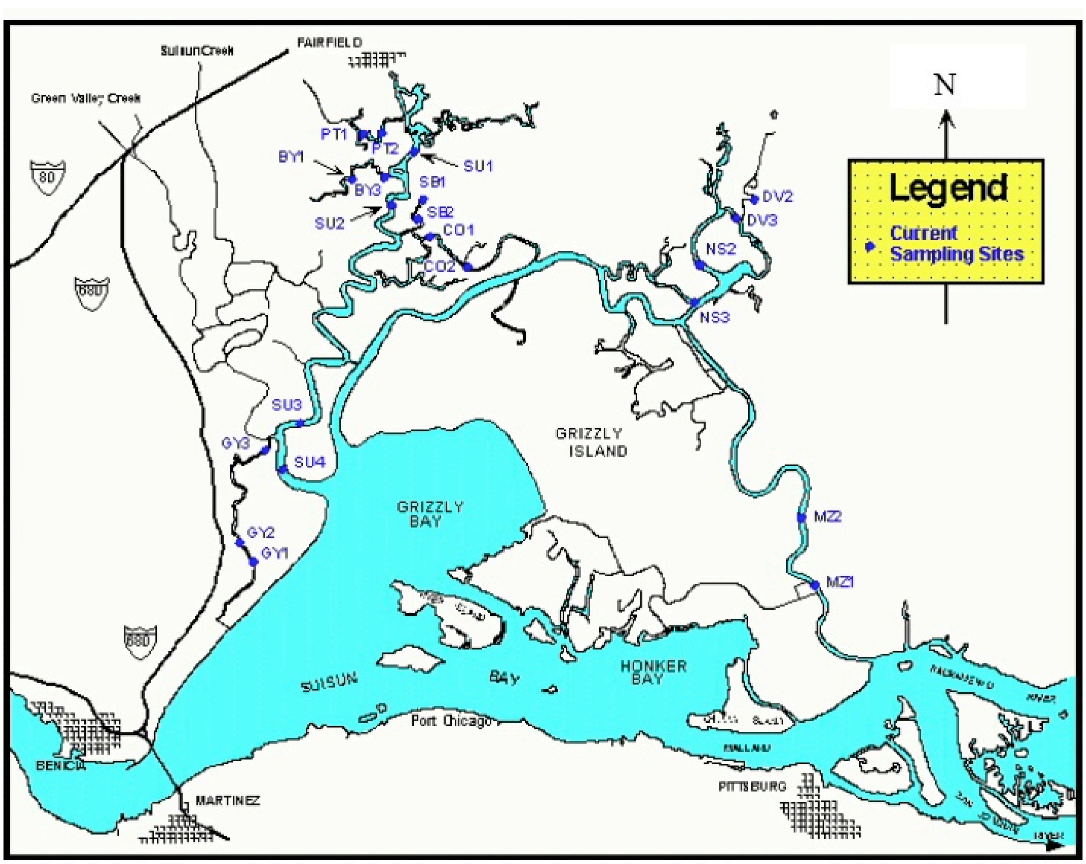

Figure 2. Map of current Suisun Marsh sampling sites (from Schroeter et al. 2006).

Contents of each trawl or seine were placed into large containers of water. Fishes were identified, measured to the nearest millimeter standard length (mm SL), and returned to the water. Sensitive native species were processed first and immediately released. Numbers of Siberian prawn (*Exopalaemon modestus*), Black Sea jellyfish (*Maeotias marginata)*, Oriental shrimp (*Palaemon macrodactylus*), California bay shrimp (*Crangon franciscorum*), overbite clam (*Corbula amurensis*), and Asian clam (*Corbicula fluminea*) were also recorded. Siberian prawn were first positively identified in February 2002, although they were probably present in 2001. Siberian prawn likely comprised a large percentage of the 2001 and early 2002 shrimp catch that was recorded as Oriental shrimp; abundances of Siberian prawn 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.

All data collected by the study is available on the Bay Delta and Tributaries website (http://bdat.ca.gov/). Catch values for all fishes and by each method from 1979 to 2008 are found in Appendix A; annual catch and amount of effort for each slough and method for 2008 are found in appendices B and C.

ENVIRONMENTAL CONDITIONS

Net Delta Outflow

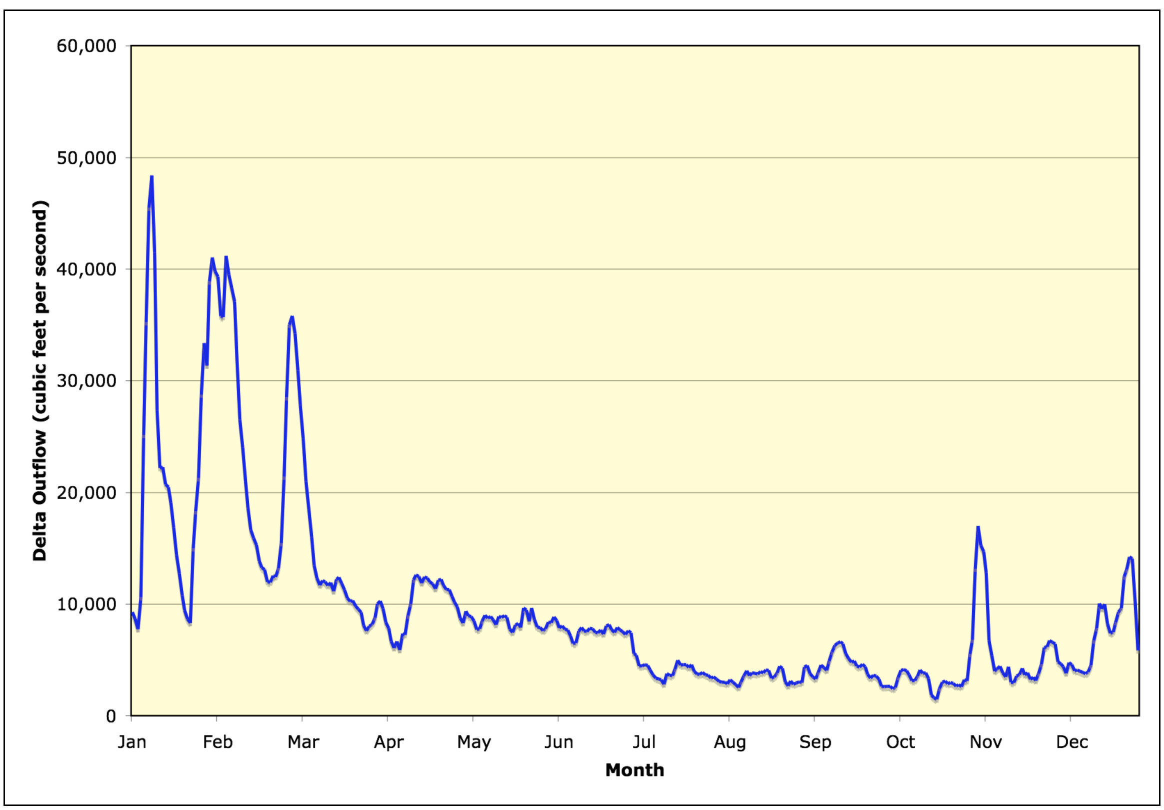

Figure 3. Daily Delta outflow for 2008 (http://www.usbr.gov/mp/cvo/vungvari/doutdly.prn).

The Net Delta Outflow Index, a proxy for water exiting the Sacramento-San Joaquin Delta, is calculated by summing river flows entering the Delta, channel depletions, in-Delta diversions, and State Water Project, Central Valley Project, and Contra Costa Water District exports. Delta outflow substantially affects myriad physical, chemical, and biological aspects of Suisun Marsh.

Like 2007, 2008 was a dry year. Above average precipitation in January elevated Delta outflow to its yearly maximum of about 48,000 cubic feet per second (cfs); storms at the end of January and beginning of February also increased the amount of water leaving the Delta (Figure 3). Late February storms raised Delta outflow into the beginning of March; however, unlike 2006, outflow declined and remained low through the remainder of spring and throughout summer (Figure 3). Delta outflow did not increase substantially again until the first significant autumn storm hit in early November. Rain in the second and third weeks of December also raised outflow, albeit mildly.

Salinity

Salinities in Suisun Marsh are strongly inversely correlated with Delta outflow (O'Rear and Moyle 2008). Reflecting the low outflow, the average annual salinity for 2008 was the

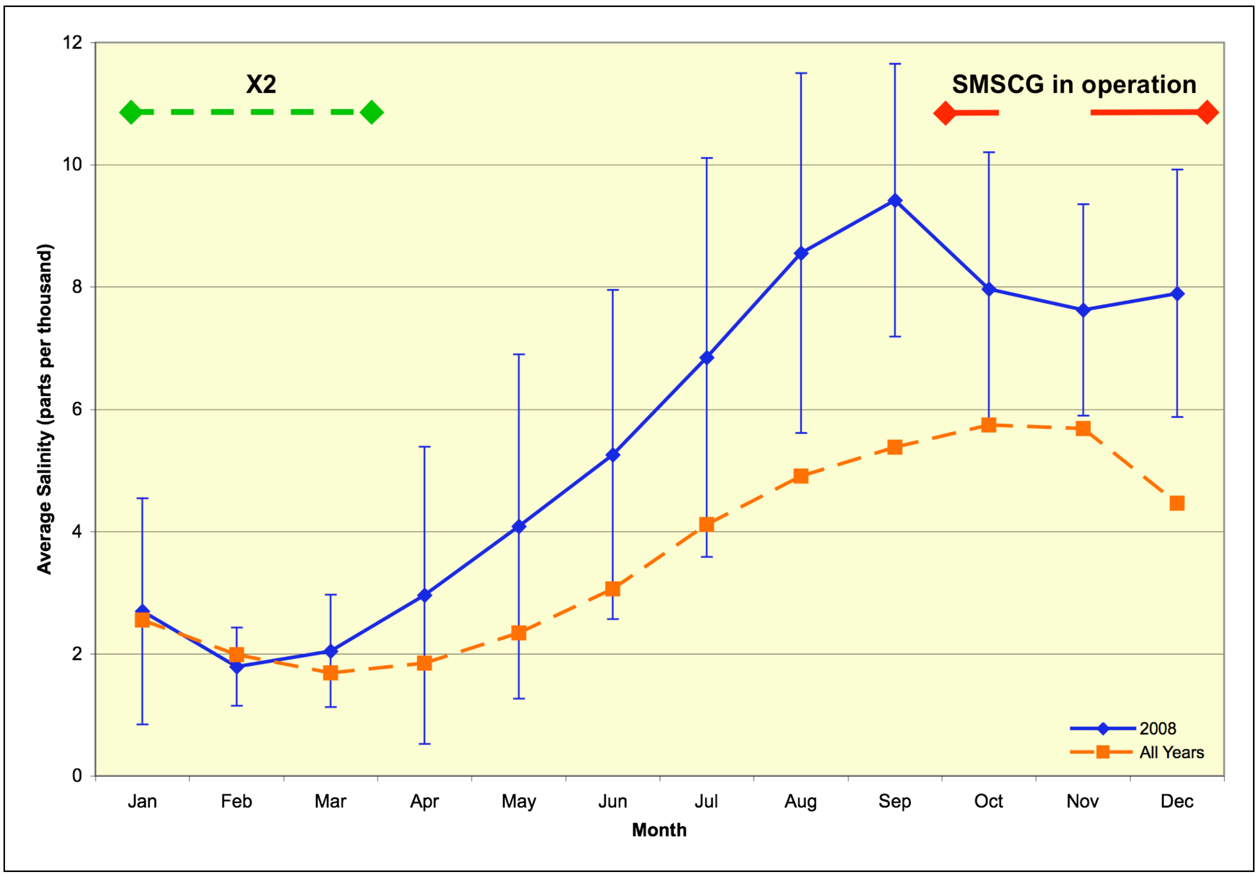

Figure 4. Average monthly salinities for 2008 and all years of the study; error bars are standard deviations for 2008. Green dashed line denotes time when X2 was within Suisun Marsh in 2008; solid red lines show when the Suisun Marsh Salinity Control Gates (SMSCG) were in operation in 2008.

saltiest recorded since 1992. Average monthly salinities in 2008 were considerably higher than that for the 28-year averages for much of spring, all of summer, and early autumn (Figure 4). The Suisun Marsh Salinity Control Gates went into operation from October 2 to October 14, noticeably reducing salinities in the marsh. They were also operated for the latter half of November and most of December and, combined with the November and December storms, decreased marsh salinities below that expected by the average for the entire study period (Figure 4).

A distinct geographical salinity gradient generally sets up in late spring as Delta outflow subsides, with salinities highest in the southwest part of the marsh and lowest in the eastern and northern portions. This pattern was followed in 2008, albeit earlier in the year (i.e., April) than in average Delta outflow years. Salinities were highest in Goodyear Slough, exceeding 16 ppt in July, August, and September. Relatively high salinities were also reached in lower Suisun Slough, which attained 12 ppt in both August and September. The lowest salinity (0.3 ppt) was recorded in Montezuma Slough in February, which was also when salinities were geographically most uniform throughout the marsh (Figure 4). Salinity changed most in Goodyear Slough and least in Denverton Slough in 2008.

The location of X2, the distance in kilometers from Golden Gate Bridge along the thalweg to the near-bed water with salinity of 2 ppt, is associated with the historically productive entrapment zone and high abundances of phytoplankton, macroinvertebrates, and several fishes (Jassby et al. 1995). Consequently, when X2 is located in Suisun Bay, the abundance of fishes in Suisun Marsh is often relatively high. It also follows that the longer X2 is within Suisun Bay, the abundance of fishes in Suisun Marsh should be greater over a longer time span.

X2 was located in Suisun Marsh for 23% of 2008, with those days occurring in winter and early spring (Figure 4). Unlike in 2006, X2 was in Suisun Marsh before the young-of-year of most marsh fishes had hatched or migrated to the marsh. Consequently, few marsh larvae or juveniles were likely to have benefited from conditions often associated with X2.

Dissolved Oxygen

Dissolved oxygen concentrations in the marsh are affected by decomposition of organic material, temperature, salinity, and in-marsh duck club operations. Because oxygen solubility decreases with higher salinities and temperatures, oxygen concentrations are frequently lower in summer and autumn than in winter. Hypoxic water is discharged into sloughs from duck ponds during autumn, further lowering oxygen concentrations. Likewise, draining ponds in spring by discharging to the sloughs also depresses marsh oxygen concentrations (R. E. Schroeter, unpublished). Consequently, marsh oxygen concentrations are usually high in winter, lower in spring and summer, and lowest in autumn.

Average monthly oxygen concentrations in 2008 generally followed the pattern for all years of the study: they were highest in winter, declined substantially in spring, remained relatively low in summer, and reached their minimum in autumn (Figure 5). However, average oxygen concentrations were noticeably lower in 2008 during late spring and summer relative to the averages for all years. Additionally, the average monthly minimum for 2008 (5.95 mg/L in November) was considerably less than that for the whole study period. It is likely that the higher salinities in 2008 contributed partially to the lower spring and summer values. Duck club operations were probably partly responsible for the low values seen in April and November. In April, the sloughs with the most diversions per river-kilometer (Boynton, Goodyear, and

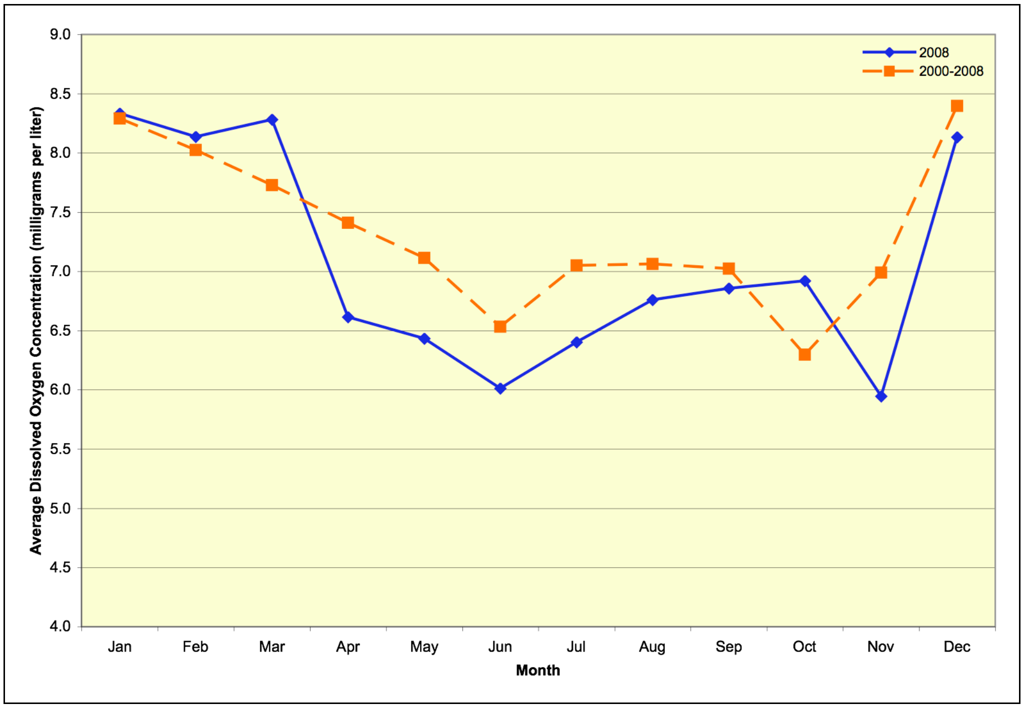

Figure 5. Monthly average dissolved oxygen concentrations for 2008 and from 2000 to 2008.

Peytonia; Matern et al. 2002) also had the lowest average oxygen concentrations. In November, Boynton and Peytonia sloughs had the lowest average oxygen concentrations. Finally, the two lowest oxygen concentration values were measured in April and October (2.2 mg/L) in Goodyear Slough.

Water Temperature and Transparency

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).

The pattern for average monthly water temperatures in 2008 was very similar to that for all years of the study (Figure 6). The only noticeable deviation from the usual trend was slightly cooler temperatures in September, which was probably due to the intrusion of cooler, more saline water from San Pablo Bay. The highest and lowest temperatures (6.1°C and 23.5°C) were both recorded in First Mallard Slough in June and January, respectively.

The magnitude of freshwater inflow (mainly from the Sacramento River) is the primary determinant of water transparency in Suisun Marsh (O'Rear and Moyle 2008). Transparencies in the marsh are usually lowest in spring when river flows are highest; conversely, transparency generally reaches a maximum in October when river flows are at their annual minimum. As a result, average monthly transparencies often mirror those for salinity. 2008 was no exception, with monthly average transparencies higher than the averages for all years during summer and much of autumn (Figure 6).

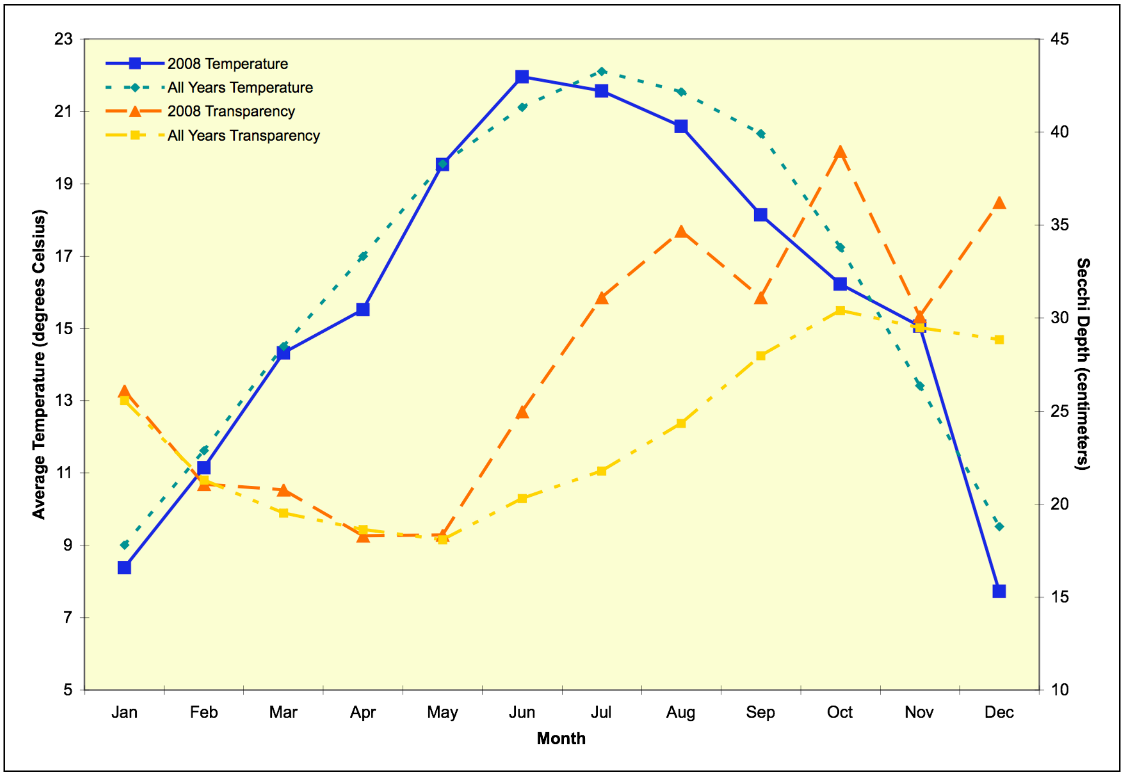

Figure 6. Monthly average temperatures and transparencies for 2008 and all years of the study.

TRENDS IN INVERTEBRATE ABUNDANCE AND DISTRIBUTION

Otter trawl annual catch per unit effort for four of the most commonly captured invertebrates in Suisun Marsh declined from 2007 to 2008 (Table 1). The decrease in abundance was more precipitous for Siberian prawn and California bay shrimp than for Black Sea jellyfish and overbite clam (Table 1). The lower numbers of these invertebrates, coupled with fewer fishes in otter trawls and more fishes in beach seines (discussed below), suggests that planktonic food sources were relatively scarce in 2008.

