■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Of Interest to Managers

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Welcome to the spring Status and Trends issue of the IEP Newsletter. We begin with highlights of Delta water operations for winter 2007 from **Kate Le**. Unlike 2006, winter 2007 did not provide much rainfall or outflow for the estuary or export.

Kate Le begins the Status and Trends section with her *Water Year 2006 annual summary* (pg 5) reporting on one of the principal physical variables influencing biological productivity in the estuary, delta outflows. She describes in detail the substantial flow increases in 2006 relative to recent years and the relative consistency and high level of exports over the same period (also see Russ Gartz's export summary, pg 41, for longer term trends).

In *Zooplankton Monitoring 2006* (pg 10), **April Hennessy** and **Kathy Hieb** report mixed responses of various important fish food organisms to high 2006 outflows: important spring and early-summer fish food organisms – *Eurytemora affinis* and *Pseudodiaptomus forbesi* – increased in abundance, whereas the brackish water copepod genera *Acartia* declined as its brackish water habitat was shifted downstream so that less was contained within sampling range. The introduced cyclopoid copepod, *Limnoithona tetraspina*, increased in abundance in 2006 and again numerically dominated upper estuary copepod species. *L. tetraspina* is relatively small and very spiny, so even though it's being found in fish diets, questions remain about how much nutrition it provides. Historically, mysids and in particular *Neomysis mercedis* were very important in the summer- fall diets of many age-0 upper estuary fishes. April and Kathy report that in 2006 mysid numbers continued to decline and were dominated by the introduced, *Acanthomysis bowmani*. None of the other upper estuary mysids attained sufficiently high or wide-spread densities to be important fish food sources even though both *Neomysis mercedis* and *N. kadiakensis* exhibited small seasonal increases in 2006.

Bay shrimps provide a vital trophic link between the benthic (bottom) community and fishes, such as white and green sturgeons, starry flounder and striped bass, among others. **Kathy Hieb**, in *Common shrimp of the San Francisco Estuary* (pg. 14), describes shrimp abundance trends from 1980 through 2005 (not 2006 like other articles) and distribution trends for 2005. She observes that *Crangon franciscorum* continues to respond favorably to increased outflow and its abundance improved in 2005. Also, since 2005 outflows were not particularly high and did not persist into summer, the marine *Crangon* species, *C. nigricauda* and *C. nigromaculata* also increased in abundance within San Francisco Estuary. In the upper estuary, Kathy reports on a regional decline of the introduced *Palaemon macrodactylus* in the lower Sacramento River subsequent to the introduction of *Exopalaemon modestus* in about 2000. The latter species is the only upper estuary shrimp that can complete its life cycle completely in freshwater and it appears to be continuing to expand its range upstream in the Sacramento and San Joaquin rivers.

In *Common Crabs of the San Francisco Estuary* (starting pg 19), **Kathy Hieb** reports a near record low abundance for the Dungeness crab, *Cancer magister*, in the San Francisco Estuary in 2006 following poor ocean conditions. This and low 2005 abundance bodes poorly for commercial crab catches 3-4 years in the future when these estuary and other coastally reared crabs begin to contribute (or not) the majority of the catch. The other *Cancer* crabs in the estuary showed mixed abundance responses in 2006, but all indices were within the lower 25 % of their respective ranges. Finally, Kathy reports that the Chinese mitten crab, which was once caught by the tens or hundreds of thousands at the salvage facilities (see also Russ Gartz's salvage article pg 41), was barely detected by sampling in 2006.

Did upper estuary pelagic fishes respond favorably to increased winter and spring outflows? Some did, some didn't. In *2006 Fishes annual status and trends report for the San Francisco Estuary*, **Tom Greiner, Max Fish, Steve Slater, Kathy Hieb, John Budrick, Jason Dubois and Dave Contreras** compile and report fish trend information from 6 IEP long-term monitoring surveys. They begin by describing the physical setting in 2006: very high winter and extremely high spring outflows; near normal sea surface temperatures winter and spring, followed by warmer than average temperatures in late summer and fall; late start to upwelling (and protracted period of northward flowing Davidson Current that carries some species eggs and or larvae, such as Dungeness crab and English sole, away from San Francisco Estuary), but average upwelling values for summer, suggesting seasonally average summer productivity. They report that among the POD species, striped bass and longfin smelt abundance increased as hoped with increased 2006 outflow, but their abundance failed to reach levels expected given the outflow; threadfin shad exhibited a mixed response based on data from 2 different surveys, and delta smelt declined to very low abundance levels. All remain important concerns among managers. Upper estuary bottom dwelling (demersal) fishes as well as lower estuary pelagic and demersal fishes also exhibited mixed responses related to their early life history environmental needs.

In *2006 Fish salvage at the State Water Project and the Central Valley Project fish facilities Export totals and fish salvage* (pg 41), **Russ Gartz** presents annual and seasonal trends in fish salvage at the State Water Project (SWP) and Central Valley Project (CVP) fish facilities. To begin, Russ describes long-term and seasonal trends in water exports (see also Kate Le's article pg. 5), both of which influence the salvage of different fishes. The trend in total exports is only slightly down in 2006. Switching to annual fish trends, of particular interest is the recent decline in threadfin shad salvage after several extremely high salvage years, while the salvage of common carp and splittail shot up substantially, particularly in 2006. Both carp and splittail responded positively to protracted high spring 2006 flows on the San Joaquin River (see Kate Le's article pg 9) resulting in floodplain inundation. Green sturgeon salvage also jumped up, primarily at the CVP. Salvage declined for all the POD fishes – delta smelt, longfin smelt, striped bass and threadfin shad. This is often the case for both smelt species in high outflow years. Similarly, 2006 salvage of steelhead tended to be low relative to the late 1990s and early 2000s. Although Chinook salmon salvage increased slightly at the CVP and declined at the SWP, overall salvage was low. Russ provides much more detail and trends on many more species.

In *Central valley Chinook salmon ocean catch and escapement* (pg 55), **Erin Chappell** reports that even with substantial ocean-fishery restrictions, total Central Valley Chinook salmon escapement in 2006 declined to the lowest level since 1998; nonetheless, escapement remained above the long-term average (1970-2006). Most individual race or tributary counts follow a similar pattern of recent declines, with none approaching what can be considered low values.

In *Specific –conductance and water temperature data, San Francisco Bay, California, for water year 2005*, **Paul Buchanan** presents time-series graphs of specific conductance and temperature data from seven USGS operated measuring sites: Benicia Bridge in Suisun Bay; Carquinez Bridge in Carquinez Strait; Mare Island Causeway in Napa River; Point San Pablo, San Pablo Bay; Petaluma River marker 1 in San Pablo Bay; NE shore of Alcatraz Island in San Francisco Bay; and the San Mateo Bridge in south San Francisco Bay. Perhaps more importantly, Paul provides web links to these data and other historical water measurement data provided by the US Geological Survey. Also note his email if any questions arise.

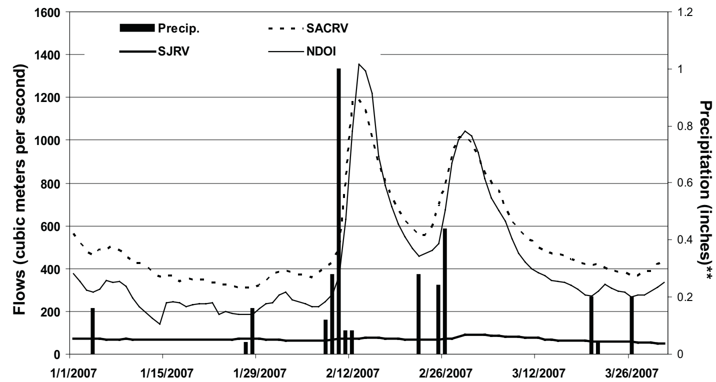
HIGHLIGHTS

DELTA WATER PROJECT OPERATIONS

Kate Le (DWR), Kle@water.ca.gov

During the January through March 2007 period, San Joaquin River (SJR) flow ranged between 51 and 93 cubic meters per second, Sacramento River flow ranged between 310 and 1,190 cubic meters per second, and the Net Delta Outflow Index (NDOI) ranged between 140 and 1,355 cubic meters per second (Figure 1). Hydrodynamic conditions in the Delta were primarily driven by precipitation during January through March of 2007. Precipitation data reported here are from the Stockton Fire House site. The largest and most frequent precipitation events occurred in February, with the monthly total of 2.52 inches, which was about 2.5 times more than the combined monthly total of January and March rainfall amounts. January and March monthly precipitation totals were 0.36 inches and 0.44 inches, respectively. As a result, January and March flows were below 566 cms, whereas, February flows were above 566 cms for most of the month. The largest Sacramento and NDOI flows occurred in mid-February, followed by the second largest flow in late February (Figure 1). The flow events occurred in response to 2 multi-day precipitation events in February that lead to high runoffs. SJR flows were stable during the January through March rainfall period, indicating that the rainfall affected runoff from the Delta northward, and not in the San Joaquin River watershed.

Export action during the January through March 2007 period at CVP was stable and normal with a rate of about 120 cms, except in mid-February where pumping decreased briefly for maintenance and late March for south Delta flow objectives (Figure 2). Unlike CVP, SWP pumping activities were erratic and fluctuated between 100 cms and 200 cms in early half of January, then between 50 cms and 100 cms from second half of January through March. The SWP varied pumping to meet south Delta flow objectives.



** Precipitation data from Stockton Fire House site.

Figure 1 January through March 2007 Sacramento River, San Joaquin River, and Net Delta Outflow Index

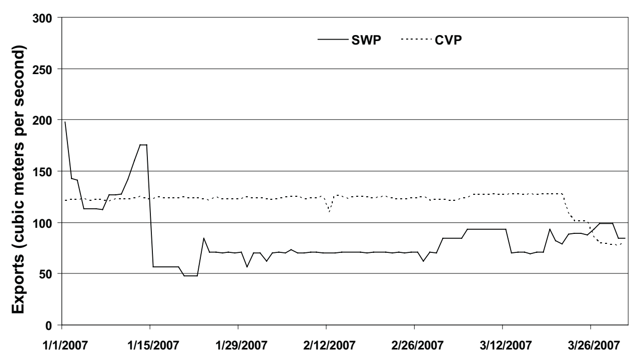


Figure 2 January through March 2007 State Water Project and Central Valley Project Pumpings

STATUS AND TRENDS

Kate Le (DWR), Kle@water.ca.gov

Water Year 2006 Annual Summary

River Flows and Net Delta Outflow Index

The hydrologic conditions for water year 2006 started normal. During the period of October to mid-December of 2005, Sacramento River flow, San Joaquin River flow, and NDOI were below 1,200 cubic meters per second (cms) (Figure 1). Thereafter, the amount and frequency of precipitation increased resulting in an increase of Sacramento River and NDOI flows. For the most part, these flows continue to fluctuate and stay above 1,200 cms through mid-May 2006 with Sacramento River and NDOI peaking at 2,400 and 10,500 cms, respectively (Figure 1). After mid-April, little rainfall activity emerged and both flows decreased below 1,200 cms by the end of May and remained below that level for the remainder of the water year.

San Joaquin River flow was stable and below 200 cms through December 2005 (Figure 1). Thereafter, San Joaquin flow was continually above 150 cms until mid-July 2006. The first peak flows of about 560 cms occurred in early January 2006, and the second peak flow, which is also the largest peak flow of about 990 cms occurred in mid-April 2006. Thereafter, flow gradually declined to about 100 cms in mid-July and leveled out for the remainder of the year.

Exports

During water year 2006, export actions at both SWP and CVP are shown in Figure 2. CVP export action was more stable than SWP throughout the year, which is typical. Highlights of both SWP and CVP pumpings during water year 2006 are listed below:

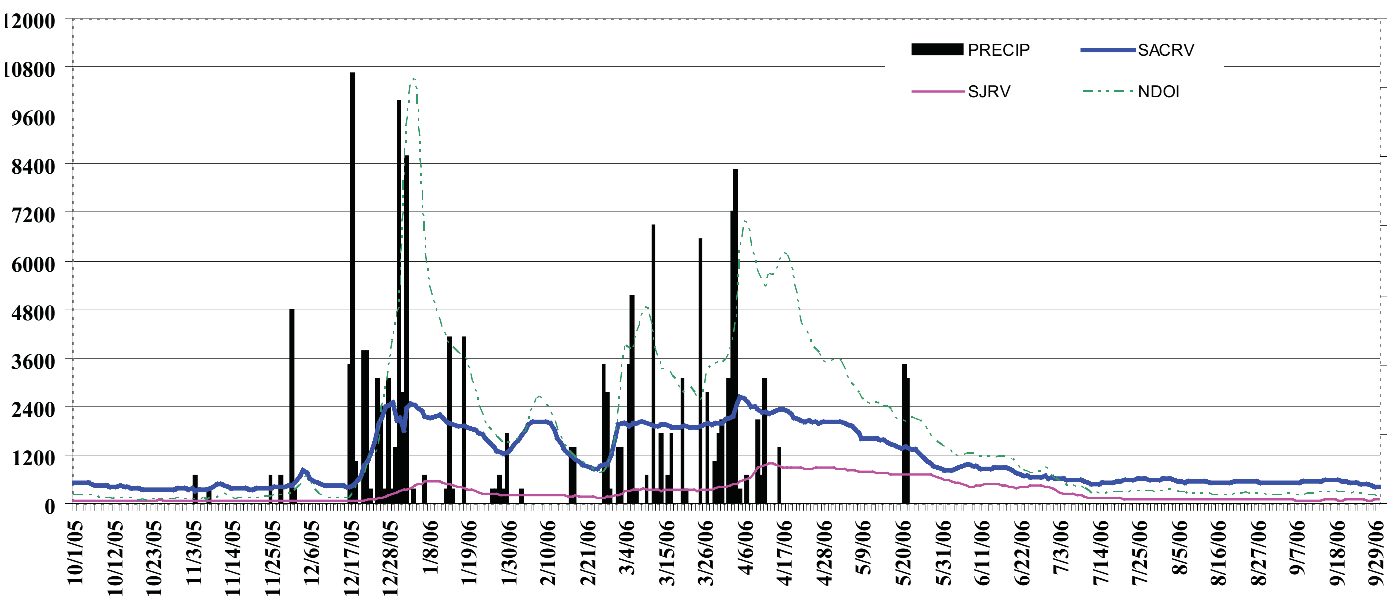


Figure 1 October 2005 through September 2006 daily flows for the Sacramento River San Joaquin River, Net Delta Outflow, and Precipitation

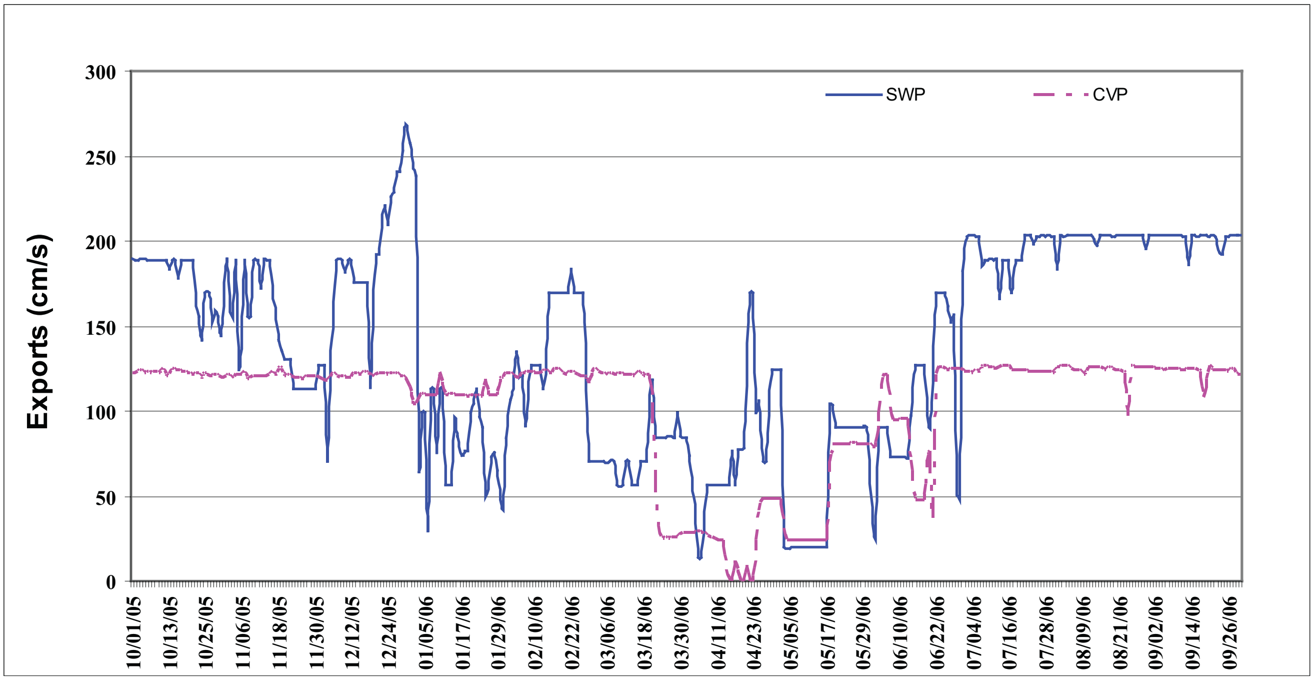


Figure 2 October 2005 through September 2006 State Water Project and Central Valley Project daily export rates

SWP

- Mid-October 2005 through mid-November 2005: EI ratio controlling
- Decreased pumping on 11/15/05, 12/4/05, and 12/17/05 to meet water quality standards
- Increased pumping on December 20, 2005 and thereafter to above 189 cubic meters per second (+189 cms + 1/3 Vernalis flow)
- Decreased pumping between January and March 2006 was to meet south Delta flow objectives
- April 2006 pumping to meet demands only; San Luis filled to capacity
- May 2006 operated for VAMP. The first 15 days combined pumping held at about 43 cms and the last 15 days combined pumping increased, but was held to about 170 cms.
- June 2006: At the beginning of June, SWP pumping reduced for weed spraying effort. On June 7, SWP reduced for fish concerns (fall and spring runs)
- Mid-July 2006 reduced pumping was to control water level issues in the south Delta. Thereafter, SWP pumping was primarily for the additional 500 cfs for EWA since the export to inflow ratio standard was 65%.

CVP

- Mid-February 2006 pumping decreased briefly for maintenance
- Late March 2006, decreased pumping for south Delta flow objectives
- April 2006 pumping to meet demands only; San Luis filled to capacity
- May 2006 operated for VAMP. The first 15 days combined pumping held at about 43 cms and the last 15 days combined pumping increased, but was held to about 170 cms
- June 21, CVP pumping reduced due to a malfunction

Precipitation

There was one precipitation event in October 2005 and three in November 2005 indicating a very dry outlook for the water year thus far, however, by mid-December 2005, the rainfall outlook changed and made up for lost time (Figure 1). Most of the water year rainfall occurred between mid-December 2005 and early January 2006 and between mid-February 2006 and mid-April 2006 (Figure 1). Most of the heavy amount of rainfall occurred the later half of December 2005 and early part of April 2006. The largest daily rainfall amount during the water year was 1.2 inches on December 31, 2005. Overall, the amount and frequency of precipitation activities during water year 2006 produced plenty of rainfall, which resulted in a wet year designation for water year 2006.

Percent of Inflow Diverted

Figure 3 is a plot of the 3-day and 14-day percent inflow diverted. During water year 2006, all percent-diverted limit-criteria were met for the year. From October 2005 through January 2006, the standard was 65%, whereas, from February through June of 2006, the standard was 35%. Export-inflow ratios remained below the standard lines all year, except for a brief spike of the 3-day average in October 2005. Operations of the water projects were adherent to the 14-day standard during that period, thus produced no exceedance of the standard for water year 2006.

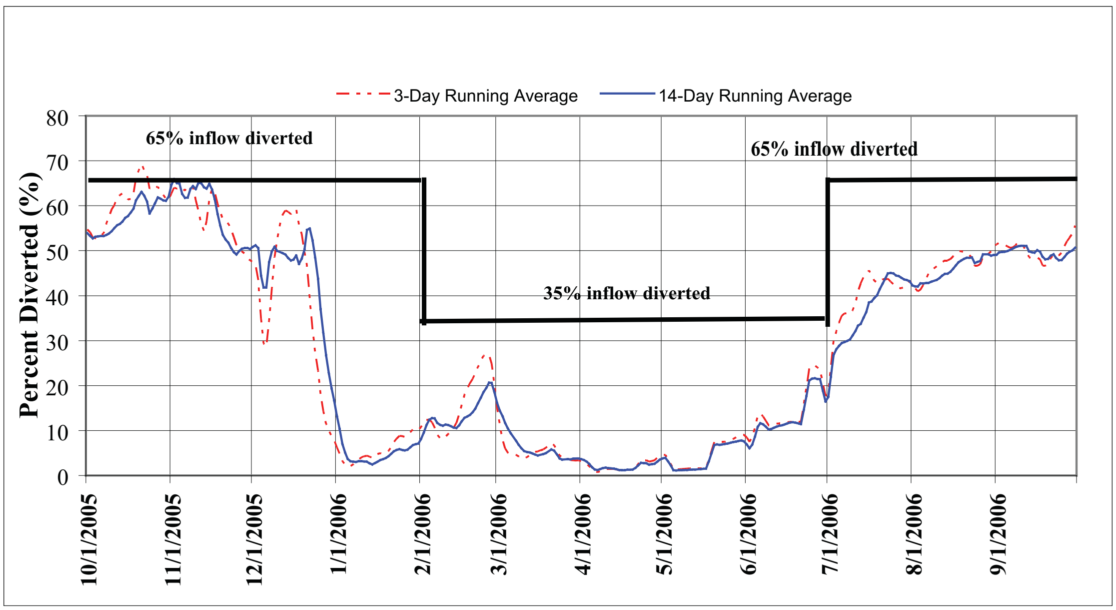


Figure 3 October 2005 through September 2006 Percent Inflow Diverted

WY 2006 Annual Totals Comparison

Water year 2006 (October 2005 through September 2006) annual totals are calculated and shown in Figure 4 for the following parameters:

- Sacramento River Flow = 27.99 MAF
- San Joaquin River Flow = 7.39 MAF
- Net Delta Outflow Index = 42.58 MAF
- State Water Project = 3.52 MAF
- Central Valley Project = 2.62 MAF
- SWP + CVP = 6.14 MAF

Compared to two previous (i.e. wy 2004 and wy2005) water year annual totals, Sacramento, San Joaquin, and NDOI during water year 2006 were much higher (Figure 4), with the largest difference seen in Sacramento and NDOI annual totals (MAF). The SWP export total remained the same, whereas CVP declined a bit, as did combined pumping (Figure 4).

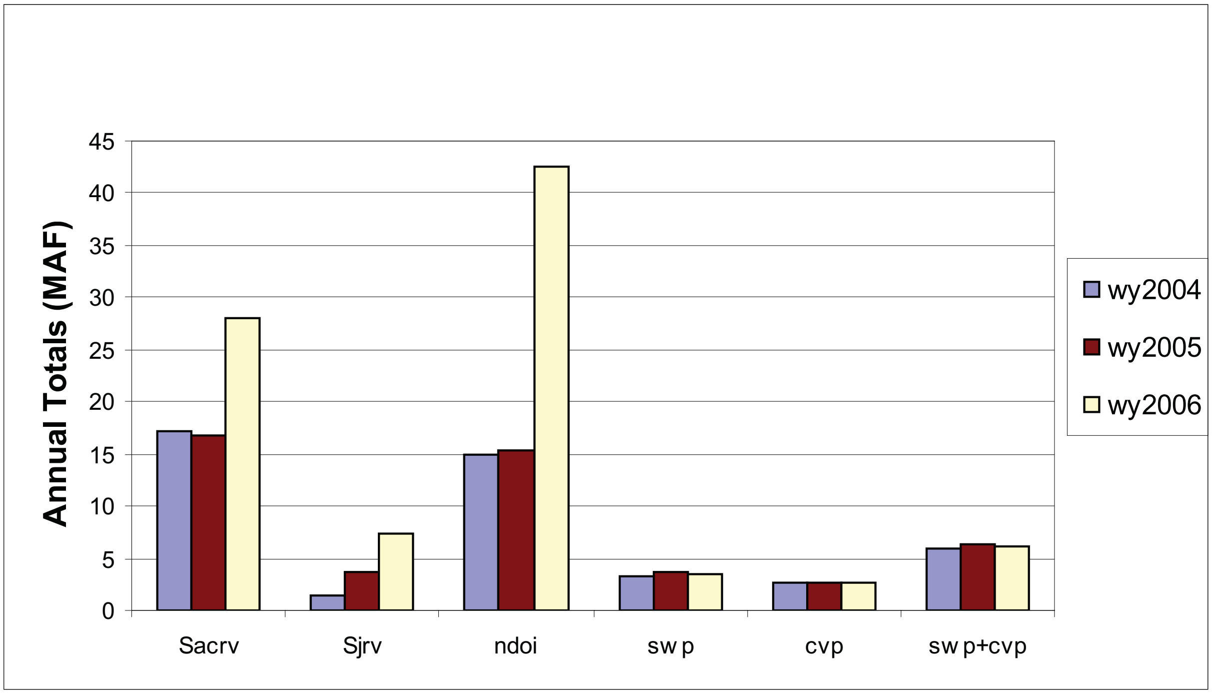


Figure 4 Water Year 2006 (October 2005 through September 2006) annual water totals for outflows and exports in comparison to those of wy 2005 and wy 2004

WY 2006 Monthly Average Inter- Annual Comparison

Sacramento River

Monthly averages in October, November, and June through September months of water year 2006 river flows were similar to the previous two years (Figure 5). However, river flows between December and May of water year 2006 were higher than previous year's monthly average values with the largest difference and largest average flow of about 2,200 cms in April.

San Joaquin River

Monthly average flows in all months during water year 2006 were higher than previous years (Figure 5). October, November, February, and July through September monthly average flows were slightly higher than previous years, whereas those between January and June months, were substantially higher than previous two years averages (Figure 5). The largest monthly flow difference was in April.

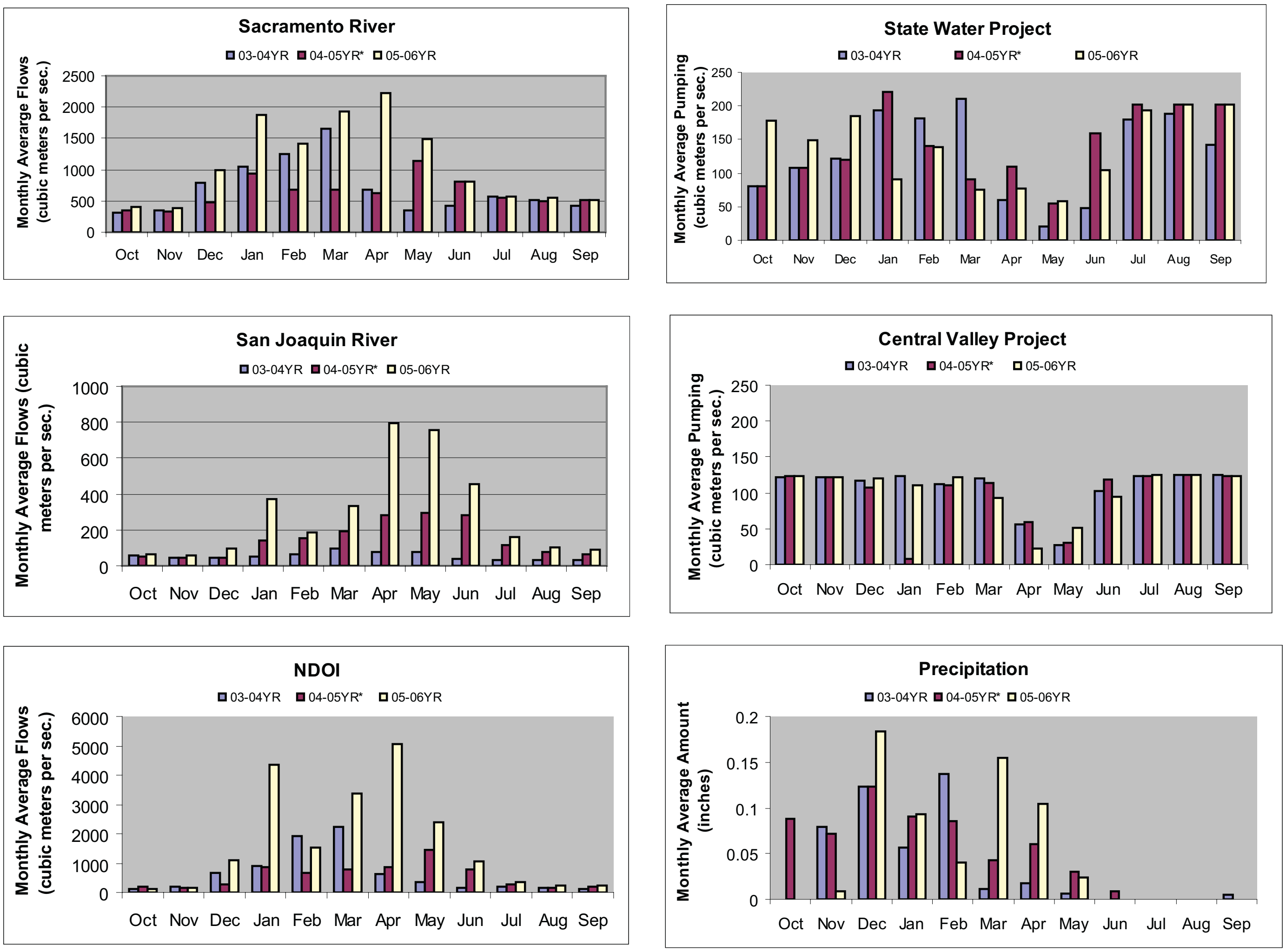


Figure 5 WY 2006 monthly average outflows, exports and precipitations in comparison to those of wy 2005 and wy 2004

NDOI

The annual outflow pattern was typical with low levels in early fall and summer, and high flows in winter and spring (Figure 5). The largest monthly average difference occurred in April of about 5,000 cms, followed by January of about 4,300 cms, March of about 3,300 cms, and May of about 2,400 cms. The largest difference in April is consistent with the largest river flow difference observed in both rivers.

