■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Of Interest to Managers

Randall D. Baxter (Department of Fish and Game), rbaxter@delta.dfg.ca.gov

Another important water parameter has been added to the DAYFLOW database, the daily location of X2. Brad Tom, Kate Le, and Chris Enright (pg. 3) report that X2 location and the other DAYFLOW parameters are now current through water year 2002 at www.iep.ca.gov/dayflow.

Two articles on low dissolved oxygen (DO) in the Stockton Ship Channel by James Guilianotti, Philip Giovannini, and Stephen Hayes (pgs. 3 and 5) describe the continuing problem in fall and the potentially more worrisome occurrence of an extreme DO drop in February 2003.

The core papers of this status and trends issue provide a mixed assessment of species responses to marine, river, and estuary conditions in 2002 as compared to previous years. Beginning at the bottom of the food web, Karen Gehrts (pg. 7) reports good levels of estuarine phytoplankton from late spring through early fall. At the next trophic level, zooplankton numbers in 2002 were similar to those of recent years, but generally greatly reduced from historic levels (Orsi and Mecum pg. 8). At the level of shrimp, crabs and fishes, species responses depended upon their life history and three strong responses were observed. First, those adapted to moderate to low-salinity, estuarine conditions and the young of anadromous species generally suffered declines (see Hieb, Greiner, and Slater pg. 14; Burmester pg. 27; Bryant and Souza pg. 37). Second, those species adapted to cool marine conditions have faired well since 2000 and again did well in 2002 (Hieb and others pg.14; Erin Chappell pg. 31). The third and last group includes both historically- and recently-introduced species whose abundance has been increasing (Dennis Michniuk pg. 23; Hieb and others pg. 14).

Steelhead salvage has been added by Steve Foss (pg. 40) to his annual assessment of fish salvage at the state and federal fish facilities. In future Status and Trends issues we hope to add more information to improve our assessment of trends in juvenile steelhead abundance.

Another potentially detrimental organism has been positively identified from San Francisco Bay. Julian Herndon, William Cochlan, and Rita Horner (pg. 46) confirm the identification of the Harmful Algal Bloom species, *Heterosigma akashiwo*, from Richardson Bay and report on four observed blooms. No fish mortalities were observed during the blooms but this is unlikely to be the end of the story.

The issue of whether the Chinese mitten crab can harbor Oriental lung flukes was investigated further by Andrew Cohen (pg. 48). His literature review indicates that the crab can in fact carry the lung fluke, but it is still not clear whether infected crabs have been imported and released, or if the fluke can complete its life cycle using the hosts available in the Sacramento-San Joaquin river system. The author argues these issues warrant further investigation.

In their report on cross-channel variability in benthic habitat and species composition, Marc Vayssières and Heather Peterson (pg. 51) point out that basic monitoring programs cannot always characterize the habitat and species variability present in a small geographic area and emphasize the need to periodically supplement long-term monitoring with additional sampling to address specific research or management questions.

Autumn Moreno (pg. 56) provides brief physical descriptions and observed ranges for jellyfish species currently identified from the estuary. Of particular concern is the potential impact to zooplankton and larval fishes of three species of small, non-native jellyfish now found in brackish water areas from the Petaluma River, Napa River and Carquinez Strait upstream into the western Delta (see also Rees, IEP Newsletter Vol 12 (3): 46-50).

IEP QUARTERLY HIGHLIGHTS

January-March 2003

DAYFLOW update

Brad Tom, Kate Le, Chris Enright (DWR), kle@water.ca.gov

The DAYFLOW database has been extended to include water year 2002. The data is now available at www.iep.ca.gov/dayflow. The daily location of X2 (km from the Golden Gate) has been added to the DAYFLOW calculation scheme.

DAYFLOW is a computer program developed in 1978 as an accounting tool for calculating historical Delta outflow and other internal Delta flows. DAYFLOW output is used extensively in studies by state and federal agencies, universities, and consultants.

X2 Background

The 1994 Bay-Delta agreement established standards for salinity in the estuary. Specifically, the standards determine the degree to which salinity is allowed to penetrate up-estuary, with salinity to be controlled through Delta outflow. The basis for the standards is a series of relationships between the salinity pattern and the abundance or survival of various species of fish and invertebrates. These relationships have been expressed in terms of X2, the distance (km) from the Golden Gate to the point where daily average salinity is 2 parts per thousand at 1 meter off the bottom (Jassby and others 1995) (Figure 1).

X2 Calculations

Autoregressive Lag Model

$X2(t) = 10.16 + 0.945X2(t-1) - 1.487\log(Q(t))$, where t = current day and t-1 = previous day

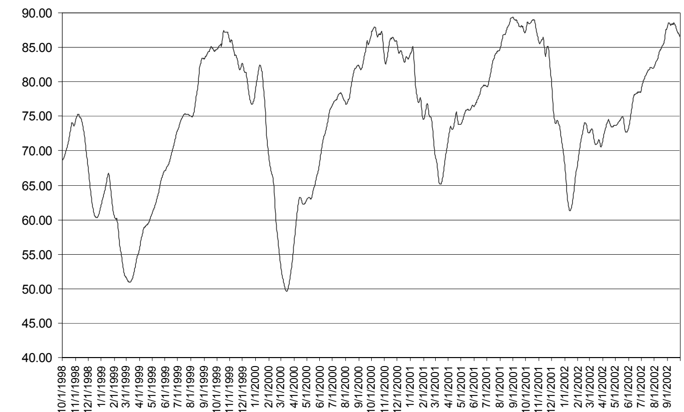

Figure 1 Historical X2 position, Water Years 1999-2002

Future Update

In the coming year, DAYFLOW output for WY 2003 will no longer include the parameter QXGEO, which is an estimate of Georgiana Slough and Delta Cross Channel flow. Since late fall 2001, actual flow measurements at the Delta Cross Channel have been added to the USGS flow monitoring network. This data will now be used directly in the computational scheme.

Reference

Jassby A, Kimmerer W, Monismith S, Armor C, Cloern J, Powell T, Schubel J, Vendlinski T. 1995. Isohaline Position as a Habitat Indicator for Estuarine Populations. Ecological Applications, 5(1):pp.272-289.

The Fall 2002 Stockton Ship Channel Dissolved Oxygen Special Study

James Giulianotti, Philip Giovannini, and Stephen P. Hayes (DWR), jgiulian@water.ca.gov

Dissolved oxygen (DO) levels within the Stockton Ship Channel (Channel) were closely monitored by staff of the Bay-Delta Monitoring and Analysis Section during late summer and fall 2002 to document the extent of a DO sag (an area within the Channel where DO levels drop to 5.0 mg/L or less) within the Channel. A DO sag historically develops within the eastern and central portions of the Channel during the late summer and early fall of most years. This DO sag is apparently due to high biological oxygen demand (BOD) exacerbated by low San Joaquin River inflows, warm water temperatures, reduced tidal circulation, and intermittent reverse flow conditions in the San Joaquin River past Stockton. Low DO levels can cause physiological stress to fish and inhibit upstream migration of salmon.

The studies also provide baseline data on Channel DO conditions that is used by management to determine if the Head of Old River Barrier (HORB), a temporary rock barrier across the mouth of the Old River, needs to be installed during periods of projected low fall outflow. The HORB increases net flows into the Channel from the San Joaquin River past Stockton. Finally, these studies document the effectiveness of the HORB in improving DO conditions within the Channel if the HORB is installed.

The HORB was installed on October 4, 2002, due to low fall flows in the San Joaquin River, and was removed on November 15, 2002, due to improved DO and flow conditions. Monitoring of DO levels in the Channel was conducted 8 times between August 20 and December 18, 2002, using the research vessel San Carlos. During each monitoring run, 14 sites were sampled from Prisoner's Point in the central Delta to the Stockton Turning Basin (Figure 1). DO and water temperature data were collected for each site at the top and bottom of the water column during ebb slack tide using traditional discrete (Winkler titration) and continuous monitoring (Seabird 9/ 11multiparameter sensor) instrumentation[1].

As in previous years, DO levels in the western Channel from Prisoner's Point to Columbia Cut (Light 14, Figure 1) were relatively high and stable throughout the monitoring season apparently due to strong tidal mixing. Surface DO levels ranged from 7.0 to 10.0 mg/L, and bottom levels ranged from 7.0 to 9.8 mg/L. DO concentrations dropped progressively within the central Channel from midway between Columbia and Turner Cuts (Light 18) to Fourteen Mile Slough (Light 34) and were more variable as sampling moved eastward. Both surface and bottom DO measurements ranged from 3.7 to 9.1 mg/L. Within the heart of this region, from west of Turner Cut (Light 19) to Light 34, surface and bottom levels dropped below 5.0 mg/L in October. Within the eastern Channel from Buckley Cove (Light 40) to the eastern end of Rough and Ready Island (Light 48), the DO sag was more pronounced. Through August and September, surface DO values within this region ranged from 3.3 to 8.8 mg/L, and bottom values ranged from 3.0 to 7.9 mg/L. The minimum bottom DO value of 3.0 mg/L was recorded at Light 40 on September 5 when water temperatures were warm (24.7-25.0 ºC) and San Joaquin River inflows past Vernalis were low (1,000 cfs).

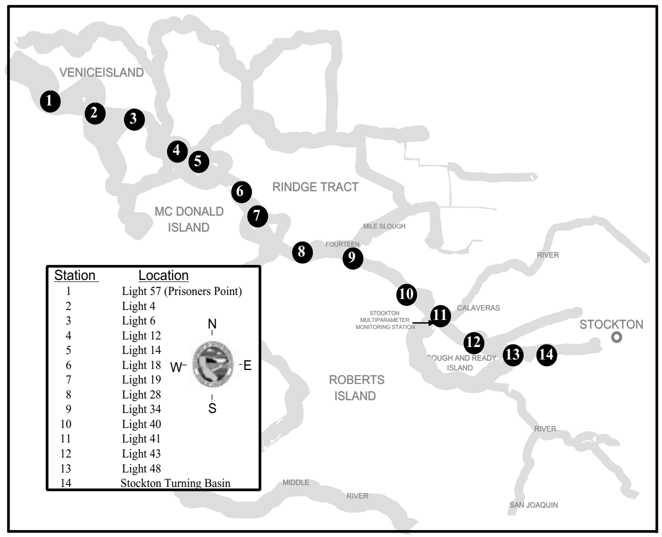

Figure 1 Monitoring sites in the Stockton Ship Channel

The low DO levels within the eastern Channel improved significantly in early October as surface DO levels ranged from 8.3 to 10.8 mg/L and bottom levels ranged from 7.4 to 8.9 mg/L. This increase coincided with improved San Joaquin River inflows to the Channel as a result of installation of the HORB, as well as an early winter storm that increased average daily flows past Vernalis from an average of 1,200 cfs in September to a peak of 2,400 cfs in October. By October 22 all DO levels were above 6.0 mg/L within the central Channel due, in part, to cooler water temperatures and higher inflows.

In late November, a bottom DO sag was detected from Light 40 to the middle of Rough and Ready Island (Light 43) within the eastern Channel. The sag intensified within this area by December 3; a minimum surface DO value of 3.6 mg/L was measured at Light 40 and a minimum bottom value of 3.3 mg/L was measured at the western end of Rough and Ready Island (Light 41). Apparently cooler water temperatures (13.7-14.6 °C in late November and 12.1-13.0 °C in early December) did

1. Monitoring by vessel is supplemented by an automated multi-parameter water quality recording station near Burns Cutoff at the western end of Rough and Ready Island.

not reduce BOD sufficiently to prevent a recurrent DO sag when inflows to the Channel dropped in mid- to late-November. Lower average daily flows of 1,500 cfs past Vernalis in the second half of November, in combination to the removal of the HORB on Nov 15, 2002, may have contributed to the return of the low DO levels in the eastern Channel.

Because DO levels within the eastern Channel had not recovered to above 5.0 mg/L, additional monitoring was conducted on December 18, 2002. Monitoring showed that DO levels throughout the western and central portions of the Channel were relatively robust and either approached or exceeded 6.0 mg/L. The persistent DO sag within the eastern Channel was reduced to a minimum bottom DO level of 4.9 mg/L measured at Light 41. Significantly cooler water temperatures (10.9-11.9 °C) and increased average daily flows past Vernalis of greater than 2,000 cfs appear to have contributed to the gradually improving DO conditions within the eastern Channel. While DO levels within the eastern Channel were below historical levels, the trend toward improvement was sufficient to terminate sampling.

Exceptionally Low Winter Dissolved Oxygen Conditions Detected in the Stockton Ship Channel March 2003

Philip Giovannini and Stephen P. Hayes (DWR), pgiovann@water.ca.gov

Bay-Delta Monitoring and Analysis Section staff conducted a mid-winter survey of dissolved oxygen (DO) conditions in the Stockton Ship Channel (Channel) on February 18, 2003, in response to low surface DO levels reported at the Rough and Ready Island Continuous Monitoring Station[1]. These findings were unexpected because cooler water temperatures and relatively high winter inflows to the Channel typically produce winter DO levels > 6.0 mg/L throughout the Channel.

DO levels within the Channel have been monitored by section staff during the late summer and fall since 1978[2] to document the occurrence and extent of DO sags (areas within the Channel with DO levels < 5.0 mg/L) that develop within the eastern and central portions of the Channel during most years. These DO sags are apparently related to low San Joaquin River inflows, warm water temperatures, high biological oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow conditions in the San Joaquin River at Stockton. Previously, DO sags have not been observed in the Channel during the winter months, when these conditions are less prevalent.

In response to the low DO levels detected in early February 2003 at the Continuous Monitoring Station and fish kills reported within the Channel, section staff conducted a monitoring study February 15, 2003, in the Channel at low water slack using the DWR monitoring vessel San Carlos. Monitoring of DO levels was conducted at 14 sites at Prisoner's Point in the central Delta, at the western end of the Channel, and to the Stockton Turning Basin at the eastern terminus of the Channel (Figure 1). DO and water temperature data were collected for each site at the top and bottom of the water column using traditional discrete (Winkler titration) and continuous instrumentation monitoring (Seabird 9/11 multiparametric sensor).

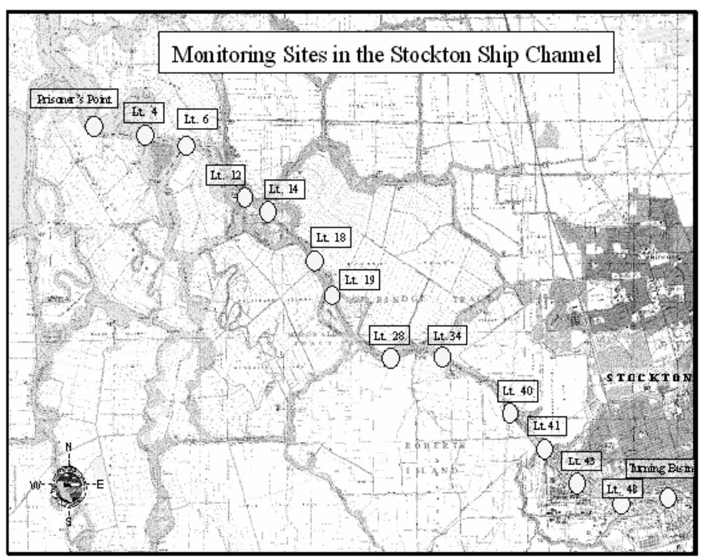

Figure 1 Monitoring Sites in the Stockton Ship Channel.

1. The Department of Water Resources operates an automated multi-parametric water quality recording station in the Stockton Ship Channel near the western end of Rough and Ready Island.

2. Funding for these Special Studies is provided by the Department of Water Resources, Division of Operations and Maintenance.

The results of the study (Figure 2) confirmed the findings recorded at the Continuous Monitoring Station. Surface and bottom DO levels in the western Channel from Prisoner's Point to Columbia Cut (Light 14) were robust at > 9.0 mg/L due to tidal mixing and relatively cool water temperatures (11-12 °C). Within the central Channel, surface and bottom DO levels dropped from > 8.0 mg/L west of Turner Cut (Light 18) to 3.0 mg/L at the surface and 2.0 mg/L at the bottom at Fourteen Mile Slough (Light 34). Within the eastern portion of the Channel from Buckley Cove (Light 40 [Station P8]) to the middle of Rough and Ready Island (Light 43), DO levels were strikingly low at the surface (< 3.0 mg/L) and at the bottom (< 2.0 mg/L). DO minima of 1.4 mg/L at the surface and 0.2 mg/L at the bottom were measured at the western end of Rough and Ready Island (Light 41).

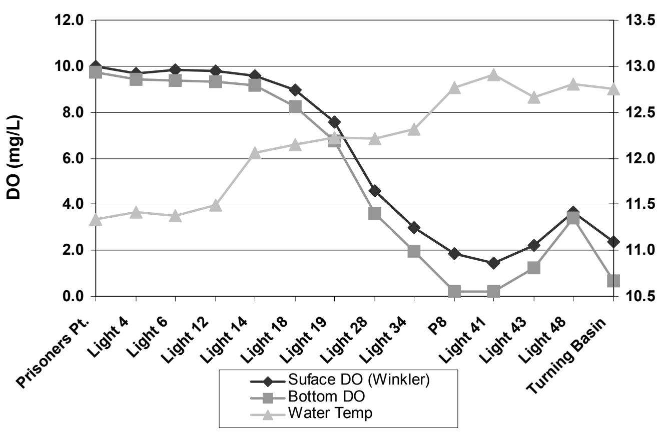

Figure 2 DO and water temperature in the Stockton Ship Channel, 2/18/03

Samples for BOD analysis were obtained from six sites from Light 19 to the Turning Basin. BOD_5 test results show levels between 22 and 29 mg/L[1], with the highest level occurring at Light 40. These BOD levels indicate the presence of a significant amount of biodegradable organic material in the water column, and are consistent with the high levels of phytoplankton biomass recorded at the Continuous Monitoring Station.

Fluorometric data recorded at the Continuous Monitoring Station (near light 41, Figure 1) throughout February showed chlorophyll *a* fluorescence at 1 meter depth increasing inversely with declining DO levels through mid-February (Figure 3). Thereafter, fluorescence declined as DO levels began to rise. The high mid-month fluorometric values indicate the presence of a high phytoplankton biomass in the water column. Because section staff detected surface DO levels as low as 1.4 mg/L at midday under sunny skies on February 18, it appears that minimal net oxygen was being produced from photosynthesis. The lack of DO stratification within the Channel also indicates that little or no net algal DO production was occurring in the photic zone. Discrete chlorophyll *a* samples are being analyzed for pheophytin components to provide a further indication of the physiological condition of the phytoplankton present. Further studies are anticipated.

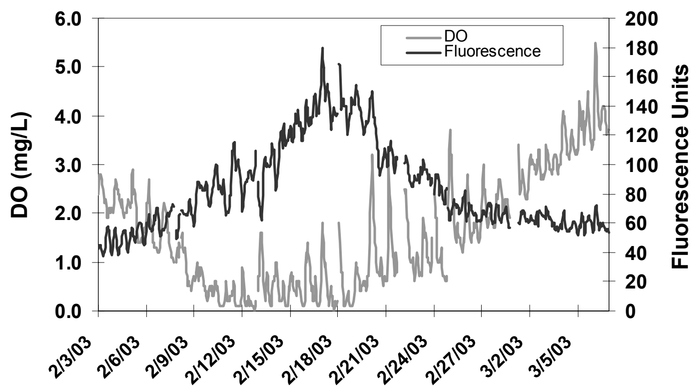

Figure 3 DO and fluorescence data from the Continuous Monitoring Station at Rough and Ready Island

1. BOD_5 analysis of water samples was performed at Sequoia Analytical Laboratories, Sacramento, CA, according to EPA method 405.1. The BOD_5 test is the standard measure for biochemical oxygen demand. The "5" refers to the number of days the sample was incubated.

Status and Trends

Chlorophyll *a* and Phytoplankton, 2002

Karen Gehrts (DWR), kagehrts@water.ca.gov

Chlorophyll *a* and phytoplankton samples were collected at 11 stations throughout the upper San Francisco Estuary. Chlorophyll *a*—used as an estimate of phytoplankton biomass—was filtered from samples using a fiberglass filter with a 47 mm diameter and 1.0 µm pore size at a pressure of 10 inches of mercury. Chlorophyll *a* extractions were completed at Bryte Laboratory according to *Standard Methods for the Examination of Water and Wastewater, 20th ed. 1998.* Phytoplankton identification and enumeration was also performed at Bryte Laboratory using the Utermohl inverted microscope method.

Percent chlorophyll *a* concentration is used as an indicator of an actively increasing phytoplankton biomass. The percentage of chlorophyll *a* increases during the initial stages of a phytoplankton bloom when cell division is exponential and decreases during the decline phase of the bloom when the pigment breakdown products increase. Percent chlorophyll *a* concentration is computed as the ratio of chlorophyll *a* concentration to chlorophyll *a* plus pheophytin concentration multiplied by 100%.

The percent chlorophyll *a* concentrations during late spring, summer, and early fall 2002 were well above 60% at most monitoring sites. The relatively high percentage of chlorophyll *a* indicates that plankton were increasing throughout the upper San Francisco Estuary during this period. Chlorophyll *a* concentrations for 2002 were below 10 µg/L for all regions except the southern Delta. Concentrations commonly ranged between 0.5 µg/L and 6.0 µg/L throughout the estuary. The maximum chlorophyll concentrations occurred during spring and were followed by smaller peaks in early summer at all stations, except those in the South Delta. The maximum chlorophyll concentration for the South Delta occurred during the late summer: 118.0 µg/L measured during August at Vernalis. This peak was well above the high of 62.6 µg/L recorded there in July 2001. Chlorophyll *a* maxima for the North Delta, Suisun, and San Pablo Bay regions occurred during February and March. The maxima for the lower Sacramento River, lower San Joaquin River, Central Delta, and East Delta regions occurred during April and June. The South Delta region was unique with a maximum biomass increase during August.

Phytoplankton species composition changes seasonally in response to many variables. Possible variables include availability of nutrients and light, extent of inflows and salinity intrusion, and the suitability of water temperature. Diatoms dominated the spring chlorophyll *a* maximum, and flagellates and diatoms dominated the summer maximum in the North Delta, lower Sacramento River, lower San Joaquin River, Central Delta, and the East Delta. The South Delta spring maximum was dominated by the diatoms *Melosira granulata, Skeltomema potamos,* and *Thalassiosira eccentrica*. The fall chlorophyll maximum was dominated by unidentified flagellates, the diatom *Cyclotella sp*., the green alga *Ankistrodesmus falcatus,* and the cryptomonad *Cryptomonas sp*. Unidentified flagellates and the diatoms *Cyclotella glomerata* and *Skeletoma potamos* dominated the spring chlorophyll *a* peak. Unidentified flagellates, the dinoflagellate *Glenodinium quadridens*, and the diatoms *Cyclotella sp*. and *Achnanthes delicatula* dominated the summer peak in the Suisun and San Pablo Bay regions.

Benthic Monitoring, 2002

Karen Gehrts (DWR), kagehrts@water.ca.gov

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

Benthic monitoring is conducted at 10 sampling sites distributed throughout the major habitat types within the estuary from San Pablo Bay through the Delta. Compliance Monitoring Program staff collected 4 bottom-grab samples and 1 sediment sample monthly at all sites. The grab samples are analyzed in the laboratory to identify organisms to genus (and to species when possible), and to enumerate all organisms collected. The field methodology for the collection of benthic macroinvertibrates is summarized in *Standard Methods for the Examination of Water and Wastewater, 20th ed. 1998.*

As a result of the environmentally diverse sampling regime, ten new organisms were added to the benthic species list in 2002. These species were new to our collections, not to the estuary. The list of new species and the locations where they were collected are as follows:

San Pablo Bay (a saline to brackish-water site west of the Delta)

- A crustacean, *Cragnon nigromaculata,* in January
- A spionid, *Pseudopolydora paucibranchiata,* in March
- A sabellide polychaete, *Myxicola infundibulum,* in September
- An amphipod, *Paradexamine sp. A*, in October
- A spionid, *Boccardia sp. A,* in November
- A spionid, *unidentified Spionid sp. A,* also in November
- A spionid, *Polydora branchycephala,* also in November
- A polychaete, *Glycera Americana,* in December

Grizzly Bay (A saline to brackish-water site west of the Delta)

- A crustacean, *Anisogammarus confervicolus,* in February

Buckley Cove (A freshwater site along the Stockton Deep Water Ship Channel near the city of Stockton)

- A chironomide, *Dicrotendipes sp. A,* in February

Of the 166 species of benthic macrofauna collected in 2002, ten species represented approximately 90% of all organisms collected. These ten species include: (1) the amphipods *Americorophium stimpsoni*, *Americorophium spinicorne*, *Corophium alienense, Monocorophium acherusicum, Ampelisca abdita*, and *Gammarus daiberi*; (2) the aquatic oligocheates *Varichaetadrilus angustipenis* and *Limnodrilus hoffmeisteri*; and, (3) the Asian clams *Potamocorbula amurensis* and *Corbicula fluminea*.

Of the ten dominant species, *Ampelisca abdita* and *Potamocorbula amurensis* represent macrofauna that inhabit a more saline environment; they were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *Americorophium stimpsoni* and *Americorophium spinicorne* tolerated a wider range of salinity. They were collected in the more saline western sites, as well as the more brackish to freshwater eastern sites such as the San Joaquin River at Twitchell Island and the Sacramento River above Point Sacramento. The remaining six species are predominantly freshwater species and were collected at sites east of Suisun Bay.

Zooplankton Status and Trends

Jim Orsi, DFG (retired) and Lee Mecum (DFG), lmecum@delta.dfg.ca.gov

The term zooplankton includes animals of varying lengths–copepods which average 1.0-1.2 mm for adults, cladocerans, 0.6-2.0 mm, and rotifers, 0.1-0.2 mm. Mysid shrimp are considered to be macrozooplankton and range from 2 to 18 mm in length. All of the native zooplankters have decreased in abundance since they were first monitored in 1968 (mysids) or 1972 (other groups). In addition, many non-indigenous copepods and several mysids have been introduced to the estuary. The general picture of greatly reduced abundance compared to baseline conditions did not change in 2002, although some taxa did increase.

Copepods

Since its introduction in 1993—shortly before its congener *Limnoithona sinensis* disappeared from the estuary delta—the cyclopoid copepod *Limnoithona tetraspina* has been numerically the most abundant copepod, having mean seasonal abundances > 10,000/m^{-3} (Figure 1). In 2002 its abundance increased somewhat in all three seasons (spring, summer, and fall) as compared to 2001. The long-term trends show that abundance has been lowest and most variable in spring and highest in fall.

Eurytemora affinis, an introduced calanoid copepod that has been in the estuary since prior to the start of monitoring, has shown abundance downtrends in all seasons, especially in summer and fall (Figure 2). The downtrends were gradual prior to 1986, then became steep. The cause is believed to be competition for food and predation by the Asian clam, *Potamocorbula amurensis*. Since 1992 an uptrend in summer is apparent.

Pseudodiaptomus forbesi, an introduced calanoid copepod, entered the estuary at about the time the Asian clam became abundant in Suisun Bay in 1989 (Figure 2). There has been a strong and variable downtrend in spring since 1992 and weaker downtrends in summer and fall since 1989. The causes are unknown. *Psuedodiaptomus forbesi* has been generally about as abundant as *E. affinis* was in the 1970s.

Several native species of the calanoid copepod, *Acartia*, enter Suisun Bay and the delta from the lower bays. Abundance has been positively correlated with salinity but fall abundance was markedly low from 1987 to 2001, and summer abundance was unusually low from 1994 to 2001 with the exception of 1999 (Figure 3).

Acartiella sinensis is an introduced brackish water calanoid copepod that is most abundant in Suisun Bay. Its spring abundance has been very variable and showed a sharp rise in 2002 after three years of very low abundance (Figure 3). It has been more abundant in summer than in spring, but 1999 and 2000 were very low years in both spring and summer. Abundance has been highest in fall but showed the same dip in abundance from 1998 to 2000 that occurred in other seasons.

The calanoid copepod genus *Diaptomus* (actually *Acanthodiaptomus*) contains several native freshwater species. Its abundance was lowest in spring and highest in summer in the early 1970s (Figure 4). After 1978 its summer and fall abundance experienced a strong downtrend, but spring abundance showed a much smaller decline.

Sinocalanus doerrii is an introduced freshwater calanoid copepod which was most abundant in summer and fall in the early 1980s (Figure 4). Long-term declines occurred in these seasons, culminating in low points in the mid-1990s. Since then abundance has increased somewhat. Spring abundance has been variable and without trends.

Cyclops (actually *Acanthocyclops*) contains several native freshwater cyclopoid species. It has experienced consistent downtrends in all seasons since the 1970s, but showed some recovery in summer in the late 1990s and 2000s (Figure 5).

Cladocerans

Cladocerans contain primarily the genera *Bosmina*, *Daphnia*, and *Diaphanosoma*. They are all native freshwater organisms that have shown downtrends since the early 1970s in all seasons, especially in fall (Figure 6). Summer abundance seems to have stabilized since the late 1980s.

Rotifers

The native brackish water rotifer, *Synchaeta bicornis,* is most abundant in summer or fall and has shown a long-term decline from its peak in the early 1970s (Figure 7). Other rotifer species have also undergone long-term declines since the early 1970s (Figure 8). The decline appears to have been least in spring.

Mysid shrimp

The native mysid shrimp, *Neomysis mercedis*, suffered a population collapse in all seasons starting after 1986 (Figure 9). This was probably caused by predation and competition from the Asian clam, *Potamocorbula sinensis*. Abundance was extremely low in 2001 and 2002. None were taken in spring and fall 2002.

The introduced mysid, *Acanthomysis bowmani*, has been much more abundant since its introduction than *N. mercedis* but has not been as abundant as *N. mercedis* was in the 1970s and early 1980s (Figure 9). Its abundance has been very variable in spring and summer with indications of uptrends. In fall it rose smoothly to a peak in 1999 and declined thereafter.

