■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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OF INTEREST TO MANAGERS

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This issue contains the annual Status and Trends articles plus some interesting highlights from the Fish Conservation and Culture Lab and articles of management interest on splittail and white sturgeon. Similar to last year, several articles normally part of this issue will be published in the Summer or Fall Issues, including the 2009 water-year retrospective, and shrimps species trends… more fall-out from the furloughs. Nonetheless all authors worked diligently to meet deadlines.

In the "Highlights" section, **Kate Le and Andy Chu** reprise some good Delta outflow news with their outflow and export summary of first-quarter-2010. They describe a good outflow pulse in late January followed by lesser pulses in early and late February extending into early March. Good flow timing for longfin smelt and some of the salmon migrants.

The second Highlights article provides an update from the Fish Conservation and Culture Lab by **Theresa Rettinghouse** who describes their endeavors to produce delta smelt for research, to develop and maintain a delta smelt refugial population, and to take on the additional challenge of developing culture methods for longfin smelt. Good news on all tasks.

The splittail is on the minds of some managers as its federal status review moves toward completion this fall. One concern -- the status of the Petaluma River stock after several very dry years -- was allayed somewhat in the third Highlights article by **Ted Sommer, Kevin Reece, Fred Feyrer, Randy Baxter and Melinda Baerwald**. These authors found at least 2 year-classes of splittail thriving in the Petaluma River Estuary during sampling earlier this year. Genetic analysis confirmed that the fish caught were part of the genetically distinct population previously identified from the Petaluma River.

The first Status and Trends article, on the phytoplankton community in 2008, begs comparison to the 2008 outflow information published in last year's spring issue. **Tiffany Brown** presents regional monthly phytoplankton abundance trends. Her results continue to show an almost estuary-wide shift in composition from diatoms to flagellates. This shift undoubtedly affected zooplankton species composition and numbers, but we're still developing diet and feeding information to describe these effects.

Heather Fuller provides a succinct update on 2009 benthic monitoring. Although she provides primarily a 'top 10 list' with some habitat and distribution discussion, it's still important to know the major players (critters) at each level. As expected the Asian clams *Corbula amurensis* and *Corbicula fluminea* made the list.

Moving higher in the water column and the food web, copepods and mysid shrimp comprise important foods for young fishes, and for delta smelt throughout its life. **April Hennessy** describes mixed responses in copepod and mysid abundance trends in 2009. Abundance decreased for important spring copepods *Eurytemora* and *Sinocalanus*, though *Sinocalanus* density remained relatively high. *Pseudodiaptomus*, a summer dominant copepod, also declined. The brackish water copepods, *Acartia* and *Acartiella*, were again abundant in the upper estuary as a result of low outflows. Mysid shrimp become an important food source for longfin smelt beginning in late spring and for striped bass in summer. The dominant upper estuary mysid shrimp, *Hyperacanthomysis longirostris,* declined sharply in spring and summer 2009. Her results suggest a stable or slightly declining feeding environment in spring 2009 but possibly a tougher situation later in the year for fishes eating mysids like young striped bass and longfin smelt.

Suisun Marsh is an important region within the upper estuary, often providing improved feeding opportunities and nursery when compared with nearby open water areas. **TeeJay O'Rear** provides an extensive update on invertebrate and fish trends in the Marsh up through 2009. He then focuses in more detail on the patterns of outflows and food resources in 2008 and 2009, and how these might have influenced fish responses.

Ten years ago the Chinese mitten crab was a substantial problem for fish salvage operations in the fall. Now none have been reported for at least 3 years notes Kathryn Hieb in her crab update. Also, an upswing in juvenile Dungeness crabs in the bay bodes well for the coastal fishery in another 2-3 yeas. Upper and lower estuary fishes continue to exhibit very different abundance responses. **Jennifer Messineo, Maxfield Fish, Dave Contreras, Kathryn Hieb and Virginia Afentoulis** provide 2009 abundance trend information derived from 5 long-term fish surveys. Of significant management concern is the continued very low abundance of the 4 Pelagic Organism Decline fish species: delta smelt, longfin smelt, age-0 striped bass and threadfin shad. Juvenile American shad declined to record lows and splittail abundance was at or near zero for trawl indices, though modest recruitment of 2009 splittail year-class was evident in the US Fish and Wildlife Service beach seine survey. Once again lower estuary bottom-oriented species and some pelagic species generally responded favorably (except northern anchovy), particularly those considered part of the Pacific northwest fauna, like Pacific herring, Pacific staghorn sculpin, and English sole.

During the water export process, some entrained fishes are diverted from the export flow and "salvaged" to be returned to the western Delta. Trends in salvaged fishes provide additional insight into Delta fish abundance, particularly for fishes that reproduce in, rear in, or migrate through the south Delta, such as threadfin shad, splittail and Chinook salmon from the San Joaquin River. **Geir Aasen** updates annual salvage trends through 2009 for 7 fishes of management concern: juvenile Chinook salmon, juvenile steelhead, juvenile striped bass, delta smelt, longfin smelt, splittail, and threadfin shad. In most cases, low salvage in 2009 was also reflected in low species abundance elsewhere in the estuary. Of particular note was the near record low salvage of threadfin shad and the continued low numbers of splittail in salvage even though they were mostly not detected by the trawl surveys.

Management of white sturgeon has been an ongoing concern for the Department of Fish and Game. First maturity late in life and highly episodic spawning creates a white sturgeon fishery often supported by one or a few year-classes, and one in which small changes in fishing mortality can have big effects on the population. To better understand white sturgeon recruitment, **Max Fish** developed an index of year-class strength using San Francisco Bay Study juvenile data, and then explored how the timing of river flow influenced sturgeon recruitment.

IEP QUARTERLY HIGHLIGHTS

DELTA WATER PROJECT OPERATIONS(January through March 2010)

Kate Le and Andy Chu, DWR

Inflows into the Delta from Sacramento and San Joaquin Rivers generally follow the precipitation pattern in these winter months (January to March). Overall, these primary water-producing months have done well enough to garner a near-average water year type so far into the season. As shown in Figure 1, San Joaquin River (SJR) average daily flow ranged between 33 and 139 cubic meters per second (1,178 cfs and 4894 cfs). Sacramento River daily average flow ranged between 261 and 1573 cubic meters per second (9238 cfs to 55,556 cfs). Daily Net Delta Outflow Index (NDOI) ranged between 162 and 1,687 cubic meters per second (5735 cfs and 59,576 cfs).

State Water Resources Control Board Bay-Delta Standards in D-1641 (see Figure 2) continues to be the primary regulatory constraint for the Projects' operations in the Delta during the January through March 2010 period. Minimum monthly outflow of 127 cubic meters per second (4,500 cfs) and the 7-day average outflow of 99 cubic meters per second (3,500 cfs) were required for January. Starting in February, the habitat protection outflows, X2, were required to be met for 28 days in February and the entire month of March at Chipps Island. Alternatively, the X2 requirements at Chipps Island can also be met with a three-day average outflow of 323 cubic meters per second (11,400 cfs). Other flow and water quality standards listed in Figur 2 to be noted were Export to Inflow ratio transition from 65% to 35% in February and the Vernalis base flow requirements in February and March.

In addition, pumping between the two Projects were also controlled by latest U.S. Fish and Wildlife Service and National Marine and Fisheries Service's Biological Opinions for fishery protections, along with CA Department of Fish and Game's Incidental Take Permit No. 2081. No significant plant maintenance activities or power outages occurred during these months except some limitations due to fish screen repair during early part of January as illustrated in Figure 3.

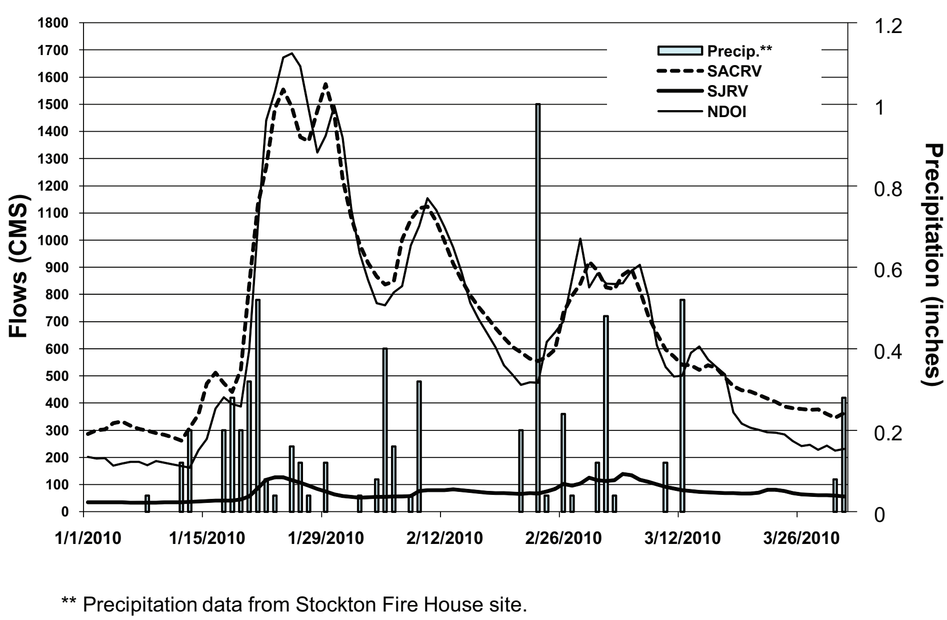

Figure 1 January through March 2010 Sacramento River, San Joaquin River, Net Delta Outflow Index, and Stockton Fire Station Precipitation.

DRAFT **Bay-Delta Standards** DRAFT

Contained in D-1641

CRITERIA	Jan 10	Feb 10	Mar 10
FLOW/OPERATIONAL			
• Fish and Wildlife			
SWP/CVP Export Limits			
Export/Inflow Ratio	65%	35%	35%
Minimum Outflow - mon.	4500 cfs		
- 7 day ave.	3500 cfs		
Striped Bass Survival			
Suisun Marsh			
Habitat Protection Outflow, X2		7,100 - 29,200 cfs or X2 days	
River Flows:		28 days at Chipps	31 days at Chipps
@ Rio Vista - min. mon. avg.			
@ Vernalis: Base -min. mon. avg.		2280 cfs	2280 cfs
- 7 day average		1824 cfs	1824 cfs
Pulse objective			
Delta Cross Channel Gates	Nov.-Jan. may be closed up to a total of 45 days	Closed	
WATER QUALITY STANDARDS			
• Municipal and Industrial			
All Export Locations		250 mg/l Chlorides	
Contra Costa Canal		Cl <= 150 mg/l for 165 days	
• Agriculture			
Western/Interior Delta			
Southern Delta		30 day running avg EC <= 1.0 mS/cm	
• Fish and Wildlife			
San Joaquin River Salinity			
Suisun Marsh Salinity		15.6 mS/cm	

Water Year Classification: (Apr 1 Forecast) -- Previous Month's Index (8RI for MAR): 2.33 MAF
SVI (40-30-30 @ 50%) = 6.2 (Dry)
SJV (60-20-20 @75%) = 2.9 (Below Normal)

Figure 2 January through March 2010 Bay-Delta Standards of D-1641.

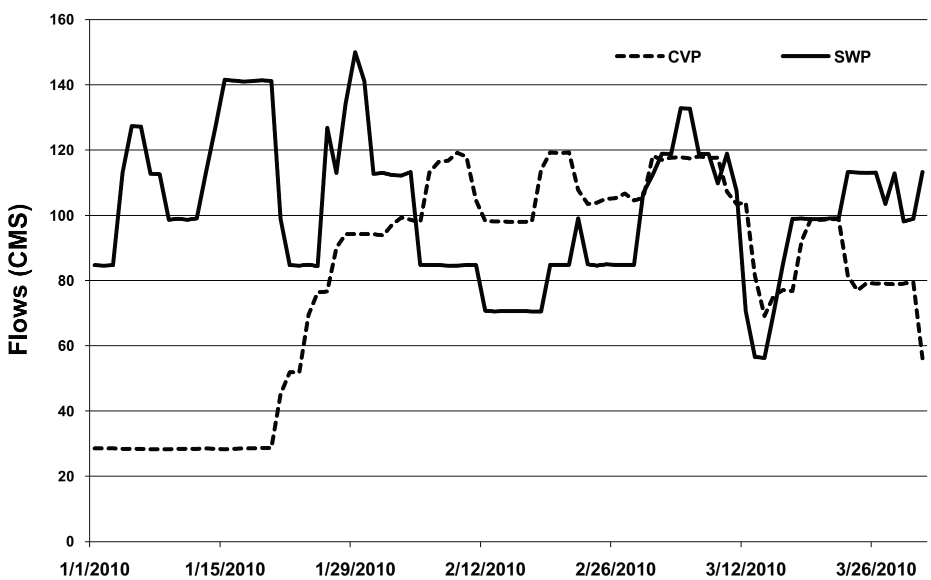

Figure 3 January through March 2010 State Water Project and Central Valley Project Pumping.

Fish Conservation and Culture Lab (FCCL), Spring 2010

Theresa Rettinghouse (UC, Davis), trettinghouse@ucdavis.edu

In 2009, Fish Conservation and Culture Lab of UC, Davis cultured delta smelt (*Hypomesus transpacificus*) of all life stages to provide over 88,000 smelt to seven academic and Federal research projects (Table 1). The FCCL works in tight collaboration with UC-Davis fish geneticists (K. Fisch & B. May) to develop a new delta smelt refugial population on site and a back-up population is maintained by the U.S. Fish & Wildlife Service (USFWS) at the Livingston Stone National Fish Hatchery (LSNFH), Shasta Lake, CA. (IEP Vol.22, #3, Summer /Fall 2009). In addition, we have begun to develop culture methodologies for longfin smelt (*Spirinchus thaleichthys*) at the FCCL.

In 2009 we were allowed a maximum take of 100 wild delta smelt and 50 longfin smelt. We collected 52 sub-adult delta smelt in 5 sets using a lampara net in the lower Sacramento River, in the early morning (0715-0915 hr) of December 2nd. Average water temperature was 10.5°C and salinity ranged between 1.1-1.8 parts per thousand (ppt) (Table 2). After 72 hours, survival was 73%, leaving only 38 delta smelt on-site (Table 3). We returned to the river on December 9th (0713-0930 hr) and caught 23 more sub-adult delta smelt, along with two longfin smelt in 6 sets; average water temperature was 8.9°C and salinity ranged between 1.0-1.7 ppt.. In the later sunny- morning (1049-1215 hr) we set the net 4 more times and caught one longfin smelt at 9.8°C in 1.5 ppt salinity (Table 2).

The refugial population is supplemented with wild fish to maintain genetic diversity and minimize genetic drift. The 3 longfin smelt collected by our lab, and 15 longfin collected by USFWS Chipps Island Trawl crew were artificially spawned. We are summarizing results from early life-stage rearing trials and the oldest 10 larvae cultured survived to 123-132 days post hatch.

Table 1 Cultured delta smelt provided in 2009 by the Fish Conservation and Culture Lab of UC Davis.

Research project type	Agency - Primary contact	Eggs	Larvae <20mm	Juveniles 20-50mm	Adults >50mm cultured 2008	Adults >50mm cultured 2009	Fish totals
Mark-recapture study	USFWS- Castillo			18054	10230		28284
Strontium tagging verification	UCD -Hobbs		181	3108			3289
Toxicity testing & exposures	UCD - Werner		6529	2240	30		8799
Feeding behavior of larvae	SFSU- Sullivan		9947				9947
Refugia-backup population	LSNFH - Rueth				1810	1501	3311
Largemouth predation study	UCD - Conrad				1800		1800
Fish screen efficiency	USBR - TFCF			695	32053		32748
Totals		0	16657	24097	45923	1501	88178

Abbreviations:
USFWS: US Fish and Wildlife Service; UCD: University of California, Davis
SFSU:San Francisco State University; LSNFH: Livingston Stone National Fish Hatchery
USBR: US Bureau of Reclamation; TFCF: Tracy fish collection facility

Table 2 Location and conditions for collection of delta and longfin smelt.

Date	Set	Temperature (^{o}C)	Conductivity (ECo)	Salinity (parts per thousand)	Number of delta smelt and (longfin smelt)
12/2/2009	1	10.7	2403/3273	1.8	1
12/2/2009	2	10.4	1827/2426	1.3	6
12/2/2009	3	10.4	1940/2698	1.4	10
12/2/2009	4	10.5	1480/2026	1.1	22
12/2/2009	5	10.6	1716/2372	1.2	13
12/9/2009	1	9.2	2142/3075	1.6	0
12/9/2009	2	9.2	2190/3212	1.7	4, (1 ripe female longfin smelt)
12/9/2009	3	9.1	2734/3590	1.7	7
12/9/2009	4	8.7	2066/2817	1.5	0
12/9/2009	5	9	1900/2677	1.5	0, (1 longfin smelt)
12/9/2009	6	8.4	1128/1700	1.0	12
12/9/2009	1	9.6	3965/5151	3.1	0
12/9/2009	2	9.6	2763/3828	2.1	0
12/9/2009	3	9.8	2275/3126	1.5	(1 ripe male longfin smelt)
12/9/2009	4	9.8	2648/2900	1.5	0
				Total fish	75, (3 longfin)

Location: Sacramento River in northern California, below Rio Vista, across from Sherman Island.
Weather: 12/2/10 fog & breezy; 12/9/10 early am - sunny and slightly overcast, calm to light breeze; 12/9/10 late am - sunny and breezy.

Table 3 2009 Wild delta smelt collection, survival, and size estimate.

	12/2/09	12/9/09	Average survival at 72 hours	Average fork length (mm) of mortalities 12/2 -12/10/09 (n=17)	Average weight (g) of mortalities 12/2-12/10/09 (n=17)
Total collected	52	23			
Number live at 72 hours	38	20	58 (77%)	56	1.52

Splittail Persistence in the Petaluma River

Ted Sommer and Kevin Reece (DWR),Fred Feyrer(USBR),Randy Baxter(DFG), Melinda Baerwald (UC Davis), tsommer@water.ca.gov

Introduction

Splittail (*Pogonichthys macrolepidotus)* is a large native minnow found only in the San Francisco Estuary (Moyle et al. 2004; Sommer et al. 2007). The distribution for much of the year is focused in the Delta and Suisun Bay, but adults undergo annual migrations to floodplain spawning habitat during winter. Splittail are also known to occur in the Napa and Petaluma rivers, two tributaries to San Pablo Bay. One of the more surprising recent findings is that Baerwald et al. (2007) determined that splittail from the Napa and Petaluma Rivers showed evidence of genetic differentiation from the Central Valley population. These results suggest some level of population structuring in the species.

Feyrer et al. (In press) provide a possible mechanism for this difference--the apparent ability of age-0 splittail to rear in brackish water almost immediately after being born may be one of the fundamental mechanisms supporting splittail production in the Napa and Petaluma rivers. However, splittail do not tolerate salinities > 23 ppt (Young and Cech 1996), which often occur between the outlets of these two tributaries in San Pablo Bay and the upstream population of splittail in Suisun Bay and the Delta. Hence, it is possible that seawater creates an isolating barrier between the Bay tributary and Central Valley populations of splittail. This barrier is "broken" during high flow periods when salinities drop throughout the upper estuary, but the typical geographical separation may be sufficient to maintain population structuring.

The discovery of genetically distinct splittail in the Napa and Petaluma rivers is of particular interest to U.S. Fish and Wildlife Service (2010), who are revaluating whether the species deserves listing status. Splittail had previously been a focus of listing actions (Sommer et al. 2007), and the new genetic evidence provided additional motivation to the USFWS to reconsider the status of the species.

We were interested in whether splittail were still present in the Petaluma River. To our knowledge, the Petaluma River had not seen targeted sampling for splittail since 2003, when Feyrer et al. (2005) conducted surveys. While Napa River was also of interest, we chose not to sample that tributary because rotary screw trapping has been initiated there by a local water district and could provide splittail information in the future.

Methods

We conducted a brief survey of the Petaluma River in the same general areas sampled by Feyrer et al. (2005). We chose June 1, 2010 for the survey, when we expected splittail would show peak abundance of young-of-the-year and sufficient size to be easily distinguishable in the field. Sampling was done on an incoming tide, so beaches were available, with a 50 foot beach seine at three sites—a large open-water mudflat and two small tidal channels.

Fin clips or whole fish samples were also collected for DNA analyses to examine the genetic composition of these fish (Baerwald et al. 2007). Microsatellite markers were used to assign individuals to either the Petaluma/Napa or the Central Valley population using the methods detailed in Baerwald et al. (2008).

Results and Discussion

The study sites had fairly consistent electrical conductivities (12,079-12,170; or about 6.8-7.0 ppt) and relatively warm temperatures (20.9-22.4°C). The survey captured thirteen splittail at two of the three sites. This compares well with previous surveys in the Petaluma River, where splittail were captured in one third of the beach seine hauls (Feyrer et al. 2005). The splittail collected ranged in size from 39 to 205 mm FL. Surprisingly, half of the fish were age-1 (e.g. >100 mm FL). Hence, it appears that splittail successfully spawned in 2010, a relatively wet year, and in 2009, a critically dry year.

All ten splittail that were genetically analyzed assigned to the Petaluma/Napa population. These individuals encompassed both young-of-year and age-1 life stages and provide further evidence of the continued persistence of this genetically distinct population in the Petaluma River.

The bottom line is that splittail appear to be alive and well in the Petaluma River. We hope that there will be additional opportunities to study this unique native fish and conduct fish surveys in the Petaluma River.

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STATUS AND TRENDS

2008 Phytoplankton Community Composition

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Introduction

The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton samples to monitor algal community composition at selected sites in the upper San Francisco Estuary (Estuary) as part of the Environmental Monitoring Program (EMP). The 13 sampling sites range from San Pablo Bay east into the lower the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Delta to broad, estuarine bays. This article describes the results of these monitoring efforts for calendar year 2008.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes which influence water quality in the Estuary. Phytoplankton are small, free-floating organisms that occur as unicellular, colonial or filamentous forms (Horne and Goldman 1994). Phytoplankton can affect pH, dissolved oxygen, color, taste and odor, and under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illness (Carmichael 1981). In freshwater, the cyanobacteria, or blue-green algae (class Cyanophyceae), are responsible for producing toxic blooms, particularly in waters that are enriched with phosphates (van den Hoek et al. 1995).

In addition to being an important food source for zooplankton, invertebrates, and some species of fish, phytoplankton species assemblages can be useful in assessing water quality (Gannon and Stemberger 1978). Due to their short life cycles, phytoplankton respond quickly to environmental changes; hence their standing crop and species composition are indicative of the quality of the water mass in which they are found (APHA 1998). However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with physiochemical and other biological data (APHA 1998).

Methods

Phytoplankton samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 1). Samples were collected using a submersible pump from 1 meter below the water's surface. The samples were stored in 50-milliliter glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed. Phytoplankton identification and enumeration were performed by EcoAnalysts, Inc. according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA 1998). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 12 hours. The aliquot volume, normally 10-20 mL, was adjusted according to the algal population density and turbidity of the sample. Aliquots are enumerated at a magnification of 630X using a Leica DMIL inverted microscope. For each settled aliquot, phytoplankton in randomly chosen transects were counted. Taxa were enumerated as they appeared along the transects. A minimum of 400 total algal units were counted, and a minimum of 100 algal units of the dominant taxon. For taxa that were in filaments or colonies, the number of cells per filament or colony was recorded. Organism counts for each sample were converted to organisms/mL using the following formula:

Organisms = *(C x Ac) / (V x Af x F)*
where:

Organisms = Number of organisms (#/mL)
C = Count obtained
Ac = Area of cell bottom (mm^2)
Af = Area of each grid field (mm^2)
F = Number of fields examined (#)
V = Volume settled (mL)

This simplifies to:

Organisms = C / cV
where:

cV = Counted volume (mL)

(Note: cV = Ac / (V x Af x F))

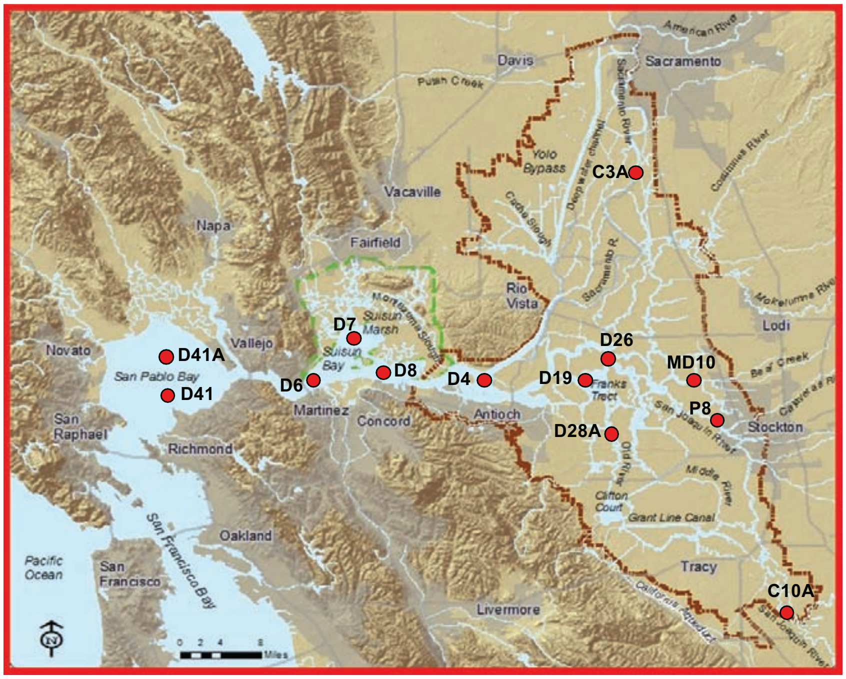

Figure 1 Map of Environmental Monitoring Program discrete phytoplankton stations.

Stations were grouped into regions based on location (Figure 1); one station north of Rio Vista was labeled "North Delta," and one station south of Tracy was labeled "South Delta." Stations east of Antioch, but west of Stockton were called "Central Delta." A single station at the confluence of the Sacramento and San Joaquin Rivers was called "Confluence." Stations west of the confluence, but east of Carquinez Strait were labeled as "Suisun Bay," and stations west of Carquinez Strait were labeled "San Pablo Bay." For each region, yearly totals for each algal group were obtained by summing the 2008 organisms per mL for all stations in that region. Monthly totals for each region were obtained by summing the monthly organisms per mL for all stations in that region for that particular month.

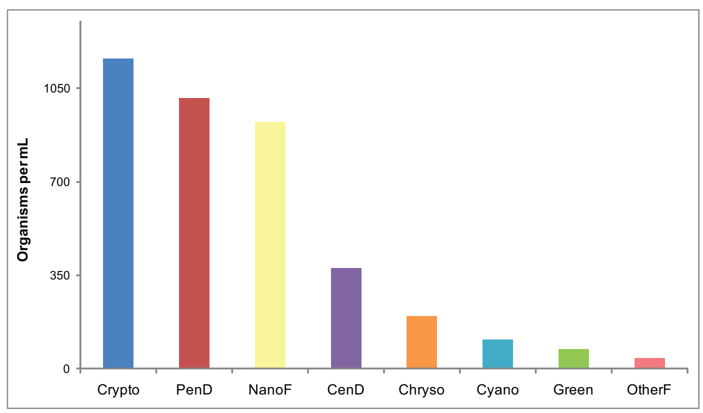

Figure 2 Total 2008 north Delta (C3A) phytoplankton by group. Abbreviations are as follows for all graphs: CenD = centric diatoms; PenD = pennate diatoms; Crypto = cryptomonads; Green = green algae; NanoF = nanoflagellates; Chryso = chrysophytes; Cyano = cyanobacteria; OtherF = other flagellates.

Results

North Delta (C3A)

This station was dominated by cryptomonads, pennate diatoms, and nanoflagellates in 2008 (Figure 2), mainly due to bloom events in the summer and fall (Figure 3). There was a bloom of centric diatoms in April (Figure 3). Other groups of phytoplankton were sparse throughout the year, never exceeding 50 organisms per mL (Figure 3)

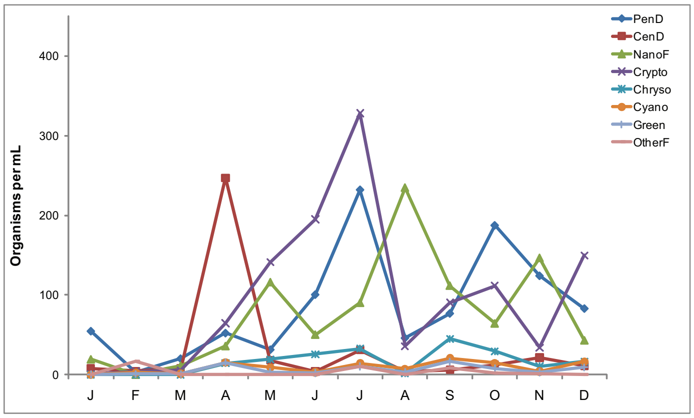

Figure 3 North Delta (C3A) phytoplankton by month, 2008.

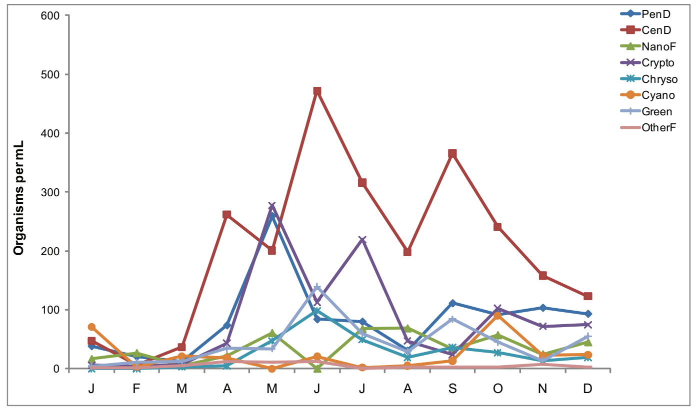

Figure 5 South Delta (C10A) phytoplankton by month, 2008.

South Delta (C10A)

The south Delta was dominated by centric diatoms for most of the year (Figures 4 and 5); pennate diatoms and cryptomonads also made large contributions during the spring and summer months. Other phytoplankton were generally in low numbers much of the year, with occasional small peaks (Figures 4 and 5).

Central Delta (D19, D26, D28A, MD10A, P8)

The central Delta was dominated by nanoflagellates and cryptomonads for most of the year (Figures 6 and 7). Centric and pennate diatoms also had occasional blooms, and there was a large bloom of cyanobacteria in October (Figure 7). Other types of phytoplankton contributed less, although their concentrations tended to be higher than at the north or south Delta stations (Figures 6 and 7).

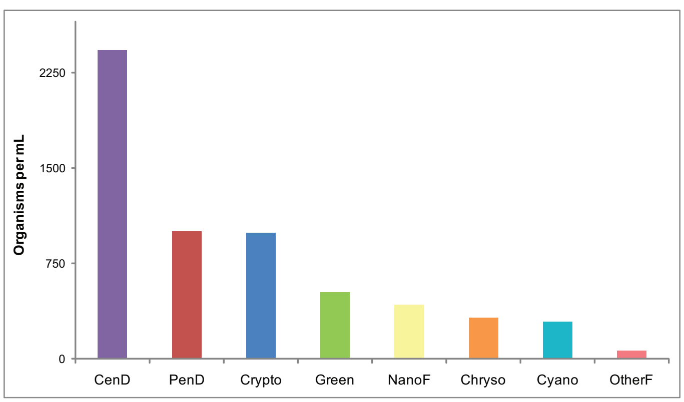

Figure 4 Total 2008 south Delta (C10A) phytoplankton by group.

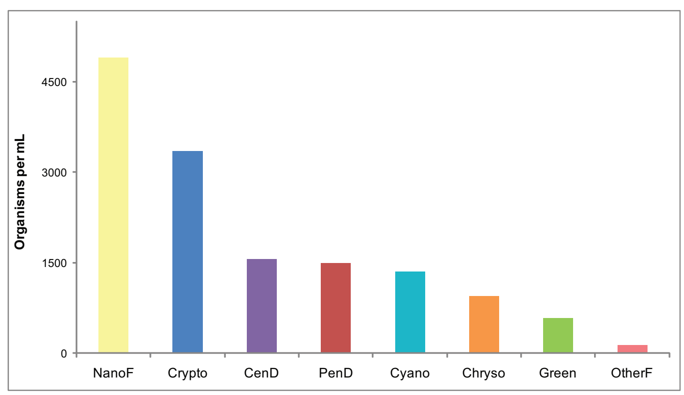

Figure 6 Total 2008 central Delta (D19, D26, D28A, MD10A, P8) phytoplankton by group.

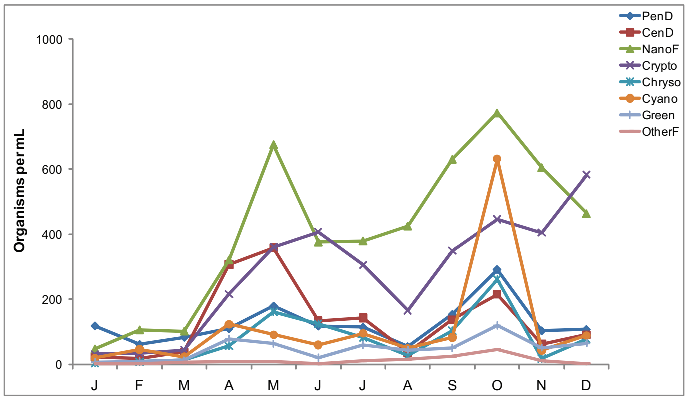

Figure 7 Central Delta (D19, D26, D28A, MD10A, P8) phytoplankton by month, 2008.

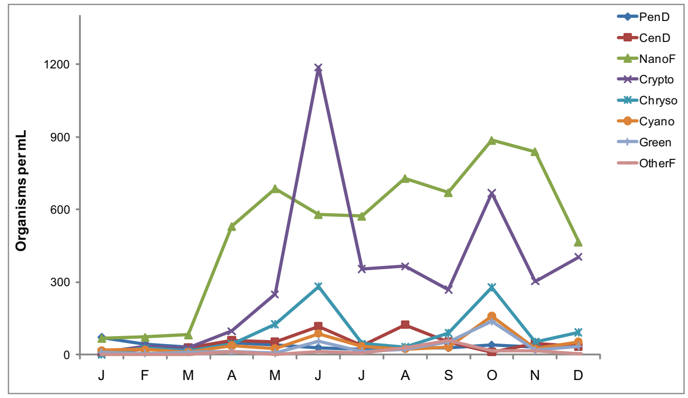

Figure 9 Confluence (D4) and Suisun Bay (D6, D7, D8) phytoplankton by month, 2008.

Confluence (D4) and Suisun Bay (D6, D7, D8)

The confluence of the Sacramento-San Joaquin rivers, and the Suisun Bay region, were heavily dominated by nanoflagellates and cryptomonads nearly all year (Figures 8 and 9). Other phytoplankton were minor in comparison, although there were blooms of chrysophytes in June and October (Figure 9).

San Pablo Bay (D41, D41A)

Like the confluence and Suisun Bay, San Pablo Bay was dominated by nanoflagellates and cryptomonads most of the year (Figures 10 and 11). Other types of phytoplankton made only minor contributions, although there was a small peak in centric diatoms and chrysophytes in October (Figure 11).

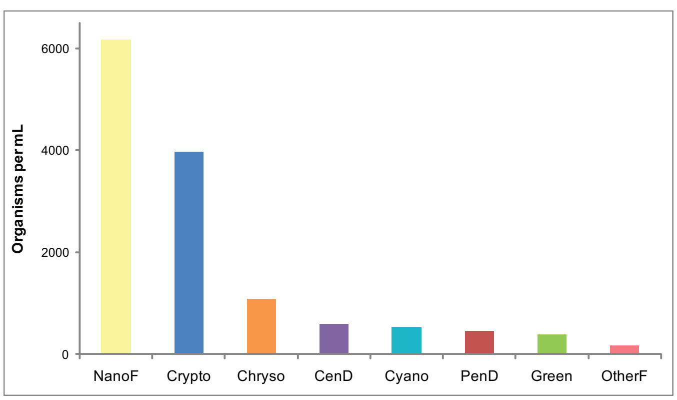

Figure 8 Total 2008 confluence (D4) and Suisun Bay (D6, D7, D8) phytoplankton by group.

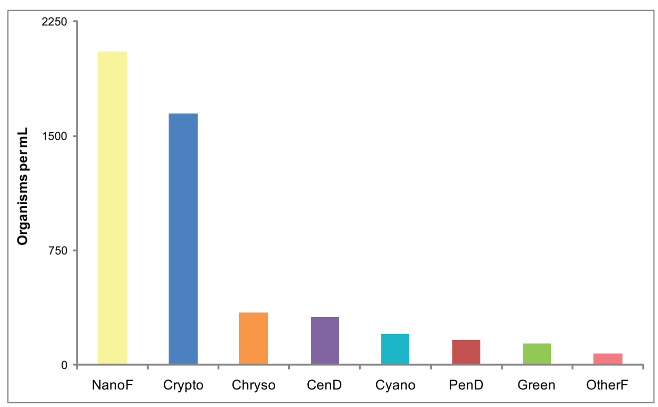

Figure 10 Total 2008 San Pablo Bay (D41, D41A) phytoplankton by group.

