■ Interagency Ecological Program for the Sacramento-San Joaquin Estuary ■

IEP NEWSLETTER

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CONTENTS

OF INTEREST TO MANAGERS

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This is the annual status and trends issue. Abundance data for many key Bay-Delta organisms are included as well as a description of the 1999 pumping and hydrology. Here are a few observations about the trend data:

- Although the 1999 water year was wet, there was little spring precipitation and spring outflows decreased to near dry year levels (Friend, page 11). The unusual flow patterns, combined with VAMP and relatively cool water temperatures may have interacted to keep juvenile delta smelt exposed to CVP and SWP pumping for an extended period (Nobriga, Hymanson, and Oltmann, page 55). The authors predict that we may be in for a similar problem in 2000.
- In a review of nutrient budget and ecosystem metabolism, Hollibaugh (page 13) points out that algae growth is generally light limited in the Bay, that the trophic status of embayments can vary seasonally (from net producer to consumer) and that nutrient loading is dominated by treated sewage input.
- Orsi (page 17) concluded that in 1999 there were no major changes in zooplankton and *Neomysis* abundance in the northern estuary. The exception was an introduced zooplankter, *Acartiella sinensis*, which continued to decrease in abundance.
- Splittail young-of-the-year abundance (Baxter, page 19) was moderate in 1999 and much lower than 1998. There was, however, strong recruitment from the strong 1998 year class, which may lead to subsequent increased adult abundance.
- Delta smelt catches, both in summer and fall, were relatively strong, being the third highest since 1981 (Rockriver and Fleming, page 21). Salvage at the State and federal intakes was estimated at more than 150,000 fish and exceeded ESA red light take levels for May, June, and July.
- There was considerable variation in the 1999 abundance of bay species (Hieb, page 22).

Bay species exhibiting moderate to strong abundance indices	
northern anchovy	California halibut
bay goby	english sole
staghorn sculpin	speckled sanddab
dungeness crab	

Bay species exhibiting poor to fair abundance indices	
bay shrimp	yellowfin goby
Pacific herring	all surfperches
jacksmelt	
white croaker	

- Delta resident fish (Kogut, page 27) indices were variable but over the years 1995, 1997, and 1999 there appeared to be increasing trend in sucker abundance and a decreasing trend in catfish catches.
- Juvenile white sturgeon abundance (Schaffter, page 30) continues to reflect lack of fish being recruited from the 1987–1992 year classes
- Juvenile chinook salmon catches in 1999 (McLain, page 31) were generally lower than average catches during the 1988–1998 period.
- Adult chinook salmon escapements (Brown and Chappell, page 34) to Central Valley streams were generally good. The ocean harvest index of 52% was the second lowest for the period of record, indicating that harvest restrictions are working.
- Summer and fall juvenile striped bass indices (Gartz, page 38) continued low in 1999. The 1999 summer townet index of 2.2 was among the lowest in the 40+ year period of record.
- Burau et al. (page 45) present a concise summary of the results of recent hydrodynamic research in the Delta and northern estuary. It should be required reading for managers and scientists working in this region.

AN UPDATE ON CALFED SCIENCE

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In the past several months there has been an increasing recognition of the importance of science by the CALFED community. The science components being discussed relate the need for reliable baseline data to assess status and trends, research and monitoring as part of adaptive management, more widespread publication, external review of proposed projects, and translation of scientific results for managers. A few of the activities of particular interest may be:

- Recommendations for aquatic and terrestrial baseline monitoring programs with initial drafts being prepared by me and Peter Stine (USGS) respectively. Many of you will be involved in reviewing the draft.
- An effort to improve coordination of monitoring and research activities in the Bay-Delta and its watershed. An initial meeting to evaluate the need and mechanisms for this coordination will be held on May 18, 2000.
- Appointment of an Interim Science Board by CALFED's Ecosystem Restoration Program. These scientists will help CALFED identify science needs, evaluate research and monitoring proposals and other science issues related to the ERP.
- Consideration of appointing an interim science leader in CALFED to provide a focal point to coordinate the broad scientific program.
- Appointing a Science Oversight Team to assume many of the duties of the Interim Science Leader until the position is filled.
- Consideration of the Delta-Watershed Science Center to provide the infrastructure needed to support data collection, analysis, and reporting during CALFEd's anticipated multi-decade program. If this Science Center were established, it would be complementary to efforts being considered by UC Davis near the Cosumnes River, and by others near Big Break.

FROM THE MANAGING EDITOR

Randall L. Brown, Chief
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This is my last issue of the *IEP Newsletter*. I thank all the contributors for your articles and many of you for suggestions on how to improve the newsletter. For those of you who have been following it since 1989, I hope you have found it to be informative and noticed changes to make it more reader friendly.

Chuck Armor (carmor@delta.dfg.ca.gov) and Zach Hymanson (zachary@water.ca.gov) are assuming managing editor responsibilities and Lauren Buffaloe will continue in her role as technical editor and production manager. The IEP has also established and editorial board to assist in obtaining and reviewing articles. I encourage you to continue providing articles, notes and suggestions for improvement. (As Wim Kimmerer does on page 44). As always, the goal is provide information in a "works in progress" style that helps keep scientists, managers, stakeholders and the general public aware of what is going on in the San Francisco Estuary and Sacramento-San Joaquin Delta. (Wim, did I get it right?) As the IEP and CALFED evolve, expect to see more articles about the watershed.

IEP staff and others thinking about contributing an article to the newsletter should also consider publishing their results in technical journals and presenting papers at local, regional, national and international scientific meetings. The IEP has accumulated a wealth of data—much of which has not been analyzed and reported. IEP scientists and engineers also must improve on our ability to communicate technical information to managers and policy makers with the objective of improved decision making.

Thanks again for all your help. Although I am retiring from State service, I plan to stay engaged in some Bay-Delta activities at least through the October 2000 CALFED Science Conference.

INTERAGENCY ECOLOGICAL PROGRAM QUARTERLY HIGHLIGHTS

DELTA FLOW MEASUREMENT

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The UVM and side-looking ADCP (SL-ADCP) continuous flow-monitoring network survived the high flows of February and March without any major operational problems. However, efforts to calibrate the SL-ADCP at Threemile Slough have not been successful, which precluded the indirect measurement of Delta outflow using flow data for Threemile Slough and three other UVM stations. The SL-ADCP was installed at Threemile Slough to replace the UVM when a transducer pile was damaged by a passing vessel. However, the complex hydraulics in the slough, such as flow asymmetry across the channel and sand wave effects, prevented the development of a usable index velocity relation. A UVM will be reinstalled at Threemile Slough during April.

Several more flow calibration measurements were made during the quarter at each of the three recently installed SL-ADCP continuous tidal flow monitoring stations in the south Delta. The three stations are Grant Line Canal at Tracy Road Bridge, Old River at the Highway 4 crossing, and Old River just east of the temporary barrier location near Delta Mendota Canal. The flow measurement data were used to calibrate the SL-ADCP measured index velocity recorded at each station. Time series of tidal flows were calculated for each site covering the period when the SL-ADCP was installed to the present.

Tidal and daily flow data from the UVM and SL-ADCP stations will soon be available in near real time from a website under development by the USGS. This new website will also have a link to the new hydrodynamics database, also being developed by the USGS. The new database will replace the old FORTRAN database that has been in use for the last 15 years or so. The new database will contain historical UVM and UL-ADCP flow and stage data and other assorted data for the Delta and Bay.

JUVENILE SALMON MONITORING

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Delta monitoring efforts continued through the winter sampling period. Lower Sacramento River seining collected 57 winter-run-sized chinook between January 11 and February 25 (68 to 111 mm), two late-fall run in mid-January (124 and 127 mm), 149 spring run (52 to 84 mm), and 4,780 fall run (52 to 84 mm) between January 18 and March 22. The intensive Sacramento area beach seine effort ended on March 9 with 42 winter run captured through February 10 (68 to 166 mm), 110 spring run (41 to 67 mm), and 4,772 fall run (28 to 58 mm). The north, central, and south Delta seines collected a total of 39 winter run through March 8 (97 to 138 mm), two late-fall in early February (145 and 158 mm), 163 spring run (44 to 87 mm) and 12,599 fall run (29 to 70 mm) by March 28. On February 1, as flows increased, and all up river sites were accessible by boat, the San Joaquin River beach seine run began capturing juvenile chinook. Through March 29, 113 fry were captured. The San Francisco Bay area beach seine collected nine fall-run chinook between February 22 and March 16 (34 to 52 mm).

The Kodiak trawl at Sacramento captured 51 winter run (79 to 141 mm), one late-fall run (154 mm), 143 spring run (47 to 94 mm), and 3,094 fall run (30 to 70 mm) between January 13 and March 29. Midwater trawling replaced Kodiak trawling beginning in April.

Kodiak trawling at Mossdale continued with 355 chinook captured since January 28. One was large enough to be classified as a winter run by the Delta size criteria (84 mm). DFG Region 4 took over sampling on April 3.

Between January 13 and April 2, the Chipps Island trawl has captured 84 winter run (90 to 144 mm), 7 late-fall run (124 to 195 mm), 71 spring run (64 to 99 mm), and 52 fall run (32 to 73 mm). One yearling fall run was captured on January 13 (223 mm). Delta smelt catches have been fairly low and take concerns have not limited sampling since December.

Fall-run fry survival experiments were initiated this year with Coleman National Fish Hatchery releases below Red Bluff Diversion Dam and at Clarksburg, and Feather River Hatchery releases at Isleton and the mouth of the Mokelumne River. Due to the low efficiency of the Chipps Island trawl for fry, the primary results of these tests will be from the adult recoveries in the ocean fishery, three and four years from now. Comparisons will be made to similar fry studies conducted from 1980 to 1986.

On March 29, a CALFED-funded health monitoring study of hatchery and natural fall run chinook juveniles began on the San Joaquin River and the Delta. The study by the California-Nevada Fish Health Center and the USFWS Stockton office is looking at natural stocks and both hatchery production at the hatchery and emigrating hatchery stocks. Fish will be examined externally for gill, skin, and eye abnormalities. Internal organ abnormalities will be noted. Samples taken will include blood, gill ATPase, bacterial, viral, percent lipid, and tissue for histological analysis. The study will end June 30, 2000.

Catches of non-adipose-clipped steelhead collected between January and March were low. The north Delta seine caught seven steelhead (160 to 247 mm). Five steelhead were captured at Sacramento Kodiak trawl (221 to 328 mm), and 15 at Chipps Island (180 to 384 mm).

For more information on the season's fisheries data, see the USFWS Stockton monitoring summary report at http://165.235.108.8/usfws/monitoring/report.asp.

DELTA OUTFLOW AND SAN FRANCISCO BAY STUDY

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The Delta Outflow-San Francisco Bay Study reinitiated monthly sampling in January 2000 after a two-month hiatus due to repairs of the RV *Longfin*. Catches of many species are at their seasonal low in winter; however, there were several noteworthy catches this year. In January we collected a record number of Pacific and river lampreys, with 198 lampreys in one tow. We began to collect age-0 Pacific herring in January—at least one month earlier than other years. By March, this cohort was 50 to 60 mm FL. We have not seen a cohort in this size range this early since 1980 and 1981. These fish are most likely from a mid-November spawn in Richardson Bay and were saved for Mike O'Farrell, a San Francisco State University graduate student who is calculating age and daily growth of age-0 herring.

We continued to collect a relatively large number of California halibut. Most were 225 to 350 mm TL, which are age-2 and age-3 fish spawned during the 1997–1998 El Niño event. We also continued to collect a few of the recently introduced goby, *Tridentiger barbartus*, in San Pablo and Suisun bays. Finally, adult Chinese mitten crabs were concentrated in Carquinez Strait and the San Pablo Bay channel. The 1999–2000 mitten crab CPUE (number/tow) was approximately 40% of the 1998–1999 CPUE (0.78 vs. 1.98); this is a much smaller decrease than reported from the USBR Tracy Salvage Facility, where approximately 90,000 adult crabs were collected in fall 1999, compared to at least 750,000 crabs in fall 1998.

SPLITTAIL INVESTIGATIONS

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Office duties dominated work during the quarter. The hiring process was initiated to replace a biologist and temporary staff in preparation for the 2000 field season. Scientific Aids will start in April and with any luck a biologist will start in May. Fieldwork investigating juvenile splittail riverine habitat should begin in late May.

Winter rains and floodplain inundation from late January through mid-March stimulated a substantial adult migration, as indicated by high angler catches in the Sacramento River and high salvage at the State and federal fish facilities. Unfortunately, rains did not persist and thus by late March peak spawning season, floodplains were draining rapidly, with most going dry by April. Nonetheless, the North Bay Aqueduct larval fish survey (see website at http://www.delta.dfg.ca.gov/index.html) caught relatively high numbers of splittail larvae from March 10 to 18 (samples identified to date), providing evidence of successful spawning and floodplain escapement from the area around Yolo Bypass, Liberty Island, and Miner Slough. Some larvae escapement is also expected from the Sutter Bypass, Cosumnes River, and the lower San Joaquin River.

Analytical tasks involved conversion of splittail databases from dBase to Microsoft Access for abundance index calculation, review of previous abundance indices, and the development of draft, short-term criteria for monitoring splittail population status to be used, in part, to evaluate the success of CALFED-sponsored restoration projects. Some abundance indices for 1999 are reported elsewhere in this newsletter. The draft document describing short-term monitoring criteria is being revised based on DFG comments for interagency distribution this spring.

Chinese Mitten Crab Habitat Use Study

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The objective of the Chinese Mitten Crab Habitat Use Study is to determine the relative abundance of juvenile and adult mitten crabs among various habitats in the Sacramento-San Joaquin Delta. This information will be used to identify the habitats that the mitten crab may potentially affect and to determine the habitat types to target for future mitten crab monitoring and research projects. Monthly sampling commenced February 2000 and will continue through December 2000. We are sampling at six sites in the central Delta: Franks Tract at False River, San Joaquin River at Hayes Point, San Joaquin River at Mandeville Point, Latham Slough at Mildred Island, Old River at Rock Slough, and Connection Slough at Little Mandeville Island. Two sites (Franks Tract and Latham Slough) are index sites, meaning they are sampled every month. Sampling at the remaining four sites occurs on a bi-monthly basis with two of the four sites sampled each month. Field sampling occurs during the two weeks surrounding the full moon when the crabs are reportedly most active. Methods of sampling are baited traps (baited with 250 to 300 g of sardines) fished for 24 hours and "crab condos" (a cluster of PVC tubes used by the crabs as cover) fished for 48 hours (for a detailed description of these gear types, see *IEP Newsletter* 13(1):10. Twenty-five baited traps and 20 crab condos are set at each site, resulting in a total of 100 baited trap samples and 80 crab condo samples per month. The sampling effort is divided between several habitat categories: shallow areas (0 to 2 m) with and without vegetation, mid-depth areas (2.5 to 5 m), and deep areas (5 m and larger). Data on additional habitat characteristics and physical factors are also recorded, such as substrate type, distance to the bank, distance to the habitat edge, vegetation type and density, tidal phase, and water quality parameters.

We have collected only one mitten crab to date. A large female (62 mm) was captured in approximately 6 m of water in a baited trap during the March sampling period. We presume the crab was a resident that did not make the seaward migration last fall despite reaching adult size. No juveniles have been collected to date; we anticipate capturing juveniles when the new year-class migrates into the Delta from the lower estuary. Commercial crayfish fishermen are beginning to capture a few mitten crabs in baited traps in the Delta (in the San Joaquin River at Hayes Point and in the lower Mokelumne River).

In addition to the main study objective, we are also investigating the habitat utilization overlap between mitten crabs and crayfish in the Delta. In February and March, 23 signal crayfish were captured with baited traps in areas 2.5- to 9.5-m deep, with the majority (78%) captured in areas over 5-m deep. Four red swamp crayfish were collected in both shallow and deep water areas (1 to 9 m) in baited traps and crab condos during this same time period. This investigation will complement research conducted by UC Berkeley on the dietary overlap, habitat utilization overlap, and behavioral interactions between these same species in South Bay tributaries.