Precipitation

Rainfall during water year 2006 was observed during the November through May period. The largest precipitation occurred in December, followed by March, April, January, February, May and then November (Figure 5). Compared to the two previous years, November, February, and May monthly averages of water year 2006 were lower. However, December, March, and April monthly averages for water year 2006 were substantially higher than the previous two years. January was the only month with a monthly average similar to water year 2005, but still higher than water year 2004 January monthly average.

State Water Project

Monthly average exports during water year 2006 were higher than previous two years during October through December months, about the same level as water year 2005 pumping in February, March, May, and July through September, but lower between January and April and for June (Figure 5). The lower pumping during these months was probably a response to south-of-the-delta reservoirs being filled to capacity and all water allocations being met for the year as a result of high runoffs from precipitation during the winter through spring period. Compared to previous years pumping, January 2006 had the largest difference: pumping occurred at a much lower rate. Perhaps, this resulted from the largest monthly rainfall totals occurring in December 2005 and transforming into large runoff in January 2006.

Central Valley Project

Water year 2006 pumping patterns were about the same level as previous years during October, November, and July through September (Figure 5). Overall, pumping was consistent and stable, except during the late-winter and spring periods when there was more pumping fluctuation compared to previous years.

Zooplankton Monitoring 2006

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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 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 the seasonal abundance trends are presented through 2006 for a select group of the most common copepods, cladocerans, rotifers, and mysids.

Methods

During 2006, 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 at bottom electrical conductivity of 2 and 6 mS/cm (about 1 and 3 ‰). January, February, and December were not always sampled historically and therefore not used for long-term trend analyses. Abundance indices were calculated as the mean number of each taxon per cubic meter by gear, season, and year at all core and floating EZ stations. Data were grouped into 3 seasons: 1) spring, March through May, 2) summer, June through August, and 3) fall, September through November. As for the 2004 and 2005 status and trends reports, indices presented here were separated by gear type and taxon, while the pre-2004 reports combined the CB and pump indices for each taxon.

The abundance indices and distributions presented here reflect the high outflow and concomitant low salinities in 2006. In high outflow years, brackish-water taxa, such as copepods of the genus *Acartia,* are found further downstream and therefore are less common in the Zooplankton Study sampling area. Conversely, freshwater and lower salinity taxa, such as the copepods *Pseudodiaptomus forbesi* and *Sinocalanus doerrii,* are more common in the sampling area due to transport downstream by outflow. Comparisons of annual and seasonal abundance indices must be analyzed in the context of changes caused by outflow variation.

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 *L. sinensis* and numerically became the dominant copepod species in the upper estuary. *L. tetraspina* is common in both brackish and freshwater. Due to its small size, *L. tetraspina* is not completely retained by the CB net, so indices for both the pump and the CB net are presented. *L.*

tetraspina abundance increased in 2006 for both gears and in all seasons, except the pump in fall, which remained unchanged from 2005 (Figure 1). *L. sinensis* continued to be collected in very low numbers in 2006. In 2006, *L. tetraspina* was most abundant in spring in San Pablo Bay and Carquinez Strait; as flows decreased during summer and fall, *L. tetraspina* was abundant throughout the study area, except the eastern and southern delta.

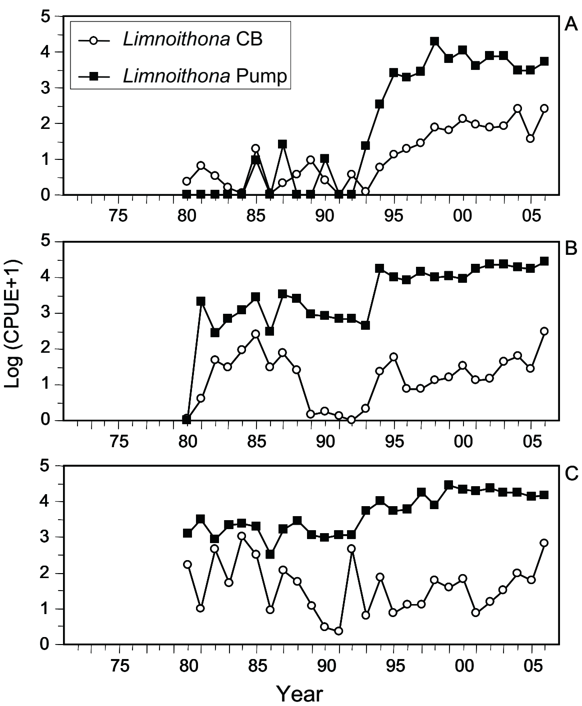

Figure 1 Abundance of *Limnoithona tetraspina* and *L. sinensis* combined (Log of mean catch*m3+1) from the pump and CB net in Spring (A), Summer (B), and Fall (C), 1972 - 2006

Eurytemora affinis, a calanoid copepod introduced to the estuary before monitoring began in 1972, was once a major food source for young fishes in spring, summer, and fall. It is found throughout the upper estuary and is most abundant in salinities less than 6 ‰. Since 1972, *E. affinis* abundance declined in all seasons, with the sharpest down-turns during summer and fall of the late-1980s (Figure 2), subsequent to the introductions of the Asian Clam, *Corbula amurensis*, and the copepod, *Pseudodiaptomus forbesi*. After a decline in 2005, spring abundance of *E. affinis* increased in 2006 to the levels of the mid-1990s (Figure 2A). In 2006, abundance peaked during spring at the floating entrapment zone stations, where mean density was over 2,600/m^3. Summer abundance, which fluctuated widely in the 1990s and 2000s, continued to increase in 2006, but remained low compared to the 1970s and mid-1980s (Figure 2B). Fall abundance sharply declined in 2006 and was the third lowest fall abundance since monitoring began (Figure 2C). In 2006, *E. affinis* was most abundant during spring in Carquinez Strait; after June, densities were very low throughout the study area.

Pseudodiaptomus forbesi is an introduced freshwater calanoid copepod that was first detected in the upper estuary in 1988. By 1989, *P. forbesi* summer and fall abundance was comparable to *E. affinis* before its decline (Figures 2B and 2C). Although *P. forbesi* abundance has declined slightly since its introduction, it has remained relatively abundant in spring and summer compared to other copepods. Spring abundance has always been highly variable, but had an overall downward trend (Figure 2A). Summer abundance has remained fairly stable since 1989, and in 2006 *P. forbesi* was the second most abundant copepod in the upper estuary during summer (Figure 2B). In 2006, *P. forbesi* was most abundant during summer in Suisun Marsh, where the mean density was over 6,000/m^3. Fall 2006 abundance was slightly higher than 2005, but the overall downward trend continued (Figures 2C). In 2006, *P. forbesi* was common during summer and fall in all regions upstream of Suisun Bay, with peak abundance in Suisun Marsh in June.

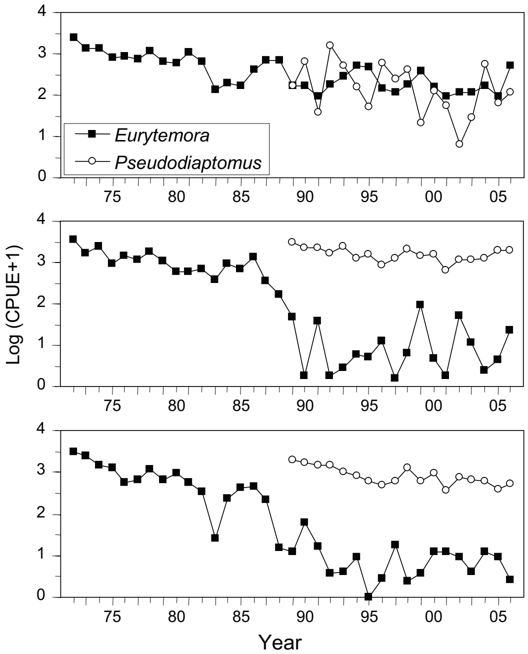

Figure 2 Abundance of *Eurytemora affinis* and *Pseudodiaptomus forbesi (*Log of mean catch*m3+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1972 - 2006

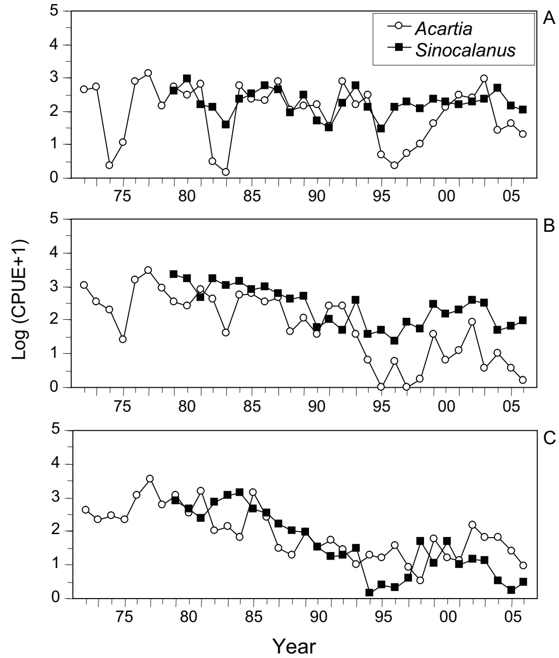

Figure 3 Abundance of *Acartia* spp. and *Sinocalanus doerrii (*Log of mean catch*m3+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1972 - 2006

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. The steadily increasing trend in spring abundance that started in 1997 was not hindered by the high spring outflows of the late-1990s. After reaching the second highest spring abundance in 2003, abundance declined sharply in 2004 and remained relatively stable in spring 2005 and 2006 (Figure 3A). The lowest summer abundances corresponded with the highest outflow years, and 2006 summer abundances were similar to 1998, the last high outflow year (Figure 3B). Fall 2006 abundance was the second lowest on record, with the lowest in 1998 (Figure 3C). Due to the high flows in 2006, *Acartia* was only common in Carquinez Strait until early spring, after which its distribution was limited mainly to San Pablo Bay.

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 by the mid-1980s (Figure 3B and 3C). This downward trend continued through the mid-1990s, followed by a modest increase until recently. Spring abundance, which has always been more variable than summer or fall abundance, was lowest in 1995 and steadily increased through 2004 (Figure 3A). Subsequently, it decreased twice in succession, in spring 2005 and 2006. After a peak in 2002, summer abundance declined in 2003 and 2004, and then increased slightly in 2005 and 2006 (Figure 3B). In the mid-1990s, fall abundance dropped to very low levels and then increased and remained higher through 2003. Fall abundance declined in 2004 and again in 2005 to levels similar to the record low of 1994, but increased slightly in 2006 (Figure 3C). In 2006, *S. doerrii* was common during spring as far downstream as Carquinez Strait, but by summer, its distribution shifted upstream of Suisun Bay into the delta.

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 4). Spring and fall abundance increased slightly from 2005 to 2006 (Figures 4A and 4C), although summer abundance decreased slightly to a record low (Figure 4B). In 2006, cladocerans were common throughout the upper estuary through June, but were most abundant in the eastern delta from July through December.

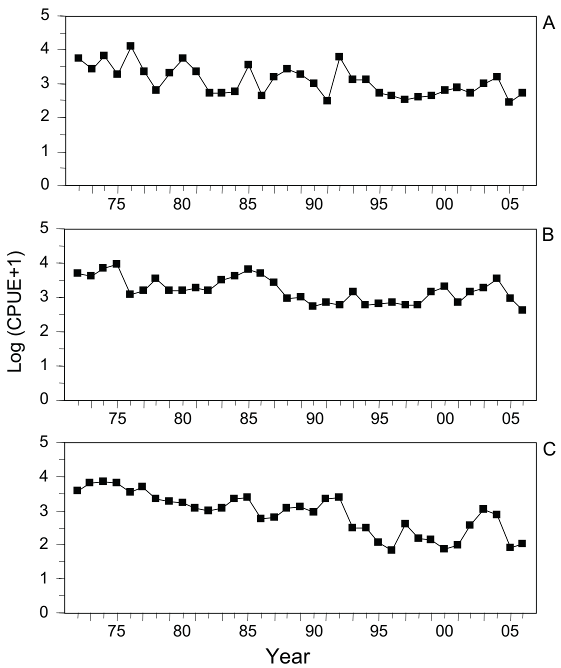

Figure 4 Abundance of Cladocera (Log of mean catch*m3+1) from the CB net in Spring (A), Summer (B), and Fall (C), 1972 - 2006

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 5). Spring abundance, although erratic, has also shown an overall downward trend (Figure 5A). After a peak in spring 2000, abundance declined sharply in 2001, and since 2002 there has been no catch during spring at any core stations. During 2006, summer abundance continued the decline that began in 2005 and fell to the third lowest summer abundance since sampling began (Figure 5B). Fall 2006 abundance increased from 2005, which was the second lowest on record (Figure 5C). In 2006, *S. bicornis* was only found from July through October and was common throughout the study area, except the southern delta.

All other rotifers, without *S. bicornis*, experienced abundance declines in all seasons from the early 1970s through the 1980s, but have stabilized since the early 1990s (Figure 5). Spring and summer abundance increased from 2005 to 2006 (Figure 5A and 5B), whereas fall abundance continued to decline for the second year and fell to the lowest on record (Figure 5C). Rotifers were common throughout the study area through July 2006; however, in fall, densities werehighest in the eastern and southern delta.

Mysids

Acanthomysis bowmani is an introduced mysid that was first captured by the study in summer 1993, and has been the most abundant mysid in the upper estuary since fall 1993 (Figure 6), *A. bowmani* is commonly found in densities of more than 10/m^3. Spring *A. bowmani* abundance increased between 1995 and 1998, and fluctuated annually thereafter (Figure 6A). After reaching a low in 2005, spring abundance continued to decline in 2006 to less than half of the average annual spring abundance (Figure 6A). *A. bowmani* is most abundant in summer with an average annual abundance of 16/m^3. Since 2001, summer abundance has had a downward trend; however, abundance remained at a moderate level in summer 2006 (Figure 6B). After a peak in 2005, *A. bowmani* fall abundance decreased in 2006 to the lowest fall abundance since being introduced (Figure 6C). In 2006, *A. bowmani* was common in Carquinez Strait during late spring. As flows decreased throughout summer, distribution shifted upstream to Suisun Bay, Suisun Marsh, and the lower Sacramento River.

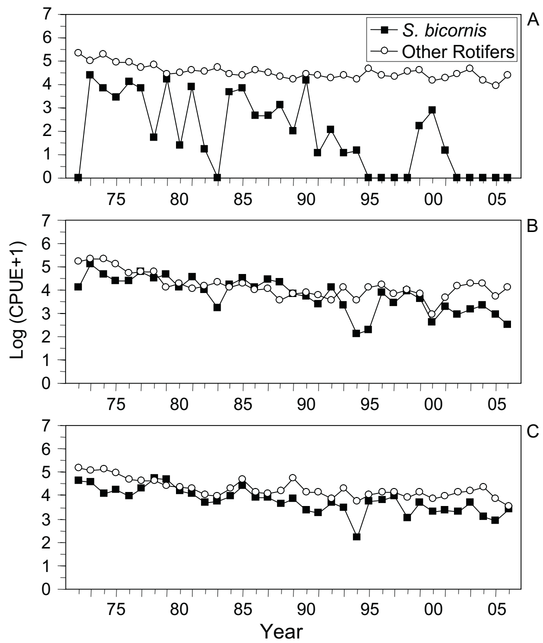

Figure 5 Abundance of *Synchaeta bicornis* and rotifers excluding *S. bicornis* (Log of mean catch*m3+1) from the pump in Spring (A), Summer (B), and Fall (C), 1972 - 2006

Neomysis mercedis, historically the only common mysid in the upper estuary, suffered a severe population crash in the early 1990s and is currently the third most abundant mysid in the sampling area (Figure 6). *N. mercedis* is most abundant in spring and summer, and prior to the population crash of the early 1990s spring and summer densities averaged more than 50/m^3. 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. Although spring abundance increased slightly from 2005 to 2006, it remained at very low levels (Figure 6A). Summer abundance declined slightly in 2006 from 2005 and continued to remain at the extremely low levels observed since 1997 (Figure 6B). In fall 2005 and 2006, no *N. mercedis* were caught at any of the stations sampled (Figure 6C). Even though 2006 was a high outflow year, *N. mercedis* was very rare throughout the study area. Abundance peaked in Suisun Marsh in May at only 5/m^3.

Neomysis kadiakensis regularly appeared in mysid samples beginning in 1996, but has never become common (Figure 6). Since 2001, *N. kadiakensis* has been the second most abundant mysid in the study area, but at relatively low levels compared to *A. bowmani*. Although spring and fall abundance decreased in 2006 from 2005 (Figure 6A and 6C), summer 2006 abundance reached the highest level across all seasons and years since being recorded (Figure 6B). *N. kadiakensis* was concentrated in San Pablo Bay and Carquinez Strait during spring 2006; as flows decreased throughout summer and fall, distribution shifted upstream to Suisun Marsh and Suisun Bay. *N. kadiakensis* has extended its range to low 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*. Currently no physical characteristics are established to separate these 2 species.

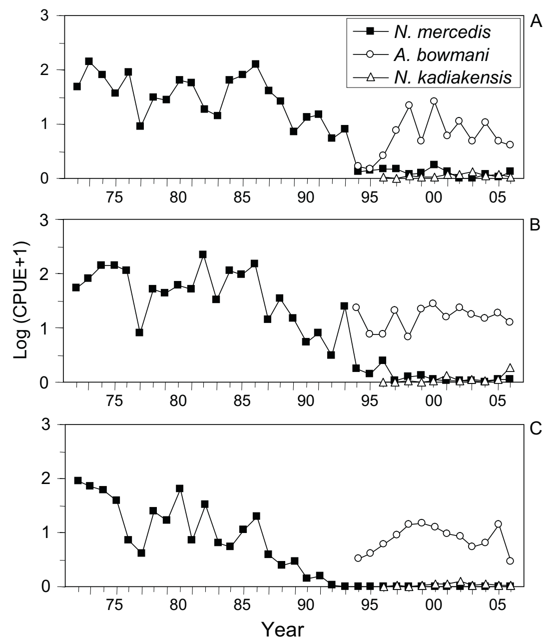

Figure 6 Abundance of *Acanthomysis bowmani, Neomysis mercedis*, and *Neomysis kadiakensis* (Log of mean catch*m3+1) from the macrozooplankton net in Spring (A), Summer (B), and Fall (C), 1972 - 2006

Common Shrimp of the San Francisco Estuary

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Annual abundance trends from 1980 to 2005 and distributional patterns for 2005 are summarized here for the most commonly collected caridean shrimp from San Francisco Estuary. The 2006 shrimp samples were not processed by April 2007, but the data should be available by late 2007. The shrimp data is from the San Francisco Bay Study (Bay Study) otter trawl survey, with additional *Exopalaemon modestus* data from the UC Davis Suisun Marsh otter trawl survey and the USFWS beach seine survey.

Crangon franciscorum, the California bay shrimp, is the largest of the common shrimp in the estuary and usually the most abundant. It is targeted by the Bay Shrimp trawl fishery because of its size and abundance. Larvae hatch in late winter and spring in higher salinity (>25 ‰) areas of the estuary and, in high outflow years, the nearshore coastal area. Juveniles rear in shallow brackish water for several months and maturing shrimp migrate back to cooler, higher salinity areas for reproduction. *C. franciscorum* reaches maturity within a year and some females live to 1.5 or 2 years.

The 2005 abundance index of juvenile *C. franciscorum* was slightly higher than the 2001 to 2004 indices (Figure 1). Based on a total index (i.e., all sizes), *C. franciscorum* was the second most common shrimp species collected in the estuary in 2005 (Table 1). Cumulatively since 1980, it remained the most common species collected by the Bay Study. In 2005, *C. franciscorum* abundance peaked from July through October, which is typical. One large cohort first appeared in the trawl gear in May and a second much smaller cohort appeared in August. Adult shrimp from 2004 were most common from January through March and in December.

C. franciscorum distribution in 2005 was very similar to the previous 4 years, although shrimp were not collected as far upstream due to the higher freshwater outflow. *C. franciscorum* collections ranged from South Bay to the lower Sacramento River just upstream of Sherman Island and the lower San Joaquin River just upstream of Antioch. The highest catches were at the channel stations south of the San Mateo Bridge in South Bay, near Angel Island in Central Bay, and from Carquinez Bridge to Pittsburg in Suisun Bay. In spring and early summer, the highest juvenile catches were from south of the San Mateo Bridge and San Pablo Bay. As salinities increased over summer, the center of distribution slowly moved upstream, and by August, the highest catches were from Suisun and Honker bays and the southern most South Bay stations. Through fall, maturing *C. franciscorum* migrated downstream while younger shrimp continued to rear in upstream areas, including the lower Sacramento River. Most adult *C. franciscorum* were collected from Central Bay and the San Pablo Bay channel in 2005, with a slight shift upstream in late fall.

The increased *C. franciscorum* abundance in 2005 was expected based on higher freshwater outflow in spring 2005 than the previous 4 years. The abundance of juvenile *C. franciscorum* continues to be strongly and positively influenced by March to May outflow (both variables log transformed, $r^2 = 0.521$, n=26; Figure 2). Since *C. franciscorum* is estuary-dependent and rears in shallow brackish areas, this relationship has been hypothesized to be partially due the quantity of low-salinity shoal habitat, which increases and decreases with outflow.

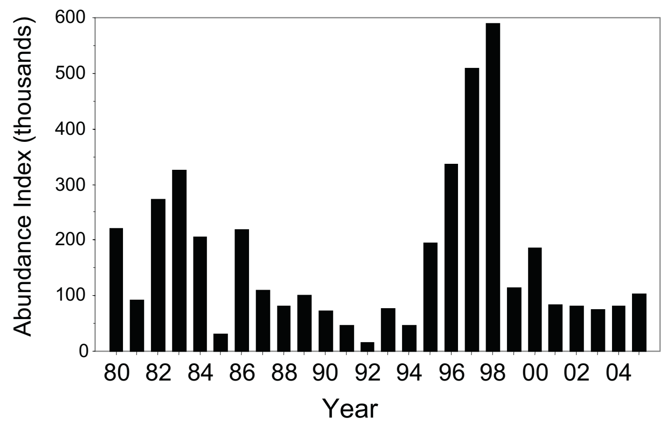

Figure 1 Annual abundance of juvenile *Crangon franciscorum*, May-October, otter trawl

Crangon nigricauda, the blacktail bay shrimp, is usually the second most common caridean shrimp in the estuary. Similar to juvenile *C. franciscorum*, juvenile *C. nigricauda* migrate to warmer, lower-salinity areas to rear and adults migrate back to cooler, higher salinity areas for reproduction. However, all life stages of *C. nigricauda* are found in cooler, higher salinity areas than *C. franciscorum* and *C. nigricauda* is not considered to be an estuary-dependent species. Peak reproduction is usually in spring, and multiple cohorts are common. *C. nigricauda* abundance increased slightly in 2005 (Table 1), continuing the trend of above-average indices since 2000. *C. nigricauda* has been the most abundant shrimp species in the estuary since 2000 and was 3 times more abundant than *C. franciscorum* in 2005. In 2005, *C. nigricauda* abundance peaked from July to September and in December. Three large cohorts of were collected: the first appeared in our gear in April, the second in May, and the third and largest in August. By November, the majority of all 2005 cohorts were mature. Adult *C. nigricauda* from the 2004 year class were most common in January and from June through December.

C. nigricauda was collected from South Bay to Carquinez Strait in 2005. The highest catches were at the shoal station near Treasure Island, where over 20,000 *C. nigricauda* were collected in September, and from the channel station near Alcatraz Island. Juvenile shrimp were most common in South Bay near the San Mateo Bridge and in the western half of San Pablo Bay, with slight shift in distribution upstream in fall. Adult *C. nigricauda* were most common in the Central Bay channels all months, with the broadest distribution in December.

Although we do not understand why *C. nigricauda* abundance increased to record high levels in recent years, this abundance pattern was shared with the Dungeness crab and several demersal marine fishes, including the bay goby, staghorn sculpin, plainfin midshipman, English sole, and speckled sanddab through 2004 (see the estuarine fish and crab articles in this newsletter). These species have varied reproductive strategies, as some spawn in the ocean and others in the estuary. All rear in higher salinity areas of the estuary and, although common in Pacific Coast estuaries, none are considered estuary-dependent.

Table 1 Annual abundance indices (thousands) of the 5 most common shrimp species and all shrimp species combined, February-October, otter trawl. The indices include all sizes (juveniles and adults) for each species.

Year	*C. franciscorum*	*C. nigricauda*	*C. nigromaculata*	*Heptacarpus*	*Palaemon*	*All species*
1980	225.7	46.4	1.7	1.0	4.7	279.5
1981	119.2	22.1	0.5	0.5	5.1	147.4
1982	366.4	16.0	1.5	0.2	3.0	387.1
1983	328.5	38.8	16.0	0.6	1.3	385.2
1984	330.9	14.7	7.8	3.1	7.0	366.4
1985	57.8	19.7	3.1	3.1	3.9	88.3
1986	258.6	55.6	6.7	2.9	5.5	334.7
1987	142.9	75.5	9.6	6.8	2.4	238.9
1988	98.6	111.8	10.7	8.6	1.7	231.5
1989	100.2	118.6	22.1	27.4	4.6	273.1
1990	67.3	168.6	44.8	19.9	3.5	304.7
1991	51.4	190.3	63.0	41.1	4.7	350.8
1992	24.8	134.7	66.4	18.5	4.5	249.0
1993	70.5	128.1	78.6	25.4	4.0	308.3
1994	48.0	102.0	56.0	15.9	2.1	224.5
1995	180.6	78.8	33.1	4.3	3.7	302.3
1996	287.0	159.4	35.3	14.9	2.2	501.3
1997	444.5	163.9	43.4	9.1	4.9	667.9
1998	540.6	128.5	53.1	4.8	9.0	739.0
1999	159.5	134.6	42.0	13.2	4.1	354.3
2000	157.5	242.7	20.7	42.2	3.1	467.5
2001	92.9	259.6	12.0	56.6	5.2	427.0
2002	96.1	652.9	15.0	78.0	4.9	848.7
2003	77.3	379.5	15.7	67.5	1.5	544.2
2004	91.7	333.7	20.5	29.0	1.9	477.5
2005	106.0	365.5	46.8	17.9	4.1	541.1

Crangon nigromaculata, the blackspotted bay shrimp, is found in cooler, higher salinity water than either *C. franciscorum* or *C. nigricauda* and is the most common shrimp collected in the nearshore ocean area adjacent to the estuary (SFWQB 2003). *C. nigromaculata* abundance continued to increase in 2005, and was almost double the 2004 index (Table 1). In 2005, catch peaked in August and September and again in December. *C. nigromaculata* ranged from South Bay to upper San Pablo Bay in 2005, with most of the San Pablo Bay catches in late fall. The highest catches were from the channel stations just south of Yerba Buena Island and near Angel Island, and from the shoal station near Treasure Island, all in Central Bay.

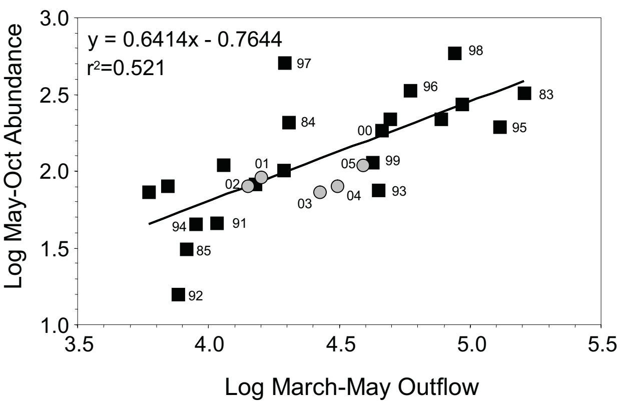

Figure 2 Annual abundance of juvenile Crangon franciscorum, May-October, vs. March-May outflow. Both axes are log transformed.

Heptacarpus stimpsoni, the Stimpson coastal shrimp, is a small shrimp common over soft bottoms and eelgrass beds. In 2005, *H. stimpsoni* abundance continued the declining trend started after the record high of 2002 (Table 1), but remained slightly above the study-period mean. Similar to *C. nigricauda*, *H. stimpsoni* abundance increased dramatically in 2000 and peaked in 2002. *H. stimpsoni* was collected from South Bay, south of the Dumbarton Bridge, to western San Pablo Bay in 2005, a range slightly contracted from 2004. The highest catches occurred at the channel stations south of Yerba Buena Island and near Alcatraz Island and at the shoal stations near Treasure Island and at Southampton Shoal, all in Central Bay.

Palaemon macrodactylus, the oriental shrimp, was introduced from Asia in the 1950s (Newman 1963). It is found in tidal brackish and freshwater areas, preferring shallow habitats with structure, such as vegetation and pilings. Such habitats are not sampled well by trawls, so *P. macrodactylus* is more common in the estuary than our sampling indicates. Although abundance increased in 2005 (Table 1) and was slightly above the study-period mean, *P. macrodactylus* remained a minor component of our total shrimp catch. In 2005, *P. macrodactylus* was most common in South Bay, near the Dumbarton Bridge, and in upper San Pablo Bay and Carquinez Strait.