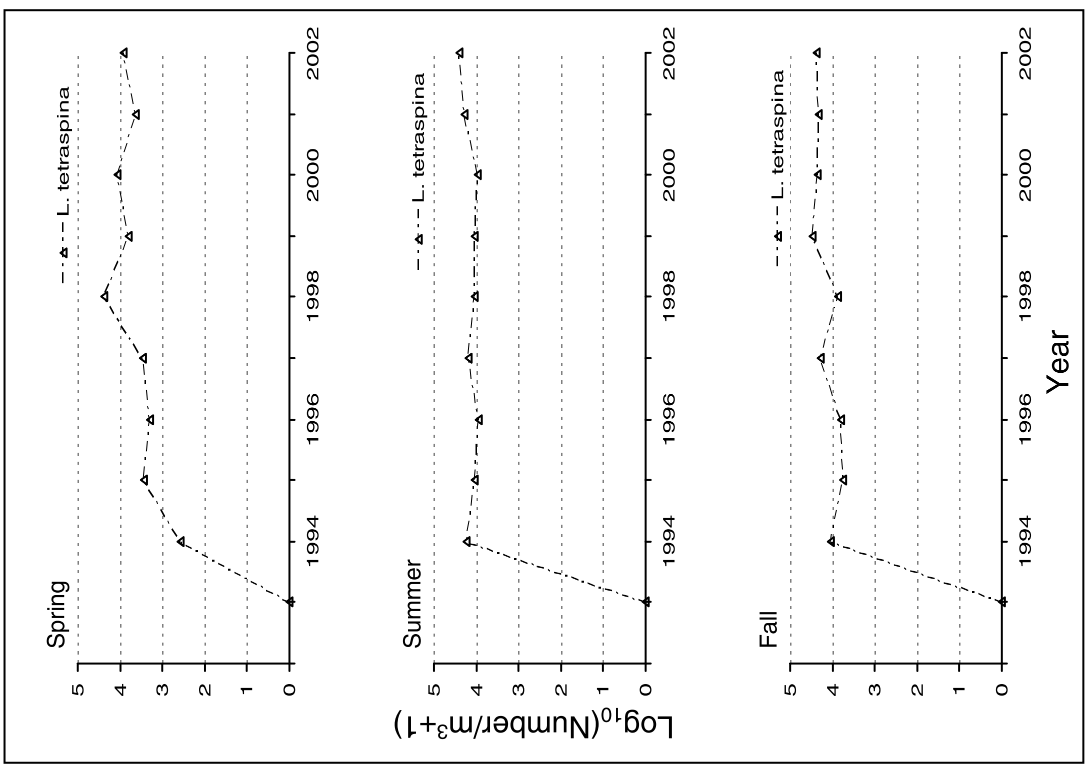

Figure 1 Log of mean abundance of *Limnoithona tetraspina* in spring, summer, and fall, 1993-2002.

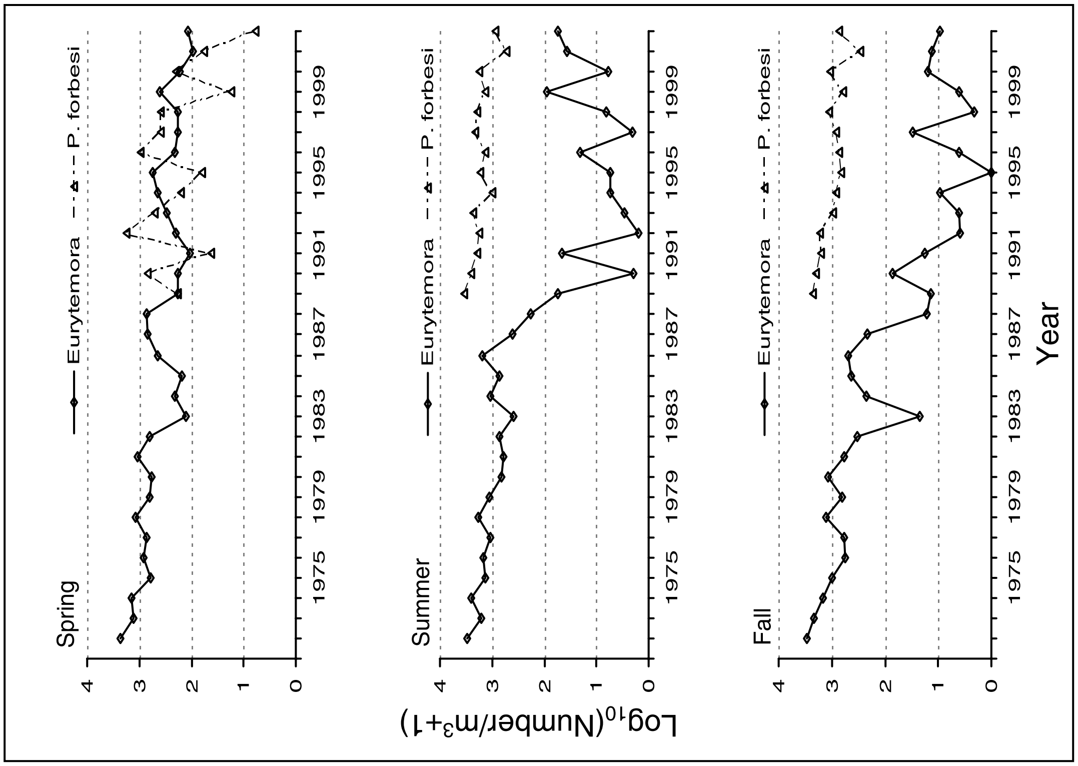

Figure 2 Log of mean abundance of *Eurytemora affinis* and *Pseudodiaptomus forbesi* in spring, summer, and fall, 1972-2002.

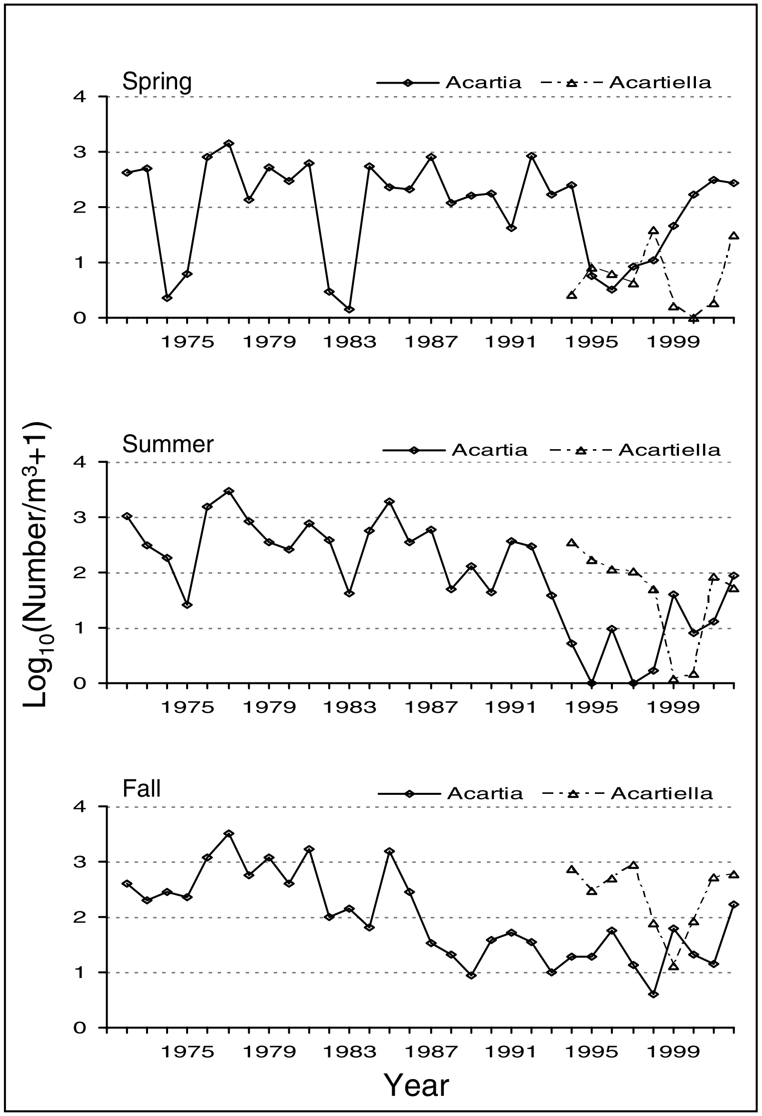

Figure 3 Log of mean abundance of *Acartia* spp. and *Acartiella sinensis* in spring, summer, and fall, 1972-2002.

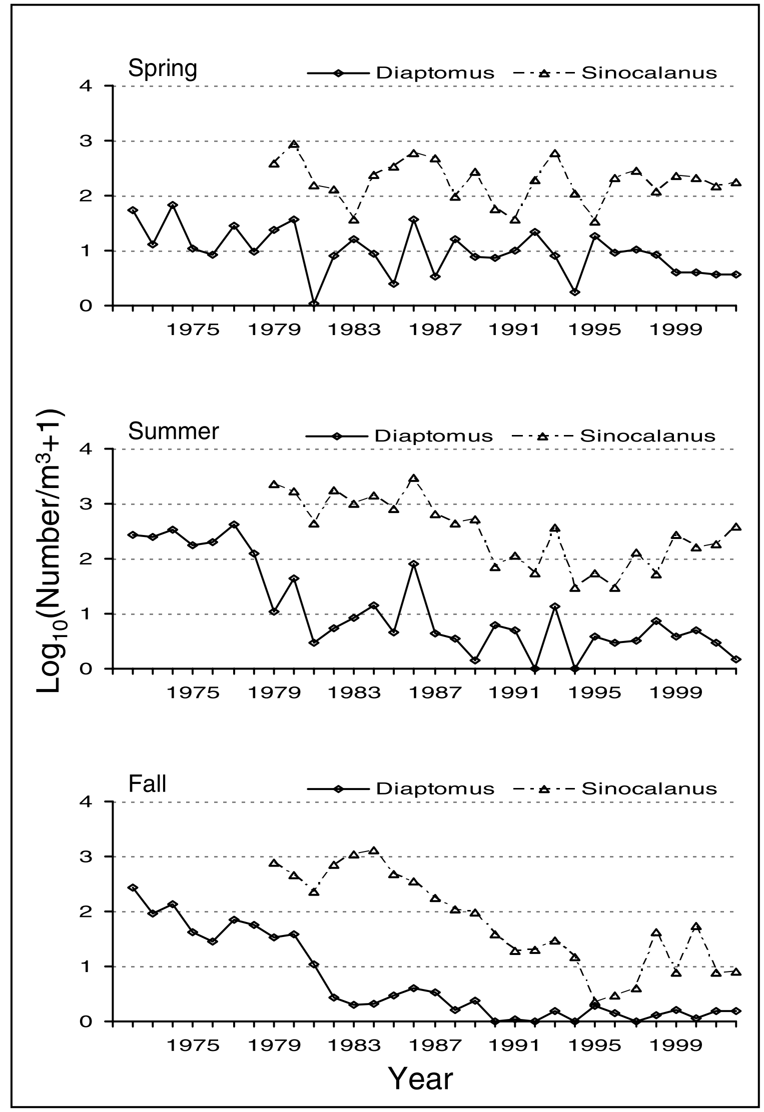

Figure 4 Log of mean abundance of *Diaptomus* spp. and *Sinocalanus doerrii* in spring, summer, and fall, 1972–2002.

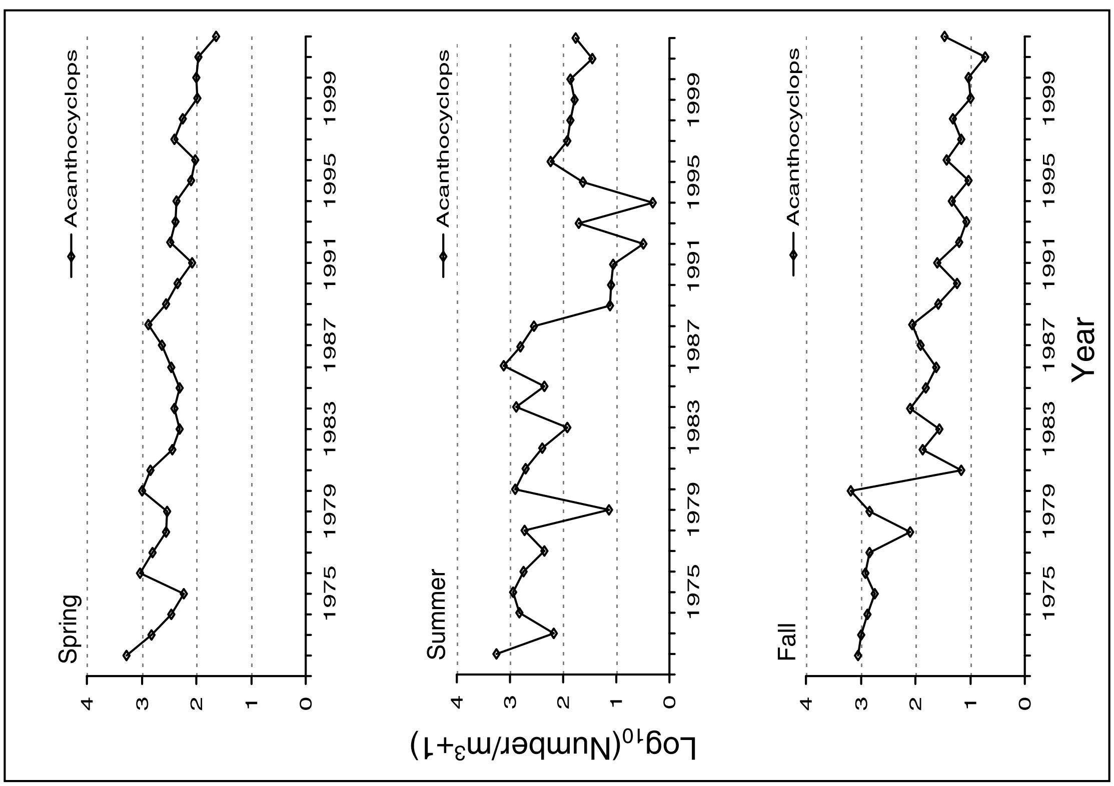

Figure 5 **Log of mean abundance of *Acanthocyclops* spp. in spring, summer, and fall, 1972-2002.**

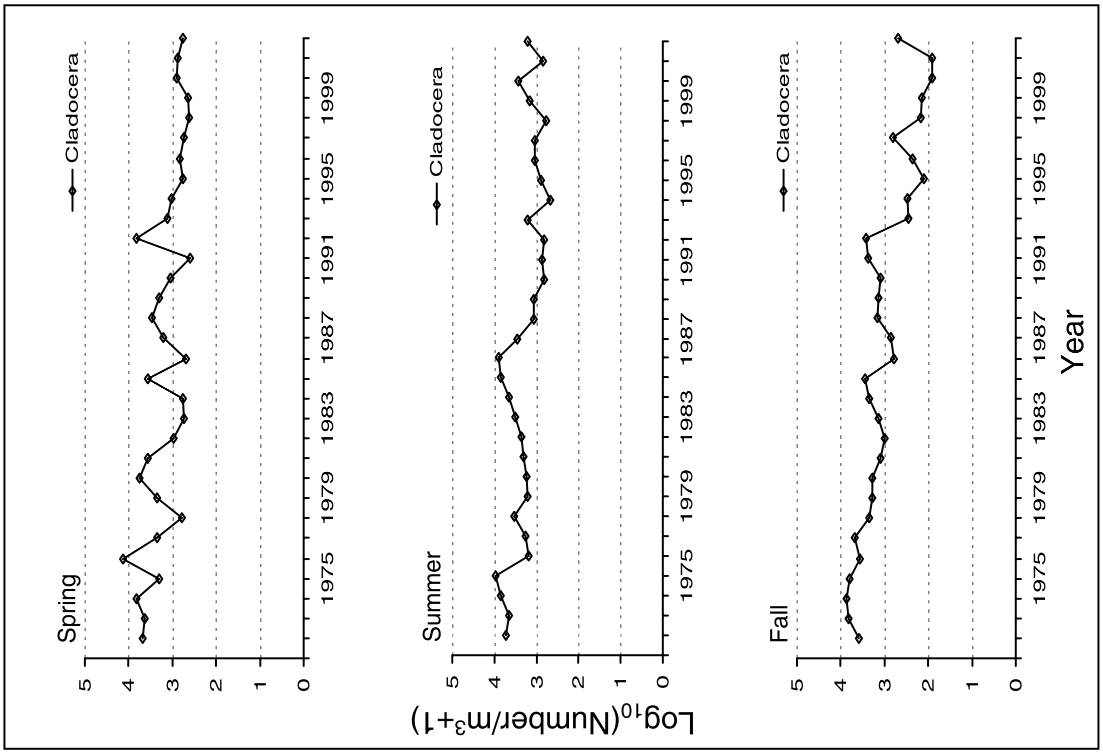

Figure 6 **Log of mean abundance of *Cladocera* in spring, summer, and fall, 1972-2002.**

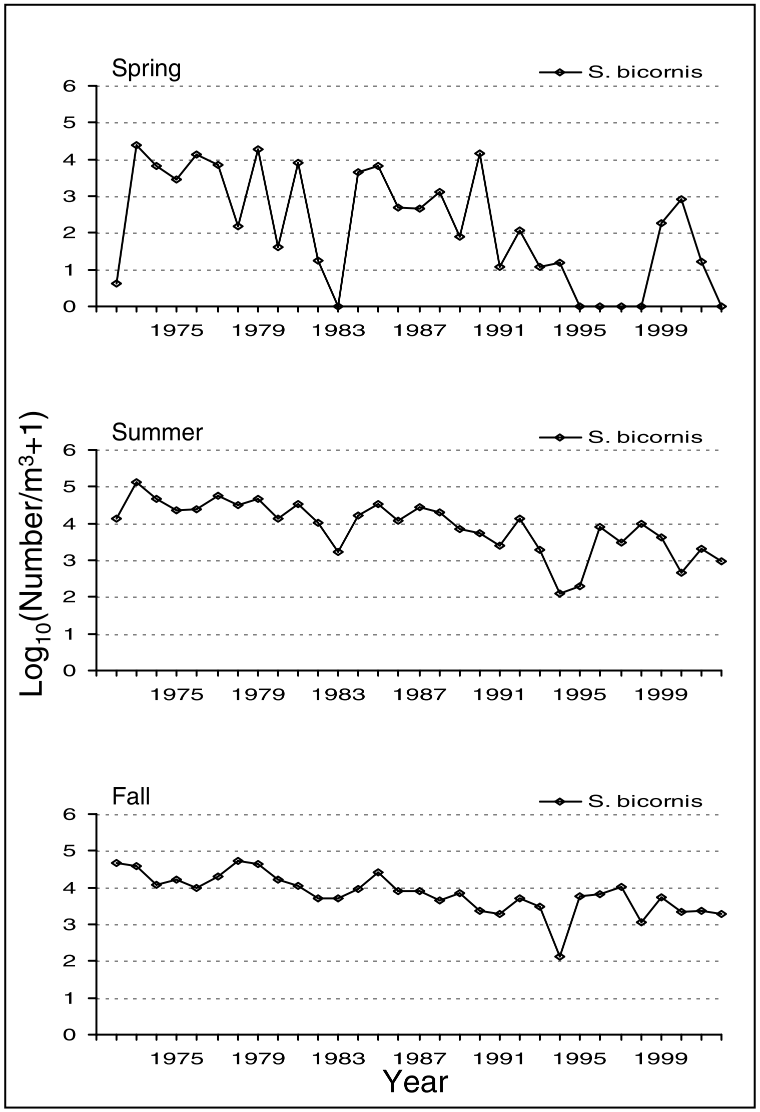

Figure 7 Log of mean abundance of *Synchaeta bicornis* in spring, summer, and fall, 1972-2002.

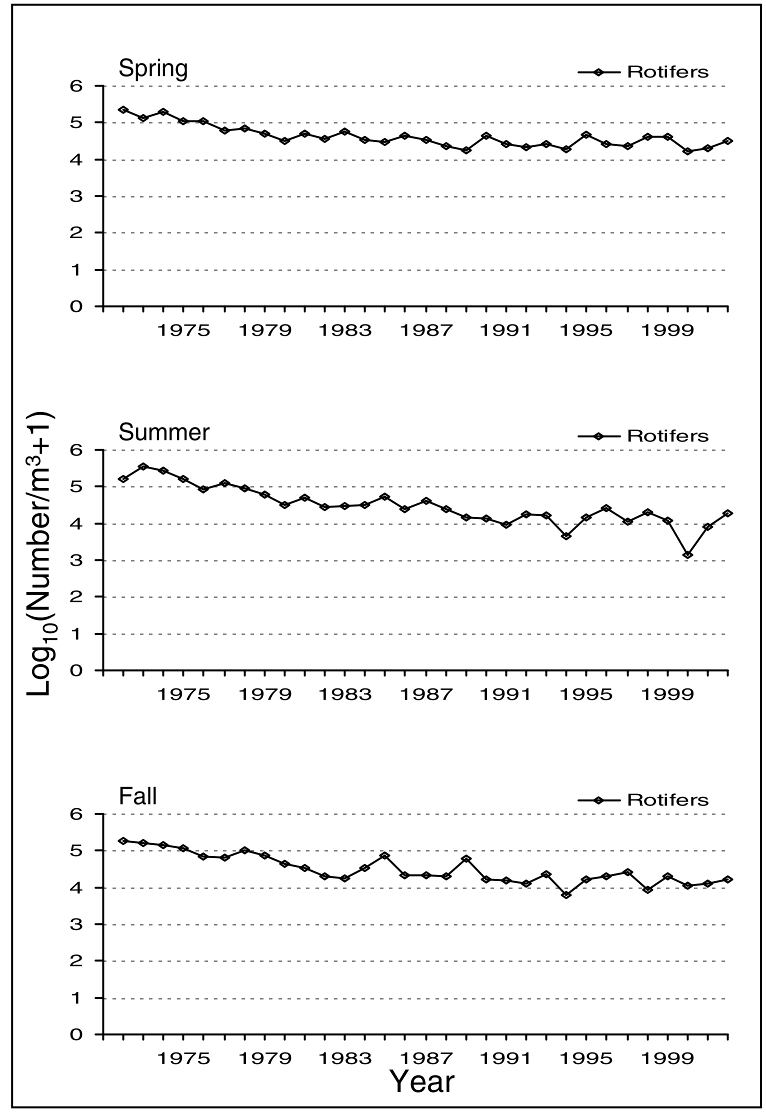

Figure 8 Log of mean abundance of rotifers other than *Synchaeta bicornis* in spring, summer, and fall, 1972-2002.

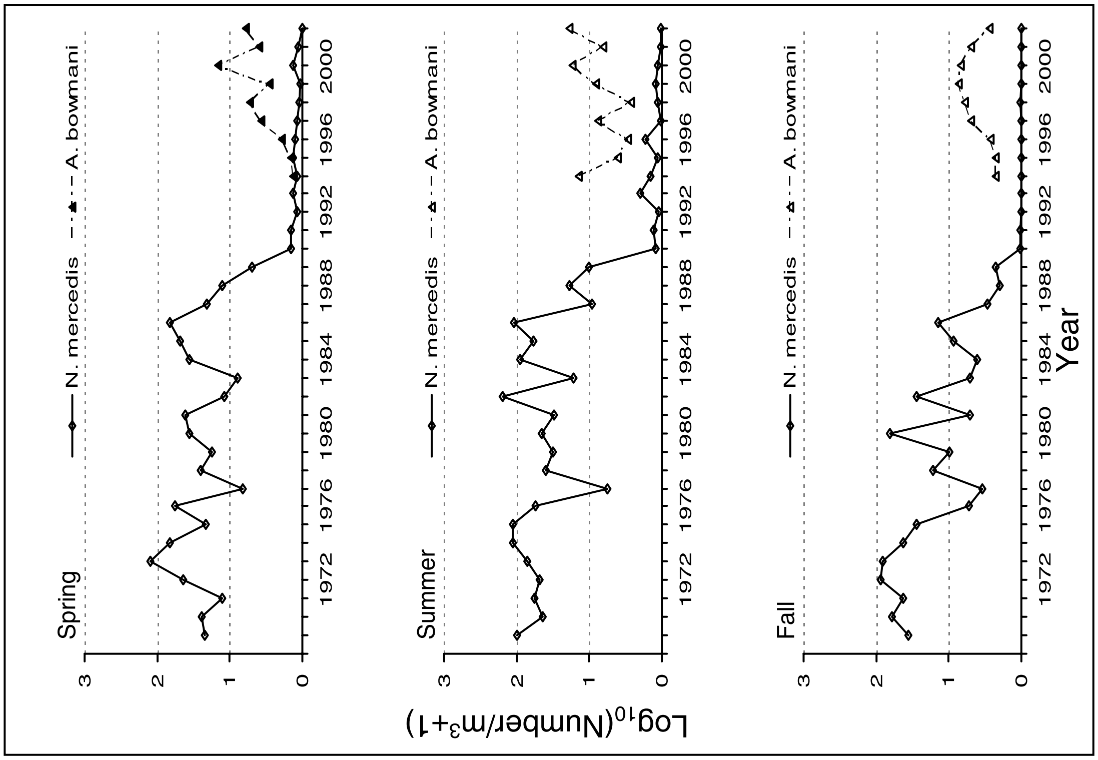

Figure 9 Log of mean abundance of *Neomysis mercedis* and *Acanthomysis bowmani* in spring, summer, and fall, 1968-2002.

San Francisco Bay Species 2002 Status and Trends Report

Kathryn Hieb, Thomas Greiner, and Steven Slater (DFG), khieb@delta.dfg.ca.gov

Annual abundance trends from 1980 to 2002 and distributional patterns for 2002 are summarized in this article for the most commonly collected Cancer crabs and fishes from San Francisco Bay. Shrimp abundance trends are summarized from 1980 through 2001 for 5 species and through 2002 for 1 species, as the 2002 shrimp samples were not completely processed by March 2003. Summary life history information for most of these species was presented in the 1997 Status and Trends reports (DeLeón 1998 and Hieb 1998); additional life history information can be found in IEP Technical Report 63 (Orsi 1999).

Ocean temperature, ocean upwelling, and freshwater outflow are three of the most important physical factors controlling abundance and distribution of species in the Bay. Gulf of the Farallones ocean temperatures have generally been below average since 1999, but based on the annual mean sea surface temperature (SST), 2002 was slightly warmer than 1999, 2000, or 2001. This was primarily due to above-average SSTs from September to December 2002. However, winter 2001-2002 SSTs were relatively cool, with monthly values 0.4-0.8 ºC below the historic (1925-2002) means. Upwelling indices in 2002 for the coastal area near the Bay were again well above average (period of record 1946-2002) from April to September, indicating strong summer upwelling; conversely, winter 2001-2002 upwelling indices were only slightly below average, typical of a year with few winter storms. Like 2001, 2002 was classified as a “Dry” water year, with an average daily outflow of 18,818 cfs for January-May. This average was slightly higher than in 2001 and the second lowest winter-spring outflow since1994.

In 2001, the abundance of juvenile *Crangon franciscorum,* the California bay shrimp, was < 50% of the 2000 index (Figure 1) and was the lowest index since 1994. This abundance decrease was consistent with the lower spring outflow in 2001, as there has been a strongly positive relationship between juvenile *C. franciscorum* abundance and March-May outflow. Since *C. franciscorum* rears in shallow brackish areas of the estuary, this relationship between outflow and abundance has been hypothesized to be in part due to the amount of nursery area. Based on the total (all sizes) *C. franciscorum* index, it was the second most common shrimp species collected in the estuary in 2001 (Table 1). *Crangon nigricauda*, which rears in cooler, more saline waters than *C. franciscorum*, was approximately 3 times more abundant than *C. franciscorum* in 2001. But over the entire study period *C. franciscorum* has been the most commonly collected shrimp species and we have collected more *C. franciscorum* than all the other species of shrimp combined.

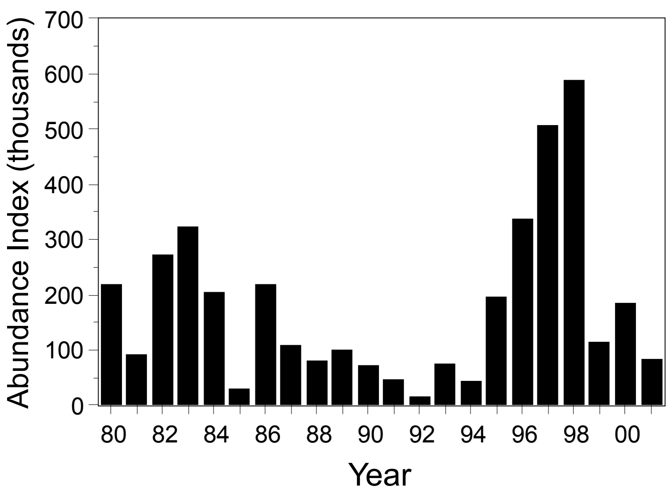

Figure 1 Annual abundance of juvenile *Crangon franciscorum*, May-October, otter trawl.

In 2001, *C. franciscorum* was collected from South Bay to the lower Sacramento River, just downstream of Three Mile Slough, and the lower San Joaquin River, at Santa Clara Shoal. In spring and summer, the highest catches were from our stations near the Dumbarton Bridge in South Bay and from Carquinez Strait to Honker Bay. As salinities increased over summer, the center of distribution moved upstream, and by fall, the highest catches were from Suisun Bay to the lower Sacramento River.

The abundance of *Crangon nigricauda*, the blacktail bay shrimp, increased slightly in 2001 (Table 1). This was the second consecutive year of record high abundance indices. *Crangon nigricauda* were collected from South Bay to Suisun Bay in 2001, with the highest catches at our Central Bay and lower San Pablo Bay stations. As with *C. franciscorum*, there was a slow movement upstream through summer and fall, with the broadest distribution in October.

Abundance of *Crangon nigromaculata*, the blackspotted bay shrimp, again decreased in 2001 to its lowest since 1988 (Table 1). It ranged from South Bay to Carquinez Strait with the highest catches at 3 stations near Angel Island in Central Bay.

Heptacarpus stimpsoni, the Stimpson coastal shrimp, increased in abundance in 2001 (Table 1). Like *C. nigricauda*, *H. stimpsoni* has had two years of record high indices in 2000 and 2001. *Heptacarpus stimpsoni* ranged from South Bay to upper San Pablo Bay in 2001, with the highest catches in Central Bay and Lower San Pablo Bay.