Shallow Water Methods Project

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Project staff are preparing for the 2000 field season, expected to begin in earnest in June. A new boat for shallow water work, a Munson Packman Beachcraft, has been ordered and will probably be delivered in the summer. Four Scientific Aides will be hired in May or June.

The 2000 field program will consist primarily of gear testing, including minnow seine, block net methods, boat-mounted electrofisher, and two new gear types for delta smelt early life history stages (see next paragraph). Field collections of piscivorous fishes will also be obtained in support of the companion Predator-Prey Dynamics Project.

A new gear intended to collect delta smelt eggs is being tested in cooperation with Delta Smelt Investigations personnel, and a new larva-sampling gear is planned. The egg gear consists of gangs of ten 6-inch or 8-inch glazed ceramic tiles, with about 1 m between adjacent tiles. The tiles provide a smooth solid surface to which smelt eggs may adhere. This gear has been used successfully elsewhere to sample rainbow smelt (*Osmerus mordax*) eggs in the Great Lakes region.

Nineteen gangs of egg tiles are presently deployed in a variety of shore habitats in Miner Slough, the Sacramento Deep Water Ship Channel, Old Prospect Island, and Prospect Slough. The gangs are now being checked approximately weekly. On March 24, after gangs had been in the water for two days, a single fish egg was found on a tile at each of two sites in Miner Slough. Both sites were margins of tule stands in less than a meter of water. The eggs have not been authoritatively examined, but one appears to be of an osmerid species. The other is probably a cyprinid egg. No eggs were found in a check on March 27.

Chinook Salmon Otolith Study

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Since 1998 the IEP has helped fund a pilot study undertaken by the DFG's Stream Evaluation Program to evaluate the efficacy of otolith microstructure analysis in measuring riverine and Delta-estuarine rearing periods of Central Valley chinook salmon and steelhead. This information will be used to evaluate the role of Delta and estuarine rearing in the success of the salmon and steelhead. Success is defined as survival to key recruitment stages, such as ocean entry and adult return.

Work to date has emphasized the development of a sampling design for the collection of both juvenile and adult salmon and steelhead otoliths throughout the system, collection coordination, and development of protocols for collection and archiving of samples, sample preparation and analysis, and data management and analysis.

The basic study approach is to sample juvenile salmon and steelhead successively in time and space as they proceed through the system to validate a change in both qualitative and quantitative otolith microstructure attributes against an associated change in major habitat zone (for example, from natal tributary to upper mainstem river to lower river to Delta to Bay). Sampling is coordinated with existing juvenile emigration monitoring activities throughout the system, including those on Clear Creek, the upper Sacramento River at Balls Ferry, Mill Creek, Deer Creek, Sacramento River at GCID, Butte Creek, Sacramento River at Knights Landing, Feather River, Yuba River, Dry Creek, lower American River, Sacramento River at Sacramento, Cosumnes River, Mokelumne River, Stanislaus River, Tuolumne River, Merced River, San Joaquin River at Mossdale, interior Delta points including the State and federal pumping facilities, and at Chipps Island. Sampling also occurs at Coleman, Feather River, Nimbus, and Mokelumne River fish hatcheries and at the Merced River Fish Facility.

During January through March 2000, sample collections were coordinated for juvenile salmon and steelhead moving through the system during the current emigration season. Current analysis is focused on describing the age (in days) of juvenile salmon and steelhead as they entered the Delta, and then exited the Delta. The 1998 data will be used to provide a gross measure of Delta residence time and a demonstration of some of the basic attributes of the methodology within this context. These results, along with documentation of all protocols developed to date, are being summarized for a future report.

Knights Landing Juvenile Salmonid Monitoring

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The monitoring program at Knights Landing on the lower Sacramento River is a potential long-term monitoring element of the IEP that is intended to identify the timing, relative abundance, and disposition of juvenile chinook salmon and steelhead emigrating into the lower Sacramento River and Delta, with emphasis on providing early detection of Delta-bound juvenile salmonids for management purposes. These objectives have been given a high priority by the Salmon Project Work Team, as a result of the Delta PWT's latest list of questions and problem areas to be addressed by the group.

Monitoring results during the 1999 emigration period, starting in late October 1999 showed little fish movement before the first major rainfall and flow increase, which occurred in late January 2000. Previous years' monitoring showed salmon migration typically began between late November and early December with a fair proportion of the late-fall, winter- and spring-run migration occurring by the end of January. For example, the percentage of winter-run juveniles migrating past Knights Landing before the end of January ranged from 64% in 1996–1997 to 83% in 1997–1998. So far, in 1999–2000, less than 30% of the winter run migration occurred before February 1, 2000. (Runs are designated using Fisher growth curves.) The influence of this year's late flow on steelhead migration has been negligible since most steelhead migrate past Knights Landing in February and March.

Delta Smelt Studies: Contaminant and Inland Silverside Effects

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We have been assessing the relative importance of contaminant exposure and other factors influencing delta smelt growth and survival, including the potential effects of exotic inland silversides. The contaminant effects study is a two-year project funded by CALFED to assess potential contaminant effects by integration of three techniques: genotoxic and histopathologic assessment of contaminant exposure with evaluation of growth by otolith analyses for individual delta smelt caught at various life-stages by IEP monitoring programs. The inland silverside study is also a two-year effort funded by IEP to analyze existing information on the delta smelt population, as well as evaluate the potential effects of exotic inland silversides in delta smelt habitat.

In the first year of the contaminant effects study we have been adapting these traditionally independent techniques for simultaneous application to individual specimens. To do this we have been accompanying IEP staff on various IEP monitoring surveys, specifically, real-time monitoring, 20-mm survey, tow-net survey, midwater trawl survey, and the Bay Study program. In 1999, we have taken over 500 blood samples from specimens, which were then prepared for histopathological and otolith analyses. Currently, Dr. Susan Anderson (UCD's Bodega Marine Lab) is analyzing blood samples for genetic abnormalities; Dr. Swee Teh (UCD) is evaluating tissue and organ samples, and I am processing otoliths to assess growth patterns of the 1999 year-class. This information will be collated for individual specimens and compared with the results of water quality studies by Dr. Kathy Kuivila (USGS) (summarized in *IEP Newsletter* 12:8–9). In 2000, we have expanded our study to include specimens from the USBR fish salvage facilities at the CVP.

In the first year of the inland silverside studies we conducted analyses of delta smelt population structure and dynamics primarily using the summer tow-net survey and midwater trawl indices, as well as an evaluation of the abundance of inland silversides as recorded in the USFWS salmon smolt beach seine survey. These analyses suggest the potential importance of 1+ year-old spawners, density dependence between the juvenile and adult stages, and wintertime salvage losses to delta smelt population dynamics. In addition, the catch per beach seine haul for inland silversides has continued to increase in the delta smelt spawning habitat and is negatively correlated with several measures of delta smelt abundance. We have also been examining gut contents and otoliths from archived specimens of inland silversides, as well as from instances when delta smelt and inland silversides were caught together in the 1999 tow-net survey. So far, these evaluations indicate most delta smelt over 70 mm are 1+ year-olds and that these older specimens exhibit higher infestations of cestode parasites.

In the second year, our goal is to assess the potential consequences of dense schools of inland silversides in shallow water habitat. First, we plan to provide a description of the spatiotemporal distribution of the expanding inland silverside population using data from a variety of IEP monitoring surveys. Then we will conduct diel sampling and marking of individuals to assess the daily movements and responses of inland silversides to spring-neap tidal variation. Results from these studies will be evaluated with laboratory feeding studies to assess potential foraging rates of inland silversides to estimate the potential predatory-competitive effect of schooling inland silversides in shoal-water areas.

SHERMAN ISLAND AGRICULTURAL DIVERSION EVALUATION

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This element will compare the relative abundance and species composition of fishes entrained in side-by-side diversion siphons (one screened, one not screened) in Horseshoe Bend. The siphons are being sampled using modified fyke nets (1600 µm mesh) that sample all of the water coming through the siphons. Although we plan to go forward begin this spring, we have not set a start date for field work. We will start sampling when the DFG 20-mm Survey begins detecting delta smelt in the vicinity of Horseshoe Bend and when water is consistently diverted for irrigation.

REAL TIME MONITORING

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The RTM PWT last met on March 23 to review and approve two special pilot study proposals for this year's program. One study will evaluate a larger Kodiak Trawl net for capture efficiency. After four meetings, the RTM PWT approved the draft program for spring 2000 on January 27. The majority of the RTM PWT voted to omit any Kodiak trawling effort in the interior Delta, as analyses of the five years of data collected through 1999 do not show any statistically significant relationship between data from those locations and salvage of salmon, delta smelt or splittail at the SWP or CVP. Stations at entry points (Sacramento and Mossdale) and the exit point (Chipps Island) from the Delta were maintained, as managers have found information from these sites to be useful in decision-making for salmon, even if they are not consistently well correlated with salvage. These three stations are also part of ongoing IEP monitoring programs, so there is little or no additional cost to keep them active five days per week and to rapidly report their data on the RTM Internet site. RTM will also begin rapid reporting of the USFWS's weekly Lower Sacramento River, San Joaquin River, and Delta beach seine surveys. This is being done as a substitute for interior Delta Kodiak trawling, and to see if upstream seine data correlates with salvage to give more timely forewarning of impending problems with salvage at the CVP and SWP.

RTM sampling for delta smelt has been more successful in assisting water managers to make operational decisions. At the Delta Smelt Working Group's request, Kodiak trawling was conducted in — at four locations in Miner and Cache sloughs and the Sacramento deep water shipping channel to look for gravid female delta smelt. Six delta smelt were collected and several were gravid. Light trapping began in March and will continue in April. The purpose is to determine when and where post-hatch delta smelt can be found. Light trapping has been conducted in Miner and Cache sloughs, Old River near Franks Tract, Victoria Canal, and Old River near Coney Island. To date No delta smelt larvae have been collected. Data from the delta smelt project's 20-mm Survey, the spring midwater trawl, RTM light trapping data and federal beach seine information are available at the DFG website at http://www.delta.dfg.ca.gov/.

The third draft of the report *Programmatic Review of the Spring Real Time Monitoring Program in the Sacramento-San Joaquin Delta* was submitted to the IEP Management Team and Coordinators for review in February. They have returned the report to staff for further analyses. Further revisions will not be made until this year's RTM Program is well underway, allowing staff to redirect time to this effort.

DELTA SMELT

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Delta smelt monitoring for North Bay Aqueduct began February 15, 2000 and will continue every other day through mid-July. Results from this survey are posted at http://www2.delta.dfg.ca.gov/data/nba/2000. Approximately 99% of the 12,080 larvae collected so far were prickly sculpins. Only three delta smelt were collected: two in the Sacramento Deep Water Ship Channel and one in Minor Slough.

The 20-mm survey began on March 20, 2000 and will run every other week through July. Results from this survey are posted at http://www.delta.dfg.ca.gov/data/20mm/2000. Distribution maps for all species collected from 1995 to the present can now be generated at this website. Of the 11,000 fish caught during the first survey of this year, only 28 were larval delta smelt. The larvae were located primarily in the lower Sacramento River and near Chipps Island. Lastly, at the end of April we will conduct a short study to determine if there is a day-night vertical migration of larval delta smelt.

CURRENT PROGRESS ON DELTA SMELT CULTURE

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This season subadult smelt were collected primarily from the lower Sacramento River from October through December 1999. Individuals weighed more (1.46 g " 0.02) (mean body weight " standard error of the mean), compared to fish collected last year (1.24 g " 0.04).

The capacity of our broodfish facility has doubled this year, with the addition of three outdoor tanks. Fish started spawning earlier in these tanks, beginning in late February. However, spawning was delayed one month for fish in the three indoor tanks exposed to dim artificial light. Video equipment is being used this year to monitor broodfish spawning activity when water clarity permits. Preliminary testing of light level, water turbidity, and varying flow rates on spawning behavior will be conducted.

The hatchery facility has been extensively modified with the addition of two new water recirculation systems for rearing larvae. Preliminary work to test the effect of temperature on growth and survival of smelt larvae is slated for this spring and summer. Broodfish spawns have yielded a few thousand larvae so far and they are feeding well; we anticipate a productive year.

SKELETONEMA COSTATUM BLOOM DETECTED IN SAN PABLO BAY

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A bloom of the diatom *Skeletonema costatum* was detected by DWR's Bay Delta Monitoring and Analysis Section staff conducting continuous, on-line water quality compliance sampling in San Pablo Bay on March 16. The bloom was located from the Carquinez Strait westward into San Pablo Bay. Although the presence of *S. costatum* has been documented in this region in the past, an intense late winter *S. costatum* bloom of this magnitude has not occurred recently.

An array of water quality data was obtained throughout the bloom area. Surface water temperature values ranged from 13.7 °C of at Carquinez Strait to 16.4 °C at the end of the rock wall in San Pablo Bay. Fluorometric values ranged from 25.0 fluorescence units at many locations to 245.9 fluorescence units at the end of the rock wall in San Pablo Bay. Nephelometric turbidity units (NTU) ranged from 10.1 NTU west of Pinole Point to 167.2 NTU at the end of the rock wall in San Pablo Bay. Surface specific conductance values ranged from 5,400 mS/cm at the end of the rock wall in San Pablo Bay to 11,643 mS/cm near the R&W Echo Buoy in San Pablo Bay. The spectrophotometric values of chlorophyll *a* and pheophytin taken at the end of the rock wall in San Pablo Bay were reported as 46.9 and 6.1 µg/L, respectively.

The high standing biomass of *S. costatum* appears to be associated with the combined effects of warmer water temperatures, higher light attenuation and water turbidities, increased nutrient concentrations, and changing salinity in San Pablo Bay. Follow-up field surveys will be conducted to further clarify the biological, chemical, and physical processes leading to the initiation and development of *S. costatum* blooms.

DELTA HYDROLOGY

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The hydrologic conditions of calendar year 1999 started normally, but a dry trend developed during October, November and December. The lack of significant precipitation after April left the late fall and early winter, when net Delta outflow typically increases, much drier than usual. This dry trend resulted in lower than normal net Delta outflow. Reduced outflow in conjunction with closure of the Delta Cross Channel to keep emigrating smolts in the Sacramento River caused water quality concerns in the South Delta. This resulted in the curtailment of exports for approximately one week in mid-December.

Net Delta Outflow

Figure 1 shows the calculated Net Delta Outflow Index (NDOI), the measured net Delta outflow for calendar year 1999,and the 40 year (1959–1998) average net Delta outflow. All outflow values are daily means. The 40-year average values were obtained from historical DAYFLOW data. The calculated values, provided by DWR's Division of Operations and Maintenance (O&M), are based on the mass-balance of flows into and out of the Delta. Rick Oltmann of the USGS provided the measured Delta outflow values. Measured Delta outflow is obtained by combining field data recorded by four ultrasonic velocity meters (UVM). The four UVMs, installed at Rio Vista, Jersey Point, Three Mile Slough and Dutch Slough, record channel velocities which are converted to flows. The measured Delta outflow is taken to be the algebraic sum of flows from the four locations. The missing data during the latter part of 1999 are due to calibration problems with the Three Mile Slough site.

Comparing the O&M calculated NDOI and the USGS measured net outflows to the 40-year average net outflow shows February and March outflows were higher than average in 1999. The calculated outflow also shows the unusually dry conditions during the late fall and early winter. September, October, November and December all show below average net Delta outflow. The small peak in the calculated outflow during mid-December is the result of decreased exports in response to water quality concerns in the South Delta.