P. macrodactylus has been uncommon at our lower Sacramento River stations since 2002, when the recently introduced *Exopalaemon modestus* became common. This trend continued in 2005, when only 24 *P. macrodactylus* were collected at the 7 Sacramento River stations, accounting for 1.7% of the total *P. macrodactylus* collected upstream of San Pablo Bay. In 2001, we collected 400 *P. macrodactylus* at these same stations, accounting for 10.9% of the total *P. macrodactylus* collected upstream of San Pablo Bay. *Exopalaemon modestus* was the dominant shrimp species in the lower Sacramento River from 2002-2005 (see next section). Since both *E. modestus* and *P. macrodactylus* rear in shallow areas with vegetation or other structure, the reduced catch of *P. macrodactylus* in the upstream portion of its distribution may have resulted from competitive interactions with or predation by *E. modestus.*

Exopalaemon modestus, the Siberian prawn, is another introduced shrimp from Asia. It is common in tidal brackish and freshwater areas of the estuary as well as in rivers and sloughs upstream of the delta. *E. modestus* is the only shrimp species in the estuary that can complete its life cycle in freshwater. Because it is most common at upstream stations not included in the Bay Study abundance indices, mean number per tow (catch per unit effort or CPUE) for all stations upstream of Carquinez Strait is used to describe trends instead of annual abundance indices. Suisun Marsh annual CPUE is mean number per tow for all stations, while USFWS beach seine CPUE is catch per (seine volume*0.25) for selected stations.

We first collected *E. modestus* in the lower Sacramento River in 2000 and its abundance and distribution rapidly expanded within 1 to 2 years. In 2005, Bay Study catch and CPUE decreased slightly while Suisun Marsh catch and CPUE increased (Table 2). Although CPUE in the Bay Study and Suisun Marsh surveys peaked in either 2002 or 2003, USFWS beach seine CPUE at several locations outside of the delta, such as the San Joaquin River upstream of Stockton, continued to increase in 2005 (Table 2).

Table 2 Annual catch and CPUE of Exopalaemon modestus from several studies and gears, 2000-2005. Bay Study and Suisun Marsh otter trawl CPUE is mean catch per tow and USFWS beach seine CPUE is catch per (seine volume*0.25). Bay Study data is from January 2000-December 2005, Suisun Marsh data is from March 2002-December 2005, and USFWS beach seine data is from July 2002-December 2005.

	CDFG OT		*UC Davis OT*		*USFWS seine*		
	Carquinez Strait to lower Sacramento and SJ rivers		*Suisun Marsh*		*Knights Landing*	*San Joaquin River, near Mossdale*	*San Joaquin River, near Tuolumne River*
Year	*Catch*	*CPUE*	*Catch*	*CPUE*	*CPUE*	*CPUE*	*CPUE*
2000	3	0.01					
2001	2163	8.94					
2002	9929	41.37	7636	36.4	0.11	0.00	0.00
2003	8022	30.39	13838	54.9	0.56	0.02	0.00
2004	3696	14.10	3441	13.7	1.26	0.04	0.01
2005	3318	12.57	5490	21.8	0.57	0.12	0.16

E. modestus was the most common caridean shrimp in the lower Sacramento and San Joaquin rivers as of 2002, outnumbering both the native *Crangon franciscorum* and the introduced *Palaemon macrodactylus* in these areas. A similar trend was reported for Suisun Marsh, where it was the most common caridean shrimp collected from 2002 to 2005 (Schroeter, Stove, and Moyle 2006).

E. modestus catch peaked from October to December in the Bay Study trawls and in September and October in the Suisun Marsh trawls. *E. modestus* reproduces in summer, so this seasonal pattern probably resulted from either juvenile shrimp moving into the sampling area or reaching a size effectively retained by the otter trawl. We again collected very few ovigerous female *E. modestus* in the Bay Study trawls; this and data from other studies indicates that the primary reproductive areas are in freshwater upstream of our study area and in Suisun Marsh.

As of late 2005, *E. modestus* ranged from Wards Landing (Colusa County) on the Sacramento River in the north, to Mud Slough (Merced County), a tributary of the San Joaquin River, in the south. It was also found throughout Suisun, Grizzly, and Honker bays to Carquinez Strait, and infrequently in San Pablo Bay. It was again most common in the lower Sacramento River near Sherman and Decker islands in the Bay Study trawls. *E. modestus* was collected at all of the Suisun Marsh stations in 2005, but was most common in Denverton, Peytonia, and Boynton sloughs.

Acknowledgements

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Common Crabs of the San Francisco Estuary

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This report summarizes the abundance trends and distributional patterns of the most common *Cancer* crabs and *Eriocheir sinensis,* the Chinese mitten crab, through 2006 in the San Francisco Estuary. Most of the data is from the San Francisco Bay Study (Bay Study) otter trawl, with additional mitten crab data from the UC Davis Suisun Marsh otter trawls and the Central Valley Project (CVP) and State Water Project (SWP) fish facilities salvage.

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 in fall and winter when approximately 100 mm CW. Estuary-reared crabs reach legal size at the end of their 3rd year, 1-2 years before ocean-reared crabs.

The abundance index of age-0 *Cancer magister* was near record low in 2006 (Figure 1), comparable to the lowest indices from the years with very strong El Niño events. However, there was not a strong El Niño event in winter 2005-06 and sea surface temperatures in the Gulf of the Farallones were near normal (see the Physical Settings section of the Fishes Status and Trends report). The frequent winter storms and resultant strong northward flowing Davidson Current most likely transported *C. magister* larvae north of the Gulf of the Farallones. San Francisco Estuary is near the southern limit of *C. magister* distribution and there is no large population to the south to replace this larval loss. The planktonic larvae were not able to return to the Gulf, resulting in poor *C. magister* recruitment here in 2006. The low abundance indices of 2005 and 2006 followed 4 years of very high age-0 *C. magister* abundance in the estuary, which resulted from cooler than average ocean temperatures and favorable nearshore currents (less northward flow) in fall and winter.

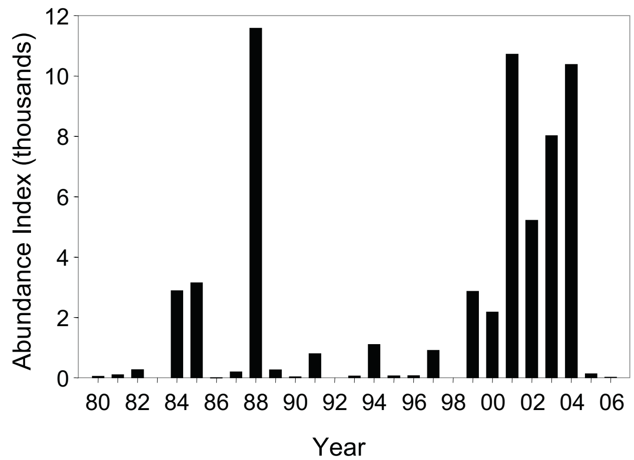

Figure 1 Annual abundance of age-0 *Cancer magister*, Bay Study otter trawl, May to July, 1980-2006

The recent strong *C. magister* year classes were reflected in the *C. magister* commercial landings. Central California landings surpassed 5 million pounds annually for the 2002-03 to 2005-06 fishing seasons, and 5.2 million pounds were landed in the 2006-07 season through late May 2007 (P. Kalvass, personal communication, see "Notes"). Central California landings last exceeded 4 million pounds in the late 1950s. The 2001 year class of estuary-reared crabs reached legal size and became available to the fishery in the 2003-04 season and the 2002 through 2004 year classes entered the fishery consecutively into the 2006-07 season.

In 2006, we collected only 4 age-0 *C. magister*, all from Central Bay. Only one age-1 crab from the 2005 year class was collected, also in Central Bay. Crabs were collected in July, September, and November.

The following 3 *Cancer* species reproduce in both the nearshore ocean and higher salinity areas of the estuary in winter, but in high outflow years, most larvae that hatch in the estuary are transported to the ocean. 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 2006 age-0 *C. antennarius* abundance index was very low, continuing a steep decline from the record high 2004 index (Table 1). The 2005 and 2006 indices were similar to the very low indices of the 1980s and early 1990s and were a substantial change from the high indices from 1994 to 2004. *C. antennarius* catches were very sporadic in 2006 and did not occur every month. The highest catch was in February, just before the highest outflow event of the year.

In 2006, all *C. antennarius* were collected in South and Central bays, except for 1 from San Pablo Bay. The highest catch was from the channel station near Hunter's Point in South Bay. Distribution differed by age class, with age-0 *C. antennarius* most common in South Bay and age-1+ crabs most common in Central Bay. The majority (92%, n=11) of *C. antennarius* <25 mm CW were collected at shoal stations, while all of the age-0 crabs ≥40 mm CW were collected at channel stations.

Cancer gracilis, the slender crab, is smaller than the other 3 *Cancer* crab species reported here, 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. Like *C. magister* and *C. antennarius*, the 2006 abundance index of age-0 *C. gracilis* decreased from an already low 2005 index (Table 1). After over a decade of relatively high indices, the 2004 to 2006 indices were well below the study-period mean. *C. gracilis* abundance was bimodal in 2006, with most collected in January and February and again from September to December. Catches were very low through spring, possibly suppressed by the consistent high outflow and resulting low salinities from March through May.

Of the 74 age-0 *C. gracilis* collected in 2006, 73 were from Central Bay and 1 from South Bay. Distribution of age-0 and age-1+ crabs was almost identical. The majority (91%, n=67) of *C. gracilis* were collected from channel stations in 2006, with the highest catches from the 2 channel stations near Angel Island.

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. The 2006 age-0 *C. productus* abundance index increased slightly from the very low 2005 index (Table 1), and was just below the study-period mean. Catch was highest in May and with a smaller peak in September and October, but 3 or fewer crabs were collected in most months.

Table 1 Annual abundance indices of age-0 Cancer crabs from the Bay Study otter trawl, 1980-2006. The index period is from May to October for all species

Year	*C. antennarius age-0*	*C. gracilis age-0*	*C. productus 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

Of the 40 *C. productus* collected in 2006, 38 were from Central Bay and 2 from South Bay. Distribution did not differ substantially by age class, although only age-0 *C. productus* were collected in South Bay. In 2006, 90% (n=36) of *C. productus* were collected at our Alcatraz Island station, which has a gravel and small rock substrate, and all were collected from channel stations.

The high freshwater outflow in winter and spring 2006 likely contributed to the low abundance of *C. anten-*

narius, *C. gracilis*, and *C. productus* through two mechanisms. First, many estuary-hatched larvae were probably transported to the ocean by outflow generated currents. Second, the principal period of juvenile crab immigration to the estuary is from April through June, when salinities were relatively low in Central Bay. For example, the mean Central Bay bottom salinity was 23.4 ‰ in June 2006, the lowest for this month since the Bay Study began sampling in 1980. The low salinities undoubtedly limited the immigration to and use of the estuary by these marine crabs for several months of 2006.

Eriocheir sinensis

Eriocheir sinensis, the Chinese mitten crab, was first collected in the estuary in the early 1990s, but likely introduced to South 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 winter 2006-07, Bay Study adult *E. sinensis* mean catch-per-unit-effort (CPUE) was 0. This was the first winter since 1994-95 that we did not collect any adult *E. sinensis* in our trawls. Suisun Marsh adult CPUE was again 0 in 2006 and the combined fish facilities estimated total adult salvage was 12, the lowest total since *E. sinensis* was first detected at the CVP fish salvage facility in fall 1996.

USFWS monitoring for juvenile *E. sinensis* in the delta and its tributaries again detected no crabs in 2006. There were also 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 2006 (J. Thompson, personal communication, see "Notes"). When numbers are low, the only detectable impact of *E. sinensis* is stealing bait from sport anglers at some locations in the delta and Suisun and San Pablo bays.

We do not understand what controls the estuary's *E. sinensis* population, although winter temperatures and outflow are hypothesized to effect larval survival and settlement time. A "boom-and-bust" cycle has been reported for some introduced species, although this may not be universally true for all introductions.

Table 2 Annual adult *Eriocheir sinensis* CPUE and estimated total salvage, 1996-2006. 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 (#/tow)*	*Suisun Marsh CPUE (#/tow)*	*CVP salvage est. total*	*SWP salvage 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

Acknowledgements

I thank Robert Schroeter of UC Davis for the unpublished *E. sinensis* size and catch data from Suisun Marsh and Russ Gartz of DFG for the CVP and SWP fish facilities salvage data.

Notes

Peter Kalvass, CDFG, email, May 25, 2007.

Jonathon Thompson, USFWS, May 9, 2007.

2006 Fishes Annual Status and Trends Report for the San Francisco Estuary

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Introduction

The 2006 Status and Trends fishes report includes data from 5 of IEP'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 USFWS Beach Seine Survey. In addition, fish facilities salvage data is used for the splittail section. 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 splittail and several of the surfperches. Several pelagic species that spawn and rear in the upper estuary and have undergone severe declines in recent years are presented first. The upper estuary demersal fishes, the marine pelagic fishes, surfperches, and marine demersal fishes follow this group. Within each section, the species are presented phylogenetically.

Methods

The TNS has been conducted annually since 1959, and indices have been calculated for all years except 1966, 1983, and 2002. It produces annual abundance indices for age-0 striped bass (the 38.1-mm index) and age-0 delta smelt. The TNS 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; as of 2003, sampling was standardized to 6 surveys per year. The striped bass index is interpolated between the 2 surveys that bracket when the mean size reaches 38.1-mm fork length (FL) (Chadwick 1964, Turner and Chadwick 1972); this occurred between surveys 4 and 5 in 2006. The delta smelt index is the average of the first 2 survey indices. The 2006 TNS completed 6 surveys at 2-week intervals from June 5 to August 21.

The FMWT has sampled annually since 1967 except for 1974 and 1979; sampling was limited in 1976 and indices were not calculated. The FMWT was designed to determine the relative abundance and distribution of age-0 striped bass in the estuary, but data is also used for other upper estuary pelagic species, including American shad, delta smelt, and longfin smelt. The FMWT survey samples 116 stations monthly from September to December in an area ranging from San Pablo Bay to Stockton on the San Joaquin River and Hood on the Sacramento River. The index calculation (Stevens 1977) uses catch data from 100 of the 116 stations; the remaining 16 stations increase spatial coverage for delta smelt.

The Bay Study has sampled from South San Francisco Bay to the western delta monthly with an otter trawl and midwater trawl since 1980. There are a few data gaps, most significantly limited midwater trawl sampling in 1994 and no winter sampling from 1989 to 1997. Abundance indices are routinely calculated for 35+ pelagic and demersal fishes and several species of crabs and caridean shrimp; only the most common fish species are included in this report, while 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 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 to July since 1995, with 9 surveys completed in 2006. Three tows are completed at each of the 48 stations with a 1,600-µm mesh net (Dege and Brown 2004). This survey gets its name from the size (20 mm) at which delta smelt are retained and readily identifiable at the CVP and SWP fish facilities.

USFWS 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 30 stations ranging from Sherman Lake at the confluence of the Sacramento and San Joaquin rivers upstream to Ord Bend on the Sacramento River, and almost to the Tuolumne River confluence on the San Joaquin River was used to calculate the annual splittail abundance index.

Fish facilities salvage calculation methods are summarized in Russ Gartz's article, page 41 of this issue.

Data from the TNS, FMWT, and Bay Study was used to describe trends and distribution of upper estuary pelagic fishes when available, while only Bay Study midwater trawl data was used for the marine pelagic fishes and Bay Study otter trawl data for demersal fishes. The 20-mm Survey data was used for delta smelt and the USFWS Beach Seine and fish facilities salvage data for splittail.

Physical Setting

Delta outflow in 2006 was very different from recent years; the mean January-June daily outflow of 3,033 cm/s was the highest for that period since 1983 and delta outflow in April was a record high. There were 3 major outflow events over 4,000 cubic meters/sec in 2006: 1) from late December to early January with a mean daily outflow of approximately 6,000 cm/s over 3 weeks; 2) in early March with a mean daily outflow of approximately 4,000 cm/s over 2 weeks; and 3) from late March to early May with a mean daily outflow of approximately 4,700 cm/s over 6 weeks. This third outflow event resulted in the highest mean daily April outflow (5,183 cm/s) in the Dayflow database, which dates back to 1956 (see Kate Le's article, page 5 of this issue) and reduced salinities throughout much of the estuary into June.

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 faunas (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. However, Gulf of the Farallones sea surface temperatures (SSTs) were near normal in winter 2005-2006, associated with very weak La Niña (cool ocean) conditions in the eastern equatorial Pacific. This was followed by slightly above average SSTs (0.5-1.0°C) in the Gulf of the Farallones from late summer to fall, associated with moderate El Niño (warm ocean) conditions that appeared in July 2006. For most of October and November 2006, daily SSTs were >14°C and occasionally >15°C at the Farallon Islands (PRBO Conservation Science, unpublished data). SSTs in fall 2006 were not as warm as in fall 2004, when a warm water event resulted in the highest SSTs for the Gulf of the Farallones since the strong 1997-98 El Niño event.

The coastal ocean along central California is marked by three 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, or the California Current. Due to the Earth's rotation (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 and coastal summer fog. When the winds weaken in fall, upwelling stops, surface coastal waters warm, and the coastal fog dissipates. 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 settle to the bottom nearshore or enter estuaries to rear before the onset of upwelling, as pelagic life stages present during the upwelling season will be transported offshore, often far from their preferred nearshore nursery areas.

The spring transition to the upwelling season was again later than usual in 2006, due in part to frequent storms through mid-April. However, the summer upwelling indices for the coastal area adjacent to the San Francisco Estuary were close to the long-term means and slightly higher than in 2004 and 2005. The period of 2004-2006 contrasts strongly to 1999-2003, which had strong summer upwelling, colder SSTs, and high ocean productivity along the central California coast (Peterson et al. 2006).

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, and migrates to the ocean in late summer into 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 2006 FMWT American shad (all ages) index increased slightly from the 2005 index (Figure 1A). With the exception of the record high index in 2003, indices have been below or near the study-period average since 1998. FMWT catch was highest in September, decreased sharply in October, increased in November, and then decreased again in December. American shad were collected throughout the study area from San Pablo Bay to the Sacramento River at Hood and the San Joaquin River near Stockton. American shad were most common in the lower Sacramento River until December, when their distribution shifted to Suisun and San Pablo bays as they emigrated from the estuary.

The 2006 Bay Study age-0 American shad index was well below that of 2005 (Figure 1B). Although the 2006 index decreased, it represented the fourth highest index for the study period and 3 of the 4 highest indices have occurred since 2003. Bay Study catch was highest in August and steadily decreased through December as fish emigrated. Age-0 American shad were collected from South Bay, south of San Mateo Bridge up the Sacramento River to near Rio Vista and the San Joaquin River to Old River Flats. They were most common in the lower Sacramento River (66%, n=1,529) over all months, but there was a distributional shift from this area to Suisun and San Pablo bays in November as age-0 fish migrated from the delta.

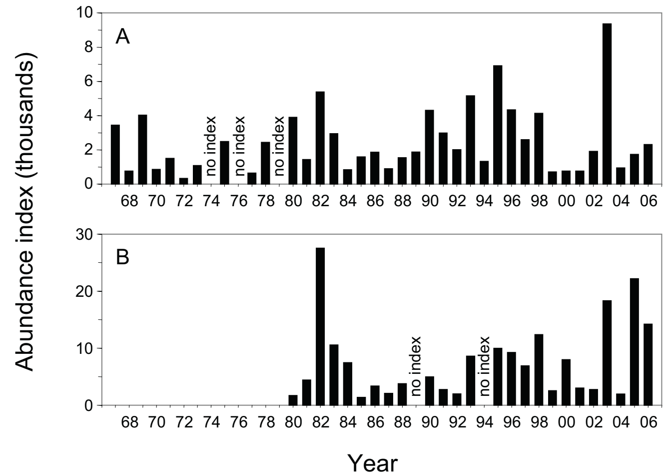

Figure 1 Annual abundance of American shad: A) FMWT, all sizes, September-December, B) Bay Study midwater trawl, age-0, July-October

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 2006 FMWT threadfin shad (all ages) decreased slightly from the 2005 index (Figure 2A). Since 2001, abundance has been relatively low, averaging only 40% of the study-period mean. In 2006, FMWT catch peaked in September and decreased sharply over the next 3 months. Threadfin shad were found throughout the study area from San Pablo Bay to the Sacramento River at Hood and to the San Joaquin River near Stockton. A high percentage of the catch came from Cache Slough (32%, n=910), the lower Sacramento River near Sherman Island (24%, n=681), and the San Joaquin River near Stockton (19%, n=544). Historically, the highest FMWT threadfin shad catch was from the San Joaquin River near Stockton, where 53% of the total catch has been collected over the entire study period.

The 2006 Bay Study threadfin shad (all ages) index was substantially higher than the 2005 index (Figure 2B). Bay Study catch peaked in August and then decreased through December. Threadfin shad were found from South Bay, south of the San Mateo Bridge, to the Sacramento River near Steamboat Slough and the San Joaquin River at Old River Flats. It was most abundant near the confluence of the Sacramento and San Joaquin rivers from August through October, and then distribution broadened to include all regions of the study area. This distribution differed from lower outflow years, such as 2005, when over half of the threadfin shad were collected in the lower San Joaquin River.

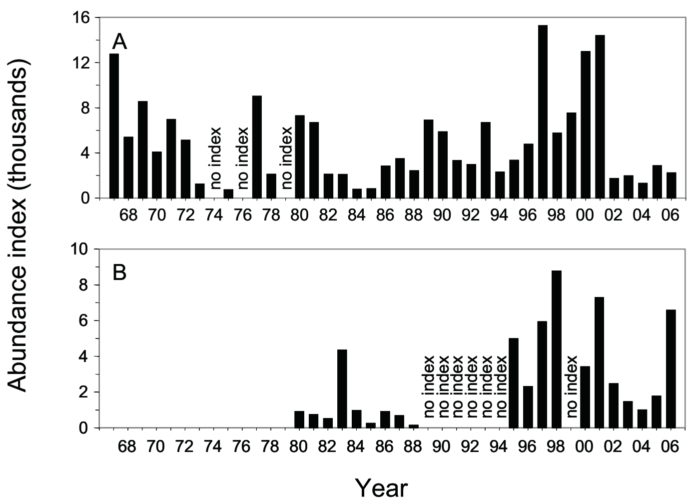

Figure 2 Annual abundance of threadfin shad: A) FMWT, all sizes, September-December, B) Bay Study midwater trawl, all sizes, August-December

Delta smelt

The delta smelt (Hypomesus transpacificus) is a small (55-70 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 produce only 1,200 to 2,600 eggs (Moyle et al. 1992). The reasons for the delta smelt's decline include reductions in fresh water outflow, extremely high fresh water outflows (which push them too far down the estuary), entrainment losses at water diversions, changes in food type and abundance, toxic substances, disease, competition, and predation.

The 2006 TNS age-0 delta smelt index was 0.4, a slight increase from the 2005 index (Figure 3A). However, it was commensurate with the low indices observed since 2001. The total number of delta smelt caught per survey increased through survey 4 and then decreased thereafter (Table 1). Distribution was very comparable to 2005: the greatest catch of delta smelt for all surveys was in Suisun Bay, followed by the Sacramento River. A few delta smelt were collected in Montezuma Slough, but none was collected by the TNS in either the eastern or southern delta or the San Joaquin River.

Table 1 Mean length, catch, and survey indices for delta smelt and striped bass for Townet surveys 1-6, 2006

	Survey 1	*Survey 2*	*Survey 3*	*Survey 4*	*Survey 5*	*Survey 6*
Delta Smelt						
Mean length (mm FL)	29	35	31	35	36	38
N	6	12	18	30	4	5
Survey Index	0.2	0.6	0.4	1.1	0.1	0.2
Striped Bass						
Mean length (mm FL)	18.0	20.8	24.0	29.6	41.0	45.5
N	165	454	251	174	21	35
Survey Index	1.7	6.1	4.5	2.6	0.3	1.2

The 2006 FMWT delta smelt index increased slightly from the record low index of 2005, but remained the second lowest index on record (Figure 3B). In September, the majority of the fish were collected from the west side of Montezuma Slough, Chipps Island, and the Sacramento River. Delta smelt were sparsely collected the remainder of the surveys, shifting distribution from Montezuma Slough and Grizzly Bay in October to Honker Bay, Chipps Island, and the Sacramento River in November. The only delta smelt collected in December was captured in Montezuma slough. As in 2005, the FMWT did not collect any delta smelt in San Pablo Bay, Carquinez Strait, or the eastern delta in 2006.

The 2006 Bay Study age-0 delta smelt index was 0, the lowest for the study (Figure 3C). The previous low index of 24 was recorded in 1985. The 2006 index contrasted with recent Bay Study indices, which showed a steady increase from 2001 to 2004, with the 2004 index above the study-period average.

The 2006 20-mm survey delta smelt index was about 40% of the 2005 index (Figure 3D). It was the second lowest index since the inception of the 20-mm survey in 1995 and reaffirmed the abundance decline observed by the other long-term monitoring surveys. Delta smelt were first collected in mid-April largely in the eastern portion of San Pablo Bay. By mid-May, they were collected throughout Suisun and Grizzly bays and at some delta stations, with the highest catch per unit effort (CPUE) in the Napa River. Distribution remained nearly unchanged until mid-June, when CPUE increased in Suisun Bay and decreased in the Napa River. Delta smelt distribution then contracted through the end of the survey in mid-July, when most fish were collected in Suisun and Honker bays and near the confluence of the Sacramento and San Joaquin rivers.

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 apparently immigrate to the ocean in late summer and fall for a short period, 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 a few living to spawn again at age-3 (Wang 1986). The strong positive relationship between longfin smelt abundance and winter-spring outflow has long been recognized (Stevens and Miller 1983). However, this relationship changed in the late 1980s, after the introduction of the clam, *Corbula amurensis*. Although the slope of the outflow-abundance relationship did not change dramatically, longfin smelt abundance post-*Corbula* declined to a fraction of the pre-*Corbula* abundance. This decline corresponded with a decline in phytoplankton and zooplankton abundance due to grazing by *C. amurensis* (Kimmerer 2002).

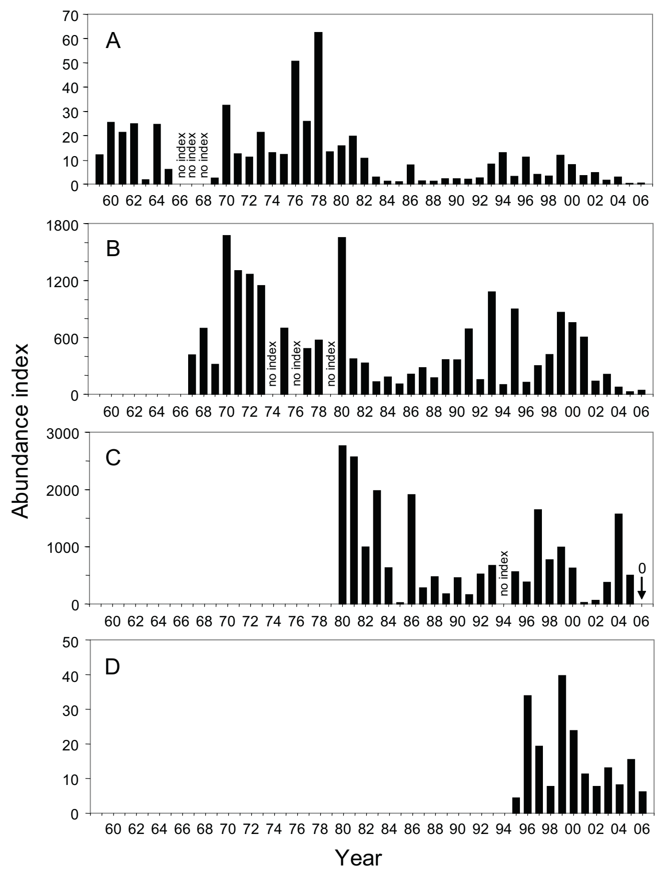

Figure 3 Annual abundance of delta smelt: A) TNS, age-0; B) FMWT, all sizes, September-December; C) Bay Study midwater trawl, age-0, June-October; D) 20-mm Survey larvae and juveniles

In 2006, longfin smelt responded to the high winter and spring outflows and the FMWT index was 15 times higher than the 2005 index (Figure 4A). Catch peaked in September, with 82% (n=658) of the fish collected this month. In September, most fish were collected in San Pablo Bay with large catches also in Suisun and Honker bays. The distributional pattern changed slightly in November, with a substantial portion of the catch in the lower Sacramento River. However, the majority of longfin smelt (66%, n=529) were collected in San Pablo Bay in 2006, unlike in 2005 when fish were distributed further upstream, from San Pablo Bay to the lower Sacramento River.

The 2006 Bay Study midwater trawl (BSMWT) age-0 longfin smelt index was almost 5 times higher than the 2005 index, which was the second lowest for the study period (Figure 4B). Age-0 longfin smelt were collected from South Bay through Central Bay and upstream into the lower Sacramento and San Joaquin rivers in 2006. Similar to the FMWT, the majority (75%, n=133) were collected from San Pablo Bay. In 2005, the BSMWT catch was predominantly from Suisun Bay; higher outflow in 2006 resulted in longfin smelt distributed further downstream.

The Bay Study otter trawl (BSOT) age-0 longfin smelt index was 2.5 times higher than the 2005 index (Figure 4C). In 2006, the vast majority of BSOT fish were collected in Central and San Pablo bays, with 43% (n=385) and 47% (n=421) respectively, of the total catch from these regions. From April through June, age-0 fish were collected only in Central and San Pablo bays, but in summer and fall, distribution slowly expanded upstream to Suisun Bay and the western delta. Distribution broadened again in December, when a substantial portion of the catch came from South Bay. This BSOT distributional pattern was typical of high outflow years.

High outflow in winter and spring 2006 resulted in increased longfin smelt abundance indices for all 3 studies. The FMWT longfin smelt index increased to a level commensurate with the abundance-outflow relationship observed after the introduction of *C. amurensis* in 1988 (Figure 5). Despite moderate winter and spring outflow, longfin smelt abundance was very low from 2003 to 2005, dropping below the post-*C. amurensis* abundance-outflow relationship.