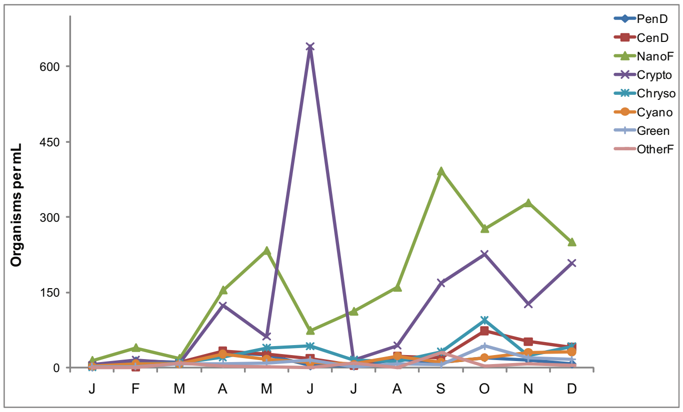

Figure 11 San Pablo Bay (D41, D41A) phytoplankton by month, 2008.

Summary

Most regions of the Estuary were dominated by flagellate taxa (nanoflagellates and cryptomonads) in 2008. The south Delta (C10A) was the only exception, being dominated by centric diatoms instead. Recently there has been an almost estuary-wide shift from a diatom-dominated community to a flagellate-dominated one (Lehman 1998; Lehman 2000a, b; Brown 2010); phytoplankton monitoring by the EMP confirms that this trend has continued through 2008 in most parts of the estuary.

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Benthic Monitoring, 2009

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The benthic monitoring component of the Interagency Ecological Program's Environmental Monitoring Program (EMP) documents changes in the composition, abundance, density, and distribution of the macrobenthic biota within the upper San Francisco Estuary. Benthic species are relatively long-lived and respond to changes in physical factors within the system such as freshwater inflows, salinity, and substrate composition. As a result, benthic data can provide an indication of physical changes occurring within the estuary. Because operation of the State Water Project can impact the flow characteristics of the estuary and subsequently influence the density and distribution of benthic biota, benthic monitoring is an important component of the EMP. The benthic monitoring data are also used to detect and document the presence of species newly introduced into the estuary.

Benthic monitoring was conducted at 10 sampling sites distributed throughout the major habitat types within the estuary from San Pablo Bay through the delta (Figure 1). Environmental Monitoring Program staff collected 4 bottom-grab samples and 1 sediment sample monthly at all sites. Samples were analyzed by Hydrozoology, a private laboratory under contract with the Department of Water Resources (DWR), and all organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at DWR' Soils and Concrete Laboratory. Field collection methodology and laboratory analysis of benthic macroinvertebrates and sediment composition are described in detail in the benthic metadata found at http://www.water.ca.gov/bdma/meta/benthic.cfm .

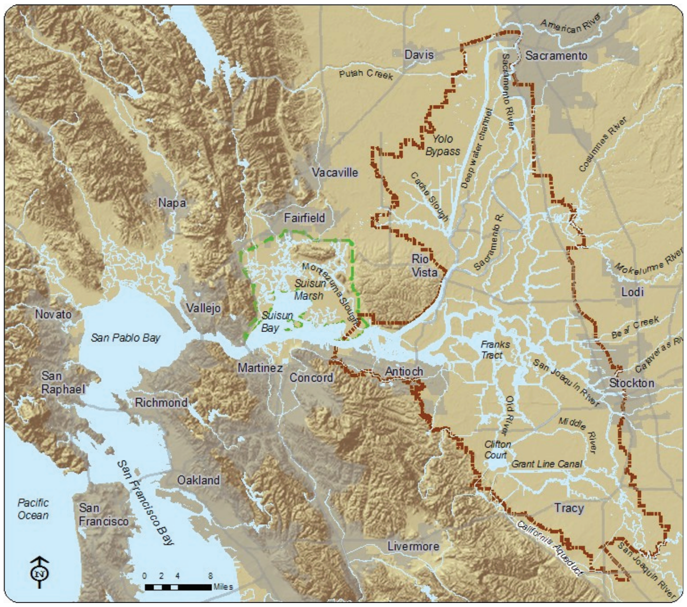

Figure 1 Locations of the Environmental Monitoring Program's benthic monitoring stations.

As a result of the geographically diverse sampling regime, 4 new species were added to the benthic species list in 2009. These species were not necessarily new to the upper San Francisco Estuary; they were merely new to the benthic monitoring component of the EMP. The new species and the locations at which they were collected are listed in Table 1.

The benthic component of the EMP collects a large number of organisms, but relatively few different species. Of the 177 total species collected in 2009, 10 represented approximately 80% of all organisms collected (n = 223,518). These 10 species included: (1) The amphipods *Ampelisca abdita*, *Americorophium spinicorne*, *Americorophium stimpsoni*, C*orophium alienense*, and *Gammarus daiberi*; (2) the Sabellidae polychaete *Manayunkia speciosa*; (3) the Tubificidae worms *Limnodrilus hoffmeisteri* and *Varichaetadrilus angustipenis*; and (4) the Asian clams *Corbula amurensis* and *Corbicula fluminea.*

Of the 10 dominant species listed above, *Corbula amurensis and Ampelisca abdita* represent macrofauna that inhabit an environment with typically higher salinity, in San Pablo Bay, Suisun Bay, and Grizzly Bay (D7). *Corophium alienense, Americorophium stimpsoni, and Americorophium spinicorne* tolerate a wider range of salinity. They were collected both in the higher saline western sites and the more brackish water to freshwater eastern sites, including the San Joaquin River at Twitchell Island (D16) and the Sacramento River above Point Sacramento (D4). The remaining 5 species – *Gammarus daiberi, Manayunkia speciosa, Limnodrilus hoffmeisteri, Varichaetadrilus angustipenis* and *Corbicula fluminea* – are predominantly freshwater species and were collected at sites east of Suisun Bay.

Table 1 Location, collection month, and lowest taxonomic identification of taxa collected for the first time in 2009 by the benthic monitoring component of the Environmental Monitoring Program.

Site Name	Location	Month(s) Collected	Family	Genus	Species	Common Name
D41	San Pablo Bay near Pinole Point	September	Syllidae	*Exogone*	*lourei*	polychaete
D41	San Pablo Bay near Pinole Point	August, September, November, December	Calyptraeidae	*Crepidula*	*plana*	gastropod
D41	San Pablo Bay near Pinole Point	November	Tubificidae	*Tectidrilus*	*diversus*	oligochaete
C9	Clifton Court Forebay intake	November	Ceratopogonidae	*Probezzia*	sp. A	diptera

Zooplankton Monitoring 2009

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Introduction

The Zooplankton Study has estimated the abundance of zooplankton taxa in the upper San Francisco Estuary, from eastern San Pablo Bay through the eastern Sacramento-San Joaquin Delta and Suisun Marsh, since 1972 as a means of assessing trends in fish food resources. The study also detects and monitors zooplankton recently introduced to the estuary and determines their effects on native species. Three gear types are used: 1) a pump for sampling microzooplankton <1.0 mm long, including rotifers, copepod nauplii, and adult copepods of the genus *Limnoithona*, 2) a modified Clarke-Bumpus (CB) net for sampling mesozooplankton 0.5-3.0 mm long, including cladocerans, copepodids (immature copepods), and adult copepods, and 3) a macrozooplankton net for sampling zooplankton 1-20 mm long, including mysid shrimp. Here seasonal abundance indices are presented from 1974 through 2009 for a select group of the most common copepods, cladocerans, rotifers, and mysids.

Methods

During 2009, sampling occurred monthly from January through December at 22 stations, including 12 core stations (i.e., stations sampled consistently since study inception in 1972) and 2 floating entrapment zone (EZ) stations located at bottom electrical conductivity of 2 and 6 mS/cm (about 1 and 3 ‰). Indices presented here were calculated using 16 stations: the 12 core stations, the 2 EZ stations, and 2 additional stations sampled consistently since 1974 (Suisun Slough station NZS42 and Disappointment Slough station MD10; www.baydelta.water.ca.gov/emp/Metadata/DiscreteWQ/discreteWQ_stations_map.html). Reports published prior to 2007 used data from 1972 forward that included only the 12 core stations and 2 EZ stations. Since this report utilizes data from 2 additional stations, indices start in 1974 and may be slightly different than those reported prior to 2007. However, overall trends remain the same.

Data were grouped into 3 seasons: 1) spring, March through May, 2) summer, June through August, and 3) fall, September through November. January, February, and December were not always sampled historically and therefore were not used for these long-term trend analyses. Abundance indices were calculated as the mean number of each taxon per cubic meter of water (reported as catch-per-unit effort, CPUE) by gear, season, and year for the 16 stations. Following a slightly different methodology, relative calanoid copepod abundance for each season of 2009, including winter (December 2008 through February 2009), used data from all 22 stations sampled. Similar to the 2004 through 2008 Status and Trends reports, indices reported below were separated by gear type and taxon, whereas pre-2004 reports combined the CB and pump data for each taxon into a single index. As in the 2008 Status and Trends report, mysid indices presented here include corrections made in 2009. Most corrections were minor and resulted in index changes of less than 1 mysid per cubic meter; however, the previously reported fall 2005 *Hyperacanthomysis longirostris* index of 11.6 m^{-3} was corrected to 3.3 m^{-3} due to an incorrect subsample at 1 station. In spite of these changes, overall mysid trends remain the same.

Copepods

Both congeners of the cyclopoid copepod genus *Limnoithona* inhabit the upper estuary: *L. sinensis*, introduced in 1979, and *L. tetraspina*, introduced in 1993. In 1993, *L. tetraspina* mostly supplanted the historically common and slightly larger *L. sinensis*, and numerically became the dominant copepod species in the upper estuary. *L. tetraspina* is common in both brackish and freshwater. As an ambush predator that feeds on motile prey (Bouley and Kimmerer 2006), *L. tetraspina* may have benefited from upper estuary phytoplankton species composition changing from non-motile diatoms to motile flagellates (Brown 2009). Despite high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators, like delta smelt, due to its small size and relatively motionless behavior in the water column (Bouley and Kimmerer 2006). Both pump and CB net indices are presented here because *L. tetraspina* is not completely retained by the CB net, especially in summer and fall when adults are smaller than in winter and spring. Pump *L. tetraspina* abundance decreased in 2009 from 2008 in all seasons (Figure 1), whereas CB abundance decreased in spring, but increased in summer and fall. Spring 2009 CB abundance has fluctuated since 2004 (Figure 1A) while summer and fall 2009 CB abundance increased for the first time since the decline that started in 2007 (Figures 1B and 1C). *L. tetraspina* was most abundant during late summer and early fall 2009 in the lower Sacramento River, Suisun Marsh, and Suisun Bay. *L. sinensis* continued to be collected in very low numbers in 2009.

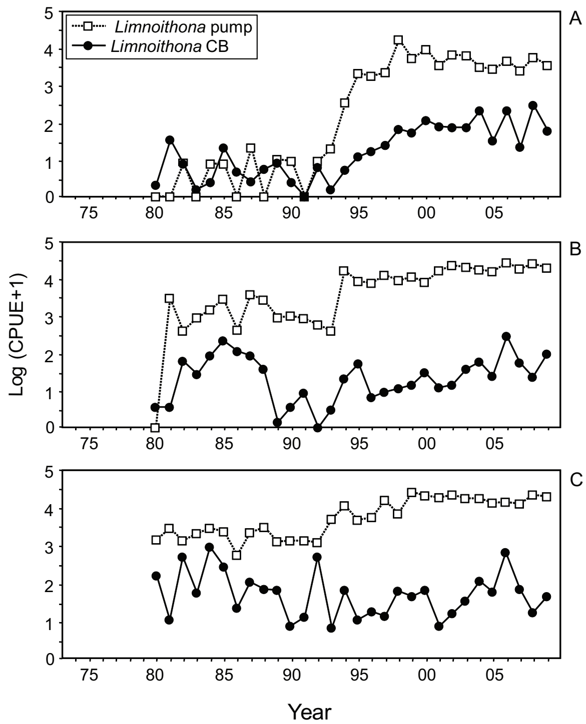

Figure 1 Abundance of *Limnoithona tetraspina* and *L. sinensis* combined (Log of mean catch*m-3+1) from the pump and CB net in Spring (A), Summer (B), and Fall (C), 1974 - 2009.

Eurytemora affinis, a calanoid copepod introduced to the estuary before monitoring began, was once a major food for larval and juvenile fishes of many species and adults of planktivores, such as delta smelt and threadfin shad. It is found throughout the upper estuary in every season and is most abundant in salinities less than 6 ‰. *E. affinis* abundance declined in all seasons since monitoring began, with the sharpest downturns during summer and fall of the late-1980s (Figure 2), subsequent to the introductions of the overbite clam, *Corbula amurensis*, and the calanoid copepod *Pseudodiaptomus forbesi*. Prior to these introductions, *E. affinis* abundance was usually highest during summer; however, since 1987 abundance has been highest in spring and has dropped abruptly in summer, when both *P. forbesi* abundance and *C. amurensis* grazing rates increase. In 2009, *E. affinis* was the fifth most abundant calanoid copepod in the study area across all months. Relative abundance was highest in spring, when it accounted for 12% of the total calanoid copepod CPUE (Figure 3). *E. affinis* abundance decreased in every season of 2009 from the 2008 seasonal abundances. Spring 2009 abundance declined sharply from 2008, when it had reached the highest abundance since 1994 (Figure 2A). Summer and fall *E. affinis* abundance decreased again in 2009 for the second year in a row, and were amongst the lowest on record (Figures 2B and 2C). In 2009, *E. affinis* abundance peaked in the eastern delta in May (596 m^{-3}) and in Suisun Marsh in April (532 m^{-3}). *E. affinis* was common in Suisun Marsh from February through May with an average abundance of 376 m^{-3}. In November and December, densities again began increasing in the eastern delta and Suisun Marsh.

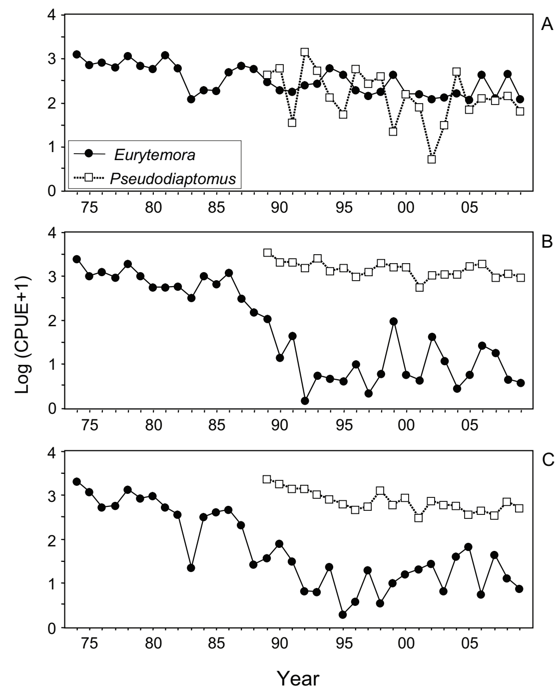

Figure 2 Abundance of *Eurytemora affinis* and *Pseudodiaptomus forbesi* (Log of mean catch*m^{-3}+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1974 - 2009.

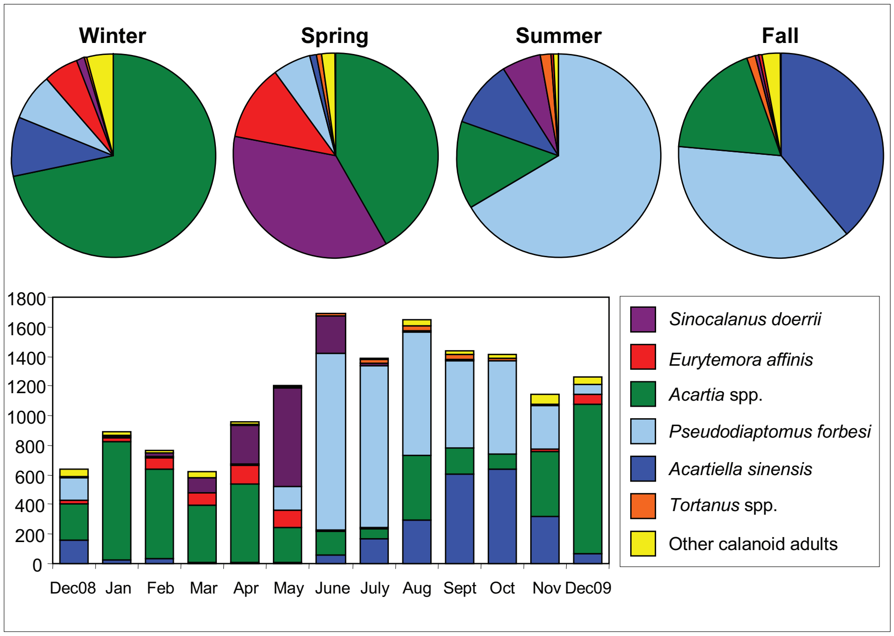

Figure 3 Relative abundance of the most common calanoid copepods (percent mean catch*m^{-3}) from the CB net from all stations by seasons and by months in 2009. Seasonal pie charts include Winter (December 2008-February 2009), Spring (March-May 2009), Summer (June-August 2009), and Fall (September-November 2009).

Pseudodiaptomus forbesi is an introduced freshwater calanoid copepod first detected in the upper estuary in 1988. By 1989, *P. forbesi* summer and fall abundance was comparable to *E. affinis* before its decline (Figure 2). Although *P. forbesi* abundance has declined slightly since its introduction, it has remained relatively abundant in summer and fall compared to other copepods. In 2009, *P. forbesi* was the second most abundant calanoid copepod in the study area across all months. Relative abundance peaked in summer, when it accounted for 66% of the total calanoid copepod CPUE (Figure 3). Spring abundance has always been highly variable and decreased slightly in 2009 (Figure 2A). Summer and fall abundance also decreased slightly in 2009 from 2008 (Figures 2B and 2C). During summer and fall 2009, *P. forbesi* was common in all regions upstream of Suisun Bay, but was most abundant June and July in the south Delta in Frank's Tract, where the mean CPUE was 5,588 m^{-3}. In July and August 2009, P. forbesi was also abundant in Disappointment Slough, where the mean CPUE was 4,978 m^{-3}.

Several species of the native calanoid copepod genus *Acartia* are abundant in San Pablo Bay and expand their range into Suisun Bay and the western delta as salinity increases seasonally and annually. Conversely, their affinity for higher salinities is sufficiently strong that their distribution shifts seaward of the sampling area during high-outflow events, resulting in low seasonal and annual abundance. In 2009, *Acartia* was the most abundant calanoid copepod in the study area based on mean CPUE across all months, which was predictable given the relatively low delta outflow (see Messineo et al. page 49 this issue). Relative abundance peaked in winter, when *Acartia* accounted for 73% of the total calanoid copepod CPUE (Figure 3). *Acartia* abundance declined in spring and summer of 2009 from 2008, but increased in fall (Figure 4). Due to low outflow from 2007 through 2009, spring abundance was higher than from 2004 through 2006 (Figure 4A). The highest summer abundances corresponded with the lowest outflow years, and 2009 summer abundance was similar to the most recent low outflow years (Figure 4B). Fall 2009 abundance was similar to the drought years 1987-1992 (Figure 4C). *Acartia* densities were high throughout the year in San Pablo Bay with peaks in January (5,463 m^{-3}) and December (5,165 m^{-3}). *Acartia* was also common in Carquinez Strait throughout the year with a peak in December (5,369 m^{-3}).

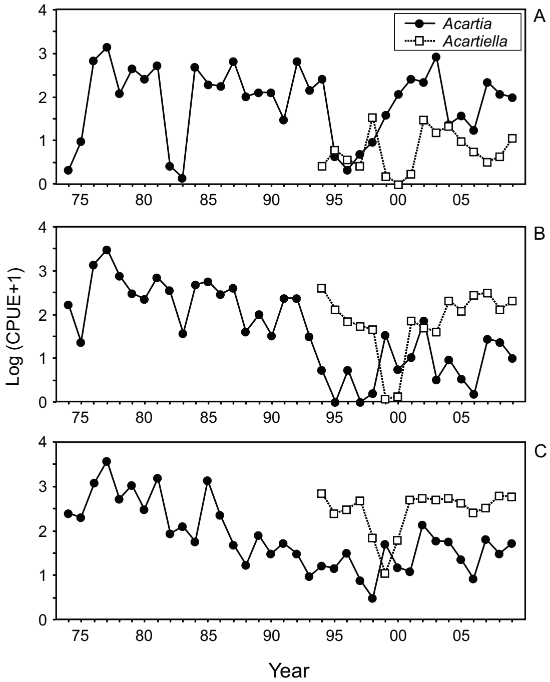

Figure 4 Abundance of *Acartia* spp. and *Acartiella sinensis* (Log of mean catch*m^{-3}+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1974 - 2009.

Acartiella sinensis is an introduced calanoid copepod first recorded in spring 1994 that is most abundant in the entrapment zone during summer and fall. In 2009, *A. sinensis* was the third most abundant calanoid copepod in the study area across all months. Its relative abundance was highest in fall, when it accounted for 40% of the total calanoid copepod CPUE (Figure 3). Spring abundance has always been highly variable, but declined steadily from 2004 through 2007, followed by slight increases in 2008 and 2009 (Figure 4A). Summer abundance decreased from 1994 through 1998, sharply declined in 1999, and remained very low in 2000 (Figure 4B). Since 2001, summer abundance rebounded from the record lows of 1999 and 2000, and in 2007, reached the second highest summer abundance since its introduction. After declining in 2008, summer abundance again increased in 2009. Fall abundance has been relatively stable since 2001, and fall 2009 abundance was the third highest level since its introduction (Figure 4C). In 2009, *A. sinensis* abundance peaked in September in the lower Sacramento River, just upstream of the entrapment zone (3,224 m^{-3}).

The introduced freshwater calanoid copepod *Sinocalanus doerrii* was first recorded in spring 1979. Initially most abundant in summer, *S. doerrii* abundance began to decline during summer and fall in the mid-1980s (Figures 5B and 5C). This downward trend continued through the mid-1990s, followed by a modest increase until recently. In 2009, *S. doerrii* was the fourth most abundant calanoid copepod in the study area across all months. Relative abundance peaked in spring, when it accounted for 36% of the total calanoid copepod CPUE (Figure 3). *S. doerrii* abundance decreased in 2009 from 2008 in all seasons (Figure 5). Spring abundance, historically more variable than summer or fall abundance, was lowest in 1995 and steadily increased through 2004 before declining again in 2005 and 2006 (Figure 5A). Subsequently, 2008 spring abundance was the highest since 1993, but decreased again in 2009. Summer and fall abundance declined sharply in 2004 and remained low through 2007 (Figures 5B and 5C). In 2008, abundance increased to the highest level since 2003, before decreasing again in 2009. In 2009, *S. doerrii* was most abundant in May in the lower Sacramento and San Joaquin rivers, and the southern delta (1,858 m^{-3}). After June, densities were low throughout the estuary.

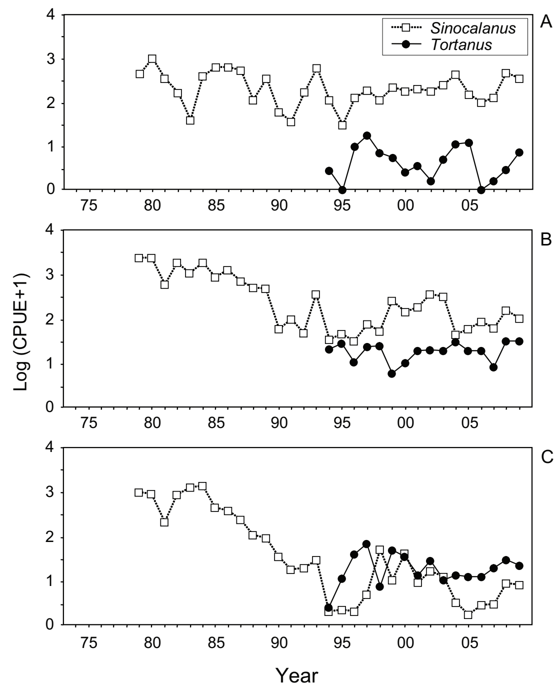

Figure 5 Abundance of *Sinocalanus doerrii* and *Tortanus dextrilobatus* (Log of mean catch*m^{-3}+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1974 - 2009.

Tortanus dextrilobatus is an introduced brackish-water calanoid copepod first recorded in spring 1994. *T. dextrilobatus* is a large carnivorous copepod whose abundance increases in the sampling area as flows decrease and salinities increase during summer and fall. In 2009, *T. dextrilobatus* was the least abundant calanoid copepod in the study area; relative abundance peaked in summer when it accounted for only 2% of the total calanoid copepod CPUE (Figure 3). *T. dextrilobatus* abundance increased in spring of 2009 from 2008, remained steady in summer, but decreased in fall (Figure 5). Spring abundance rose steadily from the low in 2006, caused by the extremely high flows, and in 2009 was the fifth highest (Figure 5A). In 2008 and 2009, summer abundance was the highest it has been since *T. dextrilobatus* was introduced (Figure 5B). Fall abundance decreased slightly in 2009 from 2008 and terminated an increase that began in 2007 (Figure 5C). In 2009, *T. dextrilobatus* was most abundant in Carquinez Strait, where abundance peaked in July (368 m^{-3}).

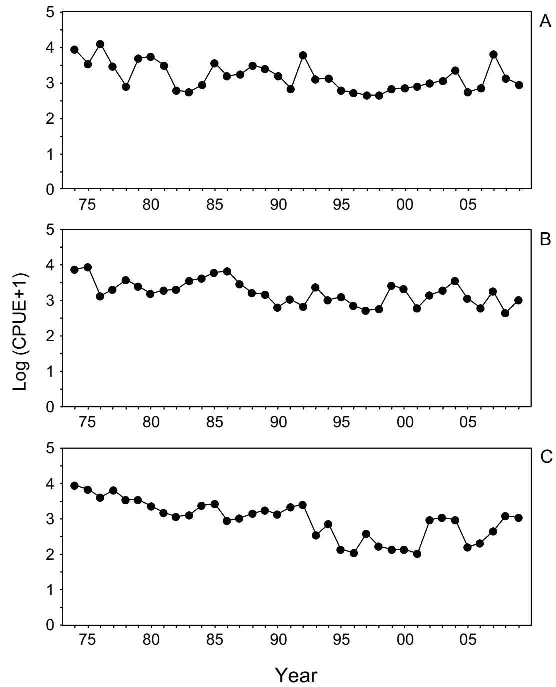

Figure 6 Abundance of Cladocera (Log of mean catch*m^{-3}+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1974 - 2009.

Cladocerans

Bosmina, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper estuary. Combined, these native freshwater cladocerans had an overall downward trend since the early 1970s, especially in fall (Figure 6). From 2008 to 2009, abundance decreased in spring and fall, but increased in summer (Figure 6). Low outflow in 2008 and 2009 reduced dispersal, which allowed for high densities of cladocerans in the eastern delta most of the year. In 2009, cladocerans were common throughout the upper estuary upstream of the entrapment zone, and were most abundant in the eastern delta from April through October. Peak densities occurred in the lower San Joaquin River near Stockton in April (28,477 m^{-3}), and in September in Disappointment Slough (22,491 m^{-3}), also in the eastern delta.

Rotifers

Synchaeta bicornis is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. However, summer and fall abundances have experienced long-term declines since the 1970s (Figure 7). Spring abundance, although erratic, has also shown an overall downward trend (Figure 7A). After a peak in spring 2000, abundance declined sharply in 2001, and from 2002 through 2007 there was no catch during spring at any core stations. Low flows in spring 2008 and 2009, resulted in the highest spring abundance since 2000. Summer 2009 abundance decreased slightly from 2008, which was the highest level in 10 years (Figure 7B). Fall 2009 abundance also decreased slightly and was the third lowest since monitoring began (Figure 7C). In 2009, *S. bicornis* was most abundant in spring in San Pablo Bay and in summer further upstream in Carquinez Strait and Suisun Bay. Peak densities occurred in Carquinez Strait in August (28,320 m^{-3}).

Abundance of all other rotifers, without *S. bicornis*, declined in all seasons from the early 1970s through the 1980s, but stabilized since the early 1990s (Figure 7). In 2008, spring abundance continued the steady increase that began in 2006 and reached the highest level since 1995, before decreasing again in 2009 (Figure 7A). Both summer and fall abundance increased in 2009 from 2008, which were amongst the lowest on record (Figures 7B and 7C). Rotifers were common throughout the study area in 2009, with the highest abundance near Stockton in the lower San Joaquin River where mean CPUE for the year was 99,711 m^{-3}, and abundance peaked at 483,871 m^{-3} in February.

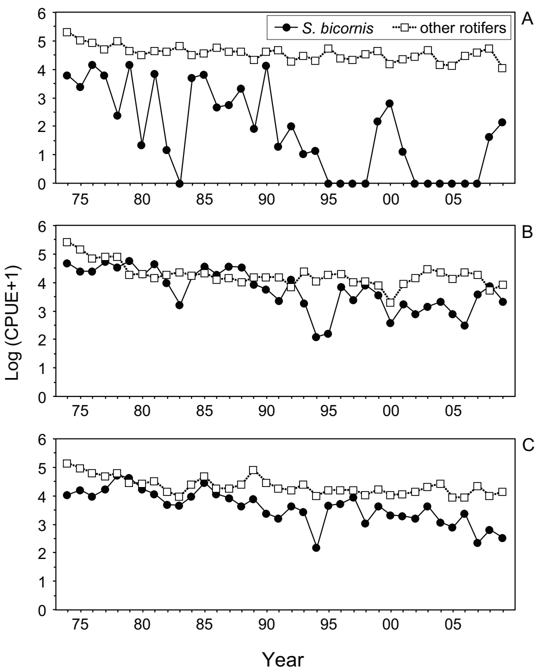

Figure 7 Abundance of *Synchaeta bicornis* and rotifers excluding *S. bicornis* (Log of mean catch*m^{-3}+1) from the pump in Spring (A), Summer (B), and Fall (C), 1974 - 2009.

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*), an introduced mysid first collected by the study in summer 1993, has been the most abundant mysid in the upper estuary every season since summer 1995 (Table 1). *H. longirostris* is commonly found in densities of more than 10 m^{-3}, and occasionally in densities of more than 100 m^{-3}. Spring *H. longirostris* abundance increased between 1995 and 1998, and fluctuated annually thereafter. In 2009, spring abundance decreased and was the second lowest since its introduction. *H. longirostris* was most abundant in summer with an average abundance (across years) of 17 m^{-3}. Since 2003, summer abundance has had a downward trend; in 2009, summer abundance decreased and was the second lowest on record. *H. longirostris* fall abundance has declined consistently since a local peak in 2004, resulting in 2007-2009 fall abundances at and near record lows of less than 1 m^{-3}. In 2009, *H. longirostris* was most abundant in July and August in the entrapment zone comprising the lower Sacramento and eastern Suisun Bay, near the confluence of the Sacramento and San Joaquin rivers. The highest density of (62 m^{-3}) in the entrapment zone occurred in August, after which densities were low throughout the estuary.

Neomysis mercedis, historically the only common mysid in the upper estuary, suffered a severe population crash in the early 1990s. In 2009, it was the fourth most abundant mysid in the sampling area across all months for the third year in a row. *N. mercedis* is most abundant in spring and summer, and prior to the population crash spring and summer densities averaged more than 50 m^{-3} (Table 1). Since 1994, mean spring abundance has been less than 1 m^{-3}, rendering *N. mercedis* inconsequential as a food source in most open-water areas of the upper estuary. After a record low in 2007, spring 2008 abundance increased slightly, but decreased again in 2009 and was the second lowest since monitoring began. Summer abundance has been extremely low since 1997, and in 2009 abundance decreased to the lowest on record. No *N. mercedis* were caught during fall at any of the stations sampled from 2005 through 2008. In fall 2009, 1 *N. mercedis* was caught in October in the lower Sacramento River in the entrapment zone. *N. mercedis* was very rare throughout the study area with densities less than 1 m^{-3} at every station since June 2006, except 1 station in the San Joaquin River near Potato Slough in June 2008 (2.9 m^{-3}). In 2009, *N. mercedis* densities were less than 1 m^{-3} at every station sampled in all months.

Neomysis kadiakensis is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1996, but was not common until recently (Table 1). Since 2001, *N. kadiakensis* has been the second most abundant mysid in the study area, but at much lower densities than *H. longirostris*. In 2009, *N. kadiakensis* abundance decreased slightly from 2008 in all seasons. After reaching a record high in spring 2008, abundance decreased in spring 2009, but was the second highest spring abundance recorded. Summer 2008 was the highest summer abundance, but was still low relative to *H. longirostris.* In 2009, summer abundance decreased and was approximately equal to the summer average across years. Fall abundance decreased from 2008 to 2009, and fell slightly below the fall average in 2009. In March 2009, *N. kadiakensis* was most abundant in Carquinez Strait; as flows decreased in late spring and summer, distribution shifted east into Suisun Bay, Suisun Marsh, and into the lower Sacramento River in the entrapment zone. Since the late 1990s, *N. kadiakensis* has extended its range into lower salinity water at the confluence of the Sacramento and San Joaquin rivers, leading to the hypothesis that some of the upper-estuary specimens may be a second species, *N. japonica*. To date no physical characteristics have been published to separate these 2 species.

Alienacanthomysis macropsis is a native brackish-water mysid found most often in San Pablo Bay and Carquinez Strait that was first consistently enumerated by the study in 1995. *A. macropsis* has never been common in the sampling area and therefore indices were not reported until 2007. *A. macropsis* was slightly more abundant than *N. mercedis* in 2009, and was the third most abundant mysid in the upper estuary across all stations and surveys for the third year in a row, although it remained a minor component of the mysid community. Spring abundance increased again in 2009, for the third year in a row, and was the highest spring abundance recorded (Table 1). Summer abundance also increased from 2008 to 2009 to the highest summer abundance on record. Fall 2009 abundance decreased from the record high in 2008, but remained above average. In 2009, *A. macropsis* was most abundant from January through April and in November and December in San Pablo Bay and Carquinez Strait. Abundance peaks also occurred in January and December in Suisun Bay.

Table 1 Seasonal abundance of the most common mysid species (mean catch*m^{-3}) from the macrozooplankton net.

Year	*Hyperacanthomysis longirostris*			*Neomysis mercedis*			*Neomysis kadiakensis*			*Alienacanthomysis macropsis*		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
1974-1989				54.506	87.293	18.154						
1990				23.458	7.612	0.436						
1991				32.058	18.331	0.489						
1992				4.223	1.989	0.076						
1993			2.470	7.850	22.503	0.008						
1994	0.932	21.604	2.063	0.449	0.733	0.004						
1995	0.437	7.180	4.407	0.590	0.370	0.000				0.000	0.000	0.004
1996	1.636	11.693	4.432	0.541	1.432	0.001	0.032	0.001	0.017	< 0.001	0.000	0.003
1997	6.939	27.630	7.714	0.565	0.063	0.000	0.011	0.011	0.385	0.006	0.000	0.004
1998	18.136	6.015	18.691	0.181	0.238	0.025	0.108	0.041	0.006	0.005	0.000	0.008
1999	3.888	34.697	14.329	0.264	0.288	0.001	0.037	0.007	0.075	0.014	0.000	0.001
2000	23.580	38.453	9.958	0.880	0.136	0.001	0.074	0.165	0.465	0.003	0.000	0.001
2001	4.767	13.441	8.956	0.422	0.052	0.001	0.285	0.351	0.143	0.013	0.001	0.001
2002	10.121	21.224	7.516	0.022	0.069	0.001	0.209	0.254	0.753	0.005	0.000	0.002
2003	4.342	21.307	4.555	0.022	0.046	< 0.001	0.314	0.209	0.166	0.038	0.000	0.003
2004	9.915	13.725	5.044	0.150	0.016	0.002	0.129	0.106	0.170	0.001	0.000	0.001
2005	4.010	16.281	3.265	0.092	0.141	0.000	0.173	0.104	0.077	0.003	0.000	0.004
2006	7.186	14.143	1.967	0.321	0.137	0.000	0.071	0.727	0.051	0.001	0.000	0.001
2007	0.969	8.997	0.575	0.005	0.023	0.000	0.176	0.306	0.122	0.004	< 0.001	0.025
2008	17.696	14.574	0.715	0.063	0.108	0.000	1.359	0.820	0.154	0.027	< 0.001	0.155
2009	0.729	6.303	0.681	0.016	0.013	< 0.001	0.418	0.240	0.128	0.064	0.003	0.096
Average:	7.205	17.329	5.726	26.229	40.305	8.098	0.243	0.239	0.194	0.012	< 0.001	0.021

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2009 Status and Trends ReportCommon Crabs of the San Francisco Estuary

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This report summarizes abundance trends and distributional patterns of the most common *Cancer* crabs and *Eriocheir sinensis,* the Chinese mitten crab, through 2009 in the San Francisco Estuary. Most of the data is from the San Francisco Bay Study (Bay Study) otter trawl, with additional *E. sinensis* data from UC Davis Suisun Marsh otter trawls and the CVP and SWP fish salvage facilities.