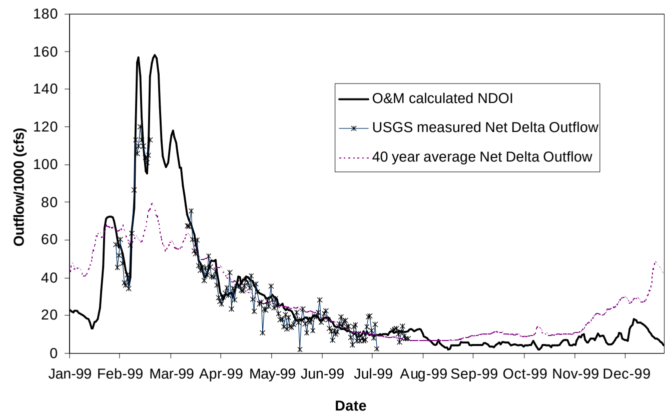

Figure 1 Calculated NDOI vs. measured Net Delta Outflow for January 1 to December 31, 1999, and 40-year average Net Delta Outflow

In comparing calculated and measured outflow, the most notable difference occurs around February 14. This difference is the result of how the two datasets are generated. During this period, there was an unusual combination of climatic events: low atmospheric pressure, and strong sustained on-shore winds which resulted in an extreme high tide. These conditions "stored" water in the Delta and decreased Delta outflow. While climatic influences on tides are inherent in field measurements, they are not incorporated into the calculated Delta outflow, which is based solely on the mass-balance of flows into and out of the Delta. Therefore, extreme climatic conditions can result in substantially different Delta outflow values. The potential for tidal conditions to cause large differences between calculated and measured Delta outflow was addressed by Rick Oltmann of the USGS in the winter 1998 issue of the *IEP Newsletter* (volume 11, number 1), "Indirect measurement of Delta Outflow using Ultrasonic Velocity Meters and Comparison with Mass-balance Calculated Outflow."

Inflows and Exports

Sacramento and San Joaquin River mean daily flows for 1999 are shown in Figure 2. Flow in both rivers peaked during the last week of February, with a maximum mean daily Sacramento flow of 86,652 cfs and a maximum mean daily San Joaquin flow of 15,586 cfs. Flows gradually decreased over the summer and remained low throughout the dry fall and early winter. Figure 2 also shows the lack of significant precipitation after early April.

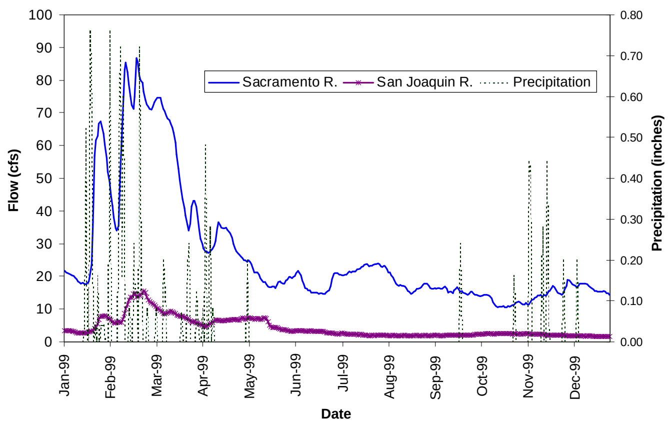

Figure 2 Mean daily Sacramento and San Joaquin River flows and daily precipitation for January 1 to December 31, 1999

Figure 3 shows the State Water Project (SWP) and Central Valley Project (CVP) mean daily export rates for 1999. Mean daily SWP exports at Banks Pumping Plant averaged about 3,700 cfs over the year with peak pumping around 7,000 cfs in the late summer and fall. Mean daily CVP exports at Tracy Pumping Plant averaged between 3,500 and 4,000 cfs throughout the year, with decreased exports during the late spring and early summer. Both show the extreme reduction in exports in mid-December to help reduce high South Delta salinity.

Figure 4 shows the percent of Delta inflow that was diverted by the SWP and CVP during calendar year 1999. Two running averages are shown, three-day and 14-day, along with the maximum allowable percent diversion for different times of the year. From February through June, diversions are limited to 35% of Delta inflow. For the rest of the year, diversions are limited to 65% of Delta inflow. The percent diverted remained below—often well below—allowable limits except for three days in mid-October when the three-day running average exceeded the 65% level. The cut back in exports in mid-December is also noticeable on this figure.

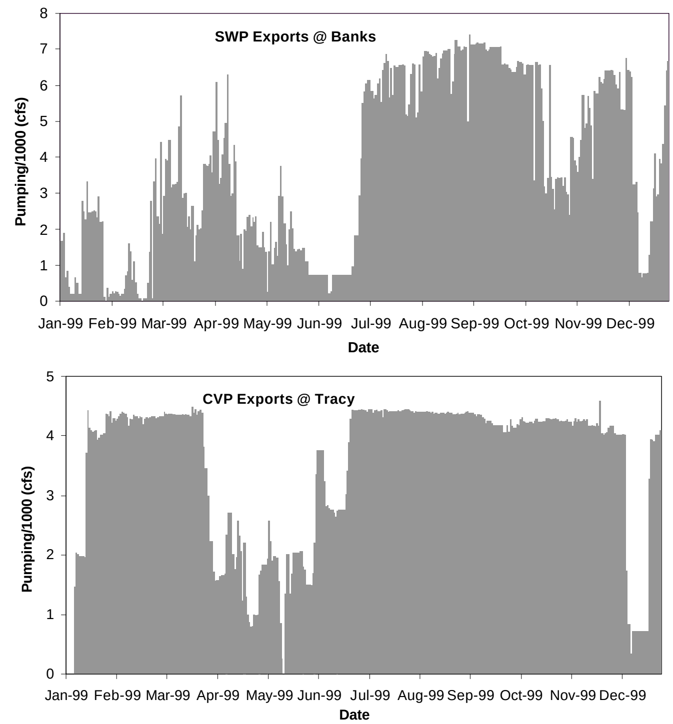

Figure 3 State Water Project and Central Valley Project mean daily export rates for January 1 to December 31, 1999

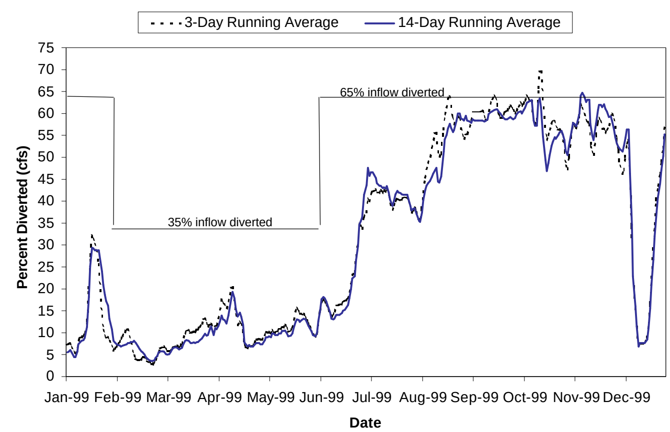

Figure 4 Percent of Delta inflow diverted for January 1 to December 31, 1999

Annual Totals

Figure 5 compares the 40 year record for total annual Delta outflow and total annual exports (SWP+CVP). The 1999 totals were calculated from DWR O&M data and the historical totals were calculated from the DAYFLOW database. The annual Delta Outflow Index for 1999 was slightly lower than the previous four years and the seventeenth highest in the last forty years. The annual exports were about average for the previous four years and the sixth highest in the last forty years.

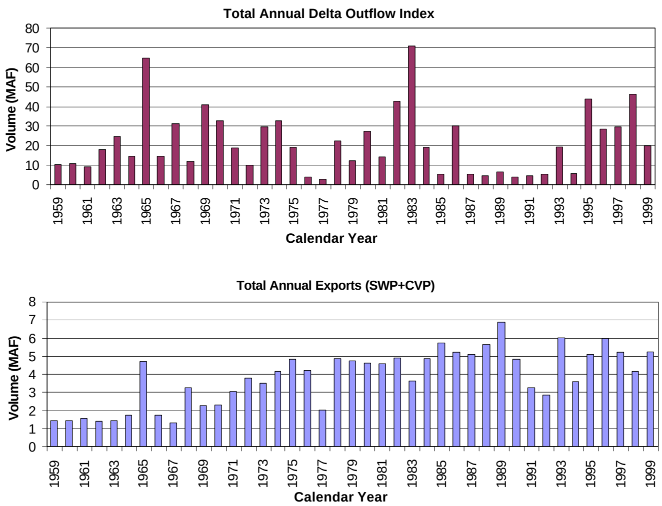

Figure 5 Total annual Delta outflow and annual exports for calendar years 1959–1999

Water Supply Forecast

As of March 1, 2000, DWR's Bulletin 120 forecasted water supply is above normal for the Delta watershed. Figure 6 shows water supply as a percent of average for the Sacramento and San Joaquin hydrologic regions. Reservoir storage, snow water supply and forecasted runoff are all at least 110% of average for both regions. Although water year 2000 has been classified as "wet," and DWR originally forecast that all SWP water supply demands would be met in calendar year 2000, a dry spring may result in some reduction in allocations.

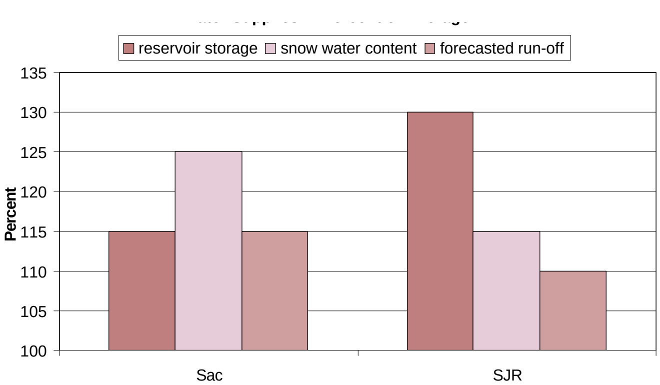

Figure 6 Water supply in percent of average for the Sacramento and San Joaquin hydrologic regions

Nutrient Budgets and Net Ecosystem Metabolism of San Francisco Bay: A Status Report

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We recently completed an analysis of the water, salt and nutrient budgets of San Francisco Bay to quantify the net non-conservative fluxes of nitrogen (N) and phosphorus (P) in the bay (Smith and Hollibaugh 2000). Related goals were to determine sources and sinks of N and P and to use the biogeochemical relationships between these elements and carbon (C) to evaluate the net production of the bay: is it a net producer of organic matter as a result of primary production in the bay ecosystem or is it a site of net decomposition of organic matter brought into the bay by river flow, point and non-point discharges?

The bay might be expected to be a net consumer of organic matter (or "net heterotrophic": respiration integrated over the whole ecosystem (R) > production integrated over the whole ecosystem (P); P/R < 1) for a number of reasons. Bay water is relatively turbid, and several studies by J.E. Cloern and co-workers (Cloern and others 1985, for example) have shown conclusively that, except for rare occasions during the South Bay spring phytoplankton bloom, phytoplankton growth rate is limited by light availability. Benthic grazing, which keeps water column phytoplankton biomass low, also contributes to reducing phytoplankton primary productivity (Cole and Cloern 1984). Primary production in salt marshes around the bay or by beds of submerged aquatic vegetation or macroalgae is limited simply by the small areal extent of these habitats. Another factor potentially contributing to San Francisco Bay being a net heterotrophic ecosystem is the large loading of organic matter delivered to the North Bay by river inflow (Jassby and others 1993). Of course, a key factor determining the actual contribution of this organic matter to bay respiration is its nutritional value to the organisms most likely to use it—bacteria. In this context, we (Hollibaugh and co-workers) have observed that bacterial productivity consistently exceeds phytoplankton primary productivity in some reaches of the estuary, particularly the North Bay.

However, other aspects of the bay's ecology suggest that it might be net autotrophic (P > R, P/R > 1). As a result of the implementation of the Clean Water Act in the

1970s, most of the nutrients reaching the bay from sewage treatment plants are in an inorganic form that can be readily used by phytoplankton. The bay also has extensive mudflats which are known to contain areas with high standing crops of benthic microalgae. We do not have any good quantitative estimates of the contribution of this group of plants to total ecosystem production, though the high standing crops and favorable light regime on the mudflats (at least during low tide) suggest that it might be large. Finally, our measurements (Hollibaugh and Wong 1996) indicate that phytoplankton primary productivity exceeds bacterial productivity in some reaches of the bay, particularly the South Bay.

What is the management significance of resolving these questions? After all, net ecosystem metabolism is a very coarse measurement that integrates across trophic levels, space, and time. It cannot be used, for example, to estimate the production of a particular primary producer or to estimate the amount of food available for fish. It does, however, provide an external and independent constraint on the balance between production and respiration in the system and allows one to be estimated from the other. It also allows us examine seasonal and interannual differences in the bay's net biogeochemical performance, providing clues as to the factors that control production and respiration. The budgeting exercise allows us to evaluate the relative contributions of different sources (for example, river flow, M&I discharges or non-point sources) to nutrient and organic matter loadings to the bay. The non-conservative behavior of nutrients provides clues about the lability of organic matter supplied from external sources, and thoughtful subdivision of the bay "box" into smaller analytical units can help to identify areas of particular significance to the non-conservative behavior of nutrients, for example sub-embayments where primary production might dominate over respiration. An example of what can be done with this kind of an analysis is given in Smith and Hollibaugh (1997).

Our actual analysis is based on a box model approach and is a four-step process. First, the bay "box" was divided into sub-regions. Sub-regions were chosen based on hydrographic considerations modulated by data density and the management or ecological questions to be addressed. Our analysis divided the bay into nine boxes for calculations; however, these were collapsed into three boxes for the final analysis with one of these (the Central Bay) used as the "oceanic" source for the other two (North Bay and South Bay). The next step is to construct a water budget for each box. Our analysis considered freshwater inputs from major streams, rainfall, evaporation, and other freshwater sources (non-point runoff, sewage and groundwater), and was solved (steady-state assumption) to find the flows (tidally-averaged residual flows) to and from adjacent boxes. Once the residual flows are known, a salt budget is used to calculate the mixing exchange of water and dissolved materials (salt is taken to be a conservative tracer) between boxes. The final step is to use the mixing exchange, all of the flows, and concentration data for each of these to quantify the non-conservative fluxes of materials of interest, here dissolved inorganic nitrogen (DIN; nitrate, nitrite and ammonium) and dissolved inorganic phosphorus (DIP, soluble reactive phosphate, predominantly orthophosphate). We did not budget dissolved organic forms of these elements due to lack of data. Further, the dynamics of particulate material can not be adequately described by this approach because they have "behavior" (sinking and resuspension) that is independent of water exchanges.

We analyzed winter (October through March) and summer (April through September) data from each of six years (water years 1990–1995) separately. This period of record contained two years of above-average river discharge (wet, 1993 and 1995) and four years of below average discharge. Due to the relative paucity of data, additional calculations based on a simple Monte Carlo analysis were made to evaluate the statistical robustness of the results. We then used standard stoichiometric relationships between C, N, and P in organic matter to make inferences about C cycling in the bay and the balance between nitrogen fixation and denitrification.

A summary of the results of our analysis is presented in Figures 1 and 2. Bearing mind that the standard errors of the estimates are large for the North Bay, particularly in winter; overall the bay appears to be slightly net autotrophic (production of new organic matter in the bay by plant growth exceeds ecosystem respiratory demands). Trophic status varies seasonally (autotrophy strongest in summer) and is complicated by abiotic P absorption in the North Bay. Both arms of the bay were net heterotrophic during the wet winters of 1993 and 1995, and both were autotrophic during the summer, regardless of water year type. Although interpretation is complicated by abiotic P adsorption in the North Bay, less N was released during heterotrophic period than would be predicted from P release, and more N was removed during autotrophic periods than would be predicted from P uptake. This indicates active denitrification in the bay at a rate of approximately 4 mmoles m^{-2} d^{-1} in the South Bay.