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. Such migrations are known to occur in the Sacramento, San Joaquin, Cosumnes, Napa and Petaluma rivers, as well as Butte Creek and other smaller tributaries. Most spawning takes place from March through May. Young disperse downstream as larvae, when river levels drop rapidly 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 duration of floodplain inundation; moderate to large splittail year classes result from inundation periods of 30 days or more (Moyle et al. 2004; Sommer et al. 1997).

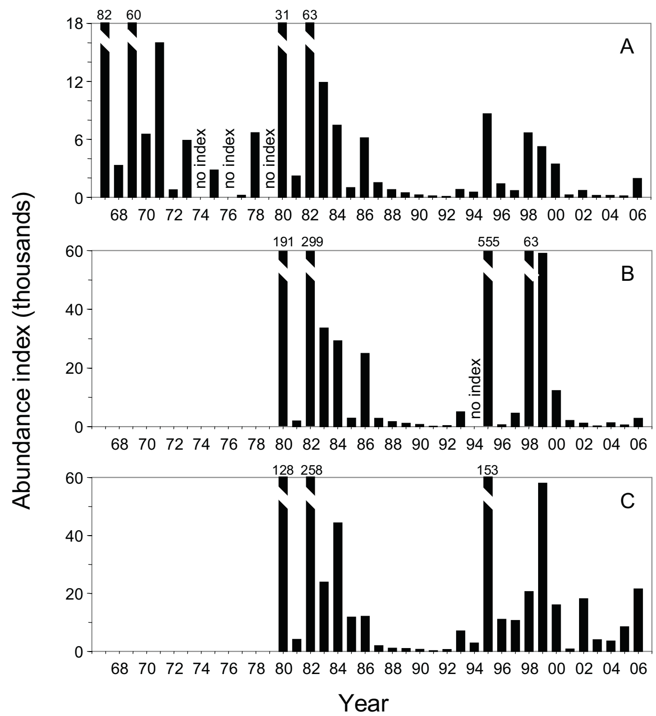

Figure 4 Annual abundance of longfin smelt: A) FMWT, all sizes, September-December; B) Bay Study midwater trawl, age-0, May-October; C) Bay Study otter trawl, age-0, May-October

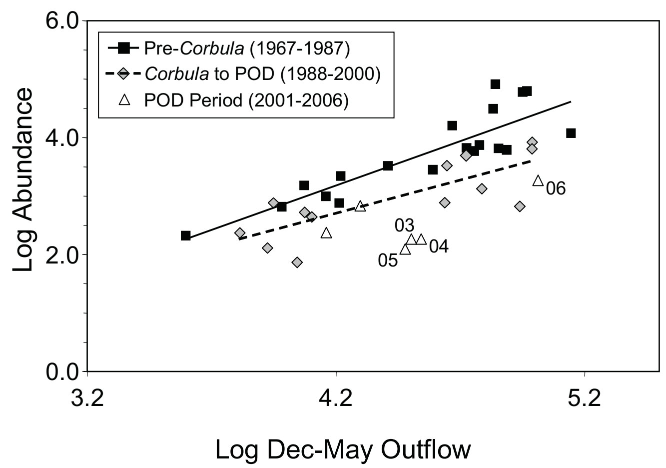

Figure 5 FMWT longfin smelt age-0 abundance vs. December-May outflow relationships pre-Corbula amurensis introduction (1967-1987; black line) and from C. amurensis to POD (1988-2000; dashed line)

The 2006 FMWT age-0 splittail index was similar to the 2005 index (Figure 6A) and much lower than expected given the high outflow and extended floodplain inundation. In the previous high outflow event of 1998, the index was much higher. The FMWT collected splittail from September through November in Montezuma Slough and the Napa River.

The 2006 BSMWT age-0 splittail abundance index was only marginally higher than the 2005 index (Figure 6B) and also did not increase as expected. The BSMWT collected only 8 age-0 splittail, all from upper San Pablo Bay to the Sacramento River near Sherman Island.

The 2006 BSOT age-0 splittail index was the highest since 1998 and the third highest for the survey (Figure 6C). The majority of the age-0 splittail were caught from June to August in the shallows of Grizzly and Honker bays and at Old River Flats on the San Joaquin River.

USFWS beach seine sampling along the lower reaches of the San Joaquin, Sacramento, and Mokelumne rivers indicated successful splittail reproduction in 2006, with age-0 abundance the highest since consistent sampling began in 1992 (Figure 6D). The majority (59%) of the juvenile splittail were caught in the South Delta in 2006, indicating good production from the San Joaquin River.

Splittail salvage from the Tracy Fish Collection Facility in 2006 was the highest on record and salvage from the South Delta Fish Protection Facility was the highest since 1998 (see Russ Gartz's article, page 40 of this issue).

In 2006, spring outflow attained its highest level since 1998, and there was a corresponding increase in splittail recruitment, as evidenced by the BSOT age-0 index, the USFWS beach seine index, and salvage at the state and federal fish facilities. However, the FMWT and BSMWT age-0 indices did not increase substantially in 2006. Splittail feed primarily on benthic invertebrates (Moyle, 2002) and as a result, may be less available to sampling with midwater trawl gear than the otter trawl or beach seine. These divergent indices highlight the sampling variability associated with trawling for a fast swimming fish that does not usually feed in the water column. In addition, most splittail reproduction was apparently from the San Joaquin River upstream of Mossdale in 2006, which may have accounted for the record high beach seine abundance and fish facilities salvage.

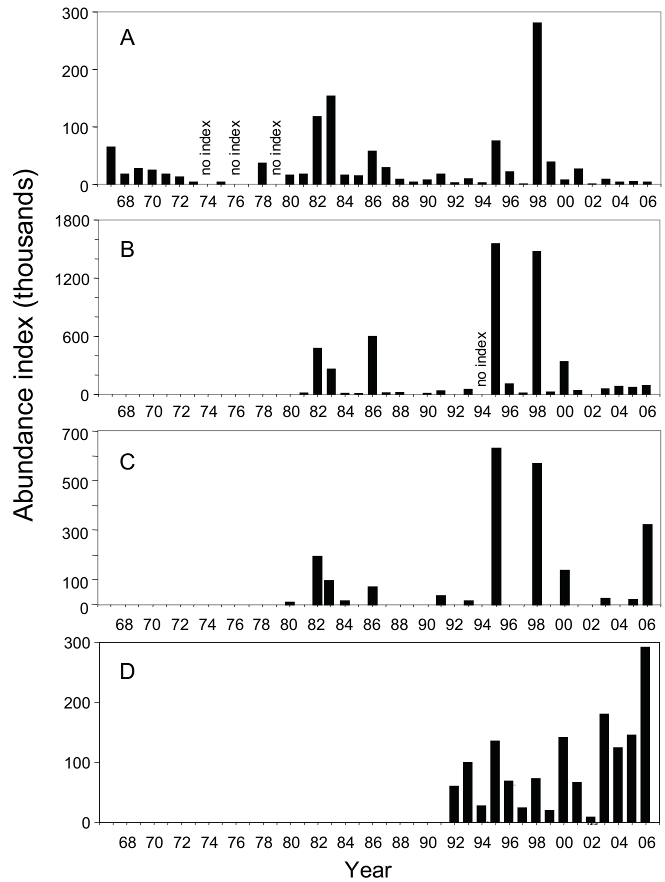

Figure 6 Annual abundance of splittail: A) FMWT, all sizes, September-December; B) Bay Study midwater trawl, age-0, May-October; C) Bay Study otter trawl, age-0, May-October; D) USFWS beach seine age 0, May-June

Striped bass

Striped bass (*Morone saxatilis*) is an anadromous fish that was introduced to the San Francisco Estuary over 125 years ago. Striped bass reproduces in spring in the rivers and rears in fresh and brackish waters of the estuary. The population of legal-size fish in the San Francisco Estuary has declined from 4.5 to 3 million in the early 1960s, to approximately 2 million in the early 1970s, and then to 600,000 in 1994. The population increased to about 1.6 million in 2000 and preliminary estimates for 2002 and 2003 were about 1 million and about 800,000, respectively (N. Kogut, personal communication, see "Notes"). In contrast to the adult population, age-0 striped bass abundance has been in steady decline since the mid-1980s, with some of the lowest TNS and FMWT indices in the past 5 years. Based on our understanding of factors controlling striped bass abundance in the estuary, this most recent adult population increase was unexpected and remains unexplained. Stevens et al. (1985) hypothesized that low recruitment was related to: 1) The declining adult population, 2) reduced planktonic food supply, 3) Loss of large numbers of young striped bass to diversions, and 4) population-level effects of contaminants. However, a recent study (Kimmerer et al. 2001) concluded that adult mortality regulated adult abundance more so than events earlier in the life cycle.

The 2006 TNS striped bass 38.1-mm index was set at 0.5 on July 30 based on results from surveys 4 and 5 (Table 1). This was the lowest index in the 48-year history of the survey and continued the downward trend observed since the mid 1960s (Figure 7A). Striped bass catch peaked in survey 2 and declined thereafter, with a slight increase from survey 5 to 6 (Table 1). The TNS collected striped bass in all sampling areas except for the eastern and southern delta in 2006, with most fish collected from Montezuma Slough and Suisun Bay. They were found exclusively in Montezuma Slough and Suisun Bay in surveys 1 and 2. Distribution expanded slightly eastward in surveys 3 and 4, as more fish were collected in the Sacramento and San Joaquin rivers. By the conclusion of the TNS in July, most young striped bass were collected in the Sacramento River.

The 2006 FMWT age-0 striped bass index was 3 times the 2005 index (Figure 7B). Despite this increase, indices since 2001 have been the lowest in the history of the FMWT survey. The peak catch and broadest geographic distribution of age-0 striped bass occurred in September, when fish were collected in all FMWT sampling areas. After September, no bass were caught in the lower Sacramento River or the eastern delta and in December, striped bass were caught primarily in Carquinez Strait and San Pablo Bay.

The 2006 BSOT and BSMWT age-0 striped bass indices were each more than 2.5 times the 2005 indices (Figures 7C and 7D). The 2006 BSMWT index was the highest since 2001 and the 2006 BSOT index the highest since 1995. Traditionally, the BSOT catches more age-0 striped bass than the BSMWT and this trend continued in 2006 with 1,014 fish collected by the BSOT and 197 collected by the BSMWT. Catches from the BSOT peaked in July and catches from the MWT peaked in August and September.

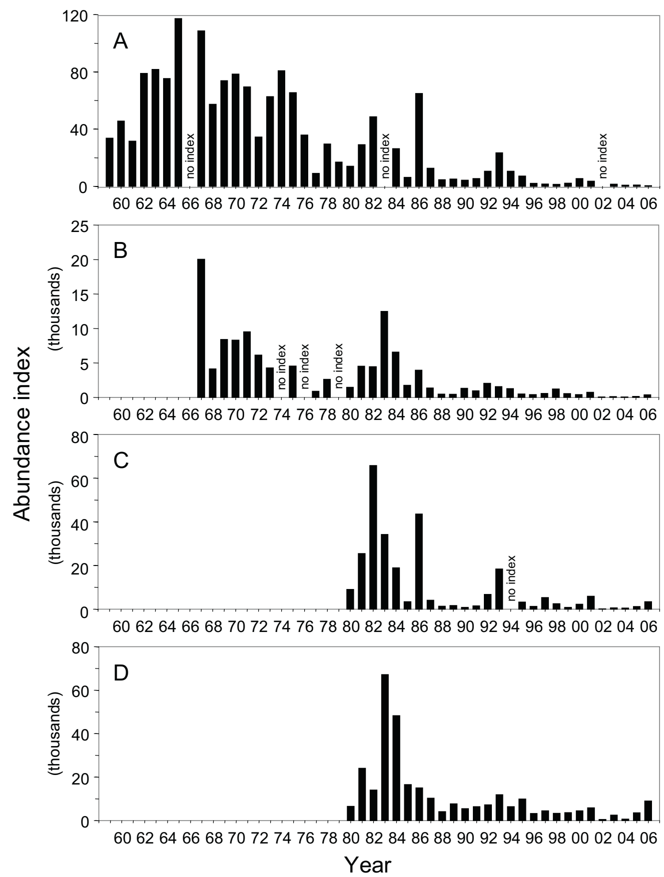

Figure 7 Annual abundance of age-0 striped bass: A) TNS 38.1-mm index; B) FMWT, September-December; C) Bay Study midwater trawl, June-October; D) Bay Study otter trawl, June-October

In 2006, the Bay Study collected age-0 striped bass from San Pablo Bay eastward to the Sacramento River near Rio Vista and San Joaquin River at Old River Flats, the upstream limits of the study area. Most fish were collected from Suisun and Honker bays and the lower San Joaquin and Sacramento rivers. In July, the majority of striped bass were collected in Suisun and Honker bays. From mid to late summer, fish were more evenly distributed throughout Suisun and Honker bays and the lower Sacramento and San Joaquin rivers. In fall distribution extended downstream and by November and December most striped bass were collected in either San Pablo Bay or the lower San Joaquin River. The BSOT age-0 striped bass catch was strongly associated with shoals (94%, n=954), however, age-0 fish from the BSMWT did not have this strong association, with 45% (n=88) collected at shoal stations.

Age-0 striped bass abundance increased slightly in response to increased outflow for all the long-term monitoring surveys except the TNS in 2006. Striped bass survival and abundance historically responded favorably to increased outflow, though these responses have been dampened since the late 1980s invasion of the clam *C. amurensis* (Kimmerer 2002; Sommer et al. 2007). High outflow possibly moved a portion of the age-0 striped bass population downstream of the TNS sampling area in 2006, biasing the index low as reported for other high outflow years (Stevens et al. 1985).

Upper Estuary Demersal Fishes

Shokihaze goby

The shokihaze goby (*Tridentiger barbatus*), native to China, Japan, Korea, and Taiwan, 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 waters in spring and early summer and then die in late summer and fall (Slater 2005). Since it is most common upstream of our original sampling area, abundance is calculated as the annual mean catch-per-unit effort (CPUE, #/10,000 m^2) for all 52 stations sampled, including the lower Sacramento and San Joaquin river stations added in 1991 and 1994.

In 2006, mean shokihaze goby CPUE was a record high for the study period, nearly double (180%) the second highest CPUE from 2005 (Figure 8). The 2006 shokihaze goby catch (n=726) far exceeded our 2006 combined catch of the 2 other introduced *Tridentiger* gobies, the shimofuri goby (*T. bifasciatus,* n=72) and the chameleon goby (*T. trigonocephalus,* n=87). Shokihaze gobies were collected from South Bay, near the Dumbarton Bridge, and in the upper estuary from San Pablo Bay to the lower Sacramento River near Rio Vista and the lower San Joaquin River near Antioch. A record number of shokihaze gobies (n=64) were collected in San Pablo Bay during the high outflow period from January through June 2006. Salinities in San Pablo Bay during this period were lower than in recent years, resulting in expansion of suitable spawning conditions downstream from Suisun Bay, where shokihaze gobies have been common in previous years. Spawning has been observed in the laboratory between 2 and 9 ‰ (Slater 2005). Age-0 fish recruited to the otter trawl in August, with large catches in the lower Sacramento River between August and November. The shokihaze goby has a strong association with deep waters of the estuary; in 2006, the majority (88%, n=637) of fish were collected at channel stations.

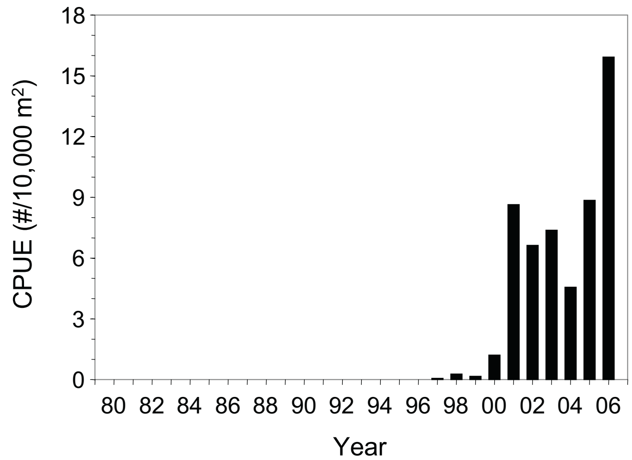

Figure 8 Annual catch-per-unit-effort (CPUE; #/10,000 m^2) of shokihaze goby (all sizes), Bay Study otter trawl, January-December

Yellowfin goby

The yellowfin goby (*Acanthogobius flavimanus*) is another introduced fish from Asia. It is partially catadromous; adults migrate to brackish waters to spawn from December through July and the small juvenile fish leave their nests and migrate upstream to lower salinity and fresh water habitats to rear through summer and fall (Moyle 2002). The 2006 yellowfin goby age-0 abundance index was 38% of the 2005 index and the lowest since 2002 (Figure 9). The 2006 year class recruited to the otter trawl in July, which is later than in low outflow years when age-0 fish were first collected as early as May. Peak abundance of age-0 fish was from July through September.

In 2006, yellowfin gobies were collected from South Bay south of the Dumbarton Bridge to our most upstream stations in the lower Sacramento River near Rio Vista and in the lower San Joaquin River at Old River Flats, making it again one of the most widely distributed species in the estuary. Age-0 fish were collected mostly in Suisun Bay (60%, n=85) and upstream to the lower Sacramento and San Joaquin rivers. Age-0 yellowfin gobies were strongly associated with shallow water, with 90% (n=75) collected at shoal stations in 2006. Age-1+ yellowfin gobies were collected throughout the year, with the majority (72%, n=88) from January through April. Age-1+ yellowfin gobies were most common in San Pablo Bay (59%, n=73).

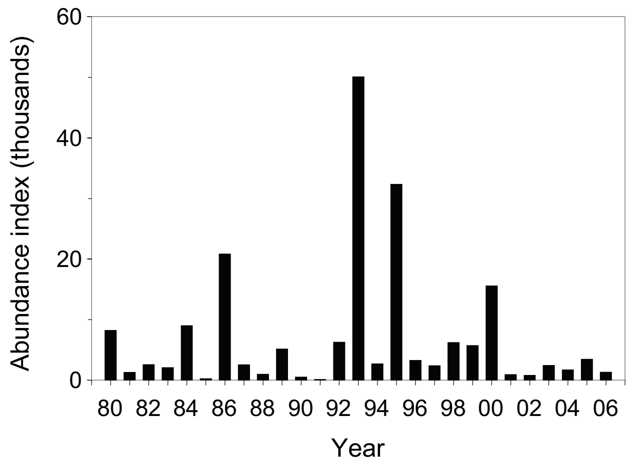

Figure 9 Annual abundance of age-0 yellowfin goby, Bay Study otter trawl, May-October

Starry flounder

The starry flounder (*Platichthys stellatus*) is an estuary-dependent species that spawns in the ocean, but rears in brackish to fresh water areas of estuaries. The 2006 age-0 starry flounder index was near the study-period average (Figure 10A), and was well above the very low indices from 1987 to 1994 and 2000 to 2002, possibly due to the high outflow in spring 2006. We collected age-0 starry flounder from May to December; the highest catch was in May (n=58) and declined thereafter, with a sharp drop in October. Collections ranged from south of the Dumbarton Bridge in South Bay to the lower Sacramento River, just downstream of the Rio Vista Bridge. Age-0 catch was high in Carquinez Strait (39%, n=63), San Pablo Bay (29%, n=46), and Suisun Bay (24%, n=39), with 91% (n=145) of all age-0 fish collected from shoal stations in 2006.

The 2006 age-1 starry flounder abundance index was 62% of the study-period average, and was nearly identical to the 2003 and 2004 indices (Figure 10B). Age-1 starry flounder were collected from January through October from Berkeley Flat in Central Bay to Decker Island on the Sacramento River and to Santa Clara Shoal on the San Joaquin River. However, catch of age-1 fish was highest (28%, n=9) in Honker Bay. Also, all age-1 starry flounder were collected at shoal stations.

The trend of declining age-2+ starry flounder abundance continued in 2006, as the index was only 41% of the average (Figure 10B). Indices averaged 1,917 from 1980 to 1987 and only 426 from 1988 to 2006. We caught age-2+ starry flounder every survey except June, October, and December. We collected age-2+ starry flounder from South Bay to our furthest upstream station on the San Joaquin River at Old River Flat. Similar to younger age groups, 71% (n=24) were collected from shoal stations. They were collected furthest upstream from January through March. Distribution was centered in San Pablo and Central bays from May through November.

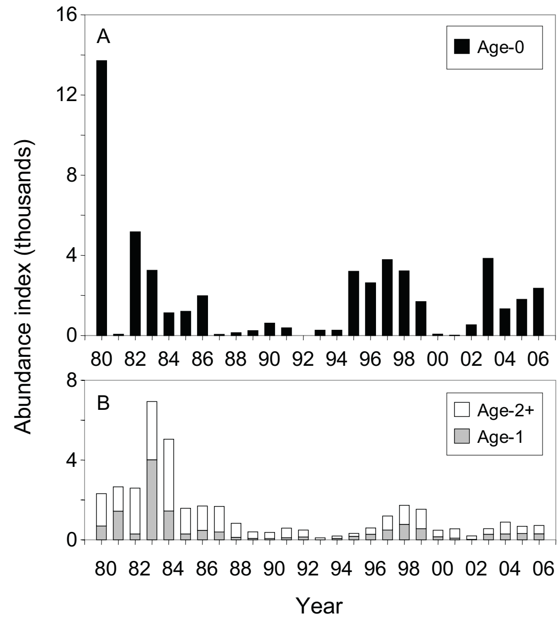

Figure 10 Annual abundance of starry flounder: A) age-0, Bay Study otter trawl, May-October, and B) age-1 and age-2+, Bay Study otter trawl, February-October

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, and young Pacific herring school in shallow bays and inlets within the estuary. In fall, Pacific herring emigrate from the estuary to spend 2-3 years rearing in the ocean before reaching maturity and returning to spawn. The 2006 age-0 Pacific herring index marked the fourth consecutive year of decline, with the 2006 index at 91% of the 2005 index and the lowest index since 1999 (Figure 11). After moderate to very low age-0 indices through the 1990s, there was a modest increase from 2000-2003, yet the 2005 and 2006 indices returned to the very low levels of 1998 and 1999. Age-0 fish were first collected in March and catches peaked in May. By November, most age-0 Pacific herring had emigrated from the estuary. In 2006, age-0 Pacific herring were most common in San Pablo Bay (58%, n=710), followed by Central Bay (37%, n=456). Age-0 Pacific herring were also most common at channel stations (72%, n=890) in 2006.

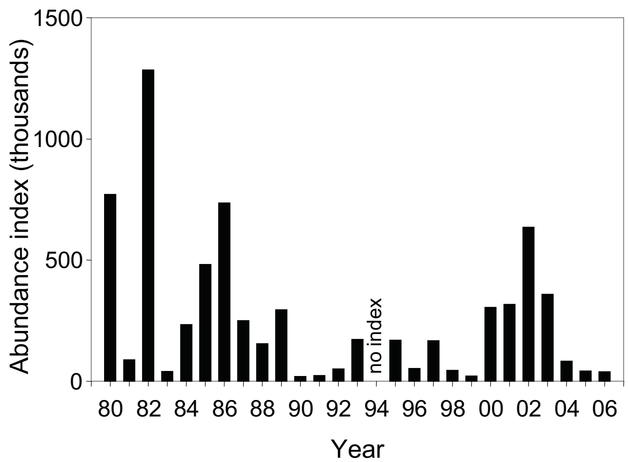

Figure 11 Annual abundance of age-0 Pacific herring, Bay Study midwater trawl, April-September

The CDFG Herring Project has recorded landings for the Pacific herring fishery in San Francisco Bay since 1972. The commercial Pacific herring fishery runs December through March, targeting adult fish entering the estuary to spawn. The 2005-2006 landings were 744 tons, the first increase since 2002. Although this was more than 5 times the 2004-2005 landings, it was still the second lowest landings for a fishing season on record and well below the 2005-06 quota of 4,329 tons. The severe declines in San Francisco Bay herring landings over the past 4 years are not necessarily indicative of a declining adult Pacific herring population. Increasing fuel prices and decreasing market value of herring products has decreased the profitability of the Pacific herring fishery, resulting in decreased fishing effort, which partially explains the small landings.

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. The 2006 northern anchovy abundance index was slightly above the study period average and over 2 times higher than 2005; it also marked the end of a 5-year trend of below average indices (Figure 12). The northern anchovy population is separated into 3 subpopulations, the northern, central, and the southern (Vrooman et al. 1981). The San Francisco Estuary is situated between the northern and central subpopulations and our catches reflect 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. Our 2006 catches were lowest in winter and highest in April and August, diminishing in spring probably because of the high outflow and reduced high salinity habitat. In 2006, we collected northern anchovy throughout South, Central, and San Pablo bays and in Suisun Bay to the Mothball Fleet, with the highest catches in South Bay near Coyote Point northward throughout Central Bay. Few anchovies were collected in San Pablo Bay until May and none was collected in Suisun Bay until July. Central Bay accounted for 57% (n=70,967) of our total 2006 catch (n=124,584). Also, 75% of the total catch (n=93,605) was from channel stations.

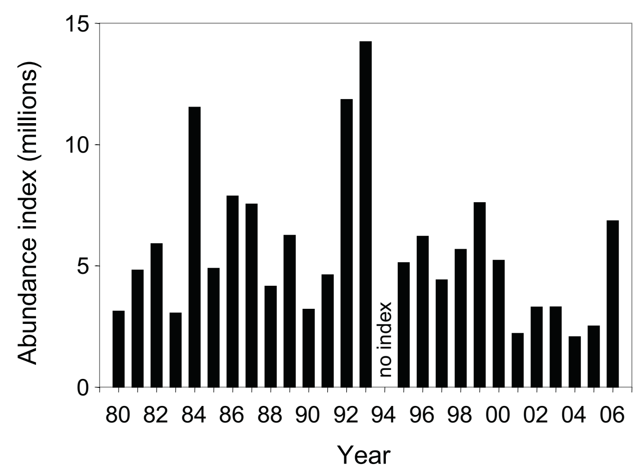

Figure 12 Annual abundance of northern anchovy (all sizes), Bay Study midwater trawl, April-October

Jacksmelt

The jacksmelt (*Atherinopsis californiensis*) seasonally migrates from the coast to bays and estuaries to spawn and rear. Age-0 jacksmelt abundance was 2.7 times higher in 2006 than 2005, but less than half of the study-period average (Figure 13). 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 our gear. In 2006, age-0 catches peaked in July and August. We collected age-0 jacksmelt from South Bay to mid San Pablo Bay, with the majority (58%, n=123) from Central Bay. Age-0 catch was evenly spread between shoal (55%, n=116) and channel (45%, n=94) stations.

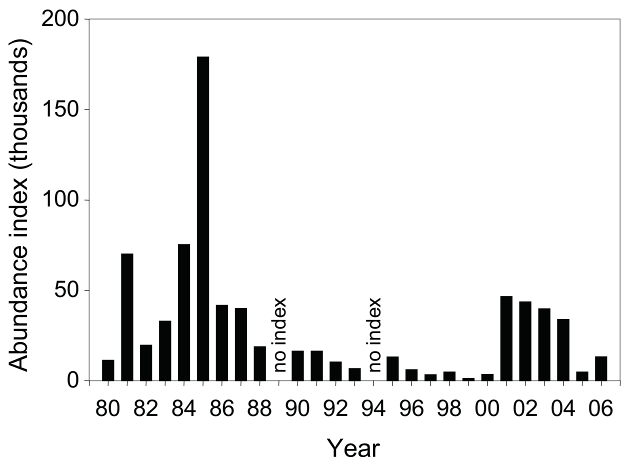

Figure 13 Annual abundance of age-0 jacksmelt, Bay Study midwater trawl, July-October

Surfperches

Most of surfperches are transient species, immigrating to bays and estuaries to give birth to live, fully formed young in late spring and summer. All of the surfperches common to San Francisco Estuary underwent abundance declines in the 1980s per Bay Study trawl and sportfish survey data (DeLeón 1998). Consequently, CDFG changed the sportfish regulations in 2002, adopting a closed season for all surfperches except for shiner perch from April 1 to July 31 in San Francisco Bay. A 5-fish combination bag limit for all species except for shiner perch and a 20-fish bag limit for shiner perch were also implemented for San Francisco Estuary.

Shiner perch

In 2006, abundance of age-0 shiner perch (*Cymatogaster aggregata*) decreased from the 2005 index to just 34% of study-period average and was the lowest index since 2000 (Table 2). Age-0 fish were collected from May to December, with the highest catches in December (n=106), a month not used for the index calculation. Central Bay shoal stations accounted for 92% (n=290) of the total catch. As fall progressed, age-0 shiner perch migrated from South Bay and Central Bay shoal to Central Bay channel stations. No age-0 shiner perch were collected in San Pablo Bay during 2006, most likely due to low salinity in this embayment.

Walleye surfperch

The 2006 age-0 walleye surfperch (*Hyperprosopon argenteum*) abundance index decreased to just 55% of the 2005 index and was 78% of the study-period average (Table 2). Four of the past 6 years had above average indices, indicating a return to the population levels observed in the early 1980s. Only 19 age-0 walleye surfperch were collected in 2006, all from June, August, and September. Age-0 walleye surfperch were collected at only 2 stations in 2006 - our station near the Berkeley Fishing Pier (n=17) and our station near the mouth of Corte Madera Creek (n=2). The age-1+ index was the lowest for the study period, just 4% of the 2005 index.

Other Surfperches

The abundance indices of the less common surfperch species remained at low levels or declined in 2006:

The 2006 barred surfperch (*Amphistichus argenteus*) abundance index was based on 1 fish and was slightly higher than the 2005 index but only 28% of study-period mean (Table 2). It was collected at our shoal station east of San Leandro in South Bay. Historically, the majority of barred surfperch have been collected from South Bay (94%, n=189), especially the shoal stations off of San Mateo on the western shore and San Leandro on the eastern shore. Barred surfperch is commonly associated with eelgrass beds in the Bay (Merkel & Associates, 2005), a habitat not sampled by our trawl.

The 2006 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 2). One age-1+ pile perch was collected in January from our shoal station near Alameda Island, which is neither an index station nor an index month.