Table 1. % decline in the annual catch per unit effort for four invertebrate species in Suisun Marsh from 2007 to 2008.

Species	California bay shrimp	Siberian prawn	overbite clam	Black Sea jellyfish
2007 CPUE	16.1	28.6	31.9	20
2008 CPUE	6.4	6.8	22.9	15.9
% Change	-60%	-76%	-28%	-21%

The pattern in the monthly shrimp catch in 2008 was similar to that in 2007 (O'Rear and Moyle 2008), although the numbers were considerably lower (Table 1). The highest catches of California bay shrimp were made in spring concomitant with increasing salinities (Figure 7), which was probably due to movement of the shrimp into the marsh from Suisun and San Pablo bays (Gewant and Bollens 2005). The geographic distribution of the catch also indicates that many of the marsh's California bay shrimp originate downstream of the marsh: 43% of the total catch was made in the most-downstream Goodyear Slough and lower Suisun Slough sites. Conversely, Siberian prawn peaked in September and were most abundant in sloughs of the northwest marsh (i.e., upper Suisun, Peytonia, and Boynton sloughs), where 64% of the total catch was made. Siberian prawns were also abundant in Denverton Slough while rare in the southwest and central marsh, suggesting a predilection for fresher, more anthropogenically altered sloughs.

As in 2006 and 2007, Black Sea jellyfish medusae and overbite clam reached their highest abundance during summer (Figure 7; O'Rear and Moyle 2008). The bulk of the overbite

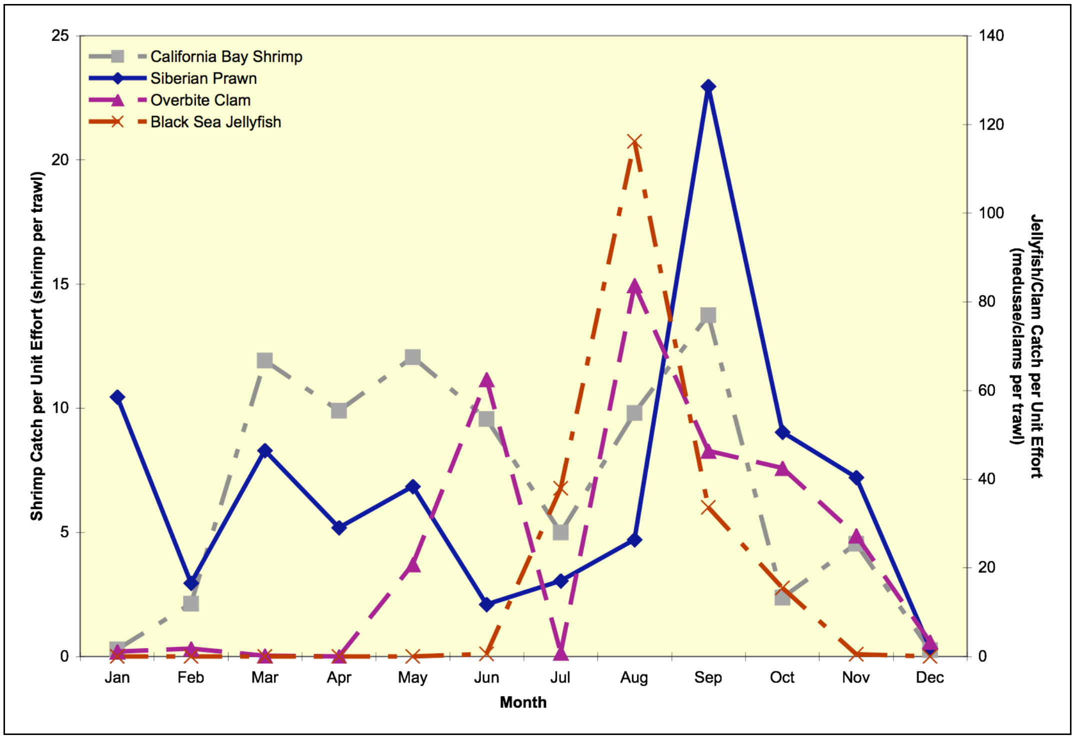

Figure 7. Monthly otter trawl catch per unit effort during 2008 for four common invertebrates in Suisun Marsh.

clam catch (76%) was made in lower Suisun and Goodyear sloughs, while 77% of the Black Sea jellyfish were caught in the northwest marsh. Black Sea jellyfish were never common in lower Suisun, Goodyear, or First Mallard sloughs, while the only slough outside the southwest marsh to host a large overbite calm catch was upper Suisun. Noticeably, both Black Sea jellyfish and overbite clam were never abundant in Denverton Slough during 2008.

TRENDS IN FISH ABUNDANCE AND DISTRIBUTION

Otter Trawls

Annual fish per trawl generally declined in the first 15 years of the study (1980-1995); since then, it has vacillated around a relatively stable mean (figures 8 and 9; O'Rear and Moyle 2008). The decrease in the annual catch per unit effort for native fish has been more precipitous and less variable than that for introduced fishes (Figure 8). Catch per unit effort for introduced fishes has been highly variable over the study's history (Figure 9).

Annual otter trawl catch per unit effort in 2008 was the second lowest recorded in the study's history, with only 1994 garnering fewer fish per trawl (10.25 and 8.86, respectively;

Figure A). From 2007 to 2008, catch per unit effort for native fishes decreased by 37% (Figure 8) and decreased for introduced fishes by 50% (Figure 9). 2008 marks the second year in declining catch per unit effort for both classes of fishes since 2006.

Annual fish per trawl in 2008 for the six introduced fishes most responsible for the numbers seen in the last few years [black crappie (*Pomoxis nigromaculatus*), shimofuri goby (*Tridentiger bifasciatus*), striped bass (*Morone saxitilis*), threadfin shad (*Dorosoma petenense*), white catfish (*Ameiurus catus*), and yellowfin goby (*Acanthogobius flavimanus*)] plummeted

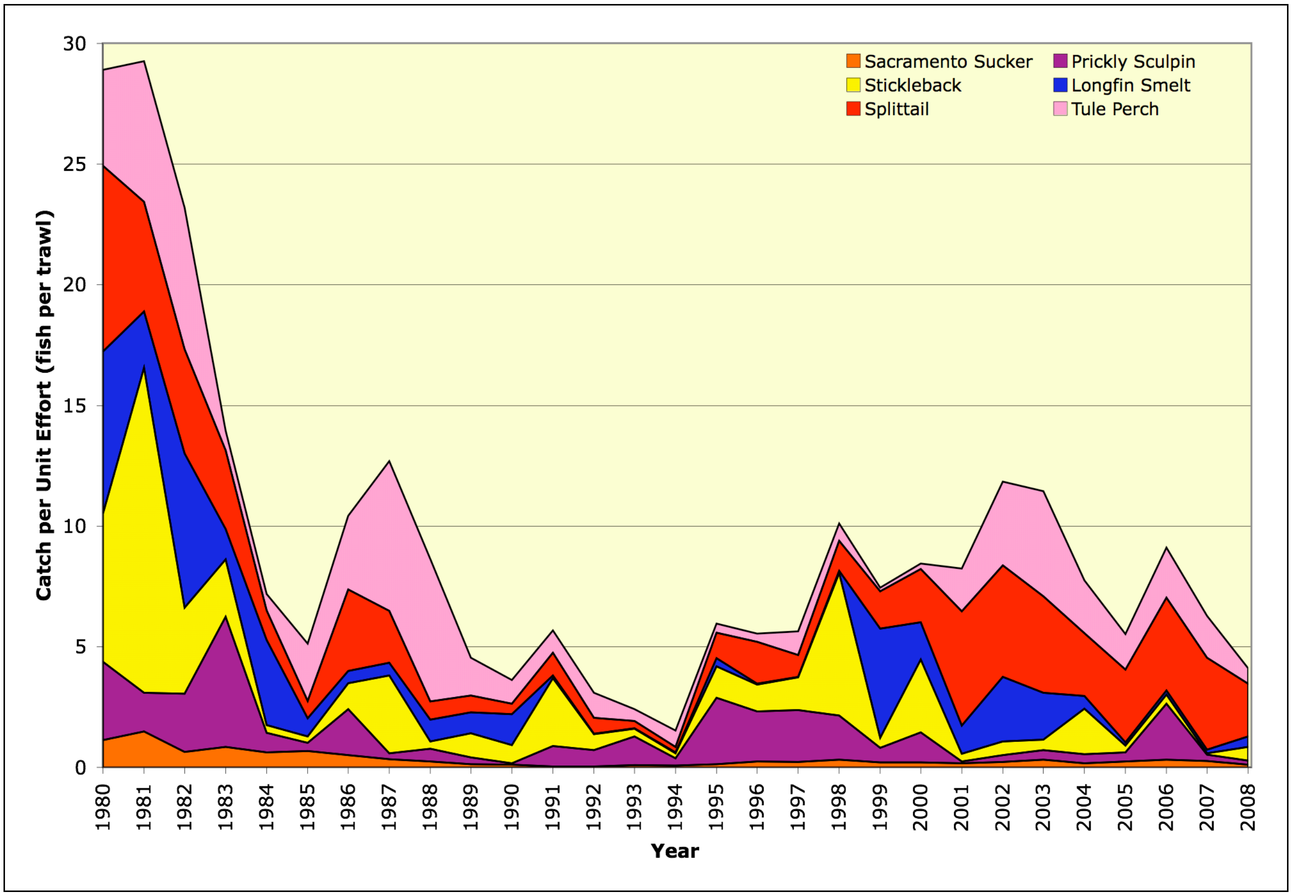

Figure 8. Annual otter trawl catch per unit effort from 1980 to 2008 for the six native fishes most commonly captured in Suisun Marsh.

relative to 2007 (Table 2). Annual beach seine catch per unit effort also decreased from 2007 to 2008 for threadfin shad and white catfish. For black crappie and white catfish, the low 2008 catches were likely due to either poor reproductive success or high mortality of early life-history stages in moderately brackish water (black crappie: O'Rear and Moyle 2008, Gelwick et al. 2001; white catfish: O'Rear and Moyle 2008). Black crappie and white catfish have spawning peaks in late spring or summer, which in 2008 coincided with monthly average salinities more than 2 ppt greater than the averages for all years of the study (Figure 4). Additionally, no young-of-year black crappie (i.e., those smaller than 70 mm SL caught after February; Moyle 2002) or young-of-year white catfish (i.e., those smaller than 88 mm SL caught after May; Moyle 2002, O'Rear, unpublished data) were captured by otter trawl. In beach seines, only one

Table 2. % decline in the annual otter trawl catch per unit effort for six of the most abundant fishes in Suisun Marsh from 2007 to 2008.

Species	Black Crappie	Shimofuri Goby	Striped Bass	Threadfin Shad	White Catfish	Yellowfin Goby
2007 CPUE	0.46	0.39	4.96	0.34	1.3	1.28
2008 CPUE	0.11	0.25	2.53	0.07	0.95	0.18
Percent Change	-76%	-36%	-49%	-79%	-27%	-86%

young-of-year black crappie and no young-of-year white catfish were captured. The decline in the threadfin shad catch may also be from poor reproductive success or poor recruitment due to higher salinities occurring earlier in the year (Wang 1986, Turner 1966), although lack of recruitment from the Delta because of low outflow may also be a culprit. Probably only three of the threadfin shad captured by otter trawl were young-of-year (i.e., fish smaller than 80 mm SL caught after August; O'Rear, unpublished data). A greater proportion of the beach seine catch was likely made up of young-of-year; however, the total number of young-of-year was less than 26 fish.

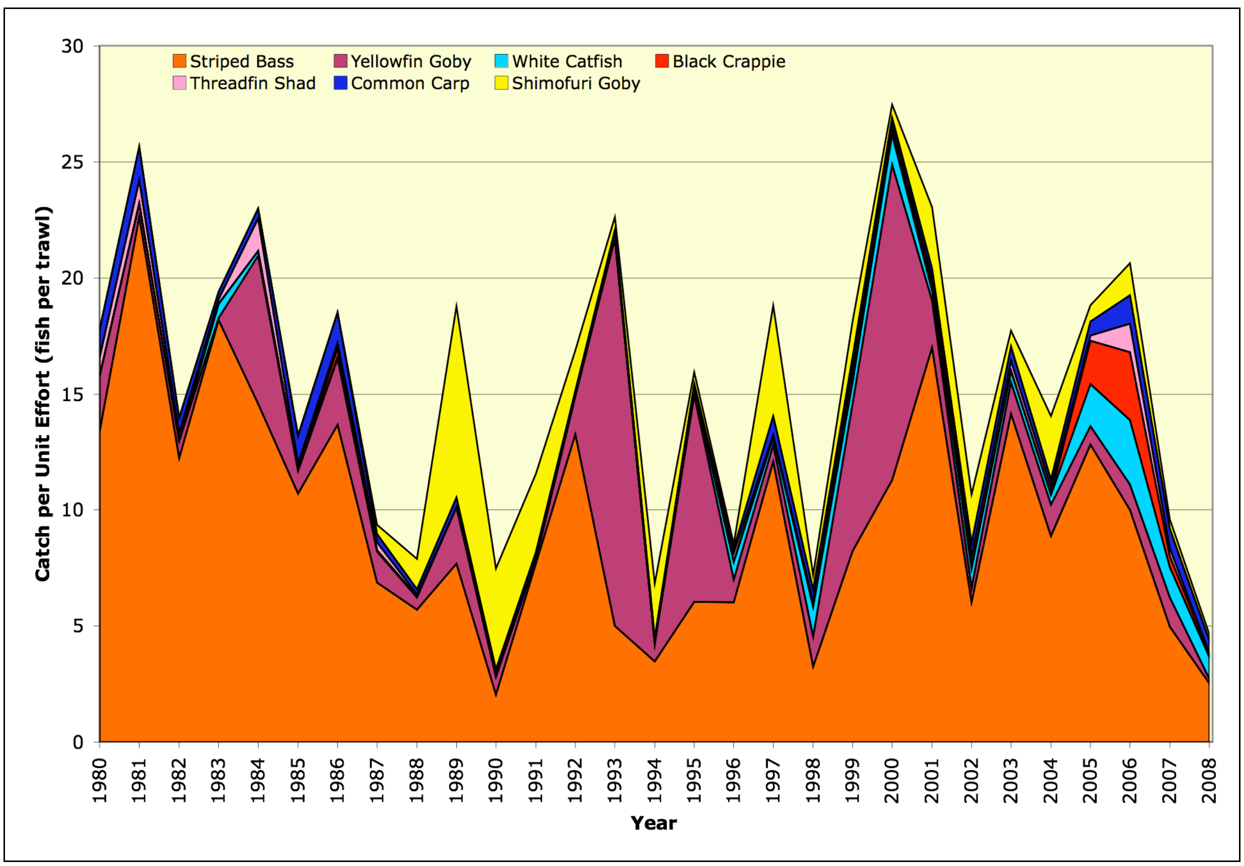

Figure 9. Annual otter trawl catch per unit effort from 1980 to 2008 for the seven introduced fishes most commonly captured in Suisun Marsh.

While the annual numbers per trawl also declined for shimofuri goby, striped bass, and yellowfin goby, they were accompanied by increases in beach seine catch per unit effort from

2007 to 2008. Young-of-year dominated the beach seine catches for all three species, and thus the lower otter trawl catches for these fishes in 2008 cannot be attributed to negative effects of elevated salinities on recruitment. Reproductive success and rearing of young for yellowfin and shimofuri gobies does not appear to be inhibited by moderately brackish water (Moyle 2002); in fact, yellowfin gobies require salinities of at least 5 ppt to reproduce successfully (Wang 1986). Additionally, although most striped bass spawn in fresh water, their juveniles grow best in brackish water (Altinok and Grizzle 2001).

Three of the most common native fishes [prickly sculpin (*Cottus asper*), Sacramento sucker (*Catostomus occidentalis*), and splittail (*Pogonichthys macrolepidotus*)] in the marsh saw their annual otter trawl catch per unit effort decline from 2007 to 2008. Although present, young-of-year numbers for prickly sculpin, Sacramento sucker, and splittail were all relatively low. Prickly sculpin and Sacramento sucker are generally most abundant in the marsh during high outflow years (O'Rear and Moyle 2008, Meng and Matern 2001), which is probably due to both more favorable spawning conditions within the marsh and a greater influx of young produced in the Delta. If all prickly sculpin less than 60 mm SL caught from March to December are assumed to be young-of-year, then the young-of-year catch per unit effort has declined from 2.23 in 2006, to 0.23 in 2007, to 0.15 in 2008. The smallest sucker captured in otter trawls measured 120 mm SL, which was likely a yearling fish. Splittail require vegetation flooded during the springtime in order to spawn successfully (Moyle et al. 2004). When flooded, the Yolo Bypass is a major spawning area for splittail (Moyle et al. 2004, Sommer et al. 1997), and years of high spring flows in the bypass are generally associated with substantial catches of young-of-year in the marsh. In 2008, the Sacramento River did not spill into Yolo Bypass, likely contributing to the lowest annual otter trawl catch per unit effort (0.24 fish per trawl) for young-of-year splittail (i.e., fish smaller than 111 mm SL; Moyle 2002) recorded since 1994. The proportion of the annual catch comprised of young-of-year also declined from 2006 to 2008 (0.58, 0.26, and 0.11 for 2006, 2007, and 2008). Additionally, the annual beach seine catch per unit effort for splittail, which has been dominated by young-of-year fish, was also at its lowest point (0.74 fish per seine haul) since 1994. Consequently, low flows probably contributed to the decline in otter trawl catches for these three species.

Table 3. % change in annual otter trawl catch per unit effort (fish per trawl) for six of the most common native species caught in Suisun Marsh (% increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled).

Species	Longfin Smelt	Prickly Sculpin	Sacramento Sucker	Splittail	Threespine Stickleback	Tule Perch
2007 CPUE	0.15	0.27	0.26	4.02	0.06	1.74
2008 CPUE	0.43	0.16	0.12	2.19	0.57	0.64
% Change	187%	-41%	-54%	-46%	850%	-63%

The 2008 annual otter trawl catch per unit effort for tule perch (*Hysterocarpus traski*) also decreased relative to 2007. Like striped bass and shimofuri and yellowfin gobies, the beach seine catch per unit increased for tule perch, although the absolute numbers captured in 2007 and 2008 were both low (15 and 32 fish, respectively). Additionally, the proportion of the tule perch population consisting of young-of-year (i.e., fish 90 mm SL and smaller) in 2008 was similar to that for 2006 and 2007 (0.41, 0.49, and 0.38, respectively), indicating that the low 2008 catch was not due to any negative effects of salinity on reproduction or recruitment. Tule perch generally require good water quality (Moyle 2002, Cech et al. 1990), and the low numbers captured in Boynton and Goodyear sloughs coupled with the below-average dissolved oxygen concentrations during late spring and summer (Figure 5) suggest that poorer water quality may have been a factor in our low 2008 catch.

Annual otter trawl catch per unit effort for two common native species - threespine stickleback (*Gasterosteus aculeatus*) and longfin smelt (*Spirinchus thaleichthys*) - increased from 2007 to 2008 (Table 3). The climb in the threespine stickleback value was almost solely due to two large catches made in Goodyear Slough during February; more than half of the year's catch (89 of 163) came from these two trawls. Goodyear Slough has a high density of duck pond outfalls; consequently, these high catches may have been due to duck pond discharges, which can contain high numbers of sticklebacks (Matern et al. 2002). Similarly, 75 of the 120 longfin smelt captured in 2008 came from one trawl in lower Suisun Slough during April. These postlarval fish likely entered from downstream (e.g., San Pablo Bay) as Delta outflow declined and saltier water intruded further into the marsh. Additionally, the annual fish per trawl value for staghorn sculpin (*Leptocottus armatus*) increased by more than fourfold from 2007 to 2008 (0.06 to 0.28 fish per trawl, respectively), which is not surprising given this species preference for higher salinities (Moyle 2002).

In sum, the otter trawl catch per unit effort for both native and introduced fishes was very low and continued the decline seen from 2006 to 2007. That fishes with different life-history characteristics and physiological tolerances (e.g., striped bass, a migratory pelagic predator; and white catfish, a relatively sedentary bottom-feeder) became less abundant indicates that multiple factors are responsible for 2008's numbers. However, it seems that low freshwater inflow and its effect on salinity partially contributed to the low 2008 values.

Beach Seines

Unlike the annual otter trawl catch per unit effort, annual beach seine catch per unit effort

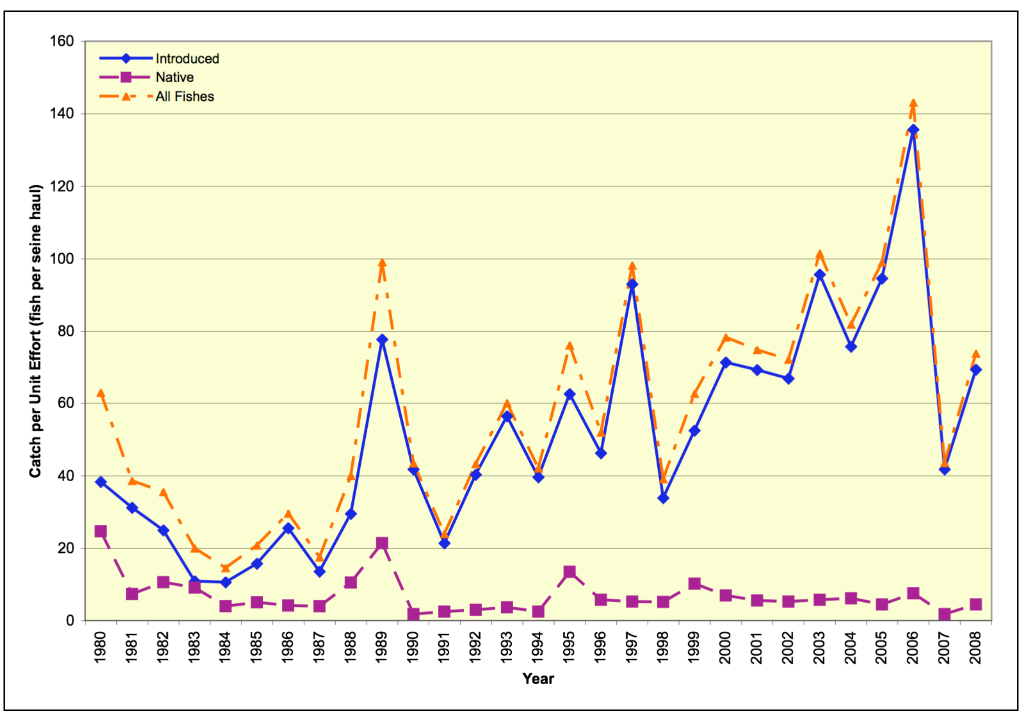

Figure 10. Annual beach seine catch per unit effort from 1980 to 2008 for introduced, native, and all fishes.

has increased since the study's inception (Figure 10). Similar to otter trawl catches, variability in native fish catch per unit effort between years has been much less than that for introduced fishes (Figure 10). 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.