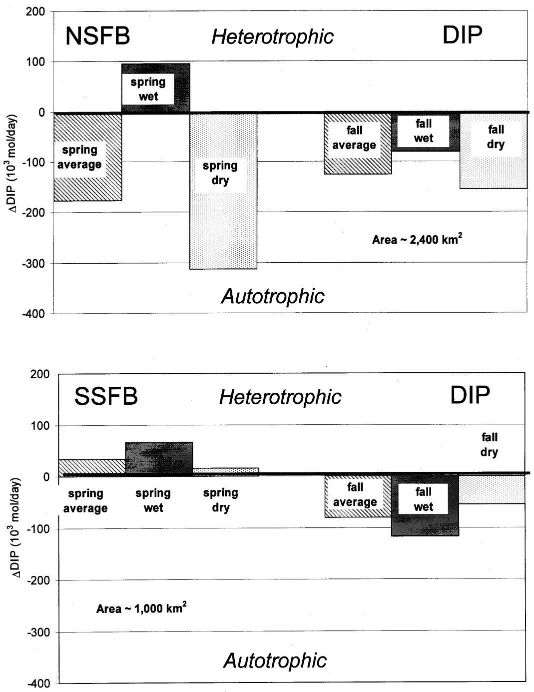

Figure 1 Summary of dissolved inorganic phosphorus net fluxes for North (NSFB) and South (SSFB) San Francisco Bay. Data are broken out by season ("spring": October-March; "fall": April-September), and water year type ("wet": water years 1993, 1995; "dry": water year 1990, 1991, 1992, 1994). "Average" is the average over all years. Net fluxes are in units of 10^3 moles/day, integrated over the area of the embayment. Also shown are the biogeochemical implications of the fluxes: "Heterotrophic" or net consumption of organic matter in the system (net respiration leading to release of nutrients) if the fluxes are positive; "Autotrophic" or net production of organic matter in the system (net primary production leading to net uptake of nutrients) if the fluxes are negative.

Peterson and others (1985) used salinity-composition plots of North Bay nutrient data collected during the 1970s to describe nutrient dynamics in this reach. Their results are qualitatively the same as ours, suggesting that the nutrient dynamics of San Francisco Bay have not changed substantially between the 1970s period of their data record and the 1990s period we analyzed. While they did not attempt to model their data or to use it to calculate net fluxes, the shape of the curves they obtained indicate net uptake of nutrients, especially silicate (Figure 6 in Peterson and others 1985), during the summer. This pattern was most pronounced during drier years. Peterson and others (1985) interpreted the non-conservative behavior of silicate as an indication of benthic diatom primary production in northern San Francisco Bay, a credible hypothesis given the high benthic chlorophyll concentrations observed in shallow areas of San Pablo and Suisun bays (Thompson, personal communication). Thus the non-conservative fluxes of DIN and DIP we observed are likely the result of a combination of abiotic processes (P adsorption), primary production and heterotrophy (denitrification).

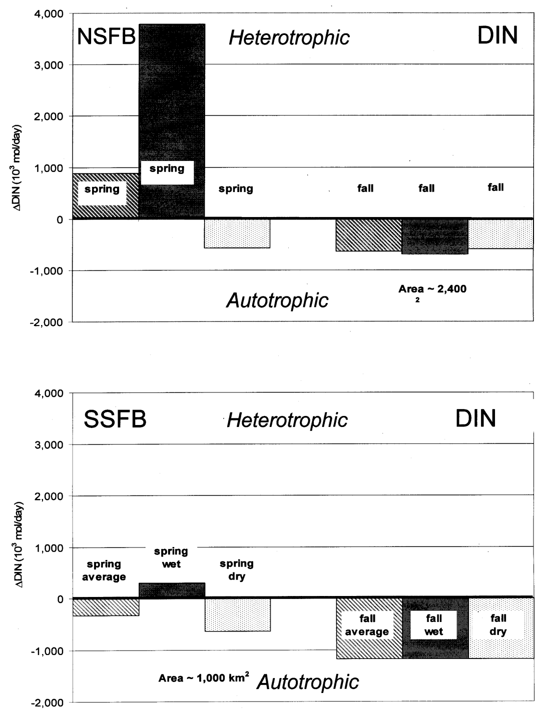

Figure 2 Summary of dissolved inorganic nitrogen net fluxes for North (NSFB) and South (SSFB) San Francisco Bay. See notes as in Figure 1.

Taken as a whole, the nutrient loading into San Francisco Bay is presently dominated by sewage. During the winter, about half the inorganic nutrient loading to the Bay is sewage; in the summer, sewage contributes about 80% of the total loading. The sources of the loading are mostly river in North Bay; mostly sewage in South Bay. There is some uncertainty as to the origin of the nutrients in the "river nutrient" signal entering the North Bay through the Delta. These nutrients are assumed to originate primarily from agricultural activities in the Delta and the Central Valley, yet the urban areas of Sacramento, Davis, Modesto, and Stockton on the periphery of the Delta may contribute significantly to this input via sewage discharges (directly or indirectly) to the river system.

Given the population of the Bay Area and assumptions about per capita waste generation, waste water treatment plants appear to currently be removing 75% to 90% of the nutrient load from the waste stream entering sewage treatment plants. Nutrient loads to the bay and nutrient concentrations in it would be substantially higher in the absence of waste treatment to the present level. However, the low primary production of the bay is not a consequence of nutrient limitation so that further nutrient elevation would probably not increase biotic uptake significantly.

The more significant role of waste treatment in this system may be with respect to the form of nutrient present and perhaps with respect to pathways of inorganic nutrient uptake. Typically, approximately half of the nutrient load in raw sewage is inorganic. Besides removing nutrients, treatment undoubtedly elevates the proportion of inorganic nutrient. In clear water with low nutrient levels, this might actually enhance biotic nutrient uptake and primary production. In San Francisco Bay, any increase in nutrient removal probably results from abiotic sorption of phosphorus onto particles and perhaps by elevated loss of nitrogen through denitrification.

Before implementation of current treatment practices, the organic carbon loading from waste is likely to have been of greater significance to the bay foodweb and geochemistry than nutrient loading. Organic carbon discharged to the bay in the untreated sewage produced by 6 million persons would total about 60 x 10^6 moles d^{-1} (720 x 10^6 g C d^{-1}). Spread evenly over the bay surface of 1,200 km^2, this is equivalent to a labile C supply of about 0.6 g C m^{-2} d^{-1}, if we assume that most of this material is relatively reactive and would support heterotrophic activity (respiration and secondary production, broadly defined to include higher organisms as well as bacteria). Primary production in San Francisco Bay averages about 0.5 g C m^{-2} d^{-1} (Cloern 1985). Phytoplankton biomass is also reactive and supports heterotrophic activity. The conclusion from this simple calculation is that the magnitude of organic matter supplied by waste loading in the absence of treatment could have exceeded the reactive organic matter supplied by primary production. It therefore seems likely that heterotrophic activity might approximately double if that waste load were currently reaching the bay. It should be noted that this simple geochemical calculation provides no insight as to where, within the food web of the bay, this elevated heterotrophy would be most strongly felt. Spatially, waste discharge data used in budgetary calculations suggest that the major impact would be in the South Bay. The slow exchange times there, particularly during the summer, would clearly exacerbate any effects from such high organic loading.

Acknowledgments

We thank the staff of the San Francisco Bay Regional Water Quality Control Board and of various municipal waste water treatment plants who helped us locate data on sewage discharge and composition. S.W. Hager and J.E. Cloern of the USGS San Francisco Bay Project provided most of the bay water quality and nutrient data we used. This study was supported by contract B–81394 from the California Department of Water resources to JTH.

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ZOOPLANKTON AND MYSID SHRIMP

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Neither zooplankton nor mysids showed any large abundance changes in 1999, with the exception of *Acartiella sinensis*, an introduced copepod (Figure 1). This species declined sharply in spring 1999 compared to 1998 and has undergone a large decline in summer and fall since 1996. A sample taken from San Pablo Bay indicates that *A. sinensis* may be abundant at salinities higher than we normally sample.

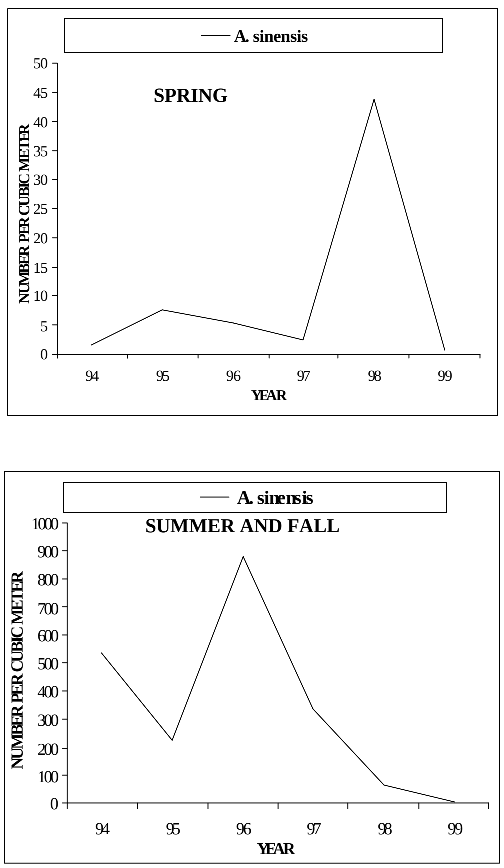

Figure 1 Mean abundance of the introduced copepod *Acartiella sinensis* in spring (upper panel) and in summer and fall (lower panel), 1994 to 1999

Pseudodiaptomus forbesi, the most abundant calanoid copepod in the upper estuary and an important food for delta smelt, continued to show widely fluctuating abundance in spring (Figure 2). Its summer-fall abundance has remained more stable, but has declined since 1988, the year after it was first detected. *Eurytemora affinis* spring abundance has increased since 1997, but remains below the concentrations seen in most years before the establishment of *Potamocorbula amurensis* (Figure 2). *Eurytemora affinis* has not been abundant in summer and fall since 1986.

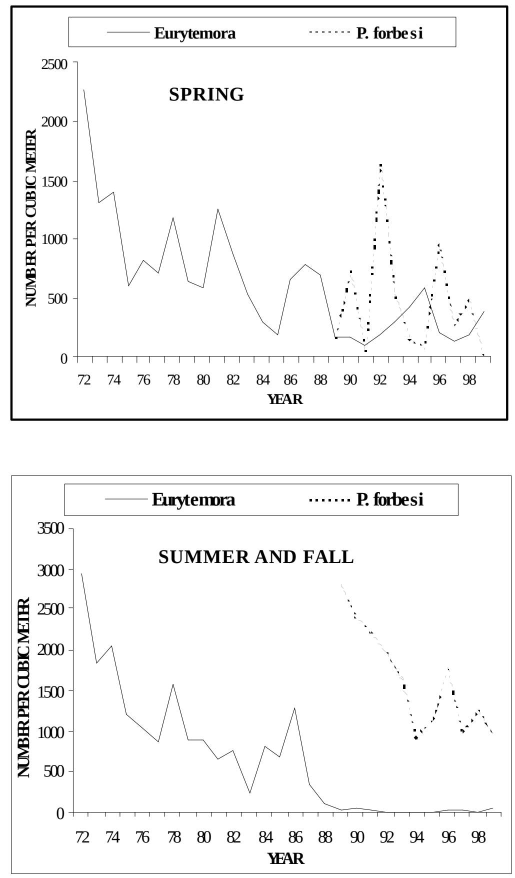

Figure 2 Mean abundance of the copepod *Eurytemora affinis* (of cryptic origin) and the introduced *Pseudodiaptomus forbesi* in spring (upper panel) and in summer and fall (lower panel), 1972 to 1999

The high outflows since 1993 have not resulted in higher abundance of any zooplankton species. Very high outflows move estuarine and freshwater species seaward and prevent them from building large populations. Moderate outflows presumably add more organic carbon to the system than low outflows do, but this does not necessarily translate into higher phytoplankton concentrations. In the low salinity zone and seaward, *P. amurensis* may filter most of the phytoplankton out of the water. Even in freshwater, upstream from the range of *P. amurensis*, phytoplankton concentrations have not been high in recent years and cladocerans and rotifer populations have remained depressed (Figures 3 and 4). Food quality for *Daphnia* appears to be poor (Anke Mueller-Solger, UC Davis, personal communication). The entire system may be suffering from a shortage of phytoplankton. Only two species, *P. forbesi* and *Limnoithona tetraspina* (Figure 5), both introduced, are doing well. *Pseudodiaptomus forbesi* would be expected to eat primarily phytoplankton, although bacteria attached to detritus and copepod nauplii are also possible but probably minor food sources. *L. tetraspina* belongs to a copepod group that is known to feed extensively on nauplii. Perhaps the lower abundance of *P. forbesi* in summer and fall since 1994 is a result of predation on its nauplii by *L. tetraspina*.

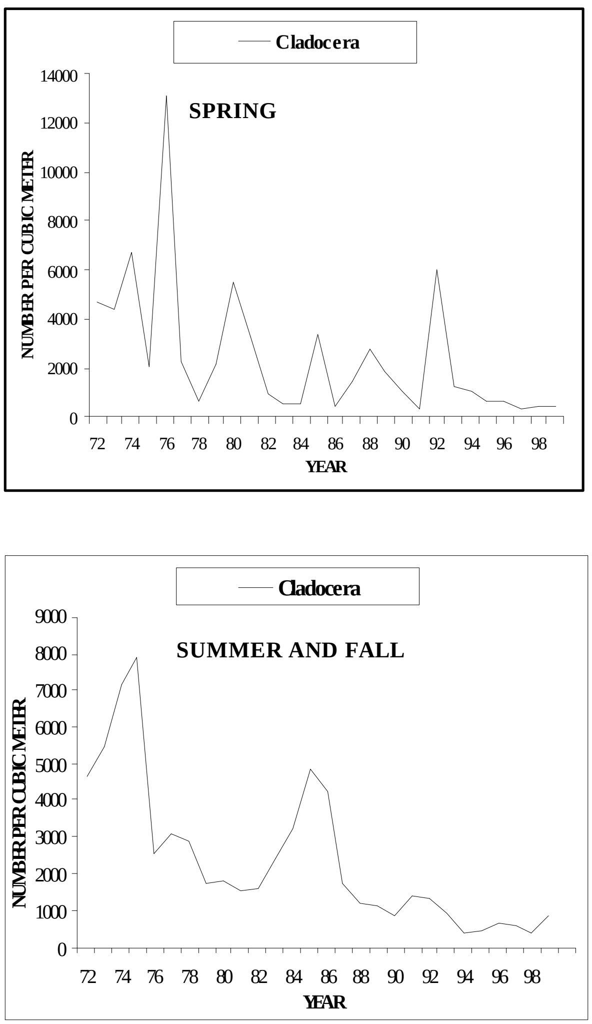

Figure 3 Mean abundance of cladocera in spring (upper panel) and in summer and fall (lower panel), 1972 to 1999

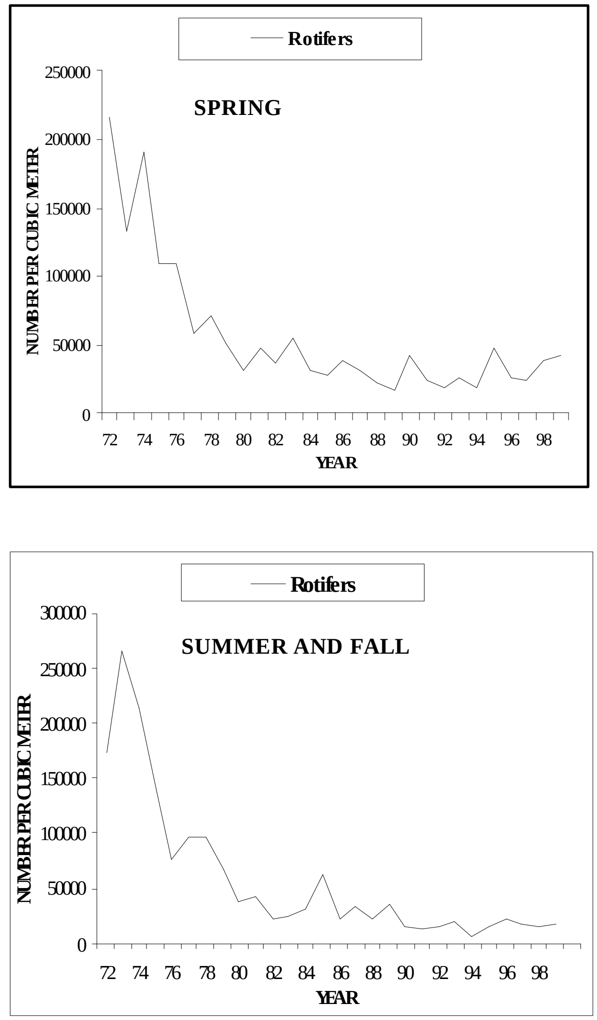

Figure 4 Mean abundance of rotifers in spring (upper panel) and in summer and fall (lower panel), 1972 to 1999

Mysid shrimp abundance remains low (Figure 6). The introduced *Acanthomysis bowmani* has not reached the historical levels of abundance of *N. mercedis*. *Acanthomysis bowmani* does at times reach impressive concentrations of several hundred per cubic meter, but does so in Suisun Slough where sampling does not go back to 1969. Suisun Slough is one of the few places where chlorophyll concentrations are high.