Cancer crabs

Cancer magister, the Dungeness crab, is a valuable sport and commercial species that reproduces in the ocean in winter and rears in nearshore coastal areas and estuaries. Small juvenile *C. magister*, 5-10 mm carapace width (CW), immigrate to San Francisco Estuary in spring, rear for 8-10 months, and then emigrate from the estuary when approximately 100 mm CW. Estuary-reared crabs reach legal size at the end of their 3rd year, 1 to 2 years before ocean-reared crabs. This faster growth is hypothesized to be due to warmer temperatures and more abundant prey resources in the estuary (Tasto 1983).

C. magister recruitment is episodic and cyclic, with several extremely strong year classes often followed by poor year classes or no recruitment. In 2009, the abundance index of age-0 *Cancer magister* was the 5th highest for the 30-year period of record (Figure 1), but was preceded by 4 very poor or moderate year classes. Favorable ocean conditions in winter 2008-2009, when larval *C. magister* hatched and reared in the Gulf of the Farallones (GOF), resulted in this strong year class. GOF sea surface temperatures (SSTs) were about 1°C cooler than the long-term mean in late 2008 and early 2009 (see Figure 4, Fishes Status and Trends report) and would have increased larval survival. Infrequent winter storms should have resulted in a weak northward-flowing surface current and retention of *C. magister* larvae in the Gulf of the Farallones. We expected good recruitment of age-0 *C. magister* in the estuary in 2009 from this combination of cooler SSTs and weaker surface currents.

Ocean conditions in winter 2007-2008 were similar to winter 2008-2009, with relatively cool SSTs and a weak surface Current, but the 2008 *C. magister* year class was smaller than expected. Relatively strong upwelling early 2008, as indicated by the Cumulative Upwelling Index (see Figure 6, Fishes Status and Trends report), may have transported a large portion of the 2008 larvae too far offshore to enter the San Francisco Estuary for rearing. Small juvenile *C. magister* entered the estuary very late in 2008, additional evidence that larvae may have been transported some distance offshore in winter or early spring. In contrast, entry of small juvenile *C. magister* was not delayed in 2009.

The strong and weak *C. magister* year classes earlier this decade were reflected in the commercial landings. Central California commercial landings surpassed 5 million pounds annually from the 2002-03 to 2006-07 fishing seasons, but 3.4 million pounds were landed in 2007-08, only 1 million pounds in 2008-09, and 2.9 million pounds in the 2009-10 season through June 2010 (P. Kalvass, CDFG). The strong year classes of estuary-reared crabs from 2001 to 2004 reached legal size and entered the fishery consecutively from the 2003-04 to 2006-07 fishing seasons, while primarily the weak 2005 and 2006 year classes contributed to the fishery in 2008-09. The increased 2009-10 landings can be partially attributed to increased age-0 *C. magister* abundance in 2007.

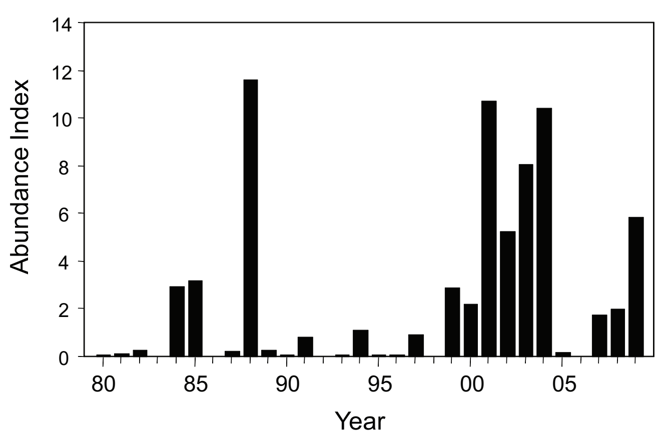

Figure 1 Annual abundance indices of age-0 *Cancer magister,* Bay Study otter trawl, May to July, 1980-2009.

In 2009, age-0 *C. magister* were most abundant in May and June, as small juveniles immigrated into the estuary. Age-0 abundance was lowest in October and December; the majority of age-0 crabs were likely still in shallow subtidal areas in October, as this was too early for emigration, but emigration would have started in December. Age-1 crabs were also collected in 2009, with abundance highest in January and rapidly decreasing from April through July. A few age-1 crabs remained in the estuary through the end of 2009.

Age-0 *C. magister* were collected from South Bay, near the San Mateo Bridge, to Chipps Island in Suisun Bay in 2009. A distinct group of age-0 crabs entered the Bay in May and migrated upstream to rear, ultimately in eastern San Pablo Bay, Carquinez Strait, and western Suisun Bay. Another group remained in Central Bay or was composed of crabs that moved between the ocean and Central Bay. The upstream group grew faster than the Central Bay group, although the Central Bay group may have had constant recruitment from the ocean. By December, the upstream group had a mean size of 81 mm CW, while the Central Bay group had a mean size of 59 mm CW.

Since 1999, there has been a trend of proportionally more age-0 *C. magister* collected in Central Bay in summer and fall, especially at the Alcatraz Island station. In 2009, 61% of the age-0 catch from June to October was from Central Bay and 20% from the Alcatraz Island station. We are not sure why a larger percentage of *C. magister* have been collected in Central Bay much of the past decade, but have reported a similar trend for English sole, speckled sanddab, plainfin midshipman, and several other demersal marine fishes.

Just over 67% (n=968) of age-0 *C. magister* were collected at channel stations in 2009, but there were seasonal trends. Channel CPUE was highest in May and June (7.0 and 11.5 crabs/tow, respectively), during immigration and upstream migration. As the juvenile crabs moved over the shoals to shallow subtidal areas to rear through summer, shoal CPUE increased. Channel and shoal CPUE was similar from September to November, but channel CPUE again increased in December, as crabs began to emigrate from the estuary.

Age-1 crabs were most common in Central Bay all months of 2009, although some were collected in San Pablo Bay and Carquinez Strait the first half of the year. The upstream crabs moved to Central Bay as emigration to the ocean proceeded through spring. As expected, age-1 crabs highly favored the channels in 2009, with 87% (n=277) of all age-1 crabs collected in the channels.

The following 3 *Cancer* species reproduce in both the nearshore ocean and higher salinity areas of the estuary, primarily in winter. Therefore, estuary and ocean conditions may control larval survival and year-class strength.

Cancer antennarius, the brown rock crab, is common to rocky areas and other areas with structure. It and *C. productus,* the red rock crab, are targeted by sport anglers fishing from piers and jetties in the higher salinity areas of the estuary. The 2009 age-0 *C. antennarius* abundance index was a third of the 2008 index, which was near the record high for the study period (Table 1). *C. antennarius* abundance in the estuary appears to be partially related to ocean temperatures, with the highest abundance often, but not always, in years with the coldest winter-spring SSTs. SSTs in winter 2008-2009 were about 1°C cooler than the long-term mean, but not as cool as winter 2007-2008 (see Figure 4, Fishes Status and Trends report). In 2009, peak abundance of age-0 *C. antennarius* occurred in August, when a large number of small juveniles <20 mm CW were collected

C. antennarius was collected from near Coyote Point in South Bay to near Point Pinole in San Pablo Bay in 2009. This was a narrower distribution than in 2008, expected due to lower abundance. The highest age-0 catches were from the shoal stations off Alameda, near Berkeley Marina, and just downstream of Point Pinole. Only 8 age-1+ *C. antennarius* were collected in 2009, all from channel stations south of the Bay Bridge, at Alcatraz Island, and just upstream of the Richmond-San Rafael Bridge. Almost 90% (n=372) of the age-0 crabs were collected at shoal stations in 2009 and there appeared to be no seasonal movement or migration of age-0 crabs to the channels.

Cancer gracilis, the slender crab, is the smallest of the 4 *Cancer* crab species reported, rarely exceeding 85 mm CW. It is common in open sandy or sand-mud habitats rather than rocky areas; researchers have hypothesized that because of its small size it cannot compete with the rock crabs for the more “preferred” protected habitats with structure. The 2009 abundance index of age-0 *C. gracilis* declined slightly from 2008 and was just above the long-term study mean (Table 1). Age-0 abundance peaked in May and June, with most of the small, recently settled juveniles collected in May. In 2009, there were also 2 smaller peaks of recently settled *C. gracilis* in February and October.

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Table 1 Annual abundance indices of age-0 *Cancer* crabs from the Bay Study otter trawl, 1980-2009. The index period is from May to October for *C. antennarius* and *C. gracilis* and from April to October for *C. productus.*

Year	C. antennarius	C. gracilis	C. productus
	age-0	age-0	age-0
1980	102	17	0
1981	76	152	6
1982	0	87	4
1983	28	151	4
1984	50	154	41
1985	20	216	38
1986	0	59	89
1987	71	93	79
1988	21	223	138
1989	29	203	30
1990	113	159	160
1991	171	656	128
1992	60	371	62
1993	398	616	71
1994	603	1,017	166
1995	367	227	40
1996	1,126	411	198
1997	351	1,131	86
1998	718	1,621	149
1999	90	222	249
2000	849	251	93
2001	276	1,921	142
2002	119	796	238
2003	424	522	140
2004	1,765	112	139
2005	144	132	57
2006	46	81	71
2007	987	418	58
2008	1,703	543	50
2009	556	471	68
1980-2009 Average	375	434	93

C. gracilis was collected from the shoal station near Candlestick Point in South Bay to the channel station near Point Pinole in San Pablo Bay in 2009, with 80% (n=297) of all crabs collected from Central Bay. The highest catches were from the shoal stations near Candlestick Point, Treasure Island, Southampton Shoal, and Paradise Cay in upper Central Bay and 2 Central Bay channel stations. *C. gracilis* was overall more common at the shoals, with 62% (n=227) collected there. However, the largest crabs, >75 mm CW, were more commonly collected at channel stations in 2009.

Cancer productus is overall the least common of the 4 *Cancer* crabs collected by the otter trawl in the estuary, reflecting its strong preference for rocky intertidal and subtidal marine habitats not sampled by the trawl, rather than its actual abundance. In a survey conducted by CDFG from 1982 to 1994 with baited ringnets at piers, it was the second most common *Cancer* crab collected. In 2009, the age-0 *C. productus* abundance index increased slightly from 2008, but remained below the study-period mean (Table 1). Including 2009, there were 5 consecutive years of below average indices. Abundance peaked in October, with only 3 age-0 crabs collected from January through June. Catch of the smallest *C. productus* (<20 mm CW) was somewhat scattered in 2009, with several collected in July, November, and December in addition to the October peak.

C. productus was collected from near Hunter's Point in South Bay to western San Pablo Bay in 2009, with 84% (n=42) from Central Bay. Crabs were collected in San Pablo Bay only early in the year, when water temperatures were the coolest. Channel habitat was favored by all sizes, with 88% collected from channel stations. It has been reported that juvenile *C. productus* settle on spatially complex substrates and move to areas with more open space as they grow (Orensanz and Gallucci 1988). Because we tow over soft substrates rather than rocky areas, we are likely not to detect this type of distributional pattern.

In general, ocean conditions, with relatively cool winter temperatures and a weak northward flowing surface current, should have favored of *C. antennarius*, *C. gracilis*, and *C. productus* recruitment in 2009. However, *C. antennarius* and *C. gracilis* abundance decreased from 2008 and although *C. productus* abundance increased from 2008, it remained below the study-period mean. Peak larval hatching of all 3 species is reportedly in winter, but multiple broods may occur and megalopae have been collected here in other seasons (Hieb 1999). Hence, timing of juvenile settlement is not identical for these 3 species and they likely respond differently to variations in upwelling and ocean currents. For example, most small juvenile *C. gracilis* entered the estuary in late April or early May 2009, a period with some of the strongest upwelling indices for the year. If peak *C. gracilis* settlement was indeed in April and May, a large proportion of the small juveniles were likely offshore, not near the mouth of San Francisco Estuary. In contrast, a large number of small juvenile *C. antennarius* and *C. productus* entered the estuary in August and October 2009, respectively. This may have been delayed immigration due to offshore settlement or the result of later reproductive events.

Eriocheir sinensis

Eriocheir sinensis, the Chinese mitten crab, was first collected in the estuary in the early 1990s, but likely introduced to South San Francisco Bay in the late 1980s. After several years of rapid population growth and expanding distribution, the *E. sinensis* population peaked in 1998 (Table 2). All data sources indicate that the population has steadily declined since 2001. In fall and winter 2009-2010, no adult *E. sinensis* were collected at either fish facility or by the San Francisco Bay Study and UC Davis Suisun Marsh trawl survey (T. O'Rear, personal communication) trawl surveys in the northern estuary. There were also no reports of adult *E. sinensis* in South Bay trawls conducted by the Marine Science Institute (M. Seiff, personal communication), the 4th consecutive year that none were collected there.

There were no public reports of *E. sinensis* sightings made to the toll-free reporting line, the web page reporting form, or from the postage-paid mailer in 2009 (J. Thompson, personal communication). One impact of *E. sinensis* commonly reported is bait stealing from sport anglers in the delta and Suisun and San Pablo bays. From such public reports, we may learn of an increase in the *E. sinensis* population before it is detected by our surveys.

In the 2008 annual report, I hypothesized that ocean conditions may control *E. sinensis* recruitment to the San Francisco Estuary (Hieb 2009). The planktonic larvae, which have minimal or no estuary-retention mechanisms (Hanson and Sytsma 2008), would be transported to the coast by freshwater outflow. In addition, successful development of *E. sinensis* larvae in the laboratory occurred only at temperatures $\geq$12°C, with the highest survival at 18°C (Anger 1991). Winter ocean SSTs were often $\geq$12°C during the El Niño events of the 1990s and several of these years had very high outflow, which would have transported larvae to the coast where larvae could have survived and developed, in contrast to the much cooler estuary. In winter 2008-2009, nearshore SSTs were <12°C (see Figure 5, Fishes Status and Trends report, this issue) and freshwater outflow was low, a combination that would not have favored *E. sinensis* recruitment.

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Notes

Pete Kalvass, CDFG, email, August 3, 2010.
Teejay O'Rear, UC Davis, personal communication, May 26, 2010.
Marilou Seiff, Marine Science Institute, email, August 11, 2010.
Jon Thompson, USFWS, personal communication, June 8, 2010.

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Table 2 Annual adult *Eriocheir sinensis* CPUE and estimated total salvage, 1996-2009. Bay Study CPUE is from October (year) to March (year+1), Suisun Marsh CPUE is from July to December, and Central Valley Project (CVP) and State Water Project (SWP) fish facilities salvage is from September to November.

Year	Bay Study CPUE	Suisun Marsh CPUE	CVP salvage	SWP salvage
	(#/tow)	(#/tow)	est. total	est. total
1996	0.02	0.00	50	
1997	0.34	0.07	20,000	
1998	2.51	0.89	750,000	
1999	0.96	1.08	90,000	34,000
2000	0.93	0.02	2,500	4,700
2001	3.25	0.17	27,500	7,300
2002	1.07	0.04	2,400	1,200
2003	0.15	0.00	650	90
2004	0.12	0.00	750	370
2005	0.01	0.00	0	18
2006	0.00	0.00	12	0
2007	0.00	0.00	0	0
2008	0.00	0.00	0	0
2009	0.00	0.00	0	0

Long Term and Recent Trends of Fishes and Invertebrates in Suisun Marsh

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Abstract

Suisun Marsh, at the geographic center of the San Francisco Estuary, is important habitat for alien 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. Otter trawl catches of native fishes declined considerably from the study's beginning until about 1995; since then, it has stabilized somewhat at relatively low levels. Although the trend was less severe, otter trawl catches of alien fishes also declined until the early 1990s. Since the study's inception, otter trawl catch of alien fishes has been highly variable, primarily due to erratic recruitment and invasions of new species. Beach seine catch has gradually increased over the study's history, which has been mainly the result of rising Mississippi silverside (*Menidia audens*) numbers. Both 2008 and 2009 were dry years, although Delta outflows remained higher and more variable later in 2009. In 2008, 286 otter trawls, 19 midwater trawls, and 76 beach seine hauls were conducted. Fish per otter trawl was the second lowest recorded in the study's history, which was partially due to the negative effects of salinity and lack of flooding on reproduction. However, many fishes that declined in otter trawls [e.g., yellowfin goby (*Acanthogobius flavimanus*), shimofuri goby (*Tridentiger bifasciatus*), striped bass (*Morone saxatilis*)] became much more abundant in beach seines. Additionally, only 14 individual fish were captured in midwater trawls, catches of 4 plankton-feeding macroinvertebrates declined in otter trawls, and the abundance of mysids was very low. In 2009, 256 otter trawls and 75 beach seines were conducted. Relative to 2008, fish per otter trawl increased while beach seine catches declined, mainly due to the

fishes that most strongly contributed to the catches in 2008: striped bass and yellowfin and shimofuri gobies. This was partially due to favorable outflows spanning the recruitment period of these fishes into the marsh. Similar to the otter trawl catch of fish, catch trends of 3 of the 4 macroinvertebrates increased from 2008 to 2009, and large mysid catches co-occurred with high catches of small fishes. Consequently, catches of 2008 and 2009 appeared to be largely determined by the magnitude, variability, and timing of Delta outflows and the abundance of pelagic food supplies.

Introduction

Suisun Marsh is a brackish-water marsh bordering the northern edge of Suisun Bay in the San Francisco Estuary; it is the largest uninterrupted expanse of estuarine marsh remaining on the western coast of the contiguous United States (Moyle et al. 1986). Most of the marsh area is diked wetlands managed for waterfowl, with the rest of the acreage consisting of tidally influenced sloughs (California Department of Water Resources 2001). The marsh's central location in the San Francisco Estuary makes it an important rearing area for euryhaline freshwater, estuarine, and marine fishes.

The University of California, Davis, Suisun Marsh Fish Study was initiated in 1979 to monitor the abundance and distribution of fishes in relation to each other, to environmental variables, and to water management activities (e.g., water exports). The study has used 2 primary methods for sampling fishes: beach seines and otter trawls. Juveniles and adults of most 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 (Meng and Matern 2001).

Moyle et al. (1986) evaluated the first 5 years of data collected by the study and found 3 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 5 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 both resulted in poor recruitment. The authors also found that native fishes tended to be more prevalent in small, shallow sloughs, while alien species were more prominent in large sloughs.

Meng et al. (1994) incorporated 8 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, alien 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 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 article builds on previous studies by reporting on trends in important fishes and invertebrates of the marsh from the study's inception to 2009. In particular, we focus on monthly catch patterns during 2008 and 2009, especially within the context of Delta outflow and its effect on salinity.

Study Area

Suisun Marsh is a tidally influenced brackish-water marsh covering about 84,000 acres (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).

There are 2 major tidal channels in the marsh: Montezuma and Suisun sloughs (Figure 1). Montezuma Slough generally arcs northwest from the confluence of the Sacramento and San Joaquin rivers, then curves southwest and terminates at Grizzly Bay (the major embayment of Suisun Bay). Major tributary sloughs to Montezuma are Denverton and Nurse; Cutoff Slough and Hunters Cut connect Suisun and Montezuma sloughs (Figure 1). Suisun Slough begins near Suisun City and trends south until emptying into Grizzly Bay southwest of the mouth of Montezuma Slough. Major tributaries to Suisun Slough, from north to south, are Peytonia, Boynton, Cutoff, Wells, Cordelia, and Goodyear sloughs (Figure 1). First and Second Mallard sloughs are tributary to Cutoff Slough and are part of 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).

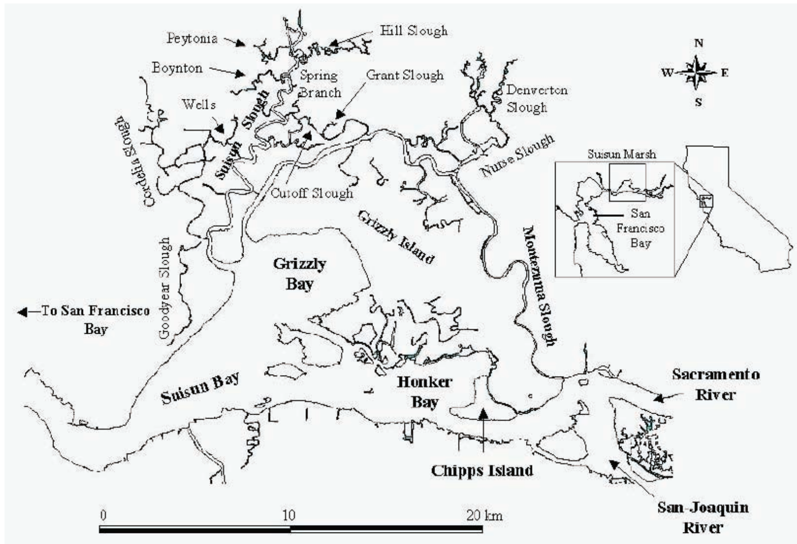

Figure 1 Suisun Marsh and Bay (from Schroeter et al. 2006).

Suisun and Montezuma sloughs are generally 330-500 ft (100-150 m) wide, 10-20 ft (3-6 m) deep, and possess partially riprapped shorelines (Meng et al. 1994). Tributary sloughs are usually 30-60 ft (10-20 m) wide, 6-10 ft (2-3 m) deep, and fringed with common reed (*Phragmites communis*) and tules (*Schoenoplectus* spp.). Substrates in all sloughs are generally fine organics, although a few sloughs also have bottoms partially comprised of coarser materials (e.g., Denverton Slough) and the larger, deeper sloughs (e.g., Montezuma Slough) can have sandy channel beds.

The amount of fresh water flowing into Suisun Marsh is the major determinant of its salinity. Fresh water enters the marsh primarily from the Sacramento River through Montezuma Slough, although small creeks, particularly on the northwestern side 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 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, inhibit saltwater intrusion into the marsh during flood tides, when operating, and thereby provide fresh water for diked wetlands (California Department of Water Resources 2001; Figure 1). Numerous diversion intakes, most of which are unscreened for fish, are located throughout the marsh; they are most commonly operated in early 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 otter trawling and beach seining 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 9 sloughs have been regularly sampled (see O'Rear and Moyle 2008).

Trawling was conducted using a 4-seam otter trawl with a 5 ft X 14 ft (1.5 m X 4.3 m) opening, a length of 17 ft (5.3 m), and mesh sizes of 1.4 in (35 mm) stretch in the body and 0.24 in (6 mm) stretch in the cod end. The otter trawl was towed at approximately 2.5 mph (4 km/hr) for 5 minutes in small sloughs and, to compensate for small catches, 10 minutes in large sloughs. In upper Suisun and Denverton sloughs, monthly sampling was augmented with 3 or 4 hauls at each site with a 33 ft (10 m) beach seine having a stretched mesh size of 0.24 in (6 mm). For each site, temperature (degrees Celsius, °C), salinity (parts per thousand, ppt), and specific conductance (microSiemens, μS) were recorded with either a Yellow Springs Instruments (YSI) 85 or 95 meter. Dissolved oxygen (DO) parameters (milligrams per liter, mg/l, and % saturation), first sampled in 2000, were also measured with the YSI 95. Water transparency (Secchi depth, cm), tidal stage (ebb, flood, high, low), and water depths (meters, m) were also recorded.

Contents of each trawl or seine were placed into large containers of water. Fishes were identified, measured to the nearest millimeter standard length (mm SL), and returned to the water. 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. The Siberian prawn was 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 request from T. A. O'Rear.

Environmental Conditions

Net Delta Outflow

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

Like 2007, calendar year 2008 was dry. Above average precipitation in January elevated Delta outflow to its yearly maximum of about 48,000 cubic feet per second (cfs; 1,359 cubic meters per second (cms); Dayflow 2008); storms at the end of January and beginning of February also increased the amount of water leaving the Delta (Dayflow 2008; Figure 2). Late February storms raised Delta outflow into the beginning of March; outflow declined and remained low through the remainder of spring and throughout summer (Figure 2). 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.

Calendar year 2009 started off with a very dry January; consequently, Delta outflow remained low while marsh salinities stayed high (Dayflow 2009; Figures 2 and 3). However, a series of storms hit the state throughout February and into March, elevating Delta outflow. Outflows generally subsided through the latter part of March and most of April, during which precipitation was weak (Figure 2). The final storm of spring occurred in early May, raising Delta outflow to nearly 30,000 cfs (850 cms). Following this storm, Delta outflow subsided until spiking dramatically in the middle of October when the remnants of Typhoon Melor made land and caused heavy precipitation. Relatively small storms in November and December mildly increased Delta outflow to close out the year.

Both 2008 and 2009 received below-average precipitation. However, the precipitation pattern and the resultant Delta outflow differed between the 2 years. First, Delta outflow in 2009 did not increase substantially until February, a month later than the previous year. Second, the storm during May 2009 contributed to Delta outflow remaining above 10,000 cfs (283 cms) for a month and a half later than in 2008. Finally, the first large Delta outflows of autumn in 2009 hit the marsh a month earlier than in 2008. These differences in hydrology likely affected, both directly and indirectly, our catches of fish.

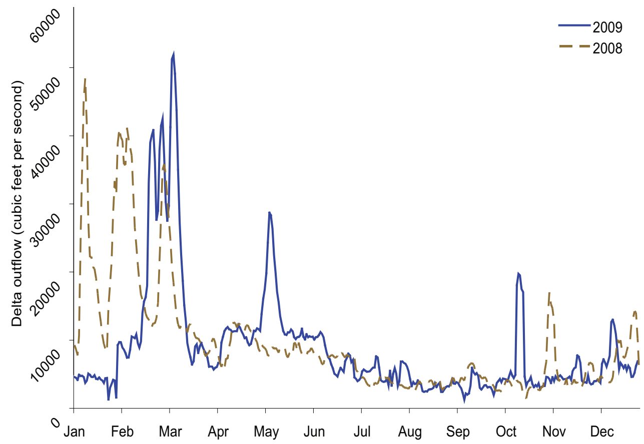

Figure 2 Daily Delta outflow for 2008 and 2009 (http://www.usbr.gov/mp/cvo/vungvari/doutdly.prn).

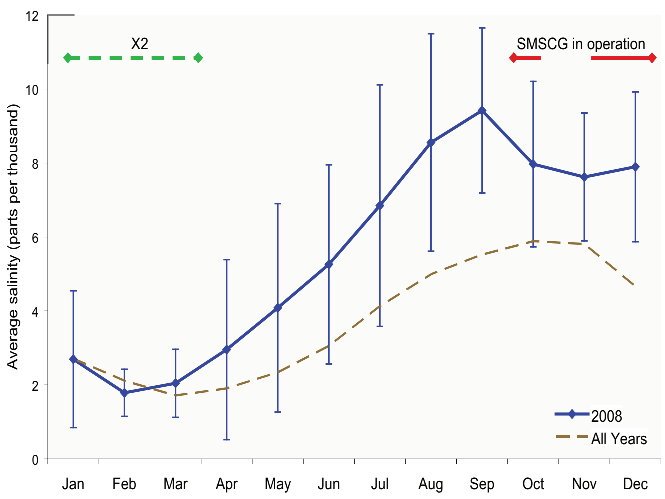

Figure 3 Average monthly salinities for 2008 and from 1980 to 2009 ("all years"), with timing of important events. Error bars are standard deviations for 2008.

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 saltiest recorded since 1992. Average monthly salinities in 2008 were considerably higher than that for the all-year (1980-2009) averages for much of spring, all of summer, and early autumn (Figure 3). The Suisun Marsh Salinity Control Gates went into operation from October 2 to October 14, the latter half of November, and most of December, noticeably reducing salinities in the marsh. Similar to 2008, the average monthly salinities in 2009 were higher than the average for all years except in March and May (Figure 4). However, salinities in 2009 remained lower than in 2008 from May through December (Figures 3 and 4). Coupled with the intense rainfall of October 2009, these lower salinities allowed the marsh to remain fresh enough, without operation of the Suisun Marsh Salinity Control Gates, for duck pond diversions.

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 (Figure 3). Somewhat differently, the salinity gradient was present throughout 2009, even during the wetter months of February and March (Figure 4). For the most part, the disparity in salinities was driven by very high values in our 2 upper Goodyear Slough sites; during March, for example, the salinity of the 2 upper Goodyear sites averaged 7.2 ppt (7.2 g/L), while the next highest salinity recorded was 2.1 ppt in Denverton Slough. Circulation in upper Goodyear Slough is often poor (Culberson et al. 2004), which probably contributed to the omnipresent gradient observed in 2009.

The location of X2, the distance in kilometers from Golden Gate Bridge along the thalweg to the near-bed water with salinity of 2 ppt, is associated with the historically productive low-salinity zone and high abundances of phytoplankton, macroinvertebrates, and several fishes (Jassby et al. 1995, Kimmerer 2004). 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 3); X2 was within the marsh for 21% of 2009, mainly during March, May, and early June (Figure 4). During 2008, X2 was in Suisun Marsh before the young-of-year of most fishes had hatched or migrated to the marsh, while it was within the marsh in 2009 when many of these fishes began to recruit. Consequently, few marsh larvae or juveniles were likely to have benefited from conditions often associated with X2 in 2008, yet our higher catches of some fishes during May and June of 2009 may have been attributable, at least in part, to X2 position.

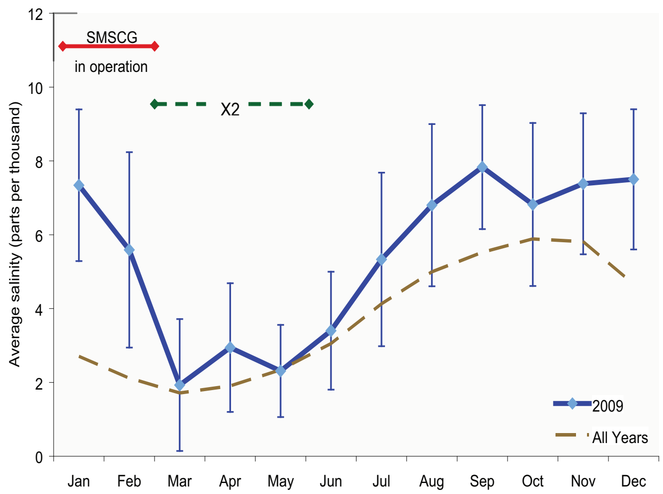

Figure 4 Average monthly salinities for 2009 and from 1980 to 2009 ("all years"), with timing of important events. Error bars are standard deviations for 2009.

Dissolved Oxygen

Disolved 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 highest 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, summer, and late autumn relative to the averages for all years. Additionally, the average monthly minimum for 2008 (5.95 ppm (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 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 2 lowest oxygen concentration values were measured in April and October (2.2 ppm) in Goodyear Slough.

The overall monthly pattern for DO during 2009 also followed the pattern for all years, with concentrations highest in winter, lower in spring and summer, and at a minimum in autumn; however, the overall trend was lower than in an average year (Figure 5). Disolved Oxygen was notably high in April, which was probably due to high wind speeds during our first day of sampling. Disolved Oxygen concentrations were especially low in October, particularly in upper Goodyear Slough and sloughs of the northwest marsh (i.e., Peytonia, Boynton, and upper Suisun sloughs). In fact, upper Goodyear Slough was anoxic when sampled in October, resulting in the deaths of adult splittail (*Pogonichthys macrolepidotus*), adult striped bass (*Morone saxatilis)*, threespine stickleback (*Gaterosteus aculeatus*), and Mississippi silversides (*Menidia audens*; Figure 6). While the water in the northwest marsh was not anoxic when sampled, it still averaged just 3.10 ppm (3.10 mg/L), with measurements below 3.0 ppm in both Peytonia and Boynton sloughs. These low concentrations coincided with both a large storm and duck club water diversions and discharges. The storm likely washed large amounts of organic material into the sloughs; with the water still relatively warm, decomposition rates were probably very high. Additionally, black anoxic water was observed being discharged from diked wetlands into the sloughs as part of autumn flood-up and pond recirculation. Consequently, what little oxygen remained in sloughs of the western marsh was quickly depleted. Conversely, oxygen concentrations were much higher (mean = 6.4 ppm) in the sloughs of the eastern marsh (i.e., Denverton, Nurse, and Montezuma sloughs), which have both less duck club outfalls per river-kilometer (Matern et al. 2002) and better circulation.

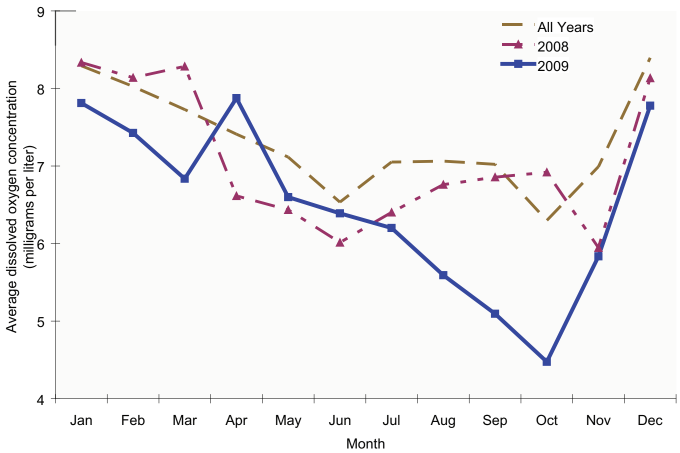

Figure 5 Monthly average dissolved oxygen concentrations for 2008, 2009, and from 2000 to 2009 ("all years").

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

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

The magnitude of freshwater inflow (mainly from the Sacramento River) is the primary determinant of water transparency in Suisun Marsh (O'Rear and Moyle 2008). Transparencies in the marsh are usually lowest in spring when river flows are highest; conversely, transparency generally reaches a maximum in October when river flows are at their annual minimum. As a result, the trend in average monthly transparencies often mirrors that for salinity. Both 2008 and 2009 were no exception, with monthly average transparencies higher than the averages for all years during summer and much of autumn in 2008 and for all months but March in 2009 (Figure 7).

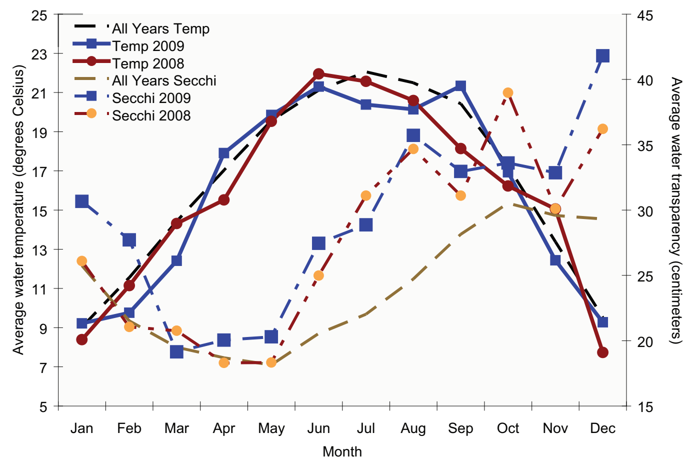

Figure 7 Monthly average temperatures and transparencies for 2008, 2009, and from 1980 to 2009 ("all years").

Trends in Invertebrate Ecology

Four plankton-feeding macroinvertebrates are commonly captured by otter trawl in Suisun Marsh: California bay shrimp, Siberian prawn, Black Sea jellyfish, and overbite clam. Annual catch of California bay shrimp has been highly variable, although decreasing trends in abundance were evident in the early 1980s and early 2000s (Figure 8). While catch of Siberian prawn, first captured in the marsh during 2002 (Schroeter et al. 2006), has also been variable, it has mirrored the catch for California bay shrimp from 2004 to 2009 (Figure 8). Black Sea jellyfish were first captured in 1981 and have been present in trawls during most years of the study's history, while overbite clam was not recorded until 1990 (Figure 8). Both the clams and the jellyfish exhibited increasing trends in the early 2000s and are now commonly captured relative to the 1980s and 1990s (Figure 8).

Otter trawl annual catch per unit effort for all 4 macroinvertebrates declined from 2007 to 2008 (Figure 8). The decrease in abundance was more precipitous for Siberian prawn and California bay shrimp than for Black Sea jellyfish and overbite clam (Figure 8). 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.

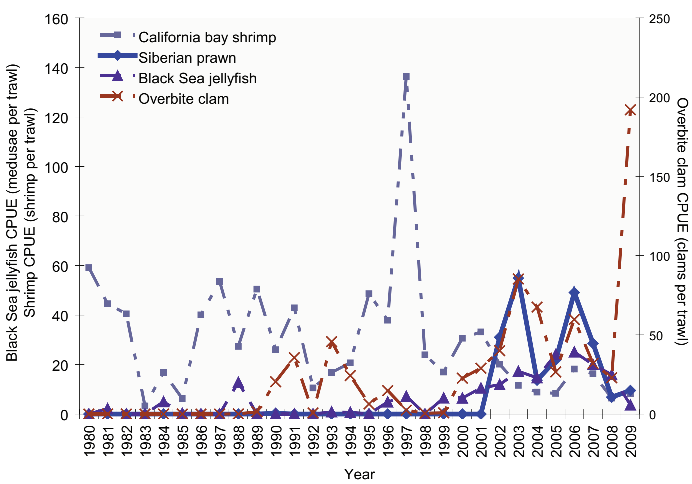

Figure 8 Annual otter trawl catch per unit effort for 4 common invertebrates in Suisun Marsh.