While the annual otter trawl catch per unit declined from 2007 to 2008, the annual beach seine catch per unit effort increased from 43.6 to 73.9 fish per seine haul. The 2008 value was above the average for all years (56.9 fish per seine haul), although it was about the same as the average from 1994 to 2008 (75.9 fish per seine haul). From 2007 to 2008, annual beach seine catch-per-unit-effort values increased for both native fishes (1.8 to 4.5 fish per seine haul) and introduced fishes (41.8 to 69.4 fish per seine haul).

Of ten fishes commonly caught in the marsh that declined in the otter trawl catches from 2007 to 2008, seven of those became more abundant in beach seine hauls: common carp (*Cyprinus carpio*), Mississippi silverside, prickly sculpin, shimofuri goby, striped bass, tule perch, and yellowfin goby. Additionally, threespine stickleback and American shad (*Alosa sapidissima*) were also more abundant in 2008 beach seines than in 2007. While it is tempting to ascribe the higher beach seine catches to inshore movements, such an assertion should be held cautiously. The number of fish caught by seining in 2008 for each of five species (American shad, common carp, prickly sculpin, threespine stickleback, and tule perch) was lower than 33. Also, the majority of the beach seine catch for American shad, common carp, prickly sculpin, and tule perch was comprised of young-of-year seined on one day in either April (American shad) or May (common carp, prickly sculpin, and tule perch). Thus, there is a possibility that our higher beach seine catch per unit effort in 2008 for several species may have been due to chance rather than reflecting a general inshore movement.

Conversely, both the total catch and the annual beach seine catch per unit effort increased substantially from 2007 to 2008 for shimofuri goby, striped bass, and yellowfin goby (Table 4).

Table 4. Annual beach seine catch and catch per unit effort for three introduced marsh fishes in 2007 and 2008.

Species	2007		2008	
	Catch	CPUE	Catch	CPUE
Shimofuri Goby	49	0.61	170	2.24
Striped Bass	225	2.81	779	10.25
Yellowfin Goby	387	4.84	586	7.71

Interestingly, high catches for shimofuri goby and striped bass occurred in July and September; yellowfin gobies were most abundant in seines during June and September. Considerably lower numbers for all three species were seined in both Denverton and Suisun sloughs in August. Black Sea jellyfish medusae reached their highest abundance in our otter trawls during August; our highest beach seine catch of Mississippi silversides in Suisun Slough was also made in August. Thus, it is possible that high jellyfish and silverside numbers could have affected our August goby and striped bass catches. However, other factors are no doubt involved: Black Sea jellyfish were never very abundant in Denverton Slough, and the peak catch of silversides in Denverton Slough did not occur until October.

Mississippi silversides were once again the most abundant fish in our seine hauls; their annual catch-per-unit-effort value increased from 30.3 fish per haul in 2007 to 47.9 in 2008. Paralleling the increase in our otter trawls, our catch of staghorn sculpin in beach seines jumped from five fish in 2007 to 202 fish in 2008. Most of these fish were young-of-year that were probably spawned downstream and subsequently moved upstream into the marsh with declining river inflows and increasing salinities.

Overall, our 2008 beach seine catch was about average, although higher than the 2007 catch. Several fishes had their beach seine catch-per-unit-effort values increase concomitant with declining otter trawl catch-per-unit-effort values, intimating an inshore movement for these fishes. Additionally, three of the most abundant fishes - shimofuri goby, striped bass, and yellowfin goby - had high summer catches interrupted by low catches in August, which coincided with peak catches of Black Sea jellyfish and Mississippi silverside in upper Suisun Slough.

Midwater Trawls

Like in 2007, our 2008 midwater trawls caught few fish. Of 19 trawls deployed in Montezuma, Nurse, and Suisun sloughs, only 7 captured fish. Striped bass was the most frequently captured fish (7 fish), followed by splittail (3 fish), Sacramento sucker (2 fish), and white catfish (1 fish). One subadult Delta smelt was caught in Montezuma Slough in August. These catches suggest that either few fish are utilizing the water column in the larger sloughs of Suisun Marsh or the trawls are not sampling the habitat effectively.

Fish Species of Interest

Fishes of the Pelagic Organism Decline

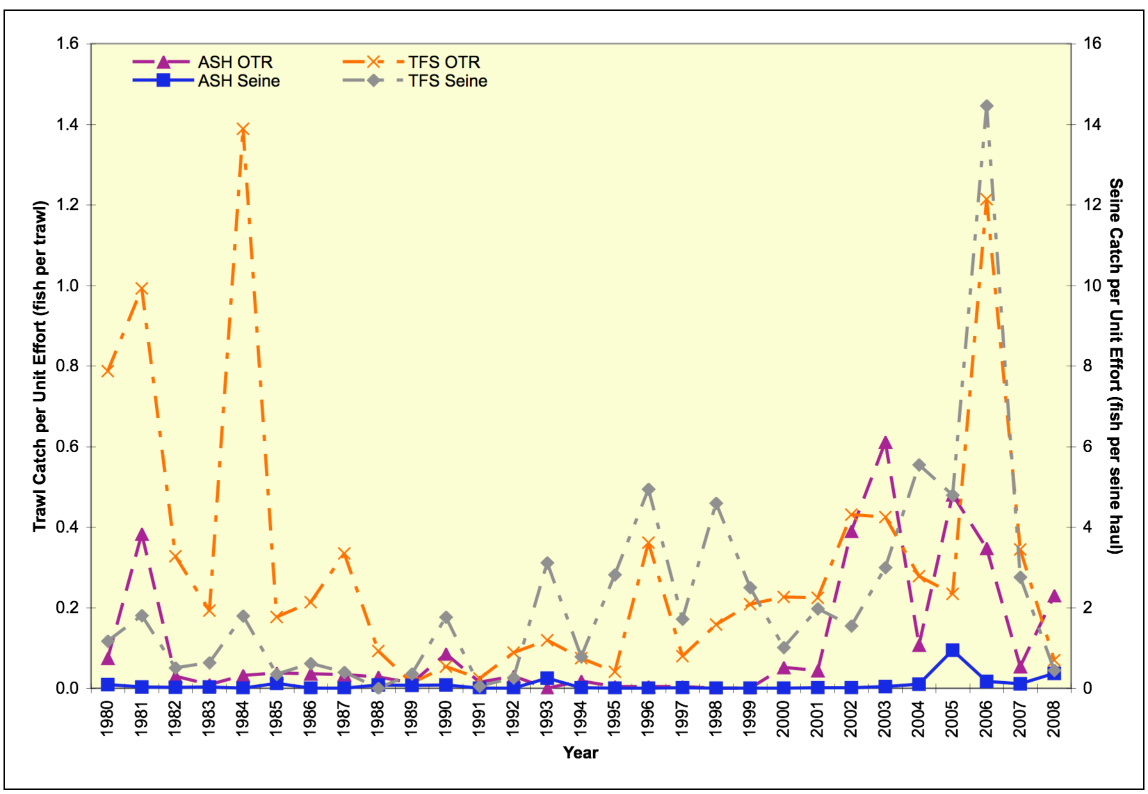

Figure 11. Annual beach seine and otter trawl catch per unit effort from 1980 to 2008 for American and threadfin shad (acronyms as in Figure B).

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 2006 (Figure 11). For the most part, this pattern has been paralleled by the beach seine catch (O'Rear and Moyle 2008). Since 2006, both otter trawl and beach seine catches have declined precipitously concomitant with higher marsh salinities. Annual otter trawl and beach seine catch-per-unit-effort values reached their lowest points in 2008 since 1995 and 1992, respectively.

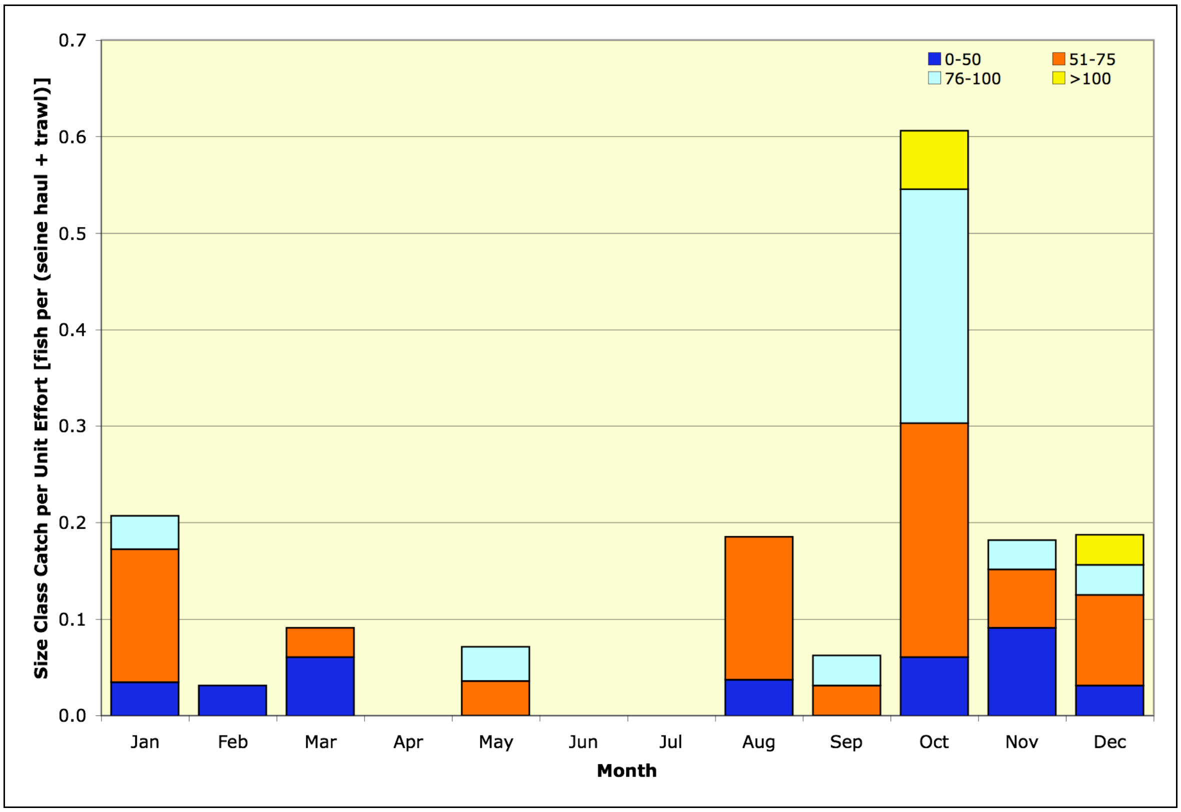

Figure 12. Monthly catch per unit effort during 2008 for size classes of threadfin shad.

Although threadfin shad catches were very low in 2008, a few patterns are still discernible. First, there was virtually a complete lack of fish in late spring and early summer (Figure 12). Second, threadfin shad were most abundant during the last five months of the year. These patterns are consistent with low recruitment, which, as discussed above, was probably the result of low river inflows or higher marsh salinities. Third, more than 50% of the otter trawl catch came from the central marsh's sloughs (i.e., First Mallard and Cutoff sloughs). Fourth, threadfin shad were captured by seine in February, March, May, and August through December (Figure 12); however, it was not until October that they were seined in upper Suisun Slough. These latter two patterns have been observed in previous years and are probably the result of smaller sloughs in the central and eastern marsh (i.e., Cutoff, First Mallard, and Denverton sloughs) providing more food, more shallow refuge habitat, and better water quality.

American Shad

American shad have been infrequently caught in otter trawls. Their ability to tolerate rapid salinity increases when larger than 25 mm total length and their anadromy suggests that American shad move rapidly through the estuary, including the marsh. Nevertheless, a relatively high catch occurred in 2008 (Figure 11), during which American shad were present in the marsh throughout much of the year (Figure 13).

The monthly pattern of catch in 2008 for American shad is quite similar to that of longfin smelt (discussed below): a very large proportion (68%) of the total catch occurred in late April and was comprised almost totally of young-of-year fish. Additionally, a disproportionate amount of the otter trawl catch (39%) in April came from lower Suisun Slough. Furthermore, 83% of the total American shad beach seine catch occurred in April, with most of these fish taken at the upper Suisun Slough seining site. It thus appears that these shad likely entered the marsh from San Pablo and Grizzly bays as river inflows declined during spring. American shad were captured in otter trawls in very low numbers throughout the rest of the year; 56% of these fish were caught in lower Suisun Slough.

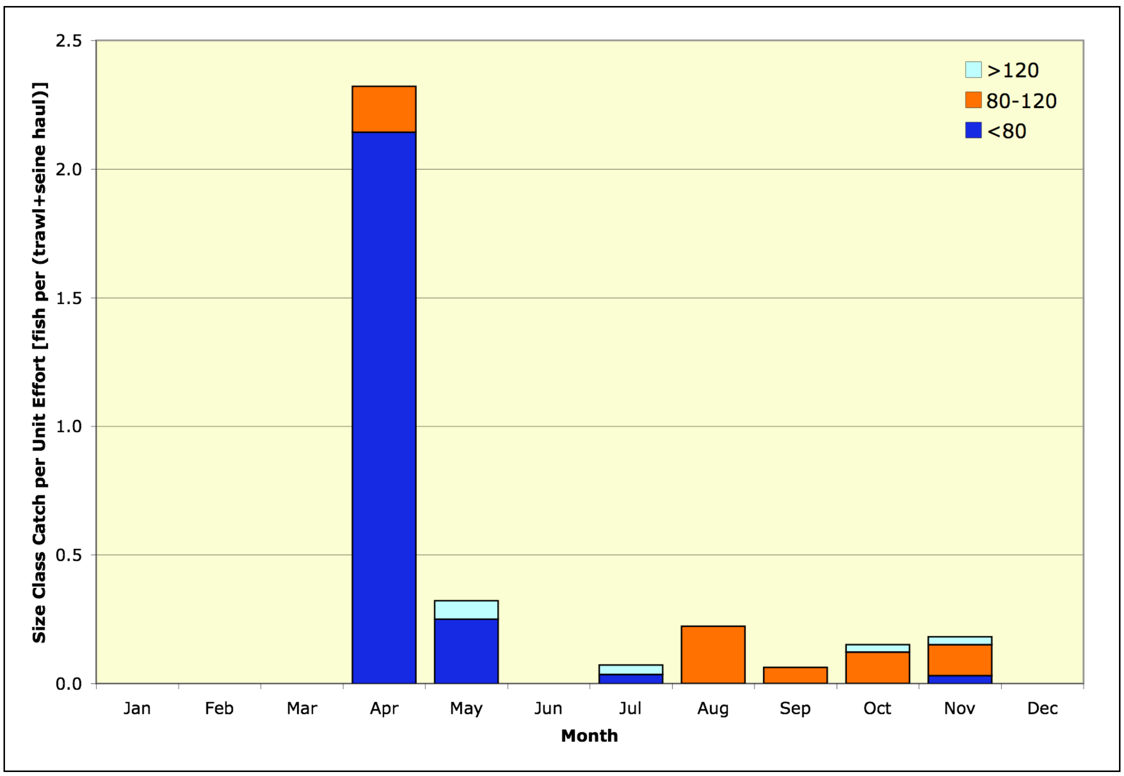

Figure 13. Monthly catch per unit effort during 2008 for size classes of American shad.

Delta Smelt

Since 1984, otter trawl catch of Delta smelt has been routinely low (less than 7 fish per year; Figure B), 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 66 midwater trawls over the study's history, it is still somewhat surprising that we have only captured four Delta smelt from the water column of the large sloughs.

We captured four Delta smelt in 2008. The first was probably an adult fish captured by otter trawling in First Mallard Slough during January. The second Delta smelt, a subadult fish, was caught by a midwater trawl in Montezuma Slough during August. The last two Delta smelt came from an otter trawl in lower Suisun Slough during October; these fish measured about 65 mm SL.

Longfin Smelt

The annual otter trawl catch per unit effort for longfin smelt in Suisun Marsh parallels that seen in other parts of the estuary (e.g., the Delta): catches were high in the early eighties, were low throughout the dry years of the late 1980s and early 1990s, increased somewhat in the

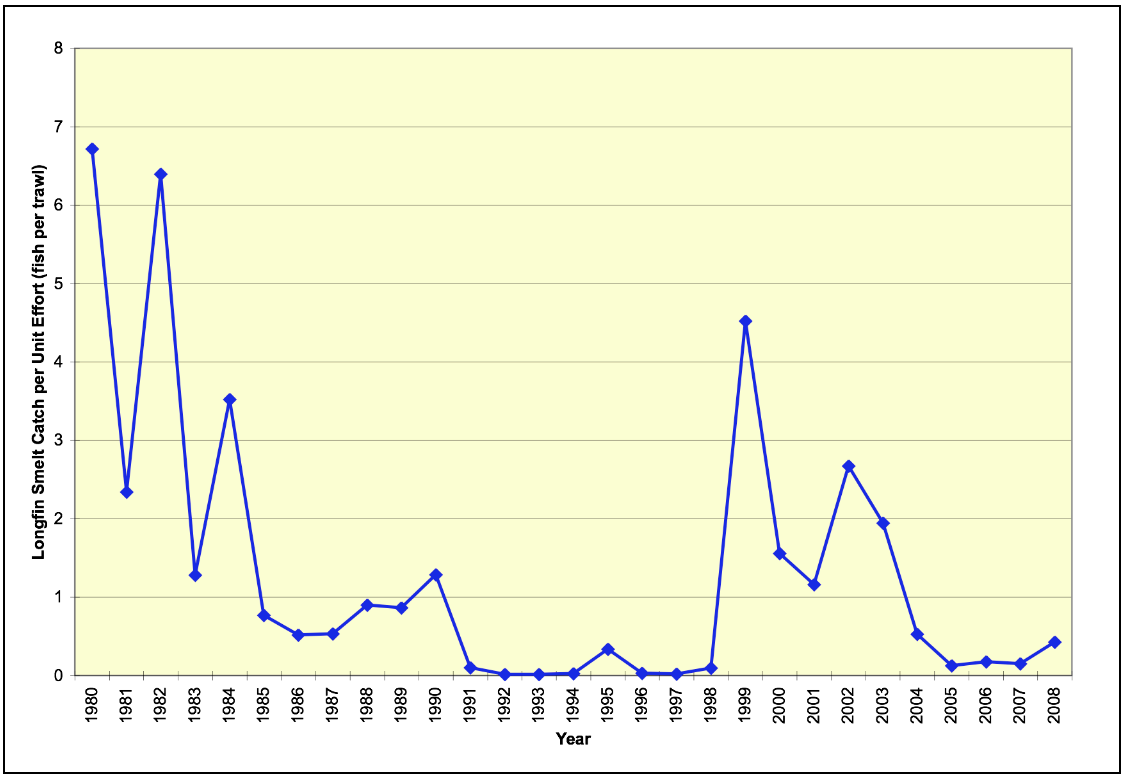

Figure 14. Annual otter trawl catch per unit effort from 1980 to 2008 for longfin smelt.

wetter years of the late 1990s and early 2000s, and declined to low levels again beginning in 2005 (Figure 14). Our catch pattern has been influenced by the amount of fresh water exiting the Delta, which, when large, transports larvae to more productive regions of the estuary (e.g., Suisun Bay; Bay Institute et al. 2007, Moyle 2002) and reduces entrainment mortality (Bay Institute et al. 2007).

Our otter trawl catch increased substantially from 42 fish in 2007 to 122 fish in 2008. As in 2007, 62% of the catch in 2008 was made in one day in lower Suisun Slough and was comprised totally of young-of-year fish (Figure 15). However, the large catch in 2008 was a month earlier than in 2007 (April 25 and May 18, respectively). Additionally, the catch in 2008 was much larger than in 2007 (75 and 26 fish, respectively). The salinities in lower Suisun

Slough on May 18, 2007 and April 25, 2008 were comparable (4.4 and 3.7 ppt), and salt water began intruding into the marsh earlier in 2008 than in 2007 (e.g., average marsh salinity exceeded 4 ppt in June 2007 and in May 2008). Thus, our spring catch in 2008 may have been due to transport of young-of-year longfin smelt into lower Suisun Slough via earlier intrusion of saltier water from San Pablo Bay than in 2007. Assuming spawning periods between 2007 and 2008 were equal, our larger 2008 catch may have resulted from a greater proportion of young-of-year that were more vulnerable to our trawl net.