The 2006 white seaperch (*Phanerodon furcatus*) abundance index was also 0, the lowest since the 10 consecutive years of zero indices from 1991 to 2000 (Table 2). White seaperch abundance increased from 2001 through 2004, but declined in 2005 and 2006.

Table 2. Annual abundance indices for selected surfperch species from the Bay Study. The age-0 shiner perch, age-0 and age-1+ walleye surfperch, and white seaperch (all sizes) indices are from May-October. The barred perch (all sizes) index is from April-September, the age-0 pile perch index is from June-October, and the black perch (all sizes) and dwarf perch (all sizes) indices are from February-October

	shiner perch	*walleye sp*	*walleye sp*	*barred sp*	*pile perch*	*white seaperch*	*black perch*	*dwarf perch*
Year	*age-0*	*age-0*	*age-1+*	*all*	*age-0*	*all*	*all*	*all*
1980	19,516	1,277	642	455	857	588	0	439
1981	42,764	8,089	1,757	942	998	1,248	129	543
1982	43,705	1,640	992	335	471	349	54	259
1983	16,148	663	135	1,330	778	271	88	460
1984	14,386	3,846	922	673	110	873	216	50
1985	16,616	362	1,031	73	301	138	66	0
1986	24,617	322	880	0	254	309	17	0
1987	18,069	1,453	2,624	239	0	265	0	0
1988	7,746	486	502	134	0	148	62	66
1989	6,953	2,046	493	101	153	48	101	97
1990	8,181	516	341	79	0	95	48	26
1991	2,724	22	505	84	0	0	0	15
1992	6,142	443	297	41	0	0	100	0
1993	6,341	617	112	43	0	0	97	0
1994	3,241	no index	no index	80	0	0	125	0
1995	6,661	405	269	0	0	0	0	0
1996	4,404	684	380	59	0	0	225	0
1997	23,896	231	643	155	0	0	231	0
1998	4,384	537	911	48	75	0	65	0
1999	6,237	848	2,985	46	0	0	36	0
2000	4,640	1,229	114	43	31	0	119	0
2001	20,594	8,121	1,003	55	0	106	248	0
2002	26,134	12,277	2,079	59	42	260	95	0
2003	15,896	2,439	567	352	0	371	63	111
2004	24,849	896	1,438	115	0	487	253	94
2005	6,225	2,916	655	51	0	47	93	32
2006	4,911	1,610	27	69	0	0	62	34

Black perch (*Embiotoca jacksoni*) was the only surfperch common in the estuary that did not show a distinct decline in Bay Study catch during the late 1980s or early 1990s (Table 2). Black perch catch has never been high, but has remained relatively constant throughout the study period. The black perch index for 2006 was 65% the historical average and slightly lower than the 2005 index. We collected 6 black perch, all from Central Bay, between January and August, but only 2 were from stations and months used for index calculation.

In 2006 we caught 4 dwarf perch (*Micrometrus minimus*), but only 1 was from an index station and month. The 2006 index was about the same as the 2005 index (Table 2). Historically, dwarf perch were commonly collected from the shoal stations at Candlestick Point in South Bay, Southampton Shoal in Central Bay and just southwest of Point San Pablo in San Pablo Bay. This is another species that is strongly associated with eelgrass beds in the Bay and under sampled by our trawls.

Marine Demersal Fishes

Brown smoothhound

The brown smoothhound (*Mustelus henlei*) is the most common shark collected by the Bay Study. It immigrates to bays and estuaries to pup in late spring and summer and young fish emigrate from the estuary in fall. The 2006 age-0 brown smoothhound abundance index was the lowest on record, only 22% of the 2005 index and only 12% of the study-period average (Figure 14). There has been a downward trend in abundance since it peaked in 1989. We collected only 8 age-0 brown smoothhound from June to December. The majority were from San Pablo Bay (n=5), with the remainder from South Bay (n=2) and Carquinez Strait (n=1).

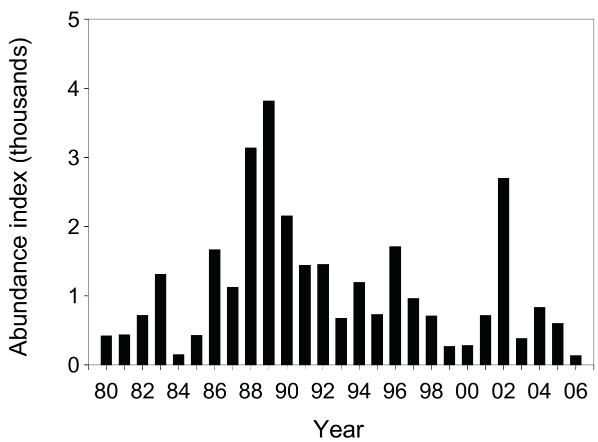

Figure 14 Annual abundance of age-0 brown smoothhound, Bay Study otter trawl, April-October

Leopard shark

The leopard shark (*Triakis semifasciata*) is a popular sportfish that immigrates to very shallow areas of the estuary, especially South Bay, to pup in summer. The Bay Study does not effectively sample age-0 leopard sharks because they are born and rear in areas too shallow to navigate with our boat. Catches are often very low, so we report catch from February to October at our original stations rather than abundance indices. Our 2006 otter trawl age-0 February-October catch was 1, while our age-1+ catch decreased to 7 and our combined catch was the lowest since 2003 and the 6th lowest for the study period (Figure 15). There has been a downward trend in catch beginning in 1984. Catch averaged 38 fish per year from 1980 to 1983, declined to 14 fish per year from 1984 to 1998, and declined again to only 8.5 fish per year from 1999 to 2006. Because of potential over harvest of leopard sharks, a 36-inch size limit and a 3-fish bag limit was implemented in 1991 for the sport fishery. We collected a total of 16 leopard sharks during 2006, from South Bay to our station near the mouth of Corte Madera Creek in Central Bay, with 63% (n=10) from South Bay.

During April, May, and June 2006 many leopard sharks were found dead and disoriented in South and Central bays. The cause of this die off has not been determined, but osmotic shock due to reduced salinities from the high spring freshwater outflow may have been a factor. Leopard sharks show signs of osmotic stress when exposed to salinities less than 19 ‰ for prolonged periods of time (W. Dowd, personal communication, see “Notes”) and South Bay bottom salinities ranged from 9.4 ‰ in the channel south of the Dumbarton Bridge to 18.6‰ in the channel off of Hunter’s Point in April and from 17.8 to 24.2‰ at these locations in mid June. It was also hypothesized that contaminants such as heavy metals and chlorinated hydrocarbons may have been factors in the die off (R. Russo, personal communication, see “Notes”), although no source was identified and necropsies conducted by CDFG and others were inconclusive.

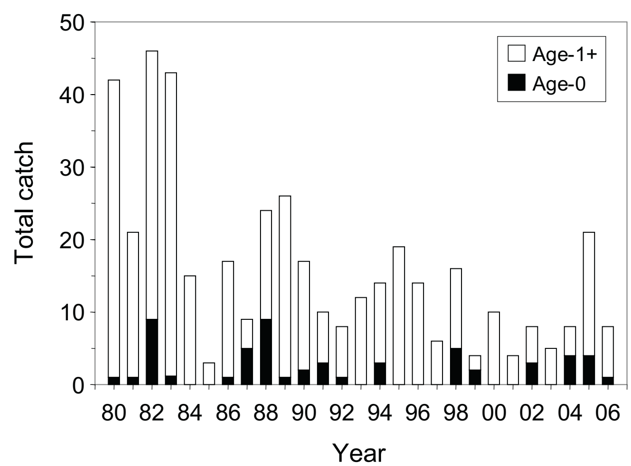

Figure 15 Annual catch of leopard shark (age-0 and 1+), Bay Study otter trawl, February-October

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 2006 age-0 index increased 3-fold from 2005 to become the fourth highest index on record (Figure 16). Age-0 plainfin midshipman were first collected in August and catch was highest in September and October. Although age-0 plainfin midshipman were collected from South Bay to San Pablo Bay in 2006, they were most common (72%, n=1,307) in Central Bay. When age-0 fish were first encountered in August, the majority (94%, n=31) were collected at shoal stations. However, from September through December 81% (n=1,213) of all age-0 fish were collected at channel stations.

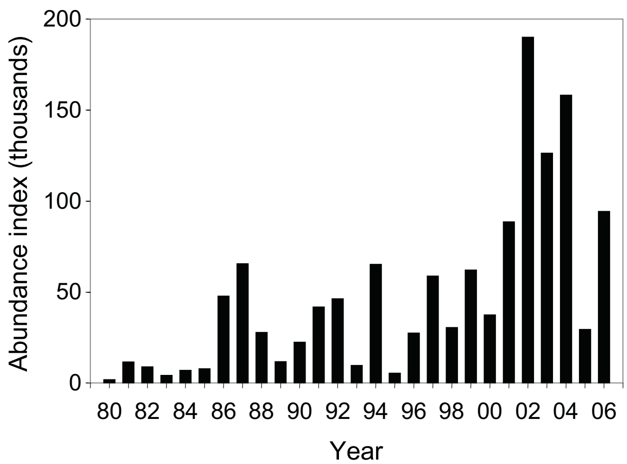

Figure 16 Annual abundance of age-0 plainfin midshipman, Bay Study otter trawl, June-October

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. The 2006 Pacific staghorn sculpin age-0 abundance index was 78% of the 2005 index, and was the lowest since 1998 (Figure 17). Indices have steadily declined since record high catches in 2002. Age-0 fish were first collected in March, only in South and Suisun bays. In April and May, the distribution broadened, and fish were collected from South to Suisun bays, with 57% (n=50) from San Pablo Bay. Migration of age-0 fish to Central Bay began in June and continued through October; 69% (n=142) were collected from Central Bay during this period. The salinity at collection reflects this migration - from March to May, age-0 Pacific staghorn sculpin were collected at a mean bottom salinity of 11.7‰ (n=92), and from June to October, they were collected at a mean bottom salinity of 20.4‰ (n=134). The majority (74%, n=221) of age-0 Pacific staghorn sculpin were collected from shoal stations in 2006.

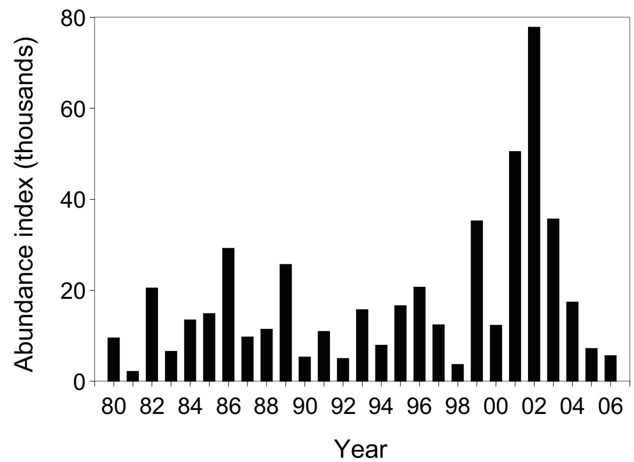

Figure 17 Annual abundance of age-0 Pacific staghorn sculpin, Bay Study otter trawl, February-September

White croaker

The white croaker (*Genyonemus lineatus*) is a common coastal species that frequents bays and estuaries. The 2006 age-0 white croaker abundance index was zero for the 1st time in the study period (Figure 18). Age-0 catch was exceptionally low the prior 4 years. White croaker is a warm-subtropical marine species and as such, age-0 abundance in San Francisco Estuary is related positively to ocean temperatures between 13 and 14ºC (Love et al. 1984); 2006 had an extended period of SSTs within this range, therefore a higher index was anticipated. The 2006 age-1+ index was also the lowest of the study period. It decreased to about 65% of the very low 2005 index (Figure 18) and was the tenth consecutive year of below-average indices. Age-1+ abundance was highest during the 1987 to 1992 drought, when salinity was high and relatively stable year-round in the estuary and SSTs were relatively high. Age-1+ white croaker were collected from our South Bay station east of Redwood Creek upstream to the Mothball Fleet in Suisun Bay in 2006, but were collected at the upstream locations only from October to December, when salinities were highest and the temperatures lowest in these areas. They were most common in Central Bay, with just over 50% (n=41) collected from 2 channel stations south of the Bay Bridge, which are considered to be in Central Bay for our analyses. Over all regions, 84% (n=67) collected from channel stations.

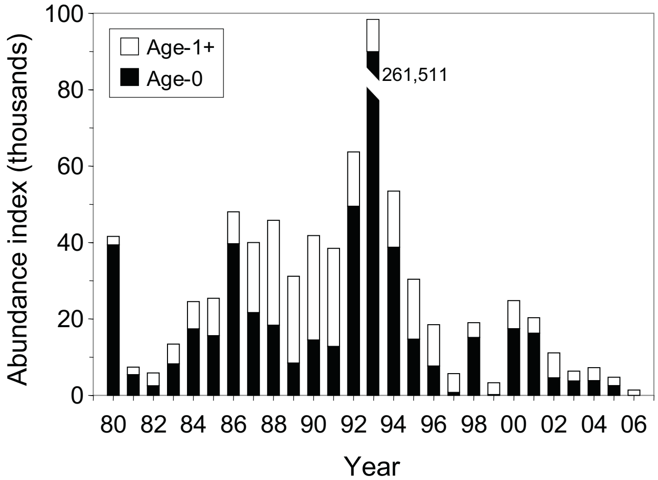

Figure 18 Annual abundance of age-0 and age-1+ white croaker, Bay Study otter trawl, February-October

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 2-3 year life span. In 2006, the bay goby abundance index was more than 3 times the 2005 index (Figure 19). The 2006 index was the highest since 2003 and was slightly above the study-period average. In 2006, bay gobies were collected at every station in South, Central, and San Pablo bays. Fish began migrating from South and San Pablo bays to Central Bay in June and remained there through December. From February to July fish were primarily collected at shoal stations (66%, n=2,173). As fish migrated to Central Bay, they also migrated to deeper water. From August to December, the majority (84%, n=529) of fish were collected from channel stations.

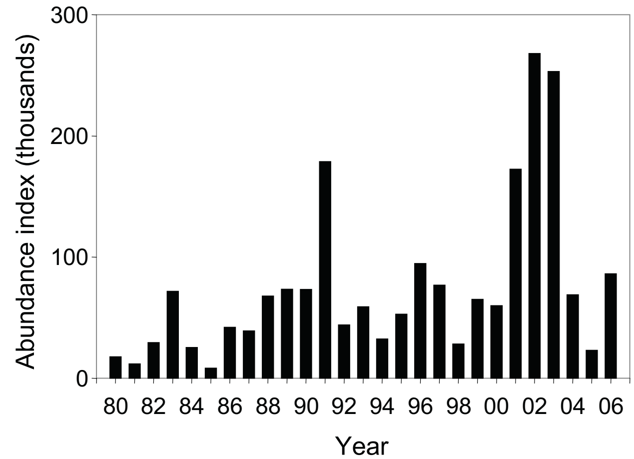

Figure 19 Annual abundance of bay goby (all sizes), Bay Study otter trawl, February-October

California halibut

The California halibut (*Paralichthys californicus)* is a subtropical species that became common in the San Francisco Estuary in the 1980s and 1990s, concurrent with the most recent warm-water regime. The 2006 combined age-0 and age-1 California halibut index was 58% of the 2005 index, yet was still the fourth largest index for the study period (Figure 20). Age-0 and age-1 fish were collected January through June, with the majority of fish from South and San Pablo bays in January, February, and March. The large index of age-0 and age-1 fish was believed to be in response to Gulf of the Farallones SSTs exceeding 14°C in August, September, and November 2004 and in August and September 2005. California halibut spawn in shallow coastal waters and laboratory experiments have shown high larval mortality at 12°C and increased survivorship and growth with higher temperatures (Gadomski and Caddell 1991).

The age-2+ California halibut index was a record high for the study period (Figure 20). Fish were collected from South Bay south of the Dumbarton Bridge to the Carquinez Strait, with 47% (n=74) from South Bay, 32% (n=50) from Central Bay, 20% (n=32) from San Pablo Bay, and 1 fish from Carquinez Strait. Age-2+ fish ranged from 200 mm to 869 mm FL, indicating several year classes were present in the estuary. The larger fish (420-869 mm FL, n=14) were collected only in South and Central bays.

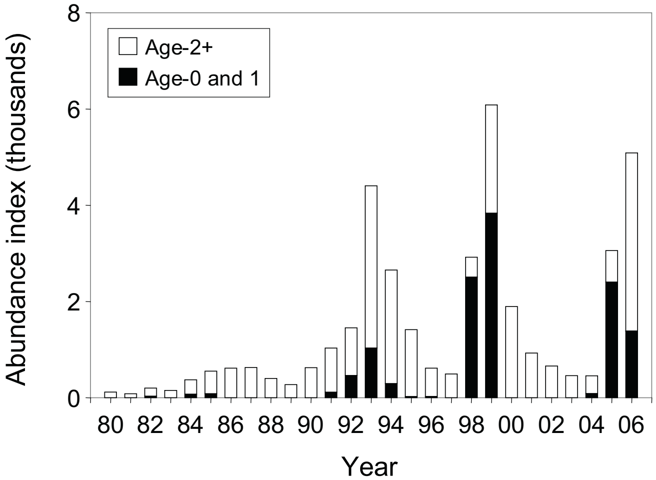

Figure 20 Annual abundance of juvenile (age-0 and age-1) and age-2+ California halibut, Bay Study otter trawl, February-October

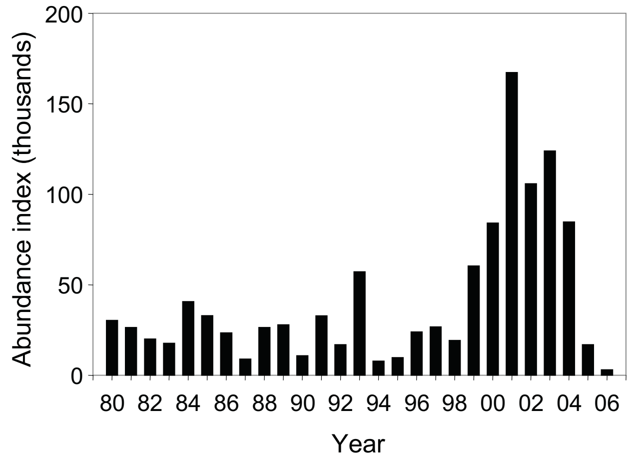

Figure 21 Annual abundance of age-0 English sole, Bay Study otter trawl, February-October

English sole

English sole (*Pleuronectes vetulus*) is a common flatfish that spawns along the coast in winter and rears in both the ocean and estuaries. The 2006 age-0 English sole abundance index was the lowest of the study period. It decreased to just 18% of the 2005 index and was only 7.5% of the study period average (Figure 21), reversing the trend of high indices from 1999 to 2004. Low abundance appeared to be due to a combination of higher ocean temperatures in winter and low salinities in San Pablo Bay in spring. English sole have reduced survival of eggs and larvae in temperatures above 11ºC (Alderdice and Forrester, 1968). We collected age-0 fish from March to September, with peak catch in July. Although fish were collected from South through San Pablo bays in 2006, 94% (n=262) were from Central Bay, and more specifically, 90% percent (n=250) were from Central Bay shoal stations. Distribution in the estuary was greatly contracted due to high outflow in spring, which resulted in salinities <12‰ in San Pablo Bay during the period that newly transformed English sole emigrate from the ocean to the estuary to rear. English sole generally rear in shallow water at salinities from 12-24‰ (Baxter et al., 1999). Distribution of age-0 English sole in 2006 was atypical, as there was not a strong seasonal movement from the shoals to the channels in summer and fall. It appears that the majority of age-0 English sole reared in Central Bay in 2006 and immigrated to the ocean relatively quickly in late summer.

Speckled sanddab

The speckled sanddab (*Citharichthys stigmaeus*) is one of the most abundant flatfishes in the estuary. It spawns along the coast and juveniles migrate into the estuary to rear for up to a year. The 2006 index declined to 85% of the 2005 index, and was the lowest since 1990 (Figure 22). Record speckled sanddab abundance indices occurred from 2000 to 2004, corresponding with strong summer upwelling and cooler ocean temperatures. Speckled sanddab has a very long pelagic period and does not settle until after the upwelling season ends. In 2006, weaker summer upwelling and associated warmer ocean temperatures were likely factors in the abundance decline. Fish were collected in South, Central, and San Pablo bays in 2006, but the vast majority (98%, n=1,309) were collected in Central Bay. Like English sole, this contracted distribution was due to lower salinities. In March, fish started to migrate to Central Bay from South and San Pablo bays and by June, fish were collected only in Central Bay. In September, fish were only collected at the 2 channel stations closest to the Golden Gate.

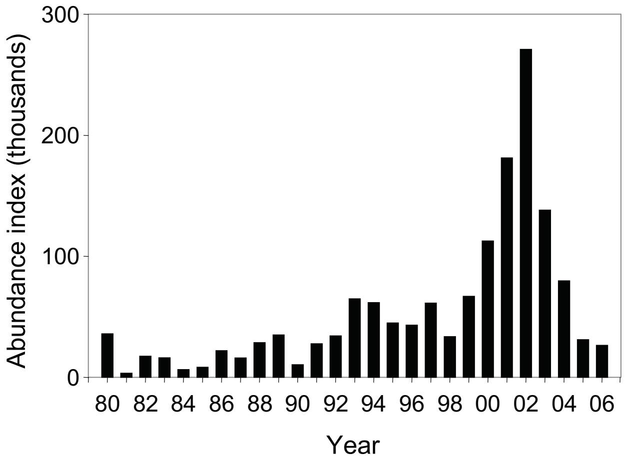

Figure 22 Annual abundance of speckled sanddabs (all sizes), Bay Study otter trawl, February-October

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- Fall Midwater Trawl and Townet surveys, Dave Contreras (dcontreras@dfg.ca.gov).
- San Francisco Bay Study, Tom Greiner (tgreiner@dfg.ca.gov), Max Fish (mfish@dfg.ca.gov), or Kathy Hieb (khieb@dfg.ca.gov).
- 20-mm Survey, Erin Gleason (egleason@dfg.ca.gov) or Julio Adib-Samii (jadibsamii@dfg.ca.gov).

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Notes

Nina Kogut, CDFG, April 18, 2007

Wes Dowd, UC Davis, email, June 13, 2006

Ron Russo, email, June 20, 2006

2006 Fish Salvage at the State Water Project and Central Valley Project Fish Facilities.

Russ Gartz (CDF), rgartz@dfg.ca.gov

Introduction

The Tracy Fish Collection Facility (TFCF) and the Skinner Delta Fish Protective Facility (SDFPF) divert (salvage) fish from water exported from the Sacramento-San Joaquin Estuary. The TFCF began operation in 1957 and the SDFPF began operation in 1967 with both facilities using a louver-bypass system to salvage fish from the exported water. The salvaged fish are returned to the San Francisco Estuary by loading the salvaged fish into tanker trucks and trucking them to predetermined release sites.

This report summarizes salvage information from the TFCF and the SDFPF in 2006. The following species are given individual consideration: Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), striped bass[1] (*Morone saxatilis*), American shad (*Alosa sapidissima*), longfin smelt[1] (*Spirinchus thaleichthys*), delta smelt[1] (*Hypomesus transpacificus*), inland silversides (*Menidia beryllina*), threadfin shad[1] [1](*Dorosoma petenense*), splittail (*Pogonichthys macrolepidotus*), green sturgeon (*Acipenser medirostris*), white sturgeon (*A. transmontanus*), common carp (*Cyprinus carpio*), and Chinese mitten crab (*Eriocheir sinensis*).

Methods

The daily volume of water exported was reported from gauge readings from the Jones Pumping Plant (Central Valley Project, CVP) and the Harvey O. Banks Pumping Plant (State Water Project, SWP). Monthly water exports were calculated as the sum of daily measurements, rounded to the nearest 0.1 million m^3, plotted, and examined for time trends. Annual exports were determined from 1993 – 2006 and rounded to the nearest 0.1 billion m^3. Water temperature was recorded during routine fish counts at both the TFCF and the SDFPF. Daily mean water temperature was calculated and examined for time trends during 2006.

Abundance of fish or mitten crabs was reported in terms of estimated salvage. Only fish that are greater than 20 mm in length were numerated (counts) as the salvage efficiency of each facility drops off rapidly for fish less than this size. Salvage estimates are primarily obtained by expanding the routine sample counts for the given time that water was pumped using the following equation:

$$\text{SALVAGE}_{\text{SAMPLE}} = \text{COUNT}_{\text{SAMPLE}} \mathbf{x} \text{ (MINUTES PUMPING / MINUTES}_{\text{SAMPLE}}\text{)}. \quad (1)$$

Fish collected from predator removals are not expanded:

$$\text{SALVAGE}_{\text{PREDAROR REMOVAL/SECONDARY FLUSH}} = \text{COUNT}_{\text{PREDAROR REMOVAL/SECONDARY FLUSH.}} \quad (2)$$

Monthly or annual salvage estimates were calculated by the summation of Equations (1) and (2) by month or year. Intra-annual abundance was examined by plotting the monthly salvage totals for selected species and for all taxa combined for 2006. Relative abundance among years was analyzed by graphing the annual salvages for selected species/all taxa combined from 1981-2006. The prevalent species in salvage were determined by ranking the annual salvage totals in descending order with the 5 most prevalent species identified.

The annual and monthly salvage estimates for Chinook salmon and steelhead were subcategorized as wild, hatchery or fish of unknown origin. Salmonids of wild or hatchery origin were determined by the presence (wild) or absence (hatchery) of adipose fins. The race of Chinook salmon was classified by the Delta Salmon Length-Race Key using body size and date of capture information. Salmonids were recorded as unknown race or origin when the count observations were insufficient to categorize their status.

Fish loss was reported for Chinook salmon only since key loss information is lacking for other species. Loss is the difference between the estimated number of fish encountered by the facility and the fish that survive salvage operations; these values were determined experimentally and are applied whenever Chinook salmon salvage occurs. Loss was subcategorized by origin and race.

1. Pelagic Organism Decline (POD) species

Length measurements were taken systematically during fish counts to determine the size of fish and mitten crabs. The annual minimum, maximum, and mean lengths measurements were calculated for all selected species. Fork length (FL) was measured for all species except for sturgeon (*Acipenser spp.*) and mitten crabs where total length (TL) or carapace width was reported respectively.

Statistical testing was conducted to determine if there was a significant difference in size of fish salvaged between the 2 facilities or their origins (e.g., wild vs hatchery). Testing consisted of using 2 sample t-tests run under SAS using PROC TTEST (SAS Institute, Inc, 1989). Calculated concurrently and run with the 2-sample t-test was a folded form F statistic analysis to test the assumption that the variances from both samples were equal (SAS Institute, Inc, 1989). If the result of this test was significant, the length data were transformed using natural logarithms (Ramsey and Schaffer 2002) and retested.

Given the size and scope of this report, more elaborate analysis and testing of the size of fish salvaged was not attempted.

Exports and Water Temperature

Annual exports were within the range of exports in recent years (2002 – 2005; Figure 1). The SWP exported roughly 4.3 billion m^3 of water in 2006; in range with recent annual exports that ranged from 3.4 -5.0 billion m^3 (Figure 1). The CVP exported roughly 3.2 billion m^3 of water in 2006; in the range of recent exports that ranged from 3.1 – 3.4 billion m^3.

The majority of water exported in 2006 occurred from June to December (Figure 2). State Water Project monthly exports ranged from 144.4 – 539.1 million m^3 of water (Figure 2). From June to December, 3.2 billion m^3 of water was exported, accounting for 74% of the 2006 annual export. Central Valley Project exports ranged from 59.8 – 333.5 million m^3 of water (Figure 2). From June – December, 2.2 billion m^3 of water was exported, accounting for 69% of the 2006 annual export.

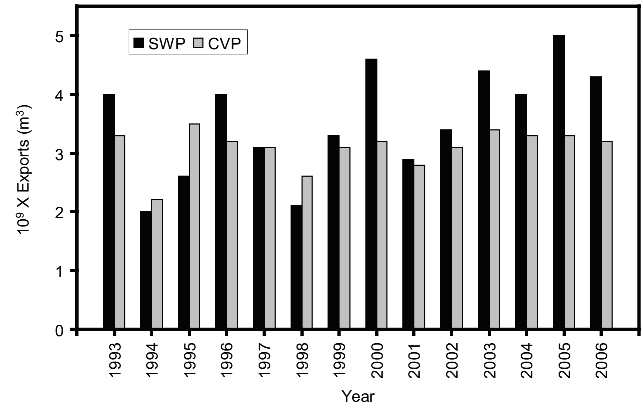

Figure 1 Annual exports in billions of cubic meters for the SWP and the CVP, 1993 - 2006

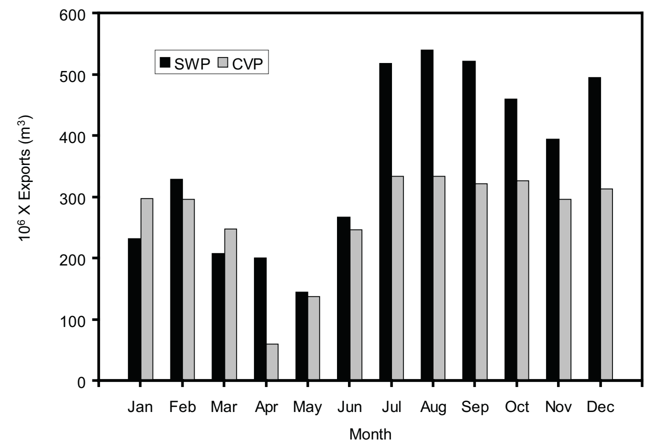

Figure 2 Monthly exports in millions of cubic meters for the SWP and the CVP in 2006

Differences in mean daily water temperature (temperature) between SDFPF and TFCF were most prevalent in the first half of the year (Figure 3). Temperature at SDFPF ranged from 7.8 – 29.4 °C. Temperature at TFCF ranged from 7.9 – 28.6 °C. The temporal pattern of temperature at both facilities followed a typical pattern of increasing from January to July and decreasing there after (Figure 3). Given the close proximity of the 2 facilities, it is reasonable to expect that the temperatures at the each facility would closely track one another. However, the temperature at SDFPF was frequently 2 and occasionally 5 degrees lower than that at TFCF during the first part of the year; most notably from mid-May – mid-June (Figure 3). After June, the temperatures at the 2 facilities very closely correlated (Figure 3).