Although abundance of *Palaemon macrodactylus*, the introduced oriental shrimp, increased slightly in 2001 (Table 1), it remained a minor component of our total shrimp catch. *Palaemon macrodactylus* was most common in South Bay, near the Dumbarton Bridge, and from Carquinez Strait to the lower Sacramento and San Joaquin rivers. As this species prefers structured shallow water habitats, such as vegetation and pilings, it is probably more common in the estuary than our sampling indicates.

We first collected *Exopalaemon modestus,* the introduced Siberian freshwater shrimp, in fall 2000 in the lower Sacramento River. We collected only 3 in 2000, all at river stations. In 2001, we collected a total of 2,164 *E. modestus*; of these, 2,141 were from our river stations. Although the 2002 shrimp samples have not yet been completely processed, we counted *E. modestus* from all of our river stations. In 2002 we collected 9,242 *E. modestus* at these stations, which is almost 4 times the 2001 total. As the population increased, distribution also expanded. In 2002, *E. modestus* was collected from Carquinez Strait to near Knights Landing on the Sacramento River and at Mossdale on the San Joaquin River, with concentrations in Suisun Marsh, the lower Sacramento River, Liberty Island, and the Yolo Bypass. In March 2003, a few specimens were collected by the U.S. Fish and Wildlife Service from Mud Slough in Kesterson National Wildlife Refuge, northern Merced County (William Beckon, pers. comm.). *Exopalaemon modestus* has become widely distributed upstream of the Delta and much more common in the watershed than the Bay Study sampling indicates.

Table 1 Annual abundance indices (thousands) of the 5 most common species of shrimp 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	53.5	2.7	3.2	4.7	289.8
1981	119.2	22.1	0.5	0.5	5.1	147.3
1982	366.2	16.0	1.4	0.2	3.0	386.8
1983	328.3	38.8	16.0	0.6	1.3	385.0
1984	330.8	14.7	7.8	3.1	7.0	366.2
1985	57.8	19.7	3.1	3.1	3.9	88.3
1986	258.5	55.6	6.7	2.9	5.5	334.6
1987	142.9	75.5	9.6	6.8	2.4	239.0
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	350.7
1992	24.8	134.6	66.4	18.5	4.6	249.1
1993	70.5	128.0	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	286.9	159.3	35.3	14.9	2.2	501.2
1997	444.4	163.9	43.4	9.1	4.9	668.0
1998	539.0	128.5	53.1	4.8	9.0	737.5
1999	159.5	134.6	42.0	13.2	4.1	354.2
2000	157.3	242.6	20.7	42.2	3.1	467.5
2001	91.9	253.3	11.6	57.7	5.2	421.8

The 2002 abundance index of age-0 *Cancer magister*, the Dungeness crab, was approximately 50% the 2001 index, but was the third highest for the study period (Table 2). This relatively high index was likely due to winter 2001-2002 ocean conditions that were again favorable to survival and retention of *C. magister* larvae in the Gulf of the Farallones. Cool ocean temperatures and a relatively weak northward Davidson Current are thought to result in increased survival and retention of larvae, which lead to increased nearshore settlement and potential for movement into the Bay. Age-0 crabs were first collected in April, with most immigrating in May. They moved upstream over the next 3 months, and by August were common in upper San Pablo Bay and Carquinez Strait. From May through July there was also a relatively large number of age-0 *C. magister* in South Bay, but we collected few there after July. From August through December, our catches at the Alcatraz Island station were very high; a similar pattern of high summer-fall catches also occurred in 1999 and 2000 at this station.

Abundance and distribution trends of the next 3 species of *Cancer* crabs were not summarized in the 2001 Status and Trends report; therefore, trends from 2001 and 2002 were summarized here. Abundance of age-0 *Cancer gracilis,* the slender crab, reached a study period high in 2001, then declined in 2002 (Table 2). Overall, age-0 *C. gracilis* indices have been higher since the early 1990s than in the 1980s. Although *C. gracilis* were collected from South Bay to lower San Pablo Bay, the majority of our catch was from several Central Bay stations. In 2001, > 60% of the age-0 *C. gracilis* catch was from 3 stations in Central Bay: the station southeast of Treasure Island, the station east of Treasure Island, and the station near Red Rock, just downstream of the Richmond-San Rafael Bridge. In 2002, approximately 55% of the age-0 crabs were collected at the east Treasure Island and Red Rock stations.

The two rock crabs—*C. antennarius*, the brown rock crab, and *Cancer productus*, the red rock crab—have usually been less common than either *C. magister* or

C. gracilis in our trawls. Both species prefer protected areas, such as rocky substrates and pilings, so low catches in a trawl survey were expected. The age-0 *C. antennarius* index decreased in 2001 and 2002, while the age-0 *C. productus* index increased in both years, culminating in its second highest index for the study (Table 2). Similar to *C. gracilis*, both rock crabs exhibited a trend of higher indices beginning in the early 1990s. In 2001 and 2002, age-0 *C. antennarius* were collected from South to San Pablo bays and were more common at shoal than at channel stations. In 2001, only 26% were collected at channel stations, whereas in 2002, 38% were from channel stations. In contrast, age-0 *C. productus* were not as broadly distributed as *C. antennarius* and were more common at our channel stations. In 2001 and 2002, approximately 75% were collected from Central Bay channel stations.

Table 2 Annual abundance indices of age-0 *Cancer* crabs from the otter trawl. The index period is May-July for *C. magister*, May-October for all other species.

Year	*C. magister* age-0	*C. gracilis* age-0	*C. antennarius* age-0	*C. productus* age-0
1980	45	17	99	0
1981	94	152	76	9
1982	268	87	0	4
1983	0	151	28	4
1984	2884	154	50	41
1985	3072	220	20	38
1986	5	59	0	89
1987	194	93	61	79
1988	11578	223	21	138
1989	263	204	29	30
1990	31	159	112	160
1991	796	656	171	132
1992	0	371	60	62
1993	54	616	398	71
1994	1097	1016	603	166
1995	58	227	367	40
1996	66	411	1126	198
1997	907	1131	351	86
1998	0	1624	718	149
1999	2862	221	89	249
2000	2176	251	849	93
2001	10700	1906	276	142
2002	5215	796	119	238

The age-0 brown smoothhound (*Mustelus henlei*) abundance index for 2002 was the highest since 1989 and the third highest of the study period (Figure 2). We collected brown smoothhound from June through December at stations throughout South, Central, and San Pablo bays.

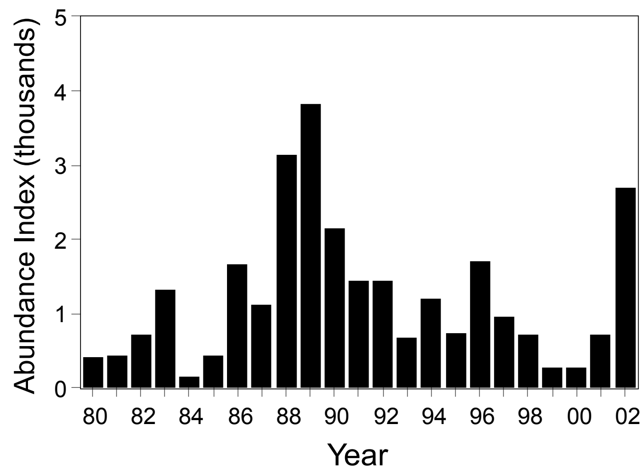

Figure 2 Annual abundance of age-0 brown smoothhound, April-October, otter trawl.

The 2002 age-0 Pacific herring (*Clupea pallasii*) abundance index increased from 2001 and was the highest index since 1986 (Figure 3). In March, a few age-0 fish appeared in Central and San Pablo bays. By April, fish were widely distributed from South through San Pablo bays with a few collected as far upstream as Suisun Bay and the lower Sacramento River. The majority of age-0 fish were collected in Central and San Pablo bays from May through July, with declining catches through September. By October, the remaining age-0 Pacific herring were in Central Bay.

The 2002 northern anchovy (*Engraulis mordax*) abundance index was higher than in 2001, but the second lowest since 1990 (Figure 4). From April through June, our 2002 indices were very low, only 16% of the average for these months. We collected northern anchovy from South Bay to Chipps Island with the largest catches occurring from July through October at channel stations near Candlestick Point and Raccoon Strait.

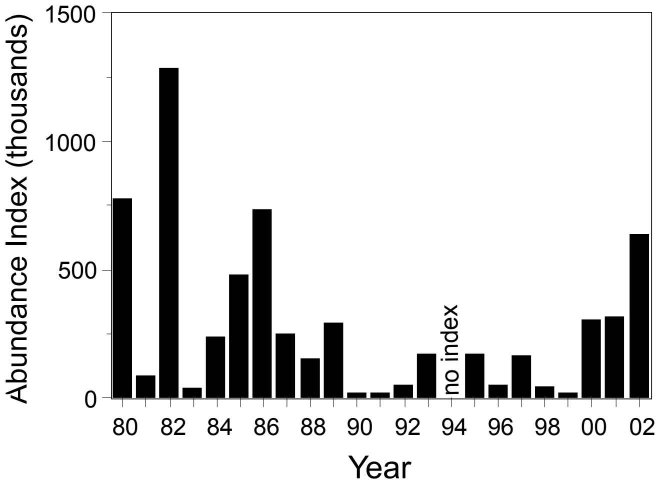

Figure 3 Annual abundance of age-0 Pacific herring, April-September, midwater trawl.

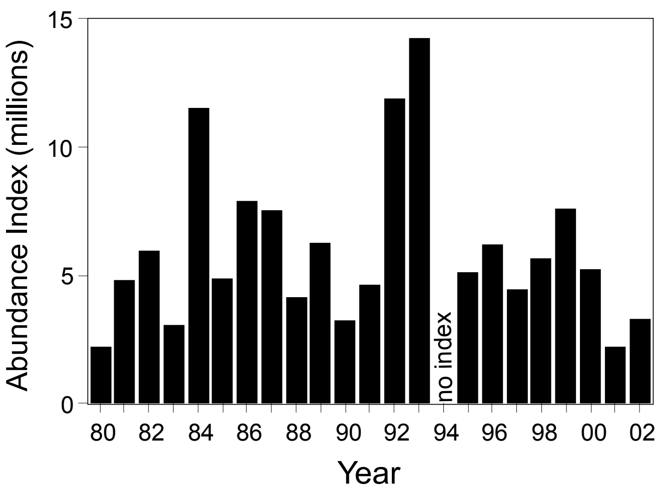

Figure 4 Annual abundance of northern anchovy (all sizes), April-October, midwater trawl.

The age-0 longfin smelt (*Spirinchus thaleichthys*) abundance index in 2002 decreased from 2001 for the midwater trawl (Figure 5A) and increased from 2001 for the otter trawl (Figure 5B). The 2002 otter trawl index was the highest since 1999, whereas the 2002 midwater trawl index was the lowest since 1996. The majority of the age-0 midwater trawl fish were collected from Suisun Bay from May through September, followed by a shift upstream to the lower Sacramento River by December. The largest otter trawl catches occurred in San Pablo Bay in May and in Central and Suisun bays from July through October. In November and December, age-0 fish moved back into San Pablo Bay and remained in Suisun Bay and the lower Sacramento River.

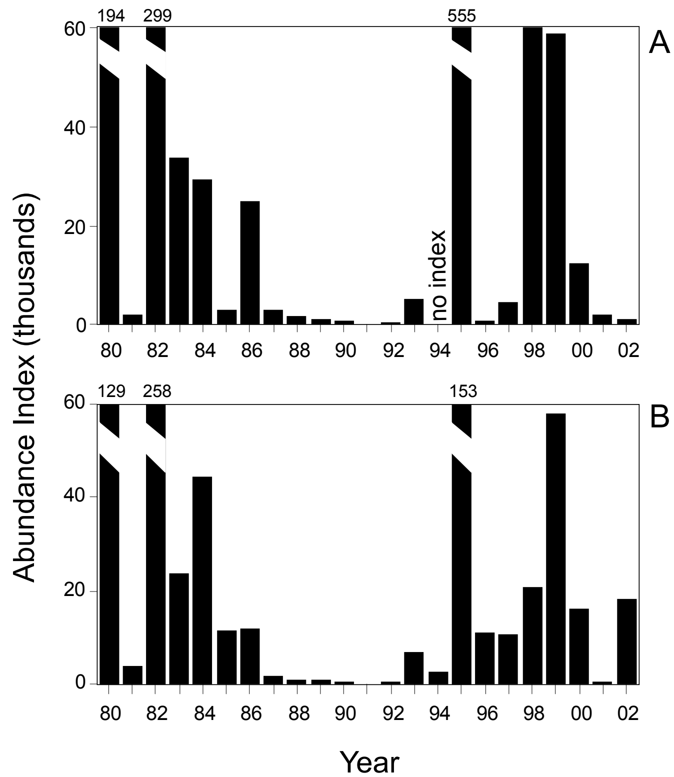

Figure 5 Annual abundance of age-0 longfin smelt, May-October. A) Midwater trawl; B) Otter trawl

The age-0 plainfin midshipman (*Porichthys notatus*) index reached a study period high in 2002 that was over 2 times the previous record high index from 2001 (Figure 6). Although age-0 midshipmen were collected from South Bay to Suisun Bay in 2002, they were most common at stations in northern Central Bay near the San Rafael-Richmond Bridge. Approximately 50% of our 2002 catch was from the channel station near Red Rock and the shoal station near Corte Madera.

Age-0 jacksmelt (*Atherinopsis californensis*) abundance was slightly lower in 2002 than in 2001, but was still the second highest since 1985 (Figure 7). During 2002, over 98% of age-0 jacksmelt were collected from July through December. We collected age-0 jacksmelt from all of our South and Central Bay stations to lower San Pablo Bay, near Point Richmond.

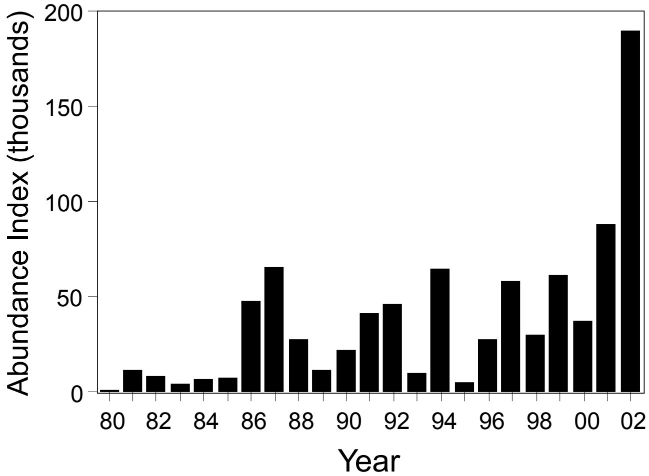

Figure 6 Annual abundance of age-0 plainfin midshipman, June-October, otter trawl.

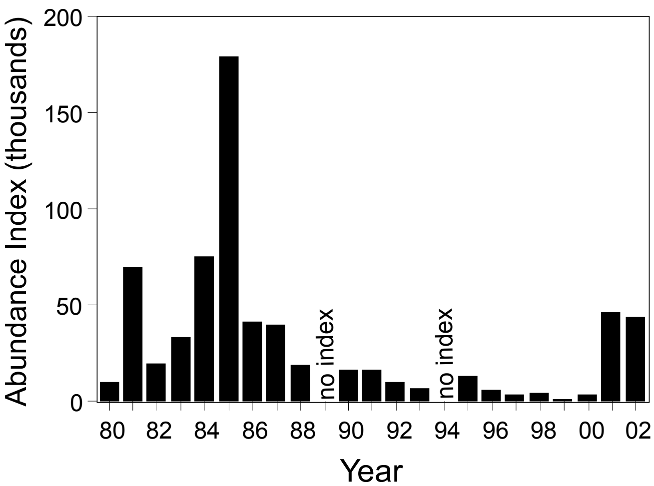

Figure 7 Annual abundance of age-0 jacksmelt, July-October, midwater trawl.

In 2002, the age-0 Pacific staghorn sculpin (*Leptocottus armatus*) abundance index was 1.5 times the 2001 index, a new record for the study (Figure 8). Pacific staghorn sculpin were collected from every station from South through Suisun bays, and from a few stations in the West Delta during 2002. The majority (71%) of fish were collected in Central Bay from June through August.

Abundance of age-0 shiner perch (*Cymatogaster aggregata*) increased for a second straight year in 2002 to the highest index since 1982 (Table 3). This increase may be due in part to sport fishing regulation changes in 2002 from no bag limit to a 10 shiner perch per day limit. We collected age-0 shiner perch in South, Central, and San Pablo bays and catch was highest during summer and fall.

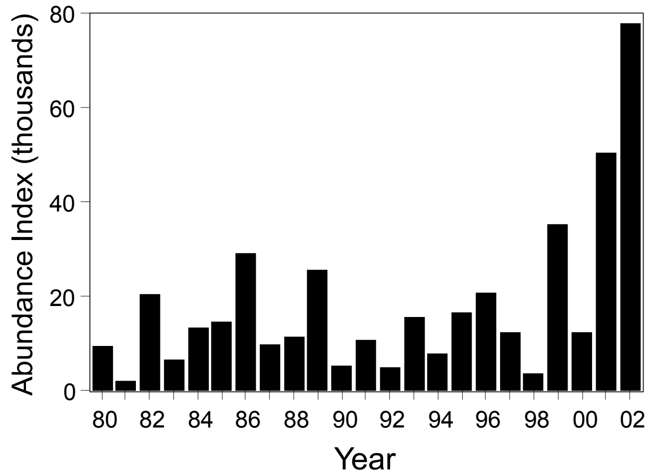

Figure 8 Annual abundance of age-0 staghorn sculpin, February-September, otter trawl.

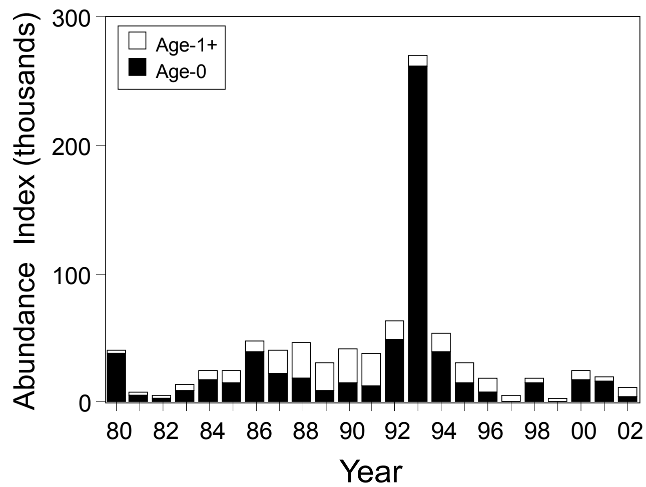

Figure 9 Annual abundance of age-0 and age-1+ white croaker, February-October, otter trawl.

The age-0 white croaker (*Genyonemus lineatus*) abundance index for 2002 decreased by almost 75% from 2001 and was the fourth lowest index for the study period (Figure 9). However, the age-1+ index increased in 2002 and was the second highest since 1996 (Figure 9). Age-0 and age-1+ white croaker were caught year-round throughout South, Central, and San Pablo bays and were common at both channel and shoal stations.

In 2002, age-0 walleye surfperch (*Hyperprosopon argenteum*) abundance decreased by approximately 75% from 2001, but was still the second highest index since 1984 (Table 3).

Table 3 Annual abundance indices for the most common species of surfperches. The shiner perch age-0, pile perch age-0, and white seaperch (all sizes) indices are from May-October, the barred perch (all sizes) index from April-September, and age-0 walleye surfperch index from May-August. The walleye surfperch indices are from the midwater trawl, indices for all other species are from the otter trawl.

Year	*shiner perch age-0*	*walleye surfperch age-0*	*pile perch age-0*	*barred surfperch all*	*white seaperch all*
1980	16673	1724	857	483	586
1981	42650	11672	998	942	1220
1982	43703	2460	472	335	348
1983	16147	994	778	1330	277
1984	14386	5589	110	673	872
1985	16616	543	301	73	137
1986	24582	454	289	0	311
1987	18069	2180	0	239	271
1988	7746	693	0	134	152
1989	6687	2046	153	101	47
1990	8181	681	0	79	95
1991	2724	32	0	84	0
1992	6142	665	0	41	0
1993	6341	925	0	43	0
1994	3241	no index	0	80	0
1995	6336	0	0	0	0
1996	4404	906	0	59	0
1997	23896	94	0	155	0
1998	4384	467	75	48	36
1999	6237	548	0	46	0
2000	4640	1843	31	43	0
2001	20594	10813	0	55	106
2002	26134	2354	42	59	260

Both pile perch (*Rhacochilus vacca*) and barred surfperch (*Amphistichus argenteus*) abundance remained low in 2002 (Table 3). These indices represent just 1 pile perch collected near Raccoon Strait and 1 barred surfperch collected from South Bay near the San Francisco Airport. The 2002 white seaperch (*Phanerodon furcatus*) abundance index was the highest since 1987 (Table 3). We caught a total of 17 white seaperch in our otter trawl in 2002, but only 6 were caught at index stations during index months. Two were from the station near Raccoon Strait and 4 were from the Treasure Island station. All of the remaining white seaperch were also collected from Central Bay, including 5 from our non-index shoal station near Corte Madera.

The 2002 bay goby (*Lepidogobius lepidus*) abundance index was the highest recorded for the study, approximately 1.5 times the previous record index from 1991 (Figure 10). Bay gobies, over the course of the year, were collected at all stations in South, Central, and San Pablo bays. The highest catches occurred at Central Bay stations from April to August.

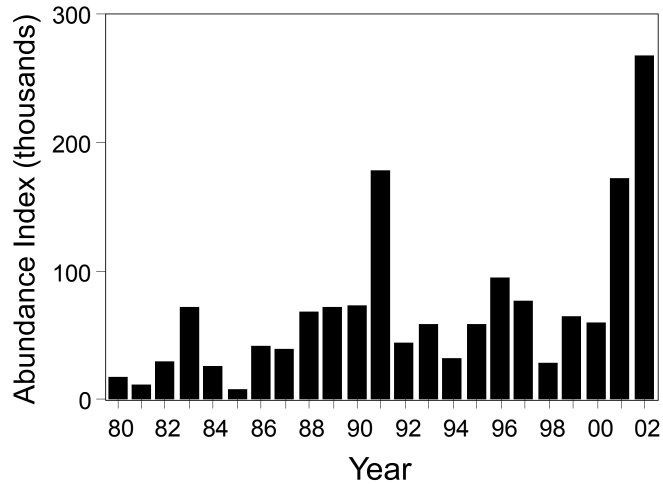

Figure 10 Annual abundance of bay goby (all sizes), February-October, otter trawl.

The shokihaze goby (*Tridentiger barbatus*) has been found upstream of our historic sampling area, which extended to the confluence of the Sacramento and San Joaquin rivers. For this reason, abundance was assessed as annual mean catch-per-unit-effort (CPUE) for all stations sampled, including those in the lower Sacramento and San Joaquin rivers that were added to the survey in 1994, rather than an abundance index based only on the original survey stations. In 2002, mean CPUE for fish $<$ 20 mm TL increased 1.5 times from the 2001 record, but for fish $\geq$ 20 mm TL, mean CPUE was approximately 75% of the 2001 record CPUE (Figure 11). In 2002, 95% of all the shokihaze gobies collected were from channel stations in Suisun Bay and the lower Sacramento River. The smaller fish ($<$ 20 mm) were collected from August to October and most (98%) were from our lower Sacramento River stations. The larger fish ($\geq$ 20 mm) were common throughout the year in Suisun Bay and the lower Sacramento River. The 2002 shokihaze goby catch exceeded our combined catch of the 2 other introduced *Tridentiger* gobies, the shimofuri goby (*T. bifasciatus*) and the chameleon goby (*T. trigonocephalus*).

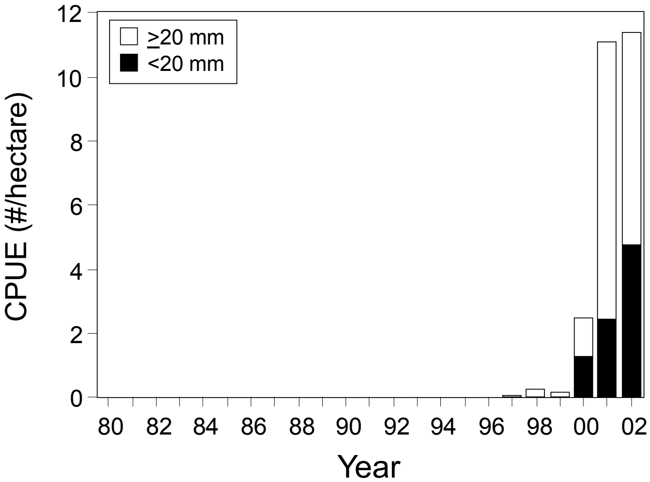

Figure 11 Annual CPUE (#/hectare) of < 20 mm TL and ≥ 20 mm TL shokihaze goby, January-December, otter trawl.

The 2002 age-0 yellowfin goby (*Acanthogobius flavimanus*) index decreased slightly from 2001 and was the lowest on record since 1991 (Figure 12). Most yellowfin gobies were collected from Suisun Bay (27%) and the lower Sacramento and San Joaquin rivers (51%) from May through September. A few yellowfin gobies were collected in Central and San Pablo bays from July through September. We also collected most yellowfin gobies (75 of the 86 fish collected in 2002) at shoal stations.

For the third consecutive year, no age-0 or age-1 California halibut (*Paralichthys californicus)* were collected (Figure 13). The age-2+ California halibut index decreased from the 2001 index, continuing the declining trend since 1999. We collected most age-2+ fish from Central Bay channel stations. All California halibut collected in 2002 ranged in length from 310 to 701 mm (TL) and most were age-4 and age-5.

The age-0 English sole (*Parophrys vetulus*) abundance index decreased from 2001 to 2002, but was still the second highest for the study period (Figure 14). Age-0 English sole migrated to the shoals of South, Central, San Pablo bays, and south-western Suisun Bay in spring. By late summer most age-0 English sole had migrated back to Central Bay and by late fall had emigrated to the ocean. We collected age-0 English sole from South Bay, south of the Dumbarton Bridge, to Suisun Bay at the Mothball Fleet in 2002. Our catches were greatest at the shoal station near Corte Madera and at the channel stations by Angel Island. They were also common at shoal stations in South, Central, and San Pablo bays.

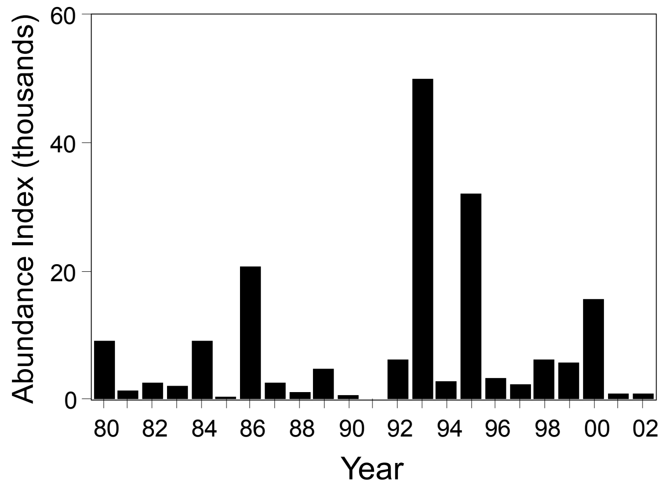

Figure 12 Annual abundance of age-0 yellowfin goby, May-October, otter trawl.

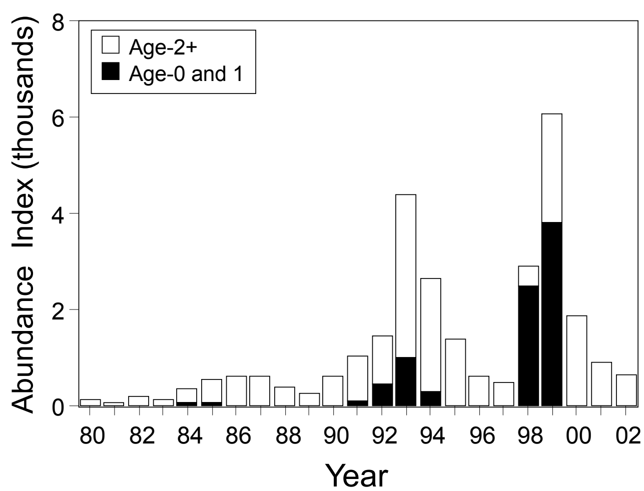

Figure 13. Annual abundance of juvenile (age-0 and age-1) and age-2+ California halibut, February-October, otter trawl.

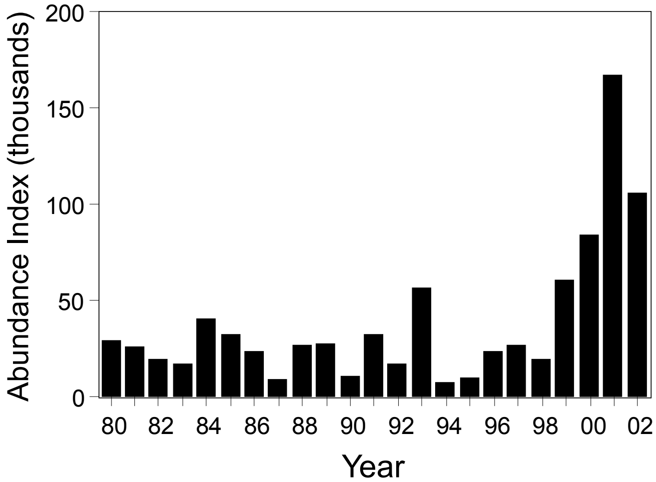

Figure 14 Annual abundance of age-0 English sole, February-October, otter trawl.

In 2002, the speckled sanddab (*Citharichthys stigmaeus*) abundance index reached a fourth consecutive record high for the study (Figure 15). The 2002 index was 1.5 times greater than the previous record from 2001 and was higher than the indices for any other flatfish collected by our study. Speckled sanddab catch was greatest at our Central Bay channel stations near Treasure Island, east and northeast of Angel Island, and at Southhampton Shoal. Distribution was broadest in April and May when fish were collected throughout South and Central bays and as far upstream as Suisun Bay.