After April, our otter trawl catch decreased substantially, possibly due to the greater ability of larger young-of-year fish to move to preferred higher salinities or to lower water temperatures found downstream of Suisun Marsh (Moyle 2002). Our catch increased from October to December (Figure 15), although the absolute numbers for each month were low (2, 7,

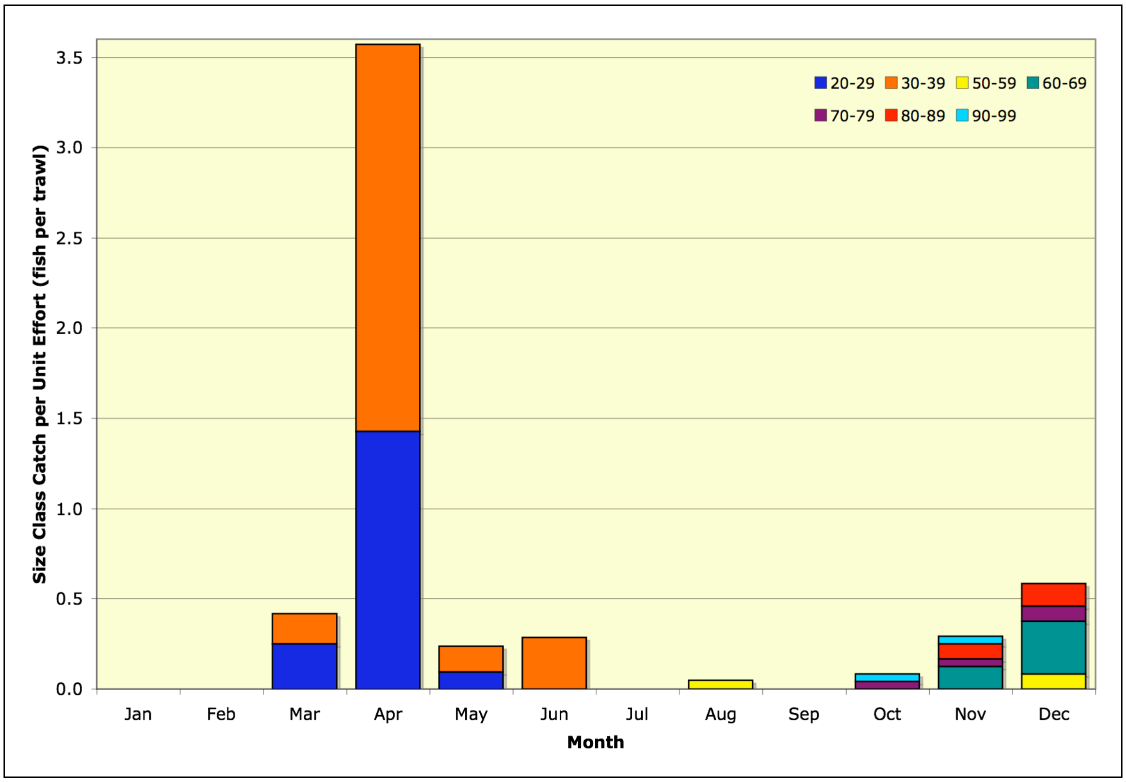

Figure 15. Monthly otter trawl catch per unit effort during 2008 for size classes of longfin smelt.

and 14 fish, respectively). It is likely that some of these fish (i.e., those larger than 70 mm SL; Moyle 2002) were captured while migrating upstream to spawn.

Striped Bass

Striped bass are consistently one of the most abundant fishes in trawl catches. Although somewhat variable, annual otter trawl catch per unit effort of striped bass decreased significantly from 1980 to 1990 (Figure 16). From 1991 to 2008, catch per unit effort had no significant increasing or decreasing trends (Figure 16). While the drought period that began in the mid-1980s likely influenced the decline in catch seen in the first 10 years of the study period, this alone cannot fully explain the pattern because large catches have been made in dry years (e.g., 1991, 2001). A plethora of other factors, such as increased water exports and altered food webs, also have no doubt contributed to the pattern of the otter trawl catch (California Department of Water Resources and Department of Fish and Game 2007, Moyle 2002).

Annual otter trawl catch per unit effort in 2008 was the second lowest recorded in the study's history, with only 1990 having a lower catch rate (2.5 and 2.0 fish per trawl, respectively). As Schroeter et al. (2006) pointed out, the bulk of our otter trawl catch consists of young-of-year fish; consequently, the trawl catch mainly reflects the success of reproduction and recruitment of fish less than a year old into the fishery. For instance, assuming that all fish smaller than 109 mm SL captured after April are young-of-year fish, then 77% of striped bass caught by otter trawl from 1980 to 2008 were young-of-year. In 2006, a year with a reasonably high otter trawl catch, 85% of the catch consisted of young-of-year. Conversely, only 46% of the catch in 2008 - a year with a very low catch - was comprised of young-of-year. As a result,

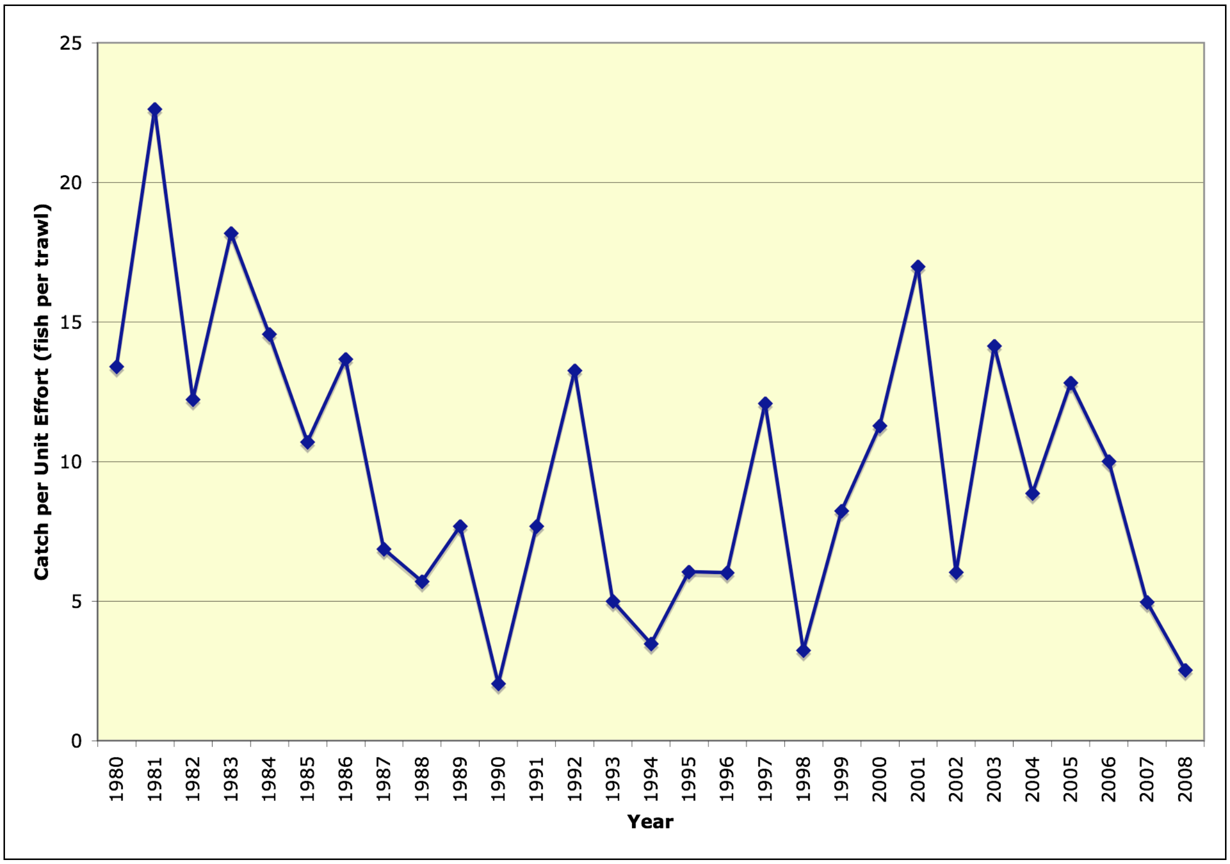

Figure 16. Annual otter trawl catch per unit effort from 1980 to 2008 for striped bass.

our low 2008 catch implies little recruitment of young-of-year striped bass into the marsh.

Monthly otter trawl catch per unit effort for 2008 was similar to that of previous years (e.g., 2006 and 2007; O'Rear and Moyle 2008). Catches were quite low in the first three months of the year; additionally, a greater proportion of these catches consisted of fish longer than 306 mm SL (Figure 17). These larger fish were probably adults that had moved into the marsh from San Pablo Bay prior to their upstream spring spawning migration. Young-of-year did not appear in the marsh until June, after which a continuing influx through summer resulted in peak catches in August and September (Figure 17). Thereafter, catches declined precipitously; several striped bass larger than 306 mm SL were captured in the southwest part of the marsh during December, which, like those caught in the first part of the year, were probably pre-spawning adults.

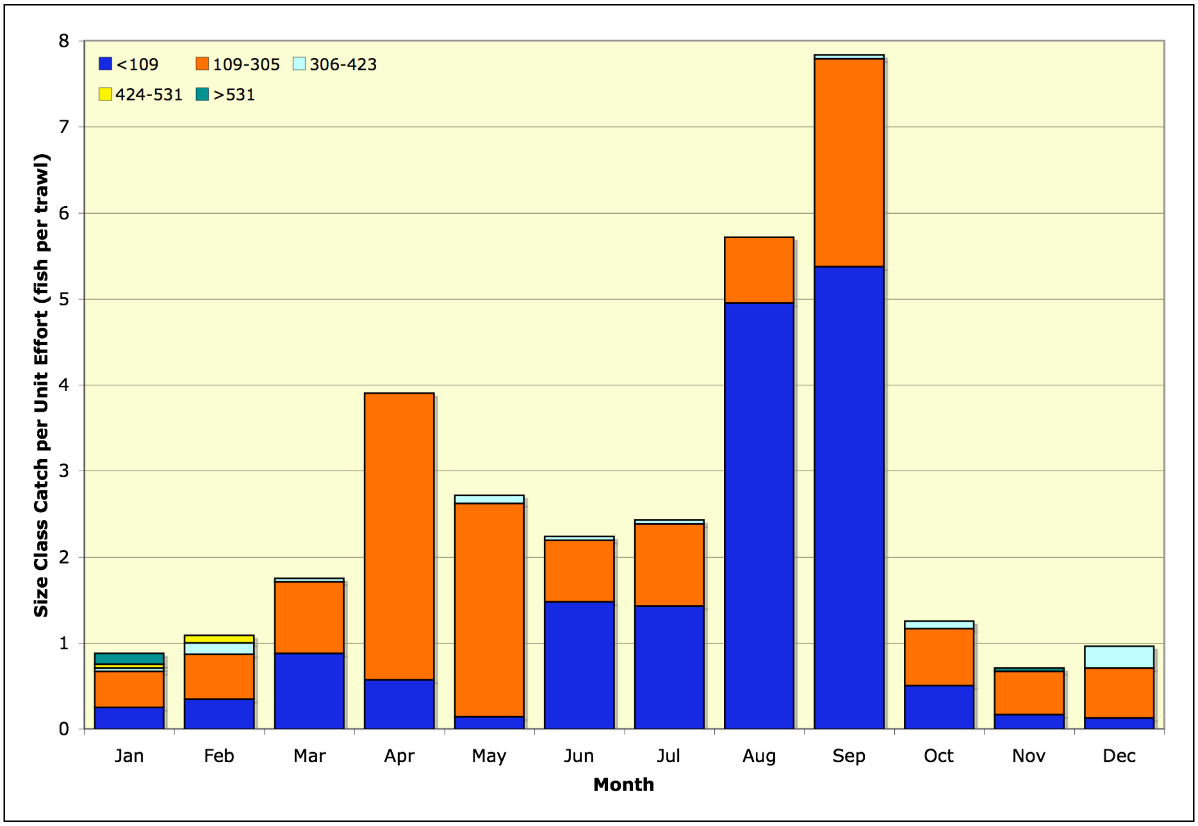

Figure 17. Monthly otter trawl catch per unit effort during 2008 for size classes of striped bass.

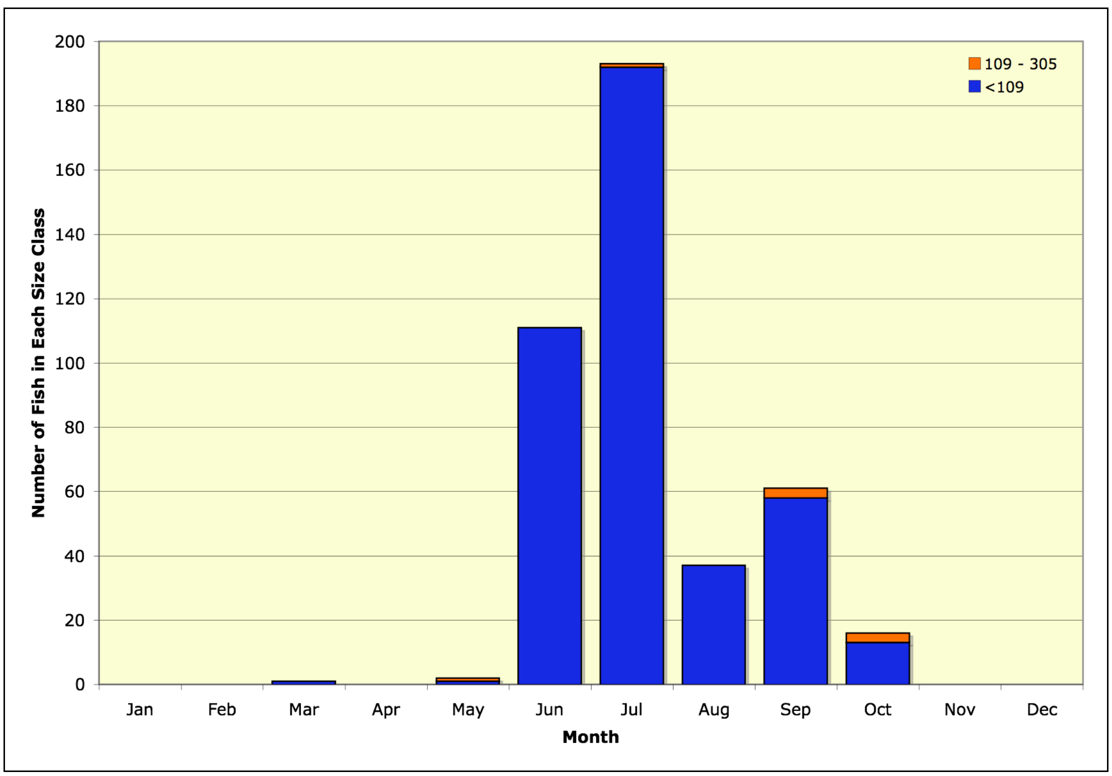

Figure 18. Monthly beach seine catch per unit effort during 2008 for size classes of striped bass.

Geographic distribution of otter-trawl-caught striped bass was much like previous years in that lower Suisun Slough had the highest annual otter trawl catch per unit effort (8.3 fish per trawl); additionally, relatively high catches were made in Goodyear Slough (2.5 fish per trawl). Schroeter et al. (2006) speculated that the proximity of Goodyear and lower Suisun sloughs to food-rich Grizzly Bay may have contributed to the high catches in these sloughs. However, substantial catches (more than five fish per trawl) were also made in Peytonia Slough during April, May, and September, and in Denverton Slough during July and September.

The beach seine catch for 2008 tells a different story than that of the otter trawl. In 2008, the annual beach seine catch per unit effort was relatively high, the sixth highest in the study's history. Because our beach seine catches are comprised almost exclusively of young-of-year fish, they are affected by recruitment even more strongly than our otter trawl catches. In 2008, more than 97% of the beach seine catch consisted of young-of-year. Concomitant with the monthly otter trawl catch per unit effort, young-of-year first appeared in seines during June (Figure 18). However, our monthly beach seine catch per unit effort peaked one month before the otter trawl catch increased substantially (figures 17 and 18); this pattern occurs in most years and implies movement of young-of-year offshore as they grow larger (O'Rear and Moyle 2008). If this is the case, then it seems young-of-year fish may have suffered higher mortality rates during 2008 while moving into more open waters.

Splittail

Splittail have been the most commonly captured native fish in Suisun Marsh. Not

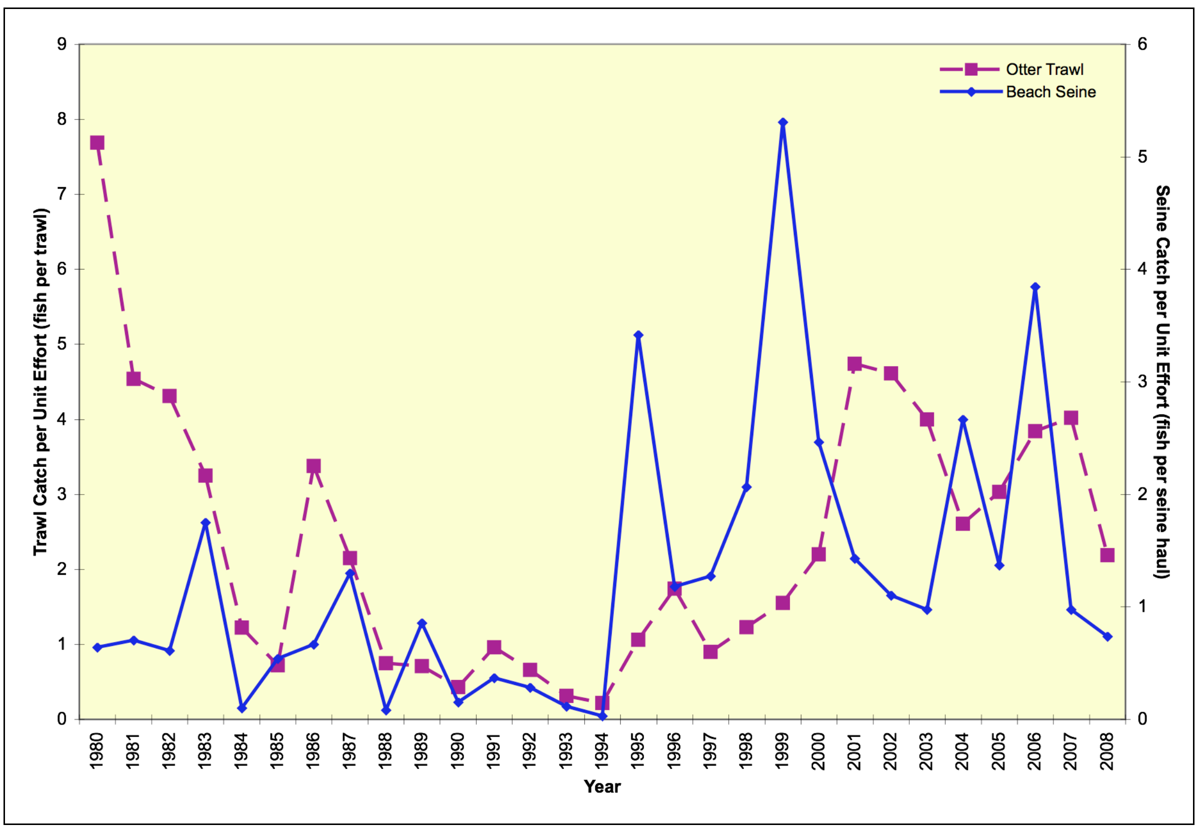

Figure 19. Annual otter trawl and beach seine catch per unit effort from 1980 to 2008 for splittail.

including 1986 and 1987, splittail annual otter trawl catch per unit effort declined considerably from 1980 to 1994; this was mirrored fairly well by the beach seine catch per unit effort, which was more variable over that period (Figure 19). From 1995 to 2008, otter trawl catch per unit effort generally increased and was accompanied by large beach seine catches in years of high springtime Delta outflow (e.g., 1995, 2006; Figure 19). The otter trawl and beach seine catch patterns are likely influenced by the amount of floodplain available for spawning and rearing during the spring (Moyle et al. 2004, Sommer et al. 1997), hence our higher catches during and just following years of high flows.

The annual splittail otter trawl catch per unit effort dropped by almost half from 2007 to 2008 (Table 3). This was primarily due to low numbers of young-of-year and yearling fish in our catches: 39% of the catch was comprised of fish from the 2006 year-class (i.e., those between 170 and 216 mm SL; Moyle 2002; Figure 20). As discussed above, lack of floodplain

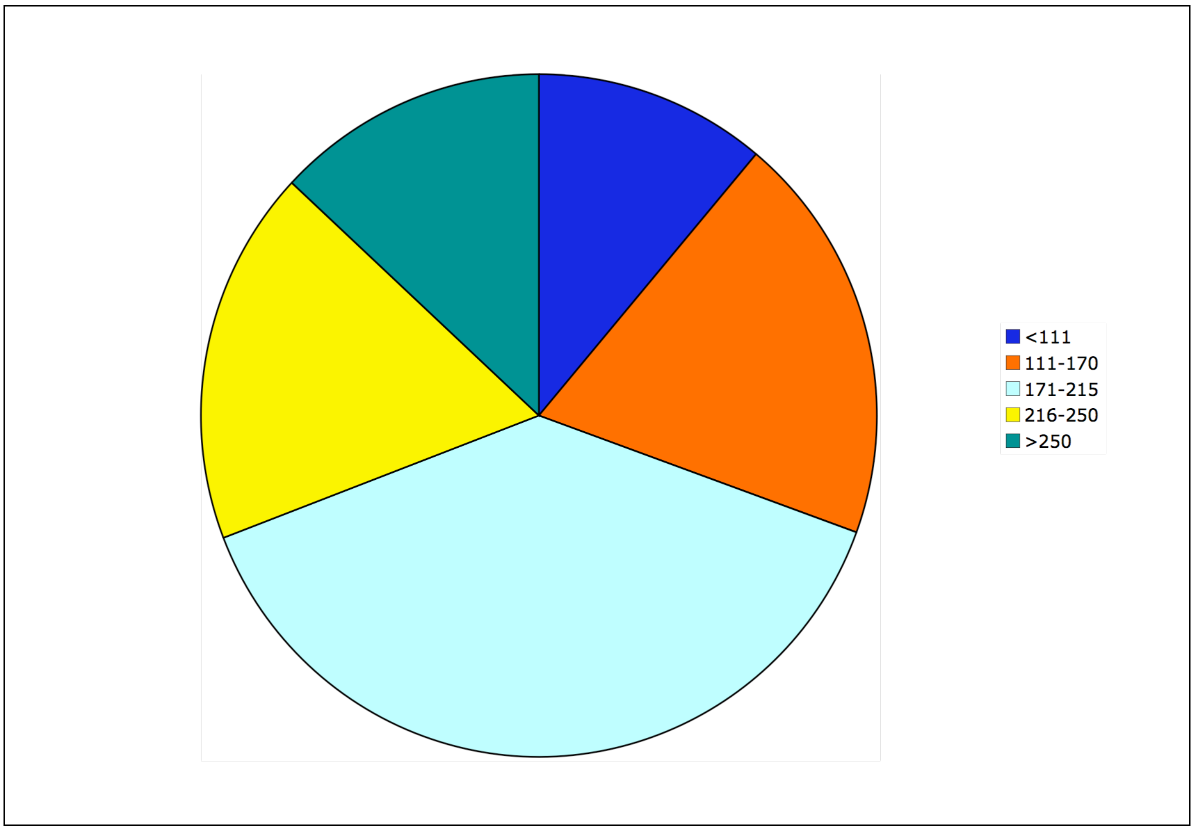

Figure 20. Size-class composition of the total otter trawl catch of splittail in 2008.

inundation in 2007 and 2008 probably contributed to the poor representation of these year-classes in the 2008 catch.