In contrast to 2008, otter trawl annual catch per unit effort for California bay shrimp and Siberian prawn increased slightly in 2009 (Figure 8). However, overbite clam and Black Sea jellyfish increased and decreased dramatically, respectively, from 2008 to 2009 (Figure 8). In fact, the highest annual catch per unit effort for overbite clam ever in the study's history was recorded in 2009, while Black Sea jellyfish medusae were at their lowest level since 1998. The low abundance of Black Sea jellyfish medusae is especially noteworthy given the favorable abiotic environment [i.e., salinity = 3-7 ppt, water temperature > 66°F (19°C); Schroeter 2008] present during the summer of 2009.

The pattern in the monthly shrimp catch in 2008 and 2009 was similar to that in 2007 (O'Rear and Moyle 2008), although the numbers were considerably lower (Figures 9 and 10). The highest catches of California bay shrimp were made in spring concomitant with increasing salinities (Figure 9), which was probably due to recruitment of the shrimp into the marsh from Suisun and San Pablo bays (Gewant and Bollens 2005). Consistent with differences in hydrology, the first large catch of California bay shrimp occurred 1 month later in 2009 relative to 2008. The geographic distribution of the catch indicates that many of the marsh's California bay shrimp originate downstream of the marsh: 43% of the total catch was made in the lower Goodyear Slough and lower Suisun Slough sites in 2008, and, while they were ubiquitous, California bay shrimp were always most abundant in the southwest marsh throughout 2009. Conversely, Siberian prawn peaked in September during 2008 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. In 2009, however, the trend in catch closely mirrored that for California bay shrimp (Figure 10), although high Siberian prawn catches were made in September and October. Siberian prawns were more abundant in fresher northwest and eastern regions of the marsh during 2009 (e.g., 45% of the total catch was from Denverton and upper Suisun sloughs) while rare in the southwest and central marsh, suggesting a predilection for fresher, more anthropogenically altered sloughs (Emmett et al. 2002).

As in previous years, overbite clams reached their highest abundance during summer (Figures 9 and 10; O'Rear and Moyle 2008). During 2008, the bulk of the overbite clam catch (76%) was made in lower Suisun and Goodyear sloughs. While the annual catch per unit effort for 2009 was the highest ever recorded, almost the entire catch (99%) came from the slough that has historically hosted high densities: lower Suisun. Overbite clams were never as abundant in any of the other sloughs, and they were completely absent from the eastern marsh (i.e., Denverton, Nurse, and Montezuma sloughs). Consequently, it appears that overbite clams have become denser in regions of the marsh where they had already been established rather than invading new areas.

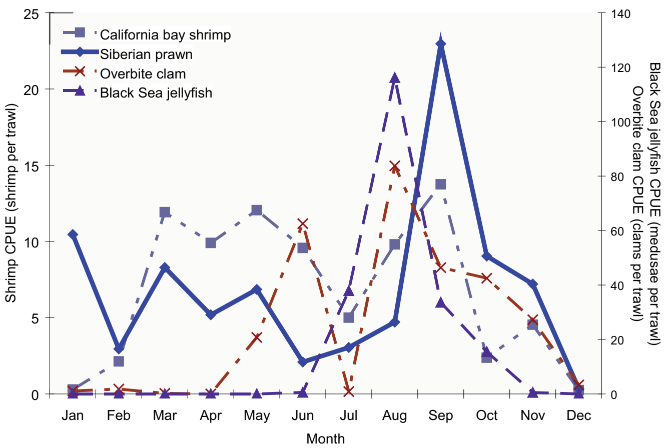

Figure 9 Monthly otter trawl catch per unit effort during 2008 for 4 common invertebrates in Suisun Marsh.

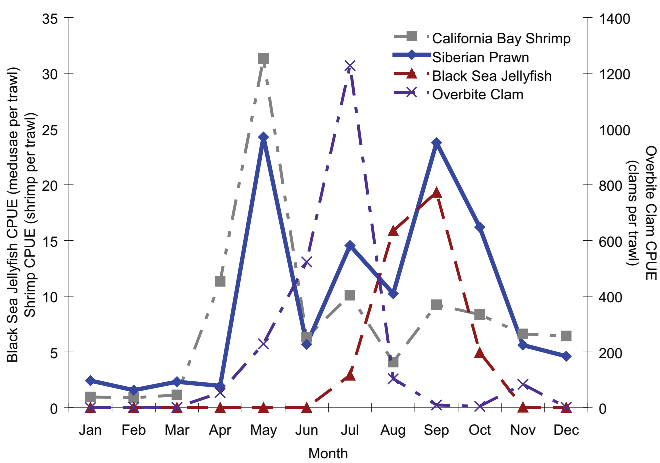

Figure 10 Monthly otter trawl catch per unit effort during 2009 for 4 common invertebrates in Suisun Marsh.

Similar to overbite clam, the monthly catch pattern for Black Sea jellyfish was typical, with medusae first appearing in summer, reaching their peak in late summer, and rapidly declining in early autumn (Figures 9 and 10; O'Rear and Moyle 2008, O'Rear and Moyle 2009). Medusae were found throughout the marsh and were most abundant in the northwest marsh; however, they were always rare in lower Suisun and Goodyear sloughs. As mentioned previously, the low catch of medusae in 2009 is surprising given the favorable abiotic environment.

The overall trend in mysid catch in the marsh has declined since the study's inception (Figure 11), mirroring the trend seen in other parts of the estuary (e.g., the Delta; Fish et al. 2009) and affecting the food web in the marsh (Feyrer et al. 2003). Catch per unit effort in 2008 and 2009 was the third lowest and second lowest in the study's history, respectively (Figure 11). However, the timing of the peak catches between the two years differed, with higher catches occurring later in 2009 concomitant with the recruitment of the bulk of young-of-year fishes into the marsh (Figure 12).

Trends in Fish Ecology

Otter Trawls

Annual fish per trawl generally declined in the first 15 years of the study (1980-1994); from then until 2006, it has increased somewhat and vacillated around a relatively stable mean (Figure 13; O'Rear and Moyle 2008). From 2006 to 2008, however, catch declined substantially, concurrent with lower Delta outflows and higher marsh salinities. The decrease in the annual catch per unit effort for native fish has been more precipitous and less variable than that for alien fishes (Figure 14). Catch per unit effort for alien fishes has been highly variable over the study's history (Figure 15).

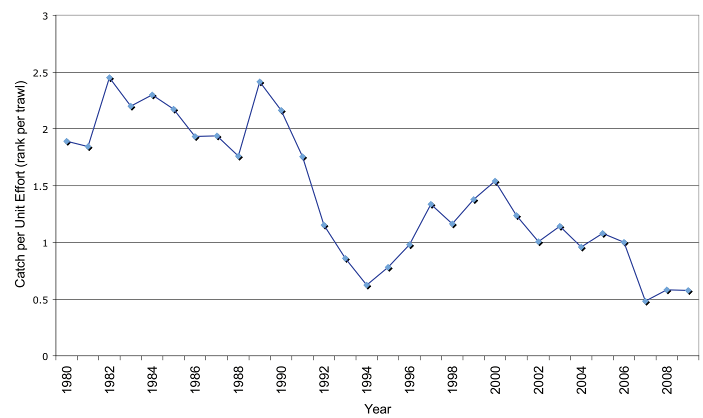

Figure 11 Annual otter trawl catch per unit effort for mysids.

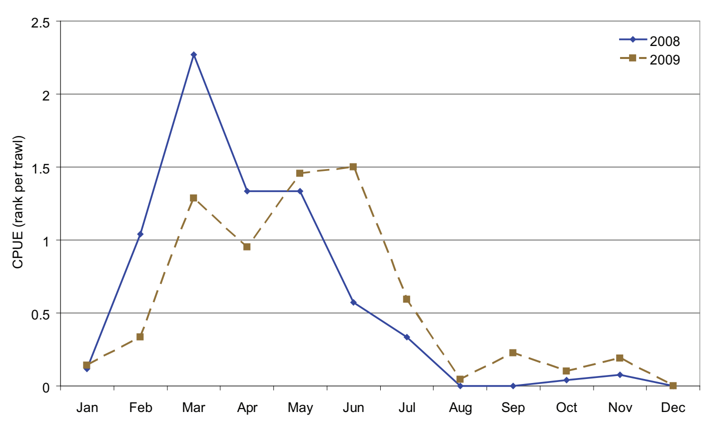

Figure 12 Monthly mysid rank catch per unit effort during 2008 and 2009.

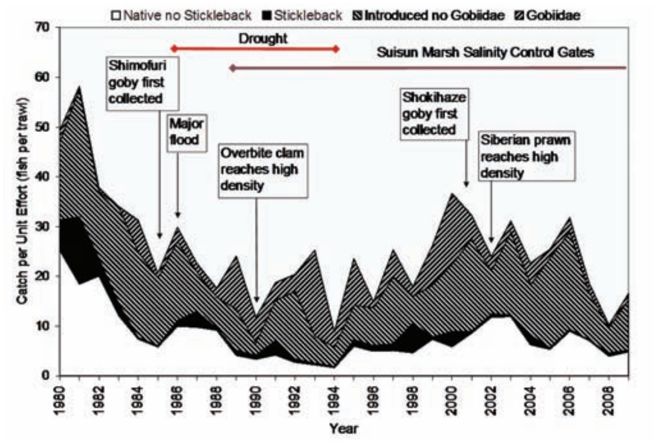

Figure 13 Annual otter trawl catch per unit effort from 1980 to 2009 for native fish without threespine stickleback, threespine stickleback, introduced fish without gobies, and gobies from 1980 to 2009, with timing of important events.

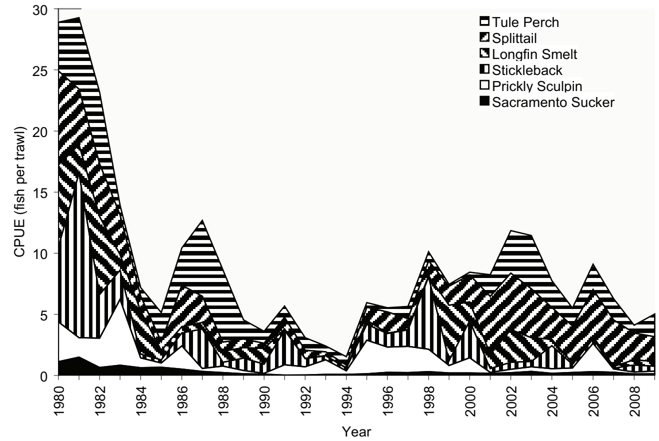

Figure 14 Annual otter trawl catch per unit effort for the 6 native fishes most commonly captured in Suisun Marsh.

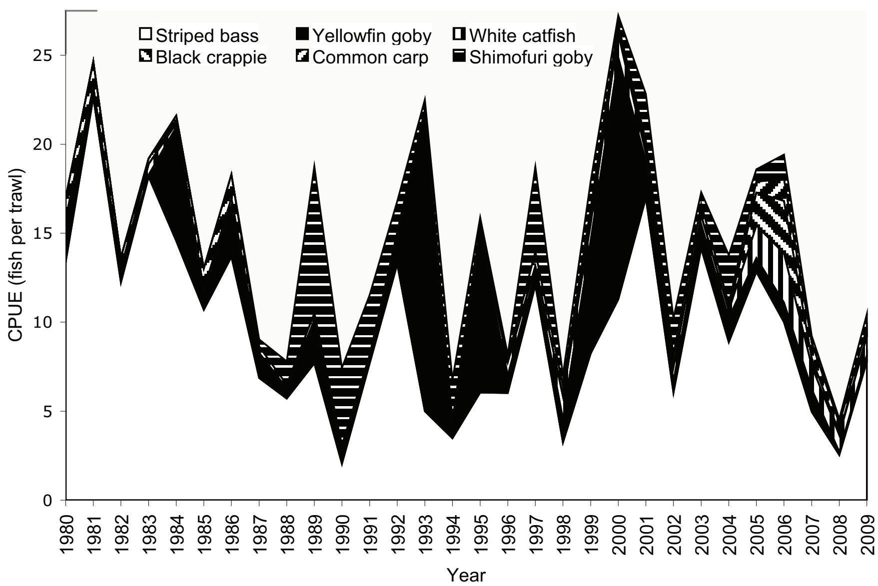

Figure 15 Annual otter trawl catch per unit effort for the 7 introduced fishes most commonly captured in Suisun Marsh.

2008

Annual otter trawl catch per unit effort for all fishes 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 fish per trawl, respectively; Figure 13). From 2007 to 2008, catch per unit effort for native fishes decreased by 37% (Figure 14) and decreased for alien fishes by 50% (Figure 15). This marked the second year in declining catch per unit effort for both classes of fishes since 2006.

Annual fish per trawl in 2008 for the 6 alien fishes most responsible for the numbers seen in the last few years [black crappie (*Pomoxis nigromaculatus*), shimofuri goby (*Tridentiger bifasciatus*), striped bass, threadfin shad (*Dorosoma petenense*), white catfish (*Ameiurus catus*), and yellowfin goby (*Acanthogobius flavimanus*)] plummeted relative to 2007 (Table 1). 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: Gelwick et al. 2001, O'Rear and Moyle 2008; 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 3). 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 1 young-of-year black crappie and no young-of-year white catfish were captured. The decline in the threadfin shad catch (Figure 17) 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 3 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.

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 3 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); conversely, yellowfin gobies require salinities of at least 5 ppt to reproduce successfully (Wang 1986). Additionally, though 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 (C*atostomus occidentalis*), and splittail] in the marsh saw their annual otter trawl catch per unit effort decline from 2007 to 2008 (Table 2). 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 (Sommer et al. 1997, Moyle et al. 2004), 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 3 species.

In sum, the otter trawl catch per unit effort for both native and alien fishes was very low and continued the decline seen from 2006 to 2007 (Figures 13, 14, and 15). 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 were responsible for 2008's numbers. However, it seems that low freshwater inflow and its effect on salinity partially contributed to the low 2008 values.

Table 1 Percent change in the annual otter trawl catch per unit effort (fish per trawl) for 6 of the most abundant alien 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%

Table 2 Percent change in annual otter trawl catch per unit effort (fish per trawl) for 3 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	Prickly Sculpin	Sacramento Sucker	Splittail
2007 CPUE	0.27	0.26	4.02
2008 CPUE	0.16	0.12	2.19
% Change	-41%	-54%	-46%

2009

Relative to 2008, annual otter trawl catch per unit effort for all fishes increased (10.25 fish per trawl to 16.62 fish per trawl) in 2009, although the year still had the fifth-lowest catch per unit effort in the study's 30-year history (Figure 13). The increase was mostly due to higher catches of alien species, the catch per unit effort of which nearly doubled from 2008 to 2009 (5.7 to 11.3 fish per trawl; Figure 13). Conversely, the annual otter trawl catch per unit effort for native species barely increased from 4.6 to 5.3 fish per trawl (Figure 14) and thus only weakly contributed to the change in the total catch from 2008 to 2009.

The higher annual otter trawl catch for alien fishes in 2009 was mostly due to striped bass, the catch per unit effort of which more than tripled from 2008 to 2009 (Table 3). Three other species were also more abundant in 2009 and contributed to the higher catch: yellowfin goby, shimofuri goby, and American shad (*Alosa sapidissima*; Table 3). Young-of-year fish comprised the bulk of the catch for all 4 species (Table 3). Conversely, black bullhead (*Ameiurus melas*) continued the decline began in 2008 and were nearly nonexistent in 2009 (Table 3).

Compared to 2008, annual otter trawl catch-per-unit-effort values for native fishes in 2009 either remained constant (e.g., Sacramento sucker) or slightly declined [e.g., longfin smelt (*Spirinchus thaleichthys*)]. A notable exception was tule perch (*Hysterocarpus traski*), the catch per unit effort of which nearly tripled from 0.64 to 1.86 fish per trawl.

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

Beach Seines

Unlike the annual otter trawl catch per unit effort, annual beach seine catch per unit effort has increased since the study's inception (Figure 16). Similar to otter trawl catches, variability in native fish catch per unit effort between years has been much less than that for alien fishes (Figure 16). 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. Alien fishes, particularly Mississippi silverside (*Menidia audens*), have dominated the catch.

Table 3 Percent change in annual otter trawl catch per unit effort (fish per trawl) for 5 of the most common alien species caught in Suisun Marsh (% increases are equivalent to percentage points, such that a 100% increase indicates that the value has doubled) from 2008 to 2009, and the proportion of 2009 otter trawl catch comprised of young-of-year (YOY[a]) fish.

Species	Striped Bass	Yellowfin Goby	Shimofuri Goby	American Shad	Black Bullhead
2008 CPUE	2.53	0.18	0.25	0.23	0.53
2009 CPUE	7.79	0.36	0.80	0.41	0.02
% Change	208%	99%	217%	78%	-96%
% YOY in 2009	75%	85%	96%	95%	0%

[a]YOY striped bass = fish less than 109 mm SL captured after April, YOY yellowfin goby = fish captured after May smaller than 140 mm SL, YOY shimofuri goby = all fish captured after June, YOY American shad = all fish captured after June smaller than 120 mm SL; YOY black bullhead = all fish smaller than 100 mm SL captured after July; Moyle 2002, O'Rear, unpublished data.

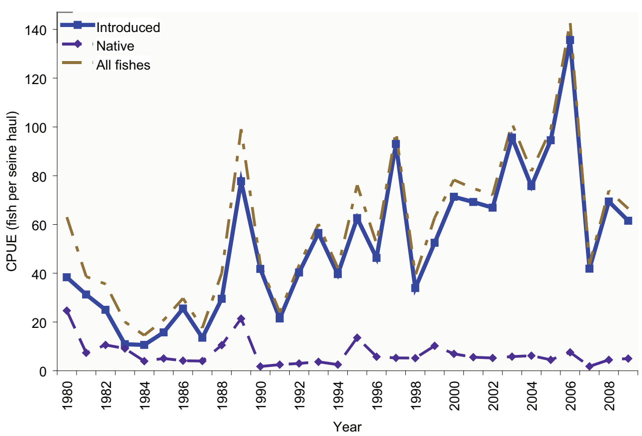

Figure 16 Annual beach seine catch per unit effort for introduced, native, and all fishes.

2008

While the annual otter trawl catch per unit for all fishes declined from 2007 to 2008, the annual beach seine catch per unit effort for all fishes increased from 43.6 to 73.9 fish per seine haul (Figure 16). 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 alien fishes (41.8 to 69.4 fish per seine haul).

Of 10 fishes commonly caught in the marsh that declined in the otter trawl catches from 2007 to 2008, 7 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 were also more abundant in 2008 beach seines than in 2007. While it is tempting to ascribe these higher beach seine catches to more fish residing inshore rather than in main-channel habitats, such an assertion should be held cautiously. The number of individuals caught by seining in 2008 for each of 5 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 1 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 higher inshore abundances. 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).

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 3 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.

2009

Annual beach seine catch per unit effort from 2008 to 2009 decreased from 73.9 to 66.5 fish per haul. The lower 2009 catch was almost solely due to a reduction in numbers of alien fishes, which declined by nearly 8 fish per seine haul (Figure 16). This drop was mainly due to smaller catches of striped bass and yellowfin goby, which decreased by 64% and 48%, respectively, from 2008 to 2009 (Table 4). Additionally, American shad, while never very abundant in seine hauls, also decreased from 2008 to 2009 (28 to 10 fish). These changes are consistent with greater food supplies in open-water habitats. Conversely, annual catch per unit effort for native fishes in 2009 (4.97) was about the same as in 2008 (4.49). This was mainly due to a drop in the staghorn sculpin (*Leptocottus armatus*; 91 less fish in 2009) catch being nearly equaled by a greater threespine stickleback catch (95 more fish in 2009).

Fish Species of Interest

Threadfin Shad

Otter trawl catches of threadfin shad were relatively high in the first 8 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 17). 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.

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 18). Second, threadfin shad were most abundant during the last 5 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 in Denverton Slough; however, it was not until October that they were seined in upper Suisun Slough. These latter 2 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.

The monthly catch patterns in 2009 for both beach seines and otter trawls (Figure 18) were similar to those of 2008 (O'Rear and Moyle 2009) and reflect little recruitment. Very few fish were captured during spring or early summer via either sampling method; for the latter half of the year, threadfin shad were present but in low numbers. Beach seine catch was highest in August (with 86% of the catch from Denverton Slough) and declined thereafter concurrent with the otter trawl catch generally increasing (Figure 18). Similar to previous years (Moyle et al. 1986, Matern et al. 2002, O'Rear and Moyle 2008, O'Rear and Moyle 2009), threadfin shad were most abundant in otter trawls during autumn and winter (Figure 18) in First Mallard Slough, which is the smallest slough in the marsh we sample.

Table 4 Annual beach seine catch and catch per unit effort for 3 alien marsh fishes in 2007 and 2008.

Species	2007		2008		2009	
	Catch	*CPUE*	*Catch*	*CPUE*	*Catch*	*CPUE*
Shimofuri Goby	*49*	*0.61*	*170*	*2.24*	*251*	*3.35*
Striped Bass	*225*	*2.81*	*779*	*10.25*	*277*	*3.69*
Yellowfin Goby	*387*	*4.84*	*586*	*7.71*	*306*	*4.08*

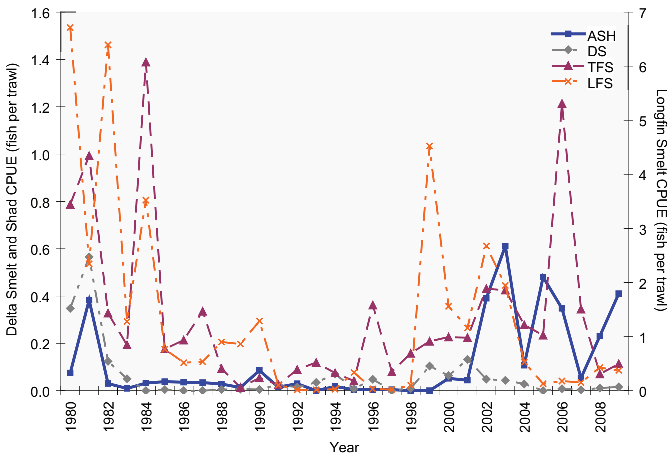

Figure 17 Annual otter trawl catch per unit effort for threadfin shad, American shad, delta smelt, and longfin smelt.

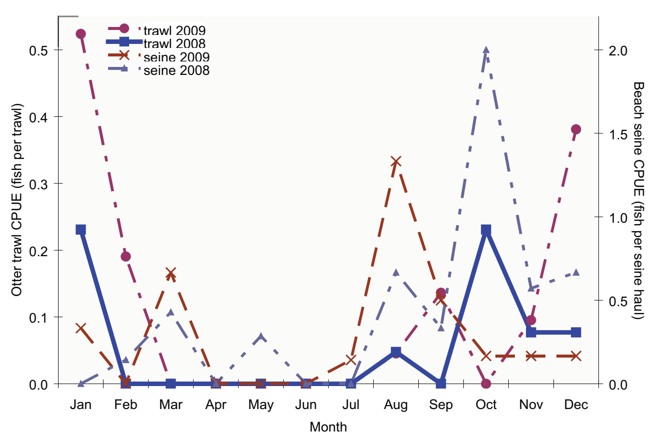

Figure 18 Monthly otter trawl and beach seine catch per unit effort for threadfin shad.

The ecology of threadfin shad in the marsh is intriguing, particularly their consistent appearance in otter trawls towed in smaller sloughs during late autumn and winter. It appears that abiotic reasons are insufficient to explain these patterns. For instance, threadfin shad are very sensitive to both absolute and rapid changes in temperatures when the water is cold (Griffith 1978, Moyle 2002), both of which are most extreme in smaller sloughs during the colder months (O'Rear, unpublished data). Rising salinities could push threadfin shad from Suisun and San Pablo bays into the fresher interior of the marsh, which would be consistent with both our higher otter trawl catches in autumn and the low abundance of threadfin shad in Goodyear Slough. However, 2 lines of evidence reject this conjecture. First, threadfin shad always show up in otter trawls in early autumn, regardless of the salinity. Second, if salinity were the major factor concentrating threadfin shad, then, once Delta outflows freshen the marsh in winter, more of the marsh would be hospitable and thus threadfin shad should disperse. This would be an expected result given more stable temperatures in the larger sloughs. Since First Mallard Slough is the shallowest we sample and hence is probably where our capture efficiency is greatest, then our otter trawl catches should decline in winter as threadfin shad spread out in the marsh. However, otter trawl catch per unit effort for the whole marsh usually reaches its maximum in January and February, mainly due to peak catches of threadfin shad in First Mallard Slough and another small slough (Peytonia) in the same months. It is likely that DO is not driving these patterns, either, because DO is nearly always higher in the larger sloughs. Instead, it appears that the threat of predation by adult striped bass might be partially responsible for the distribution of threadfin shad in the marsh. First, adult striped bass are most abundant in the marsh from October to March, spanning the period when we make our greatest otter trawl catches of threadfin shad. Second, adult striped bass can be especially dense in Denverton Slough, while they are usually much less abundant in upper Suisun Slough (O'Rear, unpublished data); assuming that shallow water would provide a refuge from predation, then this would explain why threadfin shad have been captured more commonly in beach seines in Denverton Slough yet are much rarer in otter trawls, while the opposite pattern has been seen in upper Suisun Slough. Third, First Mallard Slough is very close to the confluence of Cutoff and upper Suisun sloughs, the junction of which often hosts a large aggregation of adult striped bass. First Mallard Slough is the shallowest slough we sample in the marsh; additionally, other fishes that striped bass are known to prey on (e.g., Mississippi silversides, splittail; Stevens 1966, Moyle 2002, Nobriga and Feyrer 2008) usually co-occur with threadfin shad in this slough during the cold months. Finally, adult striped bass have been seen attacking threadfin shad during autumn (Schroeter, personal communication, see "Notes").

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 17), during which

American shad were present in the marsh throughout much of the year, and the third-highest catch in the study's history was made in 2009.

American shad appeared unusually early in 2008, when relatively large catches were made of very small fish during April in Suisun Slough (Figure 19; O'Rear and Moyle 2009). In contrast, young-of-year American shad did not appear in our catches during 2009 until July (Figure 19), and these fish were substantially larger than those captured in April 2008 (61 mm SL and 30 mm SL, respectively). However, the timing of the 2009 catch is more consistent with both the spawning period (i.e., late spring; Moyle 2002) and the historical monthly trend seen in the marsh (O'Rear, unpublished data). The spike in Delta outflow in May of 2009 basically delayed salinity intrusion relative to 2008 by 2 months. Consequently, our later catch of American shad in 2009 may have been due to preferred salinities of larger fish not occurring in the marsh until July. However, the American shad captured during April 2008 may have been misidentified Pacific herring (Clupea pallasii), especially given both the strong Pacific herring year-class (Fish et al. 2009) and higher-than-average salinities in the marsh during 2008.

Consistent with previous years, American shad were most prevalent in the southwest marsh: 46% and 77% of the otter trawl catch in 2008 and 209, respectively, came from the lower Suisun and lower Goodyear Slough sites. Pelagic fishes (e.g., longfin smelt, American shad, striped bass) are often abundant in these sites (O'Rear and Moyle 2009) while being rare in upper Goodyear Slough, implying that sloughs in the southwest marsh with good water quality may provide planktonic food sources and thus favorable habitat for American shad.

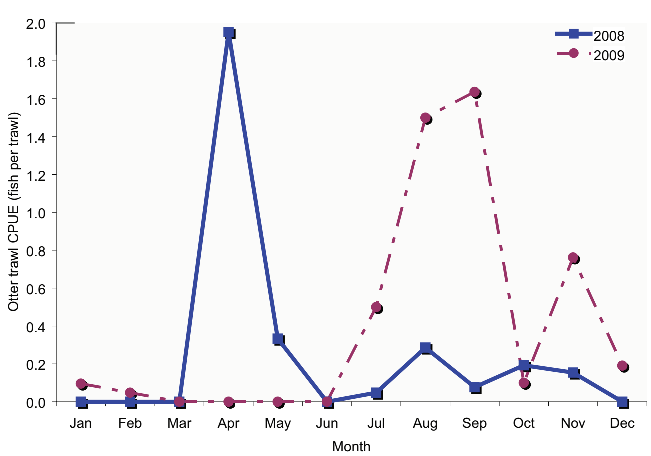

Figure 19 Monthly otter trawl catch per unit effort for American shad.

Delta Smelt

Since 1984, otter trawl catch of delta smelt (*Hypomesus transpacificus*) has been routinely low (less than 7 fish per year; Figure 17), tracking the estuary-wide decline in smelt numbers (Moyle 2002, Bennett 2005, California Department of Water Resources and Department of Fish and Game 2007). Although we have conducted just 66 midwater trawls over the study's history, it is still somewhat surprising that we have only captured 4 delta smelt from the water column of the large sloughs.

We captured 4 delta smelt in 2008 (Table 5). 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 2 delta smelt came from 1 otter trawl in lower Suisun Slough during October; these fish measured about 65 mm SL. Water quality was good in each trawl in which delta smelt were captured (Table 5).

We caught only 4 delta smelt with otter trawls in 2009; we never caught more than 1 delta smelt in any trawl. At least 3 of the 4 fish were adults (Table 5). All delta smelt were captured in December or January from the western marsh when water temperatures were low, salinities were moderate, and oxygen concentrations were high (Table 5).

The most common fish captured in trawls containing delta smelt was splittail, which occurred in 5 of the 6 otter trawls (Figure 20). Striped bass and tule were present in half of the trawls that captured delta smelt. Several other species, most of which were alien, were caught in 1 of the delta smelt trawls (Figure 20). In general, the assemblages of the trawls were disparate.

In summary, catch of delta smelt in Suisun Marsh during both 2008 and 2009 was very low, consisting of only 4 fish for each year. With the exception of the fish captured by midwater trawl, these fish did not appear until water temperatures had cooled and water quality was good. All otter-trawl-caught delta smelt were captured in the western marsh and were accompanied by different fish assemblages in each trawl. Consequently, water quality parameters appeared to be more strongly associated with the presence of delta smelt than the makeup of the fish assemblage.

Table 5 Standard length, sampling timing, and environmental data for Delta smelt captured in 2008 and 2009.

Slough	Standard Length (mm)	Sampling Date	Sampling Time	Water Temperature (°C)	Salinity (ppt)	Oxygen Concentration (mg/L)
First Mallard	60	29-Jan-08	16:00	8.4	2.6	*7.6*
Montezuma	50	19-Aug-08	12:40	20.8	5.5	*7.92*
Lower Suisun	65	22-Oct-08	10:32	16.6	10.9	*6.7*
Lower Suisun	70	14-Jan-09	10:00	8.7	9.4	*8.2*
Peytonia	70	14-Jan-09	14:54	9.6	5.3	*8.1*
First Mallard	80	15-Jan-09	8:00	8.1	6.2	*8.16*
Upper Suisun	50	15-Dec-09	7:10	8.5	5.6	*7.97*

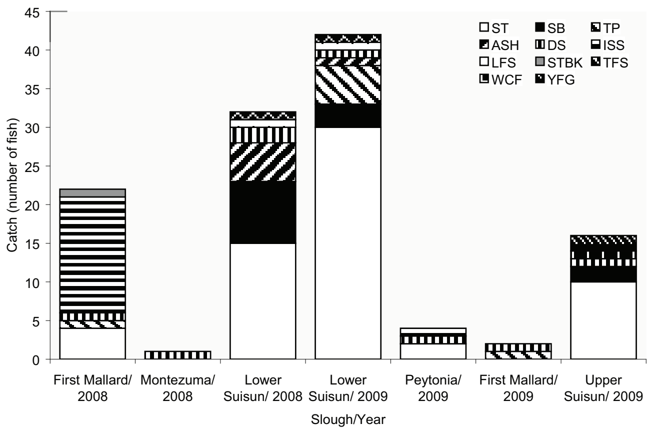

Figure 20 Fishes captured in trawls containing delta smelt (WCF = white catfish, TFS = threadfin shad, LFS=longfin smelt, ISS = Mississippi silverside, YFG = yellowfin goby, DS = delta smelt, ASH = American shad, TP = tule perch, SB = striped bass, ST = splittail, STBK = threespine stickleback).

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; Fish et al. 2009): catches were high in the early 1980s, were low throughout the dry years of the late 1980s and early 1990s, increased somewhat in the wetter years of the late 1990s and early 2000s, and declined to low levels again beginning in 2005 (Figure 17). 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; Moyle 2002, Bay Institute et al. 2007) 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 1 day in lower Suisun Slough and was comprised totally of young-of-year fish (Figure 21). 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 Grizzly and San Pablo bays 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 21), although the absolute numbers for each month were low (2, 7, 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.

The monthly catch pattern of post-larval longfin smelt in 2009 was very similar to that in 2008, albeit events occurred a month later in 2009: fish were first captured in April, reached their maximum density in May, declined to low levels thereafter, and were almost all captured in lower Suisun and lower Goodyear sloughs (Figures 21 and 22). Additionally, salinity in lower Suisun Slough (4.6 pt) when the peak catch of post-larval smelt was made (i.e., May) was similar to salinities when peak catches were made in 2007 and 2008 (4.4 and 3.7, respectively). Consequently, it appears that post-larval smelt were once again transported into the marsh with saltier water from Grizzly and San Pablo bays, with the shift in the timing of events between 2008 and 2009 due to the differences in Delta outflow.

Like in previous years, catch of longfin smelt increased through autumn (Figure 22). Most of these fish were probably adults migrating upstream to spawn. Just as in 2008, about two-thirds of the autumn catch came from lower Suisun Slough, although the total number in 2009 was lower than in 2008 (8 and 23 fish, respectively). However, 4 longfin smelt (70-105 mm SL) were seined in autumn of 2009 while none were in 2008.

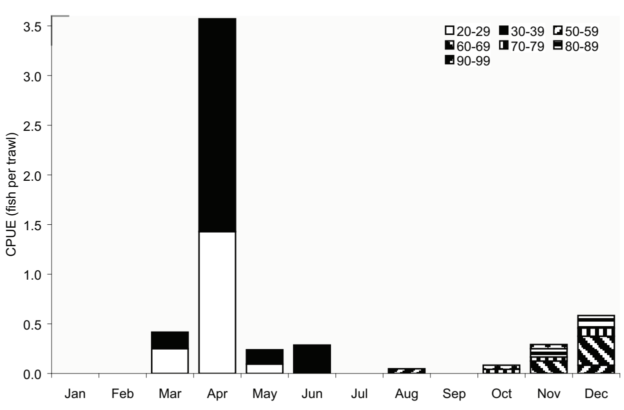

Figure 21 Monthly otter trawl catch per unit effort during 2008 for size-classes of longfin smelt.

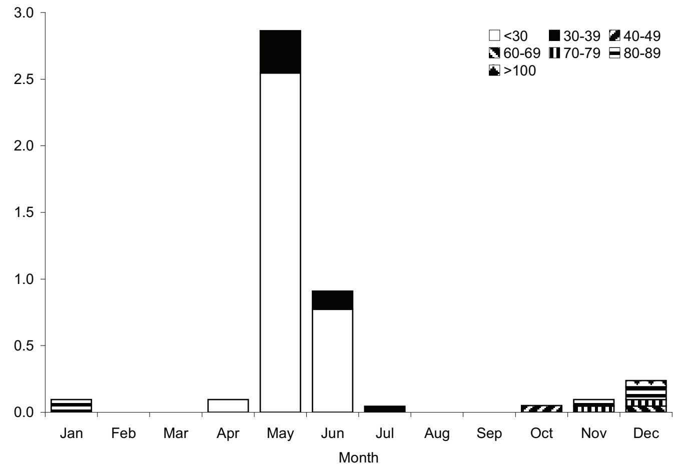

Figure 22 Monthly otter trawl catch per unit effort during 2009 for size-classes of longfin smelt.

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 substantially from 1980 to 1990 (Figure 23). From 1991 to 2008, catch per unit effort had no significant increasing or decreasing trends (Figure 23). 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 (Moyle 2002, California Department of Water Resources and Department of Fish and Game 2007).

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 1 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, our low

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

The pattern of 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 3 months of the year; additionally, a notable proportion of these catches consisted of fish longer than 306 mm SL (Figure 24). 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 24). 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-spawn adults.

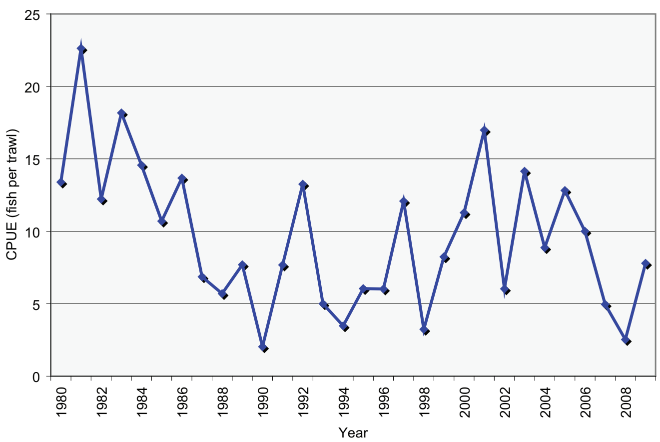

Figure 23 Annual otter trawl catch per unit effort for striped bass.