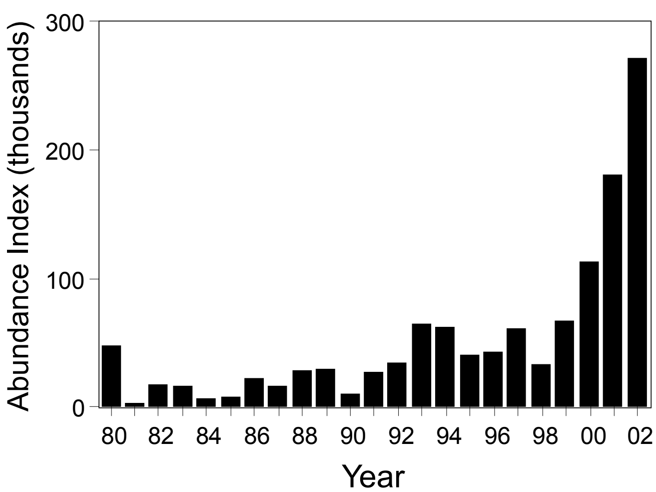

Figure 15 Annual abundance of speckled sanddab (all sizes), February-October, otter trawl.

Age-0 starry flounder (*Platichthys stellatus*) abundance increased from 2001 to 2002 but remained relatively low (Figure 16A). We collected age-0 starry flounder from June to December in 2002. They were collected from San Pablo Bay to our furthest upstream stations on the Sacramento River, just upstream of Rio Vista, and the on San Joaquin River, at Old River Flats. Catch was greatest at shoal stations. The age-1 starry flounder abundance index for 2002 represented only 1 fish and was the second lowest for the study period (Figure 16B). This was expected, as the 2001 age-0 index was very low.

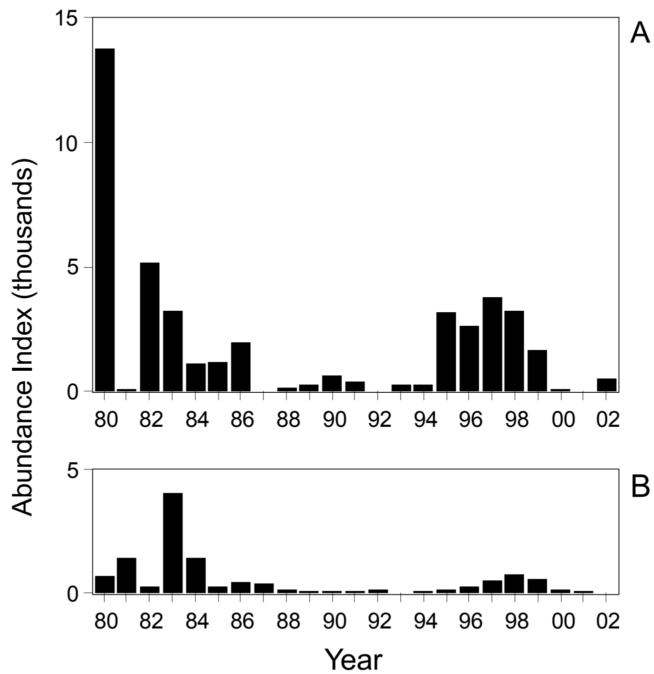

Figure 16 Annual abundance of starry flounder, otter trawl: A) Age-0, May-October; B) Age-1, February-October

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Resident Fish Surveys

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In April 2001, the Department of Fish and Game resumed year-round random sampling for the Delta Resident Shoreline Fishes Monitoring Project, at the request of the Interagency Ecological Program Management Team. The random sampling design is similar to the method used for resident fish monitoring from 1980 to 1983, but a change from the fixed-site sampling in 1995, 1997, and 1999. This modification to the sampling design will provide more statistically valid results concerning trends in resident fish abundance and community structure in the Delta. Also, a stomach content analysis component was added to examine trophic interactions in the nearshore fish community.

The Resident Fishes Monitoring Project samples 20 randomly selected 500-m-long sites each month. The Delta is stratified into five areas and sampling effort in each area corresponds approximately to the relative abundance of resident fishes. Five sites are sampled monthly in the east and central Delta, three sites are sampled in the north and west Delta, and four sites are sampled in the south Delta (Figure 1). Shoreline habitat types, along with chemical and physical variables, are recorded for each site. Stomach contents are collected from a maximum of five fish per species, per site, using gastric lavage or dissection. The collection of stomach contents was suspended in 2003 pending analysis of current samples. No stomach content analysis information will be presented in this article.

Since the inception of stratified random sampling in April 2001, a total of 42 species from 17 families has been observed (Table 1). Non-native centrarchids, primarily bluegill, largemouth bass, and redear sunfish, made up 59% of the catch (Figure 2). Threadfin shad (clupeids) accounted for an additional 24%, followed by non-native cyprinids at 5%. Native cyprinids and catostomids each contributed less than 2% of the total catch (Table 2, Figure 2).

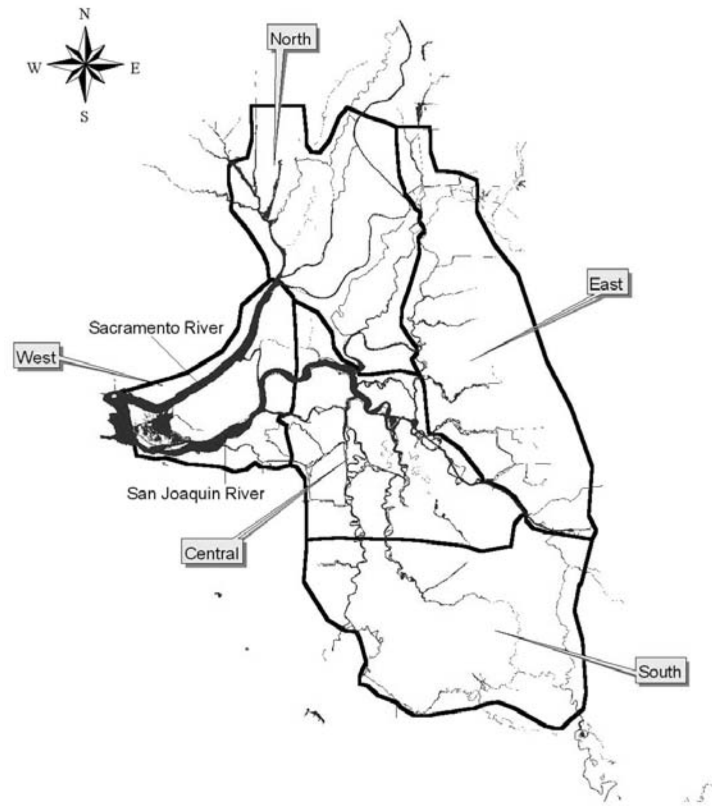

Figure 1 Delta Resident Shoreline Fishes Monitoring stratified sampling areas.

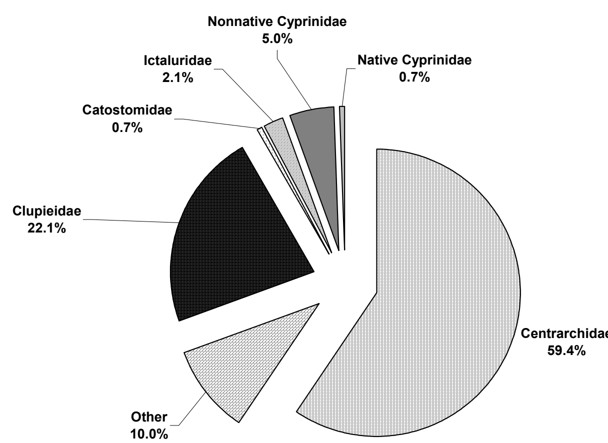

Figure 2 Catch of common families observed during resident fish monitoring in the entire Sacramento-San Joaquin Delta in 2001-2003

Table 1 Fish species observed during resident fish sampling in the Sacramento-San Joaquin Delta in 1995, 1997, 1999, and 2001-2003.

Family	*Species*	*Classification*[a]	*Species Observed 1995-1999*	*Species Observed 2001-2003*	*Family*	*Species*	*Classification*[a]	*Species Observed 1995-1999*	*Species Observed 2001-2003*
Atherinidae					Cyprinodontidae				
	Inland silverside	(i,r)	X	X		Rainwater killifish	(i,me)	X	
Catostomidae					Embiotocidae				
	Sacramento sucker	(n,fwe)	X	X		Tule perch	(n,r)	X	X
Centrarchidae					Gasterosteidae				
	Black crappie	(i,r)	X	X		Threespine stickle-	(n,fwe)	X	X
	Bluegill	(i,r)	X	X	Gobiidae				
	Green sunfish	(i,r)	X	X		Shimofuri goby	(i,r)	X	X
	Lagremouth bass	(i,r)	X	X		Yellowfin goby	(i,fwe)	X	X
	Pumpkinseed	(i,r)			Ictaluridae				
	Redear sunfish	(i,r)	X	X		Black bullhead	(i,r)	X	
	Smallmouth bass	(i,r)	X	X		Brown bullhead	(i,r)	X	X
	Spotted bass	(i,r)		X		Channel catfish	(i,r)	X	X
	Sunfish (*Lepomis* sp.)	(i,r)				White catfish	(i,r)	X	X
	Warmouth	(i,r)	X	X	Mugilidae				
	White crappie	(i,r)	X	X		Striped mullet	(i,r)		
Clupeidae					Osmeridae				
	American shad	(i,a)	X	X		Delta smelt	(n,fwe)	X	X
	Threadfin shad	(i,fwe)	X	X		Longfin smelt	(n,fwe)		X
Cottidae					Percichthyidae				
	Pacific staghorn	(n,me)		X		Striped bass	(i,a)	X	X
	Prickly sculpin	(n,fwe)	X	X	Percidae				
	Riffle sculpin	(n,fwe)	X			Bigscale logperch	(i,r)	X	X
Cyprinidae					Petromyzontidae				
	California roach	(n,fwe)	X	X		Pacific lamprey	(n,a)	X	X
	Common carp	(i,r)	X	X		River lamprey	(n,fwe)	X	X
	Golden shiner	(i,r)	X	X	Pleuronectidae				
	Goldfish	(i,r)	X	X		Starry flounder	(n,r)		X
	Hardhead	(n,fwe)		X	Poecilidae				
	Red shiner	(i,r)	X	X		Mosquitofish	(i,r)	X	X
	Sacramento blackfish	(n,fwe)	X	X	Salmonidae				
	Sacramento hitch	(n,r)	X	X		Chinook salmon	(n,a)	X	X
	Sacramento squaw-	(n,fwe)	X	X		Steelhead rainbow	(n,a)	X	X
	Splittail	(n,fwe)	X	X					

[a] Classification: n=native, I=introduced, r=resident, a=anadromous, fwe=freshwater euryhaline, me=marine haline.

Table 2 Catch-per-unit-effort (fish/km) of common species observed during resident fish monitoring in the Sacramento-San Joaquin Delta in 1995, 1997, 1999, and 2001-2003.

Family	*Species*	*1995*	*1997*	*1999*	*2001*	*2002*	*2003*
Atherinidae							
	Inland silverside	0.5	0.9	1.3	9.7	5.7	6.2
Catostomidae							
	Sacramento sucker	0.8	2	2.9	2	1.7	0.1
Centrarchidae							
	Black crappie	0.9	1.3	0.8	1	0.7	0.7
	Bluegill	41.3	55.6	47.6	61.1	71.3	83.6
	Green sunfish	0.3	1	0.5	0.8	0.8	0.6
	Largemouth bass	20.1	22.5	20.8	34.7	27.1	27.2
	Redear sunfish	12.6	23	20.2	31.3	32.6	48.7
	Smallmouth bass	1.7	2.4	0.6	0.7	0.5	0.1
	Warmouth	2.6	5.6	4.5	3.8	6	2.9
Clupeidae							
	American shad	0	0.3	0	1.5	0.2	0.1
	Threadfin shad	4.5	6	2.2	88.5	27.5	43.5
Cottidae							
	Prickly sculpin	0.9	1.2	1.5	0.5	0.4	0.1
Cyprinidae							
	Common carp	2.1	3.4	4.7	5.7	4	1.7
	Golden shiner	9.1	6.3	3.7	8.3	6.8	2
	Goldfish	0.2	0.4	0.3	0.4	0.2	0.1
	Red shiner	0.01	0.05	2	0	0.2	0.1
	Sacramento blackfish	0.01	0.3	0.3	0.2	0.2	3.1
	Sacramento pikeminnow	1.1	0.7	1.4	0.9	1.2	0.4
	Splittail	3	0.4	0.5	0.3	0.2	0.8
Embiotocidae							
	Tule perch	3.1	4.1	1.4	2.8	2.7	3.5
Gobiidae							
	Shimofuri goby	0.3	0.05	0.01	0.04	0.07	0
	Yellowfin goby	0.7	1.1	0.2	4.5	1	0.1
Ictaluridae							
	Brown bullhead	1.1	1.4	1	0.6	0.3	0.1
	Channel catfish	0.8	0.4	0.9	1.2	1.1	0.1
	White catfish	6.5	6.2	5.4	4.2	3.5	0.5
Osmeridae							
	Delta smelt	0.1	0.1	0	0.1	0.1	0.2
Percichthyidae							
	Striped bass	0.8	0.6	0.8	6.6	1.7	3.1
Percidae							
	Bigscale logperch	0.3	0.2	0.1	2.1	0.3	0.6
Petromyzontidae							
	Pacific lamprey	0.1	2	0.2	0.1	0.3	0.6
Poecilidae							
	Mosquitofish	0.1	0.1	0.05	0.1	0.1	0.2
Salmonidae							
	Chinook salmon	3.6	1.1	3.2	0.5	1.5	3.9
	Steelhead rainbow trout	0.5	0.1	0.3	0.03	0.1	0.8
Total		**119.72**	**150.8**	**129.36**	**274.27**	**200.07**	**235.7**

The catch of the five most common families (Clupeidae, Cyprinidae, Catostomidae, Ictaluridae, and Centrarchidae) accounted for more than 50% of the total catch in each of the five areas and over 90% in three of five (Figures 3 through 7). Non-native centrarchids dominated the catch in the east and central Delta and made up a large portion of the catch in the west and south Delta (Figures 4, 5, 6, 7). Native cyprinid catch was primarily limited to the north and central Delta and only made up 4.9% of the total catch in each of these areas (Figures 3 and 5). Non-native cyprinids catch was relatively constant throughout all five stratified areas, making up 4 to 7 % of the catch.

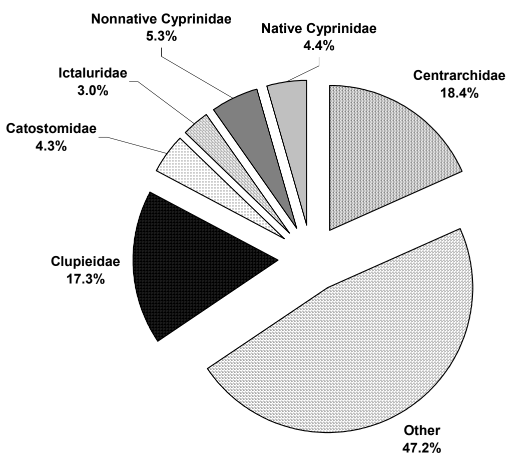

Figure 3 Catch of common families observed during resident fish monitoring in the north Sacramento-San Joaquin Delta in 2001-2003.

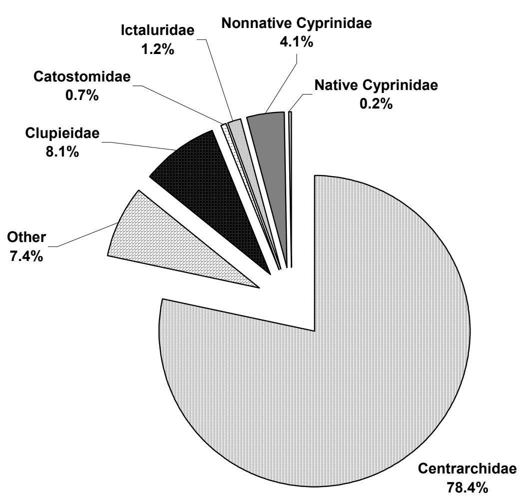

Figure 4 Catch of common families observed during resident fish monitoring in the east Sacramento-San Joaquin Delta in 2001-2003.

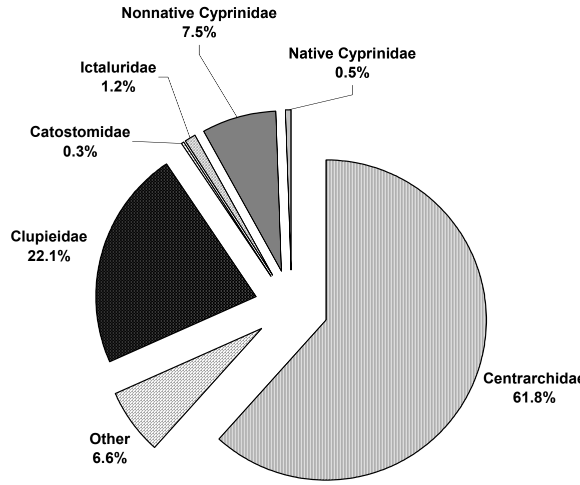

Figure 5 Catch of common families observed during resident fish monitoring in the central Sacramento-San Joaquin Delta in 2001-2003.

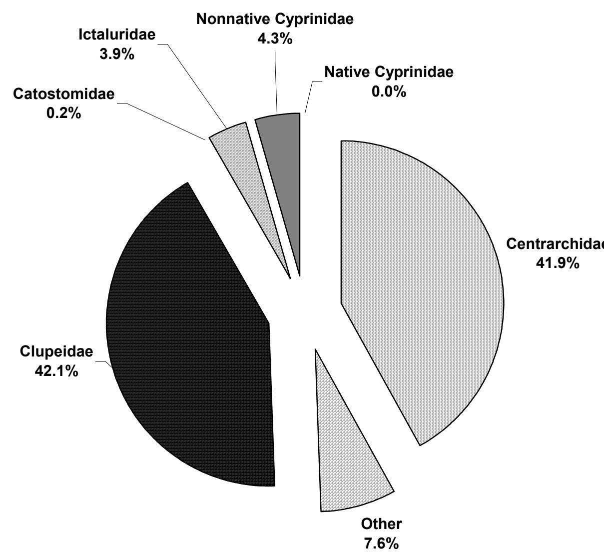

Figure 6 Catch of common families observed during resident fish monitoring in the south Sacramento-San Joaquin Delta in 2001-2003.

Comparisons to resident fish data collected in 1995, 1997, and 1999 are possible, but should be treated with caution, as these data were collected at 20 fixed stations, each 1-km long, sampled in February, April, June, and August. Catch-per-unit-effort (CPUE) is similar for nearly all of the common families and species observed during 1995, 1997, and 1999 and 2001-2003 (Figure 8, Table 2). However, CPUE of centrarchids, atherinids (inland silversides), and clupeids (threadfin shad) was higher in 2001-2002 than in 1995, 1997, and 1999 (Table 2, Figure 8). The increase in these three groups is the main reason for the substantially higher total CPUE during 2001-2003 compared to 1995, 1997, and 1999 (Table 2). This increase is partially due to the high catch of clupeids in the winter months, which were not sampled in 1995, 1997, and 1999. The difference may also be related to the acquisition of a new electrofishing boat in 2001 that may be more efficient than the boat used in earlier years.

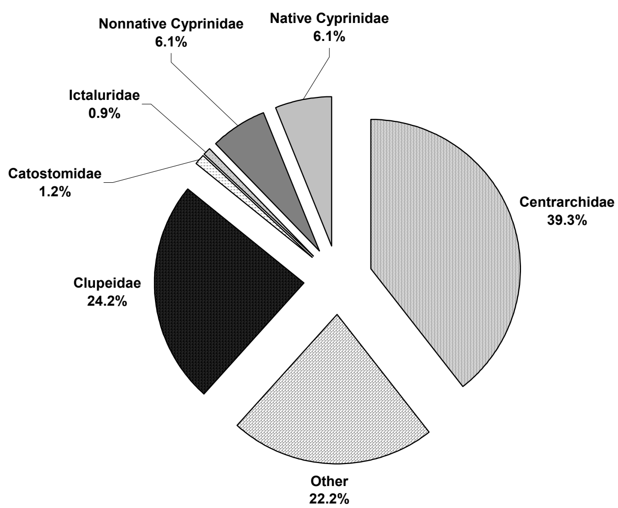

Figure 7 Catch of common families observed during resident fish monitoring in the west Sacramento-San Joaquin Delta in 2001-2003.

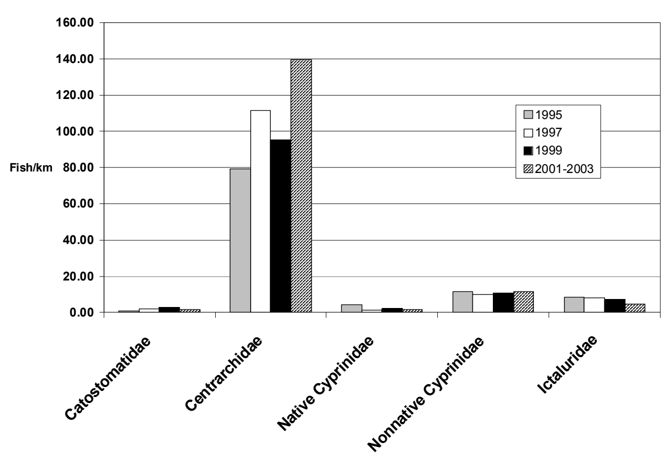

Figure 8 Catch-per-unit-effort (fish/km) of common families observed during resident fish sampling in the Sacramento-San Joaquin Delta in 1995, 1997, 1999, and 2001-2002.

Abundance of Juvenile Chinook Salmon in the Sacramento-San Joaquin Estuary

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To monitor the abundance of juvenile Chinook salmon in the Sacramento-San Joaquin rivers and the Delta, the USFWS Stockton office has employed a number of sampling methods. Current methods include beach seining, midwater trawling, and Kodiak trawling. There are six biological areas where monitoring occurs (Figure 1). These biological regions are used to better identify contributions from different rivers, the timing of emigration, and the use of the Delta and Bay for rearing. Beach seine sampling occurs over a broad geographical range, including the lower Sacramento River beach seine conducted on the Sacramento River between Elkhorn and Colusa (Area 1), the Delta area beach seines (North, Central, and South Delta) conducted from Discovery Park in Sacramento downstream on the Sacramento River to and throughout the Delta (Areas 2, 3, and 4), the San Joaquin River beach seine from Mossdale upstream to the mouth of the Tuolumne River (Area 5), and the Bay Area beach seine in San Francisco and San Pablo bays (Area 6). Trawling areas include the Sacramento midwater and Kodiak trawls conducted just downstream from Sacramento on the Sacramento River at Sherwood Harbor (Area 2), the Mossdale Kodiak trawl conducted just downstream from Mossdale on the San Joaquin River (Area 5), and the Chipps Island midwater trawl conducted below the confluence of the Sacramento and San Joaquin rivers, and directly south of Chipps Island (Area 3).

For the period covered in this report, January 1, 2002, through December 31, 2002, the water year was considered dry, the second dry year in a row (DWR 2003). This in turn led to the third lowest peak flows on the Sacramento and San Joaquin rivers since 1994.

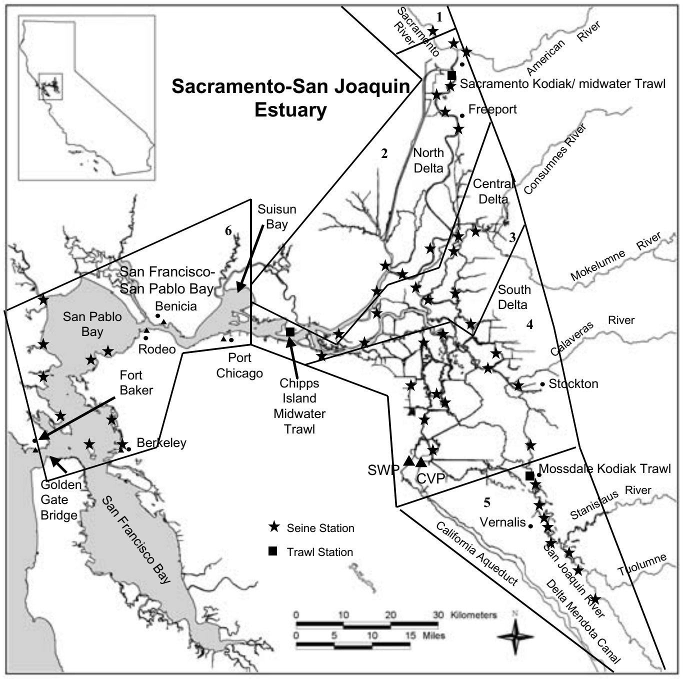

Figure 1 Trawl and beach seine sites. Beach seine routes are designated as: 1. lower Sacramento River (Knights Landing, Reels Beach, South Meridian, Wards Landing, and Colusa St. Park not shown), 2. North Delta, 3. Central Delta, 4. South Delta, 5. lower San Joaquin River, and 6. San Francisco/San Pablo Bay.

To better determine the abundance of Chinook fry (< 70 mm FL) entering the Delta, beach seining data for the months of January through March were graphed (Figure 2). Although the office started beach seining in 1976, it was not until 1985 that the catch information was quantified as catch per cubic meter (CPM^3). Multiplying the seine length perpendicular to the shore by the width taken parallel to the shore, and one half the depth taken at the point furthest from shore yielded the volume sampled. Total catch at the site was then divided by the volume sampled giving a CPM^3. A mean monthly CPM^3 was calculated from data collected at each sample site within each biological area.

Generally, in the beach seine locations, the highest CPM^3's came from the lower Sacramento and North Delta seines. In 2002, CPM^3 in the lower Sacramento seine was again the highest of the six biological areas for the year, but this was not reflected in the North Delta seine which produced the lowest CPM^3 since 1985 (Figure 2).

The relationship of fry emigration and flow was shown using the North Delta seine CPM^3 and February flow at Freeport. A mean CPM^3 for the three-month period January-March was calculated for the years 1985 through 2002. Flow information was obtained from the gauging station at Freeport in cubic feet per second (cfs). Mean daily flow during February was calculated. A positive relation ($r^2 = 0.7465$, $p < 0.01$) was shown between increased CPM3 and increasing flows, indicating that higher flows tend to move fry downstream (Figure 3). For the group of years where mean flow was below 40,000 cfs, 2002 had the lowest CPM^3.

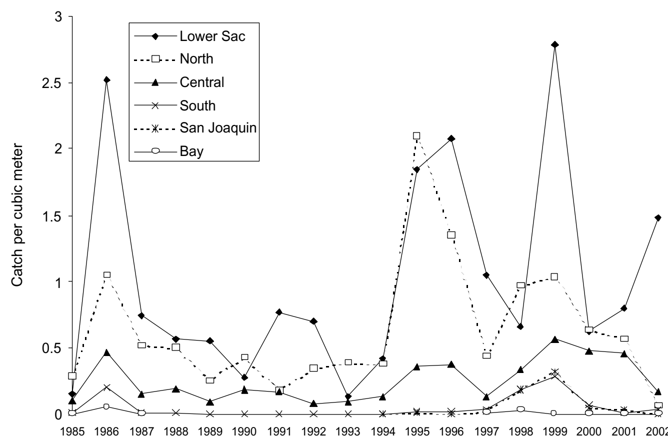

Figure 2 Mean catch per cubic meter for January through March of all unmarked juvenile Chinook in the lower Sacramento, North Delta, Central Delta, South Delta, San Joaquin, and Bay area beach seines between 1981 and 2002. Bay Area beach seining was not conducted between 1987 and 1996; lower Sacramento, North Delta, Central Delta, South Delta CPM^3 began in 1985; and the San Joaquin beach seine started 1994.

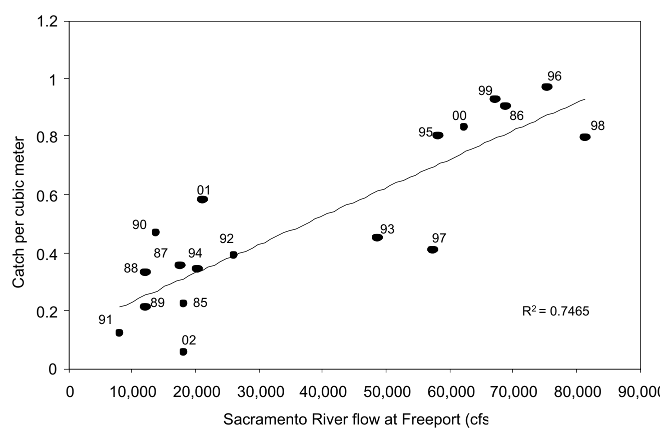

Figure 3 Regression of mean January through March Chinook fry from the North Delta beach seine on mean February flow at Freeport.

From late fall through early spring, winter run and spring run smolts emigrate using mid-channel routes. Later in spring, the more abundant fall run smolts begin exiting the rivers. Since 1988, a midwater trawl towed by a single boat has been the standard trawl gear in the Sacramento River at Sherwood Harbor. Beginning in 1994, a wider Kodiak trawl, towed by two boats was employed from October through March to more effectively capture the relatively large and rare winter and spring-run smolts as they emigrated. The midwater trawl has been consistently used from April through September to maintain consistency in the type of sampling gear used during this period, and to limit the potential of large catches possible if the Kodiak trawl were used. A standard sampling day for both trawls was ten 20-minute tows. Trawl sampling results were standardized to CPM^3 for each tow and by race. Race determinations were based upon daily size criteria developed by Sheila Greene and Frank Fisher, and derived in part from the work of R. Johnson and others (1992). Tow volumes were calculated as the product of the mouth area (previously measured), and the distance the net traveled through the water as measured by a General Oceanics flow meter. For analysis and presentation, mean CPM^3 was calculated.

The Sacramento trawl showed fall-run smolt emigration peaked in either April or May, but continued into June in most years (Figure 4). The April 1991 peak resulted from three days of extremely high catches of what were believed to be hatchery releases of fry at Miller Park, only a few miles upstream of the trawl location. For 2002, monthly CPM^3's were similar to those of 2001, and overall lower than those of previous years.