Monthly otter trawl catch per unit effort in 2008 was relatively high in January, was lower in February and March, returned to higher values in April, May and June, and generally declined through the rest of the year (Figure 21). The lower catches in February and March may have been partially due to movement of prespawn adults out of the marsh and upstream into the Sacramento River: catch per unit effort for fish larger than 215 mm SL (i.e., sexually mature fish; Moyle 2002) was greater in January and April than in the intervening months (Figure 21). Catch per unit effort was also substantially higher for fish measuring 171 to 215 mm SL in April (Figure 21), the timing of which corresponds to increasing salinities in the marsh. These fish

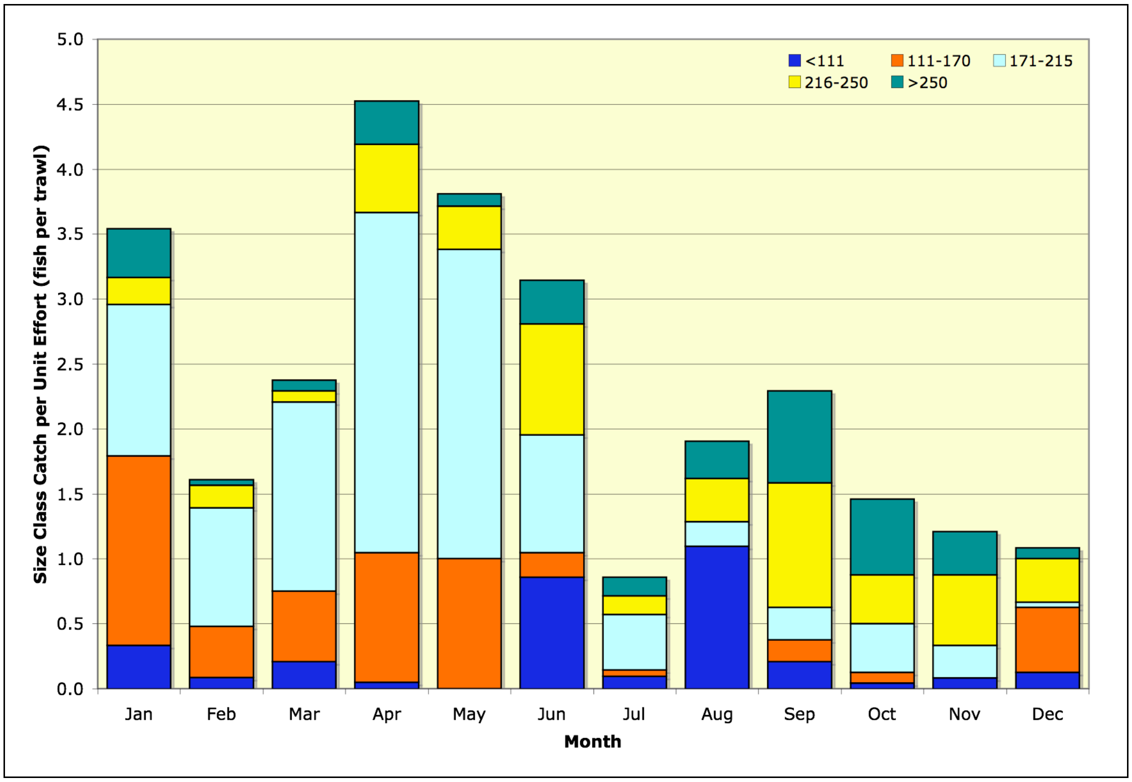

Figure 21. Monthly otter trawl catch per unit effort during 2008 for size classes of splittail.

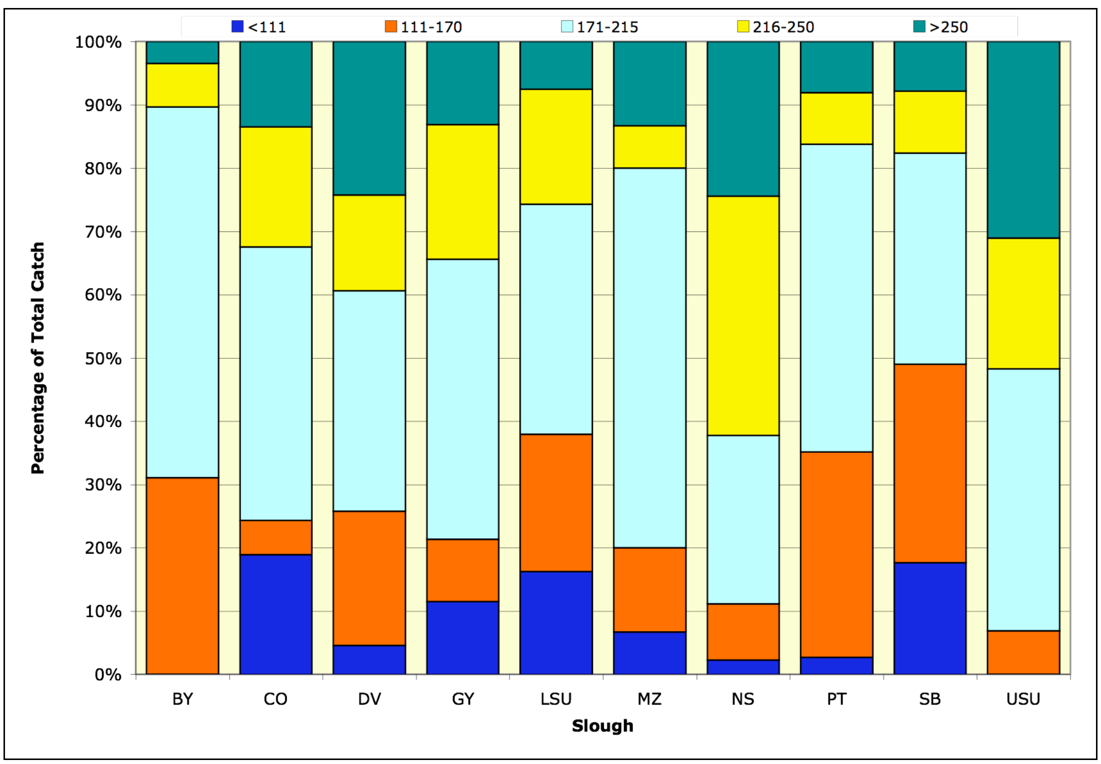

Figure 22. Proportions of each sampled sloughs's total splittail catch made up of five size classes (BY = Boynton Slough; CO = Cutoff Slough; DV = Denverton Slough; GY = Goodyear Slough; LSU = lower Suisun Slough; MZ = Montezuma Slough; NS = Nurse Slough; PT = Peytonia Slough; SB = First Mallard Slough; and USU = upper Suisun Slough).

could have moved upstream from San Pablo Bay. However, if this were the case, it is unlikely that these fish were avoiding more saline water because the salinities in the marsh were well within the tolerance ranges for this size-class (Young and Cech 1996). Young-of-year fish comprised a substantial proportion of the catch in June and August, although, as discussed above, the young-of-year numbers were very low compared to other years. The monthly beach seine catch per unit effort, comprised primary of young-of-year fish, reached its peak in July and August, corresponding to the high young-of-year otter trawl catches.

The geographical pattern for the otter trawl splittail catch in 2008 was similar to that of previous years: 49% of the catch came from lower Suisun and First Mallard sloughs. Somewhat different from previous years, Denverton Slough ranked second behind lower Suisun Slough in otter trawl catch per unit effort for 2008. Year-class distributions for the sloughs was fairly similar, with the 2006 cohort dominant in all but Nurse Slough (Figure 22).

White Catfish

With the exception of a strong year-class in 1983 that dominated the otter trawl catch throughout the 1980s, white catfish were relatively rare until 1995; since then, the annual otter

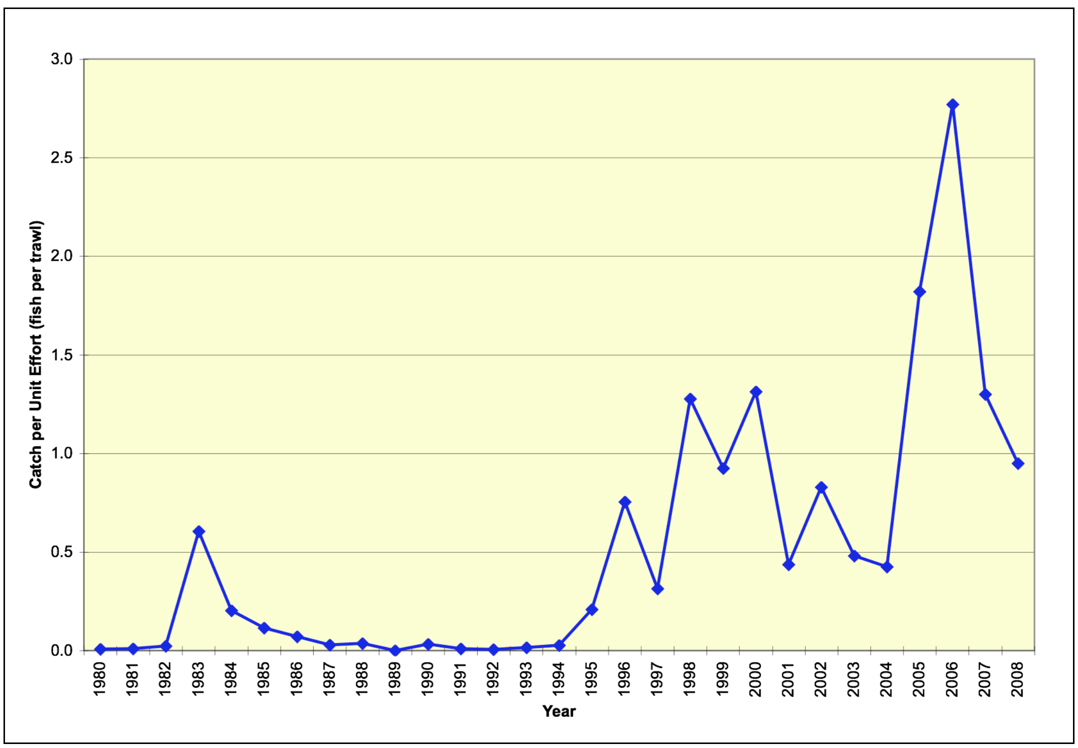

Figure 23. Annual otter trawl catch per unit from 1980 to 2008 for white catfish.

trawl catch per unit effort has increased roughly linearly (Figure 23). Salinity or a factor correlated to it appears to affect the distribution of white catfish in the marsh: from 1980 to 2007, over two-thirds of the white catfish captured by otter trawl came from the fresher eastern part of the marsh (i.e., Denverton, Montezuma, and Nurse sloughs), while only 3% of the catch was from the saltiest sloughs (i.e., Goodyear and lower Suisun sloughs). Additionally, it seems that either early life-history stages or an aspect of the reproductive cycle (e.g., egg development) are most affected by higher marsh salinities. White catfish larger than 150 mm total length (TL) persist in salinities as high as 14 ppt (Allen and Avault, Jr. 1971, Kendall and Schwartz 1968), salinities that are usually only recorded in the southwest marsh in dry years during late summer and autumn. Consequently, salinities in the marsh, both temporally and spatially, are rarely high enough to affect the larger size-classes of white catfish. However, the five highest catch-per-unit-effort values for young-of-year white catfish occurred in Suisun Marsh during years when average salinities were below 3 ppt during June, the month when white catfish spawning is at its peak (Hughes and Carlson 1986, Borgeson and McCammon 1967, Turner 1966). It is unlikely that recruitment of white catfish in the marsh is dependent on an influx of fish from upstream because (1) young-of-year fish appear when river flows have already subsided; (2) we have captured gravid females in Peytonia and Denverton sloughs in May and June; and (3) we have

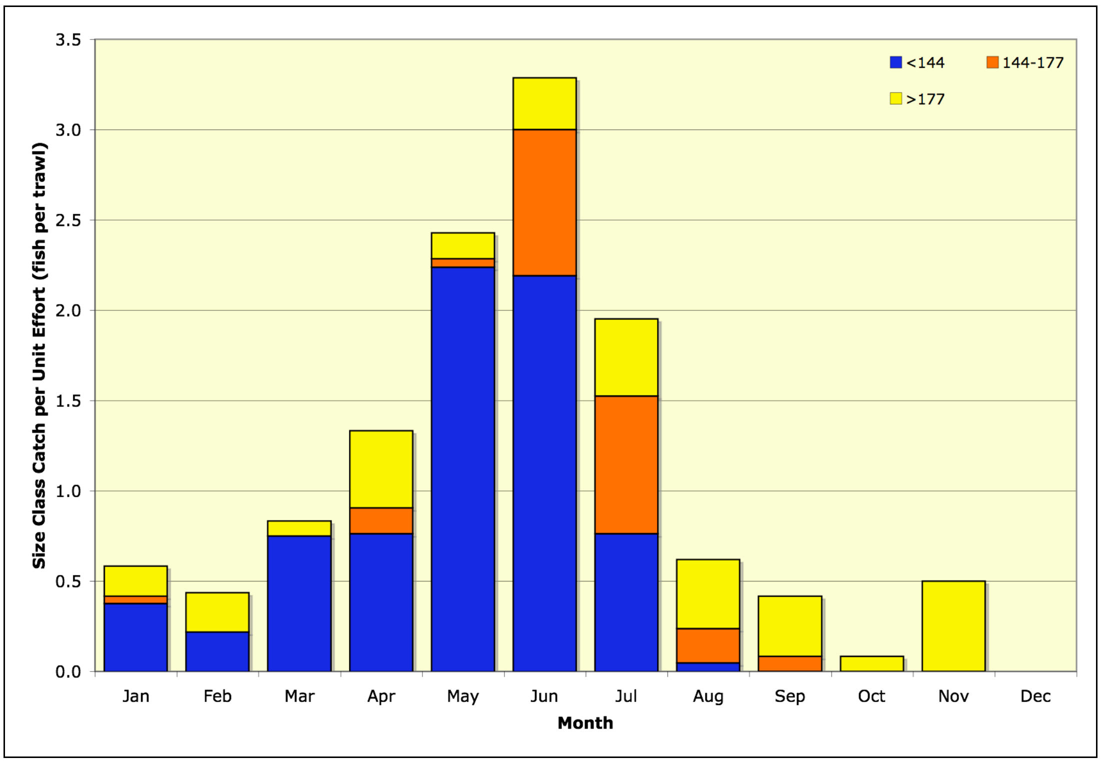

Figure 24. Monthly otter trawl catch per unit effort during 2008 for size classes of white catfish.

also captured spawning males and postspawn females in the same sloughs.

As discussed previously, annual otter trawl catch per unit effort for white catfish dropped 27% from 2007 to 2008, primarily due to the absence of young-of-year in our catches (Figure 24). The pattern in monthly otter trawl catch per unit effort in 2008 was similar to 2007: catch was low in winter, increased in spring, peaked in June, and declined thereafter (Figure 24; O'Rear and Moyle 2008). Interestingly, while our young-of-year catch in 2007 was quite low compared to 2006 and 2005 (0.3, 2.0, 1.1 fish per trawl, respectively), the 2007 year-class dominated our catches throughout 2008 (Figure 24). Sexually mature fish (i.e., those larger than 177 mm SL; Miller 1966) comprised the smallest proportion of the catch in May and June, which coincides with their spawning period. White catfish are warm-water fish, and thus our monthly catch pattern was likely due to both movement of adult white catfish into shoreline crevices for spawning in late spring (Hughes and Carlson 1986) and greater activity levels during the warmer months increasing our capture efficiency. The decline in the two smallest size-classes coupled with a greater proportion of the catch comprised of larger fish through the latter half of the year was probably a result of mortality and growth (Figure 24).

Mississippi Silverside

In the first nine years of the study, annual beach seine catch per unit effort for Mississippi silverside tended to vary around 15 fish per seine haul (Figure 25). 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 2008, catch per unit effort has grown roughly linear, with that period containing the two years with the highest catches recorded in the study's history (2003 and 2006; Figure 25). This pattern is consistent with silverside catch in the Unites States Fish and Wildlife Service beach seine survey (Moyle and Bennett 2008).

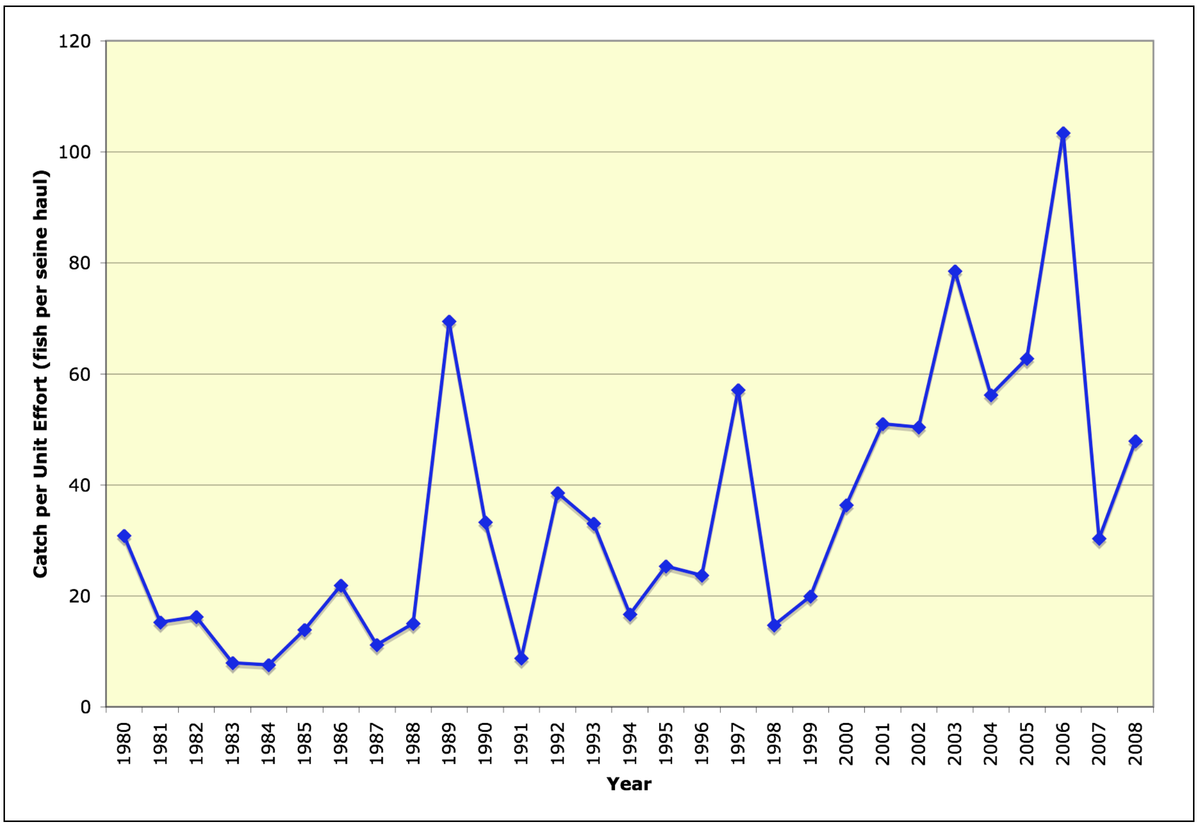

Figure 25. Annual beach seine catch per unit effort from 1980 to 2008 for Mississippi silverside.