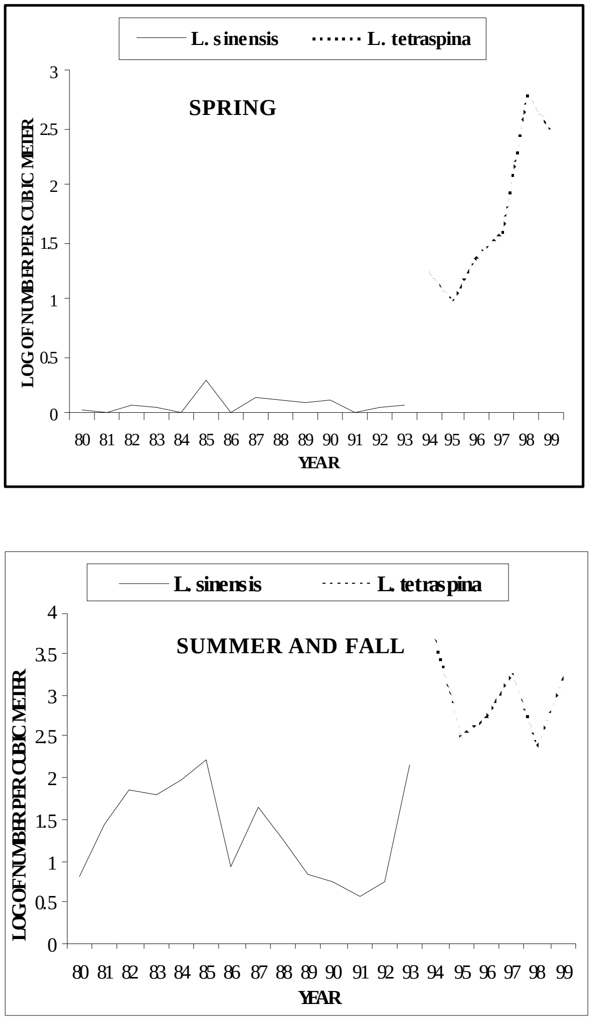

Figure 5 Mean abundance of the introduced *Limnoithona sinensis* and *L. tetraspina* in spring (upper panel) and in summer and fall (lower panel), 1972 to 1999. *Limnoithona sinensis* disappeared in 1993 and *L. tetraspina* appeared in the fall of that year.

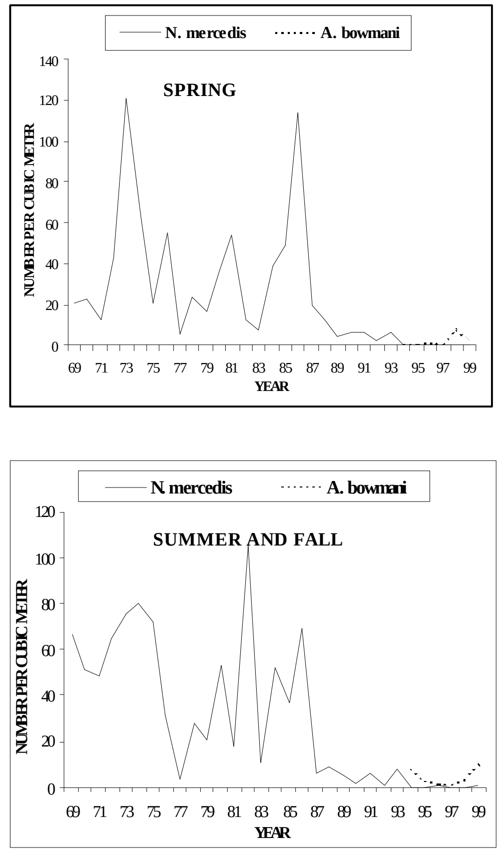

Figure 6 Mean abundance of the native *Neomysis mercedis* and the introduced *Acanthomysis bowmani* in spring (upper panel), and in summer and fall (lower panel), 1969 to 1999. *Acanthomysis bowmani* was first seen in 1993.

SPLITTAIL AND LONGFIN SMELT

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Splittail Abundance

Splittail abundance (all ages combined) dropped off substantially from 1998 in the 1999 fall midwater trawl survey (Figure 1, top graph). The moderate 1999 abundance index resulted mainly from the catch of age-1 splittail. Young-of-the-year (YOY) made up only 16% of the total index as compared to 85% in 1998. The 1999 YOY index for the Delta Outflow San Francisco Bay Study midwater trawl was low relative to 1998, but comparable to that of 1997 (Figure 1). The Bay Study otter trawl index exhibited a similar but more extreme pattern over the past three years—no YOY were caught in 1997 or 1999 (Figure 2). High YOY splittail abundance in the Delta continues to depend upon high spring river flows and floodplain inundation persisting through April and into May. In both 1997 and 1999, water levels dropped rapidly during spring, drying floodplains before or during early April.

In 1999, record high age-1 indices for both Bay Study trawl surveys reflect strong recruitment of 1998 year-class (Figures 1 and 2). Similar strong year-classes occurred in 1982, 1983, 1986, and 1995 and were apparent in adult indices two or more years later, even though neither trawl captures adult splittail well.

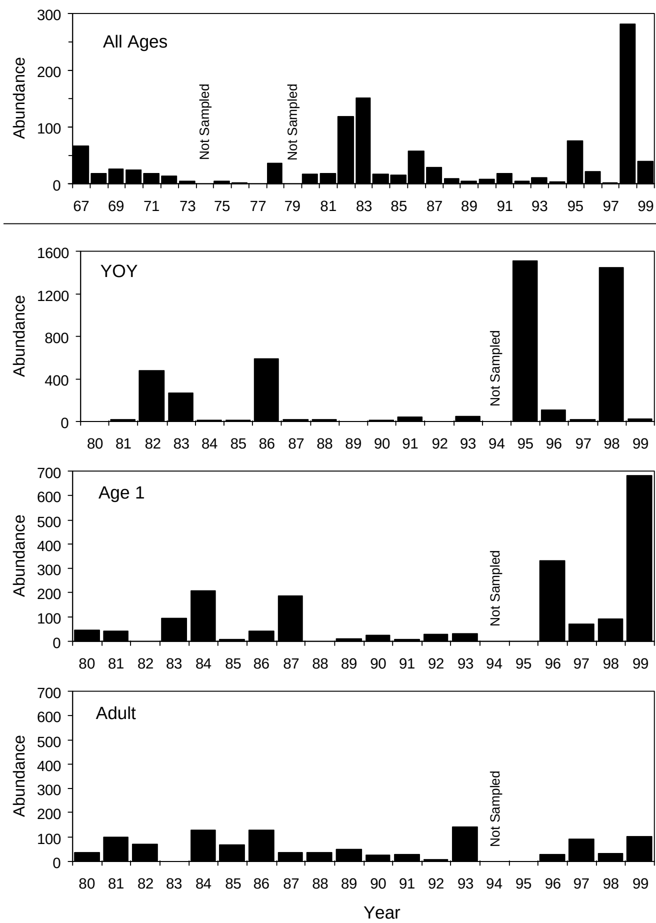

Figure 1 Splittail annual abundance indices from the California Department of Fish and Game Fall Midwater Trawl Survey (top graph, all ages combined) and Delta Outflow-San Francisco Bay Study Midwater Trawl Survey (bottom three graphs, age groups separated)

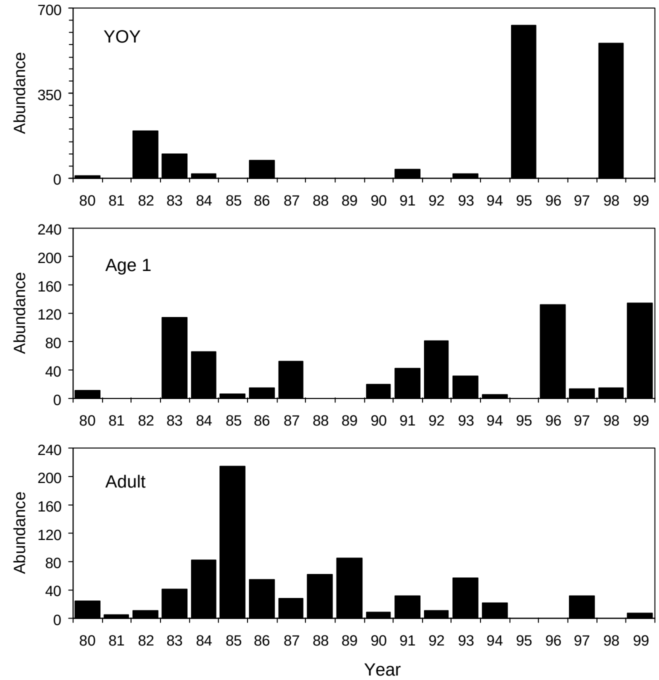

Figure 2 Splittail annual abundance indices from the California Department of Fish and Game Delta Outflow-San Francisco Bay Study Otter Trawl Survey (age groups separated)

Longfin Smelt Abundance

Longfin smelt abundance in 1999 changed little from 1998 in either the fall midwater trawl or Bay Study midwater trawl survey, but increased in the Bay Study otter trawl survey (Figures 3 and 4). Year-class strength is a function of both outflow during the spawning and larval periods and, secondarily, spawning-stock size (DFG unpublished data). In 1999, good outflow in combination with a relatively low spawning stock (1997 year-class spawners) resulted in only modest YOY indices. Similarly, in 1998, better outflow conditions and an arguably smaller spawning stock produced indices equivalent to or somewhat smaller than those for 1999, depending upon which survey's data were compared (Figures 3 and 4). In the near future these two modest year-classes will enable a stronger response to good outflow conditions or will buffer the population in the event of a one- to two-year drought.

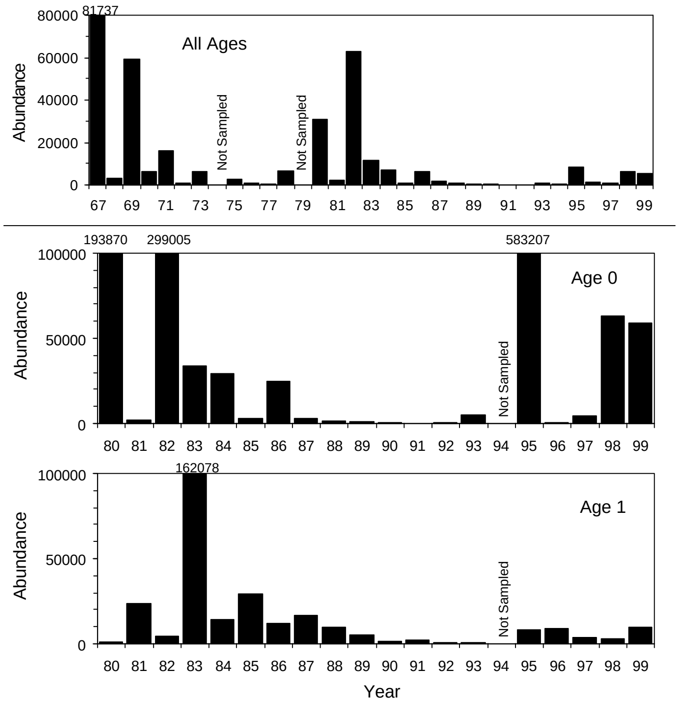

Figure 3 Longfin smelt annual abundance indices from the California Department of Fish and Game Fall Midwater Trawl Survey, 1967–1999 (top graph, all ages combined) and Delta Outflow-San Francisco Bay Study Midwater Trawl Survey, 1980–1999 (bottom two graphs, age groups separated). Numbers above graph represent indices off present scale.

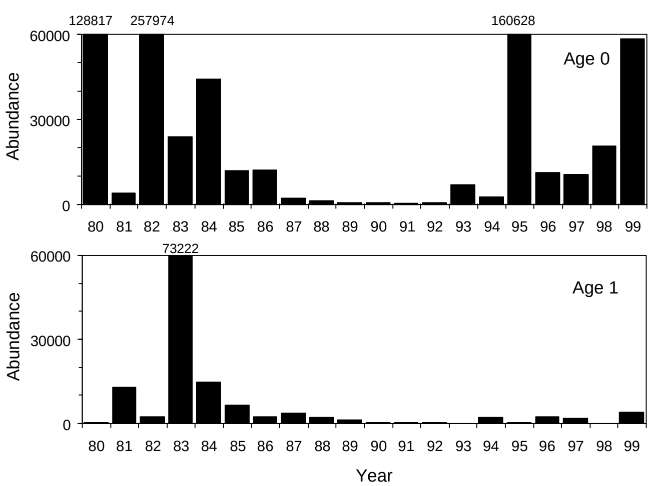

Figure 4 Longfin smelt annual abundance indices from the California Department of Fish and Game Delta Outflow-San Francisco Bay Study Otter Trawl Survey, 1980–1999 (age groups separated). Numbers above graph represent indices off present scale.

DELTA SMELT INVESTIGATIONS

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In 1999 delta smelt spawned in the Delta and their larvae remained there for much of the spring. Larval delta smelt were distributed from the south Delta, through the Lower Sacramento and San Joaquin rivers to Montezuma Slough, and in the Napa River. In April and May, the smelt were scattered throughout the Delta and Montezuma Slough. In June, a large percentage still resided in the Delta (Figure 1A), especially when compared to June, 1996 when most were located around and downstream of the confluence (Figure 1B). By July, the 20-mm Survey suggested the distribution had shifted towards the lower Sacramento River and downstream to Suisun Bay. However, juvenile delta smelt were still being caught in relatively high numbers with Kodiak trawls and at the pumps in the south Delta. Once the delta smelt reach 35 mm, the 20-mm net is no longer effective at catching delta smelt.