To assess the effects of late winter flows on subsequent smolt migration in the Sacramento River, mean April-June CPM^3 was regressed on February mean daily Sacramento River flow (Figure 5). Late winter flow had a significant negative effect on fall-run smolt catch ($r^2 = 0.494$, $p < 0.01$). The result, in combination with the flow relationship depicted in Figure 3, indicated that high winter flows transported fall-run fry downstream earlier in the year, leaving fewer to emigrate as smolts in the April-June period.

Since 1997, Kodiak trawling at Mossdale has been conducted to monitor juvenile Chinook entering the Delta from the San Joaquin drainage. DFG's Region 4 conducted sampling during the April through June period each year.

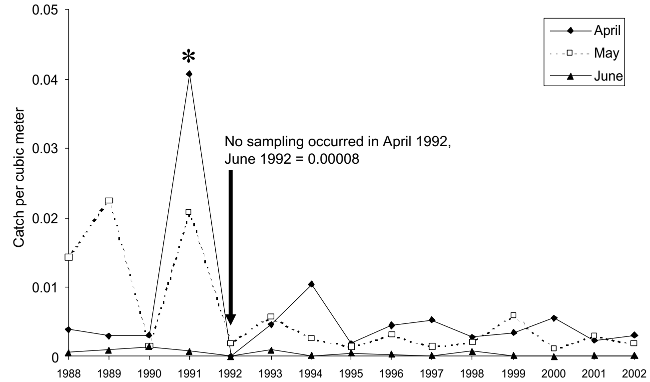

Figure 4 Sacramento trawl (Region 2) catch per cubic meter of all unmarked juvenile Chinook between 1988 and 2002, for April, May, and June. * Due to high catches on April 29, May 1 and May 3, 1991, 10-minute tows were conducted most of each sample day. Each 10-minute tow was then standardized to 20 minutes, doubling the CPM^3 for each tow.

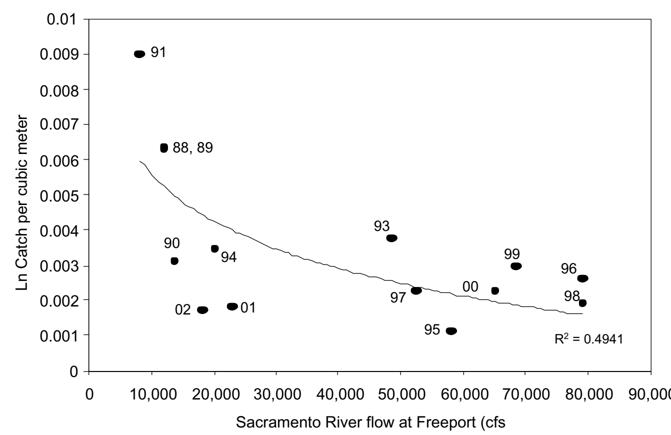

Figure 5 Mean catch of Chinook smolts between April 1 and June 30 in the midwater trawl at Sacramento regressed with mean February flow at Freeport. There was no sampling during April 1992, so that year was not included.

Between 1997 and 2002, either April or May produced the highest monthly CPM^3 for the year, except in 1998, the only year when June had the highest CPM^3 (Figure 6). In 2002 (a dry year), total CPM^3 was the lowest for the 1997-2002 period; 2001was also considered a dry year, but had the highest CPM^3. This may have been in part due to the higher survival through the tributaries in 2001 (VAMP Report 2002) (Figure 6).

Absolute abundance estimates of juvenile Chinook at Chipps Island have been calculated for fall/spring, late-fall, and winter run races for 1994 through 2002, and were used here to follow trends in smolt production. Fall and spring run were combined due to faster growing fall run being mis-identified as spring run using the size criteria. The absolute abundance of smolts of each race passing Chipps Island was calculated as the quotient of total catch by race and a "recovery rate". Calculation of a recovery rate incorporated information from one or more coded wire tagged (CWT) release experiments in which two groups of tagged Chinook were released at the same time, one upstream and one downstream of Chipps Island. CWT fish from the upstream release were recaptured at Chipps Island and fish from both groups were subsequently recaptured in the ocean fishery. The recovery rate for an experiment was calculated as the quotient of the number of CWT fish captured at Chipps Island and the number available for capture, where this latter value was the product the fraction of time the net was in the water sampling during the recovery period and the number of the upstream group that survived to reach Chipps Island. The number surviving to Chipps Island was the product of the number released upstream and the quotient of the ocean recovery rates of the upstream release group and the downstream release group. The "recovery rate" used in the absolute abundance calculation was the mean of the experimental recovery rates for all paired-releases in a year (USFWS, 1999 Annual Report and Fish Bulletin 179).

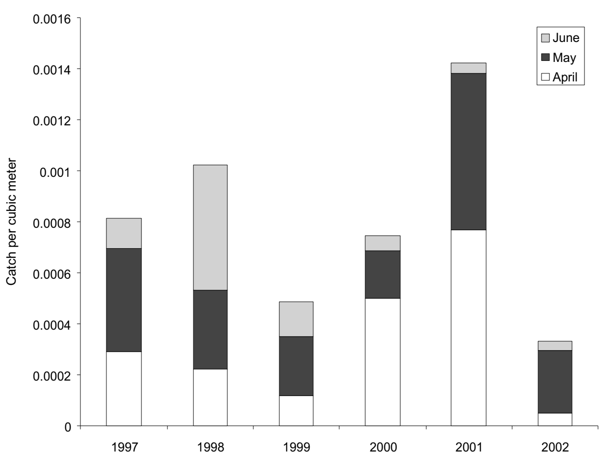

Figure 6 Mossdale Kodiak trawl (Region 5) catch per cubic meter of all unmarked juvenile Chinook between 1997 and 2002, for April, May, and June.

Fall/spring numbers for 2001 and 2002 were the lowest for the years shown (Figure 7). Late-fall numbers in 2002 were higher than the previous two years, while winter run numbers continued to decline. Overall, there has been a decline in abundance, however this may be in part due to the trawl efficiency estimates for 2000 through 2002. This may change as annual estimates of efficiencies are made and used to expand catches in these years. Efficiencies for the other races were based primarily on fall run and could bias estimates if efficiencies were significantly different for the other races.

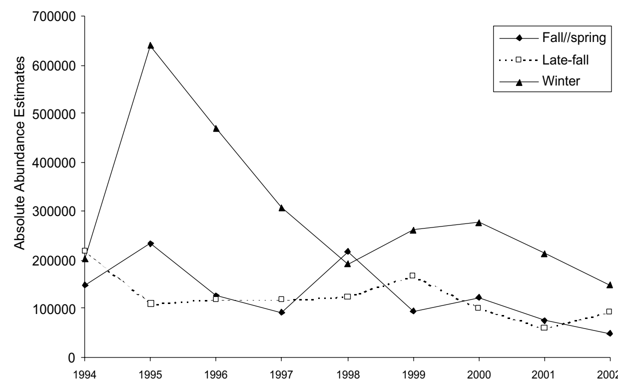

Figure 7 Chipps Island absolute abundance estimates for fall/spring (x's 0.01), late-fall, and winter run juvenile Chinook, 1994 through 2002. For 2000 through 2002, mean trawl efficiency was calculated by averaging the mean trawl efficiencies for 1994 through 2000, since there were no ocean trawl recoveries for those years. Yearly fall/spring and winter run estimates were calculated from the standard field season, August through July. Late-fall estimates were calculated from April through March to reflect the run timing.

The regression of April through June CPM[3] at Chipps Island and flows at Rio Vista showed a positive relation (Figure 8; $r^2 = 0.5841$, $p < 0.01$). Flow information was taken at Rio Vista, since it was the lowest gauging station still on the Sacramento River. It would appear that the low numbers of fall run identified above might be accounted for by the low flows in April through June in 2002. Since 1997, mean catch per cubic meter indices at Chipps Island between April and June have been lower than the established regression line. This indicates that fall run production recently has been lower on average, per unit of flow compared to past years.

Acknowledgments

We wish to acknowledge Region 4, DFG, for conducting Kodiak trawling April through June Kodiak trawling at Mossdale, and DFG boat operators for their assistance with operating FWS vessels.

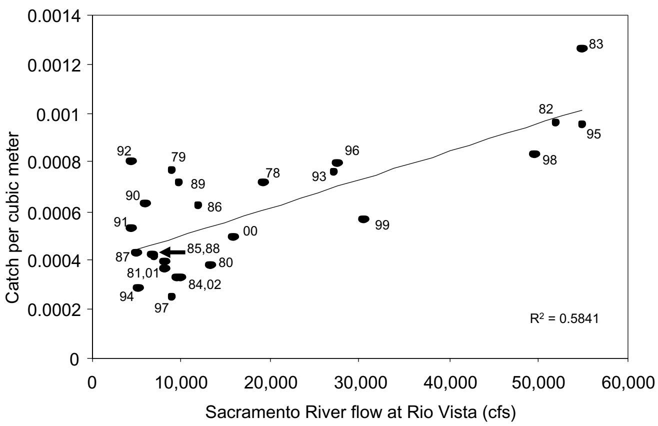

Figure 8 Mean catch of unmarked Chinook salmon smolts per cubic meter in the midwater trawl at Chipps Island between April and June of 1978 to 2002 versus mean daily Sacramento River flow at Rio Vista between April and June in cfs.

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Chinook Salmon Catch and Escapement

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In 2002 the ocean catch of Central Valley Chinook salmon increased in both the commercial and recreational fisheries from 2001. Compared to the 1970-2002 period of record the ocean catch was average but the catch per unit effort remained above average, as it has since 1994.

The total escapement of fall, spring, and winter run Chinook salmon also increased from 2001 to 2002. In 2002 the fall run Chinook escapement to the mainstem Sacramento River was the highest for the 1970-2002 period and was the greatest contributor to the Central Valley fall run escapement. The escapement remains above the average, as it has since 1995. Spring run escapement to both Mill and Deer creeks has continued to increase with the average escapement from 1995 to 2002 remaining higher than the average escapement from 1977 to 1994. Winter run escapement increased to the highest levels since 1981. The increased three-year cohort replacement rate also indicates that population is continuing the upward trend started in 1995.

The increases in both the ocean fisheries and the Central Valley escapement indicate that the Chinook populations have generally been doing better since 1995 compared to the period from 1977 to 1994. Both favorable ocean conditions and harvest restrictions contributed to this trend.

Central Valley Chinook Fall Run Ocean Harvest Index and Ocean Catch

The Pacific Fishery Management Council (PFMC) develops regulations to reduce harvest levels and protect listed Central Valley winter and spring run Chinook as well as Klamath River fall run Chinook. These include setting minimum size limits, gear restrictions and season restrictions south of Point Arena. These restrictions reduce harvest of all Chinook runs.

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 account for up to 25% of the returning adults. In 2001 the OHI decreased to the lowest level (27%) in the 1970-2002 period due to sharp increase in fall run escapement and decrease in ocean catch (Figure 1). In 2002 the OHI increased to 34% due to an increase in ocean catch, but remains well below the average ocean harvest index of 64% from 1970-2002 (Figure 1). The Central Valley fall run escapement was also the highest for the 1970-2002 period with 844,000 spawners (Figure 1).

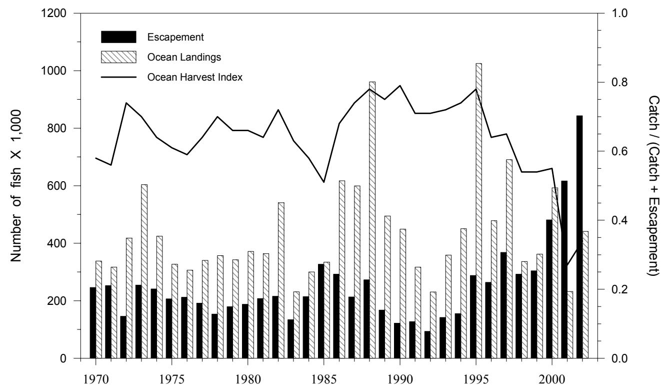

Figure 1 PFMC Chinook salmon ocean catch, the Central Valley fall run Chindook adult spawner escapement and ocean harvest index, 1970-2002.

The increase in ocean catch between 2001 and 2002 is due to an increase in both effort and the catch per unit effort (CPUE). For the commercial fishery the number of days fished increased from 14,000 in 2001 to 17,000 in 2002 and the CPUE increased substantially from 14,000 fish/day to 23,000 fish/day (Figure 2). The CPUE (fish/day) and escapement also increased in Washington and Oregon, indicating that current ocean conditions are favorable for Chinook survival along the west coast of the contiguous United States (Figure 2).

The recent shift in the Pacific Decadal Oscillation (PDO) from a "warm" PDO phase to a "cool" PDO phase in the mid-1990s has enhanced the productivity for California, Oregon, and Washington (Mantua and others 1997; Minobe 1997). During the last "warm" PDO phase, which lasted from 1977 to approximately 1994, the CPUE in California averaged 9,700 fish/day. In the period since 1994 the CPUE has averaged 20,500 fish/day. In Oregon the CPUE increased from 7,600 fish/day to 20,800 fish/day over the same period. The most dramatic increase occurred in Washington where the average CPUE increased from 7,500 fish/day to 37,000 fish/day. The "cool" PDO phase has been correlated to low salmon production in Alaska and relatively high salmon production for California, Oregon, and Washington (Hare 1996; Hare and others 1999). Therefore the increases in Central Valley fall run escapement and ocean catch are, in part, a function of favorable ocean conditions.

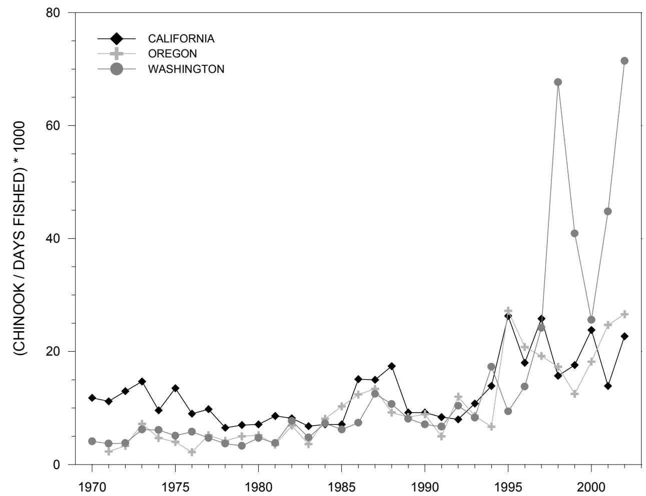

Figure 2 Chinook salmon catch per unit effort in the California, Oregon, and Washington commercial trolls, 1970-2002.

Central Valley Fall Chinook Escapement

The fall run Chinook escapement to the mainstem Sacramento River, Yuba River and the San Joaquin River system escapements increased (Figures 3, 7 and 8) from 2001 levels. The fall run Chinook escapement to the American and Feather rivers decreased, but were still higher than the average escapement for the 1970-2002 period (Figures 5 and 6).

In 2002 the PFMC set the escapement goal range of 122,000 to 180,000 natural and hatchery adults for the mainstem Sacramento River. The estimated number of natural spawners was 732,000, far exceeding the PFMC management goals (Figure 3). The cohort escapement was also at the highest level in the last three decades at about 722,000 (Figure 4). I calculated the cohort escapement by adding three-year olds from the current year and two-year olds from the previous year.

Natural spawner escapement in the American River decreased from about 180,000 in 2001 to 124,000 in 2002; however, it is the second highest escapement in the 1970-2002 period (Figure 5). In the Feather River the estimated escapement decreased to 93,000 in 2002, but it is more than double the estimated escapement of 36,000 from 1999 (Figure 6).

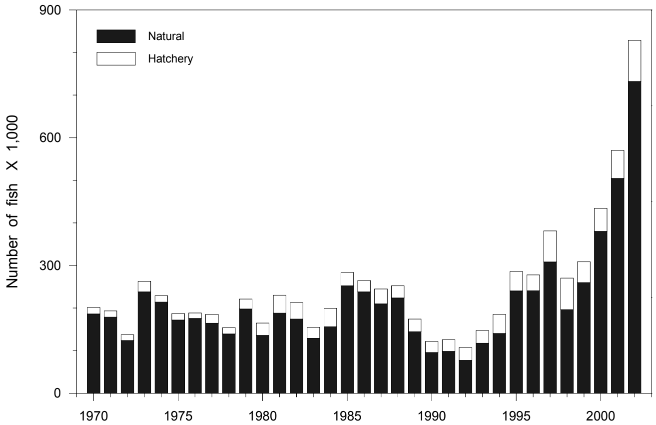

Figure 3 Annual fall run escapement to the Sacramento River and major tributaries, natural and hatchery contribution, 1970-2002.

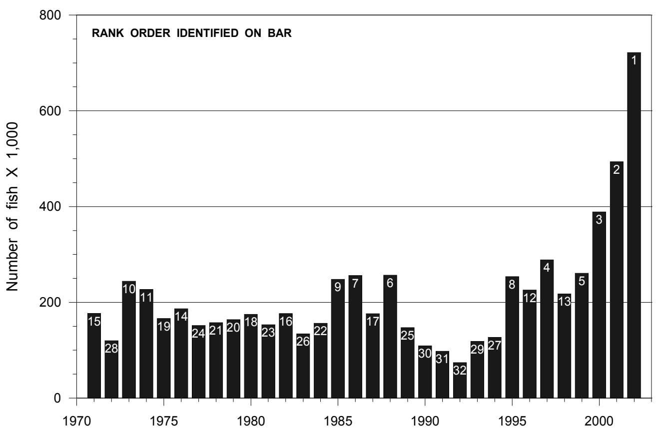

Figure 4 Annual natural, fall run cohort escapement to the Sacramento River and major tributaries, 1970-2002.

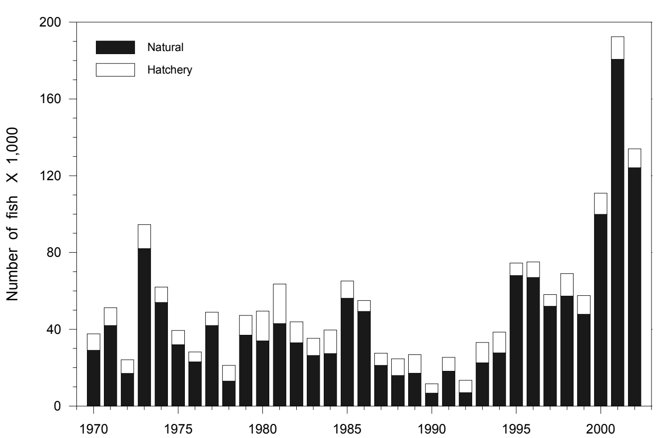

Figure 5 Annual fall run escapement to the American River, natural and hatchery contribution, 1970-2002.

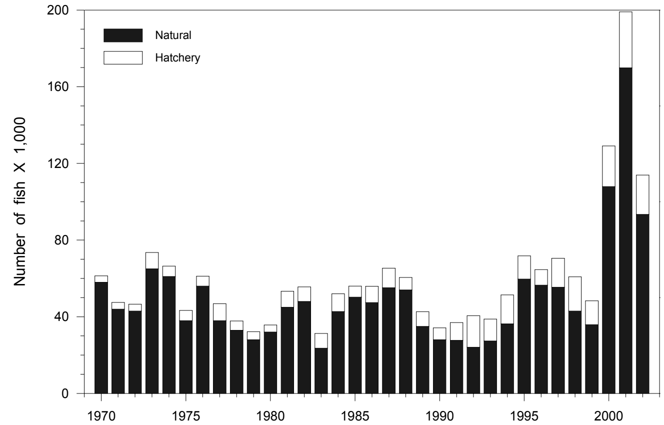

Figure 6 Annual fall run escapement to the Feather River, natural and hatchery contribution, 1970-2002.

The estimated Yuba River fall run escapement increased slightly from 22,000 in 2001 to 23,600 in 2002 (Figure 7). In 2002 the escapement was roughly equal to the escapement three years earlier (Figure 7). On the San Joaquin River system the estimated escapement also increased to about 28,000 in 2002 (Figure 8). The escapement remains higher than the thirty-year average and increased from the 1999 escapement of approximately 18,000 Chinook (Figure 8). 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.

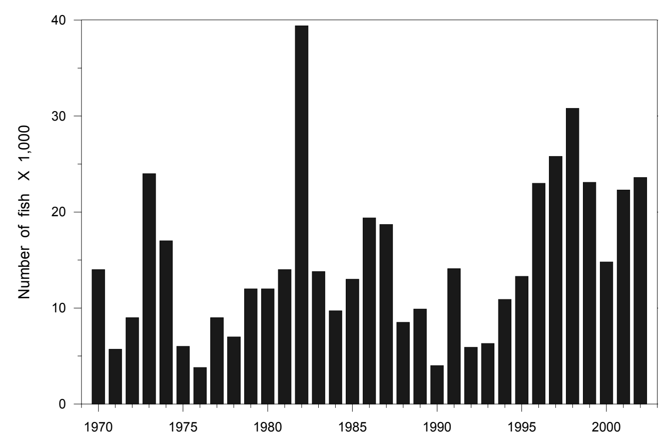

Figure 7 Annual natural, fall run escapement to the Yuba River, 1970-2002.

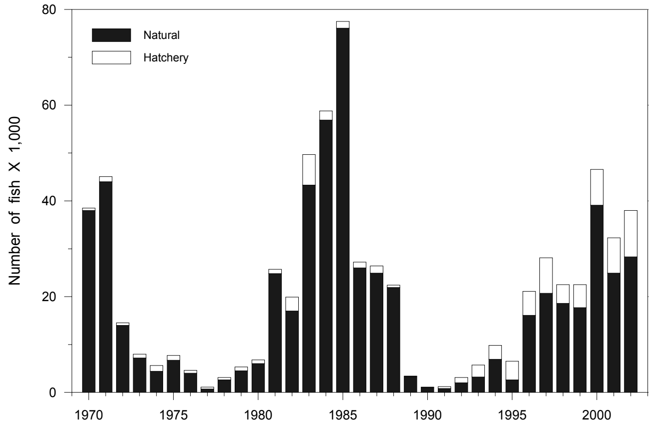

Figure 8 Annual fall run escapement to the San Joaquin River system, natural and hatchery contribution, 1970-2002.

Sacramento River System Spring Run Escapement

The number of natural spawners increased on Mill and Deer creeks at an estimated 1,600 and 2,200 respectively (Figure 9). The escapement on both Mill and Deer creeks were the highest since 1975. For Mill Creek the number of spawners more than doubled from 1999 and for Deer Creek the number of spawners increased approximately 25% from1999.

The Butte Creek escapement decreased slightly from 2001, but continues to surpass the other spring run tributaries and the mainstem Sacramento River with an estimated escapement of 8,800 (Figure 9). The estimated escapement did however more than double that from three years earlier.

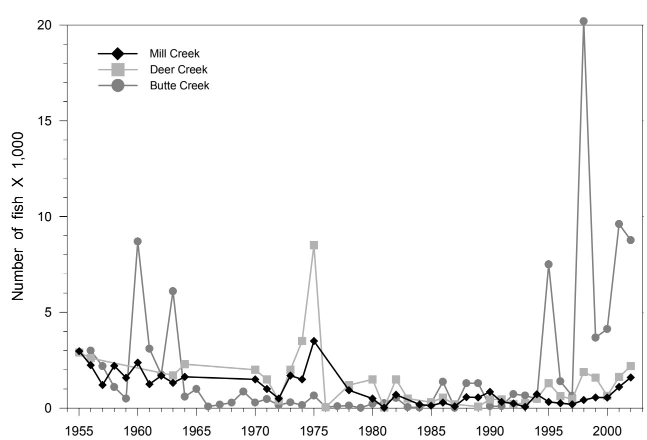

Figure 9 Annual spring run escapement to Mill, Deer, and Butte creeks, 1956-2002.

Winter Run Escapement to the Sacramento River below Keswick Dam

The PFMC estimated the winter run escapement at 9,200 based on the extrapolated counts at Red Bluff Diversion Dam in 2002 (Figure 10). This was the highest escapement since 1981 and only 17% of the fish were jacks (1,600). The three-year cohort replacement rate was 6.7, which far exceeds the PFMC target rate of 1.77. This is the highest three-year cohort replacement rate since 1983 (Figure 10). The gates at Red Bluff Diversion Dam were raised during much of the upstream migration to allow the passage of winter run Chinook.

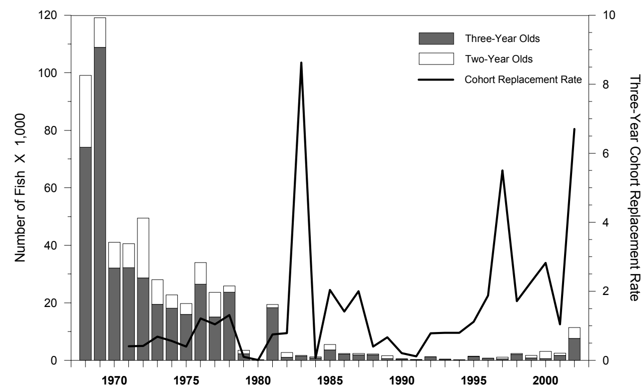

Figure 10 Annual winter run cohort escapement and the three-year cohort replacement rate to the upper Sacramento River, 1967-2002.

NMFS and DFG have used carcass surveys as an alternative method of estimating escapement since 1996. In 2002, NMFS and DFG estimated the winter run escapement at 9,172 using the carcass survey results, which is more than double the escapement of 3,300 in 1999. Currently the two methodologies are under review by NMFS, DFG, and PFMC.

Most of the data presented in this article is published in the PFMC's *Review of the 2002 Ocean Salmon Fisheries* 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 estimated spring run Chinook escapement data for Mill, Deer, and Butte creeks.

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Splittail Abundance, 2002

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In this article I summarize trends in splittail abundance and distribution based on data from the U.S. Fish and Wildlife Service's Beach Seine Survey (Beach Seine Survey) and from the San Francisco Bay Study's (Bay Study) midwater and otter trawl sampling. Trends in splittail salvage at the state and federal fish collection facilities and in the Fall Midwater Trawl Survey are presented elsewhere in this issue. The Beach Seine Survey samples at fixed sites throughout the delta and upstream in the Sacramento River to Colusa (river mile 144) and has been very effective at capturing age-0 splittail. The annual Beach Seine Survey abundance index was calculated as the sum across sampling regions of mean May through June (a period of dispersal and high vulnerability for age-0 splittail) catch per haul by region. The sampling regions follow Sommer and others (1997) for the delta, but three Sacramento River regions have been added. Bay Study trawl sampling stations used to calculate abundance indices extend from South San Francisco Bay to just upstream of the confluence of the Sacramento and San Joaquin rivers. A description of the Bay Study sampling area, sampling methods and gears, and index calculation can be found in Orsi (1999).

The current Beach Seine Survey has captured age-0 splittail in years when trawl surveys have not, including 2002, indicating that it provides a more reliable means of detecting age-0 recruitment and possibly of following age-0 trends than do trawl surveys. Age-0 splittail abundance in the Beach Seine Survey reached a near-record high level in 2000, then declined steeply through 2002 (Figure 1). The 2002 index was the second lowest for the period of record, but not unexpected given the relatively low outflow during the March-May spawning period. Similar to other years with low spring outflows (e.g., 1992, 1994, and 1997), the largest catches of age-0 splittail occurred in the Sacramento River regions, well upstream of trawl survey sampling areas. This upstream distribution partially explained the limited detection of dry-year recruitment by trawl surveys.

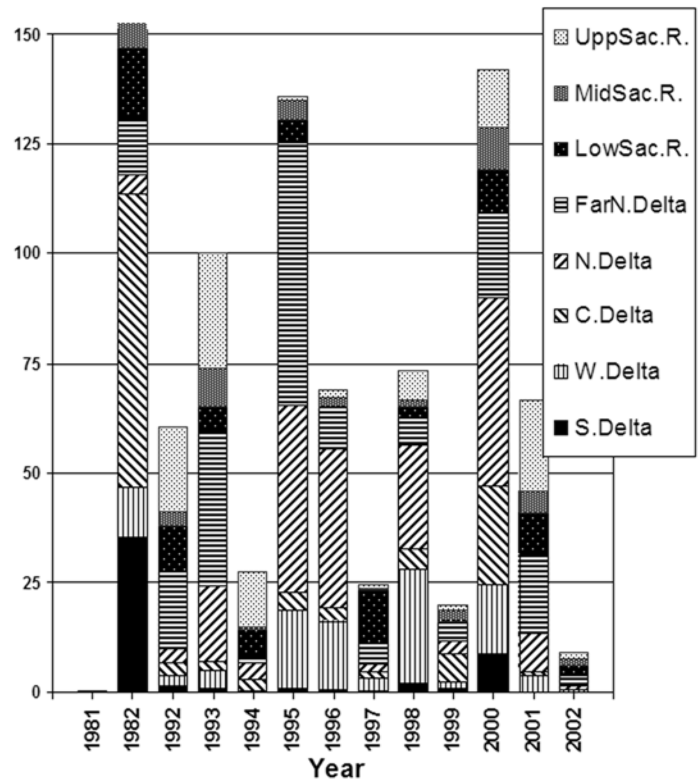

Figure 1 Splittail young-of-the-year (age-0) annual abundance indices for fish > 24 mm FL from the USFWS's Beach Seine Survey sampling, 1981, 1982, and 1992-2002. Regions follow Sommer and others 1997, except LowSac.R. (American River to Feather River), MidSac.R. (Knights Landing to Butte Creek), and UppSac.R. (Colusa State Park to Ord Bend).

Bay Study sampling provided an even less positive assessment of splittail production in 2002 than the Beach Seine Survey. No age-0 splittail were captured at index stations by either the midwater or otter trawls (Figures 2 and 3). The only Bay Study trawl evidence of 2002 recruitment came from two age-0 fish captured at non-index stations within the delta. Since 2000, the midwater trawl abundance trend mimicked the Beach Seine abundance decline, while the otter trawl abundance index dropped to zero in 2001 and remained at zero in 2002. Historically both Bay Study trawls have detected major recruitment events well, but the otter trawl in particular has missed evidence of recruitment in low outflow years.

This non-detection of initial recruitment was further exemplified by the increase in age-1 indices for both midwater and otter trawls in 2002 after few and none, respectively, were captured as age-0 fish in 2001 (Figures 2 and 3). This has occurred in the past (e.g., the 1999 year-class) and probably resulted, in part, from age-1 fish moving farther downstream and offshore than age-0 fish, increasing their vulnerability to Bay Study trawl capture.