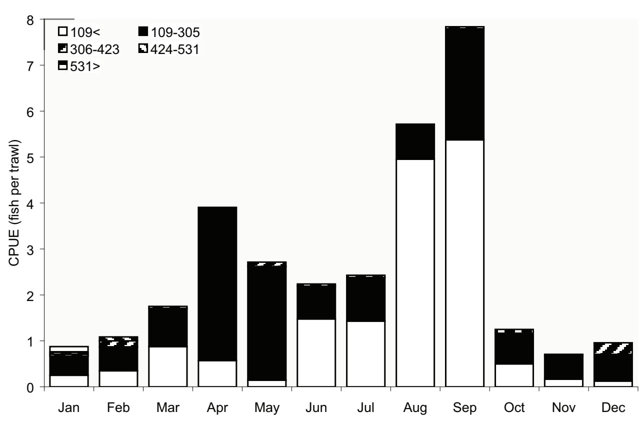

Figure 24 Monthly otter trawl catch per unit effort during 2008 for size-classes of striped bass.

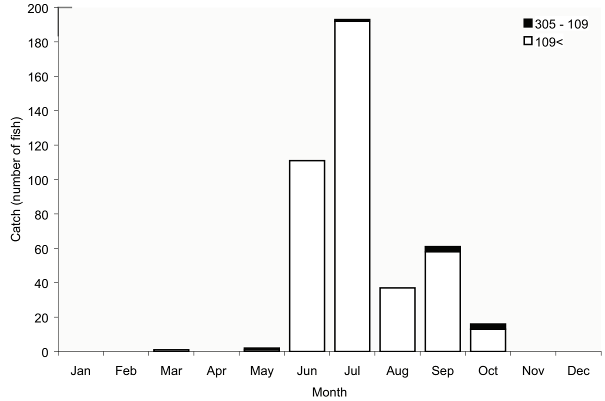

Figure 25 Monthly beach seine catch per unit effort during 2008 for size-classes of striped bass.

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 5 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 25). However, our monthly beach seine catch per unit effort peaked 1 month before the otter trawl catch increased substantially; 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 because otter trawl catches were so low.

As previously discussed, the annual catch per unit effort in 2009 increased for otter trawls while decreasing for beach seines, implying that food supplies in open water were more abundant than in 2008. This may have been the case in June, when otter trawl catches of young-of-year fish and mysids were at their peaks and X2 was within the marsh (Figures 26 and 12). After June, however, monthly otter trawl catches of young-of-year striped bass began to rapidly decrease, especially compared to the averages for all years (Figure 27); mysid abundances also began to decline (Figure B). Additionally, both Black Sea jellyfish medusae and young-of-year shimofuri goby began to recruit to the otter trawls in July (Figure 26). While the specific species of zooplankton that striped bass, shiomfuri gobies, and Black Sea jellyfish consume have been different, all 3 species have been shown to feed on crustaceans in the plankton (Feyrer et al. 2003, Schroeter et al. 2008, Grimaldo et al. 2009, Moore, personal communication, see "Notes"). In August, otter trawl catch of shimofuri gobies plummeted concomitant with both a higher Black Sea jellyfish otter trawl catch and a higher shimofuri goby beach seine catch (Figure 26). In fact, the parallel trends between the monthly shimofuri goby beach seine catch and the monthly Black Sea jellyfish otter trawl catch are striking, especially in light of predation by Black Sea jellyfish medusae on goby larvae (Schroeter 2008). In September, the beach seine catch for striped bass increased while the otter trawl catch continued to decline (Figure 26). These patterns suggest that while pelagic food supplies may have been abundant in June, they quickly became limiting and forced the young-of-year of both striped bass and shimofuri gobies inshore (Figures 26 and 12). While the aforementioned is plausible, it should be held very cautiously: 2 extremely large catches of young-of-year striped bass were made in First Mallard and Montezuma sloughs in June and July, respectively, and thus could have biased high the average otter trawl catches in those months.

Similar to previous years, lower Suisun and First Mallard sloughs had higher otter trawl catch-per-unit-effort values (10.1 and 24.7 fish per trawl, respectively) than most of the other sloughs during 2009, which has been attributed to shallow depths (Schroeter et al. 2006). Conversely, Montezuma Slough had the second-highest catch per unit effort among all sloughs in 2009, mainly due to very high catches in June and July (51 and 196 fish, respectively). However, 94% of the striped bass caught in Montezuma Slough during June and July came from our downstream site. This site has a shallow shoal on the river-left bank. In July, we observed small fish being pursued by larger fish on this shoal just before we trawled through it. The abundance of small yearling and young-of-year striped bass in that trawl, coupled with the cannibalistic habits of striped bass (Stevens 1966, Moyle 2002), suggests that the bulk of those striped bass were captured on that shoal. Thus, despite Montezuma Slough being the deepest slough we sample, it still seems that striped bass were most abundant near or in shallow water.

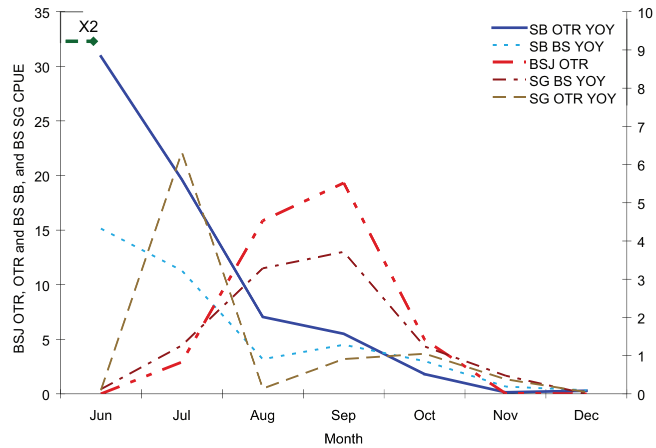

Figure 26 Monthly beach seine catch per unit effort for striped bass and shimofuri goby and otter trawl catch per unit effort for striped bass, shimofuri goby, and Black Sea jellyfish during the latter half of 2009.

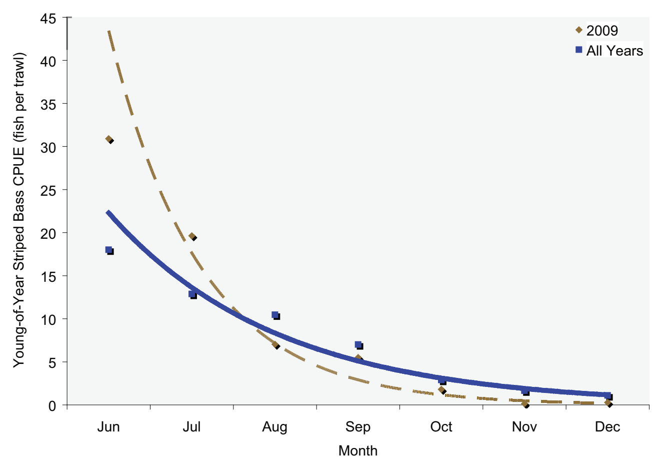

Figure 27 Monthly otter trawl catch per unit effort for young-of-year striped bass during 2009 and from 1980-2009 ("all years").

Splittail

Splittail have been the most commonly captured native fish in Suisun Marsh. Not including 1986 and 1987, splittail annual otter trawl catch per unit effort declined considerably from 1980 to 1994; this was mirrored fairly well by the beach seine catch per unit effort, which was more variable over that period (Figure 28). From 1995 to 2006, otter trawl catch per unit effort generally increased and was accompanied by large beach seine catches in years of high springtime Delta outflow (e.g., 1995, 2006). However, otter trawl catches have declined severely since 2007 concurrent with decreasing beach seine catches (Figure 28). The otter trawl and beach seine catch patterns are likely influenced by the area and duration of flooding in Yolo Bypass for spawning and rearing during the spring (Sommer et al. 1997, Moyle et al. 2004); consequently, our higher catches occur during and just following years of high river flows.

The annual splittail otter trawl catch per unit effort dropped by almost half from 2007 to 2008 (Table 2). This was primarily due to low numbers of fish from the 2007 and 2008 year-classes in our 2008 catches: 39% of the 2008 catch was comprised of fish from the 2006 year-class (i.e., those between 170 and 216 mm SL; Moyle 2002), with the remaining 61% consisting of fish spawned in different years. As discussed above, lack of floodplain inundation in 2007 and 2008 probably contributed to the poor representation of these year-classes in the 2008 catch.

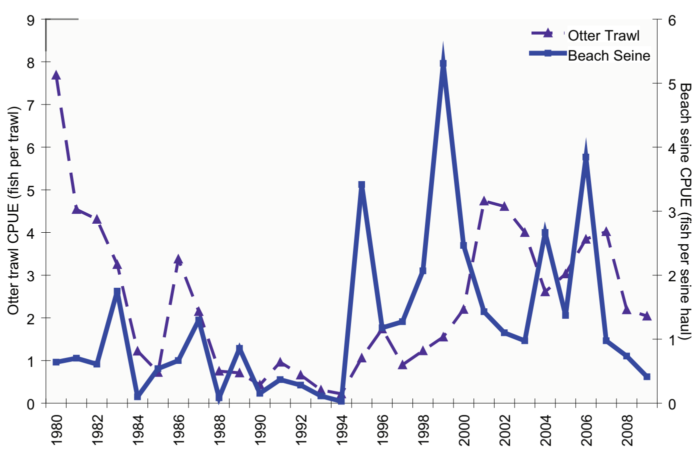

Figure 28 Annual otter trawl and beach seine catch per unit effort for splittail.

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 29). The lower catches in February and March may have been partially due to movement of pre-spawn 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 29). Catch per unit effort was also substantially higher for fish measuring 171 mm to 215 mm SL in April (Figure 29), the timing of which corresponds to increasing salinities in the marsh. These fish 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.

In 2009, annual otter trawl catch per unit effort reached its lowest point (2.0 fish per trawl) in the last 10 years, and the 2009 annual beach seine catch per unit effort was the lowest recorded (0.4 fish per seine haul) since 1994 (Figure 28). As in 2008, this was primarily due to a lack of recruitment: young-of-year fish comprised only 13% of the otter trawl catch, and the beach seine catch, the bulk of which consists of young-of-year, was similarly low. Consequently, lack of considerable floodplain inundation during spring of 2009 probably resulted in poor conditions for reproductive success and thus our low catches.

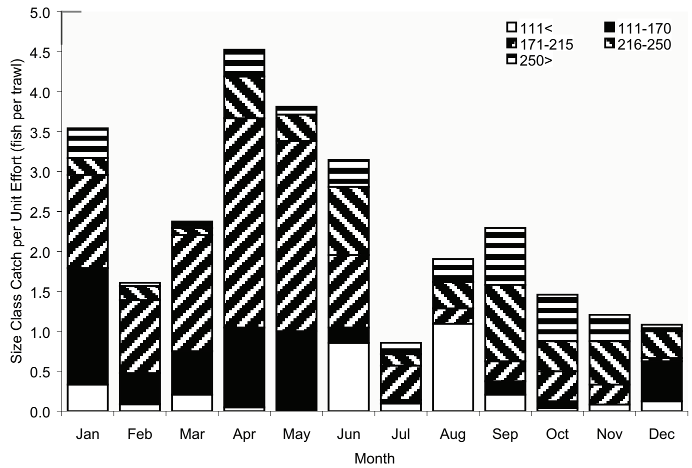

Figure 29 Monthly otter trawl catch per unit effort during 2008 for size-classes of splittail.

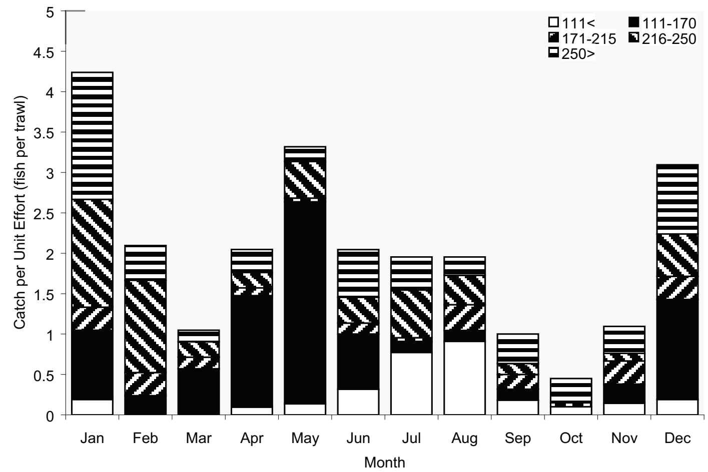

Figure 30 Monthly otter trawl catch per unit effort during 2009 for size-classes of splittail.

Similar to the 2008 year-class distribution, fish spawned in 2006 made up a substantial portion (22%) of the total otter trawl catch (O'Rear and Moyle 2009) in 2009. However, one-third of the otter trawl catch in 2009 was comprised of fish measuring 111-170 mm SL. Most of these fish were spawned in 2008 and, considering the low recruitment in the marsh for that year, intimates that survival for this cohort was high. Conversely, travel time from upstream habitats to the marsh may have been longer for the 2008 year-class, delaying recruitment into the marsh until 2009.

The trend in the monthly otter trawl catch in 2009 was typical. Catch of adult fish declined in March and April (Figure 30), reflecting movement of these fish either upstream or inshore to spawn. Adult catches thereafter increased and were followed by recruitment of young-of-year fish. Young-of-year reached their peak abundance in otter trawls during July and August and in beach seines during June and July, implying movement of fish from inshore areas to thalweg habitats (Sommer et al. 1997, O'Rear and Moyle 2008). The total otter trawl catch reached its minimum in October, increasing thereafter to close out the year (Figure 29).

As seen in previous years (Schroeter et al. 2006, O'Rear and Moyle 2008, O'Rear and Moyle 2009), a disproportionate amount of the total otter trawl catch (23%) came from lower Suisun Slough. In contrast to previous years, First Mallard Slough did not host an abundance of splittail, contributing only 7% to the total catch; given the lower numbers of young-of-year fish and the importance of First Mallard Slough as a nursery and refuge for small fishes (O'Rear and Moyle 2009), this is not a surprising result. However, First Mallard Slough had the highest young-of-year catch per unit effort (2.6 fish per trawl) of any slough we sample in the marsh, so it remains an important habitat for young splittail.

Conclusions

The timing, magnitude, and duration of Delta outflow, and consequently its effects on salinity, affected the catches of fish in Suisun Marsh during 2008 and 2009. In 2008, low Delta outflow and high in-marsh salinities during late spring and summer likely depressed reproductive success of late-spawning freshwater fishes, resulting in relatively low catches for these species (e.g., black crappie, white catfish). Additionally, low outflows during spring of 2008 reduced the area available for splittail spawning and contributed to very low catches of young-of-year fish. While outflows were also low during 2009, they were of sufficient magnitude and variability through late spring and early summer to transport upstream-spawned (e.g., striped bass, American shad) and bay-spawned (e.g., yellowfin goby) fishes to the marsh. Moreover, the timing of the appearance of certain species (e.g., longfin smelt) was tied to the intrusion of saltier water.

While Delta outflow was a factor affecting our catches in 2008 and 2009, several patterns suggest that biotic interactions were also important. Most striking is the increase in beach seine catches concomitant with decreased otter trawl catches of both fishes and planktivorous macorinvertebrates during 2008, implying that pelagic food sources were in short supply. However, considerably higher otter trawl catches for common marsh species (e.g., striped bass, yellowfin goby), coupled with lower beach seine catches, mild increases in the large-shrimp catch, and an astronomical rise in overbite clams, intimate that pelagic food sources were more abundant for at least part of 2009. That mysids were more abundant later in 2009 than in 2008 also bolsters this scenario. Furthermore, the ecology of threadfin shad in the marsh appears better explained by the presence of a predator (adult striped bass) than water-quality variables. These associations, within the context of relatively low Delta outflows, hint that drier years with less variable hydrology result in a more stable marsh where the importance of biotic interactions to the structure of the fish community is enhanced.

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. Thanks to Randy Baxter, whose helpful comments improved this article.

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Notes

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2009 Fishes Annual Status and Trends Report for the San Francisco Estuary

Jennifer Messineo, Maxfield Fish, Dave Contreras, Kathryn Hieb, and Virginia Afentoulis (CDFG)[1]

Introduction

The 2009 Status and Trends fishes report includes data from 5 of the Interagency Ecological Program's long-term fish monitoring surveys in the San Francisco Estuary: 1) the Summer Townet Survey (TNS), 2) the Fall Midwater Trawl Survey (FMWT), 3) the San Francisco Bay Study (Bay Study), 4) the Delta Smelt 20-mm Survey (20-mm Survey), and 5) the U.S. Fish and Wildlife Service (USFW) Beach Seine Survey (see Honey et al. 2004 for additional fish surveys). The most recent abundance indices, long-term abundance trends, and distributional information are presented for the most common species in the estuary and some less-common species of interest, such as delta smelt, splittail, and the surfperches. Presented first are 4 pelagic species that spawn and rear in the upper estuary and have undergone severe declines in recent years (Sommer et al. 2007). The upper estuary demersal fishes, marine pelagic fishes, surfperches, and marine demersal fishes follow this group. Within each section, species are presented phylogenetically.

Methods

We used several physical data sets to describe ocean and estuary environmental conditions. Daily outflow at Chipps Island from the Department of Water Resources (DWR) Dayflow computer program was used to calculate all outflow values: the 2009 daily values were plotted and the 1979-2009 daily values averaged by month and plotted. The daily estimated distance in river kilometers from the Golden Gate to 2 parts-per-thousand salinity, as X2, was also from the Dayflow program. Monthly Pacific Decadal Oscillation (PDO) indices were from Nathan

1. Authorship: Introduction, Methods, and Physical Setting, K. Hieb; American and threadfin shad, and longfin smelt, D. Contreras; delta smelt, striped bass, and splittail, V. Afentoulis; the gobies, flatfishes, plainfin midshipman, and Pacific staghorn sculpin, M. Fish; Pacific herring, northern anchovy, jacksmelt, the surfperches, and white croaker, J. Messineo.

Mantua (University of Washington) and plotted for 1950-2009. North Pacific Gyre Oscillation (NPGO) indices were from Emanuele Di Lorenzo (Georgia Institute of Technology) and were plotted for 1950-2009. Daily ocean upwelling indices and monthly anomalies (base period 1946-1967) from 39°N were from the National Marine Fisheries Service (NMFS) Pacific Fisheries Environmental Laboratory. The monthly anomalies were plotted from 1999-2009. A daily Cumulative Upwelling Index (CUI) was calculated for 2007, 2008, 2009, and 1967-2009 (the period of daily data) per Bograd et al. (2009). The spring transition, which is the start of the upwelling season, is the date of the minimum CUI. We used the CUI inflection points to identify the length of the upwelling period as well as strong upwelling and relaxation events. Daily sea surface temperatures (SSTs) were from Southeast Farallon Island (Scripps Institute of Oceanography); monthly values and anomalies were calculated from the daily values, and we used 1925-2009 as the base period for the anomalies. Daily SSTs from January 2008 to December 2009 and monthly anomalies from 1999-2009 were plotted. See "Notes" for the data download URLs.

The TNS has been conducted annually since 1959, and its data has been used to calculate age-0 striped bass indices for all years except 1966, 1983, 1995 and 2002. In addition, age-0 delta smelt indices have been calculated for the period of record, except for 1966-1968. The TNS currently begins in June and samples 32 sites from eastern San Pablo Bay to Rio Vista on the Sacramento River and Stockton on the San Joaquin River. Historically the number of surveys ranged from 2 to 5 each year; beginning in 2003, sampling was standardized to 6 surveys per year, starting in early June and running every other week through August. The striped bass index is an interpolation between the survey indices from the 2 surveys that bracket when age-0 striped bass reach or surpass 38.1-mm fork length (FL) mean size (Chadwick 1964, Turner and Chadwick 1972). The delta smelt index is the average of the first 2 survey indices.

The FMWT has sampled annually since 1967, except 1974 and 1979, when no surveys were conducted, and 1976, when sampling was limited and indices were not calculated. The FMWT was initiated to determine the relative abundance and distribution of age-0 striped bass in the estuary, but its data is used for other upper-estuary pelagic species, including American shad, threadfin shad, delta smelt, longfin smelt and splittail. The FMWT survey samples 116 stations monthly from September to December in an area ranging from San Pablo Bay to Hood on the Sacramento River and to Stockton on the San Joaquin River. The index calculation (Stevens 1977) uses catch data from 100 of these 116 stations; the remaining 16 stations were added to increase spatial coverage for delta smelt in 1992.

The Bay Study has sampled from South San Francisco Bay (South Bay) to the western delta monthly with an otter trawl and midwater trawl since 1980. There are data gaps in this long-term sampling, most significantly limited midwater trawl sampling in 1994, no winter sampling from 1989 to 1997, and limited sampling at stations in and near the confluence of the Sacramento and San Joaquin rivers in 2007 and 2008 to reduce delta smelt take. This most recent data gap resulted in no Bay Study delta smelt indices for 2007 and 2008. Abundance indices are routinely calculated for 35+ fishes and several species of crabs and caridean shrimp. Only the most common fish species are included in this report; the crabs and shrimp are subjects of separate annual reports. Of the 52 stations the Bay Study currently samples, 35 have been consistently sampled since 1980 ("core" stations) and are used to calculate the annual abundance indices. Additional information about study methods, including index calculation, can be found in IEP Technical Report 63 (Baxter et al. 1999).

The 20-mm Survey monitors larval and juvenile delta smelt distribution and relative abundance throughout their historical spring range, which includes the entire delta downstream to eastern San Pablo Bay and the Napa River. Surveys have been conducted every other week from early March into July since 1995, with 9 surveys completed in 2009. Three tows are completed at each of the 48 stations using a 1,600-µm mesh net (Dege and Brown 2004). The survey name is derived from the size (20 mm) at which delta smelt are readily identifiable and counted at the State Water Project and Central Valley Project fish facilities.

United States Fish and Wildlife Service has conducted beach seine sampling weekly since 1992 at approximately 40 stations in the delta and the Sacramento and San Joaquin rivers upstream of the Delta (Brandes and McLain 2001). Data from 33 stations ranging from Sherman Lake at the confluence of the Sacramento and San Joaquin rivers upstream to Ord Bend on the Sacramento River, and to Stockton on the San Joaquin River was used to calculate the annual age-0 splittail abundance index. Stations were grouped into 8 regions and the index was calculated as the sum of regional mean catch per seine haul for May and June sampling.

We used data sets from the TNS, FMWT, and Bay Study to describe abundance trends and distribution of upper estuary pelagic fishes when available, while only Bay Study midwater trawl (BSMWT) data was used for the marine pelagic fishes and Bay Study otter trawl (BSOT) data for demersal fishes. Two data sets provided only single species indices: the 20-mm Survey data for delta smelt larvae and small juveniles and the USFWS beach seine data for age-0 splittail. Catch-per-unit-effort (CPUE), reported as catch per tow, was consistently used to analyze and report distribution.

Physical Setting

Delta outflow was again very low in 2009, with a mean January to June monthly outflow at Chipps Island of 395 cubic meters per second (cm/s). This was comparable to 2008 and slightly higher than 2007 for the same period. The 3 consecutive low outflow years from 2007-2009 were the longest period of low outflow since the 1987-1992 drought (Figure 1). There were 2 outflow peaks in 2009, one from mid-February to mid-March that averaged approximately 1,000 cm/s per day and one in early May that averaged about 600 cm/s over 2 weeks (Figure 2). This first outflow event maintained X2 just upstream of Roe Island in eastern Suisun Bay (river kilometer 68) and resulted in the lowest salinities of the year in the upper estuary. X2 quickly moved upstream to Chipps Island (river kilometer 75) in April, briefly moved downstream again to near Roe Island (river kilometer 70) in mid May, and then steadily moved upstream from late May through the remainder of the water year.

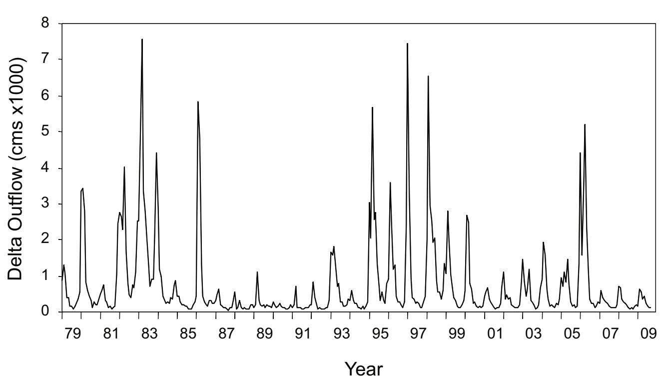

Figure 1 Mean monthly Delta outflow (cms) at Chipps Island, 1979-2009.

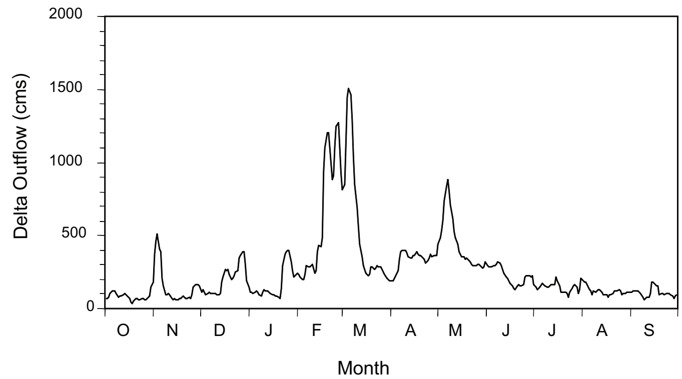

Figure 2 Daily Delta outflow (cms) at Chipps Island, October 2008 to September 2009.

The San Francisco Estuary is situated between 2 major marine faunal regions, the cold-temperature fauna of the Pacific Northwest and the subtropical fauna of southern and Baja California, and is a transitional area with elements of both faunal groups (Parrish et al. 1981). The northern Pacific Ocean reportedly entered a cold-water regime in 1999 (Peterson and Schwing 2003), which is hypothesized to be beneficial to many cold-temperate species, including Dungeness crab, English sole, and many of the rockfishes. This most recent cold-water regime was preceded by a warm-water regime from 1977 to 1998, which resulted in increased abundance of subtropical species in San Francisco Estuary, including California halibut, white croaker, Pacific sardine, and California tonguefish.

The Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) are 2 indices of basin-scale ocean climate conditions. A positive PDO index is most strongly associated with warmer ocean temperatures, a stronger Alaska Current, and a weaker California Current, while a positive NPGO index is associated with increased salinity, upwelling, nutrients, and primary production and a stronger California Current (Di Lorenzo et al. 2008, Di Lorenzo et al. 2009). Major ecosystem regime shifts have occurred in the North Pacific when the PDO and NPGO show strong, simultaneous and opposite sign reversals, such as in 1999 (Di Lorenzo et al. 2008). During cold-water regimes, the PDO indices are generally negative and the NPGO indices positive (Figures 3A and 3B), with frequent La Niña events. Warm-water regimes have positive PDO indices and negative NPGO indices, with frequent and strong El Niño events. The most recent cold-water regime is not unprecedented, but appears to be the strongest in the past 60 years based on the NPGO indices.

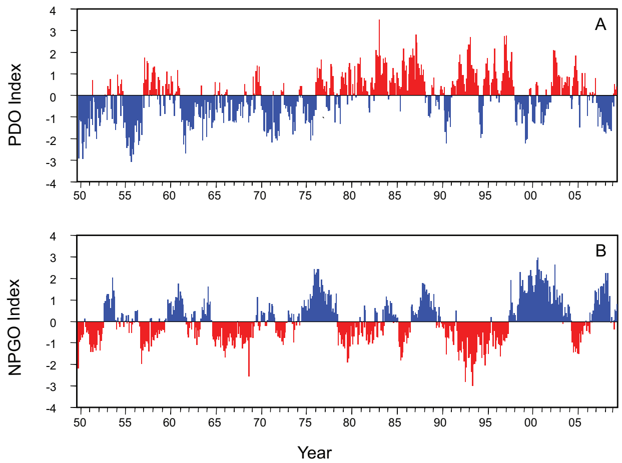

Figure 3 A. Monthly Pacific Decadal Oscillation (PDO) indices, 1950-2009 and B. Monthly North Pacific Gyre Oscillation (NPGO) indices, 1950-2009.

From summer 2007 through early 2009, there was a La Niña event in the tropics, resulting in negative PDO indices and positive NPGO indices (Figures 3A and 3B). Spring 2009 was neutral, but an El Niño event developed in summer 2009 and continued through early 2010 in the tropics. El Niño or other warm water events during a cold-water regime are not unusual. Within the past decade, there were 3 other El Niño events of 6 to 11 months in duration from summer 2002 to early 2007. Not all were apparent along the Central California coast, but we did observe many months of above average SSTs and reduced upwelling from late 2002 through 2006 (Figures 4A and 4B). The warmest SSTs of the past decade in the Gulf of the Farallones (GOF) were in 2005 and 2006. There is often a time delay between the appearance of La Niña and El Niño events in the tropics and effects along the Central California coast, and not all tropical events manifest similarly at this latitude.

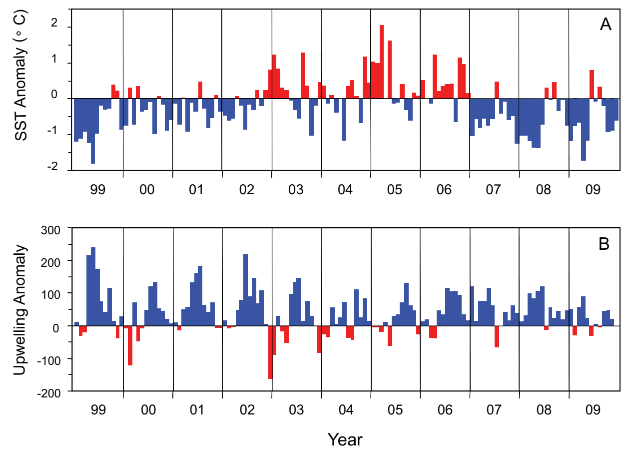

Figure 4 A. Monthly Sea Surface Temperature (SST, °C) anomalies from Southeast Farallon Island, 1999-2009 and B. Monthly upwelling index anomalies (39°N), 1999-2009.

Gulf of the Farallones sea surface temperatures (SSTs) were about 1°Celsius (C) cooler than the long-term mean in late 2008 and early 2009 (Figure 4A), when many marine fishes that rear in San Francisco Estuary spawn in coastal waters. Sea surface temperatures decreased even further in April and early May 2009 and were almost 2°C cooler than the long-term mean. April 2009 had the second coldest SSTs for the month in the period of record (1925-2009), with a mean daily SST of 9.6°C, while May had alternating periods of SSTs just below and above 10°C (Figure 5). In June, concurrent with the El Niño that developed in the tropics, ocean temperatures suddenly increased in the GOF to above 14°C (Figure 5); the June monthly mean SST was almost 1°C warmer than the long-term mean (Figure 4A). Although the El Niño event continued in the topics through late 2009, SSTs in the GOF were near the long-term mean from July through September and then about 1°C cooler from October through December. SSTs are typically at their annual maximum in fall; in late September and early October 2009, daily SSTs reached 14°C briefly and then remained above 13°C for about 3 weeks (Figure 5).

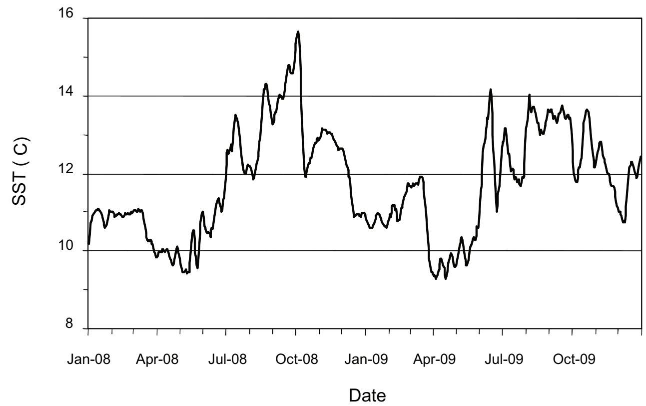

Figure 5 Daily Sea Surface Temperature (SST, °C) from Southeast Farallon Island, January 1, 2008 to December 31, 2009.

The coastal ocean along central California is marked by 3 seasons: the upwelling season, from spring to late summer; the oceanic season, from late summer to late fall; and the Davidson Current season, from late fall to spring. During the upwelling season, prevailing northwesterly winds result in a southward surface flow, known as the California Current. Due to the Earth's rotation and the Coriolis Effect, there is a net movement of surface waters offshore. These waters are replaced by nutrient-rich, cold water that is transported or upwelled from deeper areas. Upwelling is responsible for the high productivity of the California Current System. When the winds weaken in fall, upwelling stops, surface coastal waters warm, and productivity declines. In winter, southwesterly winds result in a northward surface flow, or the Davidson Current. This current, in conjunction with the Coriolis Effect, produces an onshore and downward transport of surface water, or downwelling. Many coastal fish and invertebrate species in the California Current Region reproduce in winter during the Davidson Current season, when pelagic eggs and larvae are likely to be transported to or retained in nearshore areas. Juveniles of most species settle to the bottom nearshore and enter estuaries to rear before the onset of upwelling, because pelagic life stages present during the upwelling season will be transported offshore, often far from their preferred nearshore nursery areas.

Coastal upwelling, as indicated by the monthly anomalies from near the San Francisco Estuary, was strong through early May 2009, relatively weak from late May through August with the onset of the El Niño event, then stronger than average from September on (Figure 4B). The strong upwelling in April and early May was associated with the coolest SSTs of the year. From the minimum point of the daily Cumulative Upwelling Index (Figure 6), the 2009 spring transition was in early March, which was close to the norm for this latitude. For much of the last decade, winter upwelling has been relatively strong and the spring transition has been early. For example there was strong early winter-spring upwelling and an early spring transition in 2007 and 2008 (Figure 6), although the early season upwelling was strong in January, March, and April of 2007 and March and April of 2008.

These conditions should have been favorable for primary and secondary production in the GOF in late winter-early spring 2009, but weak upwelling after early May may have hindered productivity. Several seabirds had very poor reproductive success at the Farallon Islands in 2009, most likely due to low prey abundance during the chick-rearing period (Warzybok and Bradley 2009). Euphausiids were abundant but forage fishes, such as, anchovy, sardine, and juvenile rockfish were largely absent in the GOF. The very poor foraging conditions resulted in reduced breeding success, reduced breeding effort, and increased adult mortality for the fish-eating birds, such as Brandt's Cormorants, Common Murres, Western Gulls, and Rhinoceros Auklets (Warzybok and Bradley 2009).

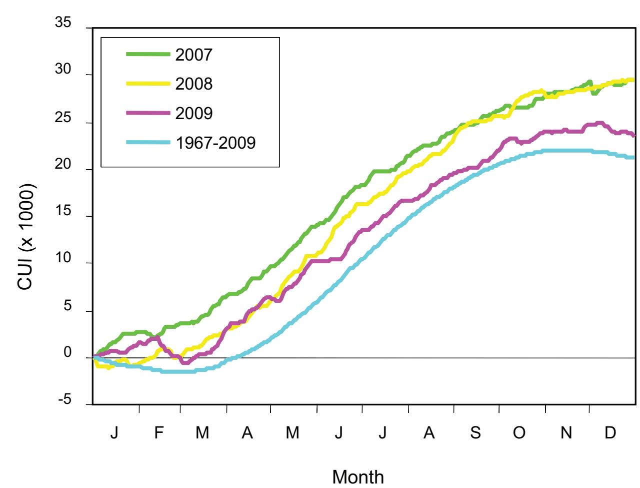

Figure 6 Daily Cumulative Upwelling Index (CUI, x 1,000) for 2007, 2008, 2009, and averaged for 1967-2009.

Upper Estuary Pelagic Fishes

American shad

The American shad (*Alosa sapidissima)* was introduced into the Sacramento River in 1871 and is now found throughout the estuary. This anadromous species spawns in rivers in late spring, rears in fresh water through summer (including the delta starting in late May), and migrates to the ocean in late summer and fall. It spends approximately 3 to 5 years maturing in the ocean before returning to freshwater to spawn. Most males reach maturity within 3 to 4 years of age, while most females reach maturity within 4 to 5 years of age. Spawning occurs in the Sacramento, Feather, and American rivers from April through June, after which a large percentage of adults die (Stevens 1966). All life stages of American shad are planktivores.

The 2009 FMWT American shad (all ages) index was 2.3 times the 2008 index, and the fourth lowest index on record (Figure 7A). With the exception of the record high index in 2003, indices have been below the study-period mean since 1998. American shad were collected in all areas of the upper estuary in 2009, but were most abundant from Suisun Bay to the lower Sacramento River. They were most common in the lower Sacramento River in September and October, the lower Sacramento River through Suisun Bay in November, and Suisun Bay in November and December.

The 2009 BSMWT age-0 American shad index was also substantially higher than the 2008 index, yet was well below the study mean (Figure 7B). The BSMWT collected age-0 American shad from July through December, and abundance peaked in August. They were collected from San Pablo Bay to the lower Sacramento and San Joaquin rivers and were most common in the lower rivers. The largest single catch occurred during August in the San Joaquin River at the Santa Clara Shoal station.