Previous studies in other waterbodies have revealed that silversides frequently have two spawning peaks per year (Moyle 2002, Middaugh and Hemmer 1992), with fish produced the previous year spawning in spring and the resultant young-of-year spawning in late summer. This pattern appeared to be followed in Suisun Marsh during 2005, 2006, 2007 (O'Rear and Moyle 2008), and also in 2008. In Denverton Slough during April 2008, a relatively large catch of fish

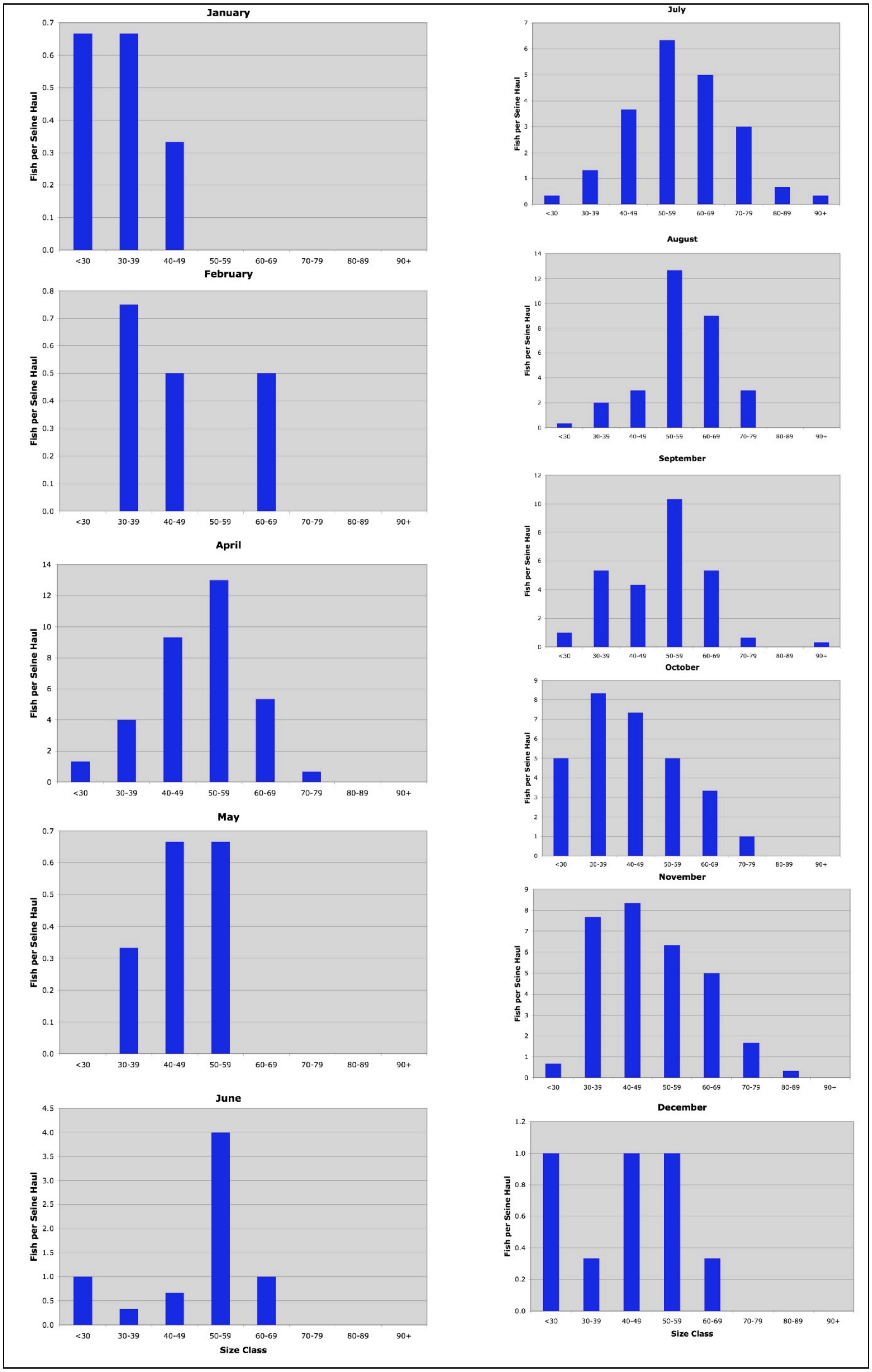

Figure 26. Monthly beach seine catch per unit effort for size classes of Mississippi silversides captured in Denverton Slough.

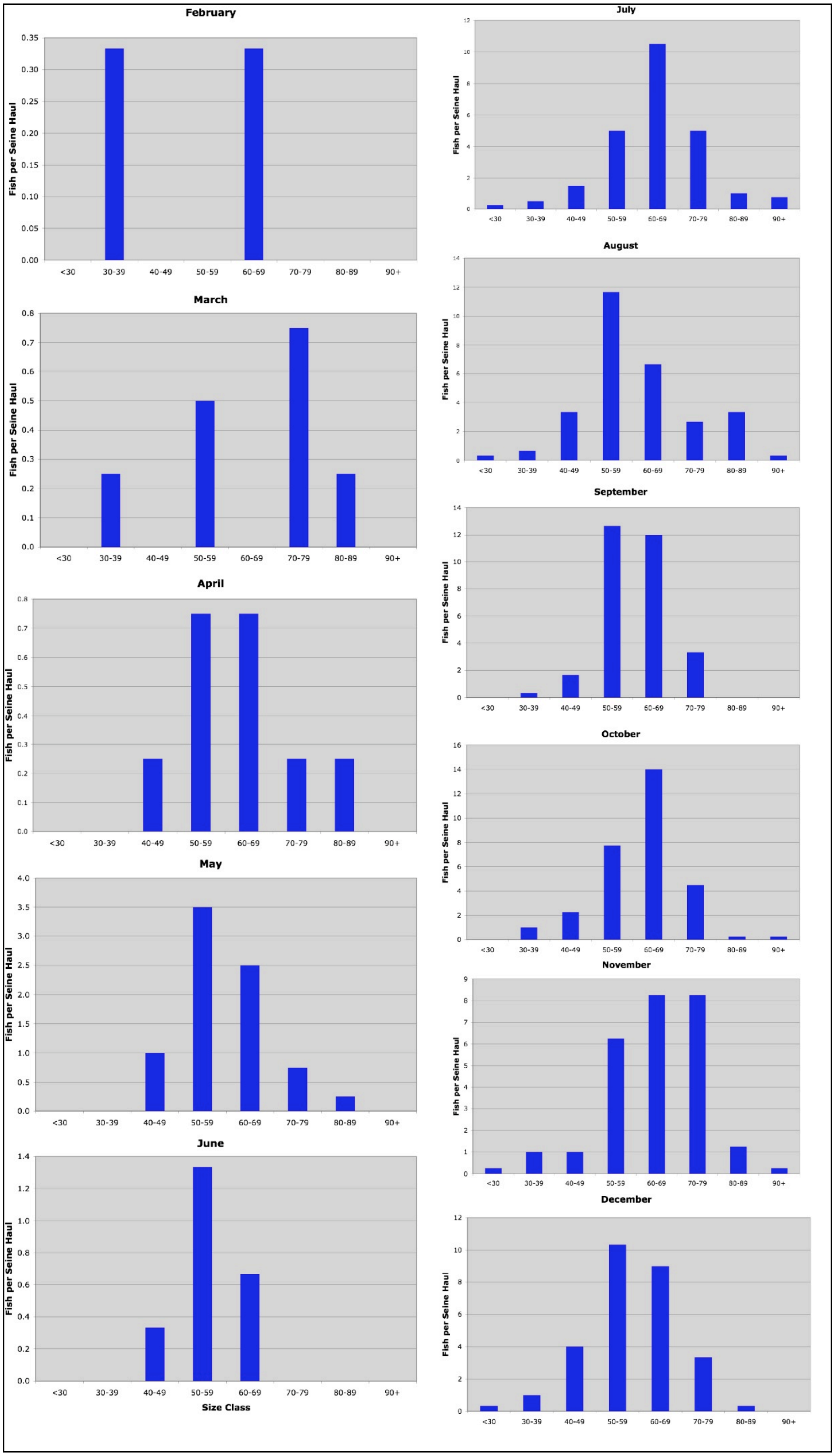

Figure 27. Monthly beach seine catch per unit effort for size classes of Mississippi silversides captured in upper Suisun Slough.

born in 2007 was followed by a much lower catch in May and the appearance of fish smaller than 30 mm SL in June (Figure 26). This pattern suggests the movement of sexually mature fish into shore to spawn once water temperature reaches about 15°C (i.e., April; Middaugh and Hemmer 1992, Hubbs 1982), the high mortality of adult fish following reproduction (i.e., May; Moyle 2002), and the subsequent recruitment of young-of-year fish about two months old (i.e., June; Gleason and Bengston 1992, Hubbs 1982) into the fishery. The same pattern was followed in Suisun Slough, albeit one month later for each event (i.e., a high catch in May, a low catch in June, and young-of-year appearing in July; Figure 27). Additionally, young-of-year fish came to dominate the catches the month after they first appeared in each slough when they measured 50 to 59 mm SL (i.e., July in Denverton Slough and August in Suisun Slough; figures 26 and 27). Most silversides are sexually mature at this size (Hubbs 1982); the bimodal size-class distribution in Denverton Slough in September (Figure 26) and the appearance of very small fish in Suisun Slough during autumn (and especially November; Figure 27) are consistent with young-of-year fish spawned in spring reproducing in summer once reaching 50 mm SL.

There are two noticeable differences in our 2008 silverside catches between Denverton and Suisun sloughs: life-history events occurred later and fish were larger in Suisun Slough. Despite the fact that the weather was very similar and the sampling times the same for our seining sites during April, Suisun Slough was more than 2°C cooler than Denverton Slough (14.7°C and 17.1°C, respectively). As previously mentioned, most silversides do not begin spawning until water temperature reaches about 15°C; thus, the earlier timing of events in Denverton Slough could have been due to warmer water. Although salinities varied more in Suisun Slough than in Denverton Slough, they never exceeded levels that may have been detrimental to eggs or early life-history stages (Hubbs et al. 1971) and thus were likely not a factor determining the timing of reproduction. Catches in Suisun Slough were much higher in July and August, which, as previously stated, coincided with high catches of Black Sea jellyfish in our otter trawls. Black Sea jellyfish are known to feed on fish larvae and on similar food items as silversides (e.g., copepods; A. Wintzer, pers. comm.). Consequently, any silversides in offshore areas could have moved shoreward to avoid negative interactions with the jellyfish, resulting in our high July and August catches.

Geographic Trends in Fish Assemblages of Suisun Marsh

Southwest Marsh

Goodyear and lower Suisun sloughs (Figure 1) are substantially different from the other sloughs sampled in the marsh by having higher absolute and more variable salinities (Figure 28). While they often share similar salinities, Goodyear and lower Suisun sloughs differ in several ways: oxygen concentrations are nearly always higher in lower Suisun Slough; Suisun Slough is much deeper and wider than Goodyear Slough; and Suisun Slough has less water diversion intakes and outfalls (Matern et al. 2002). Consequently, the two sloughs host very different fish communities.

Lower Suisun and Goodyear sloughs had the highest and fifth-highest annual otter trawl catch-per-unit-effort values, respectively, in 2008 (Table 5). Noticeably, fishes that cannot handle moderate salinities (e.g., black crappie, black bullhead) were rarely, if ever, captured in the southwest marsh. Native fishes contributed considerably to the catch-per-unit-effort values:

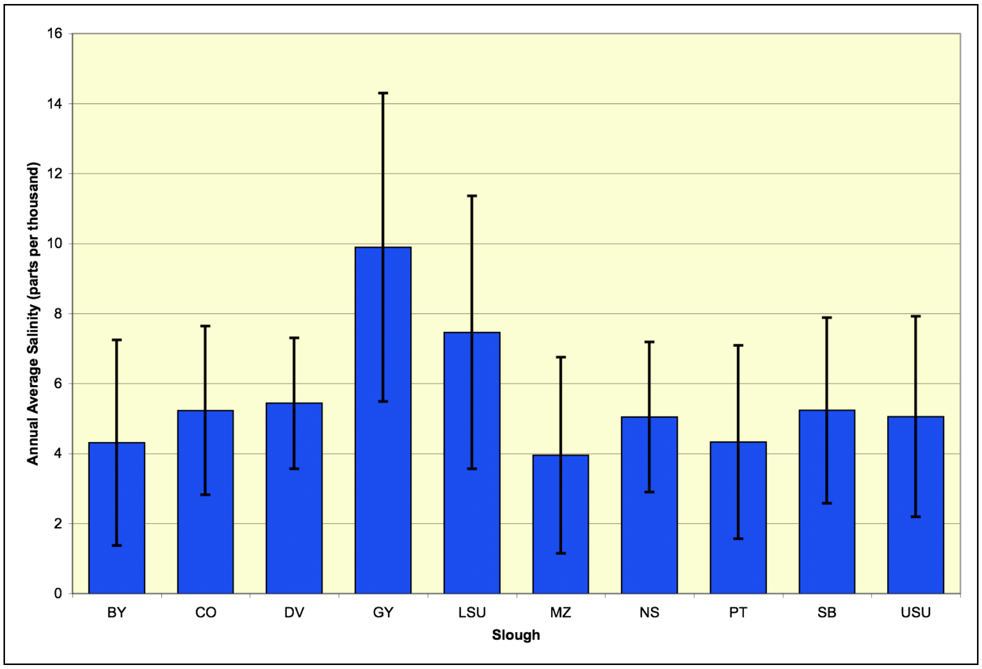

Figure 28. Annual average salinities for Suisun Marsh sloughs during 2008 (error bars are standard deviations).

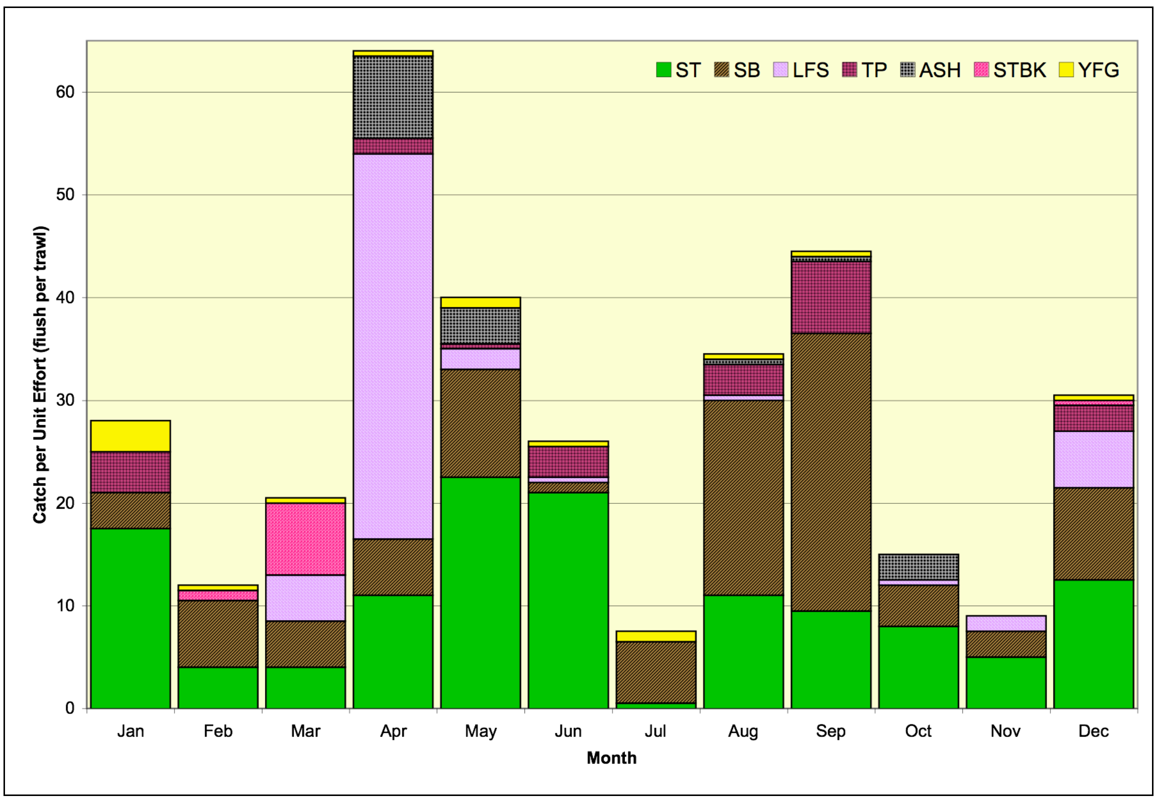

Figure 29. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in lower Suisun Slough during 2008 (ASH = American shad, LFS = longfin smelt, SB = striped bass, ST = splittail, STBK = threespine stickleback, TP = tule perch, and YFG = yellowfin goby).

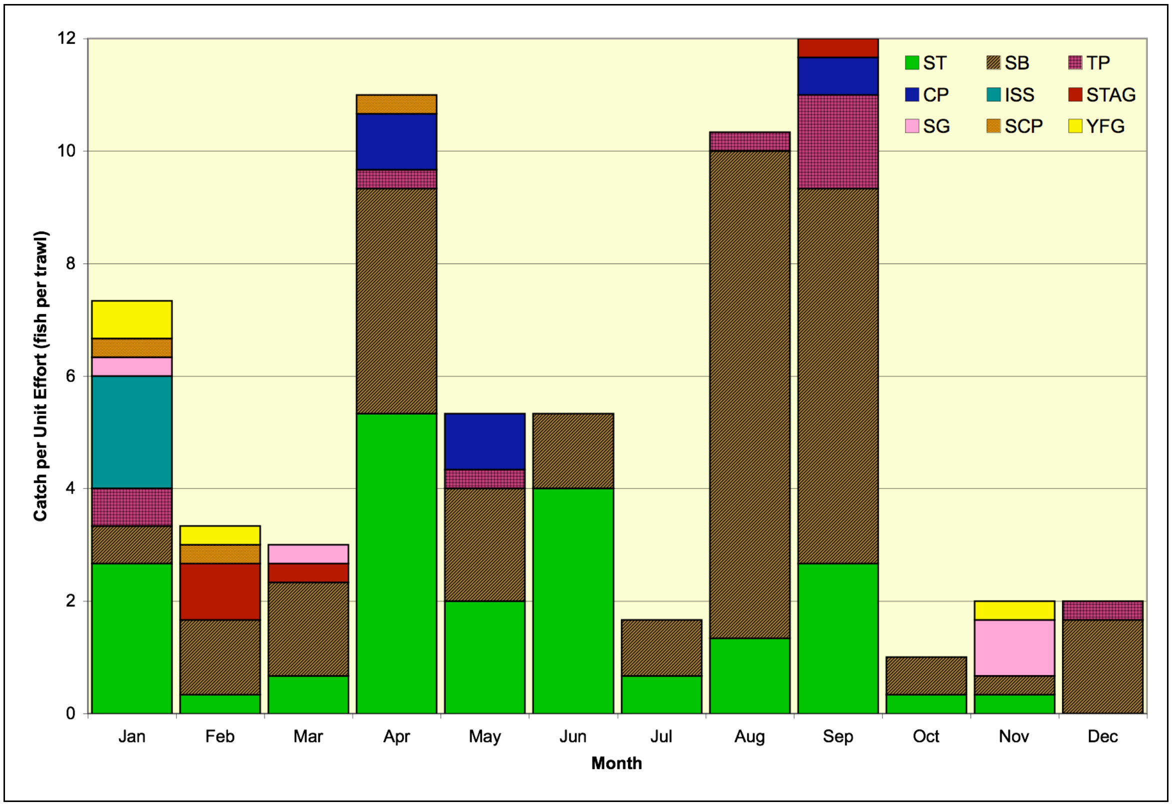

Figure 30. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Goodyear Slough during 2008 (CP = common carp, ISS = Mississippi silverside, SCP = prickly sculpin, SG = shimofuri goby, STAG = staghorn sculpin, and all other codes as in Figure 29).

only Cutoff Slough had a greater proportion of its catch comprised of native fishes (Table 5). However, the species resulting in the high native fish proportions in Goodyear and lower Suisun sloughs were different: threespine stickleback dominated catches within Goodyear Slough, while splittail and longfin smelt were especially abundant in lower Suisun Slough (figures 29 and 30).

Table 5. % of the otter trawl catch comprised of native fishes, the annual catch with both introduced and native species, and the annual otter trawl catch per unit effort for introduced and native species for sloughs sampled in Suisun Marsh during 2008 (acronyms as in Figure 22).

Slough	BY	CO	DV	GY	LSU	MZ	NS	PT	SB	USU
%Natives	26%	65%	29%	63%	63%	28%	44%	30%	41%	29%
Annual Catch	231	154	338	334	685	162	123	372	268	233
Annual Fish per Trawl	7.45	6.70	14.08	9.28	28.54	6.75	5.13	12.00	11.17	7.52

Ignoring threespine stickleback, the monthly catch per unit effort in Goodyear and lower Suisun sloughs for all species was similar in that it was relatively high in January, lower in February and March, increased from April to June, declined substantially in July, and once again increased in August and September (figures 29 and 30). This pattern is no doubt influenced by the life-history events of two of the marsh's most abundant fishes, striped bass and splittail, whose adults and juveniles migrate through/from and to the marsh, respectively. However, the other fishes contributing substantially to the monthly catch pattern for the sloughs differed considerably. Pelagic planktivores (i.e., longfin smelt and American shad; Feyrer et al. 2003) were especially abundant in lower Suisun Slough during April, and they were present in all months except January, February, and July. [Strangely, the American shad caught in April were young-of-year, appearing well before the spawning peak of this species (Moyle 2002).] Conversely, with the exception of six Mississippi silverside captured in January, Goodyear Slough was dominated by fishes that feed on macroinvertebrates (e.g., amphipods). As a result, the fish communities of the two sloughs might be partly due to the difference in availability of food types.