The 2002 age-2+ indices (age 2 and older fish) for both Bay Study trawls declined from 2001 levels, but continue to suggest a somewhat stable trend in adult numbers since 1999 (Figures 2 and 3). The 2002 midwater trawl index declined only slightly from 2001, complementing a series of relatively high and stable abundance indices, excepting 1998 and 2000, that began in 1997 (Figure 2). The 2002 otter trawl index declined substantially from 2001, but remained similar to levels in 1999 and 2000 (Figure 3). Both indices were composed primarily of age-2 splittail (as opposed to ages 3, 4, and 5 also), which suggests good survival of the 2000 year class.

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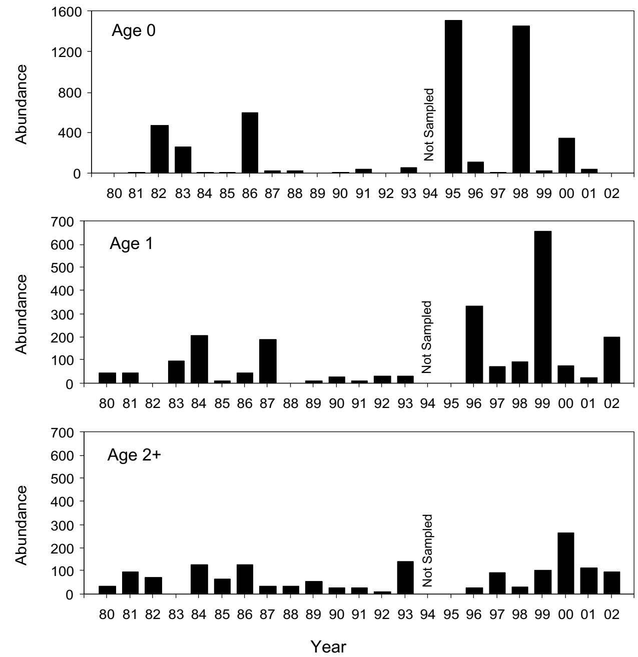

Figure 2 Splittail annual abundance indices for young-of-the-year (age-0, top), age-1 (middle), and adult (age-2+, bottom) fish captured in DFG's San Francisco Bay Study midwater trawl survey, 1980-2002. Sampling in 1994 was insufficient to calculate an index.

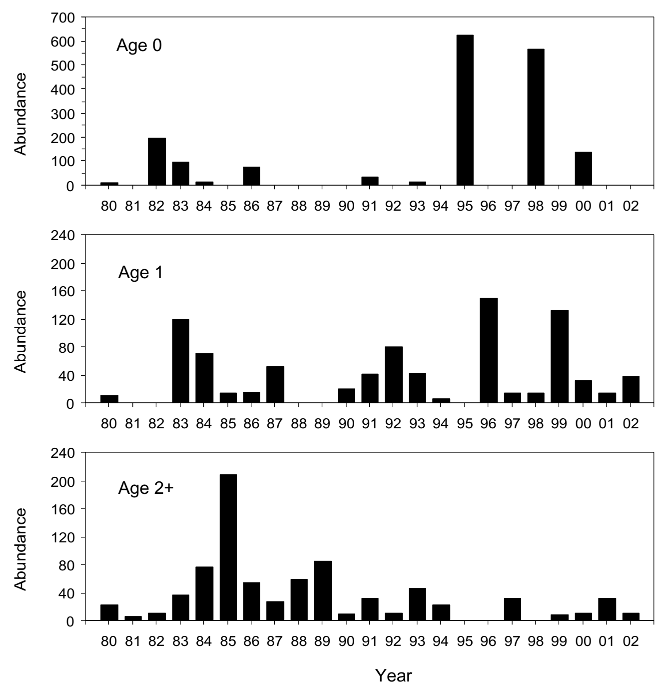

Figure 3 Splittail annual abundance indices for young-of-the-year (age-0, top), age-1 (middle), and adult (age-2+, bottom) fish captured in DFG's San Francisco Bay Study otter trawl survey, 1980-2002.

Summer Townet Survey and Fall Midwater Trawl Survey

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Introduction

Young striped bass (*Morone saxatilis*) and delta smelt (*Hypomesus transpacificus*) are indexed twice in their first year of life, first by the Summer Townet Survey (TNS) and later by the Fall Midwater Trawl Survey (FMWT). The indices are used to evaluate distribution and abundance trends in the San Francisco Estuary. These surveys have been running since 1959 (TNS) and 1967 (FMWT), with no sampling occurring in 1966 (TNS), 1974, and 1979 (FMWT). Only age-0 striped bass and delta smelt abundance indices are presented from the TNS, but for the FMWT, in addition to the aforementioned species, we also present indices for longfin smelt (*Spirinchus thaleichthys*), American shad (*Alosa sapidissima*), threadfin shad (*Dorosoma petenense*), and splittail (*Pogonichthys macrolepidotus*).

Survey Areas and Methods

The TNS begins in late June or early July, when the size of striped bass caught in the 20-mm survey averages approximately 25-mm. The TNS samples 32 stations from eastern San Pablo Bay to Rio Vista on the Sacramento River and Stockton on the San Joaquin River. All stations are sampled in a five-day period. The survey is repeated at two-week intervals until the mean length of striped bass caught exceeds 38.1-mm. Sampling at each station consists of up to three 10-minute, stepped, oblique tows with a ski-mounted net. Survey and annual index calculations for striped bass are described in Chadwick (1964) and Turner and Chadwick (1972). The TNS delta smelt index is calculated by averaging the first two survey indices.

The FMWT survey samples 116 stations from San Pablo Bay east to Stockton on the San Joaquin River and to Hood on the Sacramento River. Monthly and annual indices are based on catch data from 100 of the 116 stations. The remaining 16 stations increase the spatial coverage for delta smelt sampling. Sampling is conducted monthly from September to December. Calculations of survey (monthly) and annual indices for the FMWT are presented in Moyle and others (1992).

Striped Bass

A 2002 striped bass 38.1-mm index was not calculated. Record low catches and consistently small fish throughout the season, along with boat breakdowns during the fifth survey, made calculating an index unfeasible. The TNS striped bass total catch of 307 for 2002 was the lowest recorded and represented a 70 % decline from 2001 and 83% from 2000. The 2002 FMWT index was 71, a 90.3% decrease from the 2001 index of 729 (Figure 1). The 2002 FMWT index was the lowest of record; the previous lowest was in 2000 with an index of 390. Both surveys showed a large drop in the number of age-0 striped bass caught during the 2002 sampling season.

Age-0 striped bass moved downstream as the summer progressed. During Townet survey 1 (June 16-20), the majority of striped bass were caught in the south Delta, and during survey 2 (June 29-July 3) in the lower San Joaquin River. Sampling during survey 3 (July 14-18) and survey 4 (July 29-August 2) caught the majority in the Sacramento River. No striped bass were caught in the south or east Delta during surveys 4 and 5.

The FMWT detected the highest concentrations in Suisun Bay, followed by the lower San Joaquin River. San Pablo Bay did not contribute to the index in any of the months, differing from 2001 when San Pablo Bay accounted for the greatest proportion of the September index.

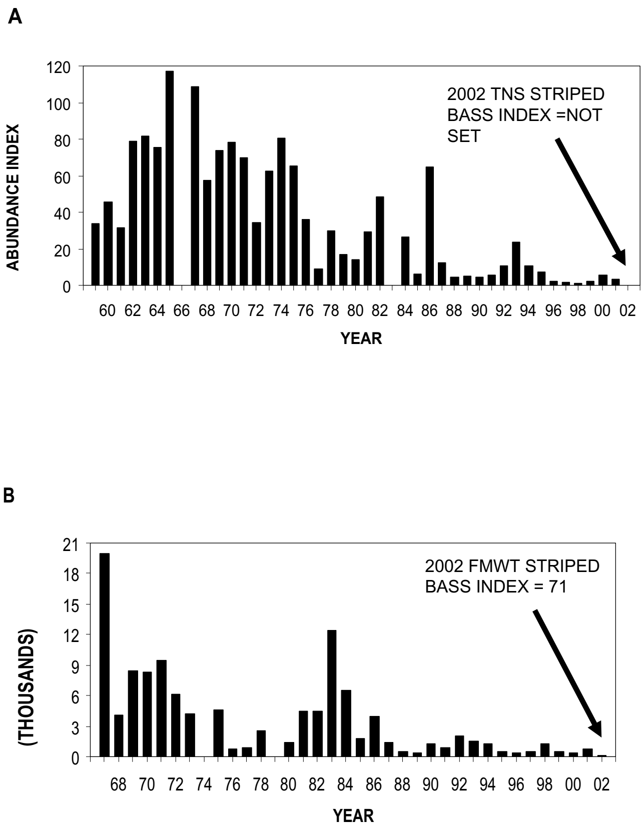

Figure 1 Age-0 striped bass abundance indices for FMWT 1967-2002 (no sampling occurred in 1974 and 1979).

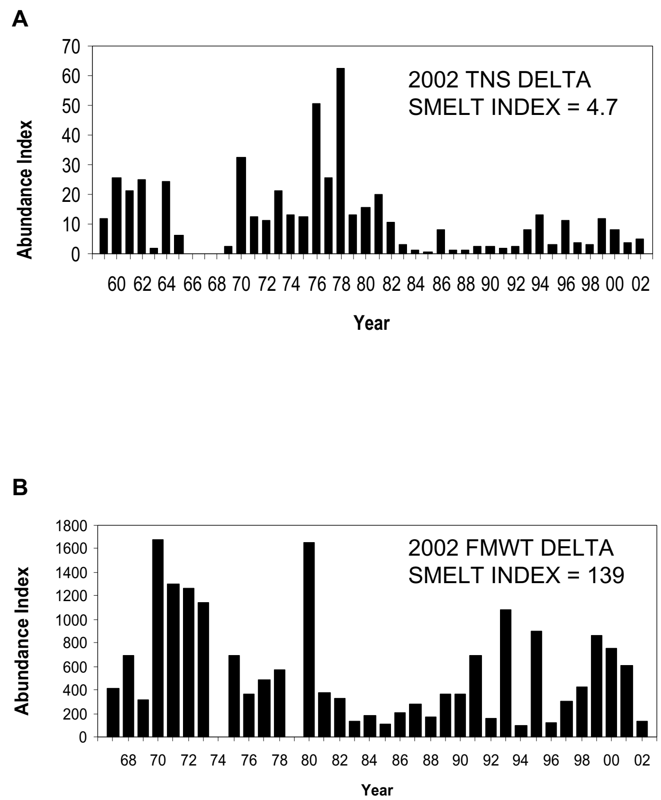

Figure 2 Delta smelt abundance indices for A) TNS 1959-2002 (no sampling occurred in 1966 and delta smelt were not enumerated in 1967-1968); and B) FMWT 1967-2002 (no sampling occurred in 1974 and 1979).

Delta Smelt

The TNS delta smelt abundance index for 2002 was 4.7, an increase over last year's 3.5 (Figure 2A), but still 92.75% lower than the historical record index of 62.5. The 2002 FMWT index was 139, 77% lower than last year's index of 603 (Figure 2B). This was the lowest FMWT delta smelt index since 1996 (127).

The majority of delta smelt caught during the TNS came from the Sacramento River. In survey 3, delta smelt were collected primarily in the Sacramento River and Suisun Bay, but in survey 4 the percentage of the total catch dropped in Suisun Bay as it increased in the Sacramento River. During the FMWT, the delta smelt distribution moved downstream over time. The majority of catch during the September survey came from the lower Sacramento River. The catch was split between Suisun Bay and the lower Sacramento River during October and November surveys and the catch came almost entirely from Suisun Bay in December. No delta smelt were caught in San Pablo Bay or Carquinez Strait in any month.

Longfin Smelt

A large portion of the longfin smelt population rears downstream of the TNS sampling area, so no TNS index was calculated. The 2002 FMWT longfin smelt abundance index was 707, an increase from the 2001 index of 247 (Figure 3). The distribution of longfin smelt gradually shifted upstream over the course of sampling. In September and October, the highest concentrations were found in San Pablo Bay (50% from each month), followed by Suisun Bay with most of the remainder of the catch (48% and 30%, respectively). In November and December, the majority were found in Suisun Bay (44% and 75%, respectively).

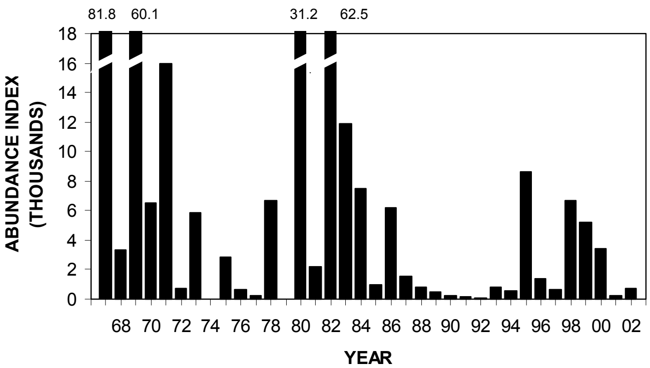

Figure 3 Longfin smelt abundance indices for FMWT 1967-2002 (no sampling occurred in 1974 and 1979).

Threadfin Shad

The 2002 FMWT threadfin shad index was 1,731, an 88% decrease from the 2001 index of 14,401, and the first decline in four years (Figure 4). This was the lowest FMWT threadfin shad index since 1985 (821). Most of the catch was concentrated in the lower San Joaquin River and Eastern Delta during all months except November, when the largest percentage of the catch (39%) came from Suisun Bay.

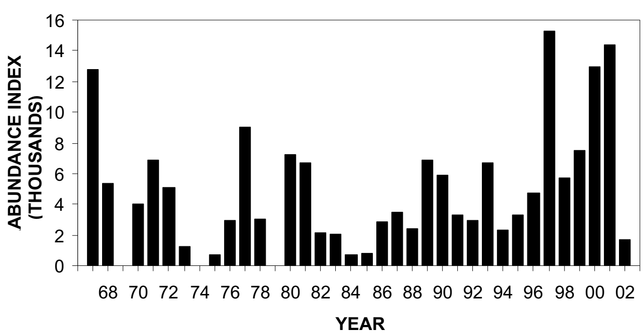

Figure 4 Threadfin shad abundance indices for FMWT 1967-2002 (no sampling occurred in 1974 and 1979).

American Shad

The TNS occurred before most of the American shad began to emigrate; therefore no index was calculated. The 2002 FMWT American shad index (1919), was nearly 2.5 times higher than the previous two years' indices of 764 (Figure 5). American shad were evenly dispersed throughout the sampling area. No American shad were caught in San Pablo Bay or Carquinez Strait in September, and most (80% of the index) were collected in the lower Sacramento River. This changed in October, November, and December when the lower Sacramento River area accounted for little (0%, 11%, 2%, respectively) of the American shad index, as distribution shifted westward into Suisun and San Pablo bays.

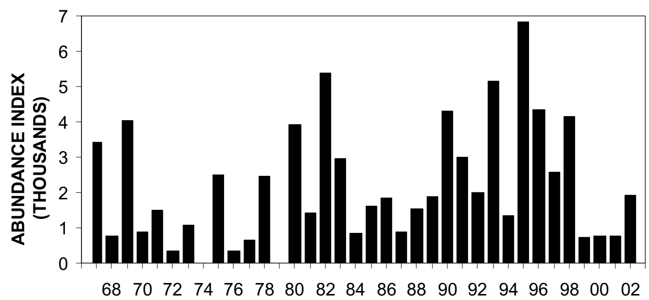

Figure 5 American shad abundance indices for FMWT 1967-2002 (no sampling occurred in 1974 and 1979).

Splittail

The TNS does not capture young splittail well; therefore, no index was presented.

The 2002 FMWT age-0 splittail index was 0 and the age-1 splittail index was 1. One age-1 splittail was caught in November in the San Joaquin River near Antioch.

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

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Introduction

Two large fish salvage facilities in the Sacramento-San Joaquin Delta—the Central Valley Project's Tracy Fish Collection Facility (TFCF) and the State Water Project's Skinner Delta Fish Protective Facility (SDFPF)—divert (salvage) fish from exported water. Both facilities use a louver-bypass system to collect entrained fish, which are then transported to release sites in the Delta. The TFCF began operation in 1957 and the SDFPF in 1968. The number of transported fish (salvage) is estimated from sub-samples of fish collected at least every two hours while water is being pumped.

Exports

State Water Project (SWP) water exports totaled about 3.44 billion m^3 (2,792,000 acre-feet) in 2002, compared to about 2.85 billion m^3 (2,319,000 acre-feet) in 2001. During 2002, monthly water exports at the SWP ranged from a low of about 47.4 million m^3 (38,455 af) in May to a high of about 510.3 million m^3 (414,034 af) in August (Figure 1), higher than the 2001 range of about 13.7 million m^3 (11,100 af) to 463.2 million m^3 (376,500 af).

Central Valley Project (CVP) water exports totaled about 3.08 billion m^3 (2,501,000 af), compared to about 2.79 billion m^3 (2,263,000 af) in 2001. Monthly water exports at the CVP in 2002 ranged from a low of about 65.2 million m^3 (53,000 af) in May to about 329.0 million m^3 (about 267,000 af) in both July and August (Figure 1), similar to the 2001 range of about 64.9 million m^3 (52,700 af) to about 313.4 million m^3 (254,280 af).

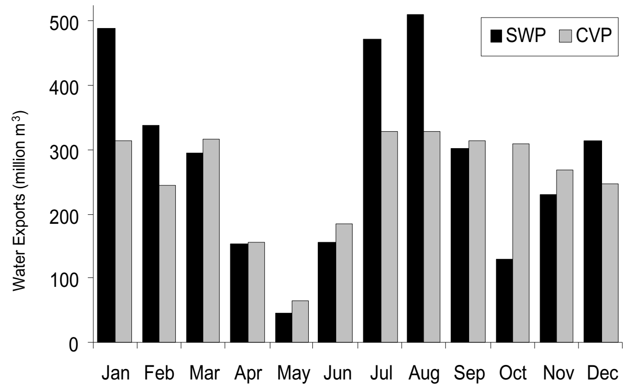

Figure 1 Monthly water exports in 2002 by SWP and CVP.

Fish Salvage

About 4.65 million fish were salvaged at the SWP in 2002, and almost 6.14 million fish were salvaged at the CVP. At both facilities, threadfin shad was the predominant species salvaged. Threadfin shad accounted for 54% of the annual salvage at the SWP (Figure 2) and 79% of the annual salvage at the CVP (Figure 3). There has been a general increase in the annual proportion of threadfin shad in the total salvage, particularly since 1995 (Figure 4).

Density of fish (individuals salvaged per 10,000 m^3) was highest at the SWP in July (578) and at the CVP in November (49) (Figure 5). Threadfin shad and striped bass together accounted for much of the salvage in July at the SWP (84%) and threadfin shad made up most of the CVP salvage during November (89%).

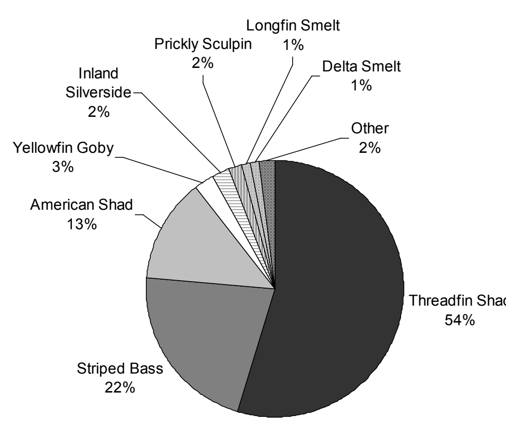

Figure 2 Relative species contribution to 2002 annual salvage at SWP.

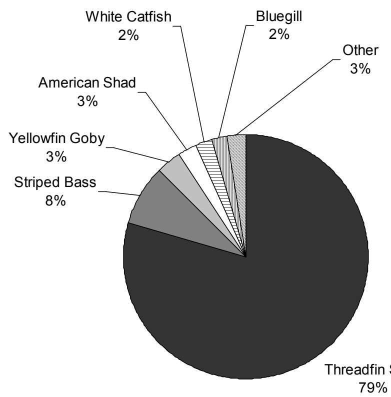

Figure 3 Relative species contribution to 2002 annual salvage at CVP.

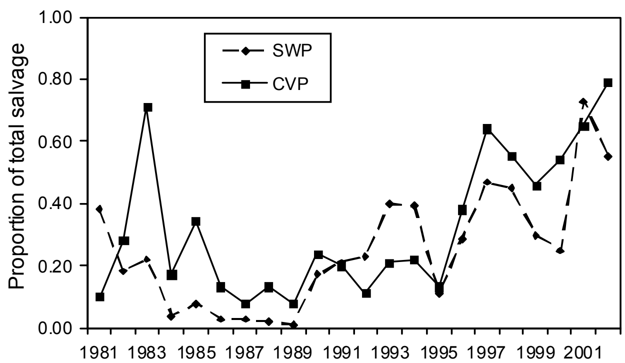

Figure 4 Relative proportion of threadfin shad in salvage at SWP and CVP.

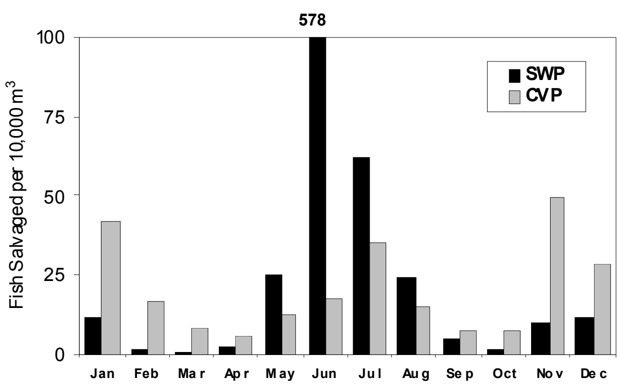

Figure 5 Fish salvage density in 2002 at SWP and CVP.

Delta Smelt

Estimated salvage of delta smelt at SWP in 2002 was 49,823, far more than the 13,219 salvaged in 2001, but still less than in 1999 and 2000 (Figure 6). Almost three quarters of the delta smelt at the SWP were salvaged during May (Figure 7).

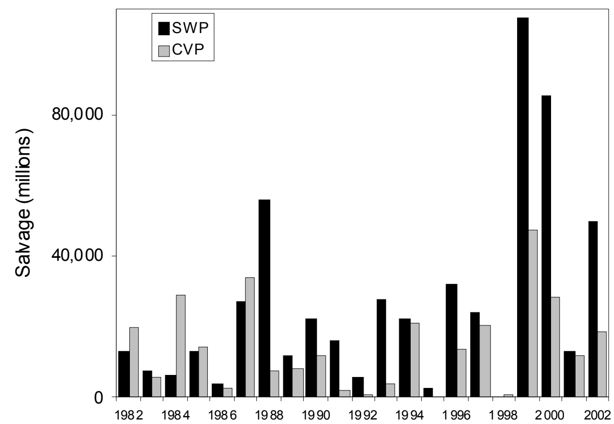

Figure 6 Annual delta smelt salvage at SWP and CVP.

In 2002, 18,396 delta smelt were salvaged at the CVP, more than the 11,700 salvaged in 2001. The highest salvage of adults (1,248) occurred in January (Figure 7) and this total was also the most in that month since 1988. The shift of peak adult salvage from February to January reversed a three-year trend of unusually high delta smelt salvage in February. About 15,700 young-of-the-year (YOY) delta smelt were salvaged in May and June, about double the 2001 YOY salvage, but only 70% of the YOY salvage in 2000.

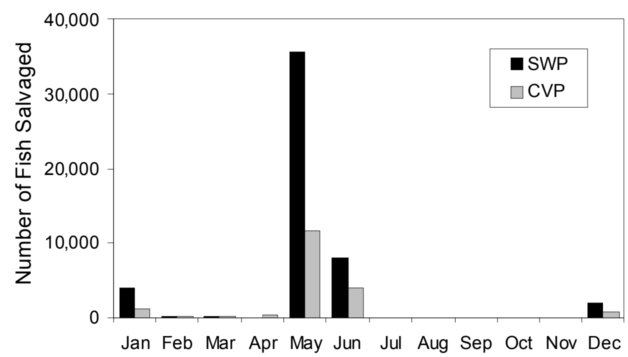

Figure 7 Monthly salvage of delta smelt at SWP and CVP in 2002.

Chinook Salmon

The combined (SWP+CVP) salvage of Chinook salmon was 21,909, lower than the 57,806 salvaged in 2001, much lower than the 1992-2001 annual average (84,950), and far lower than the 1982-1991 annual average (333,023) (Figure 8). One-third of the salmon salvaged last year were adipose-fin clipped, indicating hatchery origin. Of the naturally-produced salmon, over half (56%) were spring run, 34% were fall run, and the remainder (10%) were winter run (as determined by fork length only) (Figure 9).

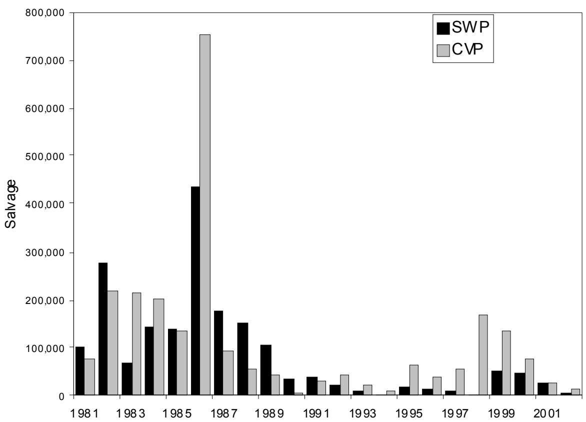

Figure 8 Annual Chinook salmon salvage at SWP and CVP

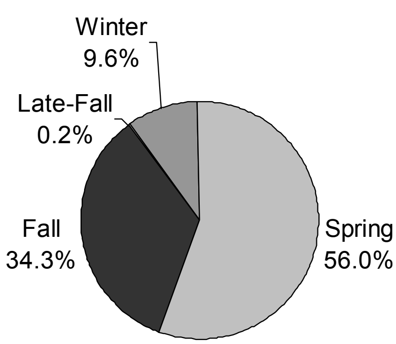

Figure 9 Percent of Chinook salmon runs in 2002 salvage at SWP and CVP. Race determined solely by length.

The CVP facility salvaged more than 3 times the number of Chinook salmon than the SWP facility during 2002 (Table 1). Salmon salvage at the SWP facility peaked in May, a month after it peaked at the CVP; almost 60% of the annual salmon salvage at the CVP came in April (Figure 10).

Salmon loss, an estimate of the mortality resulting from entrainment at the export facilities, is based on estimates of pre-screen loss (predation), louver efficiency, and handling and trucking mortality. Total salmon loss (SWP+CVP) in 2002 was 39,256, more than twice the salmon salvage. Approximately 42% of the salmon lost were adipose fin clipped, compared to only 5% in 2001. SWP loss was much higher than CVP loss (Table 2), reflecting the high predation mortality rate (75%) in Clifton Court Forebay.

Table 1 Wild Chinook salmon salvage at CVP and SWP in 2002.

Race	*SWP*	*CVP*	*Total*
Fall	1,384	3,626	5,010
Late-fall	14	12	26
Winter	606	794	1,400
Spring	1,267	6,910	8,177
Total	**3,271**	**11,342**	**14,613**

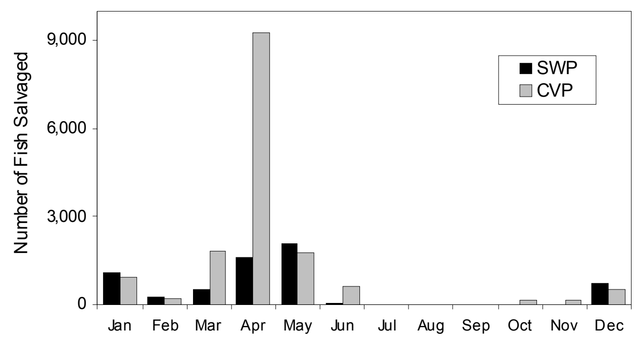

Figure 10 Monthly salvage of Chinook salmon at SWP and CVP in 2002.

Table 2 Wild Chinook salmon loss at CVP and SWP in 2002.

Race	*SWP*	*CVP*	*Total*
Fall	6,418	2,658	9,076
Late-fall	59	11	69
Winter	2,685	537	10,206
Spring	5,641	4,565	3,222
Total	**14,803**	**7,771**	**22,573**

Steelhead Trout

Steelhead salvage at both facilities in 2002 was much lower than in the previous two years (Figure 11). The SWP salvaged 2,181 steelhead, almost one-fourth of the 2001 total and about half of the 1992-2001 mean of 4,157 per year. The CVP salvaged 1,656, far below the 1992-2001 mean of 3,190 per year. Steelhead salvage was highest during March at both facilities (Figure 12).

About 68% of the steelhead salvaged at the SWP were adipose fin clipped, indicating hatchery origin, and about

42% of CVP salvaged steelhead were clipped. In 2001, about 65% of both SWP and CVP salvaged steelhead were hatchery-bred.

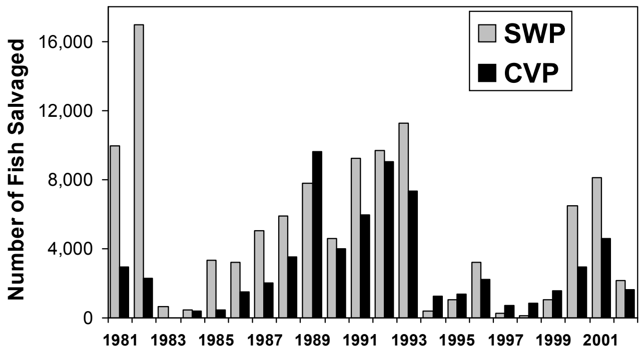

Figure 11 Annual steelhead salvage at SWP and CVP in 2002.