The American shad index increased for both surveys from 2008 to 2009. However, abundance remained relatively low for both surveys, which may have resulted from the relatively low spring outflow in 2009. American shad abundance has shown a positive correlation with delta outflow during the spring spawning and early rearing period (Figure 8; Stevens and Miller 1983). For unknown reasons this response was enhanced after the introduction of the overbite clam, *Corbula amurensis,* in the late 1980s (Kimmerer 2002). During the POD years (2001-2009) abundance was more variable and the outflow-abundance relationship became steeper (Figure 8).

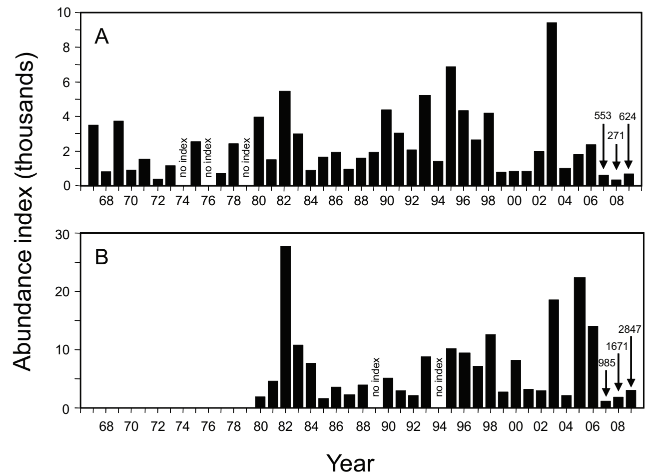

Figure 7 Annual abundance of American shad: A) FMWT, all sizes, September-December, B) Bay Study midwater trawl, age-0, July-October.

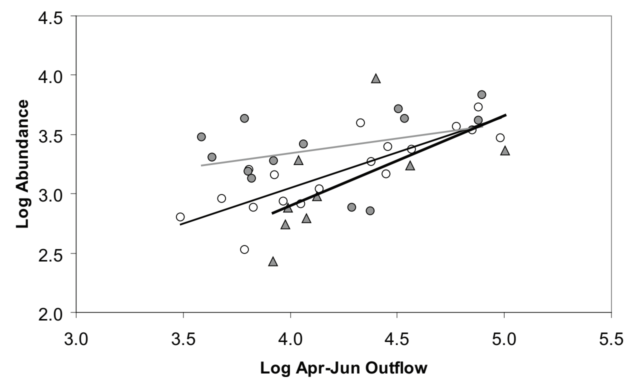

Figure 8 Fall Midwater Trawl American shad annual abundance indices (all ages; dominated by age-0 fish) plotted on April through June mean monthly Delta outflow (cfs), both variables Log[10] transformed (update of CDFG 1987). Relationships depicted are pre-*Corbula amurensis* (1967-1987; open circles, black line) and post-*C. amurensis* (1988-2000; filled circles, grey line) and more recent years during the Pelagic Organism Decline (POD) (2001-2009; grey triangles, thick black line). Lines indicate significant relationships, p<0.05.

Threadfin Shad

The threadfin shad (*Dorosoma petenense*) was introduced into reservoirs in the Sacramento-San Joaquin watershed in the late 1950s and quickly became established in the delta. Although it is found throughout the estuary, it prefers oligohaline to freshwater dead-end sloughs and other low-velocity areas (Wang 1986). It is planktivorous its entire life, feeding on zooplankton and algae (Holanov and Tash 1978). Threadfin shad may reach maturity at the end of their first year and live up to 4 years. Spawning occurs in late spring and summer and peaks from May to July (Wang 1986).

The 2009 FMWT threadfin shad (all ages) index was 10% of the 2008 index (Figure 9) and by far the lowest index on record. Since 2002, threadfin shad abundance has been below average, but showed a slight increasing trend through 2007 before dropping off precipitously. The threadfin shad catch increased from September through December and fish were caught from Carquinez Strait through the lower Sacramento River and from the south delta. They were most abundant in the lower Sacramento River.

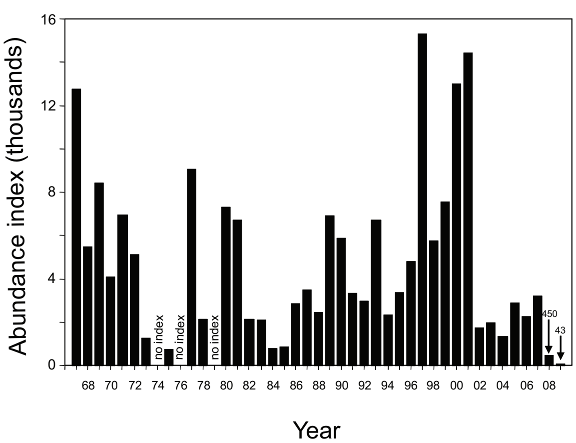

Figure 9 Annual abundance of threadfin shad (all sizes), FMWT, September-December.

Delta smelt

The delta smelt (*Hypomesus transpacificus*) is a small (55-90 mm FL) osmerid endemic to the upper San Francisco Estuary. The delta smelt population declined dramatically in the 1980s and it was listed as a state and federal threatened species in 1993. This species is considered environmentally sensitive because it typically lives for one year, has a limited diet, and resides primarily in the interface between salt and fresh water. In addition, females have low fecundity and produce on average 1,200 to 2,600 eggs (Moyle et al. 1992).

In 2009, delta smelt abundance declined in all surveys, except in the BSMWT. The 2009 20-mm Survey delta smelt index declined 21% from the 2008 index (Figure 10A), and was the second lowest index on record. Delta smelt larvae were first collected in March in Honker Bay and the lower Sacramento River. By April, larvae were broadly distributed within the delta, from the Cache Slough complex, and Sacramento Deep Water Ship Channel, to the lower San Joaquin River and within the central and southern delta (Middle and San Joaquin rivers). In May, the distribution of juvenile delta smelt expanded downstream into the western portion of Suisun Bay. By June, juvenile delta smelt were no longer being caught in Suisun Bay, but remained distributed from the confluence and the lower San Joaquin River upstream through the lower Sacramento River and into the Cache Slough complex and the Sacramento Deep Water Ship Channel. By the conclusion of the survey in late-June into July, juvenile delta smelt were mainly caught in the lower Sacramento River with a second concentration of fish caught in the Cache Slough and Sacramento Deep Water Channel region and an individual fish in western Suisun Bay.

The 2009 TNS age-0 delta smelt index declined 50% from the 2008 index (Figure 10B) and equaled that of 2005, the lowest index on record. Delta smelt TNS catch totals in 2009 were bimodal, peaking in early June with a catch of 11 and then again in early August with a catch of 10 fish. This was similar to the pattern observed in 2008, when peaks occurred in early June and the middle of July. In summer 2009, delta smelt were distributed from Carquinez Strait to the lower Sacramento and San Joaquin rivers. Delta smelt were similarly dispersed in summer 2008. Also similar to 2008, the catches in 2009 tended to be slightly higher in Honker Bay and lower Sacramento River than in other areas. In early June 2009, the delta smelt catch was greatest in Montezuma Slough and the lower Sacramento River, with individual fish caught in Broad Slough and the lower San Joaquin River. By early July, delta smelt catches only occurred in Grizzly Bay and the lower Sacramento River. By the end of July, the catches extended from Suisun Bay through the confluence and into the lower Sacramento River. In August, the majority of fish were collected near Honker Bay.

The 2009 BSMWT age-0 delta smelt index was 142, relatively low compared to historical abundance (Figure 10C). In 2007 and 2008, the Bay Study did not report an age-0 delta smelt index because midwater trawl sampling bypassed several stations where delta smelt catch might have been high. The index in 2006 was 0. In 2009, most age-0 delta smelt were distributed from Honker Bay to the lower Sacramento River. Delta smelt are not effectively sapled by the BSOT, so these data are not reported.

The 2009 FMWT delta smelt index declined 26% from the 2008 index and was the lowest on record (Figure 10D). In September of 2009, delta smelt were collected only in western Montezuma Slough and Suisun Bay. October and November catches were similar with delta smelt found in Suisun Bay, but with the added expansion upstream into the lower Sacramento River. In October, delta smelt were also present in Cache Slough. In December 2009, catches broadened downstream in the Suisun Bay region especially near Honker bay, and a few were caught in the confluence and lower Sacramento River areas.

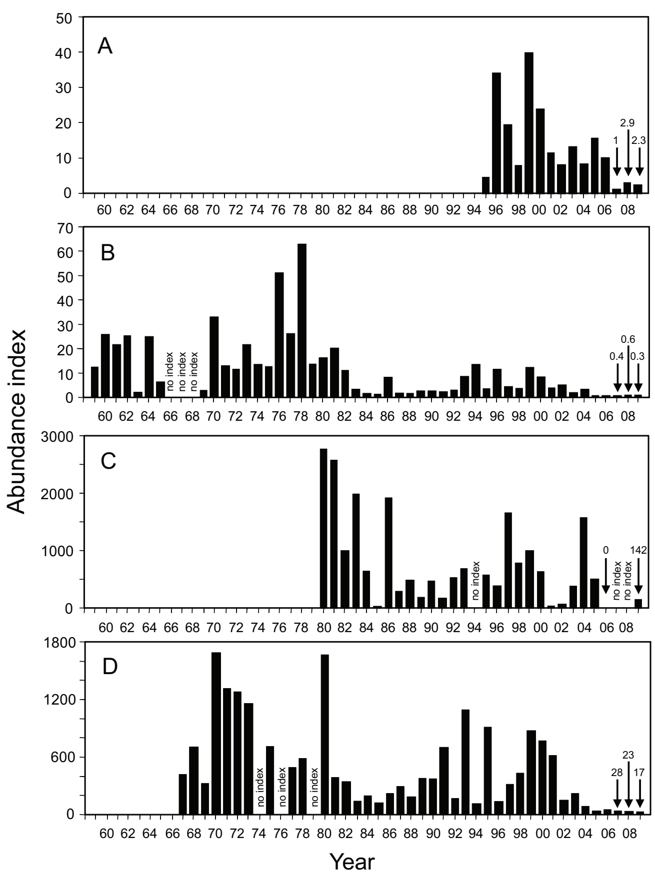

Figure 10 Annual abundance of delta smelt: A) 20-mm Survey larvae and juveniles, based on 4 surveys bounding 20 mm mean length; B) TNS, age-0, mean of survey 1 and 2 abundance indices; C) Bay Study midwater trawl, age-0, June-October; D). FMWT, all sizes, September-December.

Longfin smelt

The longfin smelt (*Spirinchus thaleichthys*) is a short-lived anadromous species that spawns in freshwater in winter and spring and rears primarily in brackish water. Some age-0 and age-1 fish migrate to the ocean in summer and fall, often returning to the estuary in late fall of the same year. A few longfin smelt mature at the end of their first year and most at the end of their second year, with some living to spawn or spawn again at age-3 (Wang 1986). A strong positive relationship between longfin smelt abundance and winter-spring outflow has long been observed (Stevens and Miller 1983). However, this relationship changed in the late 1980s, after the introduction of the overbite clam, *C. amurensis*. Although the slope of the outflow-abundance relationship did not change appreciably, longfin smelt abundance post-*C. amurensis* declined to a fraction of the pre-*C. amurensis* abundance. This decline corresponded with a decline in phytoplankton and zooplankton abundance, which has been attributed to grazing by *C. amurensis* (Kimmerer 2002). A similar downward shift of the longfin smelt outflow-abundance relationship occurred after 2000, during the Pelagic Organism Decline years (Sommer et al. 2007, Fish et al. 2009).

The 2009 FMWT longfin smelt (all ages) index was 47% of the 2008 index and the second lowest on record (Figure 11A). Longfin smelt began migrating upstream into Suisun Bay in October. By December, they were found from San Pablo Bay through the lower Sacramento and lower San Joaquin rivers. Through the entire September through December period, longfin smelt were most commonly caught in Suisun Bay.

The 2009 BSMWT age-0 longfin smelt index was 27% of the 2008 index and the third lowest in the study period (Figure 11B). The BSMWT collected age-0 fish sporadically through the year: a few each in May, August, and December. Age-0 longfin smelt were collected from South Bay upstream into the lower Sacramento River, except in Central San Francisco Bay (Central Bay), with the highest catches occurring in Suisun Bay.

The 2009 BSOT age-0 longfin smelt index was 16% of the 2008 index (Figure 11C), an abundance decrease similar to that of the BSMWT. Age-0 fish were collected from June through December and abundance peaked in July. They were collected from South Bay through Suisun Bay, but were most common in Central Bay during most months, quite different from BSMWT results.

All 2009 longfin smelt abundance indices decreased in response to the low winter/spring outflow. The FMWT longfin smelt abundance-outflow relationship shifted downward after the introduction of *C. amurensis* and again in the POD years, 2001-2009 (Figure 12). The 2009 index was below the regression line for the post-*C. amurensis* abundance-outflow relationship. This year's decrease in abundance also may be attributed, in part, to the weak 2007-year class, the parents of the 2009-year class. Mac Nally and others (2010) described the FMWT longfin smelt abundance trend as a long-term decline punctuated by abundance increases associated with high outflow periods and they too detected that abundance was most significantly influenced by outflow.

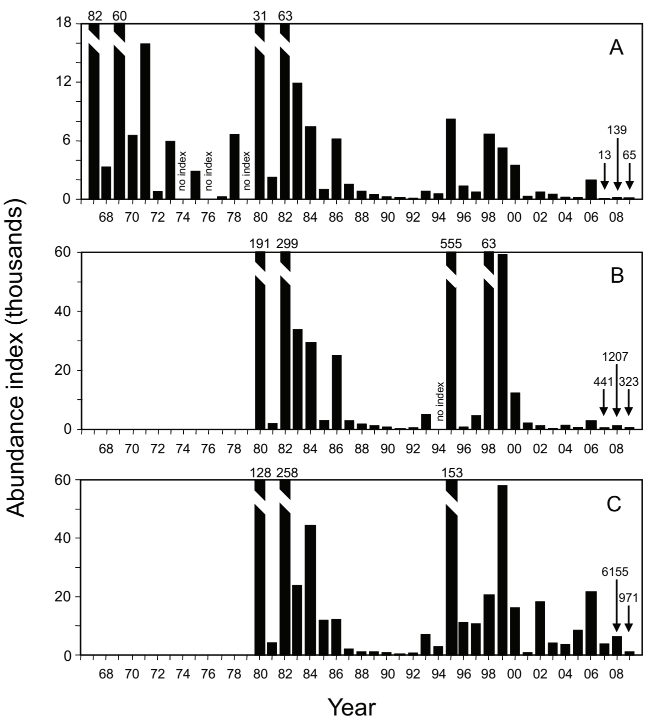

Figure 11 Annual abundance of longfin smelt: A) FMWT (all ages), September-December; B) Bay Study midwater trawl, age-0, May-October; C) Bay Study otter trawl, age-0, May-October.

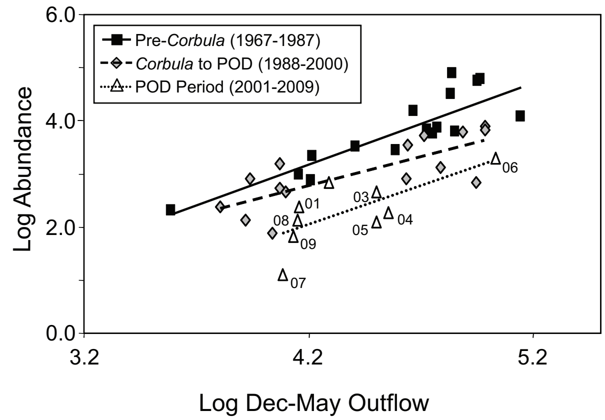

Figure 12 FMWT age-0 longfin smelt annual abundance (all ages) index plotted on December through May mean monthly Delta outflow (cfs), both variables Log_{10} transformed. Relationships depicted are pre- *Corbula amurensis* (1967-1987; black squares, solid line) and post *C. amurensis* (1988-2000; grey diamonds, dashed line) and POD years (2001-2009, open triangles, dotted line). Lines indicate significant relationships, $p < 0.05$.

The clam *C. amurensis,* through its affect on the food web, appears to have affected longfin smelt distribution. Longfin smelt distribution in the FMWT shifted towards higher salinity waters after 1989, a few years after *C. amurensis* was introduced, and this pattern has remained consistent since (Figure 13). This suggests that *C. amurensis* displaced longfin smelt through a reduction in food availability, similar to that proposed for the northern anchovy (*Engraulis mordax*) distribution shift downstream reported by Kimmerer (2006). The longfin smelt diet once contained a high proportion of the mysid, *Neomysis mercedis* (Freyrer et al. 2003). The decline of *N. mercedis* also has been attributed to competition for food with *C. amurensis* (Kimmerer and Orsi 1996). One study found that *Neomysis* spp. primarily fed on diatoms, rotifers, and copepods (Siegfried and Kopache 1980), food resources shared with *C. amurensis* (Kimmerer and Orsi 1996). Longfin smelt may have displaced to higher salinity areas to find food sources not impacted by *C. amurensis*.

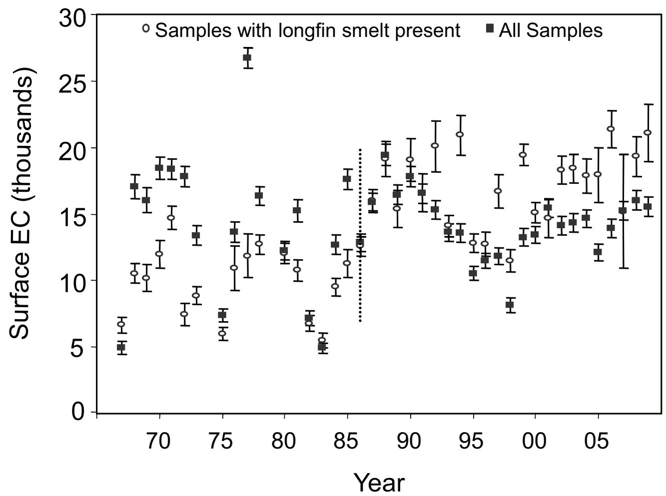

Figure 13 Mean (± 1 SD) surface water electrical conductivity (EC) for FMWT samples with longfin smelt present (open circles) and all samples (black squares). Dotted line represents the year *C. amurensis* was discovered in the San Francisco Estuary.

Splittail

The splittail (*Pogonichthys macrolepidotus*) is endemic to the San Francisco Estuary and its watershed. Adults migrate upstream from tidal brackish and freshwater habitats during increased river flows from late fall through spring to forage and spawn on inundated floodplains and river margins (Sommer et al. 1997, Moyle et al. 2004). Such migrations are known to occur in the Sacramento, San Joaquin, Cosumnes, Napa and Petaluma rivers, as well as Butte Creek and other small tributaries. Most spawning takes place from March through May. Young disperse downstream as larvae, when river levels drop or as juveniles in late spring and early summer, when backwater and edge-water habitats diminish with reduced flows. Year-class strength is related to the timing and duration of floodplain inundation; moderate to large splittail year classes resulted from inundation periods of 30 days or more in the spring months (Sommer et al. 1997, Moyle et al. 2004).

Age-0 splittail may not be effectively sampled by long-term monitoring surveys employing trawling that requires fishing in open, moderately deep (= 2 m) water, because young splittail possess a strong affinity for shallow water. The USFWS Delta Juvenile Fish Monitoring Program conducts an annual beach seine survey and can calculate an abundance index for age-0 splittail. In addition to sampling along the shoreline, this survey samples throughout the delta and upstream on the Sacramento River to Colusa (see methods), so it is able to detect recruitment upstream in the rivers. The beach seine index was not updated for 2008 until this year. The 2009 age-0 splittail beach seine index as reported by the USFWS was 62.4, an increase (36%) from the 2008 abundance index of 45.8. The range of index values since 2007 were an order of magnitude less than those of the 4 prior years were. Both the highest and lowest abundances (in 2006 and in 2002, respectively) have been recorded in the last 10 years (Figure 14A). The variability of the age-0 splittail abundances likely reflects the variability in outflows in recent history.

The BSMWT collected no age-0 splittail in 2009, resulting in 9 consecutive years with very low or 0 indices (Figure 14B). No age-0 splittail were collected in 2009 by the BSOT, resulting in a zero index for the 3rd consecutive year (Figure 14C). The 2009 FMWT splittail (all ages) index was 1 (Figure 14D). This is following a 2008 index of 0 and 6 prior years of very low indices.

Age-0 splittail were virtually not detected by trawl surveys in 2009, but there was some evidence of splittail recruitment from the USFWS beach seine sampling. Aasen (page 72, this issue) reported some, but low splittail salvage for 2009 for both state and federal fish salvage facilities; typically, salvage is dominated by age-0 fish (Moyle et al. 2004).

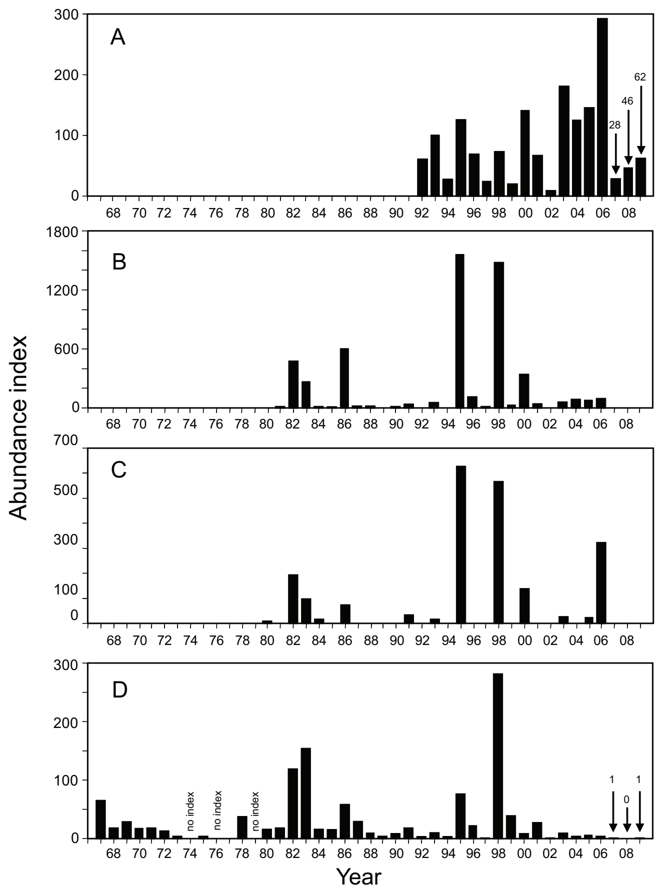

Figure 14 Annual abundance of splittail: A) USFWS beach seine, age-0, May-June; B) Bay Study midwater trawl, age-0, May-October; C) Bay Study otter trawl, age-0, May-October; D) FMWT, all sizes, September-December.

Striped bass

Striped bass (*Morone saxatilis*) is an anadromous fish first introduced to the San Francisco Estuary over 125 years ago. Adult striped bass forage in the near-shore ocean and coastal bays and migrate up rivers to spawn in spring. Juveniles rear in fresh and brackish waters of the estuary. The population of legal-size fish in the San Francisco Estuary declined from nearly 4.5 million in the early 1960s, to only 600,000 in 1994, and then increased to about 1.6 million in 2000. More recent population estimates of legal-size age-3 and older fish were about 946,000 in 2002, 829,000 in 2003, 1.3 million in 2004, 1 million in 2005, and 588,000 in 2007 (the 2004-2007 estimates are preliminary, Marty Gingras, personal communication, see "Notes"). Age-0 striped bass abundance steadily declined since the mid-1980s, and TNS and FMWT indices were generally low in the late 1990s and early 2000s when the adult population had a modest recovery. Although the adult population exhibited a modest recovery, the fraction of females in the spawning run has been very low (ca 10%) since the early or late 1990s, depending on the data set examined, and has remained low thereafter (Jason DuBois, personal communication 2008). Such low female numbers could explain the low juvenile abundance indices. Stevens et al. (1985) hypothesized that low striped bass recruitment was related to: 1) the declining adult population, 2) reduced plankton food supply, 3) loss of large numbers of young striped bass to water diversions, and 4) population-level effects of contaminants. Based on our understanding of factors controlling striped bass abundance in the estuary, the adult population increases in 2000 and 2004 were unexpected and remain unexplained.

The 2009 TNS striped bass 38.1-mm index was 0.8. This was a 27% decrease from the 2008 index and consistent with the 5 lowest indices on record for the 50 year survey (Figure 15A) since 2003. Age-0 striped bass catch peaked in late-June and declined sharply (by 57%) by early July. After mid-July, abundance continued to decrease through the end of the survey in mid-August. In June, striped bass were distributed from Suisun Bay upstream through the central and south delta, with the largest concentration found in Montezuma Slough. In July, age-0 striped bass distribution extended downstream with fish collected from Carquinez Strait to the lower Sacramento and San Joaquin rivers, the largest concentration occurring in the lower Sacramento River. In early August, the distribution contracted from Suisun Bay up to the confluence. By mid-August at the end of the survey, catch was restricted to Montezuma Slough and consisted of only 3 fish.

The 2009 FMWT age-0 striped bass index decreased to 32% of the 2008 index. This was the 2nd lowest index on record and consistent with the low indices seen since 2002 (Figure 15B). In September 2009, age-0 striped bass were caught by the midwater trawl only in Suisun Bay. In October, Suisun Bay continued to be the area with the highest catch, but in addition, they were caught in the lower Sacramento and San Joaquin rivers. October was also the month with the highest catch for the FMWT survey. By November, age-0 striped bass ranged from Carquinez Strait to the lower Sacramento River. In December, catch expanded into San Pablo Bay.

The 2009 BSMWT age-0 striped bass index declined 54% from the 2008 index and was the second lowest on record for the survey (Figure 15C). This continued the trend of very low indices since 2002 and of consistently low indices since the establishment of *C. amurensis* in 1987. In 2009, the BSMWT first collected age-0 striped bass in July and abundance peaked in July. The BSMWT sporadically collected age-0 striped bass from Suisun Bay upstream into the lower Sacramento and San Joaquin rivers.

The BSOT striped bass age-0 index for 2009 declined 67% from the 2008 level and was the fourth lowest index on record for the gear type (Figure 15D). Similar to the BSMWT, the BSOT first collected age-0 striped bass in July and abundance peaked in July. Age-0 striped bass were detected from a broad range of the upper estuary by the BSOT: eastern San Pablo Bay upstream and throughout the Sacramento and San Joaquin river stations sampled by the study. The BSOT has been more effective at catching age-0 striped bass than the BSMWT, as was observed again in 2009, when the BSOT collected 837 age-0 striped bass, while the BSMWT collected only 46 fish during the same July through December period.

The BSOT again collected greater numbers of age-0 striped bass at shoal stations than at channel stations (87% of total June through December catch in 2009; 91% in 2008). In contrast to the BSOT, only 29% of the total BSMWT age-0 catch occurred at shoal stations in 2009.

The 2009 water year was classified as dry for the Sacramento River and below normal for the San Joaquin River and similar to the two prior years' low outflows. Age-0 striped bass abundance declined in all long-term monitoring surveys. This was perhaps due to the different timing of peak outflows and more plentiful food resources for larvae in 2008 than in 2009 (April Hennessy, Figures 2 and 5, pages 15 and 16 this issue). Striped bass survival and abundance has historically showed a positive correlation to outflow, although these responses have been dampened since the invasion of the clam *C. amurensis* in the late 1980s (Kimmerer 2002, Sommer et al. 2007). Although age-0 striped bass abundance has been very low for almost 2 decades, juvenile striped bass remain more abundant in benthic shoal habitats than in channel habitats. Age-0 striped bass CPUE declined more at channel stations then shoal stations per the Bay Study otter trawl data. The mean CPUE from channel stations post-*Corbula* (1987-2008) was 9% of the mean pre-*Corbula* (1980-1986) CPUE. In comparison, the mean shoal-station post-*Corbula* CPUE was 25% of the mean pre-*Corbula* CPUE. This suggests that juvenile striped bass more successfully exploited benthic shoal habitats for food resources such as amphipods than benthic or pelagic channel habitats where the more pelagic mysids were historically abundant and a large part of their diet (Bryant and Arnold 2007, Feyrer et al. 2003). Mysids continue to be important in the young striped bass diet (Slater 2009), but now striped bass appear to have a stronger influence on mysid abundance than the other way around (Mac Nally et al. 2010)

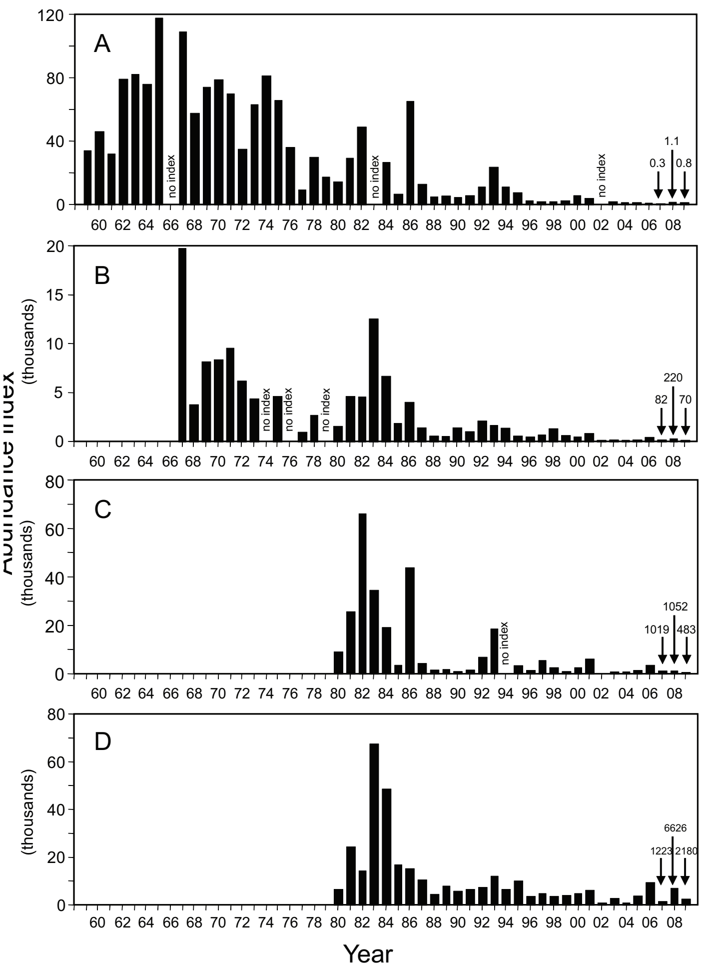

Figure 15 Annual abundance of age-0 striped bass: A) TNS 38.1-mm index; B) FMWT, September-December; C) Bay Study midwater trawl, June-October; D) Bay Study otter trawl, June-October.

Upper Estuary Demersal Fishes

Shokihaze goby

The Shokihaze goby (*Tridentiger barbatus*) is native to China, Japan, Korea, and Taiwan, and was first collected in the San Francisco Estuary by the Bay Study in 1997 (Greiner 2002). It is a short-lived species; age-1 fish spawn in brackish water during spring and early summer, and die in late summer and fall (Slater 2005). Since the Shokihaze goby is most common upstream of the Bay Study original sampling area, abundance is calculated as the annual mean catch-per-unit effort (CPUE, #/tow) for all 52 stations sampled by the otter trawl, including the lower Sacramento and San Joaquin river stations added in 1991 and 1994.

In 2009, the Shokihaze goby mean CPUE (all sizes) was 60% of the 2008 CPUE and slightly above the mean since the species' first collection (Figure 16). Shokihaze gobies were collected in all embayments except for Central Bay. They exhibited a strong association with deep-water habitat, with densities almost 15 times higher at channel stations (1.18 fish/tow) than at shoal stations (0.08 fish/tow).

Shokihaze goby densities were highest in Suisun Bay most months, but CPUE increased substantially in South Bay and the lower Sacramento and San Joaquin rivers from August to December as age-0 fish recruited to the gear. The Sacramento River channel station near lower Sherman Island was the most productive Shokihaze goby station, averaging 7.1 fish/tow for the year and reaching a maximum of 29 fish/tow in December.

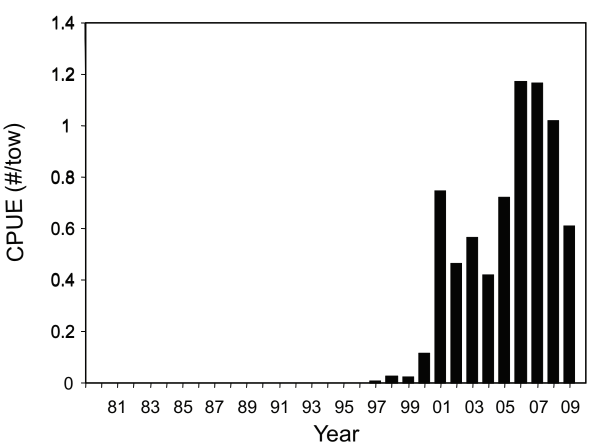

Figure 16 Annual catch-per-unit-effort (CPUE; #/tow) of Shokihaze goby (all sizes), Bay Study otter trawl, January-December.

Yellowfin goby

The yellowfin goby (*Acanthogobius flavimanus*) is an introduced fish from Asia. It is partially catadromous: adults migrate to brackish water to spawn from December through July and most die after spawning. Juvenile fish migrate upstream to lower salinity and fresh water habitats to rear through summer and fall (Moyle 2002).

The 2009 age-0 yellowfin goby abundance index declined from 2008 and was the lowest index since 1985 and the second lowest index on record (Figure 17), continuing the trend of very low indices since 2000. Age-0 yellowfin gobies first recruited to the gear in June in Suisun Bay and the lower Sacramento and San Joaquin rivers. Age-0 fish were collected from every embayment in 2009, with highest densities in Suisun Bay and the lower San Joaquin River, each averaging 0.38 fish/tow, May to December. As expected, age-0 yellowfin gobies were associated with shallow water; the CPUE for shoal stations (0.23 fish/tow) was more than double that for channels stations (0.11 fish/tow).

A total of 55 age-1+ yellowfin gobies were collected in 2009 and they occurred in every embayment. Age-1+ CPUE was highest in channels (0.31 fish/tow) during the months of December to February as mature fish migrated from Suisun Bay and the lower Sacramento and San Joaquin rivers to the lower estuary. For the remainder of the year, CPUE was highest at shoal stations (0.09 fish/ tow).

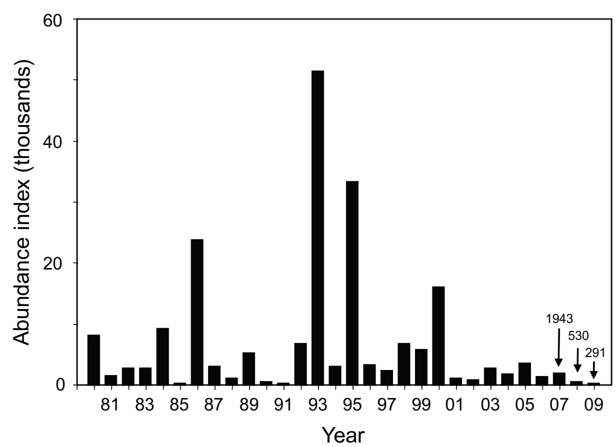

Figure 17 Annual abundance of age-0 yellowfin goby, Bay Study otter trawl, May-October.

Starry flounder

The starry flounder (*Platichthys stellatus*) is an estuary-dependent species that spawns in the ocean, but rears in brackish and fresh water areas of estuaries. In 2009, the age-0 starry flounder abundance index dropped to 30% of the 2008 index and only 13% of the study-period mean (Figure 18A). This was the lowest age-0 index since 2001. The 2009 year class first recruited to the gear in May and was collected through the end of the year.

Age-0 starry flounder were concentrated upstream of Carquinez Straight, although 1 fish was collected at a shoal station in South Bay in July. They were most common in Suisun Bay (0.4 fish/tow, May to December), followed by the lower Sacramento River and the confluence. Age-0 starry flounder were strongly associated with shallow water across all regions, from the time they were first collected through the end of the year; CPUE at shoal stations (0.18 fish/tow) was 9 times higher than at channel stations (0.02 fish/tow).

In 2009, the age-1 index dropped to 44% of the 2008 index and was only 50% of the study-period mean (Figure 18B). Age-1 starry flounder were collected from San Pablo Bay upstream in 2009 and were 20 times more abundant at shoal stations (0.23 fish/tow) than channel stations (0.01 fish/tow) all year.

The age-2+ index dropped to 27% of the 2008 index and 31% of the study-period mean (Figure 18), bringing all 3 age classes below study period mean for the first time since 2005. Most age-2+ starry flounder were collected from San Pablo Bay upstream, with 1 fish collected at the shoal station outside of Berkeley Marina. Densities were highest in Suisun Bay with catches averaging 0.19 fish/tow from January to December.