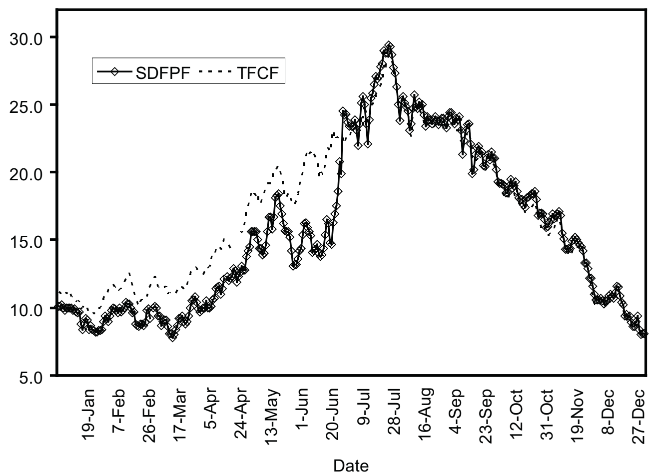

Figure 3 Daily mean water temperature at the SDFPF and the TFCF for 2006

Total Salvage and Prevalent Species

Annual combined salvage (annual, all species salvage) in 2006 at the TFCF, 37,266,449 was a record high for the period of record, regardless of facility. Generally, annual salvage values were below 10 million/year (Figure 4). However the 2006 annual salvage at TFCF dwarfs any previous value and represents an order of magnitude increase from the TFCF annual salvage in 2005 (2,430,642). This is in stark contrast to the modest increase in annual salvage at the SDFPF, from 3,019,512 in 2005 to 5,138,458 in 2006. The next highest annual salvages were at the SDFPF in 1986 and 1993; in both cases, slightly below 18 million (Figure 4).

The annual salvage at both facilities was dominated by carp. At the TFCF, carp accounted for 81.8% of the annual salvage. The only other species to be salvaged in comparable numbers at the TFCF was splittail (Figure 5). The situation was less lopsided at SDFPF where carp accounted for 53.3% of the annual salvage. The other species that occurred in comparable numbers at SDFPF were threadfin shad, American shad, and splittail (Figure 6). These 4 species accounted for 89.6% of the annual salvage at SDFPF. Generally, threadfin shad has made up the bulk of salvage at both facilities, especially in later years (Figures 7 and 8). Large occurrences of carp and splittail have also occurred only in 1995 and 1998 (Figures 7 and 8). Therefore, the domination of salvage by carp and splittail may be ephemeral and is suggested by the "boom and bust" nature of splittail salvage (see below).

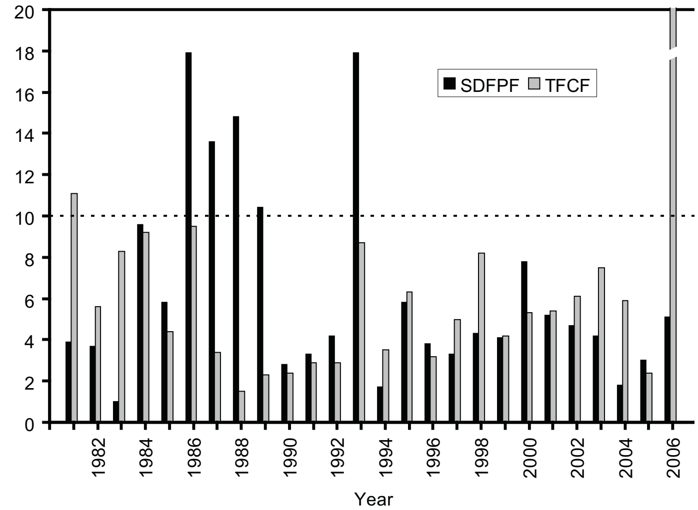

Figure 4 Annual salvage of all taxa combined at the SDFPF and the TFCF, 1981 - 2006. The TFCF 2006 annual salvage of 37.3 million has been truncated for scale considerations

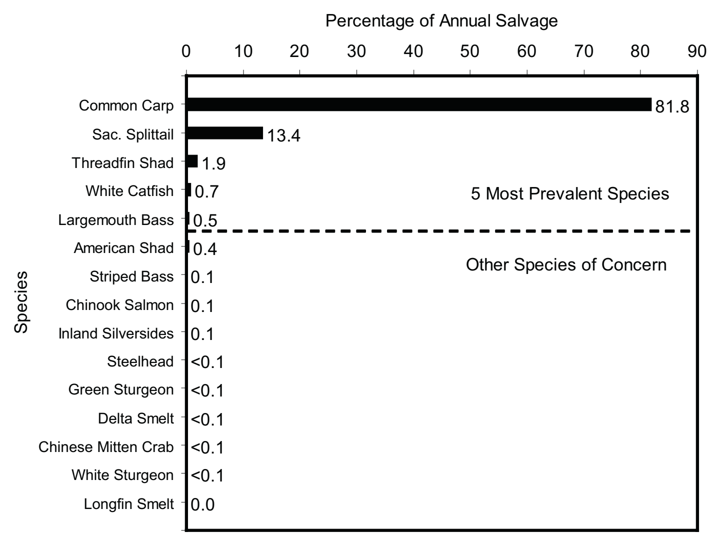

Figure 5 Percentages of annual salvage for the 5 most prevalent species and species of special interest at the TFCF, 2006

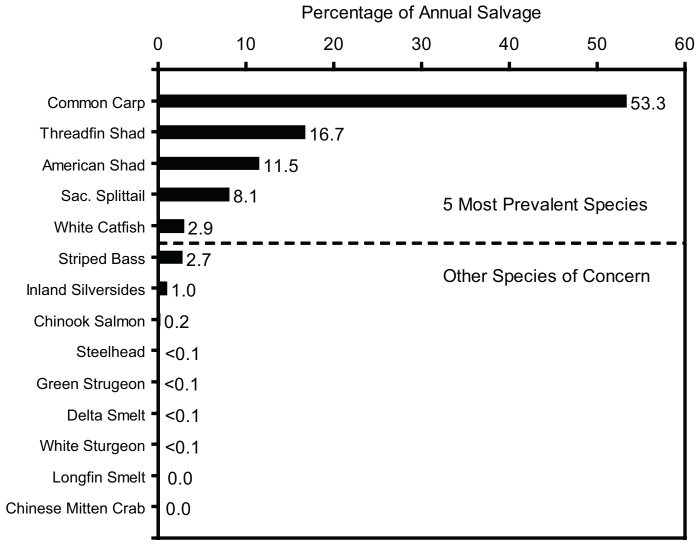

Figure 6 Percentages of annual salvage for the 5 most prevalent species and species of special interest at the SDFPF, 2006

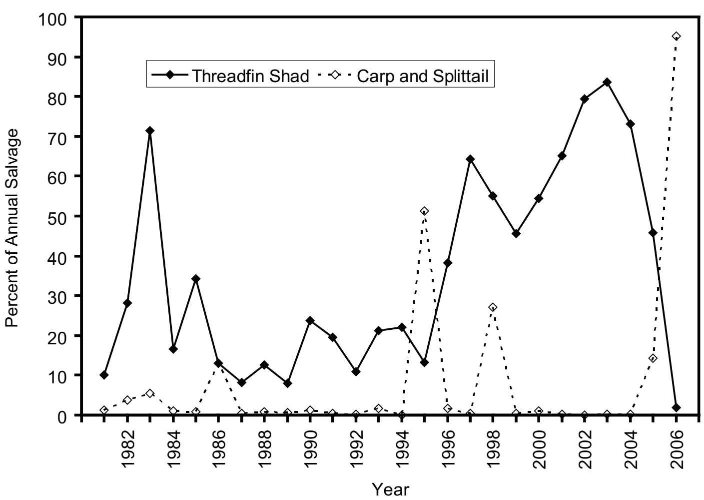

Figure 7 Percentages of annual salvage represented by threadfin shad and carp+splittail at the TFCF, 1981 - 2006

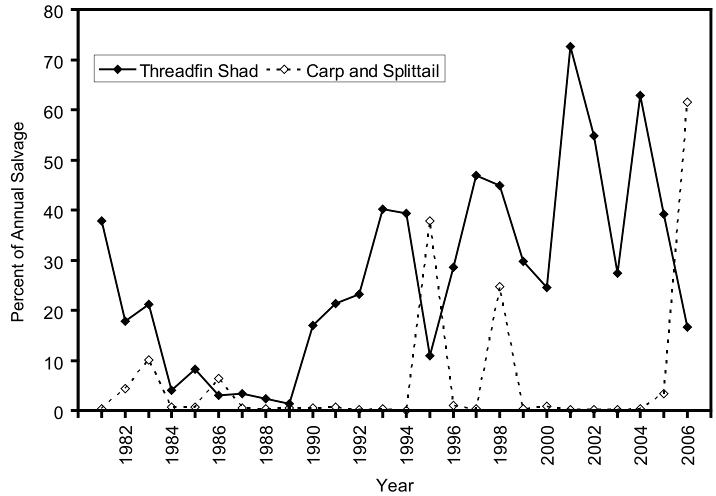

Figure 8 Percentages of annual salvage represented by threadfin shad and carp+splittail at the SDFPF, 1981 - 2006

The month of June accounted for the majority of the 2006 annual salvage at both facilities (Figure 9). At the SDFPF, the June salvage of 3,017,683 accounted for 59% of the 2006 annual salvage. At the TFCF, the June salvage of 34,913,860 accounted for 94% of the 2006 annual salvage. Salvage from January – April accounted for a very small faction of annual salvage at each facility (Figure 9).

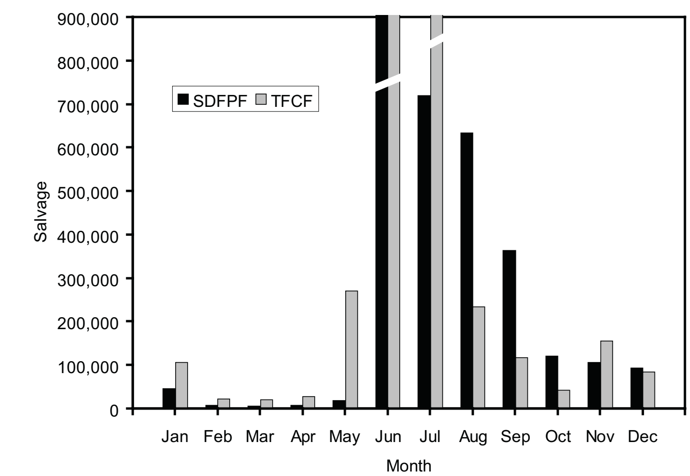

Figure 9 Monthly salvage of all taxa combined at the SDFPF and the TFCF, 2006. The June salvage (3,017,683) at the SDFPF has been truncated for scale considerations. The June salvage (34,913,860) and the July salvage (1,276,708) at the TFCF have been truncated for scale considerations.

Chinook Salmon

Annual salvage (all races and origins combined) of Chinook salmon continued to be low at both facilities with higher salvage at the TFCF than at the SDFPF (Figure 10). The annual salvage of salmon at the SDFPF in 2006, 8,629, decreased from the annual salvage of 13,065 observed in 2005, continuing the slight declining trend that started in 2003 (with the exception of 2005, Figure 10). The annual salvage of salmon at the TFCF in 2006, 35,319, was an increase from the annual salvage of 25,637 observed in 2005 and continuing the slight increasing trend that started in 2002 (Figure 10). However, these annual salvages are dwarfed by annual salvages observed in the 1980's and the late 1990's (Figure 10).

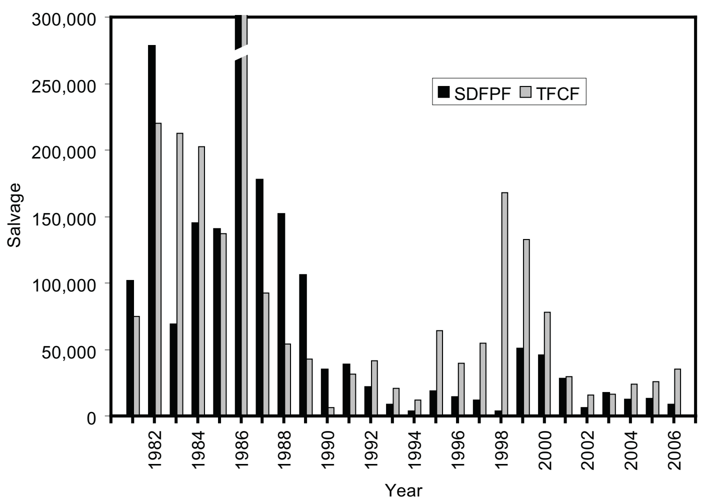

Figure 10 Annual salvage of Chinook salmon (all races and origins combined) at the SDFPF and the TFCF, 1981 - 2006. The SDFPF 1986 salvage of 435,233 and the TFCF 1986 salvage of 752,039 have been truncated for scale considerations.

Salvage of Chinook salmon at both facilities was composed primarily of wild, fall run fish followed wild, spring run fish (Table 1) with the majority of salvage occurring in a narrow time frame. Wild fall run fish comprised 63% of the annual salvage at the SDFPF and 82% of the annual salvage at the TFCF. Wild spring run fish comprised 27% of the annual salvage at the SDFPF and 10% of the annual salvage at the TFCF. The majority of wild fall run fish, 88% at the SDFPF and 83% at the TFCF, were salvaged in June (Figure 11). The majority, 78%, of wild spring run fish salvage at the SDFPF were salvaged in April (Figure 12). At the TFCF the majority of wild spring run salvage, 69%, occurred in May (Figure 12).

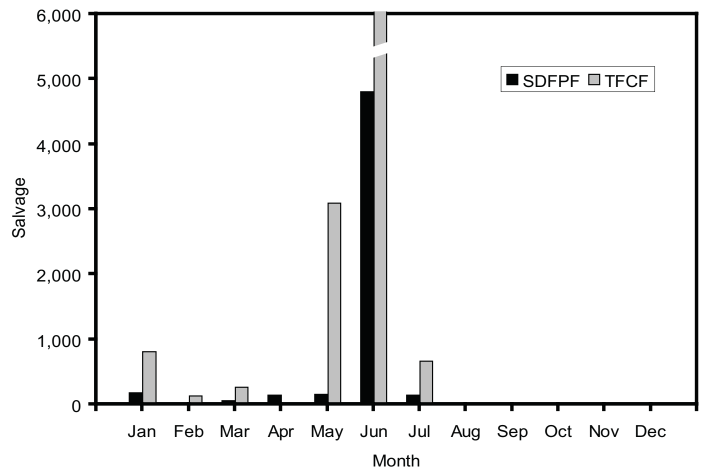

Figure 11 Monthly salvage of wild, fall run Chinook salmon at the SDFPF and the TFCF, 2006. The June salvage of 23,928 at the TFCF has been truncated for scale considerations.

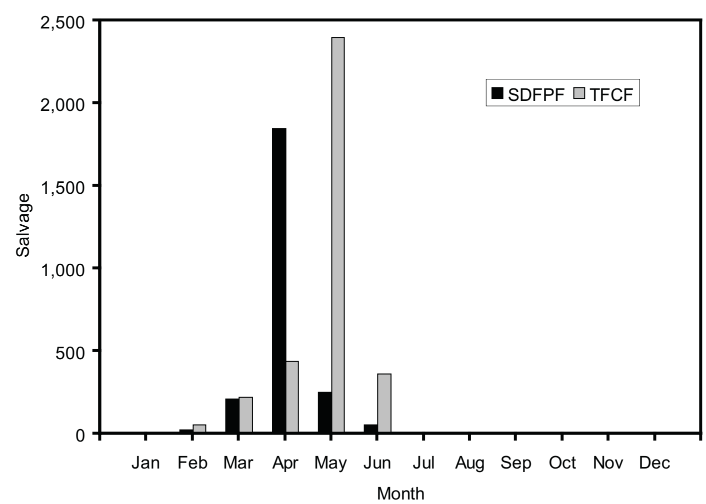

Figure 12 Monthly salvage of wild, spring run Chinook salmon at the SDFPF and the TFCF, 2006

Loss of salmon in 2006 was higher at the SDFPF than at the TFCF (Table 1). At the SDFPF the loss of salmon was estimated at 38,227 while at the TFCF the estimated loss was 23,508. The primary reason for this is the higher mortality associated with Clifton Court Forebay. The losses estimated at each facility parallel the salvage at each facility (Table 1).

Table 1 Annual salvage, percentage of annual salvage, Chinook salmon by race and origin (wild, hatchery, or unknown) and loss of at the SDFPF and the TFCF, 2006

Facility	*Origin*	*Race*	*Salvage*	*Percentage*	*Loss*[1]
SDFPF					
	Wild				
		Fall	5,444	63	24,362
		Late-fall	2	<1	9
		Spring	2,366	27	10,282
		Winter	480	6	2,135
	Total Wild		8,292		36,788
	Hatchery				
		Fall	112	1	510
		Late-fall	9	<1	40
		Spring	45	1	204
		Winter	153	2	685
	Total Hatchery		319		1,439
	Unknown		18	<1	
	Grand Total		8,629		38,227
TFCF					
	Wild	Fall	28,841	82	18,863
		Late-fall	12	<1	8
		Spring	*3,456*	*10*	*2,720*
		Winter	*519*	*1*	*337*
	Total Wild		*32,828*		*21,928*
	Hatchery				
		Fall	*1,323*	*4*	*912*
		Late-fall	*12*	*<1*	*8*
		Spring	*556*	*2*	*428*
		Winter	*204*	*1*	*132*
	Total Hatchery		*2,095*		*1,480*
	Unknown		*396*	*1*	
	Grand Total		*35,319*		*23,508*

1. Loss is not calculated for fish of unknown origin.

Results suggest different sizes of wild salmon were salvaged between the 2 facilities (Table 2). Testing was not done on late-fall (wild or hatchery) or hatchery spring run due to small sample sizes (Table 2). The SDFPF salvaged significantly larger winter run salmon ($t = 3.00$, $p = 0.0032$, $df = 139$) while the TFCF salvaged significantly larger fall and spring run salmon (fall: $t = -3.97$, $p < 0.0001$, $df = 2,281$; spring: $t = -8.57$, $p < 0.0001$, $df = 775$)

Table 2 Minimum length, mean length, maximum length, and sample size by origin and race for Chinook salmon salvaged by the SDFPF and the TFCF, 2006. With the exception of sample size, all lengths are in millimeters, FL. An asteisk beside a mean length indicates a significant difference in mean length between the 2 facilities for that origin or race.

Facility	*Origin*	*Race*	*Mean Length*[1]	*Min. Length*	*Max. Length*	*n*
SDFPF						
	Wild					
		Fall	*89	30	121	701
		Late-fall[1]	169	142	195	2
		Spring	*98	65	129	453
		Winter	*137	76	198	95
	Hatchery					
		Fall	100	89	112	18
		Late-fall[1]	174	156	216	4
		Spring[1]	102	93	121	8
		Winter	138	104	208	37
TFCF						
	Wild					
		Fall	*92	30	125	1,582
		Late-fall[1]	139	n/a	n/a	1
		Spring	*105	55	130	324
		Winter	*127	98	182	46
	Hatchery					
		Fall	99	78	114	86
		Late-fall[1]	165	143	186	2
		Spring[1]	112	94	132	40
		Winter	127	100	173	17

1. Difference in means test not given due to small sample sizes at either facility.

A difference in variances was suggested was for spring run fish ($F = 1.23$, $p = 0.0440$, df, numerator = 323, df, denominator = 452). Log transforming the spring run data did help the situation ($F = 1.39$, $p = 0.0014$, df, numerator = 323, df, denominator = 452). No significant differences in mean length were observed for hatchery salmon: fall, $t = 1.07$, $p = 0.4804$, df = 102; winter, $t = 1.65$, $p = 0.1044$, df = 52.

Steelhead

The annual salvage of steelhead (all origins combined) at both facilities continued to be low in 2006 (Figure 13). Annual salvage at the SDFPF in 2006 was less than in 2005; 1,287 as compared to 2,196. The reverse was observed at the TFCF as the annual salvage in 2006 was greater than in 2005; 2,516 as compared to 1,347.

The majority of steelhead salvaged at the SDFPF were wild while at the TFCF the majority of steelhead salvaged were hatchery. At the SDFPF the salvage breakdown was: wild – 919, hatchery – 350, unknown origin – 18. At the TFCF the salvage breakdown was: wild – 688, hatchery – 1,828, unknown origin – 0.

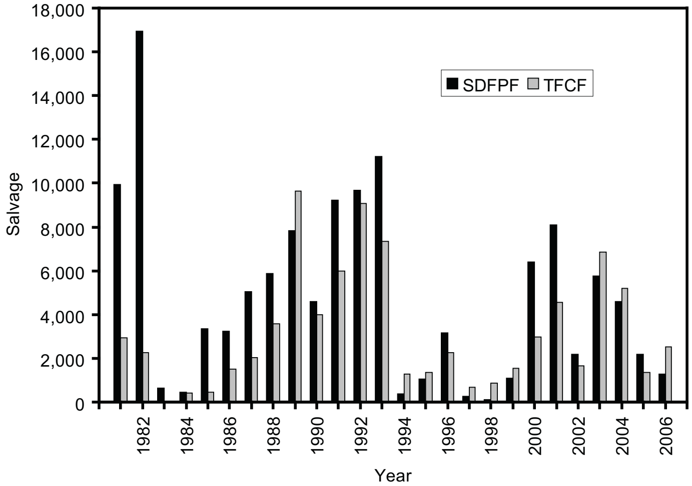

Figure 13 Annual salvage of steelhead (all origins combined) at the SDFPF and the TFCF, 1981 - 2006

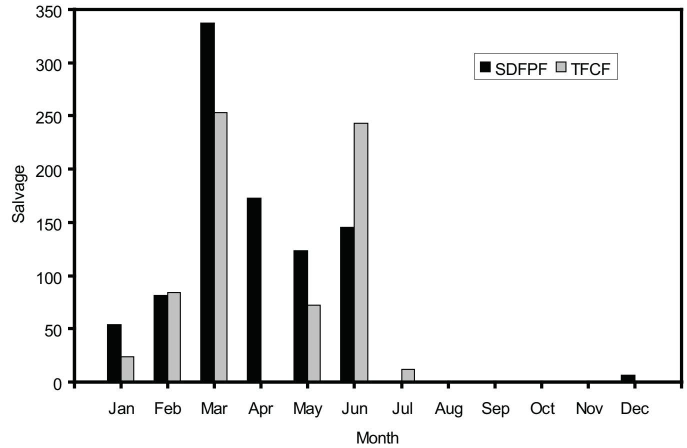

Figure 14 Monthly salvage of wild steelhead at the SDFPF and the TFCF, 2006

Wild steelhead salvage occurred over a greater part of the year than that of hatchery steelhead. Most salvage of wild steelhead occurred in the first half of the year for both facilities. Wild steelhead were salvaged from January – June (again in December) at the SDFPF and from January – March and May – July at the TFCFF (Figure 14). At the SDFPF hatchery steelhead were salvaged in: February (117), March (198), April (26), and June (9). For the TFCF, steelhead were salvaged in: February (240), March (1,587), and April (1).

Results are suggestive that different sizes of hatchery steelhead were salvaged at each facility but results are not suggestive that different sizes of wild steelhead were salvaged (summary statistics are in Table 3). The results from the 2 sample t-test for hatchery fish is: $t = 2.02$, $p = 0.0442$, (237 df). The result of the 2 sample t-test for wild fish is: $t = 1.64$, $p = 0.1030$ (220 degrees of freedom).

Table 3 Steelhead Summary Length Statistics - Minimum, maximum, mean lengths (mm, FL) and sample sizes for hatchery and wild steelhead measured at the SDFPF and the TFCF, 2006.

Facility	*Mean*	*Minimum*	*Maximum*	*n*
		Hatchery		
SDFPF	*241*	*130*	*400*	*70*
TFCF	*230*	*104*	*345*	*169*
		Wild		
SDFPF	*271*	*170*	*520*	*167*
TFCF	*258*	*127*	*423*	*55*

Delta Smelt

Very few delta smelt were salvaged by either facility in 2006, continuing the decline in salvage that started in 2002 (Figure 15). At the SDFPF the annual salvage in 2006 was 24 (a new record low), markedly less than the 2005 annual salvage of 2,922. At the TFCF the annual salvage in 2006 was 312, less than half the annual salvage in 2005 of 818.

Delta smelt were salvaged in only a few months in 2006. At the SDFPF delta smelt were salvaged in January (12) and April (12). At the TFCF delta smelt were salvaged in January (24), February (72) and March (216).

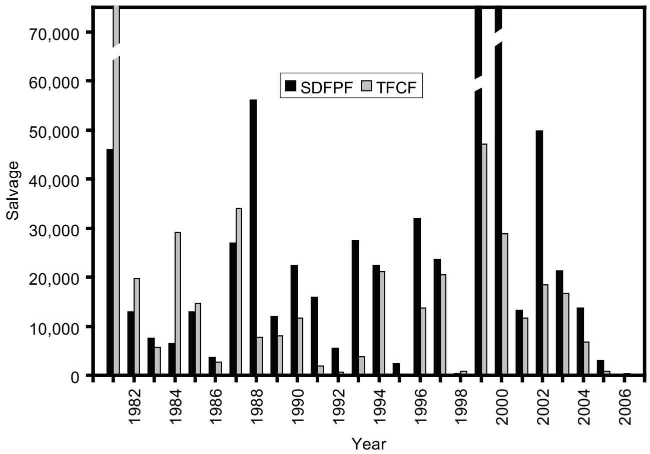

Figure 15 Annual salvage of delta smelt at the SDFPF and the TFCF, 1981 - 2006. The annual salvages in 1999 (107,640) and 2000 (85,188) at the SDFPF have been truncated for scale considerations. The annual salvage of 274,288 in 1981 at the TFCF has been truncated for scale considerations.

Salvaged delta smelt did not differ in size between the facilities, and all were adults. Additional delta smelt were collected incidentally at the SDFPF during the Capture, Handling, Transportation, and Release (CHTR) study. These fish did not count towards salvage as they were collected during non-routine activities but their length data have been included for this analysis. At the SDFPF delta smelt lengths ranged from 56 – 77 mm FL with a mean of 70 mm FL (n = 28). At the TFCF delta smelt lengths ranged from 57 – 77 mm FL with a mean of 72 mm FL (n = 27). Delta smelt did not significantly differ in mean lengths between the 2 facilities ($t = -1.15$, $p = 0.2553$, 53 df).

Green Sturgeon

Relatively large numbers of green sturgeon were salvaged in 2006: 39 at the SDFPF and 324 at the TFCF. Salvage of green sturgeon has been relatively low in recent years (Figure 16).

Green sturgeon were salvaged only in specific months at both facilities. At the SDFPF green sturgeon were salvaged in January (6), July (6), September (12) and December (15). At the TFCF green sturgeon were salvaged from June – December with monthly salvage ranging from 12 – 96.

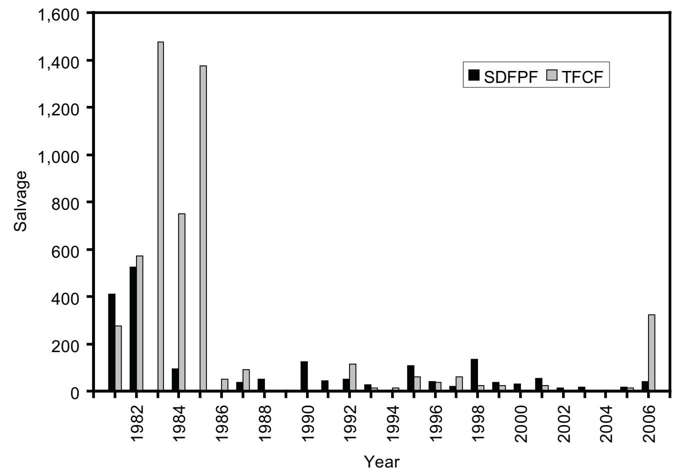

Figure 16 Annual salvage of green sturgeon at the SDFPF and the TFCF, 1981 - 2006

The SDFPF salvaged larger green sturgeon than the TFCF. At the SDFPF green sturgeon lengths ranged from 280 – 540 mm TL with a mean of 388 mm TL (n = 5). At the TFCF green sturgeon lengths ranged from 125 – 400 mm TL with a mean of 248 mm TL (n = 25). No statistical testing was done given the small sample size at the SDFPF.

Splittail

The annual salvage of splittail was higher for both facilities in 2006 than in 2005, and 2006 numbers at both facilities were exceptionally high (Figure 17). At the SDFPF the 2006 annual salvage was 417,859 as opposed to 102,308 in 2005. At the TFCF the 2006 annual salvage was 5,002,611 (a record high), and a dramatic increase from the 2005 value of 342,595. However, large salvages (greater than 150,000) are not uncommon and have been seen in 1982, 1983, 1986, 1995, 1998, 2005, and 2006 (Figure 17).

Almost all of the splittail salvaged by both facilities in 2006 occurred during May – July. At the SDFPF, the combined salvage of May (13,034), June (285,229) and July (116,097) accounted for 99% of the annual salvage. Monthly salvage outside of the above time frame ranged from 7 – 3,118. At the TFCF, the combined salvage of May (231,858), June (4,565,037), and July (205,032) accounted for 99.99% of the annual salvage. Salvage outside the above time frame ranged from 0 – 576.