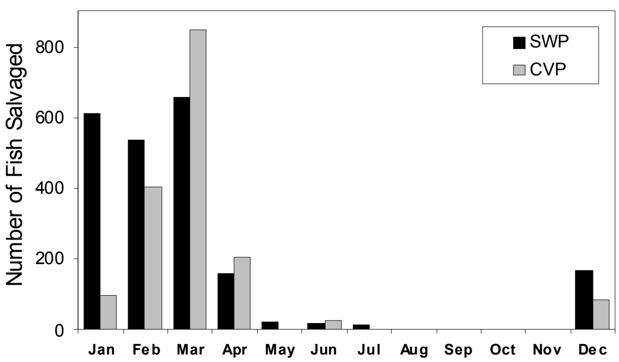

Figure 12 Monthly salvage of steelhead at SWP and CVP in 2002.

Striped Bass

In 2002, the SWP salvaged over 1 million striped bass, about half the 1992-2001 average of 2.07 million per year (Figure 13). At the CVP, almost 500,000 striped bass were salvaged, less than half the 10-year average of 1.24 million per year. Striped bass salvage peaked in June at the both facilities (Figure 14).

American Shad

About 608,000 American shad were salvaged in 2002 at the SWP and about 156,000 at the CVP, both lower than the 1992-2001 averages (Figure 15). The 2002 total at the CVP was the lowest since 1992. Monthly salvage of American shad at the SWP peaked at just over 200,000 in August. In contrast, relatively few American shad were salvaged in August at the CVP (about 12,000). At the CVP, salvage of American shad was highest in December. Since 1981, there has been a general trend of higher American shad salvage at both facilities (Figure 15).

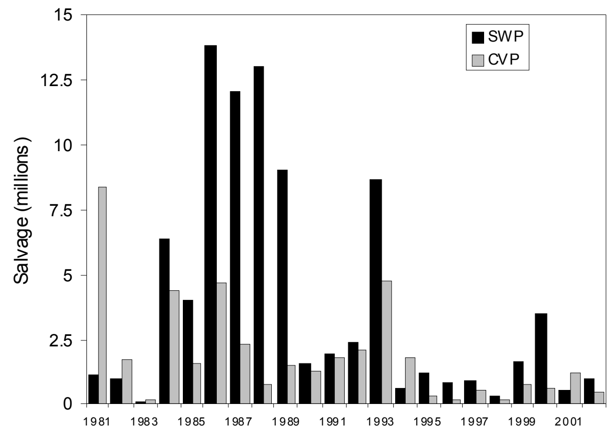

Figure 13 Annual striped bass salvage at SWP and CVP.

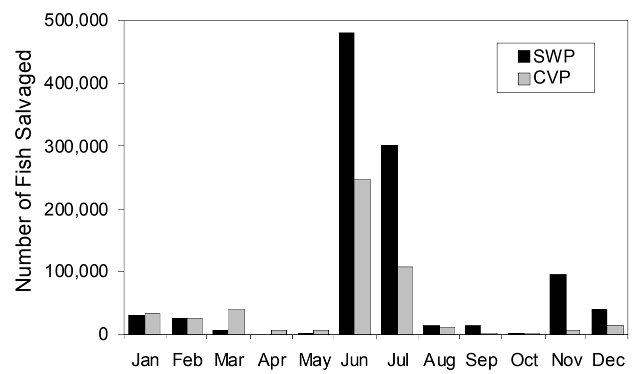

Figure 14 Monthly salvage of striped bass at SWP and CVP in 2002.

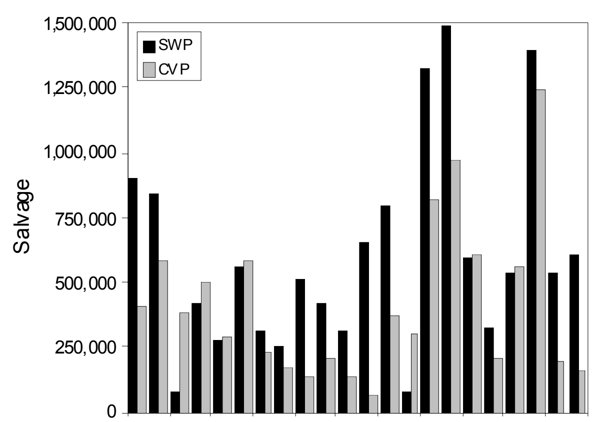

Figure 15 Annual American shad salvage at SWP and CVP.

Splittail

Combined splittail salvage (SWP + CVP) was slightly more than half of the 2001 combined total, and was also lower than every other year since 1980, except 1994 (Figure 16). Splittail salvage totals in 1986, 1995, and 1998 dwarf the salvage totals for 2002 and all other years since 1980.

Splittail salvage in 2002 showed an atypical pattern in which adult splittail salvage during January through April was much higher than YOY salvage in the early summer (Figure 17). Adult salvage was highest at the SWP in January (Figure 17), historically a month with proportionally fewer adults salvaged.

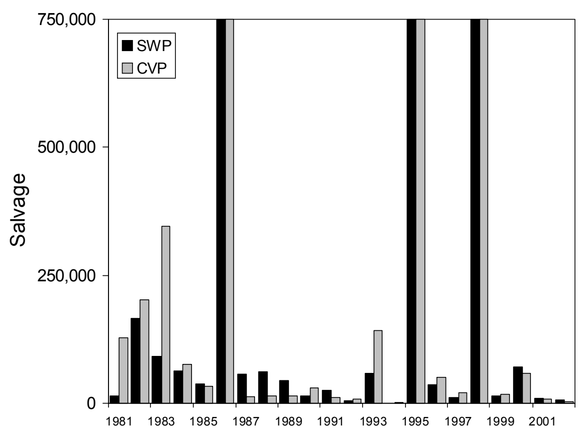

Figure 16 Annual splittail salvage at SWP and CVP. Columns for 1986, 1995, and 1998 were truncated for scale considerations.

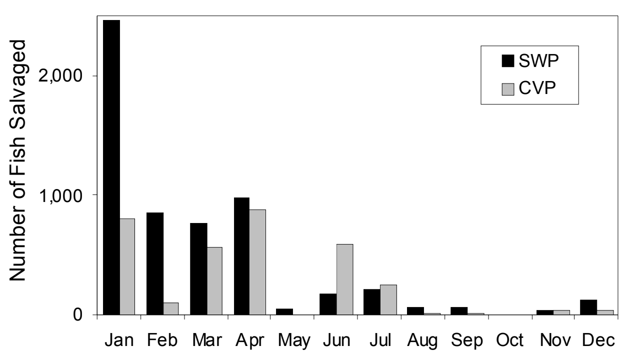

Figure 17 Monthly splittail salvage at SWP and CVP in 2002.

Longfin Smelt

Almost 98,000 longfin smelt were salvaged at the fish facilities in 2002, more than any other year in the last 22 years, except 1988. At the CVP, many more longfin smelt were salvaged in 2002 than in any year in the last 22 years; over 43,000 were salvaged in 2002 compared to about 24,000 in the previous high salvage years, 1988 and 1990. Most of the salvage occurred in May at the SWP and in April at the CVP and was made up of YOY fish.

Chinese Mitten Crab

The highest numbers of adult mitten crabs at the fish facilities occur during September through December, during their downstream migration for reproduction. Mitten crabs are considered a nuisance at the fish facilities because they interfere with the effective salvage of fish.

At the CVP, the first adult mitten crab of the fall migration appeared on September 9, at least two weeks later than usual. CVP daily crab numbers peaked on October 4, when about 190 crabs entered the facility (Figure 18). In 2002, about 1,191 crabs entered the holding tanks and an additional 1,259 crabs were removed by the traveling screen control device, for a total of 2,450. The 2002 seasonal total of crabs was much lower than any of the last five years. Including the traveling screen counts, about 82% of the crabs were male, a much higher percentage of males than in 2001 (66%).

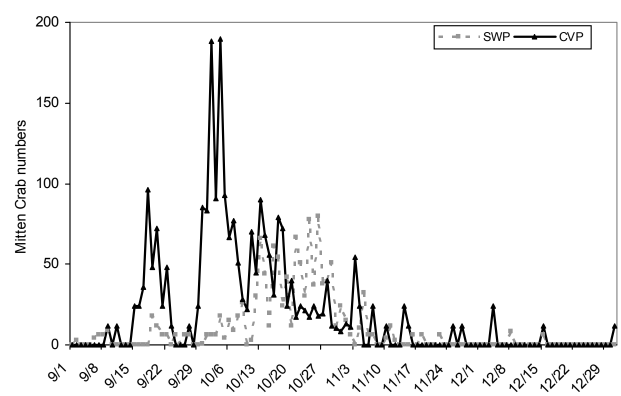

Figure 18 Daily mitten crabs counted at SWP and CVP in 2002.

At the SWP, only 1,178 mitten crabs entered the holding tanks during the 2002 fall season. This total was less than half the number estimated at the CVP and it resulted from a SWP export curtailment during the height of the migration in October. SWP water exports were about 40% of CVP water exports during October.

Crab control devices have been designed and used at both facilities with the goal of excluding crabs from the fish holding tanks. A traveling screen, originally designed to remove debris (Siegfried 1999, White and others 2000), has been placed in the secondary channel at the CVP. The traveling screen device has undergone many modifications since it was first tested in 1998, but consists of a belt of vertical plastic-coated cables held in place by horizontal rods (White and others 2000). As they grasp the cable, crabs are lifted from the channel by the rotating belt and, after being dislodged by a high-pressure water stream, are deposited into a hopper and then moved by conveyer to a disposal container. Crabs are then counted and their sex determined.

In 2002, the traveling screen was in operation from September 30 through November 3. The traveling screen was successful in removing about 72% of the crabs entering the secondary channel during October 1 through November 2, even though the screen was down for maintenance for brief periods during that time. No crab control device was installed at the SWP in 2002.

Water Temperatures

The mean annual water temperature at the CVP facility was 17 °C, compared to almost 18 °C in 2001. The temperature recorder at the SWP facility was malfunctioning for much of the year, so data is not presented. Water temperatures peaked approximately July 10, at about 27 °C. The coolest temperatures occurred near February 1 and again in the last week of December, when they fell to about 8 °C (Figure 19).

Salvage data can be obtained from DFG's Central Valley Bay Delta Branch Web Site (http://www.delta.dfg.ca.gov/data/salvage).

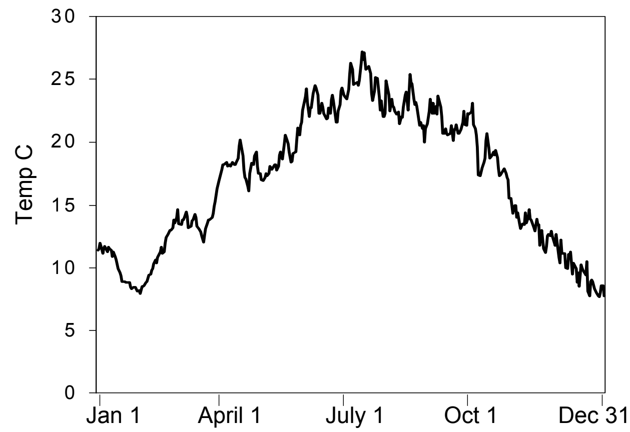

Figure 19 Daily water temperatures at SWP and CVP fish facilities.

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Contributed Papers

Heterosigma akashiwo Blooms in San Francisco Bay

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Four episodic blooms of the Harmful Algal Bloom (HAB) species *Heterosigma akashiwo* (Hada) Sournia (Raphidophyceae; IOC 1997) were recorded in San Francisco Bay during summer 2002. Blooms of this potentially harmful species have not been recorded previously in San Francisco Bay, despite its cosmopolitan distribution in coastal regions of the World Ocean. Although there are anecdotal observations of its occurrence in SF Bay (G. Langlois, pers. com.), definitive identification of this flagellated phytoplankter in SF Bay has not been made previously. We believe this is the first study to quantify such blooms in SF Bay, and to positively identify its presence using both microscopic and molecular techniques. Although no fish deaths were observed, *H. akashiwo* blooms have been associated with massive mortality of cultivated (pen-raised) fin-fish and lesser (but unknown) losses of wild fin-fish worldwide. Closest to SF Bay, fish-killing blooms have been reported in the Pacific Northwest (Washington State) and southwestern British Columbia, Canada. The affected fish were mainly cultivated Atlantic (*Salmo salar*) and Pacific (*Oncorhynchus* spp.) salmon (Taylor and Haigh 1993), although recently there have also been reports of wild salmon mortalities in Washington (Horner and others 1997).

Absence of this potentially harmful organism as an identified member of the phytoplankton communities of SF Bay may be due, in part, to its delicate nature, small size, and the clumping and loss of cells following some fixative methods (Tyrrell and others 2001; Connell 2002; Herndon 2003). Not only is the identification of *H. akashiwo* hampered when utilizing preserved samples, accurate enumeration of *H. akashiwo* is severely compromised when using chemical preservatives and subsequent examination. The use of traditional chemical fixatives, such as acidic Lugolís iodine or gluteraldehyde, to preserve either natural or cultured samples results in severe underestimates of cell abundance; furthermore, these decreases in cell abundance are a direct function of preservation time (Herndon 2003). Additionally, live raphidophytes may shed their flagella and lose surface detail during microscopic examination (e.g., Throndsen 1997), and disrupted cells and fragments of *H. akashiwo* generally result from net tow sampling (Connell, unpublished data). All of these factors may have contributed to the lack of previously identified blooms of *H. akashiwo* in SF Bay, but during summer 2002, local cell concentrations were exceptionally high, samples were analyzed generally within 0.5-2 days of collection, and both microscopic and molecular methods were employed to ensure accurate identification and better quantification of these episodic blooms.

The first bloom started on or about June 23, 2002, in northwestern Richardson Bay and ended on approximately June 28, 2002. A survey (using surface sampling from a kayak and binocular observation from elevated height) revealed that the bloom extended as far south as Strawberry Point, and was more pronounced in protected portions of the Bay. Cell concentrations were sufficient to cause discoloration of surface waters to form a rusty red color. The *H. akashiwo* cells appeared in highly localized regions, and formed surface “structures” with well-defined edges. Three subsequent bloom events were observed and sampled in Richardson Bay: July 10-16, July 25-29, and September 1-12, 2002. All bloom events coincided with periods of clear skies, calm waters and warm weather; ambient air temperatures were *ca.* 25 °C and water temperatures > 20 °C (Table 1). Bloom samples were positively identified by one of us (RAH) using light (phase-contrast) microscopy, and samples from the second and fourth blooms were additionally identified as *H. akashiwo* using a ribosomal RNA (rRNA)-targeted sandwich hybridization assay (SHA; Tyrrell and others 2001, 2002) by CA Scholin (Monterey Bay Aquarium Research Institute). All cell abundance estimates reported in Table 1 were preserved with gluteraldehyde (0.2-0.5% final concentration), and stored at 4-5 °C until microscopic enumeration using a Palmer-Maloney counting chamber (Hausser Scientific Co.). A minimum of 400 cells were counted per slide. Due to the losses expected from chemical preservation, reported abundance estimates should be considered conservative. The June and July blooms were almost exclusively *H. akashiwo* (*ca*. 95% by abundance), but other phytoplankton—including euglenoids, dinoflagellates (in particular, *Katodinium rotundatum* and colorless *Gyrodinium* spp.) and cryptomonads—were present in small concentrations. These other phytoplankton typically comprised less than 7% of the phytoplankton assemblage. No centric diatoms and only a single pennate species, *Cylindrotheca closterium,* were observed in association with the *H. akashiwo* blooms.

The September bloom event covered a much greater area than the previous blooms, which were largely confined to the northern portions of Richardson Bay. During September, the bloom appeared to extend along the entire coast of the Tiburon Pennisula from northern Richardson Bay to the Paradise Cay Marina. Surface samples for identification were collected at Richardson Bay, the Romberg Tiburon Center and the Paradise Cay Marina, but surface patches, reddish-brown in color, were observed throughout this area. Additionally, samples collected off of the Berkeley City pier on September 7 were positively identified as *H. akashiwo* using SHA (C. O'Halloran, pers. com.). Although the bloom was almost unialgal in nature, another raphidophyte, *Fibrocapsa japonica* was identified in association with the September bloom.

A strain of *H. akashiwo* was isolated by sequential dilution from samples collected at Richardson Bay, accepted into the Provasoli-Guillard National Center for Culture of Marine Phytoplankton (CCMP), and is available as CCMP 2274.

Acknowledgements

We thank Dr. Chris Scholin (MBARI) for his timely SHA analyses of field samples. We acknowledge the excellent assistance of K. A. Boyle (RTC/SIO) during field sampling and laboratory analyses, and A. Roberts (UCSC) for her assistance with nitrate analysis. This study was supported by an Environmental Defense mini-grant awarded to W. P. Cochlan.

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Table 1 Environmental conditions of the surface waters during three *Heterosigma akashiwo* blooms in San Francisco Bay during summer 2002. The sampling locations "In" and "Out" of the blooms were generally about 10 m apart.

	6/25/02		*7/10/02*		*9/6/02*
Environmental Parameter	*In*	*Out*	*In*	*Out*	*In*
Cells (x 10^8 L^{-1})	1.36	0	-	-	3.03[b]
Chl. *a*[a] ($\mu g \cdot L^{-1}$)	506	3.9	-	-	985
Secchi depth (cm)	-	-	35	60	-
Water temperature (ºC)	21.3	21.3	25.3	25.6	20.5
Salinity[c] (ppt)	30.1	30.1	30.8	30.5	29.4
Oxygen[c] ($mg \cdot L^{-1}$)	14.0	10.0	16.3	7.57	14.07
NO_3- (µM)[d]	1.37	5.50	4.4	10.1	< 0.05
NH_4+ (µM)[d]	0.28	1.06	1.05	4.46	0.49
Urea (µM)[d]	0.45	0.72	0.56	0.98	0.49
Sub-surface irradiance[e] ($\mu E \cdot m^{-2} \cdot s^{-1}$)	1550		1900		1450

[a] chlorophyll concentration measured using extractive (*in vitro*) fluorometric analysis

[b] cell abundance data collected on 9/10/02; cell numbers may be severely underestimated due to poor cell preservation

[c] using a YSI Model 85 hand-held dissolved oxygen, conductivity, salinity, temperature system

[d] measured using colorimetric techniques and reported in terms of nitrogen (i.e., 2 µM urea-N = 1 µM urea)

[e] measured 2-3 cm below sea surface with a Biospherical Instruments QSL-100 quantum scalar irradiance meter

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On Mitten Crabs and Lung Flukes

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Parasitology textbooks have long reported that grapsid crabs in the genus *Eriocheir*, commonly known as mitten crabs, are important second intermediate hosts of the Oriental Lung Fluke, *Paragonimus westermani*, along with several other crab and crayfish species in Asia (e.g., Hegner and others 1929; Chandler and Read 1961; Muller 1975; Cheng 1986; Smyth 1994). Epidemiologic reviews have specifically noted the Chinese Mitten Crab, *E. sinensis,* as an important source of human infection in China and Korea (Yokogawa 1965, 1974; Miyazaki 1974; Choi 1990). Many of these texts include a diagram of the lung flukes' life cycle, often with a drawing of a mitten crab host, to illustrate the passage of digenetic trematodes through multiple host species (e.g., Lapage 1963, p. 154; Miyazaki 1974, p. 104; Kim 1984, p. 1181). Recently, however, some Chinese fisheries experts—including Prof. Zhao, director of the Anhui Weiqing Aquatic Products Company, and Prof. Zhang (retired) of the Shanghai Fishery Research Institute—have said that this commonly-reported association of lung flukes with mitten crabs is incorrect. According to these experts, *P. westermani* does not occur in *E. sinensis* and the true intermediate hosts of the lung fluke are various potamid crabs commonly known as creek crabs (Hymanson *and others* 1999; Wang and Hess 2002). Wang and Hess (2002) suggest that an old translation error may have resulted in a misstatement of the fluke's crab host in western literature, which was then copied from paper to paper. To clarify the matter they recommend examining the early papers describing the lung fluke to determine if there were translation errors, and comparing the range of infection in humans with the distribution of mitten crabs and creek crabs.

Kerbert (1878) described the lung fluke, as *Distoma westermanii*, from the lungs of a tiger in the Amsterdam Zoo, and in 1879 Ringer found it in the lungs of a man from Taiwan. Its crustacean intermediate hosts were unknown until 1915, when Nakagawa, working in northern Taiwan, found that encysted metacercariae of the lung fluke were common in two potamid crabs collected in mountain streams and rare in the Japanese Mitten Crab, *Eriocheir japonicus,* collected from lowland streams.

Higher rates of infection were reported in *E. japonicus* collected from mountain streams in this region in 1955-57, and Kuntz (1969) reported that ten years of investigations by various workers had shown *E. japonicus* to be the main crustacean host in Taiwan. Lung flukes were also commonly found in *E. japonicus* in Japan, where the crab inhabits virtually all rivers and streams, in 1915-16. *Eriocheir sinensis* and various crayfish species were reported to be the fluke's crustacean hosts in Korea in 1916-17 and in northeastern China in 1939. In the 1930s the lung fluke was found in east China in a third potamid crab, and rarely in a fourth, mainly in small, rapidly-flowing mountain streams (Yokogawa and others 1960; Kuntz 1969; Cabrera 1984). A total of 12 decapod species were reported as hosts of *P. westermani* in Asia by 1960, 22 species by 1974, and 46-50 species, representing 19-21 genera in 5 families, by 1999 (Yokogawa and others 1960; Miyazaki 1974; Blair and others 1999).

A review of recent literature yielded one study reporting *P. westermani*'s collection in *E. sinensis* in east China (Li 1989), and several studies reporting its frequent and sometimes abundant collection in *E. japonicus* in Korea, Japan, and Taiwan (Fan and Khaw 1965; Huang and Chui 1966; Kuntz 1969; Miyazaki 1974; Cho and others 1991; Lou and others 1992), although one Taiwan study found the lung fluke common in several potamid crabs and absent from *E. japonicus* (Su and others 1989). Kuntz (1969, p. 122) included a photograph of the crab that he found to be the main host of *P. westermani* in Taiwan and which he identified as *E. japonicus*, which from the photograph is clearly a species of *Eriocheir.* Thus over a period of about eight decades *P. westermani* has been identified in *E. sinensis* by at least a few researchers, and in *E. japonicus* by a considerable number of researchers, including Japanese, Korean, Chinese, and American workers. There is no evidence of gross mis-identification or mistranslation in their publications such that a potamid crab could be mistaken for a mitten crab. In addition, Chinese fisheries experts have received reports of *P. westermani* being found in *E. sinensis* in Canada and Hong Kong, presumably in shipments of live crabs from China (Hymanson and others 1999). It seems clear that the trematode known as *Paragonimus westermani*, which causes pulmonary paragonimiasis in humans, routinely occurs in *E. japonicus* and is at least occasionally found in *E. sinensis* in some parts of northeast Asia.

How then could Chinese scientists working with the *E. sinensis* fishery believe that *P. westermani* does not occur in mitten crabs? It may be that the most common form of *P. westermani* in the Yangtze River watershed and east China, where these scientists work, rarely occurs in mitten crabs. Recent molecular genetic analyses of *Paragonimus westermani* have demonstrated the existence of one relatively uniform population in northeast Asia (Japan, Korea, China, and Taiwan) and one or more genetically distinct population groups in south Asia (the Philippines, Thailand and Malaysia), which may warrant description as separate species (Blair and others 1997; Iwagami and others 2000). Within northeast Asia, cytological studies have documented a sexually reproducing diploid form, a parthenogenetic triploid form[1] (which is more pathogenic to humans), and a rare tetraploid form (Kim 1984; Agatsuma and others 1992; Smyth 1994; Terasaki and others 1995; Blair and others 1997, 1999). The triploid form is primarily found in *E. japonicus* in Taiwan, Japan, and Korea, and is also found in crayfish in Korea and northeastern China (Terasaki and others 1995; Blair and others 1999). The diploid form is reported mainly in potamid crabs and rarely in mitten crabs throughout northeast Asia, and this is the main form reported from the Yangtze watershed/east China region (Li 1989; Blair and others 1999).

Another possibility is that the fishery scientists work mainly with cultured mitten crabs, while the lung fluke may occur primarily in wild mitten crabs in China. Wild mitten crabs have declined in China's larger rivers in recent decades, and mitten crab populations in these rivers now consist mainly of commercially cultured crabs (Hymanson and others 1999), which occupy the low-gradient, lower reaches of these rivers and associated "side lakes," ponds, and rice paddies. Wild mitten crabs persist in smaller coastal streams, where they are typically smaller and shorter-lived (Veldhuizen 2000). Since Kuntz (1969) and Kim (1984) report from their studies in Taiwan and Korea that *P. westermani* is most common in *E. japonicus* in well-oxygenated, flowing waters in hilly or mountainous regions, and Zhang, quoted in Wang and Hess (2002; see also Hymanson *and others* 1999), states that the snail that serves as the first intermediate host of *P. westermani* in China prefers such waters, the wild mitten crabs of lotic waters may be more likely to carry lung flukes than the cultivated crabs in lentic waters.

1. Miyazaki proposed the name *Paragonimus pulmonalis* for the triploid form, but this has not been accepted as a valid species by most workers.

From a U.S. public health perspective, there are two issues to consider: Could mitten crabs imported from Asia carry *P. westermani* to the U.S.? and could mitten crabs established in the U.S. serve as second intermediate hosts, if *P. westermani* were introduced? It appears that either *E. japonicus* or *E. sinensis* (at least from Korea or northeastern China) are potential carriers of *P. westermani*, especially of the triploid form, which is more pathogenic to humans, and which reproduces parthenogenetically and therefore may more easily become established. Both could also serve as second intermediate hosts for the triploid form, probably along with many of the crayfish species already present in the U.S. To the extent that the establishment of *P. westermani* would be a significant public health concern, appropriate cautionary measures should be taken.

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Cross-channel Variability in Benthic Habitat

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Introduction

Benthic invertebrates play an important role in estuarine food webs and biogeochemical cycling of carbon, nutrients, and contaminants. The generally sedentary benthic invertebrates continuously integrate local water, sediment, and food conditions. This makes them good indicators of the type and quality of aquatic habitat at the location where they are found.

The Interagency Ecological Program's Environmental Monitoring Program (EMP) has monitored benthic invertebrates since the mid-1970s. A recent review of the EMP found that the spatial study design of the benthos monitoring element was in need of a thorough reexamination through intense special studies and extensive historic data analyses. This article reports the results of preliminary analyses of historical EMP data focusing on cross-channel variability. Specific questions are: (1) do benthic habitats and community assemblages vary between positions across a river channel? (2) Are benthic samples taken at a single channel position sufficiently representative of benthos assemblages across the channel to characterize long term changes in the benthos community of a particular section of a river?

Materials and Methods

The EMP has sampled benthic macrofauna (organisms larger than 0.5 mm) at 3 cross-channel positions in the Sacramento River near the confluence with the San Joaquin River (Figure 1) since 1977. The "right", "Center", and "Left" positions were sampled biannually from 1977 to 1979 and monthly from 1980 to 1995, at depth of about 12, 35, and 12 feet, respectively. Benthic invertebrates were counted in three replicate samples collected at each of the three positions. We summarized these counts in terms of benthic organism abundance, species richness, species constancy, and the Shannon diversity index (Shannon 1948). As part of its benthos monitoring component, the EMP also collected sediment samples. Here, we summarize sediment analysis results for organic matter, fines (particles < = 0.08 mm), and sand (0.08 to 2.5 mm) (no gravel was found). Salinity was measured each month by the EMP at the same location. Water year classification information was obtained from the Department of Water Resources (DWR). We interpolated 22,450 bathymetric soundings data acquired since 1990 by DWR, the US Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA) using kriging to produce a surface of the bathymetry in the vicinity of the sampling positions (Figure 1).

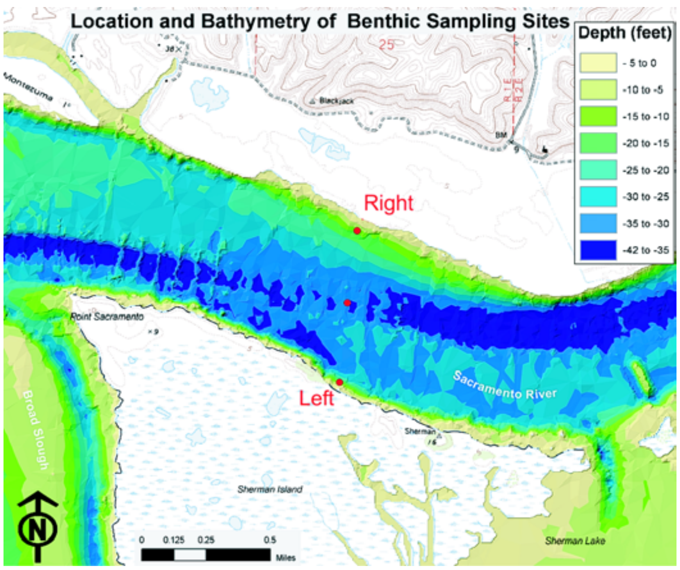

Figure 1 Location and bathymetry of the benthic sampling positions across the channel.

Results

The channel bottom substrate varied markedly with position in the channel (Figure 2). The middle position had the coarsest sediments with the least amount of organic matter while the right position tended to have the finest sediments. The left position was intermediate in its sediment composition and had the highest relative concentration of organic matter.

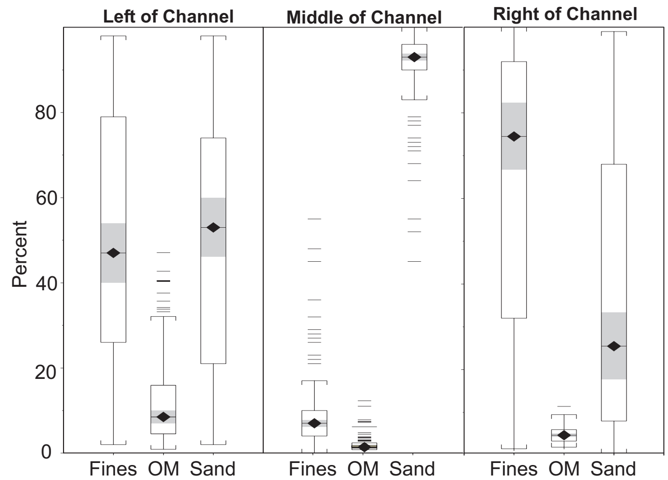

Figure 2 Sediment composition. Box plots show the distribution of values over the period. The diamond indicate the median and the shaded area shows its 95% confidence interval, the box extends from the first to the third quartile, the whiskers extend either to the extreme value of the data or a distance 1.5 time the interquartile range from the median whichever is less, dash symbols represent values falling outside.