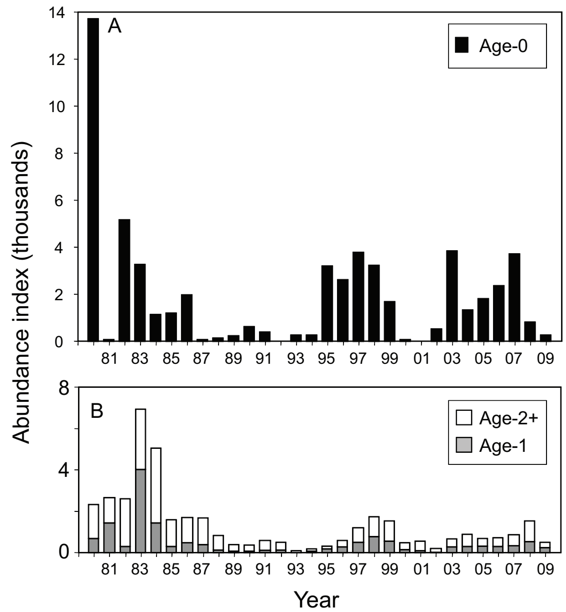

Figure 18 Annual abundance of starry flounder: A) age-0, Bay Study otter trawl, May-October, and B) age-1 and age-2+, Bay Study otter trawl, February-October.

Marine Pelagic Fishes

Pacific Herring

The Pacific herring (*Clupea pallasii*) is an estuary-dependent species that spawns and rears in higher salinity areas (>20‰) of the estuary. Spawning occurs in late winter and early spring; the adhesive eggs are deposited on substrates such as aquatic vegetation, rocks, pier pilings, and other man-made structures. After hatching and larval development, young Pacific herring remain in shallow waters and begin to school. Juveniles can be found in shallow subtidal areas and sloughs until late spring, when they migrate to deeper waters within the estuary. By fall, age-0 Pacific herring emigrate from the estuary to spend 2 to 3 years rearing in the ocean before reaching maturity and returning to spawn.

The 2009 age-0 index was less than a third of the 2008 index (Figure 19), but was nearly equal to the study-period mean. Although age-0 fish were collected all months except February, 97% of the total catch was collected between April and June, with peak abundance in May. In 2009, distribution was widest in late spring when fish were collected from South Bay to Chipps Island near the confluence of the Sacramento and San Joaquin rivers. Most age-0 fish began recruiting to the gear in March and by mid-summer had emigrated from the estuary. This emigration coincided with increased water temperatures in San Pablo and South bays. CPUE was consistently highest in Central Bay (36 fish/tow, April to December), followed by San Pablo Bay (19 fish/tow). This year's low numbers of age-0 Pacific herring may be linked to the weak year classes observed in 2005 and 2006 and the resultant low adult population spawning in 2008-2009. The California Department of Fish and Game (CDFG) Herring Project also reported low numbers of spawning age-2, age-3 and age-4 fish in this year's fishery (CDFG 2009).

The CDFG Herring Project has recorded landings for the Pacific herring fishery in San Francisco Bay since 1972. The commercial Pacific herring fishery runs from December through March, targeting adult fish entering the estuary to spawn. The 2008-2009 landings totaled 510 tons, almost 30% lower than the previous year's landings. The spawning biomass estimate of 4,844 tons for 2008-2009 was the lowest ever reported and consequently there was no herring fishery in San Francisco Bay in 2009-2010. The recent declines in San Francisco Bay herring landings and biomass may be attributed to poor environmental and biological conditions in San Francisco Bay and the ocean. Multiple years of drought have increased salinity within the bay, which in turn reduced the number of spawning events. In addition, ocean conditions were poor in 2005 and 2006, when juveniles that comprise a large number of the 2008-2009 returning adult population entered the ocean. Warmer sea surface temperatures and low ocean productivity in those years reduced fish survival, as evident by low numbers of adult fish returning in 2009.

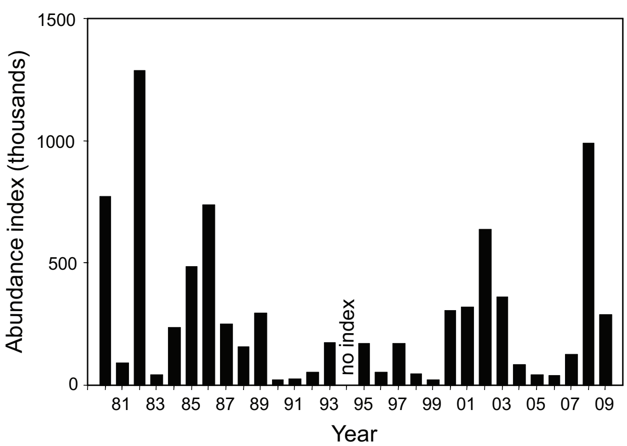

Figure 19 Annual abundance of age-0 Pacific herring, Bay Study midwater trawl, April-September.

Northern anchovy

The northern anchovy (*Engraulis mordax*) is the most common fish in the lower estuary and an important prey species for many fishes and seabirds (Bergen and Jacobson 2001). The 2009 northern anchovy abundance index (all sizes) decreased 11% from the 2008 index (Figure 20). It was the fourth lowest index on record, and only half of the study-period mean. Two-thousand nine marks the fourth consecutive year of declining indices, following the trend of colder ocean temperatures since 2006. The low 2009 anchovy abundance was linked to reproductive failure of several seabird species whose diet primarily consists of anchovies, including cormorants, seagulls and murres, and to recent seabird and sea lion deaths in San Francisco Bay. Commercial bait fishermen also reported low anchovy catches in the bay and near-shore coastal area in 2009.

Vrooman et al. (1981) separated the northern anchovy population into northern, central, and southern subpopulations. The San Francisco Estuary is situated between the northern and central subpopulations, and our catches reflect changes in the size and coastal movements of these subpopulations. Although the central subpopulation is the largest and historically the most heavily fished, there are currently no stock assessments, so we cannot confirm subpopulation movements or size from fisheries data. However, there were unpublished reports from CDFG and NMFS that northern anchovy was more common in the Southern California Bight in 2008 and 2009, leading to the conclusion that the central subpopulation shifted south with colder ocean temperatures.

Northern anchovies were collected every month in 2009, but abundance peaked in August, and was very low in January, February, November, and December. Fish were collected from South Bay near the Dumbarton Bridge to Chipps Island, just downstream of the confluence, with CPUE (April to December) highest in Central Bay (321 fish/tow), followed by San Pablo (232 fish/tow) and South (79 fish/tow) bays. Distribution shifted seasonally, with few anchovies collected in San Pablo and Suisun bays until May. Once upwelling increased in summer, CPUE in the estuary increased dramatically. In August, the highest regional CPUE was in San Pablo Bay, where catches averaged 1036 fish/tow. Anchovies used deeper waters of the estuary most months of 2009, with channel CPUE (134 fish/tow) almost twice as high as shoal CPUE (77 fish/tow).

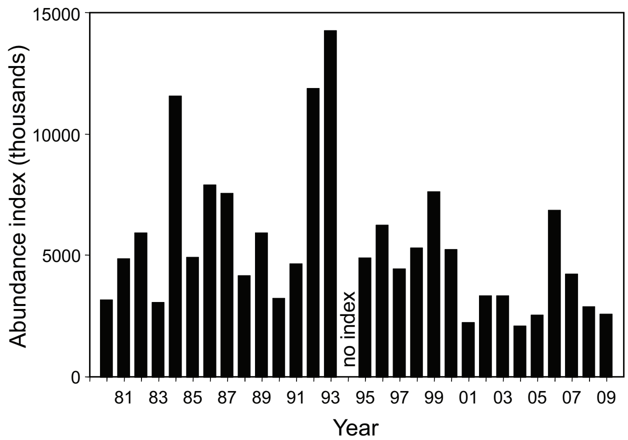

Figure 20 Annual abundance of northern anchovy (all sizes), Bay Study midwater trawl, April-October.

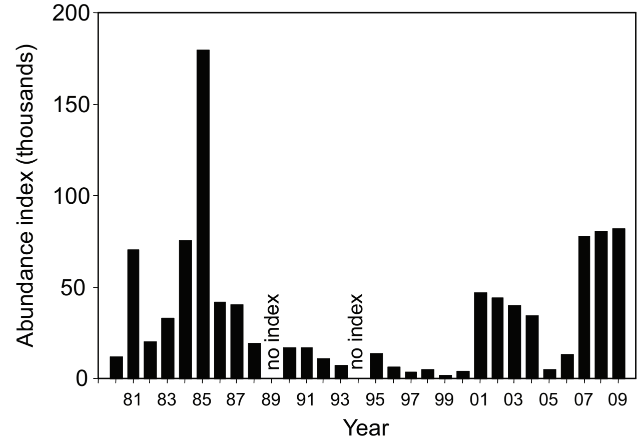

Figure 21 Annual abundance of age-0 jacksmelt, Bay Study midwater trawl, July-October.

Jacksmelt

The jacksmelt (*Atherinopsis californiensis*) seasonally migrates from nearshore coastal waters to bays and estuaries to spawn and rear. Most reproduction within the San Francisco Estuary occurs from September to April based on the presence of ripening and ripe females in San Pablo Bay (Ganssle 1966). Juvenile jacksmelt rear in shallow (<2 m) areas of South, Central, and San Pablo bays in late spring and summer. After growing to about 50 mm FL, they begin to migrate to deeper water, where they become vulnerable to the midwater trawl.

The 2009 age-0 jacksmelt abundance index was slightly higher than the 2008 index (Figure 21). It is the second highest index on record and marks the third consecutive year of above average indices. This follows the trend of increased abundance in low outflow years. In 2009, all but one age-0 jacksmelt were collected between June and October with peak abundance in July. Age-0 fish were collected from South Bay near the Dumbarton Bridge to lower San Pablo Bay, but over 50% of the total catch was caught in Central Bay. Overall, CPUE was highest in Central Bay (9.1 fish/tow, July to December), followed by South Bay (7.9 fish/tow). The high CPUE observed in South Bay can be attributed to a large catch of 237 fish in September. Seasonal movement was evident as fish were more common on the shoals in summer (9.1 fish/tow, July to September) and then moved to the channels in October (3.7 fish/tow) before emigrating from the estuary in late fall.

Surfperches

Most surfperches are transient species, migrating into bays and estuaries to give birth to live, fully-formed young in late spring and summer, and returning to the coastal ocean in fall and winter. All of the surfperches common to San Francisco Estuary underwent abundance declines in the 1980s per Bay Study trawl and sport fish survey data (DeLeón 1998). Consequently, in 2002 CDFG changed the sport fish regulations for San Francisco Bay, adopting a closed season for all surfperches, except shiner perch (*Cymatogaster aggregata*), from April 1 to July 31 and a 5-fish combination bag limit for all species except shiner perch, which was given a 20-fish bag limit.

Shiner perch

In 2009, the abundance of age-0 shiner perch (*Cymatogaster aggregata*) decreased from 2008, and was only 26% of the study period mean (Table 1). It was the lowest index since 1994. Although a few age-0 fish were collected in spring, the majority were caught between June and December. Abundance peaked in December, but was mostly driven by a large catch (68 fish) near Angel Island. Age-0 shiner perch were collected from South Bay through lower San Pablo Bay in 2009, but overall were most common in Central Bay, where CPUE averaged 1.9 fish/tow (May to December). In 2009, shiner perch were concentrated further downstream than in 2008. Some apparent seasonal movement was observed in late fall, when fish migrated from South Bay to Central Bay, and subsequently emigrated from the estuary in winter. Age-0 shiner perch were most common at shoal stations through summer and fall and shifted to the channels in December, concurrent with their migration from the estuary.

Walleye surfperch

The 2009 age-0 walleye surfperch (*Hyperprosopon argenteum*) abundance index was only 6% of the 2008 index and 13% of the study-period mean (Table 1). Only 14 age-0 walleye surfperch were collected in the MWT in 2009, all from shoal stations in southern Central and South bays. The 2009 age-1+ index was about half of the 2008 index and a third of the study-period mean (Table 1). Twenty-two age-1+ walleye surfperch were collected in the MWT during 2009 ranging from South Bay, near Oakland Airport, to lower San Pablo Bay; most came from Central Bay near Alameda. All but 1 age-1+ fish were collected from shoal stations on the eastern side of the estuary.

Other Surfperches

The 2009 barred surfperch (*Amphistichus argenteus*) abundance index for all sizes was over 3 times the 2008 index (Table 1), but was mostly driven by a large catch from a shoal station near the Oakland Airport. In 2009, the Bay Study collected 11 barred surfperch in the otter trawl, with one from a non-core station that did not contribute to the index. All fish were collected at shoal stations in Central and South bays. Historically, the majority of barred surfperch have been collected from South Bay shoal stations, especially stations along the eastern shore. Barred surfperch is commonly associated with eelgrass beds in San Francisco Bay (Merkel & Associates 2005), a habitat not sampled by our trawls.

The 2009 age-0 pile perch (*Rhacochilus vacca*) abundance index was 0, showing no sign of recovery in the estuary and continuing the trend of very low or 0 indices since 1987 (Table 1). The 2009 white seaperch (*Phanerodon furcatus*) index returned to 0 (Table 1), following a short-lived increase in 2008. One adult fish was collected in Central Bay from a non-index station in August.

Black perch (*Embiotoca jacksoni*) was the only surfperch common in the estuary that did not show a distinct decline during the late 1980s or early 1990s (Table 1). However, black perch catch has remained low relative to the most common surfperches throughout the study period. The 2009 black perch index (all ages) was based on only 1 fish collected from a shoal station near the San Mateo Bridge, and was the lowest index since 1995.

For the second year in a row, the 2009 dwarf perch (*Micrometrus minimus*) index was 0 (Table 1). One dwarf perch was collected in 2009 from a non-index shoal station in Central Bay. Historically, dwarf perch were commonly collected from shoal stations in Central and South bays. Dwarf perch is another species strongly associated with eelgrass beds in the San Francisco Bay, a habitat that is under-sampled by our trawls.

Marine Demersal Fishes

Plainfin midshipman

The plainfin midshipman (*Porichthys notatus*) migrates from coastal areas to bays and estuaries in late spring and summer to spawn. Most juveniles rear in the estuary through December, with some fish remaining until spring. The 2009 age-0 abundance index was less than 40% of the 2008 index and below the study period mean (Figure 22). The 7 highest abundance indices for the study period occurred in the past decade. Although we are not certain of the mechanism, these strong year classes were possibly associated with cool ocean temperatures. It appears likely that during the current cool water regime adult plainfin midshipman distribution has shifted southward, increasing the relative abundance of spawning stock entering the San Francisco estuary (Cloern et al. forthcoming).

Age-0 plainfin midshipmen were collected from June to December, with peak abundance in September. Age-0 midshipmen were most abundant in South Bay from June to July (0.5 fish/tow), but CPUE was highest in Central Bay for the rest of the year (12.4 fish/tow). Geographic range was widest in October, when fish were collected from South Bay to Suisun Bay, with 1 fish collected as far upstream as Sherman Island on the lower Sacramento River. Age-0 fish were more abundant at channel stations (5.0 fish/tow June to December) than shoal stations (1.3 fish/tow June to December) in 2009, and this was consistent across all embayments.

Since the late 1990s, plainfin midshipmen were collected in higher densities in Central Bay and lower densities in South and San Pablo bays. This trend persisted through various water year types and continued in 2009. The mechanism behind this apparent distributional shift is currently unexplained, but a similar increase in Central Bay CPUE was observed for other marine demersal species such as speckled sanddab (*Citharichthys stigmaeus*), bay goby (*Lepidogobius lepidus*), and English sole.

Table 1 Annual abundance indices for selected surfperch species from the Bay Study. The age-0 shiner perch, age-0 and age-1+ walleye surfperch, age-0 pile perch, and white seaperch (all sizes) indices are from May-October. The barred perch (all sizes), black perch (all sizes), and dwarf perch (all sizes) indices are from February-October.

Year	shiner perch age-0	walleye sp age-0	walleye sp age-1+	barred sp all	pile perch age-0	white seaperch all	black perch all	dwarf perch all
1980	19516	1277	642	415	857	588	0	439
1981	42760	8089	1757	691	998	1248	129	543
1982	43704	1640	992	223	471	349	54	259
1983	16147	663	135	1030	778	271	88	460
1984	14386	3846	922	502	110	873	216	50
1985	16616	362	1031	81	301	138	66	0
1986	24617	322	880	0	254	309	17	0
1987	18069	1453	2624	159	0	265	0	0
1988	7746	486	502	90	0	148	62	66
1989	6953	2046	493	109	153	48	101	97
1990	8181	516	341	105	0	95	48	26
1991	2724	22	505	75	0	0	0	15
1992	6142	443	297	27	0	0	100	0
1993	6341	617	112	29	0	0	97	0
1994	3241	no index	no index	53	0	0	125	0
1995	6661	405	269	36	0	0	0	0
1996	4404	684	380	39	0	0	225	0
1997	23896	231	643	104	0	0	231	0
1998	4384	537	911	32	75	0	65	0
1999	6237	848	2985	30	0	0	36	0
2000	4640	1229	114	29	31	0	119	0
2001	20594	8121	1003	41	0	106	248	0
2002	26131	12277	2079	76	42	260	95	0
2003	15898	2439	567	302	0	371	63	111
2004	24849	896	1438	76	0	487	253	94
2005	6225	2916	655	34	0	47	93	32
2006	4911	1610	27	46	0	0	62	34
2007	5193	248	1237	123	0	0	36	42
2008	5935	4128	529	105	0	61	69	0
2009	3408	257	289	318	0	0	26	0

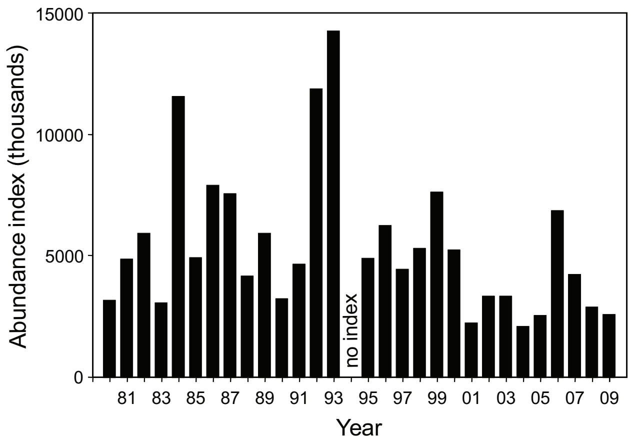

Figure 22 Annual abundance of age-0 plainfin midshipman, Bay Study otter trawl, February-October.

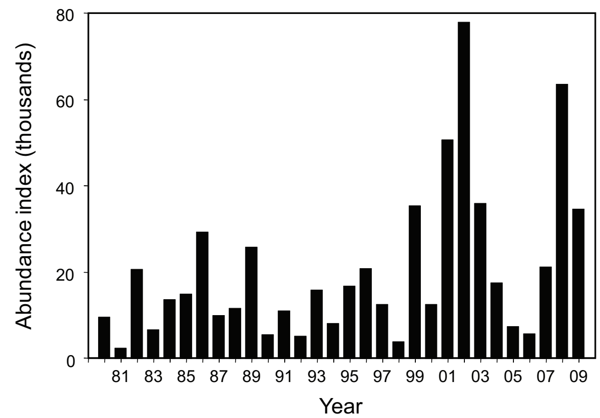

Figure 23 Annual abundance of age-0 Pacific staghorn sculpin, Bay Study otter trawl, February-September.

Pacific staghorn sculpin

The Pacific staghorn sculpin (*Leptocottus armatus*) is a common native species that usually rears in higher salinity areas, but is also found in brackish and occasionally fresh water. Throughout the estuary, it rears in intertidal and shallow subtidal areas from late winter to early spring and migrates to deeper water through summer. The 2009 staghorn sculpin age-0 abundance index was 54% of the 2008 index, but was still well above the study period mean (Figure 23). Five of the 6 highest abundance indices have occurred in the past decade, in association with cool ocean temperatures. As with other cold-temperate species, it is likely that the adult distribution has expanded southward with the recent shift in climate regime, resulting in an increase in relative abundance of spawning stock inside and surrounding the San Francisco Estuary (Cloern et al. forthcoming).

Age-0 Pacific staghorn sculpin were collected from South Bay upstream through the lower Sacramento and San Joaquin rivers adjacent to Sherman Island in 2009. Highest densities were in Central Bay, where catches averaged 8.4 fish/tow from February to September, followed by Suisun and San Pablo bays. Age-0 Pacific staghorn sculpin first recruited to the gear in February and were collected through September. Abundance was highest at shoal stations through July (3.7 fish/tow) after which distribution shifted to channel stations (5.0 fish/tow, August to September).

White croaker

The white croaker (*Genyonemus lineatus*) is a common coastal species that frequents bays and estuaries. It is a member of the subtropical fish fauna, more commonly found south of Point Conception. It spawns from November through April in shallow, nearshore waters, and juveniles progressively move into deeper water as they grow. The 2009 age-0 white croaker index was 140 times the 2008 index and the highest since 2002, but still just 20% of the study period mean (Figure 24). This year's substantial increase may be attributed to warmer sea surface temperatures in early summer 2009. Since 1995, age-0 white croaker indices have been below the study-period mean. Fish were collected throughout the year, with abundance peaking in June and again in October. In 2009, age-0 white croaker were collected from South Bay through San Pablo Bay between May and July, but by September had migrated into Central Bay. Overall, CPUE was highest in Central Bay at 1.2 fish/tow (February to December). Age-0 white croaker were more common in channels (0.57 fish/tow, February to December) than shoals (0.08 fish/tow).

The 2009 white croaker age-1+ index decreased nearly 30% from 2008 (Figure 24) and was only 15% of the study-period mean. In 2009, age-1+ fish were collected throughout the year, with no visible abundance peak. Age-1+ white croaker were collected from South Bay near Coyote Point through western Suisun Bay. Annual CPUE was highest in Central Bay (0.29 fish/tow), followed by South Bay (0.13 fish/tow). Age-1+ white croaker were more commonly caught in the channels than the shoals, with mean annual channel CPUE 3 times the shoal CPUE (0.15 vs. 0.05 fish/tow).

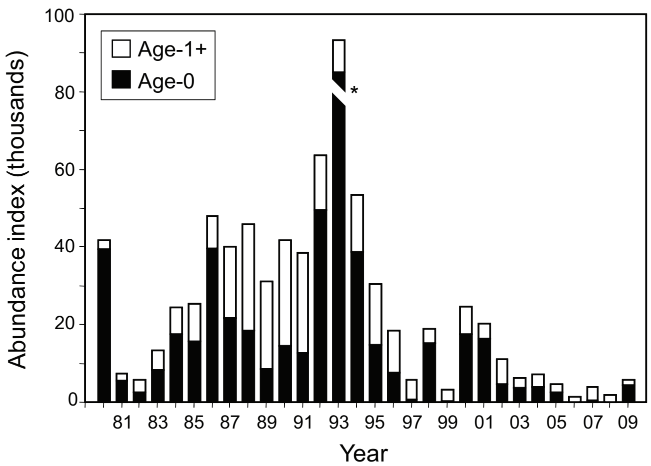

Figure 24 Annual abundance of age-0 and age-1+ white croaker, Bay Study otter trawl, February-October. The 1993 age-0 abundance index was 261,511 and has been truncated for scale considerations.

Bay goby

The bay goby (*Lepidogobius lepidus*) is one of the most common gobies in the estuary. It is a native resident species that rears in the higher salinity areas and has a 2 to 3 year life span. The 2009 bay goby index (all sizes) was 72% of the 2008 index, but was the fourth highest index on record (Figure 25). Bay gobies were collected from South through Suisun bays, but were most abundant in Central Bay all months except February and April, when densities were highest in San Pablo Bay. Central Bay CPUE averaged 46 fish/tow (January to December) and peaked in June at 143 fish/tow. CPUE was highest at shoal stations from January to June and in August when small juveniles were abundant in San Pablo Bay. By mid-summer, distribution began to shift to the channels, where CPUE was consistently highest from September through the end of the year. This pattern was driven by the appearance of high densities of larger individuals in the summer months in Central Bay. These larger individuals may have moved in from near shore habitat outside of the Golden Gate or alternatively from in-bay habitats inaccessible to the trawl gear. The 2009 bay goby distribution was consistent with the long-term trend of increased Central Bay CPUE observed for plainfin midshipman and several other marine demersal species.

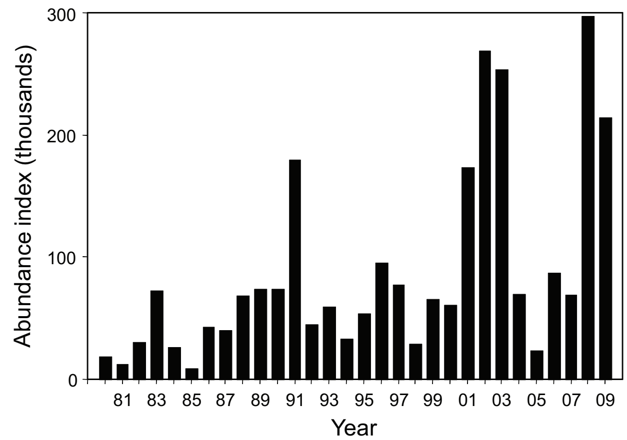

Figure 25 Annual abundance of bay goby (all sizes), Bay Study otter trawl, February-October.

California halibut

The California halibut (*Paralichthys californicus)* is a member of the subtropical faunal group that became common in the San Francisco Estuary in the 1980s and 1990s, concurrent with the most recent warm-water regime. It spawns in shallow coastal waters and juveniles rear in very shallow subtidal and intertidal areas of bays and estuaries, and to a much lesser extent on the open coast. The 2009 juvenile (age-0 & 1) California halibut index was 0 for the second consecutive year (Figure 26). Three juvenile halibut were collected in non-index months of 2009 and did not contribute to the index. Two were collected in San Pablo Bay and 1 in South Bay, all from shoal stations. Continued cool ocean conditions likely limited local recruitment, exemplified by Bay Study's collection of only 5 juvenile California halibut since early 2006.

The 2009 adult (age-2+) California halibut index declined for the third consecutive year to reach the lowest level since 2004 (Figure 26). Adult fish were collected from South through San Pablo bays, but were most common in Central Bay over all months (0.14 fish/tow, January to December). Fish ranged in length from 150 mm (a juvenile) to 688 mm and most appeared to be from the large 2005-06 cohort, produced concurrent with the strongest of the recent warm-water events. Over the past several years, the publicity of the high rate of angler success and lack of other fisheries to pursue has placed considerable pressure on the San Francisco Bay California halibut fishery. This fishing pressure and associated harvest mortality has likely been a key contributor to the 2009 adult California halibut index decline.

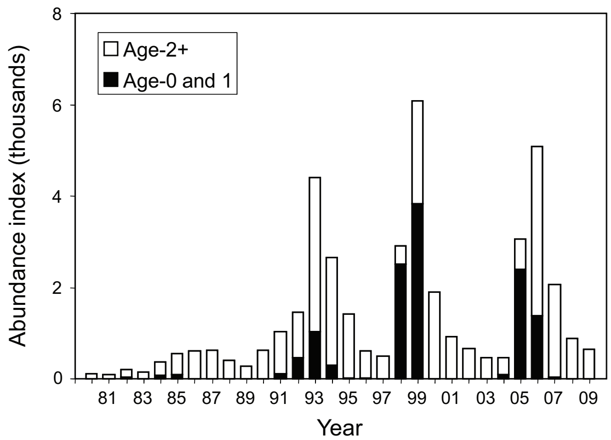

Figure 26 Annual abundance of juvenile (age-0 and age-1) and age-2+ California halibut, Bay Study otter trawl, February-October.

English sole

The English sole (*Pleuronectes vetulus*) is a common flatfish that spawns along the coast in winter and rears in both the coastal ocean and estuaries. The 2009 age-0 English sole abundance index was 88% of the 2008 index and was the third highest index on record (Figure 27). Except for 2005 and 2006, abundance was very high this decade, with the 8 highest indices for the study period occurring since 2000. It appears likely that during the current cool water regime adult English sole distribution has shifted southward, increasing the relative abundance of near shore spawning stock adjacent to the SF estuary (Cloern et al. forthcoming). In addition, cooler SSTs, weak periodic winter storms mixing subsurface nutrients with larva-bearing surface layers and strong post-settlement upwelling have likely enhanced egg and larval survival and growth.

Age-0 English sole were collected from South through Suisun bays in 2009 and were most common in Central Bay all months except January, March, and April, when highest densities occurred in San Pablo Bay. Central Bay CPUE averaged 31 fish/tow from January to December and peaked at 90 fish/tow in May. Distribution of age-0 English sole in 2009 was typical of low outflow years, with extensive immigration of very young fish in winter followed by a strong seasonal movement from South and San Pablo bays to Central Bay in late spring and from the shoals to the channels in late summer and fall. Some of the increased Central Bay channel catch in late summer was due to immigration of larger juveniles from the ocean. This aspect of the 2009 English sole distribution was consistent with the long-term trend of increased Central Bay CPUE observed for plainfin midshipman, bay goby, and several other marine demersal species.

In 2009, there appeared to be English sole from 4 distinct origins within San Francisco Estuary. From January to April at least 2 year classes were apparent, one spawned in fall 2007 (age-1+ fish), one spawned in winter 2008-2009 (age-0 fish, at least 2 cohorts), and several larger individuals, which were likely age-2+ fish migrating from nearshore costal areas. From May to July large numbers of 60-110 mm English sole appeared in Central Bay, yet proportional numbers of smaller fish were not observed in earlier surveys, which indicates that these larger juveniles entered the estuary to rear after settlement and rearing on the near-shore coast. The 2009 age-0 English sole abundance index was composed of two components: the smaller (both physically and numerically) early season group and the larger juvenile coastal migrants, though the index was dominated by the latter.

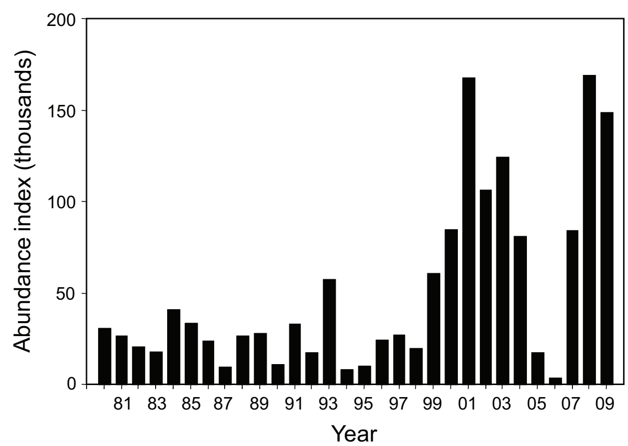

Figure 27 Annual abundance of age-0 English sole, Bay Study otter trawl, February-October.

Speckled sanddab

The speckled sanddab (*Citharichthys stigmaeus*) is one of the most abundant flatfishes in the estuary. It is a short-lived species with an estimated maximum age between 36 and 42 months. Spawning occurs along the coast and peaks in summer. In southern California, spawning is coincident with a sudden drop in bottom temperature due to upwelling (Ford 1965). Larvae may be pelagic for many months, riding ocean currents first offshore then onshore, before settling to the bottom in or near coastal and estuary rearing areas, generally in less than 40 m of water (Rackowski and Pikitch 1989, Kramer 1990).

Juveniles rear for up to a year in the estuary before immigrating to the ocean.

The 2009 speckled sanddab abundance index (all sizes) was slightly higher than the 2008 index and just above the study period mean (Figure 28). After 4 very high indices in the early 2000s, abundance dropped substantially, and then has remained relatively stable since 2005. The 2009 index was composed primarily of fish from 2 year classes: the 2008 year class that hatched in summer 2008 and the larger 2009 year class that hatched in summer 2009. Abundance peaked in December; these were fish that hatched and settled in 2009, not 2008. Distribution ranged from South Bay to Suisun Bay but densities were highest in Central Bay all months. Over 90% of the 2009 speckled sanddab otter trawl catch came from Central Bay stations. CPUE was higher at channel stations (7.7 fish/tow) than shoal stations (3.3 fish/tow) for the entire year. The 2009 speckled sanddab distribution was consistent with the long-term trend of increased Central Bay CPUE also observed for plainfin midshipman, bay goby, English sole, and several other marine demersal species.

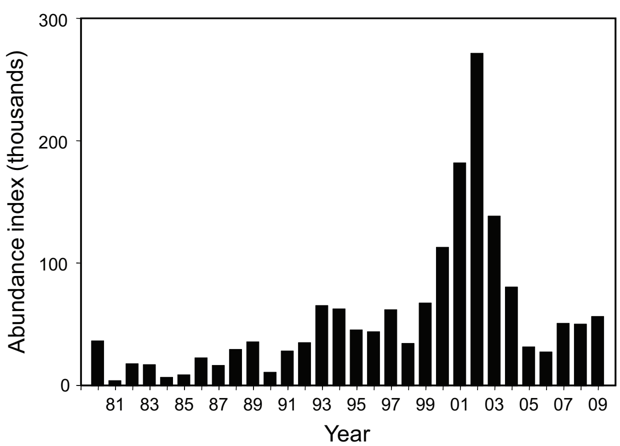

Figure 28 Annual abundance of speckled sanddab (all sizes), Bay Study otter trawl, February-October.

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- 20-mm Survey, Julio Adib-Samii (jadibsamii@dfg.ca.gov).

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Notes

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NPGO indices from www.o3d.org/npgo/data/ NPGO.txt

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Sea Surface Temperatures from shorestation.ucsd.edu/

Marty Gingras, California Department of Fish and Game, email June 29, 2009.

Jason DuBois, California Department of Fish and Game, email October 3, 2008.

Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during 2009

Geir Aasen (CDFG), gaasen@dfg.ca.gov

Introduction

Two facilities reduce the fish loss associated with water export by the federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP's Tracy Fish Collection Facility (TFCF) and the SWP's Skinner Delta Fish Protective Facility (SDFPF) divert (salvage) fish from water exported from the southern end of the Sacramento-San Joaquin Delta. Both facilities use louver-bypass systems to remove fish from the exported water. The diverted fish are periodically loaded into tanker trucks, transported to fixed release sites, and returned to the western Delta. The TFCF began operations in 1957. Operations at the SDFPF began in 1967.

This report summarizes the 2009 salvage information from the TFCF and the SDFPF, and discusses data from 1982 to 2009 for its relevance to recent conditions. The following species are given individual consideration: Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), striped bass[1] (*Morone saxatilis*), delta smelt[1] (*Hypomesus transpacificus*), longfin smelt[1] (*Spirinchus thaleichthys*), threadfin shad[1] (*Dorosoma petenense*), and splittail (*Pogonichthys macrolepidotus*).

Systematic sampling was used to estimate the numbers and species of fish salvaged at both facilities. Bypass flows into the fish-collection buildings were sub-sampled once every 2 hours for 10 to 30 minutes. Fish 20 mm (fork length: FL) or larger from the sub-sampled bypass flows were identified and numerated. These fish counts were expanded (based on sub-sample duration: sub-sample 10 minutes of 120 minutes = expansion factor of 12) to estimate the total number of fish salvaged in each 2-hour period of water export. These incremental salvage estimates were then summed across time to develop monthly and annual species-salvage totals for each facility.

Chinook salmon loss estimates are presented because the loss model has been widely accepted and has undergone extensive field validation. Loss is the estimated number of fish entrained by the facility minus the number

1. Pelagic Organism Decline (POD) species

of fish that survive salvage operations (California Dept. of Fish and Game 2006). Loss was subcategorized by origin (i.e., hatchery or wild) and race (fall, late-fall, winter, spring).

In 2009, as in the recent past, larval fish (< 20 mm FL) were collected and examined to determine the presence of sub-20mm delta smelt. Larval sampling at TFCF ran from February 25 through June 24, while it ran from March 3 through June 30 at SDFPF. Larval samples were collected once for every 6 hours of water export. To retain these smaller larval fish, the fish screen used in the routine counts was lined with a 0.5 mm Nitex net. Larval fish from TFCF were identified to species by TFCF personnel and larval fish from SDFPF were identified to species by California Dept. of Fish and Game.

Water Exports

Water export was substantially reduced from recent years due to reduced delta inflow and measures to protect delta smelt. The SWP exported roughly 2.2 billion m^3 of water in 2009. Annual SWP exports ranged from 1.5 to 5.0 billion m^3 during the years 2003 through 2008 (Figure 1). The CVP exported roughly 2.4 billion m^3 of water in 2009. CVP exports in 2009 were similar to exports in 2008 (2.2 billion m^3) and exports were reduced in both years compared to exports in recent years, which ranged from 3.2 to 3.4 billion m^3 annually during 2003 through 2007.

The water-export patterns of the two water projects differed seasonally. Exports peaked July-October at the CVP and in July at the SWP (Figure 2). From July-October, 1.2 billion m^3 was exported by the CVP, which represented about 50% of annual export. In July, 471.6 million m^3 was exported by the SWP, which represented about 35% of annual export. SWP monthly exports ranged from 37.5 to 471.6 million m^3. CVP monthly exports ranged from 78.8 to 311.9 million m^3.