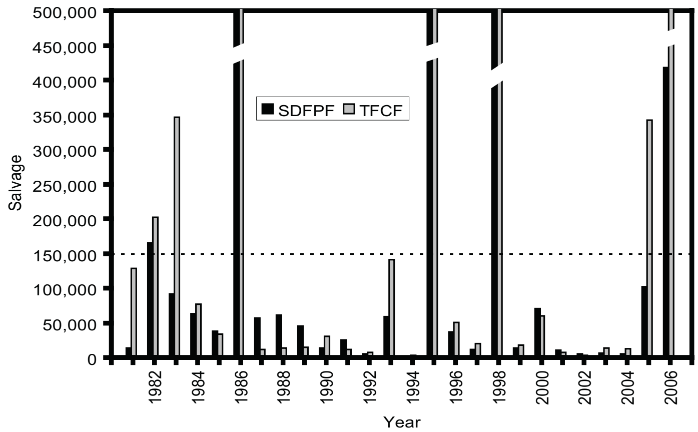

Figure 17 Annual salvage of Sacramento splittail at the SDFPF and the TFCF, 1981 - 2006. The annual salvages at the SDFPF for the following years have been truncated for scale considerations: 1986 (1,160,305), 1995 (2,190,517), and 1998 (1,042,239). The annual salvages at the TFCF for the following years have been truncated for scale considerations: 1986 (1,231,283), 1995 (3,143,156), 1998 (2,051,660), and 2006 (5,002,611).

The TFCF salvaged slightly larger splittail then the SDFPF and that the majority of splittail salvaged at both facilities were young-of-the-year. At the SDFPF splittail lengths ranged from 20 – 350 mm FL with a mean of 46 mm FL (n = 4,935) and the 99th percentile estimated at 85 mm FL. At the TFCF splittail lengths ranged from 20 – 350 mm FL with a mean of 48 mm FL (n = 4,891) and the 99th percentile estimated at 85 mm FL. The variance ratio test suggested that the variances were unequal (F = 1.48, $p < 0.0001$, df, numerator = 4,934, df, denominator = 4,890). Length data were transformed using natural logs to normalize distributions, equalizing the variances (F = 1.00, p = 0.8622, df, numerator = 4,934, df, denominator = 4,890). Results of the 2 sample t-test (transformed data) are t = -10.59 (df = 9,824), $p < 0.0001$.

Longfin Smelt

No longfin smelt were salvage at either facility in 2006; annual salvages in 2005 were 183 at the SDFPF and 36 at the TFCF (Figure 18). Low or zero annual salvages of longfin smelt are not unknown, and are associated with high outflow years. The 2006 annual salvage of 0 at the SDFPF is new record low for the recent period (the previous low was 52 in 1982) but not for the TFCF were no longfin smelt were salvaged in 1982 and 1995. Large (greater than 10,000) annual salvages of longfin smelt have also been observed at one or both facilities in: 1984, 1985, 1987-1990, and 2002 (Figure 18). Longfin smelt tend to be “boom and bust” in terms of salvage (Figure 18).

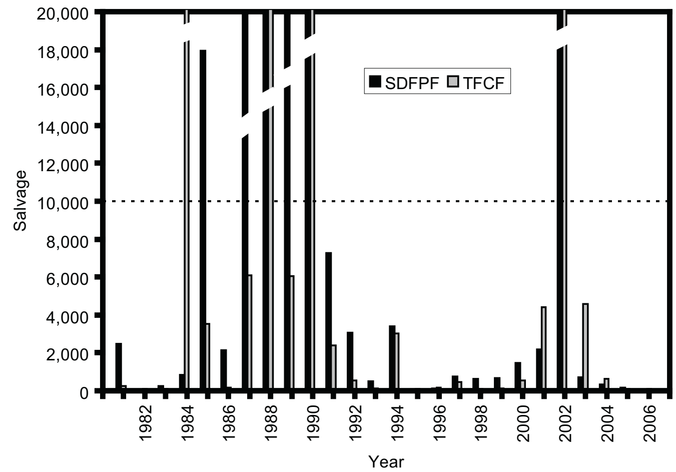

Figure 18 Annual salvage of longfin at the SDFPF and the TFCF, 1981 - 2006. The annual salvages in following years at the SDFPF were truncated for scale considerations: 1987 (50,753), 1988 (140,040), 1989 (61,509), 1990 (26,257), and 2002 (54,606). The annual salvages in 1984 (22,535) and 2002 (43,080) at the TFCF were truncated for scale considerations.

White Sturgeon

Annual salvage of white sturgeon in 2006 was low for both facilities: 23 for the SDFPF and 1 for the TFCF (Figure 19). These annual salvages are not uncommonly low for the period of record as no white sturgeon were salvaged by the SDFPF in 2003 or 2004 or by the TFCF in 1988 – 1991, 1994, 2002, or 2005. Annual salvage of white sturgeon as occurred in 2 large pulses: from 1981 – 1987 and from 1995 – 1998 (Figure 19). Relatively large annual salvages have occurred, notably in 1982 and 1983 at the SDFPF (Figure 19).

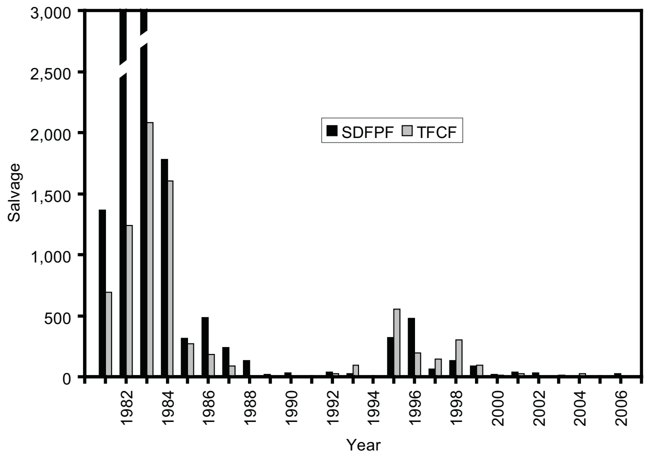

Figure 19 Annual salvage of white sturgeon at the SDFPF and the TFCF, 1981 - 2006. The annual salvages in 1982 (10,806) and 1983 (3,177) at the SDFPF have been truncated for scale considerations.

White sturgeon were salvaged only in certain months in 2006. At the SDFPF white sturgeon were salvaged in: January (6), July (7), August (1), October (3), and November (6). At the TFCF white sturgeon were salvaged in October (1) only.

Due to small sample sizes, no statistical testing was done using white sturgeon length data. At the SDFPF, white sturgeon lengths ranged from 280 – 428 mm TL with a mean of 336 mm TL (n = 4). At the TFCF, a single white sturgeon was measured, 247 mm TL.

Carp

The annual salvage of carp in 2006 reached record highs at both facilities (Figure 20). At the SDFPF, the 2006 annual salvage was 2,739,126 with the range from 1981 – 2005 being 0 – 27,928. At the TFCF the 2006 annual salvage was 30,495,884 with the range from 1981 – 2005 being 84 – 175,374. Generally, annual salvages of carp are less than 4,000 at both facilities (Figure 20). Annual salvages above 4,000 have occurred in: 1982-1984, 1995, 1998, and 2005-2006 (Figure 20).

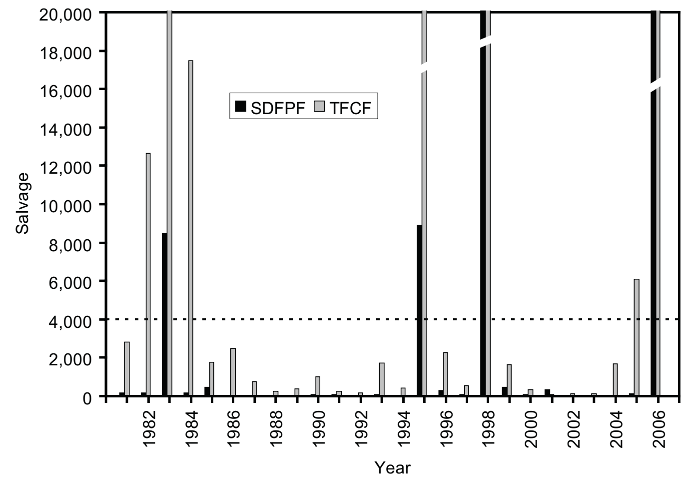

Figure 20 Annual salvage of carp at the SDFPF and the TFCF, 1981 - 2006. The annual salvages in 1998 (27,928) and 2006 (2,739,126) at the SDFPF for the following years have been truncated for scale considerations. The annual salvages at the TFCF for the following years have been truncated for scale considerations: 1983 (109,549), 1995 (75,654), 1998 (175,374), and 2006 (30,495,884).

Almost all of the carp were salvaged in June and July at both facilities. At the SDFPF the June salvage of 2,682,495 and the July salvage of 55,719 accounted for 99.97% of the 2006 annual salvage of carp. At the TFCF, the June salvage of 30,018,630 and the July salvage 463,488 accounted for 99.95% of the annual salvage of carp. Carp were salvaged in every other month except March at the SDFPF and February at the TFCF.

Results suggest larger carp were salvaged at the TFCF however; the assumption of equal variances was violated. Carp salvaged at the SDFPF ranged from 20 – 245 mm FL with a mean of 50 mm FL (n = 2,245) and the 75% percentile estimated at 56 mm FL. Carp salvaged at the TFCF ranged from 20 – 285 mm FL with a mean of 58 mm FL (n = 4,420) and the 75th percentile estimated at 67 mm FL. T-test results are $t = -15.14$, $p < 0.0001$ (df = 6,663). The folded form F statistic analysis suggested that the variances were unequal ($F = 4.74$, $p < 0.0001$ df, numerator = 4,419, df, denominator = 2,244). Log transforming of these data did not adequately address this situation ($F = 2.97$, $p < 0.0001$, df, numerator = 4,419, df, denominator = 2,244).

Striped Bass

In 2006, the facilities reported record low or near record low annual salvages of striped bass. The low annual salvages continue the trend in low annual salvage numbers observed since 2000 (Figure 21). At the SDFPF, the 2006 annual salvage was 140,795, just slightly more than the low for the period of record, 131,039 in 1983. At the TFCF, a new low annual salvage of 37,359 was observed. The next lowest annual salvage was observed in 2005, 124,645.

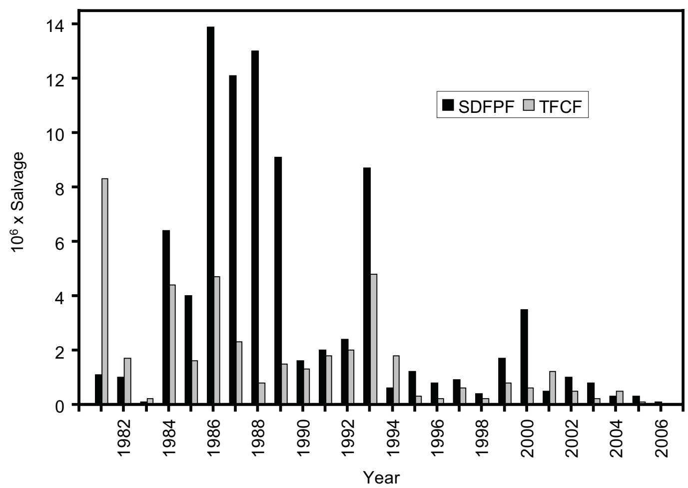

Figure 21 Annual salvage of striped bass at the SDFPF and the TFCF, 1981 - 2006

The months of July and August accounted for the majority of striped bass salvage at both facilities (Figure 22). At the SDFPF the July salvage of 75,220 and the August salvage of 23,522 accounted for 70% of the 2006 annual salvage. At the TFCF the July salvage of 14,016 and the August salvage of 6,511 accounted for 55% of the annual salvage. Striped bass were salvaged every month at both facilities with the lowest monthly salvage in May for both facilities: 253 at the SDFPF and 278 at the TFCF.

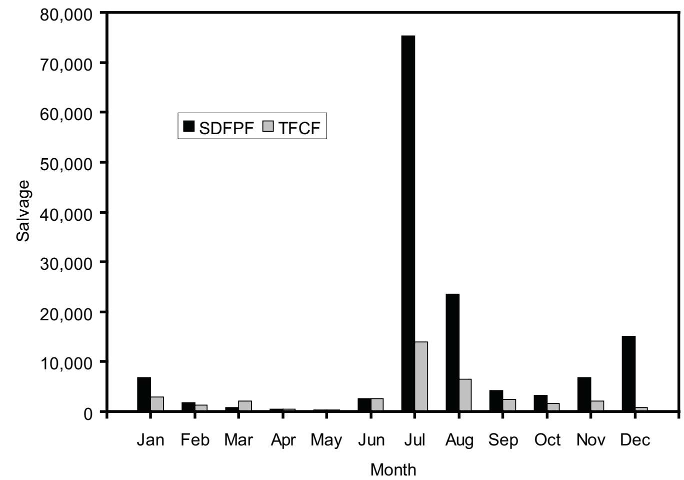

Figure 22 Monthly salvage of striped bass at the SDFPF and the TFCF, 2006

The TFCF caught larger striped bass than the SDFPF and multiple year classes were salvaged however the assumption of equal variances was violated. Striped bass at the TFCF ranged from 20 – 560 mm FL with a mean length of 125 mm FL (n = 924). Striped bass at the SDFPF facility ranged from 20 – 541 mm FL with a mean length of 79 mm FL (n = 3,251). A significant difference for mean length is strongly suggested from the 2-sample t-test (t = -17.50, p< 0.0001, df = 4,173)

The folded form F statistic analysis suggested that the variances were unequal (F = 2.18 p < 0.0001 df, numerator = 923, df, denominator = 3,250). Log transforming of these data did not adequately address this situation (F = 1.44, p < 0.0001, df, numerator =923, df, denominator = 3,250).

American Shad

Annual salvage of American shad was lower at both facilities in 2006 as compared to 2005 (Figure 23). At the SDFPF the 2006 annual salvage was 591,252, less than the 1,229,815 American shad salvaged in 2005. At the TFCF the 2006 annual salvage was 151,068, less than the 329,119 American shad salvaged in 2005. The declining trend in American shad salvage observed from 2003 – 2006 at the TFCF was not observed at the SDFPF (Figure 23). Generally, salvage of American shad is higher at SDFPF than at the TFCF (Figure 23).

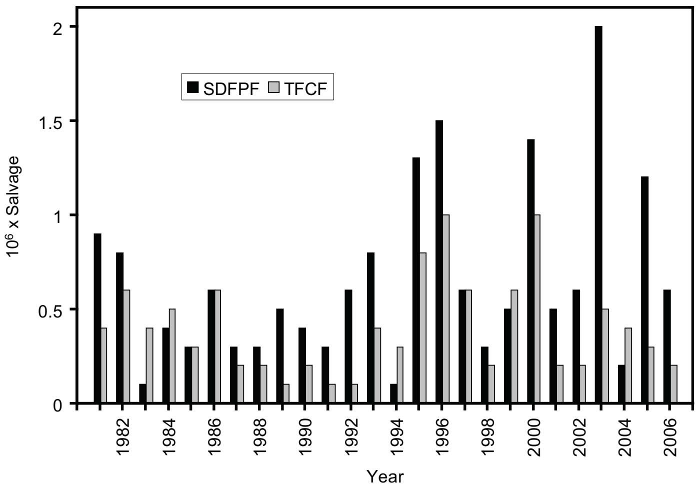

Figure 23 Annual salvage of American shad at the SDFPF and the TFCF, 1981 - 2006

The majority of American shad salvaged in 2006 were salvaged in the last half of the year at both facilities (Figure 24). At the SDFPF monthly salvage ranged from 91 – 216,864 with the salvage from July – December salvage accounting for 96% of the annual salvage. At the TFCF the monthly salvage ranged from 0 – 47,460 with the July – December salvage accounting for 83% of the annual salvage.

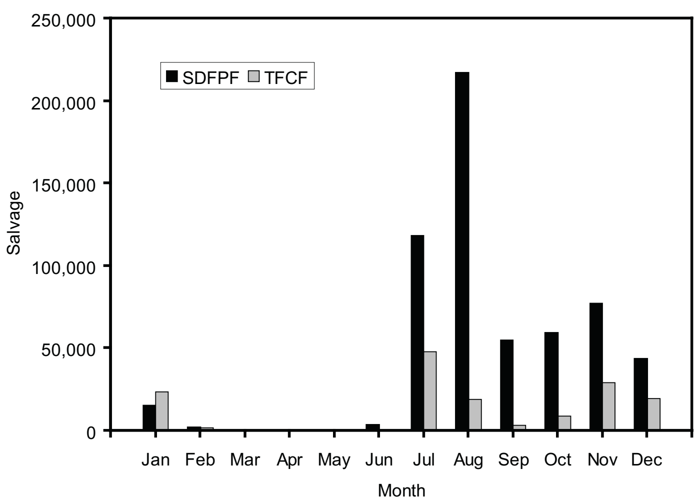

Figure 24 Monthly salvage of American shad at the SDFPF and the TFCF, 2006

Results suggest that the TFCF salvaged larger American shad however; the assumption of equal variances was violated. At the SDFPF American shad ranged from 20 – 405 mm FL with a mean of 65 mm FL (n = 11,587) and the 90th percentile estimated at 97 mm FL. At the TFCF American shad ranged from 20 – 470 mm FL with a mean of 80 mm FL (n = 3,506) and the 90th percentile estimated at 112 mm FL. T-test results are t = -21.52 (df = 15,091), p < 0.0001. The folded form F statistic analysis suggested that the variances were unequal (F = 1.35 p < 0.0001 df, numerator = 3,505, df, denominator = 11,586). Log transforming of these data did not adequately address this situation (F = 1.29, p < 0.0001, df, numerator = 3,505 df, denominator = 11,586). The large range of lengths at both facilities suggests multiple year classes of American shad were salvaged.

Threadfin Shad

Annual salvage of threadfin shad at both facilities was lower in 2006 than in 2005, but neither was a record low (Figure 25). At the SDFPF the 2006 annual salvage was 857,140, less than the 2005 annual salvage of 1,183,267. At the TFCT the 2006 annual salvage was 717,112, less than the 2005 salvage of 1,111,569. The record low for both facilities occurred in 1989: 133,755 for the SDFPF and 182,112 for the TFCF.

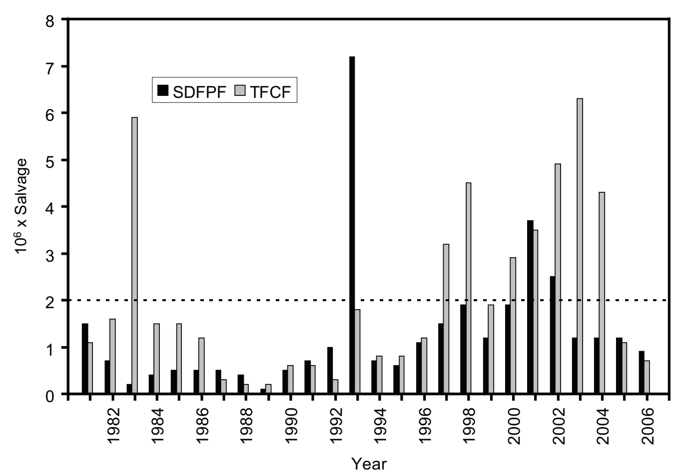

Figure 25 Annual salvage of threadfin shad at the SDFPF and the TFCF, 1981 - 2006

Annual threadfin shad salvage values over 2 million are historically the exception and not the rule. At the TFCF, 8 years out of 26 had annual salvages over 2 million. At the SDFPF only 3 years out of 26 had annual salvages over 2 million. The majority of annual salvages over 2 million occurred in years since 2000 and at the TFCF (Figure 25).

The majority of threadfin shad were salvaged in the summer months (Figure 26). At the SDFPF the July – September salvage accounted for 89% of the annual salvage. At the TFCF the June – September salvage accounted for 76% of the annual salvage.

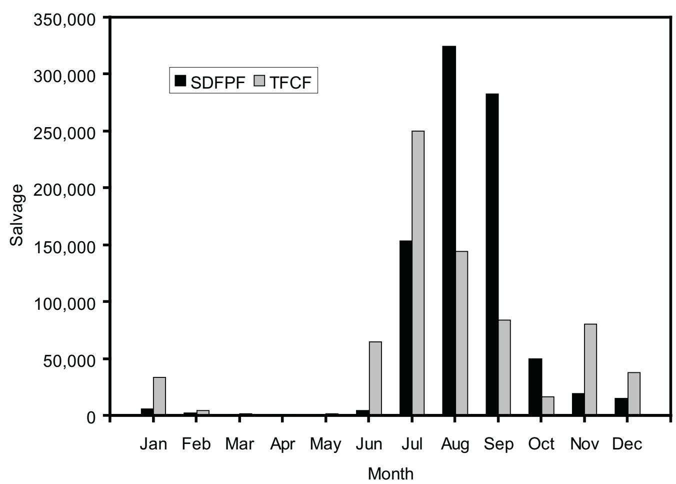

Figure 26 Monthly salvage of threadfin shad at the SDFPF and the TFCF, 2006

Results suggest that larger threadfin shad were salvaged at the TFCF however the assumption of equal variances was violated. At the SDFPF the threadfin shad lengths ranged from 20 -191 mm FL with a mean length of 56 mm FL (n = 11,921) with the 99th percentile estimated at 98 mm FL. At the TFCF threadfin shad lengths ranged from 20 – 192 mm FL with a mean length of 64 mm FL (n = 8,670) with the 99th percentile estimated at 115 mm FL. The 2 sample t-test results are t = -26.45 (df = 20,589), p < 0.0001. The folded form F statistic analysis suggested that the variances were unequal (F = 1.73 p < 0.0001 df, numerator = 8,669, df, denominator = 11,920). Log transforming of these data did not adequately address this situation (F = 1.51, p < 0.0001, df, numerator = 8,669 df, denominator = 11,920). Threadfin shad lengths greater than 200 mm FL (2 at the SDFPF and 4 at the TFCF) were excluded from the analysis.

Inland Silversides

Annual salvage of inland silversides (silversides) increased at the SDFPF and decreased at the TFCF in 2006 (Figure 27). The 2006 annual salvage at the SDFPF was 52,978 as compared to 18,162 in 2005. The 2006 annual salvage at the TFCF was 18,809 as compared to 22,686 in 2005.

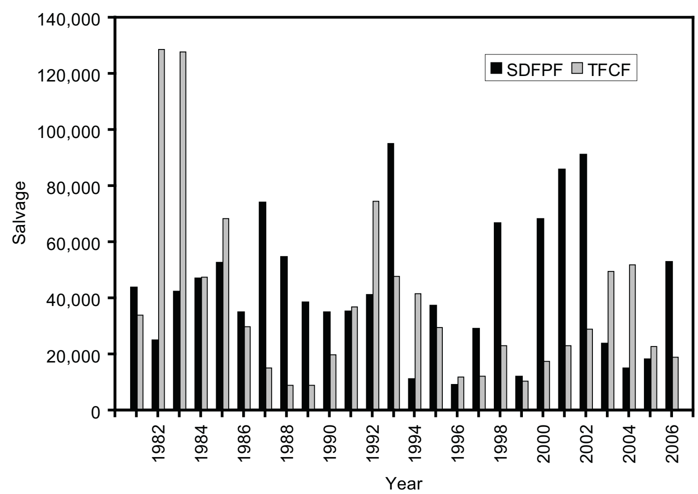

Figure 27 Annual salvage of inland silversides at the SDFPF and the TFCF, 1981 - 2006

The majority of silversides salvage occurred in July at both facilities (Figure 28). At the SDFPF, the July salvage of 36,695 accounted for 69% of the annual salvage. Excluding July, monthly salvage at the SDFPF ranged from 27 to 5,821. At the TFCF, the July salvage of 10,560 accounted for 56% of the annual salvage. Excluding July, monthly salvage at the TFCF ranged from 81 to 2,124.

Results suggest that TFCF salvaged larger silversides than the SDFPF however the assumption of equal variances was violated. At the SDFPF silversides lengths ranged from 20 – 98 mm FL with a mean of 39 mm FL (n = 1,633).

At the TFCF silversides lengths ranged from 20 – 102 mm FL with a mean of 46 mm FL (n = 378). Results of the 2 sample t-test are t = -7.21 (df = 2,009), p < 0.0001. The folded form F statistic analysis suggested that the variances were unequal (F = 1.72 p < 0.0001 df, numerator = 377, df, denominator = 1,632). Log transforming of these data did not adequately address this situation (F = 1.54, p < 0.0001, df, numerator = 377 df, denominator = 1632).

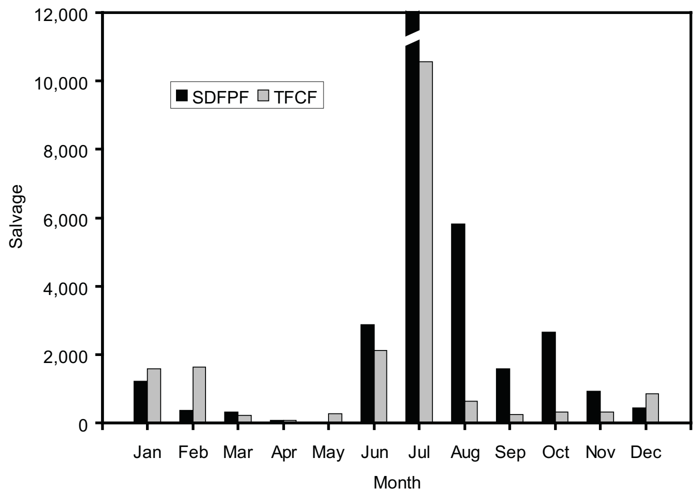

Figure 28 Monthly salvage of inland silversides at the SDFPF and the TFCF, 2006. The July salvage of 36,695 at the SDFPF has been truncated for scale considerations

Chinese Mitten Crabs

Only 12 mitten crabs were salvaged in 2006, all at the TFCF. No length or sex data is available. With the exception of 2001, mitten crab annual salvage has declined since 1999.

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CENTRAL VALLEY CHINOOK SALMON CATCH AND ESCAPEMENT

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In 2006, the ocean catch of Central Valley Chinook salmon south of Point Arena, California decreased in both the commercial and recreational fisheries to the lowest level in the 1970-2006 period of record. The catch per unit effort (CPUE) statewide also decreased to the lowest level since 1993.

The total escapement of Central Valley Chinook salmon was also the lowest since 1998 but remained above the average escapement for the 1970-2006 period of record. In 2006, the fall-run Chinook escapement to the Sacramento River system decreased from 2005 but was the greatest contributor to the Central Valley fall-run escapement. Spring-run total escapement to Mill, Deer, and Butte creeks also decreased from 2005 to 2006 while winter-run escapement increased slightly between 2005 and 2006 based on the mark-recapture carcass survey estimate.

Central Valley Chinook Ocean Harvest Index and Ocean Catch

The Pacific Fisheries Management Council (PFMC) sets spawner escapement goals for Sacramento River system fall-run Chinook and Klamath River fall-run Chinook. They also develop harvest regulations to protect listed Central Valley winter and spring-run Chinook. These include setting minimum size limits, gear restrictions and season restrictions south of Point Arena. In 2006, the PFMC did not have any specific restrictions for Central Valley fall-run since projected escapement exceeded the upper end of the conservation objective range (PFMC 2007). The restrictions for Sacramento River winter-run and Central Valley spring-run Chinook were similar to 2005. In 2006, the Northern California Coast Chinook escapement was projected to be below the minimum spawner escapement under the Klamath River Fall Chinook conservation objective; so, the PFMC adopted regulations that restricted harvest in California and Oregon (PFMC 2007). The combination of these regulations restricted harvest of all Chinook runs in California.

The PFMC's Central Valley Chinook ocean harvest index (OHI) is an approximate harvest rate. The OHI is calculated by dividing the total ocean catch south of Point Arena by the catch plus escapement. The ocean harvest index does not include inland harvest, which may be up to 25% of the returning adults. In 2006, the OHI decreased to 27% due to substantially decreased ocean harvest outpacing reduced escapement (Figure 1). The estimated Central Valley Chinook escapement decreased to approximately 317,000 spawners in 2006 (Figure 1).

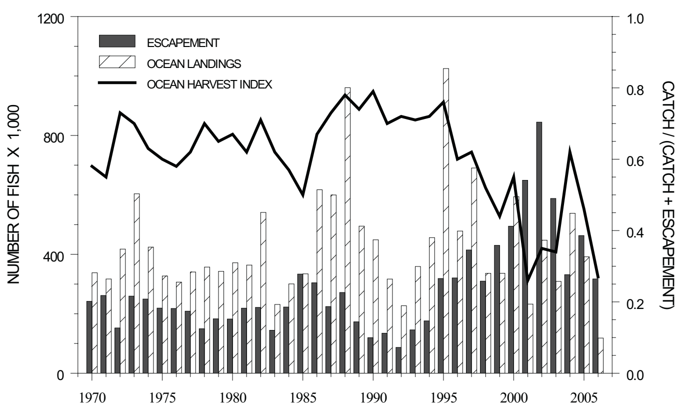

Figure 1 PFMC Chinook salmon ocean catch, the Central Valley Chinook total adult spawner escapement, and the ocean harvest index, 1970-2006

Statewide the ocean catch decreased between 2005 and 2006. For the commercial fishery, the number of days fished (boat days) decreased from 17,000 in 2005 to 8,200 in 2006 and the CPUE decreased from about 20.1 fish/day to 8.4 fish/day (Figure 2). The CPUE (fish/day) also decreased in Oregon and Washington. The CPUE for Washington remained above average for the 1970-2006 period of record but dropped below the average for Oregon and California for the first time since the early 1990's (Figure 2).

Pacific Northwest salmon numbers increased during the last period of cool, productive ocean conditions between 1999 and 2002 associated with the shift in the Pacific Decadal Oscillation (PDO) from the "warm" phase to the "cool" phase (Peterson 2006). However, in late 2002, ocean conditions reversed with warmer, less productive conditions for the last four years (Peterson 2006). Warmer water temperature is associated with weaker upwelling, delayed "spring transition", and reduced zooplankton biomass (DFO 2006). In addition to the reduced zooplankton biomass, the proportion of typical cold-water, or northern species, was low compared to the warm-water, or southern species. The northern species are lipid-rich species and these lipids are essential for many pelagic fishes for growth while southern species are smaller and have low lipid reserves (Peterson 2006). The combination of these factors reduces survival of Pacific salmon during their early marine periods (DFO 2006).