The abundance of benthic invertebrates was much lower (by an order of magnitude or more) in the middle of the channel than on the channel sides. The highest total number of organisms was usually found on the left side of the channel (Figure 3a). Species richness was lower in the middle; while approximately 13 species were usually present on the sides, only about 5 species were regularly found in the middle of the channel (Figure 3b). As measured by the Shannon index, species diversity was also much higher on the sides than in the middle (Figure 3c). Species found at the middle position were usually also found at the left and the right positions. The middle position was dominated by suspension feeding organisms, including the bivalves *Corbicula fluminea* (Figure 4a) and *Potamocorbula amurensis*. In contrast, several species occurred regularly on the sides, but were not or seldom found in the middle, e.g., the tubificid worm *Bothrioneurum vejdovskyanum* (Figure 4b). Four of the species commonly found on the left side were not found at other positions: *Laonome* sp. A (Figure 4c), *Microturbellarian* sp. A, *Synidotea laevidorsalis*, and *Grandidierella japonica*. On the other hand, 6 tubificid worm species, such as *Ilyodrilus frantzi capillatus,* were found almost exclusively at the right channel position (Figure 4d).

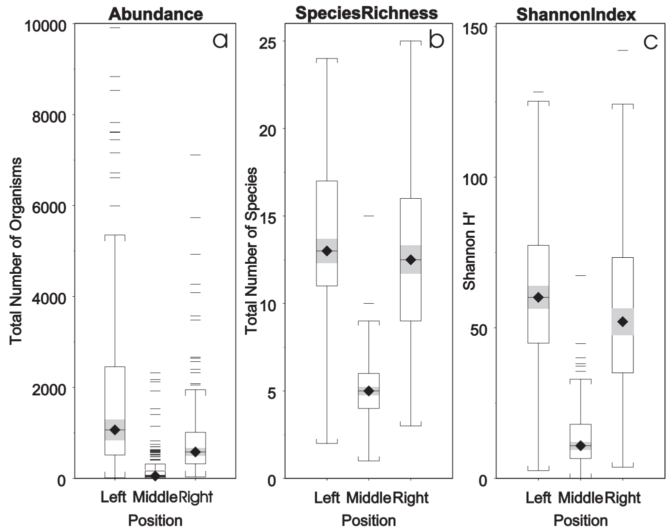

Figure 3 Abundance, species richness and diversity. Box plots as in Figure 1.

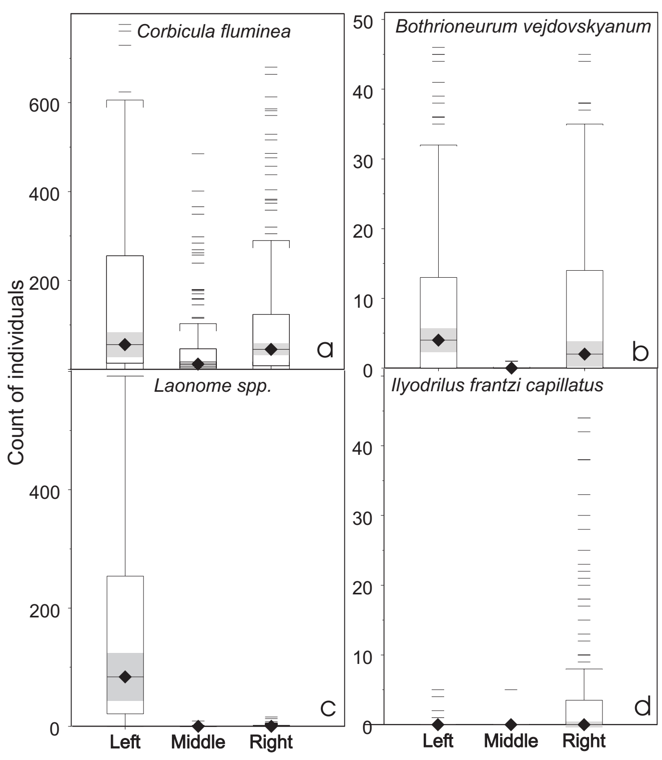

Figure 4 Individual species counts by channel position. Box plots as in Figure 1.

Variations in precipitation in the Sacramento River watershed resulted in a period of low salinity at the sampling location from 1978 to 1986, and high salinity from 1987 to 1994 (Figure 5). The introduction of *Potamocorbula amurensis* in 1986 corresponded to a large decrease in the abundance of several other benthic species such as *Corbicula fluminea* and *Americorophium stimpsoni* (Figure 6). Over the 18-year data record, benthic species diversity was often much higher on one side than on the other side of the channel. Species diversity appeared to generally be higher on the right side of the channel during higher flow and lower salinity periods, and higher on the left otherwise.

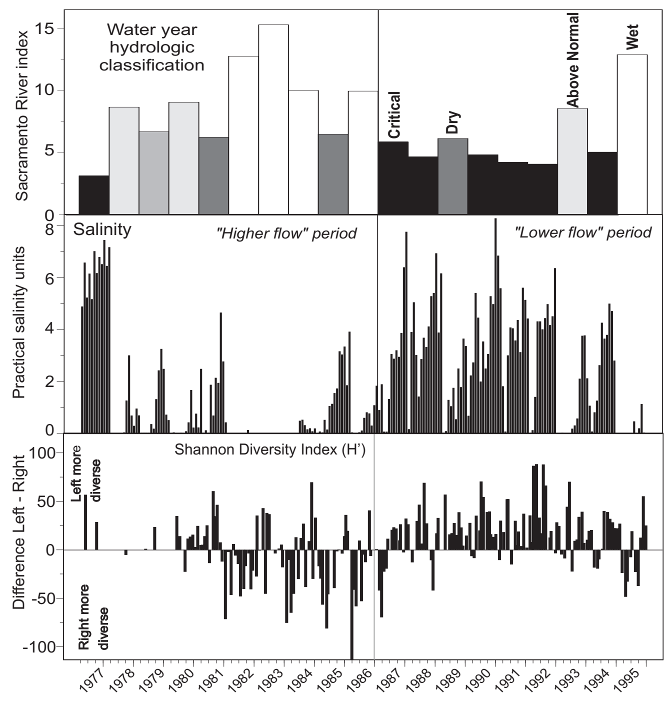

Figure 5 Sacramento River index, Salinity and Shannon's diversity index of left position minus that of right position.

Discussion

Benthic habitat, species assemblage, and organism density varied considerably between cross-channel positions at this EMP monitoring location on the lower Sacramento River. The benthic community varied not only in terms of species diversity and abundance, but also in terms of dominant life forms, functional groups, and presumably its ecological function, as characterized by the primary feeding habits of the dominant benthic species at the three cross-channel positions (Table 1). The differences in dominant feeding habits may be linked to variations in physical processes across the channel such as particle transport to the benthos, as indicated by differences in substrate particle size and organic matter content. Variations in river current can be inferred from channel bathymetry (Figure 1) and substrate size fraction, indicating most rapid current in the middle of the channel and slowest current on the right. All the species found only on the left side depend on organic matter deposited at the sediment surface. On the other hand, the tubificid worm species unique to the right channel position generally feed on organic material deposited below the sediment surface and tend to favor substrates with a higher percentage of fine sediment.

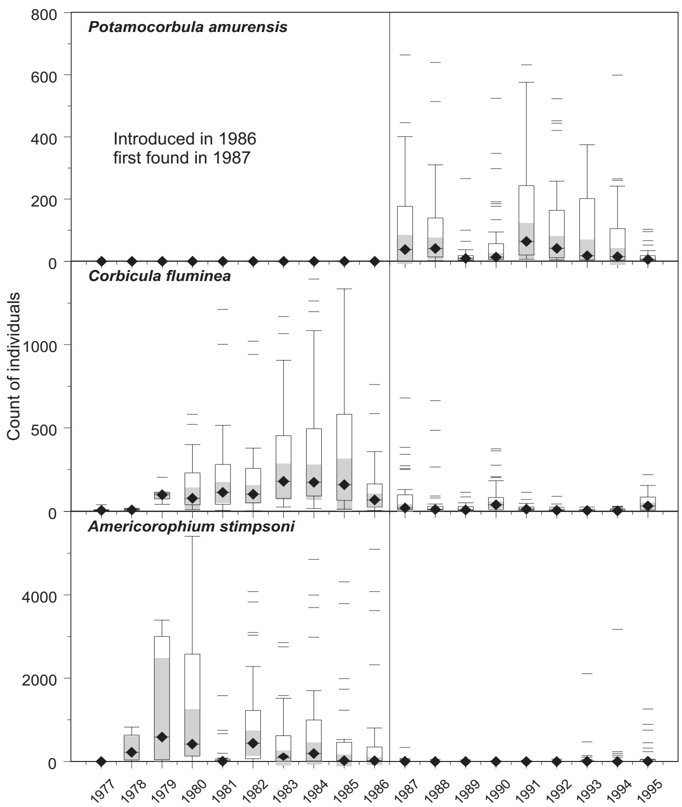

Figure 6 Individual species counts of introduced Asian clam *Potamocorbula amurensis* and two other species.

Our results also indicate that sampling at a single cross-channel position at this lower Sacramento River sampling location (as implemented by the EMP in 1996) fails to provide data on benthic community composition and abundance representative of this particular section of the lower Sacramento River. This suggests that more spatially intensive monitoring surveys are needed to provide meaningful data and information about the status, trends, and ecological role of benthic organisms in river reaches and larger regions of the upper San Francisco Estuary.

Changes in species occurrence and species richness during the 1977-1995 monitoring period are difficult to interpret because of the simultaneous onset of both a period of predominantly dry or low-flow water years and the invasion of the Asian clam, *Potamocorbula amurensis*, in 1987. Future analysis of benthic community change at the current sampling position (the left position) may help clarify which assemblage patterns are linked with the bivalve invasion, and which assemblage patterns are more likely associated with changes in flow and salinity.

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Table 1 Characteristics and favored channel position of species found in at least 10% of the samples at any of the three channel positions.

Genus-species	*Taxon*	*Life form*	*Feeding habit*	*Situation in or on the sediment*	*Date, if Introduced*	*Favored Channel Position*
Corbicula fluminea	Mollusca	Bivalve	Suspension and pedal deposit[10]	Usually partially exposed[A]	1945	_
Potamocorbula amurensis	Mollusca	Bivalve	Suspension[11]	Usually partially exposed[A]	1986	_
Nippoleucon hinumensis	Crustacea	Cumacean	Surface deposit[1,3]	Probably near-surface[1]	1986	_
Synidotea laevidorsalis	Crustacea	Isopod	Surface deposit - detritivore[9]	Probably near surface[1]	1897	_
Americorophium spinicorne	Crustacea	Corophiid amphipod	Suspension and surface deposit[6,B]	Sediment and mucus tubes above surface[6]	Uncertain	LEFT
Americorophium stimpsoni	Crustacea	Corophiid amphipod	Suspension and surface deposit[6,B]	Sediment and mucus tubes above surface[6]	Uncertain	LEFT
Grandidierella japonica	Crustacea	Gammarid amphipod	Cannibal, filter feeder and epiphytes grazer[4]	U-shaped tubes on muddy bottoms, sometimes epibenthic[4]	1966	LEFT
Gammarus daiberi	Crustacea	Gammarid amphipod	Surface deposit		1983	LEFT
Boccardia ligerica	Polychaeta	Spionid worm	Surface deposit[2]	Sediment and mucus tubes above sediment surface[12]	1954	LEFT
Marenzelleria viridis	Polychaeta	Spionid worm	Surface deposit[6]	Sediment and mucus tubes above sediment surface[12]	1991	RIGHT
Neanthes limnicola	Polychaeta	Nereid worm	Surface deposit and prey[8,12]	Subsurface in mucus lined tubes, excursions for prey[12]	Native	SIDES
Laonome spp.	Polychaeta	Sabellid worm	Suspension and surface deposit[8,12]	Silty tubes at surface[12]	1989	LEFT
Aulodrilus pluriseta	Oligochaeta	Tubificid worm	Deposit[1]	Subsurface, living in reinforced tubes of silty, enriched, weedy areas[C]	Uncertain	RIGHT
Bothrioneurum vejdovskyanum	Oligochaeta	Tubificid worm	Deposit[1]	Found in large rivers, favoring coarse sand[C]	Uncertain	SIDES
Brancihiura sowerbyi	Oligochaeta	Tubificid worm	Deposit[1]	Prefers rivers[C]	Uncertain	RIGHT
Ilyodrilus frantzi capillatus	Oligochaeta	Tubificid worm	Deposit[1]	Subsurface[1]	Uncertain	RIGHT
Ilyodrilus templetoni	Oligochaeta	Tubificid worm	Deposit[1]	Subsurface[1]	Uncertain	RIGHT
Limnodrilus hoffmeisteri	Oligochaeta	Tubificid worm	Deposit[1]	Occurs in clean water and grossly polluted sites[C]	Uncertain	SIDES
Limnodrilus udekemianus	Oligochaeta	Tubificid worm	Deposit[1]	Rarely abundant and found in both oligotrophic and polluted waters[C]	Uncertain	RIGHT
Varichaetadrilus angustipenis	Oligochaeta	Tubificid worm	Deposit[1]	Subsurface[1]	1982	SIDES
Microturbellarian spp. A	Miscellaneous	Triclad flatworm	Deposit[1]	Surface[1]	Uncertain	LEFT
Prostoma graecense	Miscellaneous	Nemertean worm	Deposit[1]	Burrow[1]	Uncertain	LEFT
Mermithid spp. a	Miscellaneous	Parasitic nematode	Parasite[1,C]		Uncertain	SIDES

Notes: [A] Personal observation; [B] *Corophium* are assigned to the "mixed strategy" feeders by inference from Dixon and Moore (1997) who reported that *Corophium* of several different feeding habits occasionally acquired deposited matter, and personal communication with J. W. Chapman (Oregon State University), who indicated that consumption of both suspended and epibenthic phytoplankton and particle bound bacteria is not unexpected since for many particles in this pool suspension versus deposition of particles is influenced by tidal current activity. [C] Information found 24MAR03 at http://www.esg.montana.edu/dlg/aim/annelid/oligo0.html, maintained by Daniel L. Gustafson, Biology Department MSU, Bozeman.

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Jellyfish of the San Francisco Estuary

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In July 2000, the California Department of Fish and Game's San Francisco Bay Study (Bay Study) began recording species and numbers of jellyfish caught. Bay Study sampling takes place monthly, year-round at 52 stations in the San Francisco Estuary. At each station single tows are made with a midwater trawl and an otter trawl. This abundance and seasonal distribution data has been recorded to provide baseline information and to gain some insight on the significance of jellyfish in the San Francisco Estuary.

The San Francisco Estuary has more than 20 native jellyfish species and over the last few years 4 introduced species have been identified (Rees and Kitting 2002). Most of the native species of jellyfish are typically found in higher salinity and cooler waters, like those of San Pablo and San Francisco bays. Introduced species have been primarily found in Suisun Bay and the Sacramento-San Joaquin Delta, where there is lower salinity and, in summer, higher water temperature. These introduced species are native to the Black and Caspian seas (Rees and Kitting 2002). In this article I describe the general appearance and estuary-wide distribution of the more common jellyfish caught by the Bay Study.

Jellyfish are composed of a few main body parts. These include the bell, tentacles, mouth, gonads, and the radial canals (Figure 1). Variations in these structures, along with coloration, are used to distinguish jellyfish. The size measurements of the bell are taken as bell height if the bell is higher then wide or bell width if the bell is wider then high.

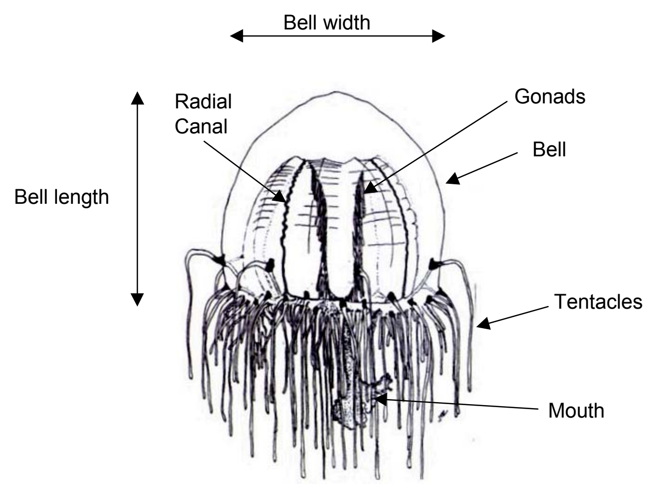

Figure 1 Main body parts of a jellyfish.

Common Jellyfish Species

Polyorchis penicillatus is a native species of jellyfish. This jelly is found year-round, but catch increases during the winter months. *Polyorchis penicillatus* has been found as far upstream as Suisun Bay and as far south as the Dumbarton Bridge, with the highest concentration in Central Bay (Figure 2). *Polyorchis penicillatus* is approximately 4-6 cm in maximum bell height. It has long tubular gonads hanging on each radial canal and the 4 radial canals have 15-25 lateral diverticula across them. *Polyorchis penicillatus* can have up to 160 tentacles with red pigment at the base of each tentacle. It feeds mostly on zooplankton (Wrobel and Mills 1998).

Pleurobrachia bachei is a native ctenophore with the common name "Sea Gooseberry" or "Comb Jelly". *Pleurobrachia bachei* is seasonal and occurs only in winter and spring. It has been found as far upstream as Suisun Bay and as far south as the Dumbarton Bridge, with the highest concentration in South Bay (Figure 2). The body of *P. bachei* is transparent, spherical, and approximately 15 mm in diameter. The comb rows are evenly spaced and extend the entire length of the body. It feeds on copepods, larval fish, and some small plankton (Wrobel and Mills 1998).

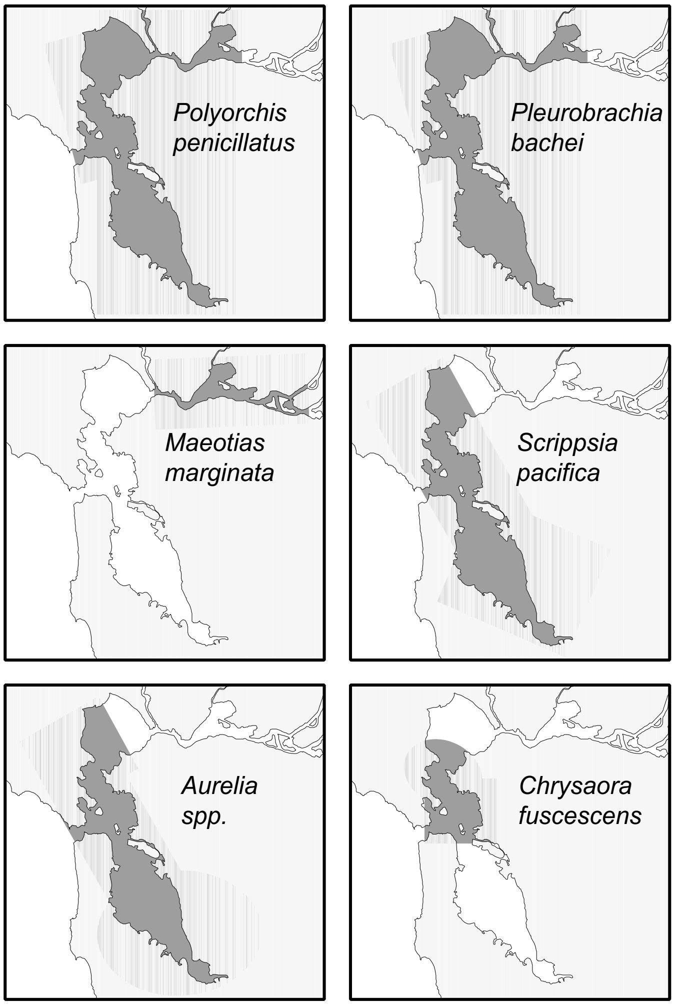

Figure 2 Maps of jellyfish species found in the San Francisco Estuary

Maeotias marginata is an introduced species, most commonly found in Suisun Bay and West Delta areas (Figure 2). This jelly is highly seasonal, found only during summer and fall. *Maeotias marginata* can reach 5 cm in maximum bell width. It has 4 radial canals and very short tentacles. The body is dark in color with a distinctive reddish brown rim around the bell margin. It feeds on small zooplankton (Rees and Kitting 2002).

Scrippsia pacifica is a native jellyfish with a distribution ranging from the southern half of San Pablo Bay to most of South Bay (Figure 2). *Scrippsia pacifica* is most common in Central Bay. It is transparent with red at the base of the tentacles. *Scrippsia pacifica* is highly seasonal, found primarily in winter. *Scrippsia pacifica* can reach up to 10 cm in bell height and has 30-60 long tubular gonads suspended on each radial canal. This jelly can have up to 256 tentacles, some going a partial distance up the side of the bell (Wrobel and Mills 1998).

Aurelia aurita/Aurelia labiata have the common name of "Moon Jelly". *Aurelia labiata* is a native species. *Aurelia aurita* is thought to be introduced (Wrobel and Mills 1998). Both species are found year-round, but peak in numbers during the late summer and fall. *Aurelia spp*. is found from San Pablo to South bays (Figure 2). The bell width for is 40-50 cm in the largest individuals. The major difference between the two is *A. aurita* has 8 lobes around the base of the bell and the oral arms extend beyond the bell, whereas *A. labiata* has 8 major lobes which are notched, so it appears to be 16 lobes and the oral arms stop at the edge of the bell (Wrobel and Mills 1998). These two species are very fragile and unless in perfect condition, they are very difficult to distinguish, so for this purpose we call both species *Aurelia spp*. A distinctive characteristic for both species is 4 horseshoe shaped gonads in the center near the top of the bell. The gonads are usually dark purple.

Chrysaora fuscescens or "Sea Nettle" is a native species of jellyfish. This jellyfish is found in the southern part of San Pablo Bay and Central Bay (Figure 2). *Chrysaora fuscescens* is seasonal, found during the fall and winter. This species of jelly can give a mild sting. The bell color is usually yellowish-brown or reddish-brown and the oral arms and tentacles are darker than its body. The bell can reach 30 cm wide and has 24 tentacles. *Chrysaora fuscescens* feeds on larval fish, planktonic crustaceans, mollusks, and other jellyfish (Wrobel and Mills 1998).

Blackfordia virginica is an introduced species, primarily found in the Napa River. The Bay Study collected a few in Central and San Pablo bays. *Blackfordia virginica* is seasonal, found only in the later summer and early fall. Adults can reach up to 15 mm in bell width and have 50-60 tentacles. It feeds on copepods and other small zooplankton (Rees and Kitting 2002). These jellies are relatively small and rarely caught in Bay Study's sampling gear.

Moerisia sp. is an introduced species, found in Suisun Bay and Napa River. This *Moerisia* has a maximum bell height of 5 mm and up to 32 tentacles. A distinguishing characteristic of *Moerisia* is the cross-shaped gonads (Rees and Kitting 2002). These jellies are also too small to be caught by Bay Study's sampling gear, but are frequently caught by other DFG projects with smaller mesh nets.

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Delta Water Project Operations

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From January through March 2003, river flow for the San Joaquin River ranged between 1,690 cfs and 2,648 cfs (48 and 75 m^3/s), Sacramento River flow ranged between 15,890 cfs to 93,500 cfs (450 and 1,850 m^3/s), and the Net Delta Outflow Index (NDOI) ranged between 7,060 cfs and 84,740 cfs (200 and 2,400 m^3/s) (Figure 1). Precipitation during this period ranged from 0.04 in. (January 20, 2003) to 0.88 in. (March 15, 2003). The results of these storm events lead to increased Sacramento flow and Net Delta Outflow.

Export actions at SWP during the January through March 2003 period were not stable; however, CVP pumping was more stable than SWP. The significant increases or reductions in SWP pumping from January through March 2003 were made to meet fish, water quality, or exports to inflow standards (Figure 2). Reductions in SWP pumping in the following months were due to the following reasons:

- January 2003: fish concerns
- February 2003: water quality standard
- March 2003: E/I standard. However, in accordance with D-1641, USFWS, DFG, and NMFS concurred with allowing Project Delta diversions to exceed 35% of Delta inflow. All water diverted above 35% will be held by the SWP for use by the Environmental Water Account.

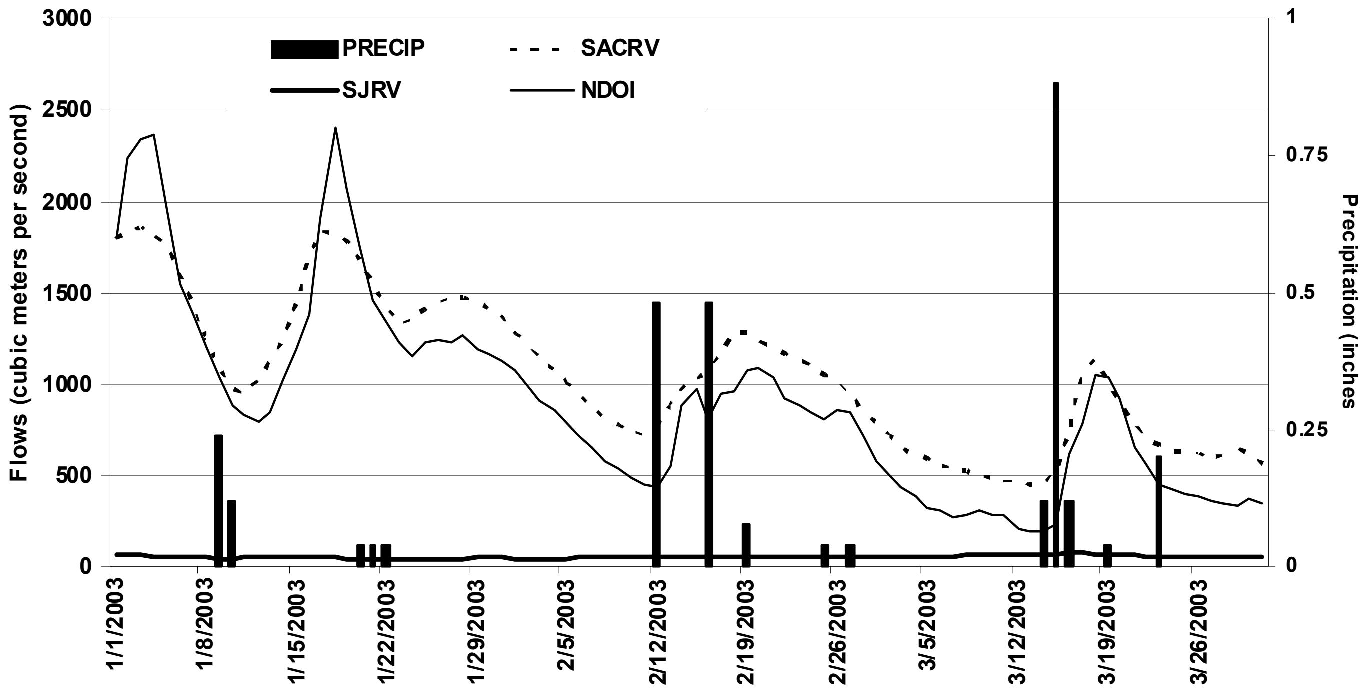

Figure 1 Sacramento River, San Joaquin River, Net Delta Outflow Index, and Precipitation, January through March 2003

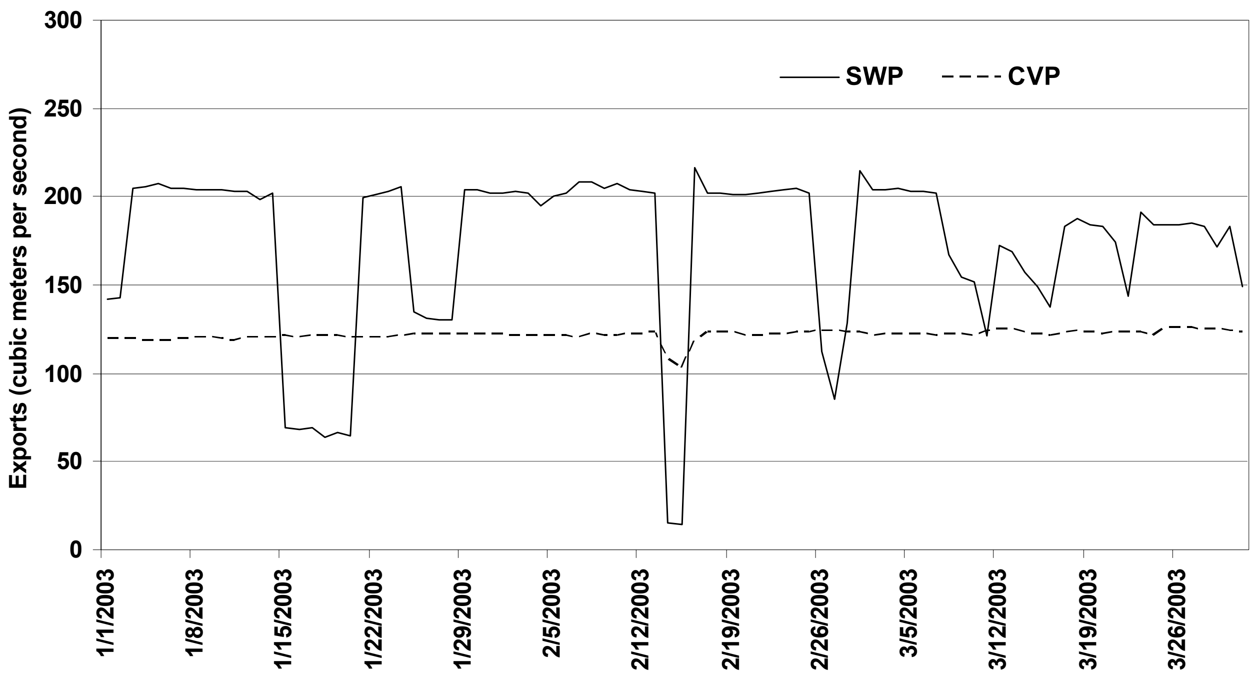

Figure 2 State Water Project and Central Valley Project Exports, January through March 2003

■ Interagency Ecological Program for the San Francisco Estuary ■

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■ Interagency Ecological Program for the San Francisco Estuary ■

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