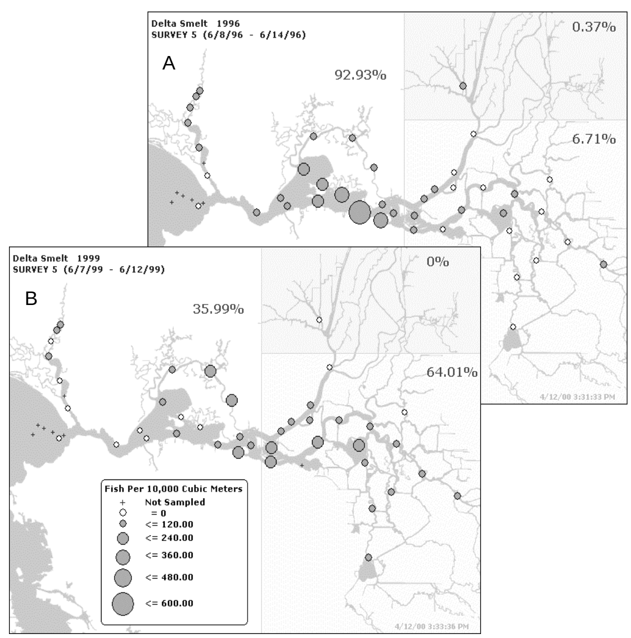

Figure 1 Distribution maps for delta smelt caught during 20-mm survey number 5 in 1996 (A) and 1999 (B). Bubbles represent the number of delta smelt per 10,000 cubic meters. Percentages represent the proportion of the total weighted catch found in each region: upstream, Delta, and bay.

Water temperatures remained relatively cool (generally less than 20 °C) throughout much of spring 1999. The prolonged period of cool temperatures may have contributed to an apparent protracted spawn and the extended residence time of juvenile delta smelt within the south Delta.

The 1999 delta smelt summer townet abundance index was 11.9 and the fall midwater trawl index was 864. The summer townet index was the highest since 1994 (Figure 2) and the fall midwater trawl index (Figure 3) was the highest since 1995; both were the third highest since 1981. Except for 1997, the fall midwater trawl indices continued a pattern of a high abundance index in odd years for the past ten years. A similar pattern is not found in the summer townet indices.

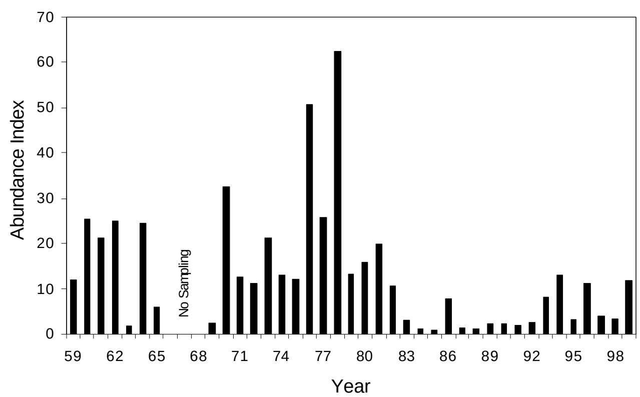

Figure 2 Summer townet abundance index for delta smelt. Values represent the sum of volume-weighted means of eight sampling areas. The average of the first two surveys is used. No sampling occurred in 1966–1968.

Salvage of delta smelt at the Central Valley Project and the State Water Project in 1999 exceeded "red light" conditions for three consecutive months from May through July. A total of 152,583 delta smelt was salvaged during this time. We are currently developing a model to predict salvage based upon continual monitoring of salvage densities and projected pumping rates. During February 2000 the model was used for the first time and projections of salvage were off by less than 100 fish. We will continue to test both the model and our luck.

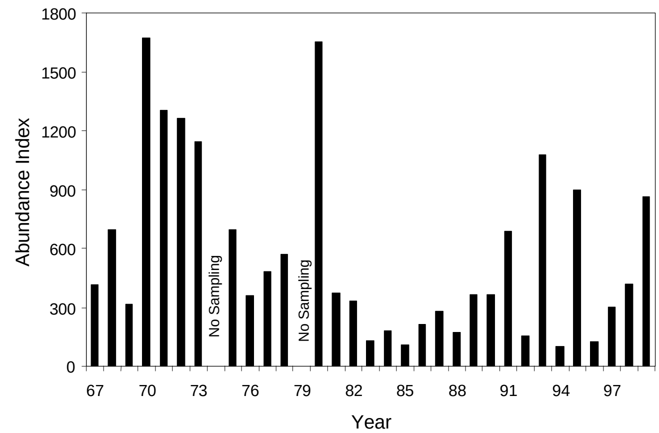

Figure 3 Fall midwater trawl abundance index for delta smelt. Values represent the sum of volume-weighted means of 17 sampling areas sampled monthly, September through December. No sampling occurred in 1974 and 1979.

1999 was the first year that light traps were tested as a means of sampling larval delta smelt. The traps were successful. A number of configurations was tried, from anchoring the traps in fixed locations to setting the traps adrift. Setting the traps adrift with the currents was by far the most effective method for collecting delta smelt. We believe that the difference may be attributed to the absence of approach velocity problems for the larvae attracted to the light. Interestingly, the best results were found when the traps were set adrift near the bottom of the channel, indicating a change in the vertical distribution between from the surface orientation seen in earlier studies. Light trapping will continue in 2000 as part of Real Time Monitoring.

San Francisco Bay Species

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Annual abundance trends from 1980–1999 and distributional information for the shrimp *Crangon franciscorum*, Dungeness crab, and 14 common San Francisco Bay fishes are summarized in this article. Summary life history information was included in the 1997 Status and Trends reports for many of these species (DeLeón 1998; Hieb 1998). In 1999, below average ocean temperatures, strong summer upwelling, and moderate freshwater outflow in winter and spring (daily mean of 52,856 cfs for January to May) followed by relatively low outflow in summer (daily mean of 4,970 cfs for July to September) were important in determining the abundance and distribution of species in the bay.

Abundance of juvenile *C. franciscorum* declined dramatically in 1999 from 1998 (Figure 1), reversing the trend of increasing indices from 1995 to 1998. The 1999 index was intermediate to other years with similar spring outflow (for example, 1980, 1993) and does not appear to be an outlier. Unlike the recent "wet" years, juvenile distribution was centered in Suisun Bay rather than San Pablo Bay in late spring and early summer 1999.

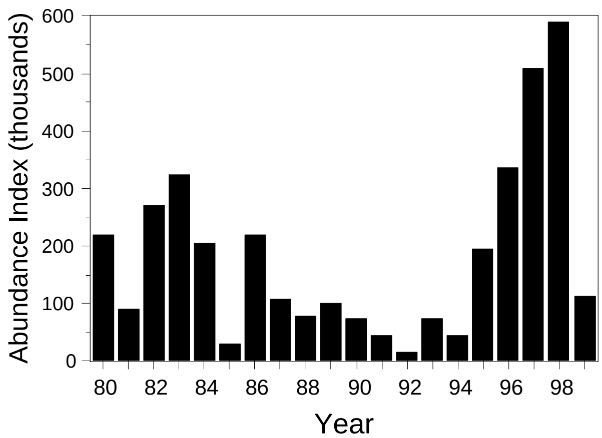

Figure 1 Annual abundance of juvenile *C. franciscorum*, May to October, otter trawl

The 1999 abundance index of age-0 Dungeness crab was the highest since 1988 and was comparable to the 1984 and 1985 indices (Figure 2). This increase was most likely a result of favorable ocean conditions in winter 1998–1999. Cool ocean temperatures and a relatively weak northward Davidson Current are thought to result in increased survival and retention of Dungeness crab larvae in the Gulf of the Farallones and increased nearshore settlement. From April through August, catches were highest in Central Bay, although distribution ranged from south of the Dumbarton Bridge to Suisun Bay. By late fall, crabs were concentrated in western Suisun Bay. Our Tidal Marsh Study also collected Dungeness crabs in northern Napa-Sonoma Marsh and the lower Petaluma River in summer 1999.

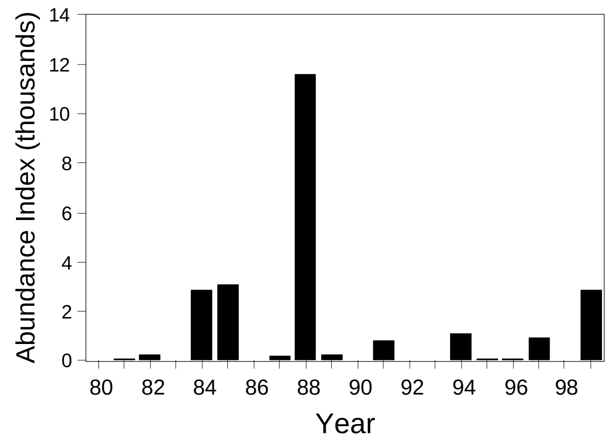

Figure 2 Annual abundance of age-0 Dungeness crab, May to July, otter trawl

Abundance of age-0 Pacific herring was very low in 1999, comparable to the lowest indices of 1990 and 1991 (Figure 3). Juvenile Pacific herring were broadly distributed from South to western Suisun bays in April and May, but by July, most were collected in Central Bay.

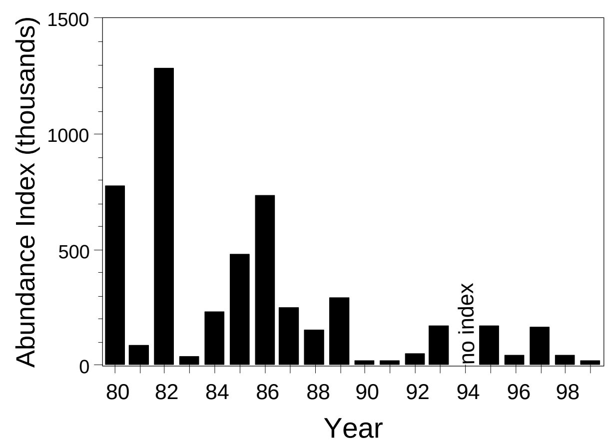

Figure 3 Annual abundance of age-0 Pacific herring, April to September, midwater trawl

In 1999, the abundance of northern anchovy increased slightly from 1998 (Figure 4); indices have been remarkably stable since 1995. We collected northern anchovy from South to Suisun bays, with the highest catches predictably in Central Bay and lower San Pablo Bay.

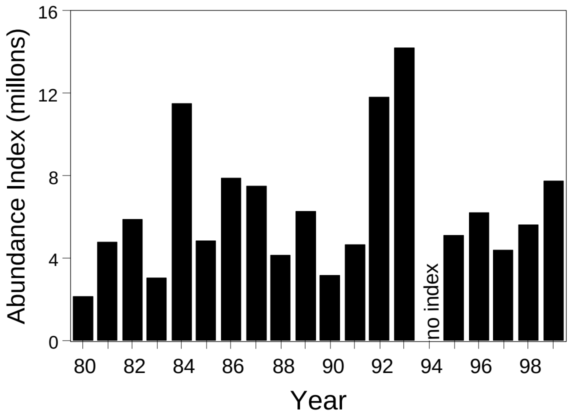

Figure 4 Annual abundance of northern anchovy (all sizes), April to October, midwater trawl

Abundance of age-0 jacksmelt was the lowest for the study period in 1999, continuing the trend of low indices since 1988 (Figure 5). We collected only 24 age-0 jacksmelt the entire year, scattered from South to San Pablo bays.

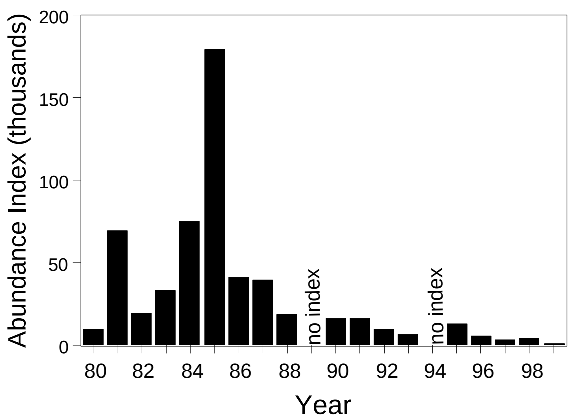

Figure 5 Annual abundance of age-0 jacksmelt, July to October, midwater trawl

White croaker abundance was also the lowest for the study period in 1999, primarily due to a record low abundance of age-0 fish (Figure 6). The age-1+ abundance index was the third lowest for the study period (only the 1980 and 1981 indices were lower). In 1999, distribution of white croaker was very similar to recent years, with fish most common from northern South Bay to lower San Pablo Bay.

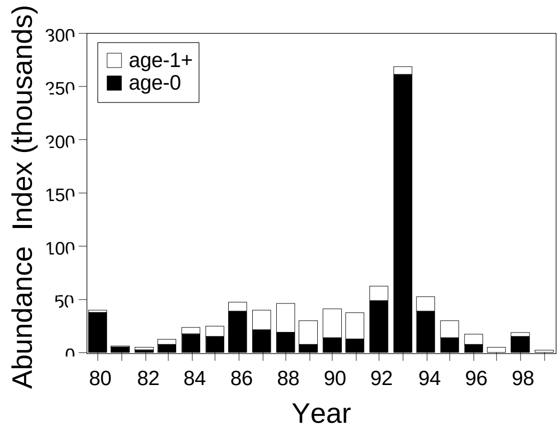

Figure 6 Annual abundance of age-0 and age-1+ white croaker, February to October, otter trawl

Bay goby abundance increased in 1999 from 1998, and the index was very close to the study period average (Figure 7). Bay gobies were more broadly distributed in 1999 than 1998, as they were common in South, Central, and San Pablo bays, with a few collected in Carquinez Strait.

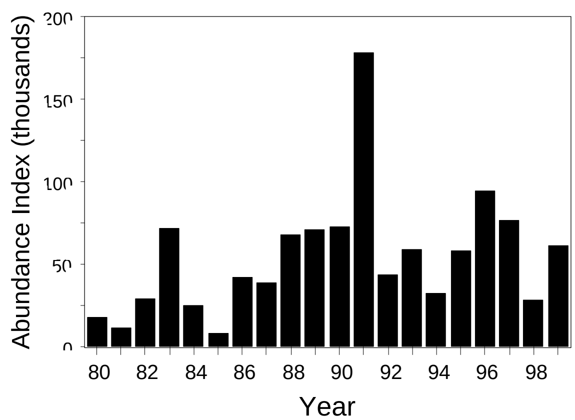

Figure 7 Annual abundance of bay goby (all sizes), February to October, otter trawl

The 1999 yellowfin goby abundance index decreased slightly from 1998 (Figure 8). In 1999, age-0 yellowfin gobies were most common in Suisun Bay and the lower Sacramento River, with relatively few collected from San Pablo Bay.

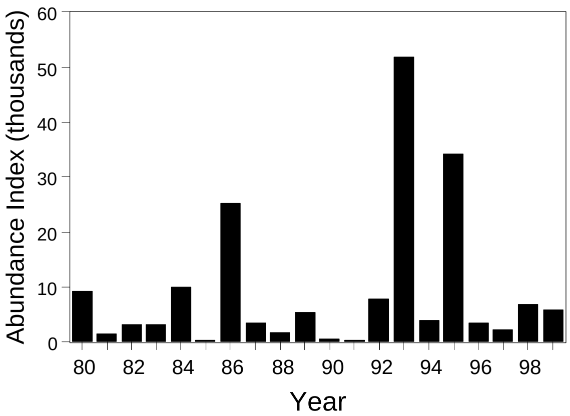

Figure 8 Annual abundance of age-0 yellowfin goby, May to October, otter trawl

After a very low index in 1998, the abundance index of age-0 staghorn sculpin was the highest for the study period in 1999 (Figure 9). Fish were widely distributed from South Bay to the lower Sacramento and San Joaquin rivers, with the highest catches in Suisun Bay in spring and early summer and in Central Bay in late summer and fall.