In California, the catch per unit effort (CPUE) peaked in 2003 in response to the increased salmon survival associated with the cool, productive ocean conditions from 1999 to 2002. However, the CPUE has been declining for the last three years with the CPUE in 2006 being the lowest since 1993. The 2006 CPUE is similar with the CPUE's observed during the last "warm" phase of the PDO which occurred from 1977 to 1998 (Figure 2). Therefore, the decrease in salmon survival associated with the warm, less productive ocean conditions of the last four years contributed to both the decrease in the CPUE and low Central Valley Chinook escapement observed in 2006.

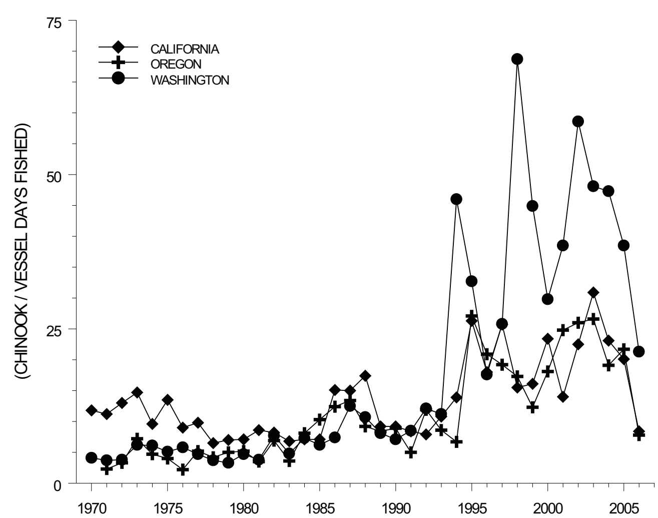

Figure 2 Commercial troll Chinook salmon catch per unit effort (estimated total number of fish caught / total number of boat days fished) in California, Oregon, and Washington, 1970-2006

Central Valley Fall-run Chinook Escapement

Escapement data reported to the PFMC are partitioned into “natural” and “hatchery” categories. Natural escapement includes all fish returning to spawn in natural areas (in other words, not in the hatchery) these fish are of both natural and hatchery origin. Available data indicate that hatchery-produced fish constitute a majority of the natural fall-run Chinook spawners in the Central Valley (PFMC 2007). Hatchery escapement includes all fish returning to the hatcheries; these fish are also of both natural and hatchery origin. These terms, as defined here, are used throughout this paper and in each of the figures.

In 2006, a spawner escapement goal of 122,000 to 180,000 Sacramento River system fall-run Chinook (hatchery and natural adults combined) guided PFMC management for this stock. The estimated number of spawners was approximately 278,200, exceeding the PFMC management goals, but below the projected escapement of 368,000 (Figure 3).

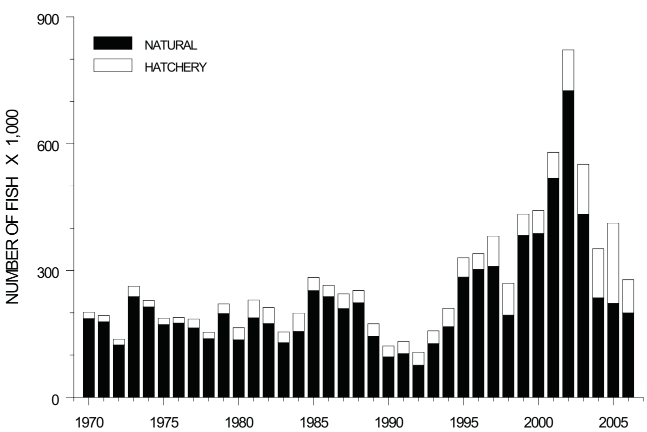

Figure 3 Annual natural and hatchery fall-run Chinook escapement to the Sacramento River and major tributaries, 1970-2006

Natural spawner escapement to the mainstem Sacramento River decreased from about 100,000 in 2005 to 89,000 in 2006 and remained below the average escapement for the 1970-2006 period of record (Figure 4). Natural spawner escapement in the American River decreased from about 56,800 in 2005 to 21,000 in 2006, the lowest escapement since 1992, but remained above the average escapement for the 1970-2006 period (Figure 4). In the Feather River, the estimated escapement increased from 48,500 in 2005 to 81,700 in 2006 and increased above the average escapement for the 1970-2006 period (Figure 4). The estimated Yuba River fall-run escapement decreased from 17,300 in 2005 to 8,100 in 2006, the lowest since 1993, and dropped below the average escapement for the 1970-2006 period of record (Figure 4).

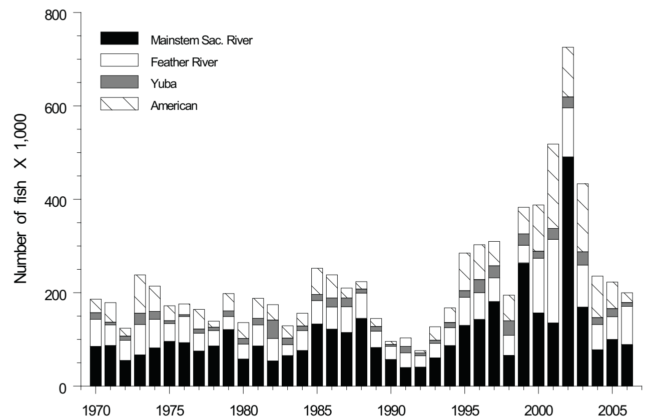

Figure 4 Annual natural fall-run Chinook escapement to the mainstem Sacramento River and major tributaries, 1970-2006

On the San Joaquin River system, the estimated natural spawner escapement decreased from about 17,400 in 2005 to 7,900 in 2006, the lowest escapement since 1995 and remains below the average escapement for the 1970-2004 period of record (Figure 5). In 2006, the hatchery spawners accounted for approximately 35% of the total escapement (Figure 5). The San Joaquin River system includes spawners from the Mokelumne, Stanislaus, Tuolumne, and Merced Rivers and has constituted less than 10% of the total Central Valley spawner escapement since 1986.

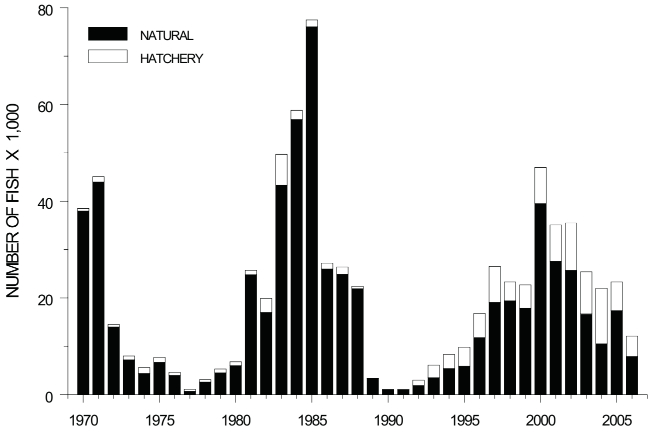

Figure 5. Annual natural and hatchery fall-run Chinook escapement to the San Joaquin River system, 1970-2005

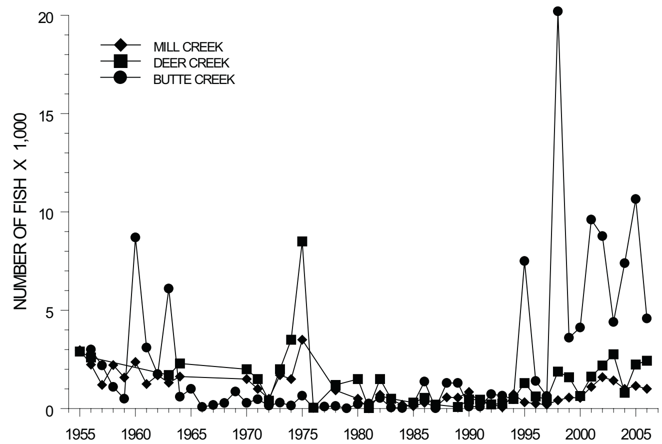

Figure 6 Annual spring-run Chinook escapement to Mill, Deer, and Butte creeks, 1995-2005

Sacramento River System Spring-run Chinook Escapement

In 2006, the escapement to Deer Creek increased to approximately 2,432 natural spawners (Figure 6). The number of spawners was lower than estimated 2,759 spawners from three years earlier (Figure 6). Spring-run Chinook salmon mature and spawn predominantly in a 3-year cycle, so comparisons to 3 years previous provide an indication of whether the year-class is replacing itself and trending up or not. The number of natural spawners decreased on Mill Creek with an estimated escapement of 1,002 which was also lower than estimated 1,426 spawners from three years earlier (Figure 6).

The Butte Creek escapement decreased from about 10,600 in 2005 to 4,600 in 2006 based on the snorkel survey methodology (Figure 6). The estimated escapement increased slightly from the estimated 4,400 spawners three years earlier. Based on the carcass survey, the escapement was approximately 6,300 spawners. The estimated escapement to Butte Creek continues to surpass the other spring-run tributaries and the mainstem Sacramento River (Figure 6).

Winter-run Escapement to the Sacramento River below Keswick Dam

DFG has been using the mark-recapture carcass survey data to estimate escapement since 2002. The estimated in-river escapement of winter-run Chinook increased from about 15,800 in 2005 to 17,200 in 2006 (Figure 7). The escapement was the highest total escapement estimated since 1981 and more than doubles the escapement from three years earlier (Figure 7). However, the number of adult females returning to spawn in 2006 was similar to the number of females in 2005.

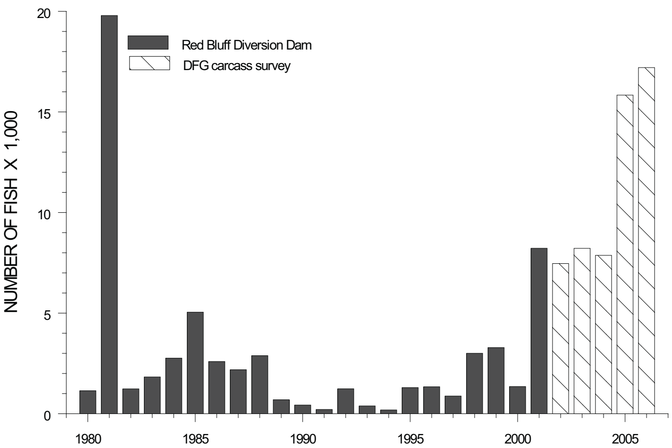

Figure 7 Annual winter-run Chinook escapement to the upper Sacramento River based on Red Bluff Diversion Dam data from 1980 to 2001 and DFG carcass survey data from 2002 to 2006

Escapement estimates based on extrapolated counts at Red Bluff Diversion Dam from 1967 through 2006 were examined for long-term population trends (Figure 8). The estimated escapement increased from approximately 5,300 in 2005 to 7,500 in 2006. A cohort replacement rate was calculated by dividing the sum of the current year's three-year olds and the previous year's two-year olds by the same values from three years earlier. This cohort replacement rate was 0.9 in 2006 based on Red Bluff Diversion Dam data (Figure 8).

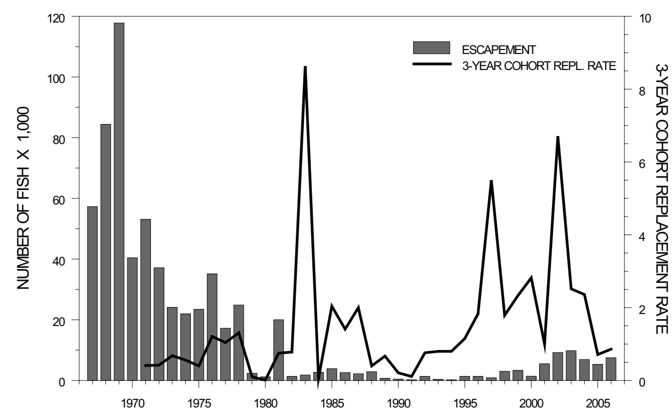

Figure 8 Annual winter-run Chinook escapement to the upper Sacramento River and the three-year cohort replacement rate, based on extrapolated counts at Red Bluff Diversion Dam, 1967-2006

Most of the data presented in this article is published in the PFMC's *Review of the 2006 Ocean Salmon Fisheries* and the PFMC's 2007 Preseason report. A copy of the report is available by calling (503) 820-2280 or on-line at www.pcouncil.org. I thank Colleen Harvey Arrison (DFG) for providing the spring run Chinook escapement data for Mill and Deer creeks and Tracy McReynolds (DFG) for providing the spring run Chinook escapement data for Butte Creek.

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CONTRIBUTED PAPERS

Specific-Conductance and Water-Temperature Data, San Francisco Bay, California, for Water Year 2005

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Introduction

This article presents time-series graphs of specific-conductance and water-temperature data collected in San Francisco Bay during water year 2005 (October 1, 2004, through September 30, 2005). Specific-conductance and water-temperature data were recorded at 15-minute intervals at seven U.S. Geological Survey (USGS) locations (Figure 1, Table 1).

Specific-conductance and water-temperature data from PSP and SMB sites (see Table 1 for complete site name) were recorded by the California Department of Water Resources (DWR) before 1988, by the USGS National Research Program from 1988 to 1989, and by the USGS–DWR cooperative program since 1990. BEN, CARQ, and MIC were established in 1998 by the USGS. CM1 initially was established in 1998 at Channel Marker 9 but was moved to Channel Marker 1 in 2003. The monitoring station, ALC, was established in 2003 by the USGS to replace the discontinued monitoring station San Francisco Bay at Presidio Military Reservation.

Data Collection

Specific-conductance and water-temperature data were collected at two depths in the water column (Table 1) to help define the vertical stratification. However, at the CM1 and ALC sites, data were collected only at mid-depth.

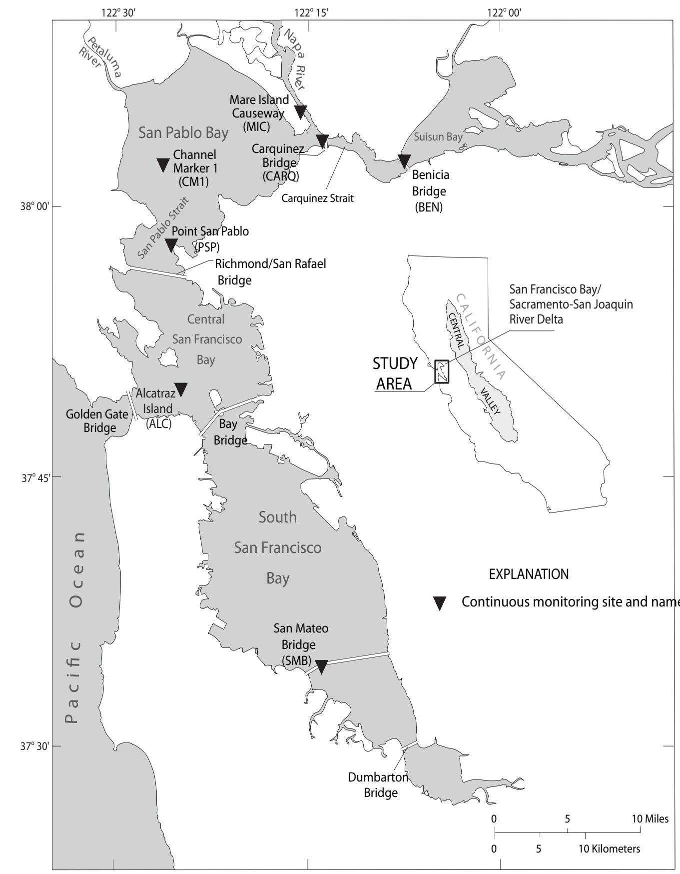

Figure 1 Location of continuous monitoring sites in San Francisco Bay, California, water year 2005

Several types of instrumentation were used to measure specific-conductance and water-temperature data in San Francisco Bay. Specific conductance [reported in microsiemens per centimeter at 25°Celsius (C)] was measured using either a Foxboro[1] electrochemical analyzer (calibrated accuracy ±0.5%), a Hydrolab Datasonde 4 multiprobe (conductivity cell calibrated accuracy ±0.5%) or a YSI 6920-M multi-parameter water quality logger (conductivity cell calibrated accuracy ±0.5%). Water temperature (reported in degrees Celsius) was measured using a Campbell Scientific thermister (accuracy ±0.2°C), a Hydrolab Datasonde 4 multiprobe (temperature probe accuracy ±0.2°C), or a YSI 6920-M multi-parameter water-quality logger (temperature probe accuracy

1. The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or California Department of Water Resources.

±0.2°C). The calibrated accuracies stated here are manufacturer specifications and do not reflect the accuracy of collected data. In an environmental monitoring program, potential sources of introduced error include but are not limited to electronic drift, calibration standard inconsistencies, and fouling of sensors.

Monitoring instrument calibrations were checked every 2–3 weeks. Calibration of the Foxboro specific-conductance instrument was checked by using an WTW model 197 conductivity meter (calibrated accuracy ±1%), which was calibrated to a known specific-conductance standard (direct checks against a known standard are not possible with the Foxboro large-bore probe because of the large volume of standard needed). Calibration of the Hydrolab and YSI specific-conductance instruments were checked by using a range of known specific-conductance standards. Calibration of the water-temperature instruments were checked by using a NIST traceable Cole Parmer thermister (accuracy ±0.2°C). Data corrections (necessary because of biological fouling or instrument electronic drift) were applied to the record following the guidelines described by Wagner and others (2000).

Data Presentation

Figures 2–7 show time-series graphs of the specific-conductance and water-temperature data measured at the seven sites in San Francisco Bay. Gaps in the data primarily are caused by equipment malfunctions and fouling. Tidal variability (ebb and flood) affects specific conductance and water temperature (Cloern and others, 1989; Ruhl and Schoellhamer, 2001). Tidal variability is greater in San Pablo Bay than in South San Francisco Bay (Schoellhamer, 1997). To illustrate tidal variability, Figure 8 shows the near-surface and near-bottom specific conductance and the corresponding water-level data at BEN for the 24 hours of August 6, 2005. The water-level data are not published or referenced to a known datum and are shown only to detail how specific conductance varies with tidal change.

Daily maximum and minimum values of specific-conductance and water-temperature data for the seven sites are published annually in the USGS California water data report series, which is available on the USGS website (http://ca.water.usgs.gov/archive/waterdata/; USGS, accessed March 5, 2007). The complete data sets through October 1, 2005, also are available (http://sfbay.wr.usgs.gov/sediment/cont_monitoring/index.html; USGS, accessed March 5, 2007).

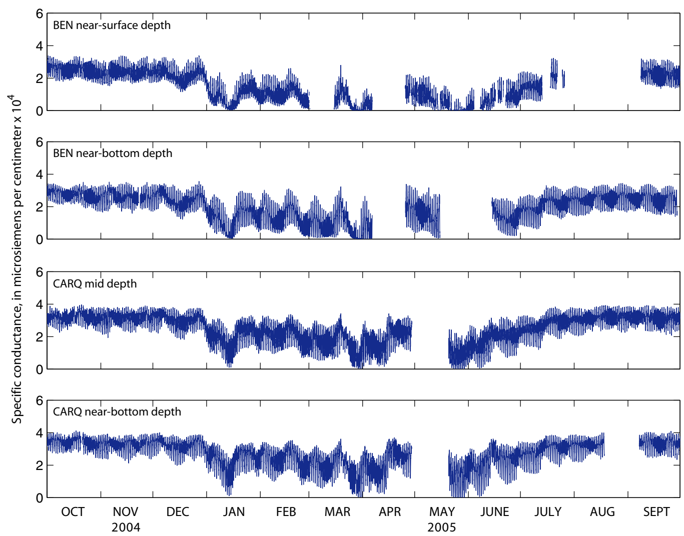

Figure 2 Measurements of specific conductance at Benicia Bridge (BEN) and Carquinez Bridge (CARQ), San Francisco Bay, water year 2005. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

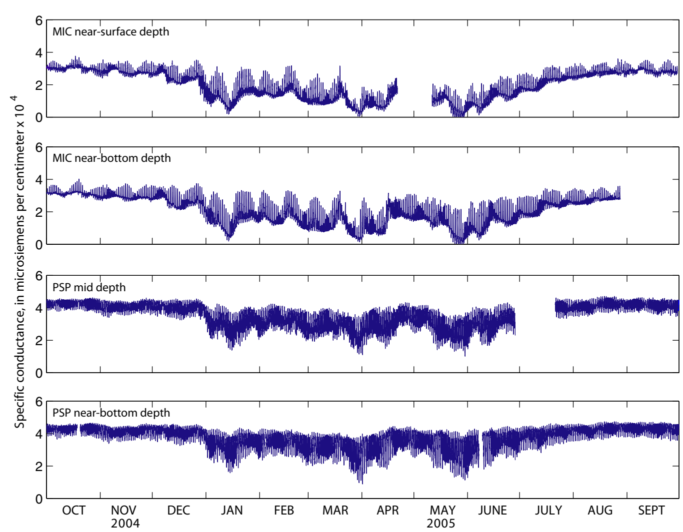

Figure 3 Measurements of specific conductance at Mare Island Causeway (MIC) and Point San Pablo (PSP), San Francisco Bay, water year 2005. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

Table 1 Sensor depths (in feet) below mean lower low water[1] (MLLW), San Francisco Bay, California, water year 2005

Site.	Abbreviation	Station No	Latitude	Longitude	Sensor depth	Depth belowMLLW	Water depth at MLLW
Suisun Bay at Benicia Bridge,near Benicia, Ca.	BEN	11455780	38°02'42"	122°07'32"	Near-surface Near-bottom	6 55	80
Carquinez Strait at Carquinez Bridge, near Crockett, Ca.	CARQ	11455820	38°03'41"	122°13'2326	Mid-depth Near-bottom	40 83	88
Napa River at Mare Island Causeway, near Vallejo, Ca	MIC	11458370	38°06'40"	122°16'25"	Near-surface Near-bottom	5 25	30
San Pablo Strait at Point San Pablo, Ca.	PSP	11181360	37°57'53"	122°25'42"	Mid-depth Near-bottom	13 23	26
San Pablo Bay at Petaluma River Channel Marker 1, Ca.	CM1	380240122255701	38°02'40"	122°25'57"	Mid-depth	4	8
San Francisco Bay at NE shore Alcatraz Island, Ca.	ALC	374938122251801	37°49'38"	122°25'18"	Mid-depth	6	16
South San Francisco Bay at San Mateo Bridge, near Foster City, Ca	SMB	11162765	37°35'04"	122°14'59"	Near-surface Near-bottom	4 38	48

1The mean lower-low water depth is the average of the lower-low water height above bottom of each tidal day observed during the National Tidal Datum Epoch (NTDE). The NTDE is the specific 19-year period (1960-1978 for values given in this report) adopted by the National Ocean Service as the official time segment during which tidal observations are made and reduced to obtain mean values (Hicks, 1983).

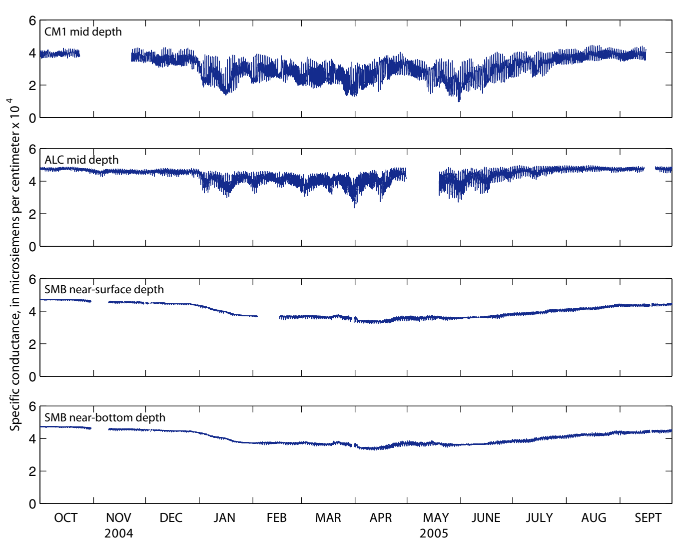

Figure 4 Measurements of specific conductance at Channel Marker 1 (CM1), Alcatraz Island (ALC), and San Mateo Bridge (SMB), San Francisco Bay, water year 2005

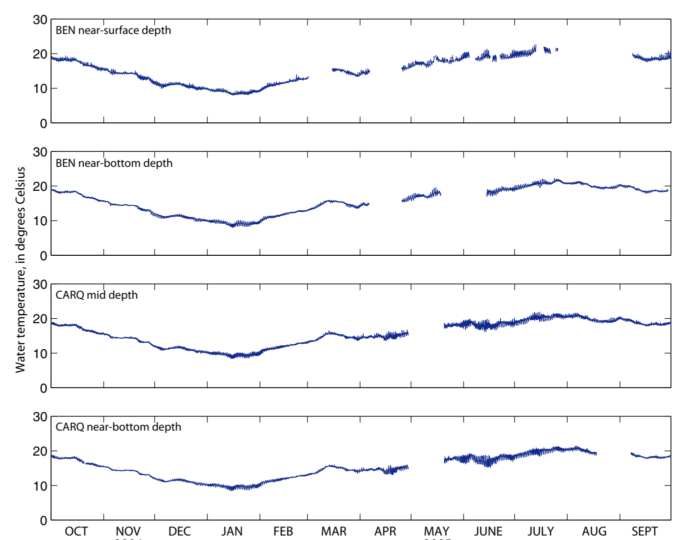

Figure 5 Measurements of water temperature at Benicia Bridge (BEN) and Carquinez Bridge (CARQ), San Francisco Bay, water year 2005

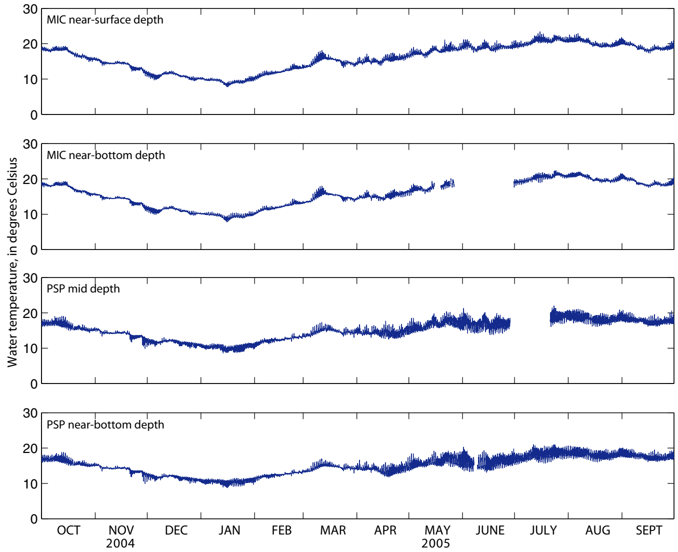

Figure 6 Measurements of water temperature at Mare Island Causeway (MIC) and Point San Pablo (PSP), San Francisco Bay, water year 2005

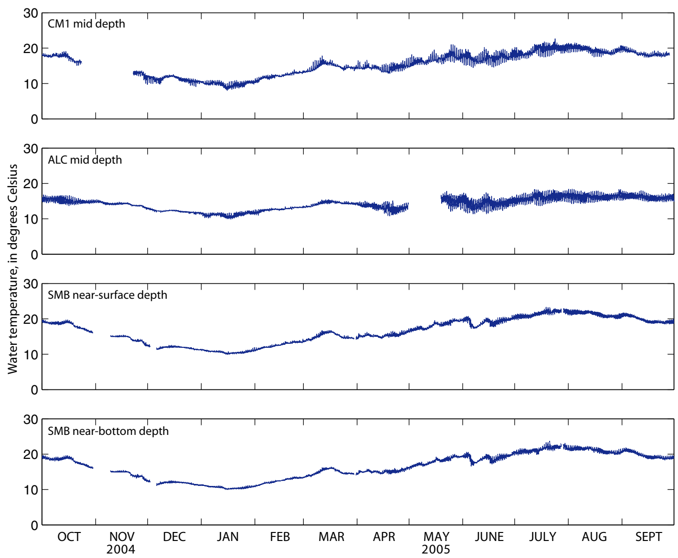

Figure 7 Measurements of water temperature at Channel Marker 1 (CM1), Alcatraz Island (ALC), and San Mateo Bridge (SMB), San Francisco Bay, water year 2005

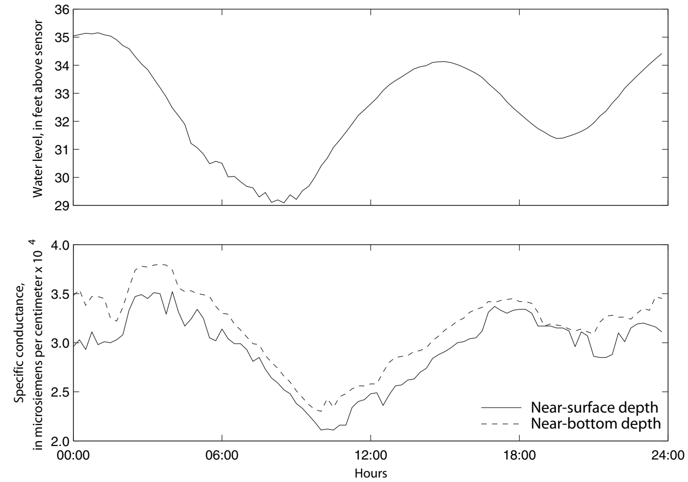

Figure 8 Near-surface and near-bottom measurements of specific conductance and water levels at Benicia Bridge, Suisun Bay, August 6, 2005. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

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