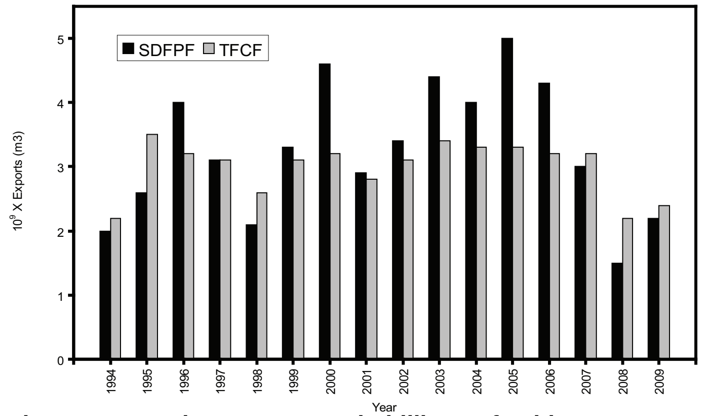

Figure 1 Annual water exports in billions of cubic meters for the SWP and the CVP, 1994 to 2009.

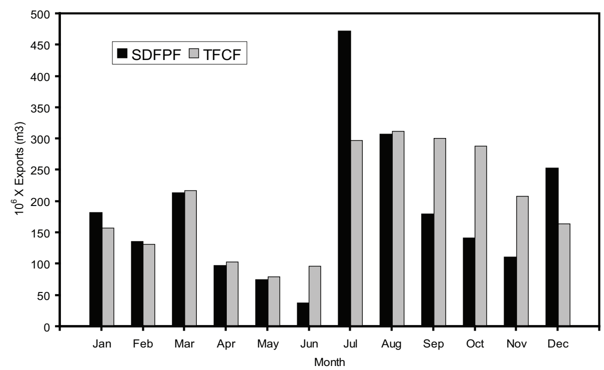

Figure 2 Monthly water exports in millions of cubic meters for the SWP and the CVP in 2009.

Total Salvage and Prevalent Species

Annual salvage (all species combined) at the SDFPF was a near-record low of 837,150 fish (Figure 3). SDFPF salvage in 2009 and 2008 (648,797) decreased substantially in contrast to 2007 (2,239,066) and 2006 (5,138,457). Salvage at the TFCF in 2009 was a record-low (859,501) fish and was substantially lower than in 2008 (5,365,057) or in previous years, which ranged 1.5-37.3 million from 1982 through 2007.

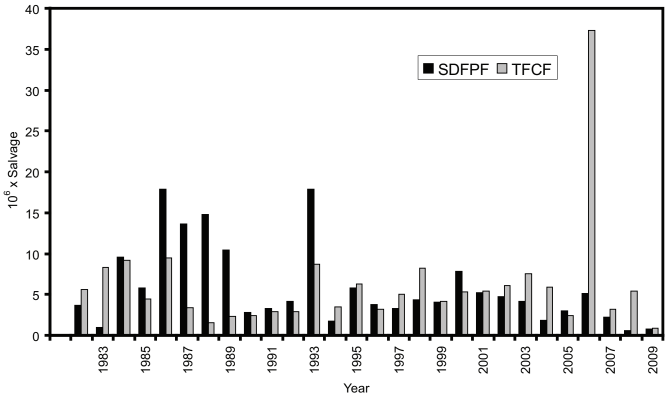

Figure 3 Annual salvage of fishes of all taxa combined at the SDFPF and the TFCF, 1982 to 2009.

Threadfin shad was the most-salvaged species at both facilities (Figure 4). Threadfin shad dominated salvage at the TFCF (Figure 4). Striped bass and American shad were the only other species to be salvaged in substantial numbers at each facility. Threadfin shad dominated salvage at the SDFPF. Relatively few Chinook salmon, steelhead, delta smelt, longfin smelt, and splittail were salvaged at the SDFPF (< 0.6% of total annual salvage) or the TFCF (< 0.8% of total annual salvage).Salvage of Chinook salmon (all races and origins combined) continued to be low at both facilities in 2009 (Figure 5). SDFPF salvage (2,463) continued a declining trend which started in 2001 (Figure 5). Salvage of Chinook salmon in 2009 decreased from 2008 levels (4,928) but was greater than 2007 levels (1,941). Mean 2001-2009 SDFPF salvage was about 8-fold lower than salvage in the 1980's and the late 1990's. Salvage of Chinook salmon in 2009 at the TFCF (4,666) was lower than in 2008 (8,786) or 2007 (7,622). Mean 2001-2009 TFCF salvage was about 6-fold lower than salvage in the 1980s and the late 1990s.

Salvaged Chinook salmon at both facilities were primarily wild spring-run fish and wild fall-run fish (Table 1). Wild spring-run fish comprised 61% and 72% of the salvage of wild Chinook salmon at the SDFPF and the TFCF, respectively. Wild fall-run fish were 27% of the salvage of wild salmon at the SDFPF and about 22% of the wild salmon salvaged at the TFCF. The majority of wild fall-run fish at the SDFPF and TFCF were salvaged in May (Figure 6).

Loss of Chinook salmon (all origins and races) was higher at the SDFPF (10,620) than at the TFCF (3,682; Table 1). Relatively-greater entrainment loss at the SWP was attributable to loss within Clifton Court Forebay.

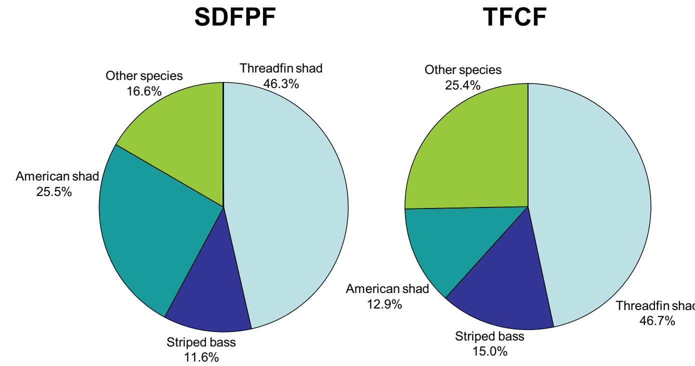

Figure 4 Percentages of annual salvage for the 3 most prevalent species and other species combined at the SDFPF and TFCF, 2009.Chinook Salmon.

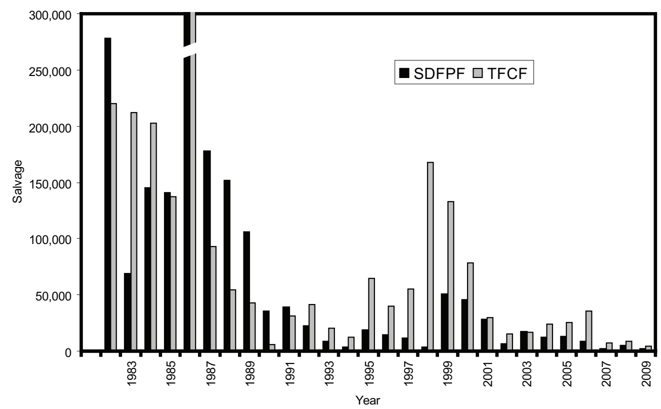

Figure 5 Annual salvage of Chinook salmon (all races and origins combined) at the SDFPF and the TFCF, 1982 to 2009. The SDFPF 1986 salvage of 435,233 and the TFCF 1986 salvage of 752,039 have been truncated.

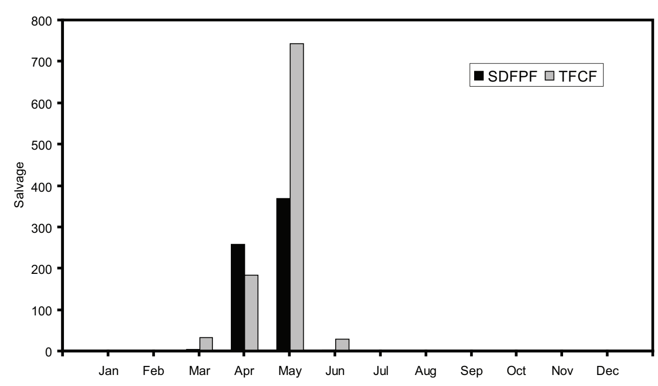

Figure 6 Monthly salvage of wild, fall-run Chinook salmon at the SDFPF and the TFCF, 2009

Table 1 Chinook salmon annual salvage, percentage of annual salvage, race and origin (wild or hatchery), and loss at the SDFPF and the TFCF, 2009

Facility	Origin	Race	Salvage	Percentage	Loss
SDFPF					
	Wild				
		Fall	633	27	2,723
		Late-fall	0	0	0
		Spring	1,459	61	6,256
		Winter	287	12	1,291
	Total Wild		2,379		10,270
	Unknown Race		6		NA
	Hatchery				
		Fall	0	0	0
		Late-fall	0	0	0
		Spring	0	0	0
		Winter	78	100	350
	Total Hatchery		78		350
	Grand Total		2,463		10,620
TFCF					
	Wild	*Fall*	986	22	778
		Late-fall	*0*	*0*	*0*
		Spring	*3,270*	*72*	*2,585*
		Winter	*290*	*6*	*219*
	Total Wild		*4,546*		*3,582*
	Hatchery				
		Fall	*0*	*0*	*0*
		Late-fall	*4*	*3*	*4*
		Spring	*15*	*13*	*12*
		Winter	*101*	*84*	*84*
	Total Hatchery		*120*		*100*
	Grand Total		*4,666*		*3,682*

NA: loss cannot be calculated since lengths were missing

Steelhead

In 2009, salvage of steelhead (all origins combined) declined at both facilities, continuing the pattern of mostly low salvage observed since 2005 (Figure 7). Salvage at the SDFPF (658) in 2009 was lower than in 2008 (1,944). Similarly, TFCF salvage (712) in 2009 was lower than in 2008 (1,887).

Hatchery fish made up the majority of steelhead salvaged at both facilities. The TFCF salvaged 511 hatchery steelhead and 201 wild steelhead. The SDFPF salvaged 483 hatchery steelhead and 175 wild steelhead.

Salvage of wild steelhead at both facilities occurred predominantly in the first half of the year (Figure 8). Wild steelhead were salvaged January-May and in July and December at the SDFPF and February-June at the TFCF. Wild steelhead at both facilities were salvaged most frequently February-April.

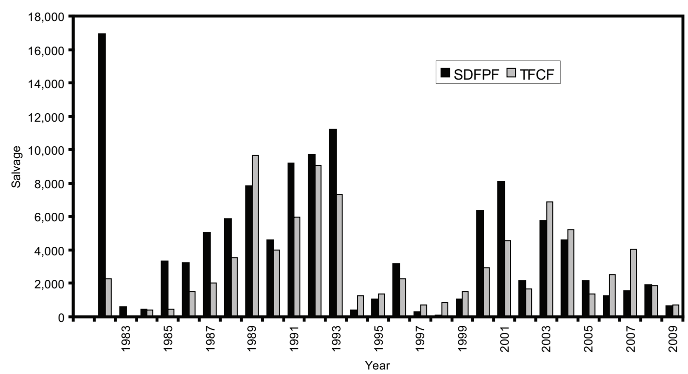

Figure 7 Annual salvage of steelhead (all origins combined) at the SDFPF and the TFCF, 1982 to 2009.

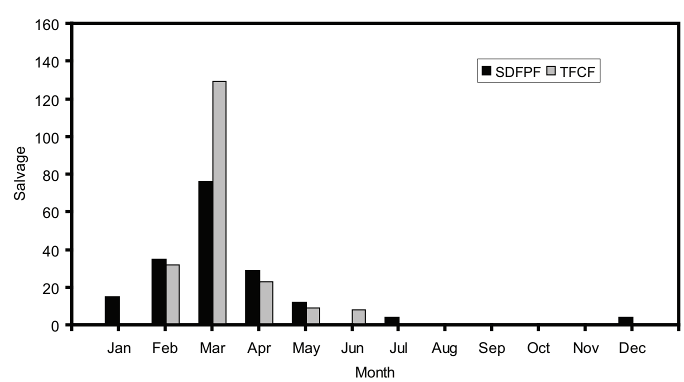

Figure 8 Monthly salvage of wild steelhead at the SDFPF and the TFCF, 2009

Striped Bass

Salvage at the SDFPF (97,208) in 2009 was a record-low. Salvage at the SDFPF and TFCF (128,622) continued the generally-low trend observed since the mid-1990's (Figure 9). Prior to 1995, annual striped bass salvage was generally above 1,000,000 fish.

Most striped bass salvage at the SDFPF happened in October and November 2009, whereas most striped bass salvage at the TFCF happened in June and July (Figure 10). At the SDFPF, October salvage (30,974) and November salvage (22,307) accounted for 55% of annual salvage. At the TFCF, salvage during June (62,084) and July (48,825) accounted for 86% of annual salvage. Striped bass were salvaged every month at both facilities, with the lowest monthly salvage occurring in April at the SDFPF (442) and in January at the TFCF (294).

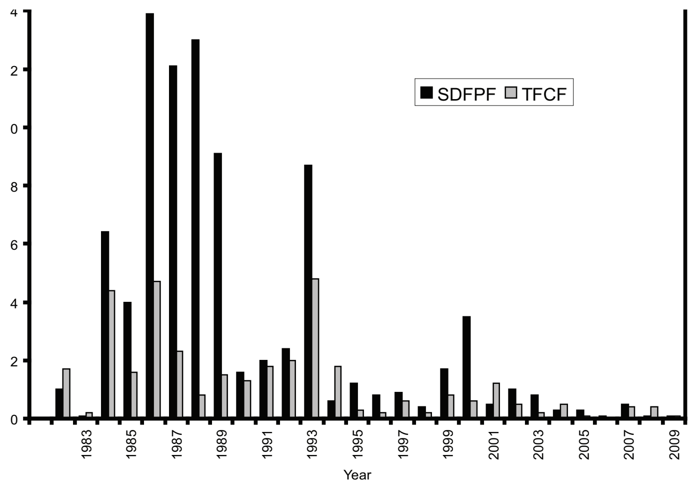

Figure 9 Annual salvage of striped bass at the SDFPF and the TFCF, 1982 to 2009

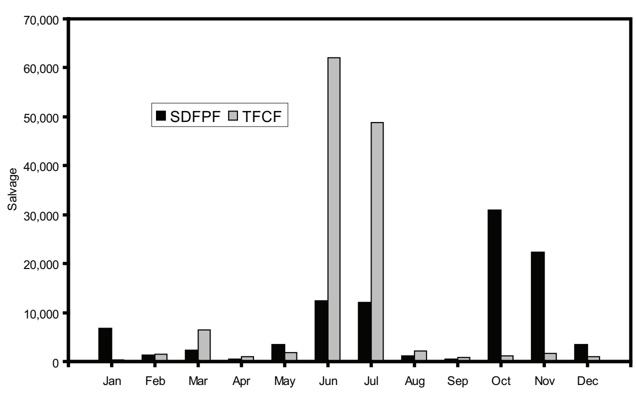

Figure 10 Monthly salvage of striped bass at the SDFPF and the TFCF, 2009

Delta Smelt

Compared to the historical levels, very few delta smelt were salvaged (Figure 11). Salvage in 2009 at the SDFPF (479) was lower than in 2008 (1,029). Salvage at the TFCF (286; a near-record low) was lower than in 2008 (1,009).

Most delta smelt were salvaged in a few months during the first half of the year (Figure 12). Juvenile delta smelt were most-frequently salvaged in May (211) and June (256) at the SDFPF, which together accounted for 97% of the total annual salvage. Delta smelt (juveniles) were also most-frequently salvaged in May (212) and June (58) at the TFCF, which accounted for 94% of the total annual salvage.

Delta smelt less than 20 mm were first detected at the TFCF on April 10 in 2009 (Table 2). Larval delta smelt were observed on 19 days of monitoring at the TFCF. The longest period of consecutive daily detections was May 5-8. Larval delta smelt were most-frequently detected in May (14 days).

Delta smelt less than 20 mm were first detected at the SDFPF on April 20 in 2009. Delta smelt larvae or post-larvae were observed on 12 days of monitoring at the SDFPF. The longest periods of consecutive daily detections were May 15-16 and June 5-6. Larval delta smelt were most-frequently detected in May (8 days).

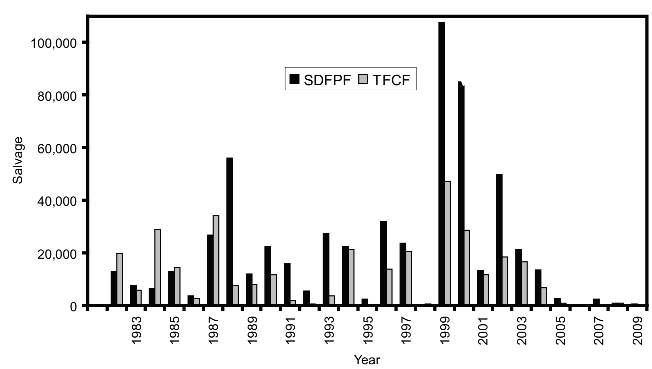

Figure 11 Annual salvage of delta smelt at the SDFPF and the TFCF, 1982 to 2009

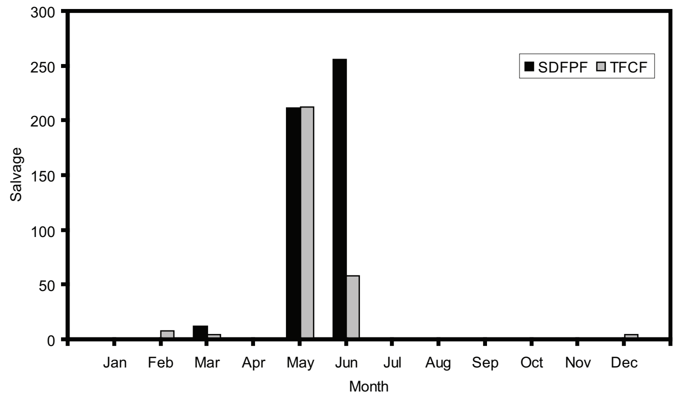

Figure 12 Monthly salvage of delta smelt at the SDFPF and the TFCF, 2009

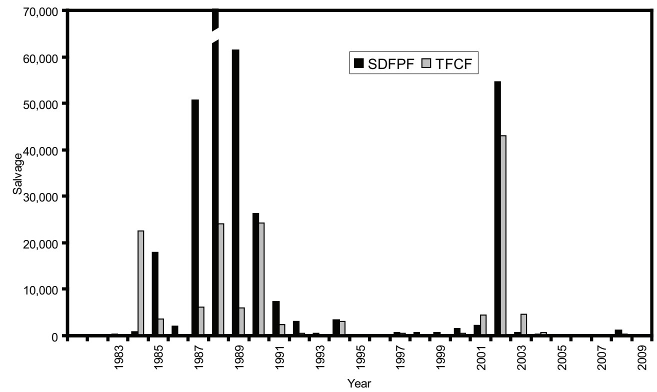

Figure 13 Annual salvage of longfin smelt at the SDFPF and the TFCF, 1982 to 2009. The annual salvage at the SDFPF for 1988 has been truncated for scale considerations (140,040).

Longfin Smelt

Longfin smelt at both facilities continued to be salvaged at very low levels compared to the early 2000s and the late 1980s (Figure 13). In 2009, salvage at the SDFPF (22) was lower than at the TFCF (66). Longfin smelt were salvaged in winter and spring at both facilities (Figure 14). Juvenile longfin smelt were most-frequently salvaged in April (8) and June (6) at the SDFPF, which accounted for 64% of salvage. The salvage of longfin smelt peaked in March (28) at the TFCF, which accounted for 42% of salvage.

Larval longfin smelt were collected on 10 occasions at the TFCF, mostly in March (Table 2). Only 3 longfin smelt larvae were collected (March 4, April 7, and May 8) at the SDFPF. Longfin smelt larvae or post-larvae were first collected at the TFCF on February 25. The longest-period of consecutive daily detections was February 25-26.

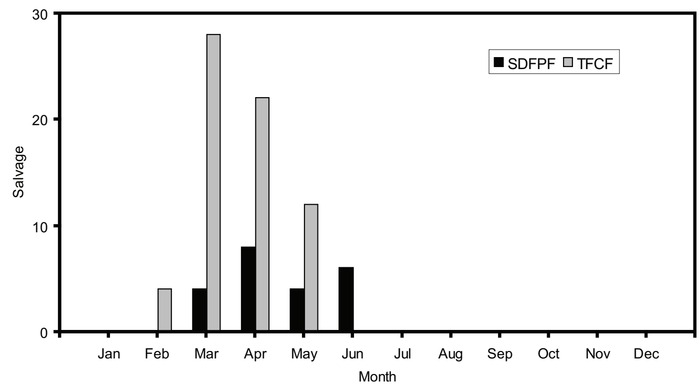

Figure 14 Monthly salvage of longfin smelt at the SDFPF and the TFCF, 2009.

Table 2 Occurrence of delta smelt and longfin smelt larvae among larval fish collected from the SDFPF and TFCF in 2009 based on sampling from March 3 through June 30 at SDFPF and from February 25 through June 24 at TFCF. A "Y' indicates that larval delta or longfin smelt < 20 mm FL were found while an "N" indicates no detection. Number of counts per day with larval smelt were recorded in parenthesis.

DATE	SDFPF Delta smelt larvae Y or N	SDFPF Longfin smelt larvae Y or N	TFCF Delta smelt larvae Y or N	TFCF Longfin smelt larvae Y or N
2/25/2009	N	N	N	Y
2/26/2009	N	N	N	Y
3/3/2009	N	N	N	Y
3/4/2009	N	Y	N	N
3/8/2009	N	N	N	Y (2)
3/10/2009	N	N	N	Y
3/16/2009	N	N	N	Y
3/24/2009	N	N	N	Y
4/7/2009	N	Y	N	N
4/10/2009	N	N	Y	N
4/20/2009	Y	N	Y	Y
4/22/2009	Y	N	Y	N
4/25/2009	N	N	Y	N
4/29/2009	N	N	N	Y
5/3/2009	N	N	N	Y
5/4/2009	Y	N	N	N
5/5/2009	N	N	Y	N
5/6/2009	Y	N	Y (2)	N
5/7/2009	N	N	Y	N
5/8/2009	N	Y	Y	N
5/11/2009	N	N	Y	N
5/13/2009	N	N	Y	N
5/14/2009	N	N	Y	N
5/15/2009	Y	N	N	N
5/16/2009	Y	N	N	N
5/17/2009	N	N	Y	N
5/18/2009	Y	N	Y	N
5/19/2009	N	N	Y	N
5/21/2009	Y	N	Y	N
5/22/2009	N	N	Y	N
5/23/2009	Y	N	N	N
5/26/2009	N	N	Y (2)	N
5/28/2009	Y	N	N	N
5/30/2009	N	N	Y (2)	N
6/1/2009	N	N	Y	N
6/5/2009	Y	N	N	N
6/6/2009	Y (2)	N	N	N

Splittail

Salvage of splittail in 2009 at both facilities was lower than in 2008 and low compared to recent years (Figure 15). Salvage at the SDFPF (1,418) was lower than in 2008 (4,979). Salvage at the TFCF (1,405) was slightly lower than in 2008 (1,439). TFCF salvage in 2007 (780) was the lowest since 1982 and a marked decrease from the record-high salvage in 2006 (5.0 million). Splittail salvage has followed a boom-or-bust pattern, often varying year to year by several orders of magnitude.

Threadfin Shad

In 2009, annual salvage at the SDFPF (387,940) was lower than at the TFCF (401,911) and both were near record low levels (Figure 16). Salvage, particularly that of TFCF, differed markedly from recent years (Figure 16). Similar to splittail, annual salvage of threadfin shad has varied greatly through time.

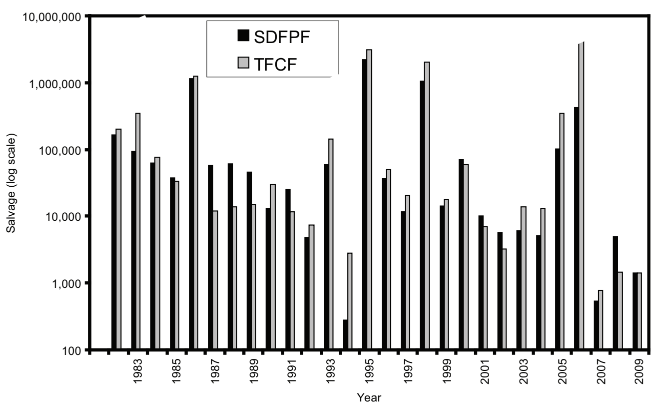

Figure 15 Annual salvage of splittail at the SDFPF and the TFCF, 1982 to 2009.

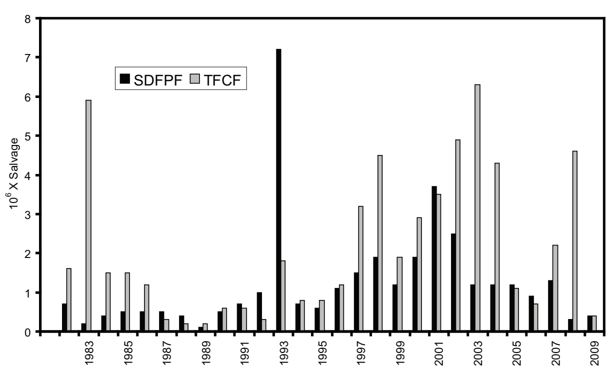

Figure 16 Annual salvage of threadfin shad at the SDFPF and the TFCF, 1982 to 2009.

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CONTRIBUTED PAPERS

A White Sturgeon Year-Class Index for the San Francisco Estuary and Its Relation to Delta Outflow

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Introduction

Little is known regarding recent trends in white sturgeon (*Acipenser transmontanus*) recruitment in the San Francisco Estuary. Tremendous variations in white sturgeon year-class strength and long periods between strong recruitment events have been obvious in the age distribution data since the 1930s (Pycha 1956, Shirley 1987). High Delta outflow during spring has long been associated with strong year classes (Kohlhorst 1980, Shirley 1987, Kohlhorst et al. 1991). Management actions to address the sporadic and infrequent recruitment have been limited to increasingly restrictive regulations on the sturgeon sport fishery, plans to improve passage of migrating adults past impediments, research, monitoring, and outreach. To aid the development and application of management options, I describe a 28-year time series of year-class strength (as in Kohlhorst et al. 1991) and its relationship to aspects of Delta outflow (as in CDFG 1992). The objective of this analysis was to: 1) Develop a year-class index (YCI) and 2) Determine the response of the index to various outflow periods and magnitudes from 1980-2007.

Methods

White sturgeon catch data was provided by the California Department of Fish and Game's (CDFG) San Francisco Bay Study (Bay Study). The 1980-2007 YCIs were calculated from 163 age-0 fish and 164 age-1 fish collected from 1980 through 2008 at the original 35 Bay Study stations by otter trawl sampling. Collected white sturgeon were designated age-0, age-1, or age-2+ based on total length (TL, mm) using criteria developed from historic monthly length-frequency distributions (Table 1). Additional information about Bay Study sampling methods can be found in IEP Technical Report 63 (Baxter et al. 1999).

Table 1 Monthly age-class cutoff lengths for San Francisco Bay Study otter trawl catch of white sturgeon.

Month	Minimum (mm)	Age-0 (mm)	Age-1 (mm)
January	20	80	380
February	20	80	390
March	20	80	400
April	20	80	410
May	20	160	420
June	20	200	440
July	20	240	460
August	20	280	480
September	20	320	500
October	20	340	510
November	20	360	520
December	20	380	530

Once catch by age was determined, monthly abundance indices were calculated for age-0 and age-1 fish independently. Indices for each age class were determined by first calculating catch-per-unit-effort (CPUE) at each station as:

CPUE= (# caught / tow area)*10,000

Next, the mean monthly CPUE for all stations in a region was multiplied by a regional weighting factor to account for the size of each embayment and all 5 regional indices were summed. Once monthly indices were calculated, annual indices were determined by averaging the monthly indices for when fish of each age group were most effectively captured. April to October was used for the age-0 indices and February to October was used for the age-1 indices. To develop the YCI, the age-0 index from the year in question was added to the age-1 index from the following year:

$$YCI_{(t)} = (\text{age-0 index})_{(t)} + (\text{age-1 index})_{(t+1)}$$
Where t=year

Associations between the YCI and Delta outflow were explored with correlation analysis using least squares linear regression in Microsoft® Excel. To determine the correlation coefficient (r) between white sturgeon recruitment and several measures of freshwater outflow, Dayflow (available at www.iep.ca.gov/dayflow/index.html) was used to calculate average monthly outflow at Chipps Island. For the purposes of presentation, the YCI was plotted against the mean monthly Delta outflow for two periods: 1) November to February, which represented the winter period of spawning migration and 2) March to July, which represented spring conditions experienced by eggs, larvae, and small juvenile fish. Outflow values and YCI values were both $\log_{10}$ transformed for use in correlation analyses and plots.

Results

Year-class strength varied greatly, from several very high indices to 2 long periods of zero or near-zero indices (Figure 1, Table 2).

Positive correlations existed between the YCI and all monthly and seasonal outflow periods (Table 3). The strong relationship between winter outflow and YCI (Figure 2, r = 0.74) was likely due to attraction flows. Spring outflow also showed a strong correlation with the YCI (Figure 3, r = 0.71), which likely indicates a positive relationship between outflow and successful spawning, hatching, rearing, and increased downstream transport of small juveniles to the estuary.

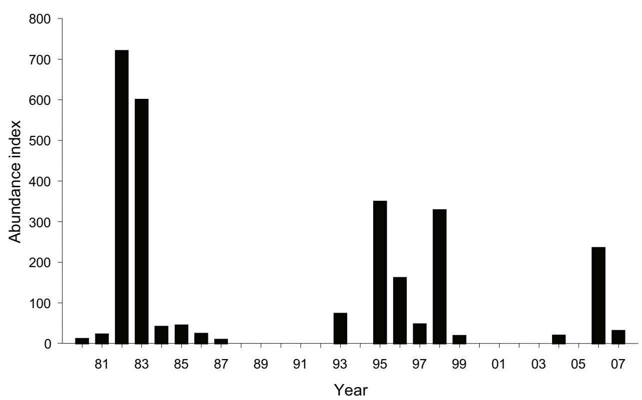

Figure 1 White sturgeon year class indices for the San Francisco Estuary developed from otter trawl catch by the San Francisco Bay Study.

Table 2 1980-2008 age-0 (April-October) and age-1 (February-October) San Francisco Bay Study white sturgeon abundance indices and YCI (combined age-0 and age-$1_{(t+1)}$).

Year	Age-0 Abundance Index April-Oct	Age-1 Abundance Index Feb-Oct	YCI (age-0 & age-1(t+1))
1980	11	6	11
1981	0	0	22
1982	487	22	720
1983	104	233	600
1984	0	496	41
1985	16	41	44
1986	0	28	24
1987	0	24	8
1988	0	8	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	51	0	72
1994	0	21	0
1995	267	0	349
1996	120	81	161
1997	33	41	47
1998	312	14	328
1999	8	16	18
2000	0	10	0
2001	0	0	0
2002	0	0	0
2003	0	0	0
2004	19	0	19
2005	0	0	0
2006	151	0	235
2007	0	84	30
2008	0	30	

Table 3 Correlation coefficients between the 1980-2007 San Francisco Bay Study white sturgeon year-class indices (Log_{10}(YCI+1)) and Delta outflow (Log_{10}). November and December outflow data is from the year prior toindex year.

Outflow Period	Correlation Coefficient
Nov(Y-1)	0.474
Dec(Y-1)	0.577
Jan	0.633
Feb	0.680
Nov-Feb	0.738
March	0.662
April	0.727
May	0.636
June	0.686
July	0.728
Mar-Jul	0.711

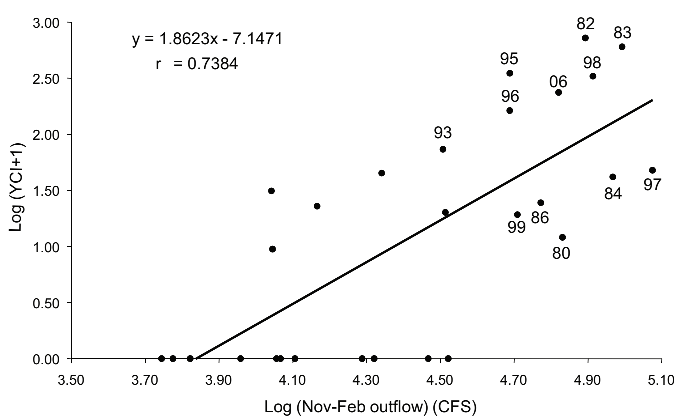

Figure 2 White sturgeon year-class index (YCI) from San Francisco Bay Study otter trawl catch versus mean daily Delta outflow for November through February. Numbers adjacent to points designate select year classes.

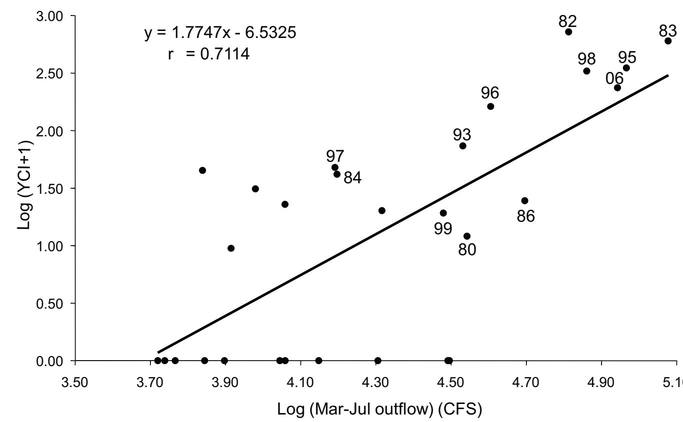

Figure 3 White sturgeon year-class index (YCI) from San Francisco Bay Study otter trawl catches versus mean daily Delta outflow for March through July. Numbers adjacent to points designate select year classes.

Discussion

River hydrology has long been known to influence the behavior and recruitment of anadromous fishes in the San Francisco Estuary (Turner and Chadwick 1972, Stevens 1977, Stevens and Miller 1983, Stevens et al. 1985). White sturgeon is known to migrate to spawning areas well before its recognized spawning season (Kohlhorst et al. 1991). In addition, juvenile recruitment appears related to the magnitude of spring flows as found by Stevens and Miller (1970) and this analysis. Based on this information, sturgeon year-class strength is probably a function of fall and winter flows providing stimuli for adult migration and gonadal maturation and spring flows providing stimuli for spawning, increased egg, larval, and early juvenile survival, and transport of juveniles to the estuary.

It appears that recruitment is a function of both spring and winter outflow, but that large year-classes are dependent on high spring outflows in particular. All years with exceptionally high spring outflow on record produce large year-classes regardless of the magnitude of the preceding winter outflow (the record does not include any years with very low winter outflow and very high spring outflow), where as winter outflows of exceptional magnitude only produce large year-classes when followed by wet springs. For example, years with the 5 highest spring outflows produced the 5 highest YCIs on record (1982, 83, 95, 98 and 2006; Figure 3). In contrast, 2 of the 3 highest winter outflows on record (1984 and 97; Figure 2), which were followed by dryer than average springs, produced only the 10^{th} and 8^{th} highest indices respectively. Similar, though less striking patterns can be seen in 1980, 1986, and 1999.

The sporadic and highly variable nature of this YCI was expected based on previously published YCIs (Kohlhorst et al. 1991, CDFG 1992) and length-frequency data from 3 sources: 1) Sturgeon Fishing Report Cards (DuBois et al. 2010), 2) Catch from tagging during the DFG sturgeon population study (Schaffter and Kohlhorst 1999, DuBois and Mayfield 2009), and 3) A pilot effort to determine the relative abundance of juvenile sturgeon using setlines (Schaffter 2000).

Previous San Francisco Estuary white sturgeon year-class indices were developed from age-0 through age-5 fish assigned birth years through the use of a growth equation (Kohlhorst et al. 1991, CDFG 1992) and from length-frequency distributions of subadult and adult fish (Shirley 1987). Because very little recent data exists on growth of white sturgeon in California and length-frequency distributions have been developed using sampling methods likely to be size biased, I think the present YCI is likely more reliable than those developed from historical growth data or length data from relatively old fish. I believe that the year-class index presented here effectively identifies substantial production years. Furthermore, a strong correlation (r = 0.77) between the 1986-2002 YCI series and a year-class index of white sturgeon 40-116 cm (16-46”) TL collected by setline (CDFG in prep.) indicates that this YCI can be used to predict recruitment to the sport fishery. Thus, I am confident that the YCI is useful for detecting substantial recruitment events, although it probably does not vary strictly in proportion to the true abundance of age-0 white sturgeon. In addition, YCIs of zero indicate very poor recruitment, but not necessarily a complete lack of recruitment for the estuary.

White sturgeon from the few relatively strong 1990s year classes form the foundation of the current recreational fishery, which allows for the harvest of individuals 46-66” (TL, the slot limit). The relatively strong 2006 year class has recruited to sport fishing gear (DuBois et al. 2010), but will likely have a prolonged recruitment to the slot limit near the middle of the present decade due to variations in growth rate. The periodicity and magnitude of YCIs over the past 20 years suggest a decline in abundance of legal-size fish is likely through the rest of this decade.

It has been suggested that in certain scenarios the proportion of positive tows (Ep) may be more precise than a CPUE based index (Uphoff 1993, Counihan et al. 1999). Because a strong correlation (r = 0.95) exists between the YCI and the age-0 Ep, I plan to explore the relative merits of both indices independently in a different analysis.

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U.S. Bureau of Reclamation
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