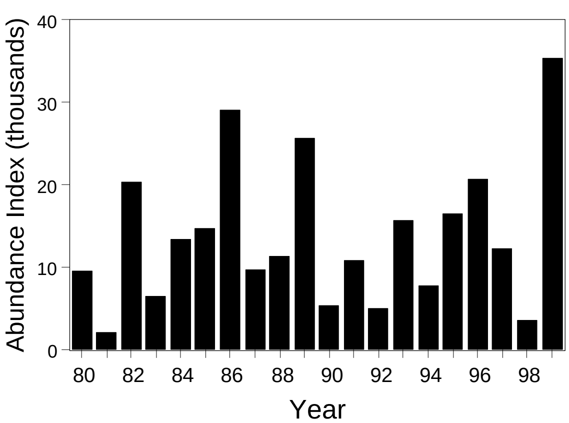

Figure 9 Annual abundance of age-0 staghorn sculpin, February to September, otter trawl

The 1999 age-0 shiner perch abundance index was low for the second year in a row (Figure 10). With the exception of 1997, indices for the past 11 years have been very low. Abundance of age-0 pile perch was again zero in 1999 (Figure 11) and abundance of age-0 walleye surfperch continued to be very low (Figure 12). In 1999, age-0 shiner perch were collected from South to San Pablo bays, with most from Central Bay. As in previous years, most walleye surfperch were collected at the Berkeley Pier station.

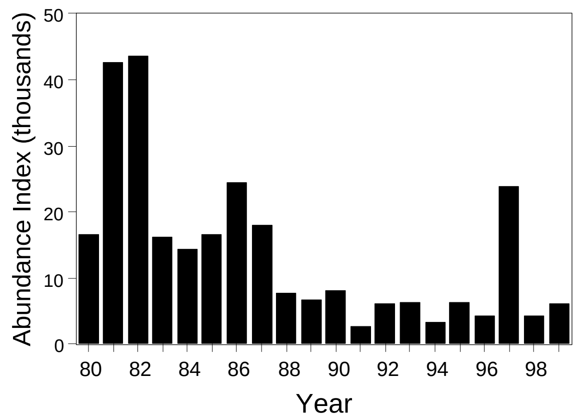

Figure 10 Annual abundance of age-0 shiner perch, May to October, otter trawl

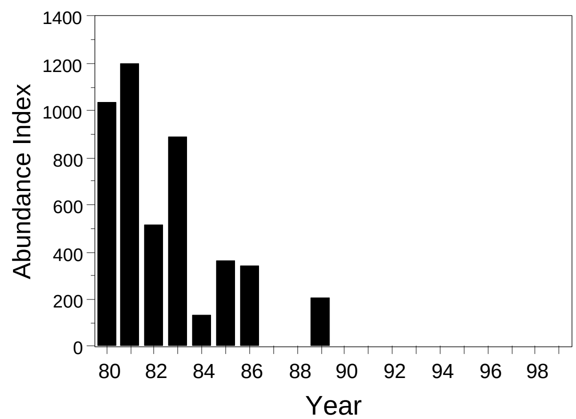

Figure 11 Annual abundance of age-0 pile perch, June to October, otter trawl

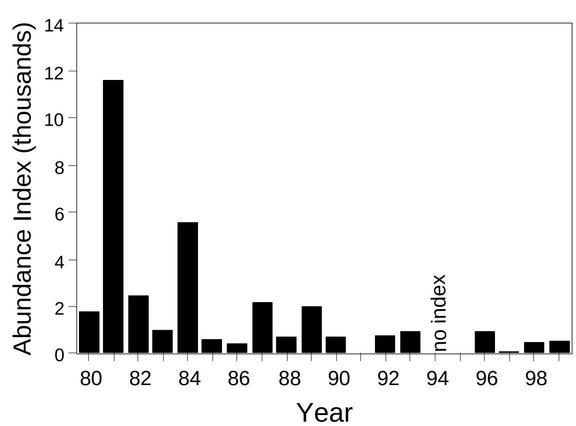

Figure 12 Annual abundance of age-0 walleye surfperch, May to August, midwater trawl

Abundance of juvenile California halibut (<200 mm TL) was the highest for the study period in 1999 (Figure 13). Two cohorts dominated the catch, one of age-1 and age-2 fish from winter 1997–1998 and another larger cohort of age-0 and age-1 fish from late summer and fall 1998. The majority of California halibut were collected at South Bay and Central Bay shoal stations (<6 m) in 1999.

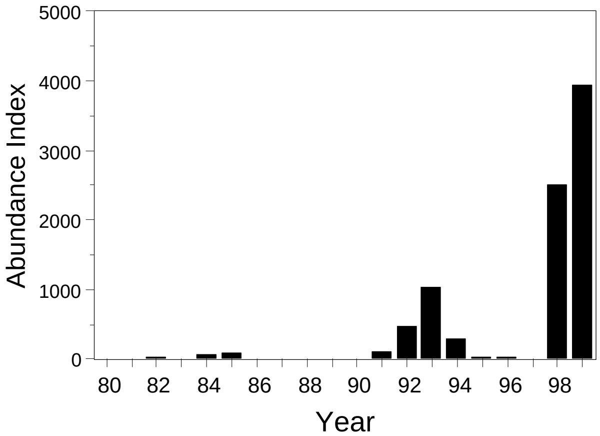

Figure 13 Annual abundance of juvenile California halibut (<200 mm TL), February to October, otter trawl

The abundance of age-0 English sole was also the highest for the study period in 1999 (Figure 14). Although cooler ocean temperatures may have resulted in a stronger year class, factors controlling recruitment of English sole to the bay are not well understood. Age-0 fish were more broadly distributed in 1999 than 1998, as they were common from South to San Pablo bays. In spring and early summer, the highest catches were over the shoals of Central and San Pablo bays; in late summer, the highest catches were in the Central Bay channel.

Abundance of speckled sanddab increased in 1999 (Figure 15) to the highest index of the study period. In spite of the large English sole year class, speckled sanddab was again the most abundant species of flatfish in the bay. In 1999, most were collected from Central Bay (initially the channel, then moving to the shoals through spring and summer), with a few ranging as far upstream as Carquinez Strait.

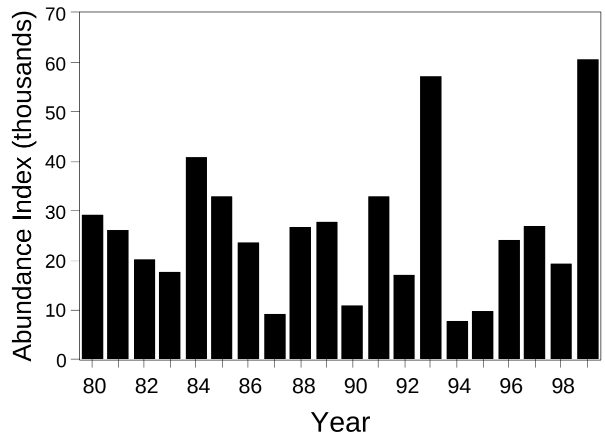

Figure 14 Annual abundance of age-0 English sole, February to October, otter trawl

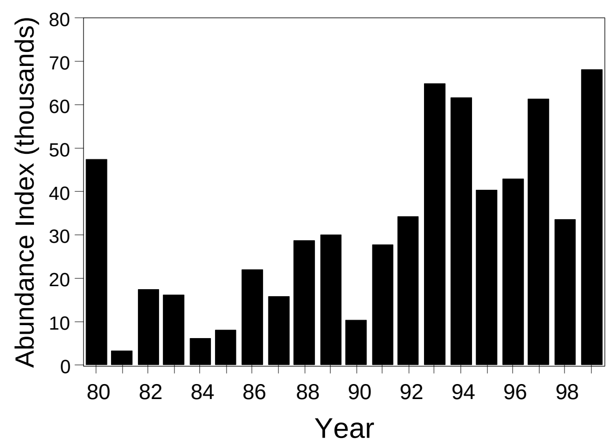

Figure 15 Annual abundance of speckled sanddab (all sizes), February to October, otter trawl

In 1999, the abundance of age-0 starry flounder declined slightly from the previous “wet” years (1995–1998), but remained well above the 1987–1994 indices (Figure 16A) The 1999 index of age-1 starry flounder (the 1998 year class) decreased slightly (Figure 16B). In 1999, age-0 fish were distributed from San Pablo Bay to the lower Sacramento and San Joaquin rivers but were most common at Suisun Bay shoal stations. Most age-1 fish were collected over the shoals of San Pablo and Suisun bays.

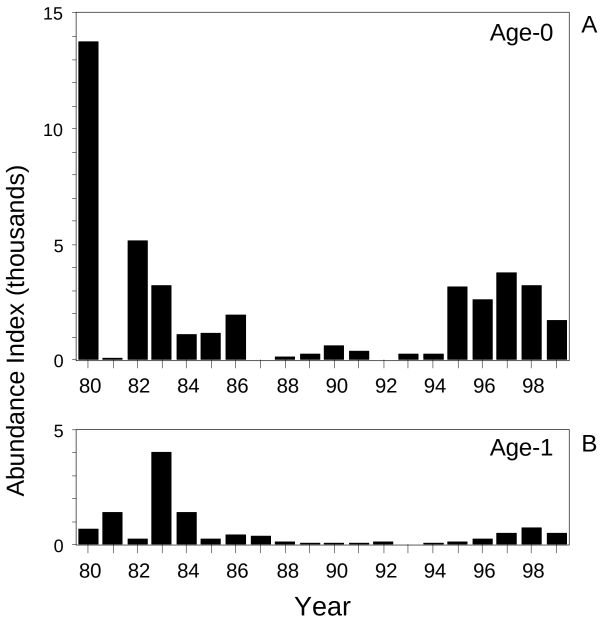

Figure 16 Annual abundance of starry flounder, otter trawl: (A) age 0, May to October, (B) age 1, February to October

References

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Hieb K. 1998. Bay species. IEP Newsletter 11(2):46–9.

RESIDENT FISH SURVEYS

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Boat electrofishing surveys have been performed biennially since 1995 at 20 stations, one kilometer in length, throughout the Sacramento-San Joaquin Delta to monitor trends in resident fish populations (Figure 1). Fish are sampled in February, April, June, and August. The sampling protocol is designed to collect data that are representative of relative temporal and spatial variability in fish abundance and species composition associated with differences in habitat and geographic area. However, boat electrofishing is a very selective sampling technique and does not represent true relative abundance of species or size classes.

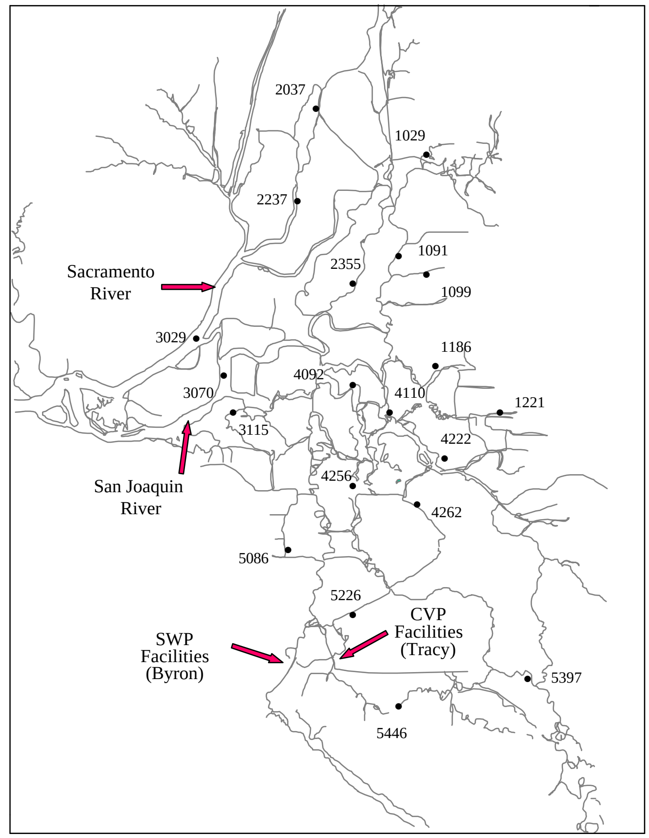

Figure 1 Resident fish monitoring stations in the Sacramento-San Joaquin Delta

A total of 17 families and 40 species was observed during sampling in 1995–1999 (Table 1). The most common fishes encountered were nonnative centrarchids, primarily bluegill, redear sunfish, and largemouth bass (Table 1). Centrarchids comprised over 80% of the fish observed during these three years, followed by nonnative cyprinids (minnows) and ictalurids (catfish). Native cyprinids (minnows) and catostomids (suckers) were caught less frequently than nonnative species.

Three years are too few to define trends; but over that period, catches of catostomids consistently increased while ictalurids declined (Figure 2). Catch of centrarchids was highest in 1997.

In contrast, 19 families and 42 species were observed during 1980–1983 sampling (Table 2), two more families and species than in 1995–1999. Although the random 1980–1983 survey sampled at many more stations (280), most of the taxonomic groups were represented in the 20 stations sampled in 1995–1999 (Table 2).

Table 1 Total catch of the common fish species observed during resident fish monitoring in the Sacramento-San Joaquin Delta in 1995, 1997, and 1999

	Total Catch		
Family and Species	*1995*	*1997*	*1999*
Atherinidae			
Inland silverside	38	76	104
Catostomidae			
Sacramento sucker	61	158	228
Centrarchidae			
Black crappie	75	108	64
Bluegill	3329	4455	3807
Green sunfish	23	76	36
Largemouth bass	1624	1806	1666
Redear sunfish	1013	1842	1613
Smallmouth bass	140	196	49
Warmouth	208	452	363
Clupeidae			
American shad	0	24	0
Threadfin shad	367	483	172
Cottidae			
Prickly sculpin	70	100	116
Cyprinidae			
Common carp	173	274	373
Golden shiner	738	501	296
Goldfish	18	36	27
Red shiner	1	4	162
Sacramento blackfish	1	21	24
Sacramento pikeminnow	91	53	115
Splittail	244	31	41
Embiotocidae			
Tule perch	250	328	115
Gobiidae			
Shimofuri goby	21	4	1
Yellowfin goby	53	91	17
Ictaluridae			
Brown bullhead	88	115	76
Channel catfish	68	36	68
White catfish	526	498	433
Osmeridae			
Delta smelt	12	10	0
Percichthyidae			
Striped bass	66	48	61
Percidae			
Bigscale logperch	28	20	9
Petromyzontidae			
Pacific lamprey	8	163	12
Poecilidae			
Mosquitofish	10	11	4
Salmonidae			
Chinook salmon	292	91	258
Steelhead rainbow trout	39	6	25

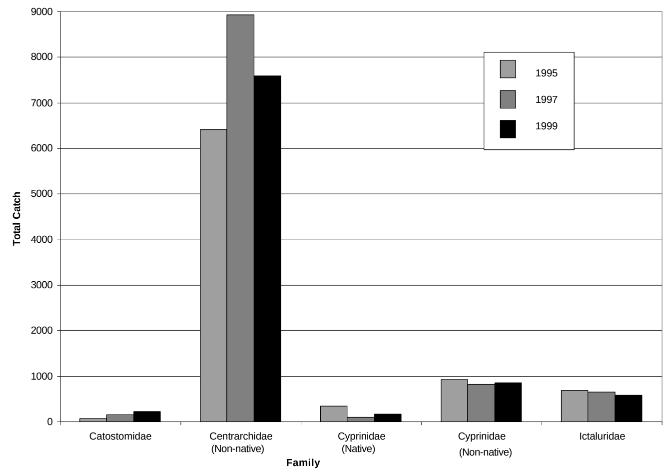

Figure 2 Total catch of the common families observed during resident fish monitoring in the Sacramento-San Joaquin Delta in 1995, 1997, and 1999

I compared catch per unit effort between 1980–1983 and 1995–1999 for the eleven 1995–1999 stations which were sampled during comparable months (January to September) in 1980–1983 (Table 3). Catostomids, centrarchids, and native cyprinids increased slightly between 1980–1983 and 1995–1999, while nonnative cyprinids and ictalurids decreased (Figure 3). Mann-Whitney U tests indicated that none of these differences were statistically significant, except for ictalurids (P = 0.002). I applied the same statistical test to largemouth bass and found no significant difference in catch per unit effort for that species.