Northwest Marsh

The three sloughs we sample in the northwest part of the marsh (i.e., Boynton, Peytonia, and upper Suisun sloughs) differ from those in the southwest by having considerably lower salinities (Figure 28) for much of the year. Fresh water flows into the northwest marsh via Ledgewood Creek and a wastewater treatment plant, which discharge into Peytonia and Boynton sloughs, respectively. Additionally, the northwest sloughs are too far away to be much

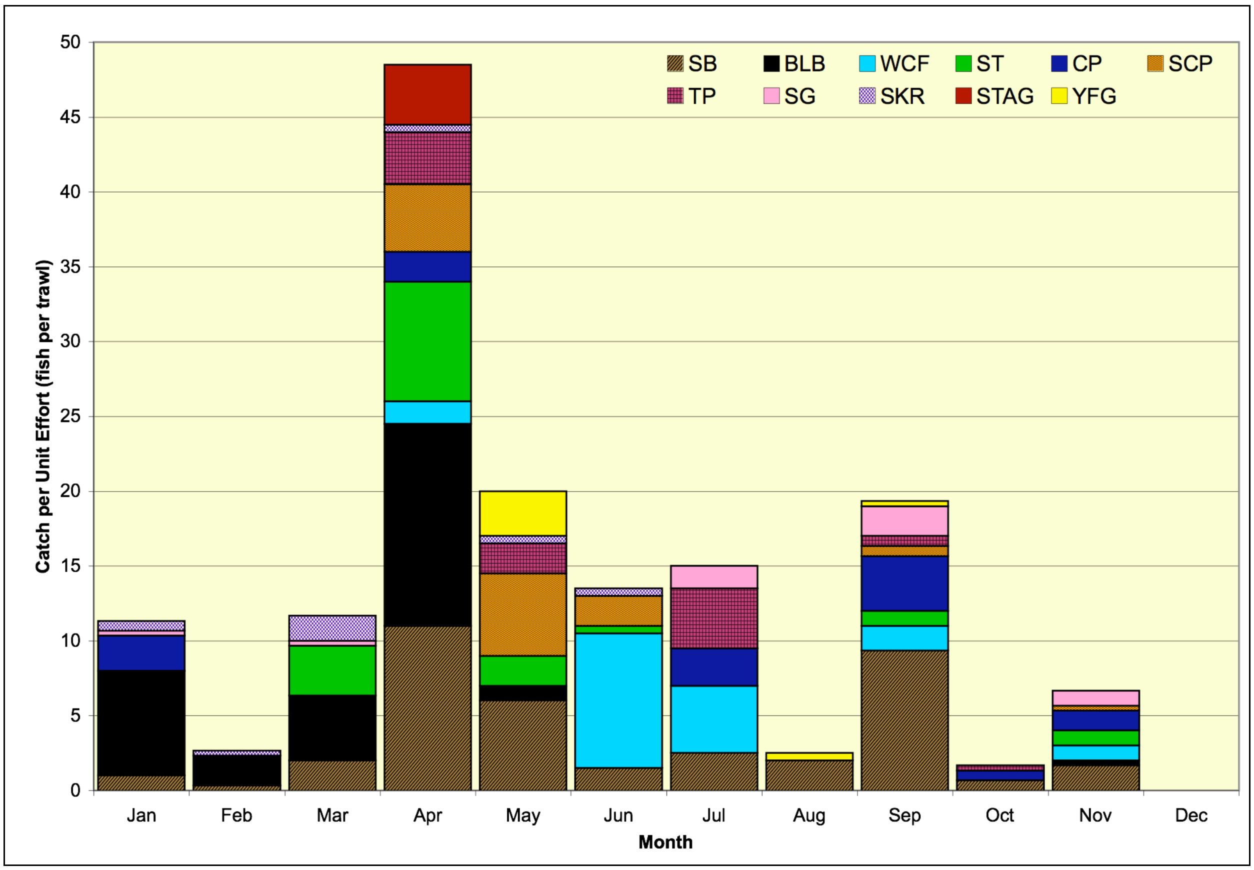

Figure 31. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Peytonia Slough during 2008 (BLB = black bullhead, SKR = Sacramento sucker, WCF = white catfish, and all other codes as in figures 29 and 30).

influenced by the marsh's primary source of salt water (i.e., Grizzly Bay). Like the southwest marsh, the northwest marsh's large slough is dissimilar to its smaller sloughs. Peytonia and Boynton sloughs have narrow, shallow channels and water that is low in oxygen during spring and autumn. Conversely, upper Suisun Slough is wide, deep, and usually well oxygenated.

Annual catch-per-unit-effort values for Boynton and upper Suisun sloughs were about the same; more fish were caught in Peytonia Slough per trawl than in the other two sloughs (Table

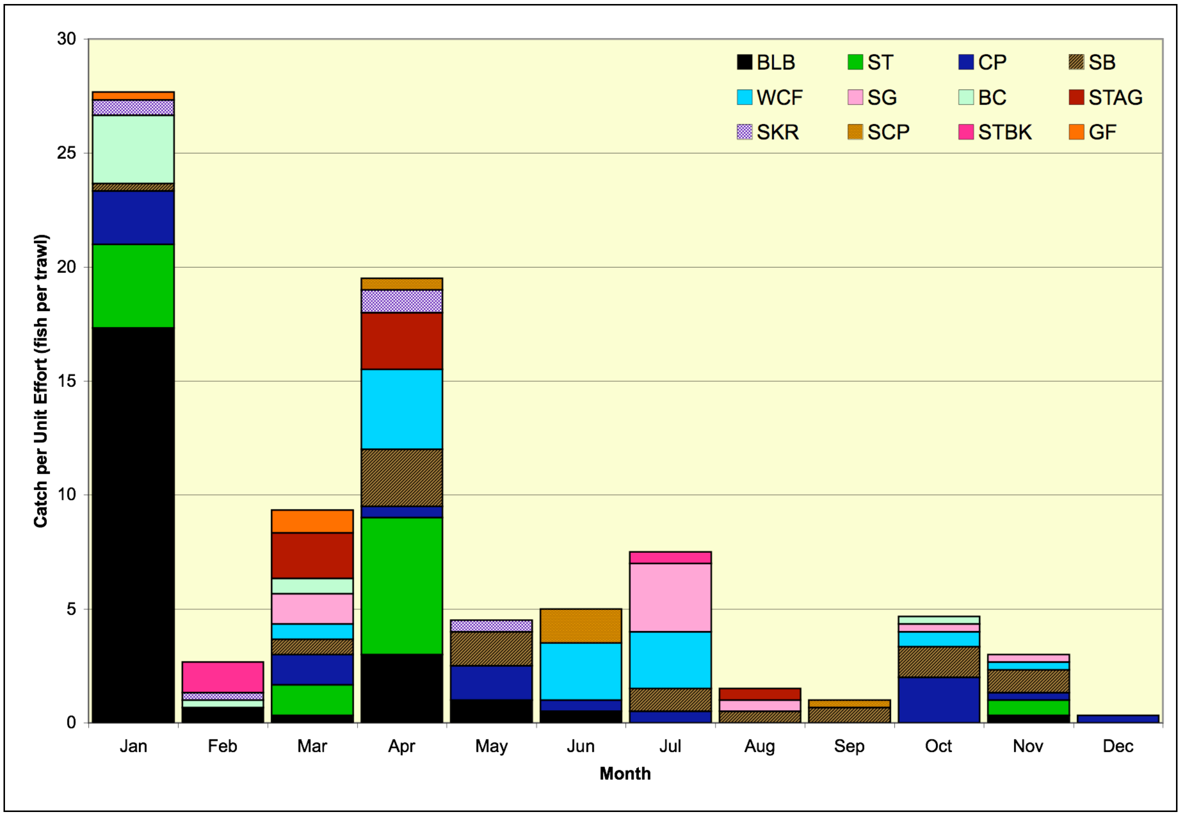

Figure 32. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Boynton Slough during 2008 [BC = black crappie, GF = goldfish (*Carassius auratus*), and all other codes as in figures 29-31].

5). For all three sloughs, introduced fishes dominated the catches (Table 5). However, not considering striped bass and splittail, black bullhead *Ameiurus melas*, common carp, and white catfish were the most abundant fishes in Peytonia and Boynton sloughs, while white catfish, tule perch, and shokihaze gobies *Tridentiger barbatus* were the most common fishes in upper Suisun Slough. Given the dissolved oxygen concentrations, it is not surprising that the species dominating Peytonia and Boynton sloughs can handle very hypoxic conditions (i.e., black bullhead, common carp, and white catfish; figures 31 and 32).

The patterns of monthly catch-per-unit-effort values for several species were quite similar, suggesting some degree of synchrony. For fishes captured in all three sloughs, white catfish were most abundant in June and July; black bullhead were most commonly caught in January, March, and April; and the largest staghorn sculpin catches occurred in April (figures 31, 32, and 33). Additionally, prickly sculpin were most abundant in the smaller sloughs during late spring and early summer. However, the catch pattern for two species was noticeably different. Catch of striped bass increased substantially in upper Suisun Slough during July and August while remaining low in Peytonia and Boynton sloughs. Because the majority of the catch for those months consisted of the 2008 year-class, it appears that Peytonia and Boynton sloughs were not used as nursery areas by young-of-year fish. This could have been due to higher densities of Black Sea jellyfish in the smaller sloughs, which may have been competing with young-of-year striped bass for food and thereby forcing the fish into upper Suisun Slough. Splittail were more frequently captured in the smaller sloughs during spring, whereas they were more abundant in upper Suisun Slough in the summer. Most of the splittail in the three sloughs

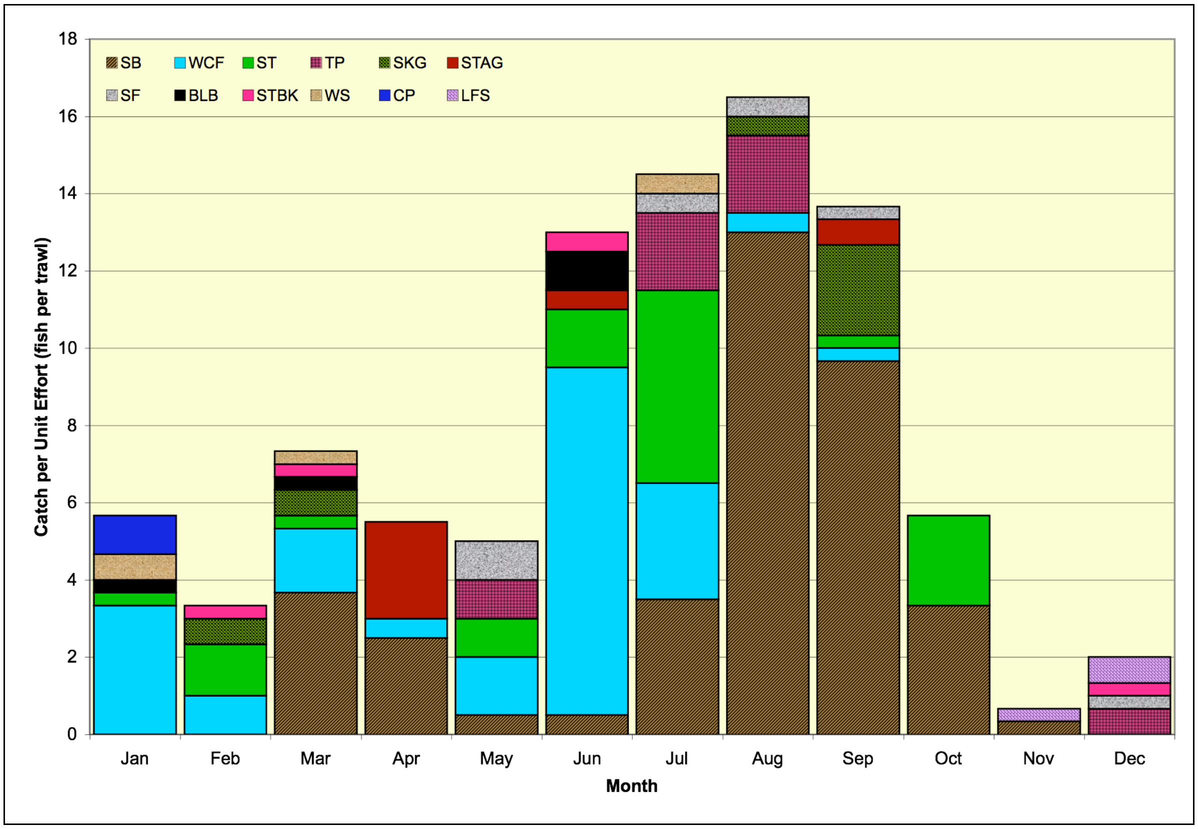

Figure 33. Monthly otter trawl catch per unit effort for the most common species (that made up 95 percent of the slough's total catch) in upper Suisun Slough during 2008 [SF = starry flounder (*Platichthys stellatus*), SKG = shokihaze goby, WS = white sturgeon (*Acipenser transmontanus*), and all other codes as in figures 29-32].

were from the 2006 year-class, intimating that they may have been moving into upper Suisun Slough from Boynton and Peytonia sloughs. If these movements did occur, it is doubtful that they were related to spawning because most of the fish were probably sexually immature.

Central Marsh

Of the sloughs we sample in the marsh, First Mallard and Cutoff sloughs are the least disturbed: First Mallard has no duck-pond outfalls or intakes, and, of the remaining sloughs, only Nurse Slough has less diversions per river-kilometer than Cutoff Slough (Matern et al. 2002). Additionally, none of First Mallard Slough and only a small proportion of Cutoff Slough have been riprapped. The relatively central location of the two sloughs in the marsh predisposes them to moderate salinities. Because First Mallard Slough is the shallowest slough in the marsh, it tends to have the greatest variability in temperature throughout the year. Also, during low spring tides, much of First Mallard Slough becomes very shallow and thus hypoxic due to the proximity of the water to decomposition within the sediments (R. E. Schroeter, pers. comm.).

First Mallard Slough had the fourth-highest annual catch per unit effort, while Cutoff Slough had a relatively low annual catch-per-unit-effort value (Table 5). Introduced fishes were

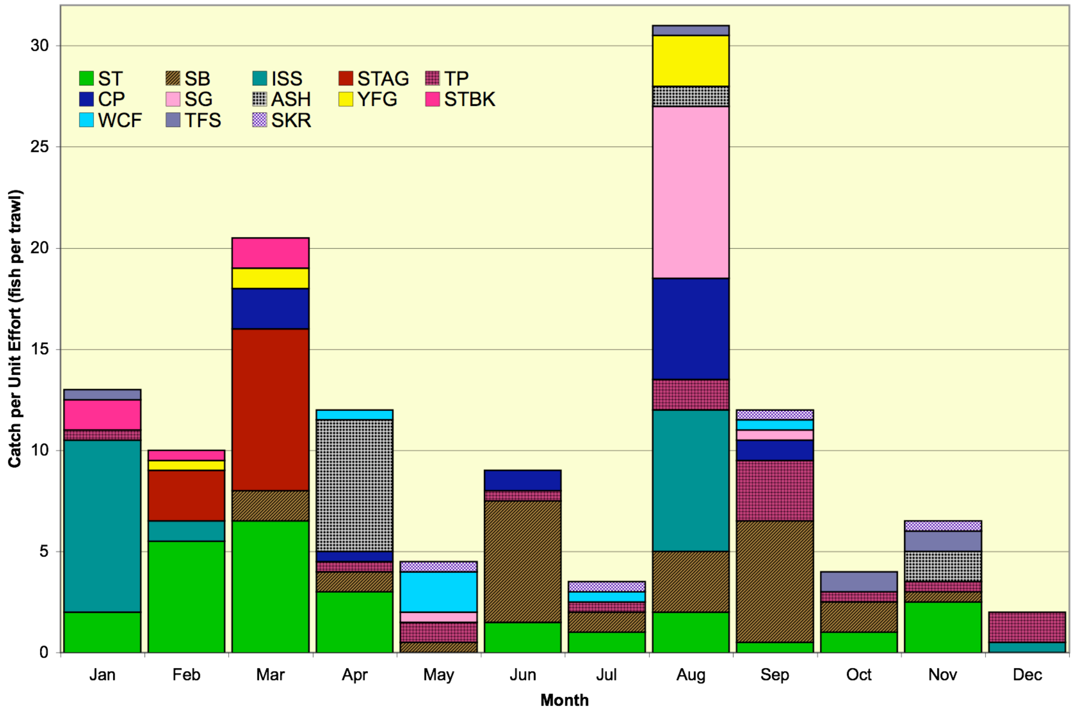

Figure 34. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in First Mallard Slough during 2008 (codes as in figures B and 29-32).

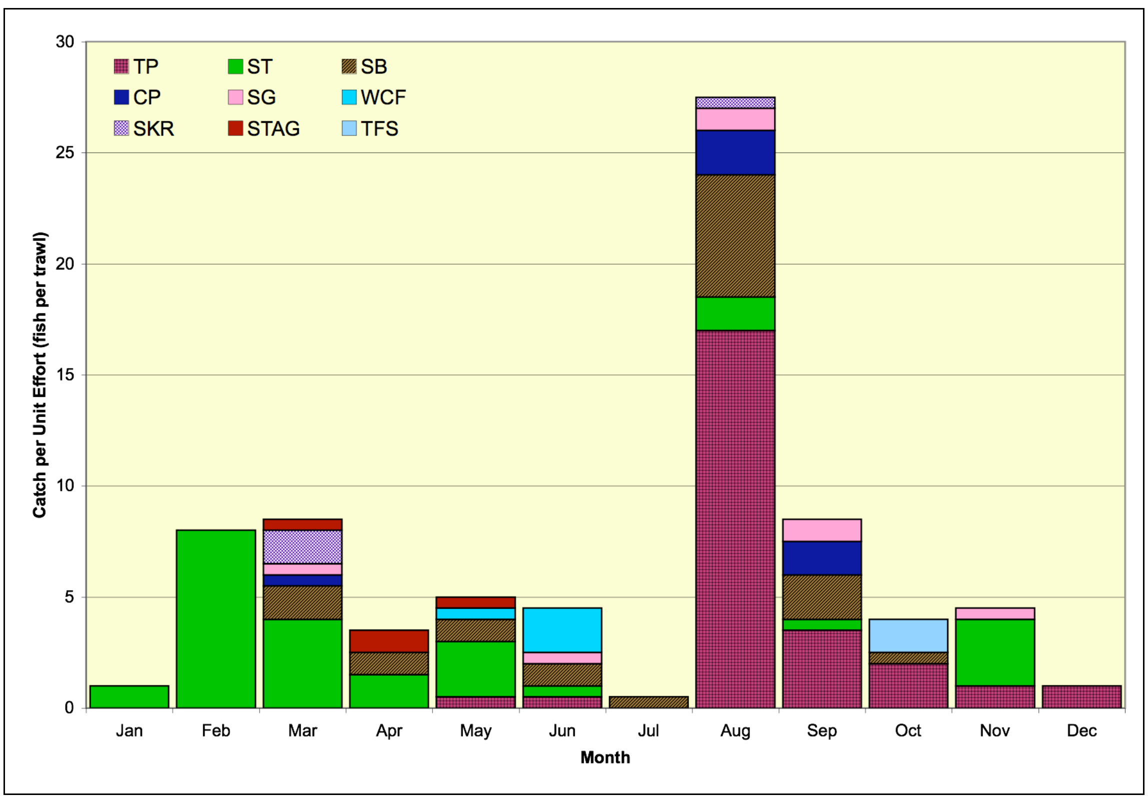

Figure 35. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Cutoff Slough during 2008 (codes as in figures B and 29-32).

slightly more abundant than native fishes in First Mallard Slough, with the most common introduced species being striped bass, Mississippi silverside, and common carp (Figure 34). Noticeably, many of the fishes caught in First Mallard Slough were either young-of-year (e.g., many of the common carp, staghorn sculpin) or small-sized species (e.g., Mississippi silversides, American and threadfin shad, threespine stickleback), suggesting that this slough was primarily used as shallow-water refuge for small fishes. Cutoff Slough had a higher proportion of its catch comprised of native fishes than of any slough in the marsh, mainly due to high catches of young-of-year tule perch in the latter half of the year (Figure 35). Cutoff Slough usually hosts the greatest density of tule perch in the marsh (O'Rear and Moyle 2008, Schroeter et al. 2006), which may be the result of good water quality, a rich food supply (R. E. Schroeter, pers. comm.), and abundant emergent vegetation (e.g., tules). However, both the catch and diversity of Cutoff Slough was substantially lower than that for First Mallard Slough (Table 5; figures 34 and 35).

Like sloughs in the northwest marsh, the pattern in monthly catch per unit effort for several species was similar between First Mallard and Cutoff sloughs. Staghorn sculpin catches peaked in spring; white catfish, though not very abundant in either slough, were most frequently caught in late spring and early summer; and tule perch, shimofuri goby, and striped bass were all most abundant in both sloughs during late summer (figures 34 and 35). The monthly catch pattern for these species in the central marsh was mirrored in the northwest marsh. However, the pattern of the splittail catch was noticeably different than in other parts of the marsh: catches were highest in Cutoff and First Mallard sloughs in February and March. Although the timing of this pattern coincides with the spawning period of splittail and thus suggests that First Mallard and Cutoff sloughs may have been used for spawning, many of the splittail caught in the central marsh during these months were probably juveniles.

Eastern Marsh

Generally, environmental conditions are mildest in the eastern marsh's sloughs (i.e., Denverton, Nurse, and Montezuma sloughs). Of the sloughs we sample in the marsh, salinities vary the least and are usually quite low in Denverton and Nurse sloughs. Due to the Suisun Marsh Salinity Control Gates and its proximity to the Sacramento River, the reach we sample in Montezuma Slough is usually one of the freshest in the marsh. Dissolved oxygen concentrations are commonly quite high throughout the eastern marsh, which may be partially the result of fewer outfalls and intakes in Denverton and Nurse sloughs relative to sloughs in the western marsh. Additionally, Montezuma and Nurse sloughs are subject to strong wind- and tidally driven water currents that oxygenate the water. Of the abiotic data we collect, the largest disparity among the sloughs of the eastern marsh is size: Denverton Slough is relatively narrow and shallow, Montezuma is wide and deep, and Nurse Slough is moderate in both depth and width.

Denverton Slough had the second-highest annual catch per unit effort of all sloughs in the marsh, while Nurse and Montezuma sloughs had relatively low values (Table 5). Because of their size, the lower catches in Montezuma and Nurse sloughs were partly due to a lower capture efficiency; however, this cannot solely explain the low numbers since lower Suisun Slough, which is comparable in size to Montezuma, had the highest annual catch per unit effort of any slough in the marsh. More than two-thirds of the catch from Montezuma and Denverton sloughs consisted of introduced species; native species made up about half of the catch in Nurse Slough (Table 5). Other than striped bass, white catfish and common carp were the most abundant introduced species and were especially abundant in Denverton Slough (Figure 35). A substantial proportion of the catch in Denverton and Nurse sloughs was comprised of splittail (figures 36 and 37). Denverton Slough was unique in that black crappie were relatively common, and pelagic planktivores (i.e., American shad and longfin smelt) were present in the catches.

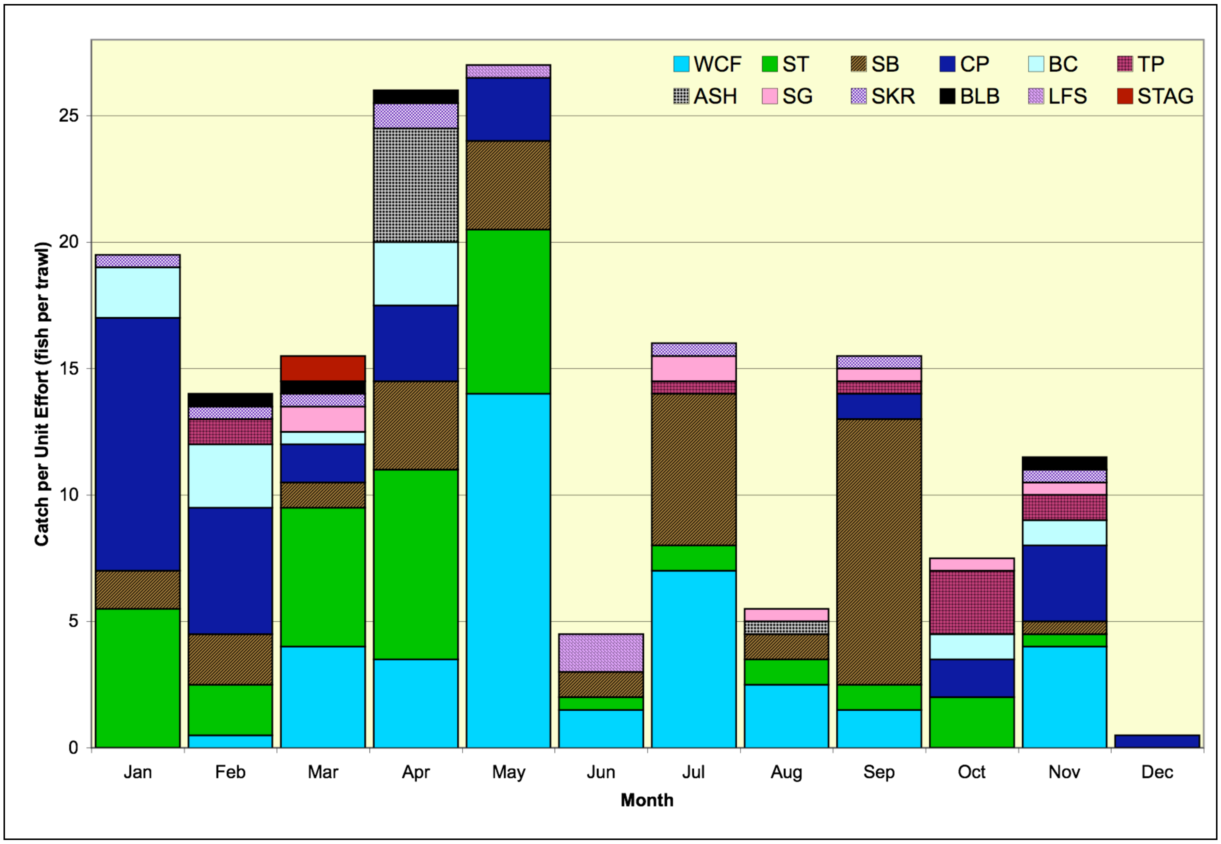

Figure 36. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Denverton Slough during 2008 (codes as in figures 29-32).

Consequently, the fish community in Denverton Slough was more diverse than in Montezuma or Nurse sloughs, which, though dominated by introduced species, consisted of fishes with quite different life histories and niches (e.g., longfin smelt, a migratory pelagic planktivore; common carp, a benthic omnivore that scatters eggs on vegetation; black crappie, a nest-building water-column predator).

The monthly catch pattern for species found throughout the eastern marsh was not the same among the three sloughs. White catfish were most commonly captured in Montezuma and Denverton sloughs during late spring and summer (figures 36 and 38), whereas they were most abundant in Nurse Slough during the first five months of the year (Figure 37). Splittail were most abundant during spring in Denverton Slough, during summer in Montezuma Slough, and during autumn in Nurse Slough. The highest catches of striped bass were made during summer in Denverton and Nurse sloughs, while the bulk of the striped bass were caught in Montezuma Slough in spring. Finally, most tule perch caught in Nurse and Denverton sloughs were captured in autumn or late winter, whereas most of the tule perch from Montezuma Slough were caught in spring. These catch patterns suggest that these fishes may be moving among the eastern sloughs through the seasons in response to factors other than the water-quality parameters we measure.

59% and 36% of the total black crappie and common carp catches, respectively, came from Denverton Slough. Interestingly, both species were abundant during January and February, April, and then in autumn (Figure 36). Relatively large catches of common carp were made in Boynton and Peytonia sloughs in January and during autumn (figures 31 and 32). The remaining 41% of the black crappie catch came form Boynton Slough, which were also most abundant

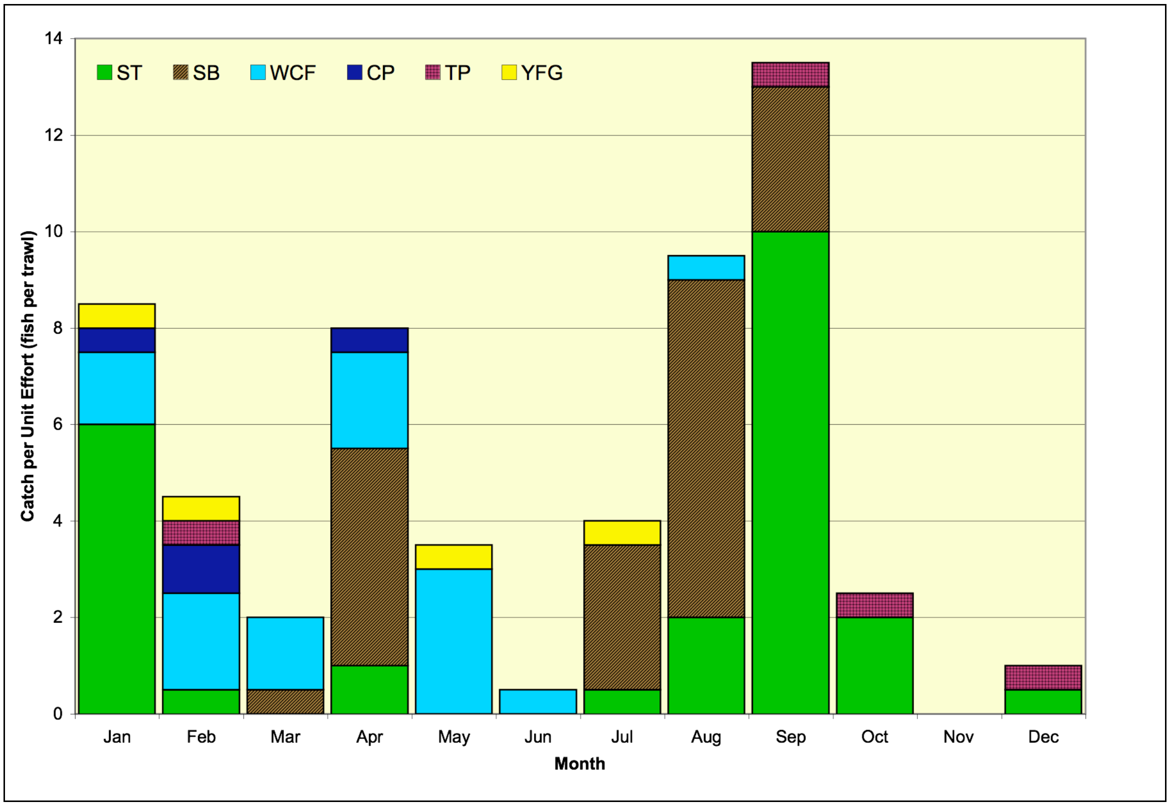

Figure 37. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Nurse Slough during 2008 (codes as in figures 29-31).

in January and during autumn (Figure 32). The majority of longfin smelt and American shad appeared in Denverton Slough during spring, coinciding with rapidly increasing salinities in the marsh and their presence in the lower Suisun Slough trawls. Thus, the pattern in the monthly catch for these species is mirrored elsewhere in the marsh.

CONCLUSIONS

In 2008, most fishes and the four most common macroinvertebrates declined in the otter trawl catches; midwater trawls also captured few fishes. However, beach seine catches increased for several fishes that decreased in the otter trawls. The effects of low river flows on reproduction contributed partially to the decline of several species (e.g., splittail, black crappie, white catfish). Additionally, the higher beach seine catches coupled with the low otter and midwater trawl catches for both fishes and macroinvertebrates suggests that pelagic food sources may have been limiting.

Otter trawl catches of POD fishes were low in 2008. When POD fishes were captured, they were usually in sloughs that provide abundant food and good water quality (i.e., lower

Suisun, Denverton, and First Mallard sloughs). With the exception of striped bass, POD fishes were very uncommon during summer. These results suggest that either few POD fishes were recruited into the marsh, or conditions within much of the marsh were less favorable for survival because of poorer water quality and reduced food supplies.

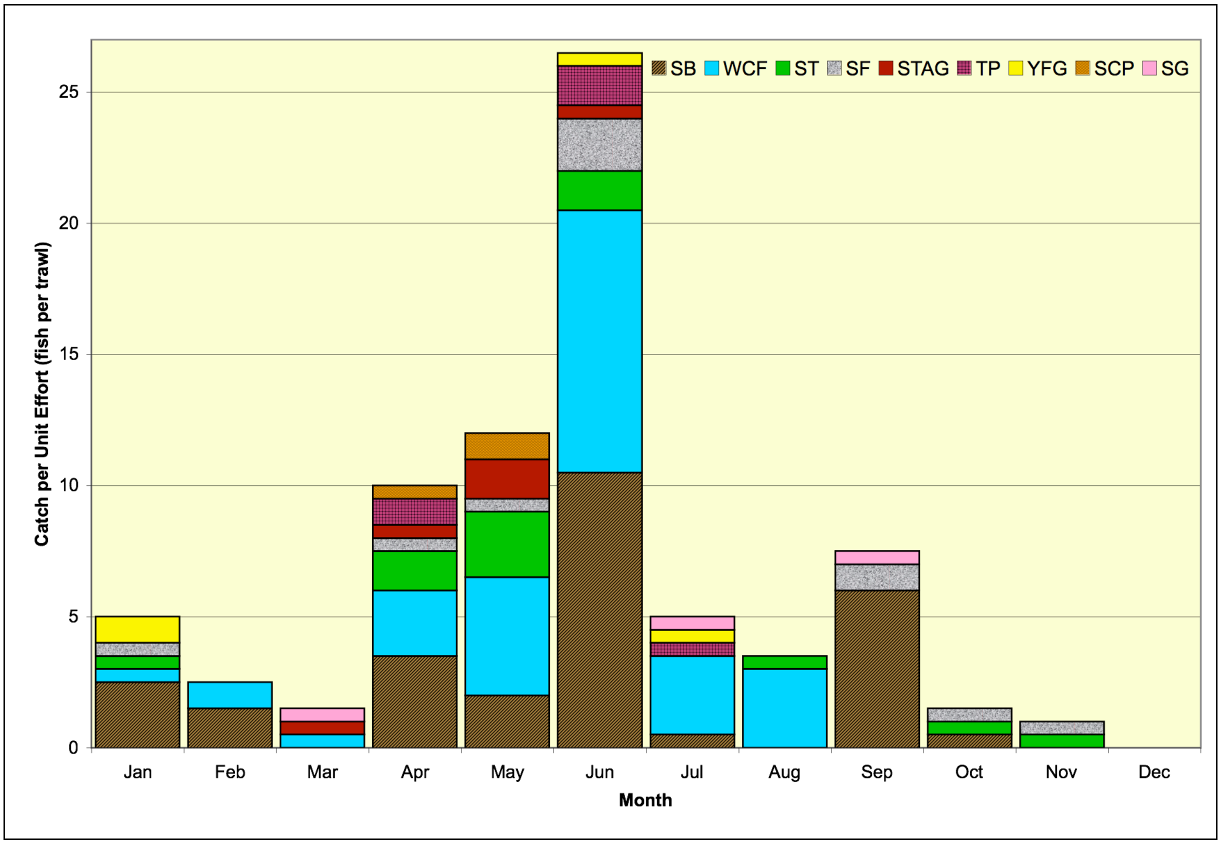

Figure 38. Monthly otter trawl catch per unit effort for the most common species (that made up 95% of the slough's total catch) in Montezuma Slough during 2008 (codes as in figures 29-31).

The factors structuring fish assemblages in different regions of the marsh appeared to be different. In the southwest marsh, the fish assemblage seemed controlled in part by the availability of food sources (mainly invertebrates) and higher salinities. Conversely, water-quality parameters - especially dissolved oxygen - contributed to the structure of the fish assemblages of the northwest marsh. The good water quality and abundant shallow-water habitat were probably partially responsible for the abundance of small fishes and tule perch found in the central marsh. Finally, abiotic factors seemed less important in structuring the eastern marsh's fish assemblages, implying that biotic interactions may play a stronger role in that region of the marsh.

The monthly catch pattern for several species (e.g., staghorn sculpin, common carp, POD species) appeared to be synchronized both within and among different regions of the marsh. This suggests that these species were responding to factors that were similar throughout the marsh for a given period. Species with pelagic larvae generally appeared in different regions of the marsh at the same time, indicating the importance of the timing and magnitude of river flows on these species' catch patterns. However, the monthly catch pattern for species (e.g., black bullhead, black crappie) whose catch was comprised of primarily subadult and adult fish seems less driven by river flows, implying a greater role in temperature or photoperiod on these species' patterns.

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.

Altinok, I., and J. M. Grizzle. 2001. Effects of brackish water on growth, feed conversion and energy absorption efficiency by juvenile euryhaline and freshwater stenohaline fishes. Journal of Fish Biology 59: 1142-1152.

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.

Borgeson, D. P., and G. W. McCammon. 1967. White catfish (*Ictalurus catus*) of the Sacramento-San Joaquin Delta. California Fish and Game 53: 254-263.

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.

Cech, Jr., J. J., S. J. Mitchell, D. T. Castleberry, and M. McEnroe. 1990. Distribution of California stream fishes: influence of environmental temperature and hypoxia. Environmental Biology of Fishes 29: 95-105.

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

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 24: 285-296.

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.

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

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

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.

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

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.

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

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

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

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

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.

Turner, J. L. 1966. Distribution and food habits of ictalurid fishes in the Sacramento-San Joaquin Delta. Pages 130-143 *in* J. L. Turner and D. W. Kelley, eds. Ecological Studies of the Sacramento-San Joaquin Delta, part 2. California Department of Fish and Game Fish Bulletin 136.

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.

Young, P. S., and J. J. Cech, Jr. 1996. Environmental tolerances and requirements of splittail. Transactions of the American Fisheries Society 125: 664-678.

APPENDIX A

Total number of fishes caught in Suisun Marsh by otter trawl, beach seine, midwater trawl, and all methods from 1979 to 2008.

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	All Gear Types
American shad	*Alosa sapidissima*	881	178		965
bay pipefish	*Sygnathus leptorhynchus*	2			2
bigscale logperch	*Percina macrolepida*	17	2		19
black bullhead	*Ameiurus melas*	848	3		698
black crappie	*Pomoxis nigromaculatus*	1776	79	1	1818
bluegill	*Lepomis macrochirus*	19	18		37
brown bullhead	*Ameiurus nebulosus*	28			28
California halibut	*Paralichthys californicus*	5			5
channel catfish	*Ictalurus punctatus*	164	6		167
Chinook salmon	*Oncorhynchus tshawytscha*	72	383	1	456
common carp	*Cyprinus carpio*	4570	393	1	4779
Delta smelt	*Hypomesus transpacificus*	621	135	4	756
fathead minnow	*Pimephales promelas*	26	29		55
golden shiner	*Notemigonus crysoleucas*	5	3		7
goldfish	*Carassius auratus*	277	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
largemouth bass	*Micropterus salmoides*		1		1
longfin smelt	*Spirinchus thaleichthys*	11170	32	5	11085
longjaw mudsucker	*Gillichthys mirabilis*	1			1
Mississippi silverside	*Menidia audens*	603	68053		64974
mosquitofish	*Gambusia affinis*	18	269		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*	9444	807	1	10189
rainbow trout	*Oncorhynchus mykiss*	7	4		11
rainwater killifish	*Lucania parva*	24	89		112
redear sunfish	*Lepomis microlophus*	2			2
Sacramento blackfish	*Orthodon macrolepidotus*	24	116		137
Sacramento pikeminnow	*Ptychocheilus grandis*	132	212		340
Sacramento sucker	*Catostomus occidentalis*	3017	95	5	3080
shimofuri goby	*Tridentiger bifasciatus*	8901	1785	1	10445

Common Name	Scientific Name	Otter Trawl	Beach Seine	Midwater Trawl	All Gear Types
shiner perch	*Cymatogaster aggregata*	17			17
shokihaze goby	*Tridentiger barbatus*	464	2	6	446
speckled sanddab	*Citharichthys stigmaeus*	3			3
splittail	*Pogonichthys macrolepidotus*	21268	2727	14	23323
staghorn sculpin	*Leptocottus armatus*	2266	3032		5015
starry flounder	*Platichthys stellatus*	1846	259	4	2080
striped bass	*Morone saxatilis*	75709	11628	30	85857
surf smelt	*Hypomesus pretiosus*	5			5
threadfin shad	*Dorosoma petenense*	2496	4894	1	7337
threespine stickleback	*Gasterosteus aculeatus*	16370	4184	6	20365
tule perch	*Hysterocarpus traski*	16953	1819	6	18564
wakasagi	*Hypomesus nipponensis*	10	6		16
warmouth	*Lepomis gulosus*	1			1
white catfish	*Ameiurus catus*	3747	104	13	3591
white crappie	*Pomoxis annularis*	112			112
white croaker	*Genyonemus lineatus*	1			1
white sturgeon	*Acipenser transmontanus*	104		2	98
yellowfin goby	*Acanthogobius flavimanus*	18512	15003		32878
Total		203429	116515	138	311526

APPENDIX B

Total 2008 otter trawl catch of each fish species in each slough of Suisun Marsh (slough codes as in Figure 22).

Species	Slough											Total
	BY	CO	DV	GY	LSU	MZ	MZN	NS	PT	SB	USU	
American shad	1		10	2	30	2		1	0	18	2	66
black crappie	13		19									32
Sacramento blackfish			3									3
black bullhead	65	1	4	2		2	1	1	70	3	4	153
channel catfish	1		2									3
Clupeidae unknown											1	1
common carp	25	8	56	8		1		4	33	19	3	157
Delta smelt					2					1		3
goldfish	4		1							2		7
golden shiner									1			1
Mississippi silverside		2	1	6				1		34		44
longfin smelt		2	4	2	105	2	2	1		1	3	122
mosquitofish				1								1
rainwater killifish				1								1
striped bass	23	26	61	90	198	54	12	36	91	42	91	724
prickly sculpin	5		1	3		3	3	1	27	2	1	46
starry flounder		1		1	1	11	2	2	2	2	6	28
shimofuri goby	13	7	8	5		3	1		14	19	2	72
shokihaze goby	1	1		2	3	1	1		5		12	26
Sacramento sucker	6	4	8			1			11	4	1	35
Sacramento pikeminnow			1	2								3
splittail	29	37	66	61	253	15	4	45	37	51	29	627
staghorn sculpin	12	4	2	5	13	6	1	1	8	21	8	81
threespine stickleback	5	1		126	17				3	7	4	163
threadfin shad	2	3		1	3		3		2	6		20
tule perch	2	51	11	11	43	6		4	22	20	12	182
unknown larvae										1		1
white catfish	22	5	77	1		50	1	22	38	7	48	271
white sturgeon			2			1	1				4	8
yellowfin goby	2	1	1	4	17	4		4	8	8	2	51
Total	231	154	338	334	685	162	32	123	372	268	233	2932

Total 2008 beach seine catch for each fish species in Denverton and upper Suisun sloughs.

Species	Denverton Slough	Upper Suisun Slough	Total
American shad	5	23	28
black crappie	6		6
common carp	7	21	28
Mississippi silverside	1135	2503	3638
largemouth bass	1		1
mosquitofish		1	1
striped bass	245	534	779
prickly sculpin	13	4	17
starry flounder		1	1
shimofuri goby	161	9	170
Sacramento pikeminnow		1	1
splittail	1	55	56
staghorn sculpin	28	174	202
threespine stickleback	11	21	32
threadfin shad	18	16	34
tule perch	16	16	32
white catfish		1	1
yellofin goby	161	425	586
Total	1808	3805	5613

Total 2008 midwater trawl catch for each species and slough (slough codes as in Figure 15).

Species	Slough				Total
	LSU	MZ	NS	USU	
Delta smelt		1			1
striped bass	1		2	4	7
Sacramento sucker				2	2
splittail				3	3
white catfish			1		1
Total	1	1	3	9	14

APPENDIX C

Number of otter trawls for each slough and each month in 2008.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Boynton	3	3	3	2	2	2	2	2	3	3	3	3	31
Cutoff	2	1	2	2	2	2	2	2	2	2	2	2	23
Denverton	2	2	2	2	2	2	2	2	2	2	2	2	24
First Mallard	2	2	2	2	2	2	2	2	2	2	2	2	24
Goodyear	3	3	3	3	3	3	3	3	3	3	3	3	36
Lower Suisun	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma	2	2	2	2	2	2	2	2	2	2	2	2	24
Montezuma New	2	2	2	0	0	0	0	0	2	2	2	2	14
Nurse	2	2	2	2	2	2	2	2	2	2	2	2	24
Peytonia	3	3	3	2	2	2	2	2	3	3	3	3	31
Upper Suisun	3	3	3	2	2	2	2	2	3	3	3	3	31
Total	26	25	26	21	21	21	21	21	26	26	26	26	286

Number of beach seine hauls for each slough and each month in 2008.

Slough	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Denverton	3	4	3	3	3	3	3	3	3	3	3	3	37
Upper Suisun	0	3	4	4	4	3	4	3	3	4	4	3	39
Total	3	7	7	7	7	6	7	6	6	7	7	6	76

Number of midwater trawls for each slough and each month in 2008.

Slough	Jun	Jul	Aug	Sep	Oct	Nov	Total
Lower Suisun	1	1	1	1	1	1	6
Montezuma	0	1	1	1	1	1	5
Nurse	0	1	1	1	1	1	5
Upper Suisun	1	0	0	0	1	1	3
Total	2	3	3	3	4	4	19