Table 2 Fish species observed during resident fish sampling in the Sacramento-San Joaquin Delta in 1980–1983 and 1995–1999

Family and Species	Classification [a]	Species Observed 1980–1983	Species Observed 1995–1999
Atherinidae			
Inland silverside	(i,r)	X	X
Catostomidae			
Sacramento sucker	(n,fwe)	X	X
Centrarchidae			
Black crappie	(i,r)	X	X
Bluegill	(i,r)	X	X
Green sunfish	(i,r)	X	X
Lagremouth bass	(i,r)	X	X
Pumpkinseed	(i,r)	X	
Redear sunfish	(i,r)	X	X
Smallmouth bass	(i,r)	X	X
Spotted bass	(i,r)	X	
Sunfish (*Lepomis* sp.)	(i,r)	X	
Warmouth	(i,r)	X	X
White crappie	(i,r)	X	X
Clupeidae			
American shad	(i,a)	X	X
Threadfin shad	(i,fwe)	X	X
Cottidae			
Prickly sculpin	(n,fwe)	X	X
Riffle sculpin	(n,fwe)		X
Cyprinidae			
California roach	(n,fwe)		X
Common carp	(i,r)	X	X
Golden shiner	(i,r)	X	X
Goldfish	(i,r)	X	X
Hardhead	(n,fwe)	X	
Red shiner	(i,r)		X
Sacramento blackfish	(n,fwe)	X	X
Sacramento hitch	(n,r)	X	X
Sacramento squaw-fish	(n,fwe)	X	X
Splittail	(n,fwe)	X	X
Cyprinodontidae			
Rainwater killifish	(i,me)		X
Embiotocidae			
Tule perch	(n,r)	X	X

[a] Classification: n = native, i = introduced, r = resident, a = anadromous, fwe = fresh water euryhaline, me = marine haline.

Table 2 Fish species observed during resident fish sampling in the Sacramento-San Joaquin Delta in 1980–1983 and 1995–1999 (Continued)

Family and Species	Classification [a]	Species Observed 1980–1983	Species Observed 1995–1999
Gasterosteidae			
Threespine stickle-back	(n,fwe)	X	X
Gobiidae			
Shimofuri goby	(i,r)	X	X
Yellowfin goby	(i,fwe)	X	X
Ictaluridae			
Black bullhead	(i,r)	X	X
Brown bullhead	(i,r)	X	X
Channel catfish	(i,r)	X	X
White catfish	(i,r)	X	X
Mugilidae			
Striped mullet	(i,r)	X	
Osmeridae			
Delta smelt	(n,fwe)	X	X
Longfin smelt	(n,fwe)	X	
Percichthyidae			
Striped bass	(i,a)	X	X
Percidae			
Bigscale logperch	(i,r)	X	X
Petromyzontidae			
Pacific lamprey	(n,a)	X	X
River lamprey	(n,fwe)		X
Pleuronectidae			
Starry flounder	(n,r)	X	
Poecilidae			
Mosquitofish	(i,r)	X	X
Salmonidae			
Chinook salmon	(n,a)	X	X
Steelhead rainbow trout	(n,a)	X	X

[a] Classification: n = native, i = introduced, r = resident, a = anadromous, fwe = fresh water euryhaline, me = marine haline.

Comparison between these two periods should be treated with caution, not only because so few sampling instances (location multiplied by month) are directly comparable, but also because of differences in sampling protocol. Many samples in 1980–1983 were collected at night; all sampling in 1995–1999 was completed during the day.

Table 3 Sample months for which catch per unit effort (fish/km) from 11 resident fish sampling stations in the Sacramento-San Joaquin Delta was compared between 1980–1983 and 1995–1999

	1980–1983 [a]								*1995–1999* [b]					
Station	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Feb*	*Apr*	*Jun*	*Aug*	*n*
1029					x		x				x	x	x	11
1091	x					x				x		x		8
1099	x			x						x	x			8
2237						x						x		4
2355									x				x	4
3029		x							x	x			x	8
3070			x							x	x			7
4092									x				x	4
4110		x				x				x		x		8
4262		x								x				4
5446							x					x	x	7
Total														73

[a] 16 samples for 1980–1983.
[b] 57 samples for 1995–1999 (19 samples times 3 years).

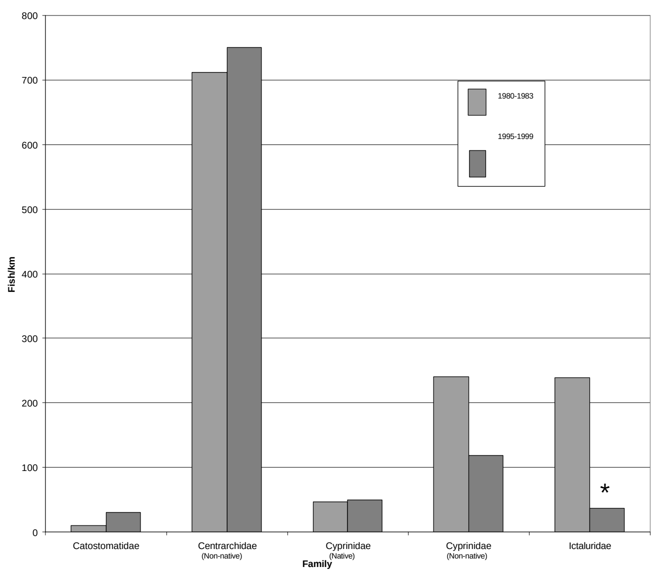

Figure 3 Catch per unit effort (fish/km) of the common families observed during resident fish sampling in the Sacramento-San Joaquin Delta from 1980–1983 and 1995–1999. (* indicates statistically significant; Mann-Whitney U test, *P* = 0.002.)

JUVENILE WHITE STURGEON

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During a preliminary survey in 1991 and annual surveys since 1996, DFG has sampled juvenile white sturgeon to predict future recruitment to the fishery. Juvenile sturgeon are captured with 550-m set-lines, each with 70 to 100 baited hooks, which are fished overnight at 21 locations from the western Delta to San Pablo Bay. Fish are measured, a pectoral fin ray segment is taken from a subsample for aging, and fish are released near the location of capture. In 1996 and 1997, we sampled during late summer and fall. Since 1998, we have sampled during spring and early summer to avoid loss of bait to maturing mitten crabs that begin to enter the sampling area in late summer.

Irregular recruitment brought about by highly variable year classes is apparent from length-frequency distributions of juvenile white sturgeon (Figure 1). In 1991, five- or six-year-old fish (broad peak centered at 72 cm total length) were most abundant (1985 or 1986 year class). The right-hand tail of the distribution that year is made up of seven- to ten-year-old fish from early 1980's year classes, a period that includes two wet years (1982 and 1983). In 1996, the mid-1980s year classes (about 88 to 112 cm) dominated the catch. The 1995 year class

(42 to 50 cm) appeared in catches as it was recruited to the sampling gear in October near the end of its second growing season. Few fish from the drought years 1987–1992 were caught. The 1997 length-frequency distribution shows continued growth of the post-drought year classes and again demonstrates the lack of fish from the 1987–1992 drought. The surprisingly low catch of fish from the mid-1980s year classes in 1997 compared to 1996 is unexplained, but may be the result of movement to locations outside the sampling area. Post-drought year classes (1993–1996) remain prominent in catches in 1998 and 1999.

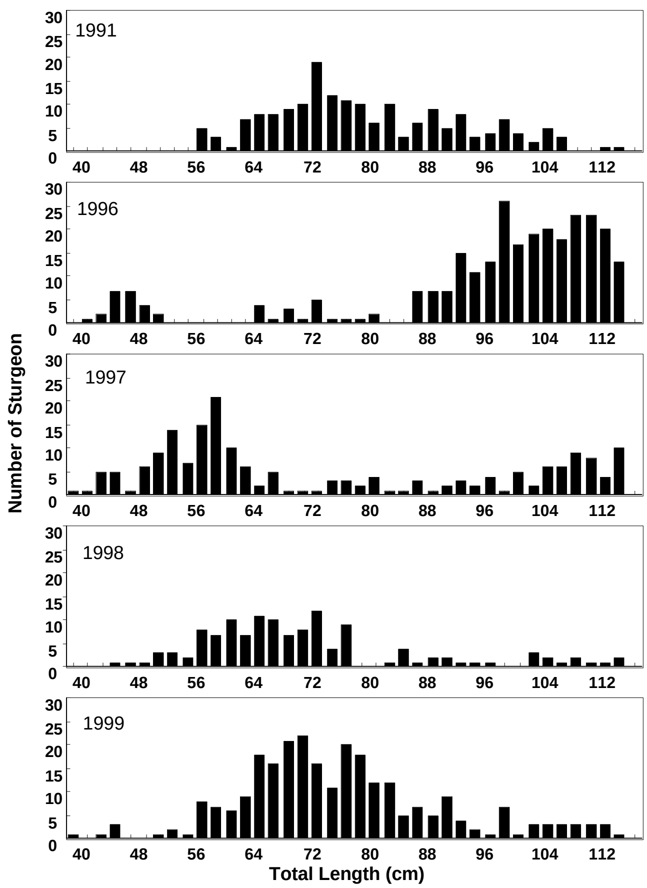

Figure 1 Length-frequency distributions of juvenile white sturgeon captured by longline surveys, 1991 through 1999

Highly variable year classes of white sturgeon have been noted since the first ageing of sturgeon from the Sacramento-San Joaquin Estuary (Pycha 1956) and strong year classes have been associated with wetter-than-normal water years (Kohlhorst and others 1991). These recent data on juvenile white sturgeon abundance corroborate the hypothesis that the most successful white sturgeon year classes are produced in years of high spring flows. Although in the near-term the legal-sized white sturgeon population will decline as the result of poor recruitment from the drought years, an increase in legal-sized white sturgeon abundance is expected as fish from the good production years since 1993 recruit to legal catch size classes (Schaffter and Kohlhorst 1999).

This work is partially supported by Federal Aid to Sport Fish Act funding.

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JUVENILE CHINOOK SALMON RELATIVE ABUNDANCE AND REAL TIME PROTECTION

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The U.S. Fish and Wildlife Service (USFWS) monitors the abundance and distribution of juvenile chinook salmon (*Oncorhynchus tshawytscha*) in the lower Sacramento and San Joaquin rivers, Delta, and San Francisco and San Pablo bays using the beach seine. In addition, trawling is conducted at Sacramento and Mossdale to document the movement of juveniles into the Delta (from the Sacramento and San Joaquin basins respectively) and at Chipps Island to document the relative density of juveniles leaving the Delta.

Following is a discussion of relative abundance during the 1999 field season as well as a brief discussion of winter-run and spring-run yearling protection efforts between October and March of the 1999 field season.

Relative Abundance

Between January and March 1999 densities of chinook fry (<70 mm) in the North Delta beach seine were relatively high. Catches during these months were mostly composed of fall-run and spring-run fry, as beach seining is most efficient at capturing smaller juveniles rearing near the shore. The high catches in the Delta during this time in 1999 are likely a result of the high outflow conditions which possibly moved more fry into the Delta from upstream. There is a significant relationship between flow at Freeport during February and mean density of fry in the north Delta beach seine between January and March (Figure 1). The 1999 field season index improved this historic correlation.

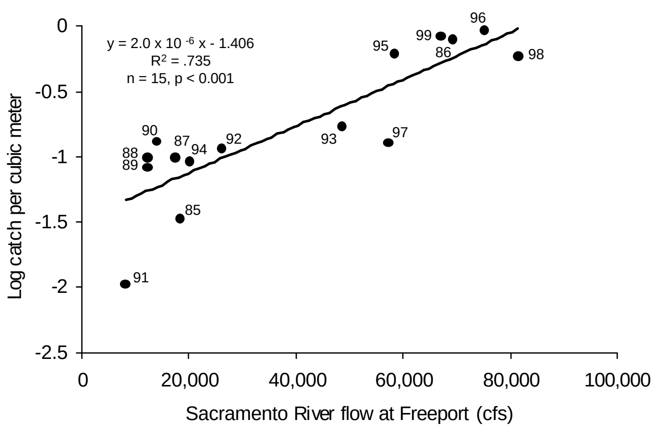

Figure 1 Log of catch per cubic meter of juvenile chinook salmon fry in the north Delta beach seine (between Sherman Island and Discovery Park on or adjacent to the Sacramento River) between January and March versus mean February flow on the Sacramento River at Freeport for the years 1985 to 1999

Relative densities of juvenile salmon in the Sacramento midwater trawl between April and June 1999 were slightly below the 1988–1998 average (Figure 2). Catches between April and June mostly consist of fall-run smolts and can be influenced by hatchery salmon released from Coleman National Fish Hatchery. The near-average densities of juveniles observed in the Sacramento trawl and the high densities of fry observed in the north Delta beach seine suggest high fall-run juvenile production during 1999. This is in contrast to 1996 and 1997 where smolt abundance was lower at Sacramento and fry abundance in the north Delta beach seine was similar or lower than in 1999.

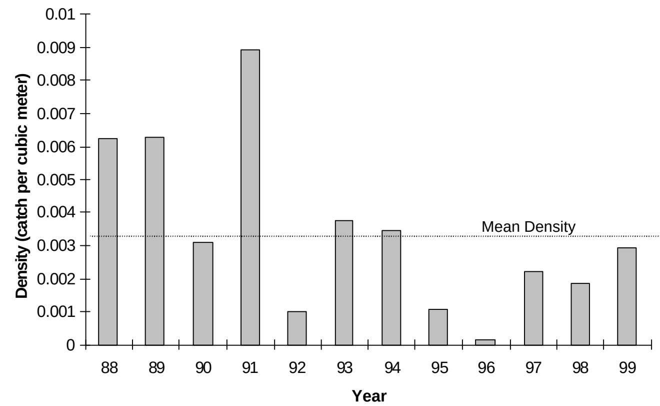

Figure 2 Mean catch of juvenile chinook salmon per cubic meter between April 1 and June 30, from 1988 to 1999 in the Sacramento midwater trawl. There was no sampling in April 1992. In 1990, trawling occurred at Courtland, about 20 mi downstream of the Sacramento site. Dotted line is 1988 to 1998 mean density.

Between February and June 1999 density of fall run in the beach seine on the lower San Joaquin River was much higher than in previous years and appears to be related to prior year adult escapement (Figure 3).

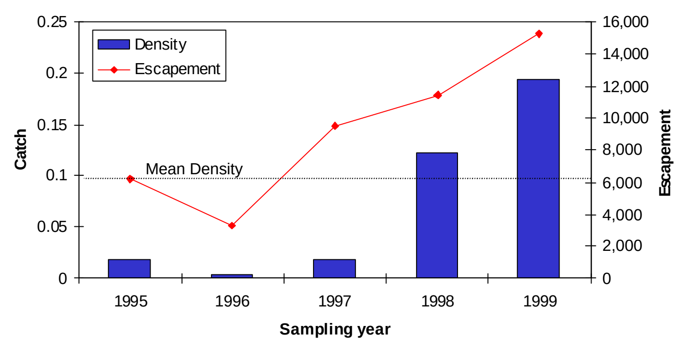

Figure 3 Mean catch of juvenile chinook salmon per cubic meter between February 1 and June 30 in the beach seine on the lower San Joaquin River between 1995 and 1999 and San Joaquin Basin adult escapement one year before juvenile migration

Salmon captured at Chipps Island (catch per cubic meter) between April and June mostly consisted of fall-run and spring-run smolts. Catch in this trawl is often influenced by releases of hatchery salmon. The density during 1999 fits within the established significant relationship between mean flow at Rio Vista and mean catch per cubic meter at Chipps Island (Figure 4).

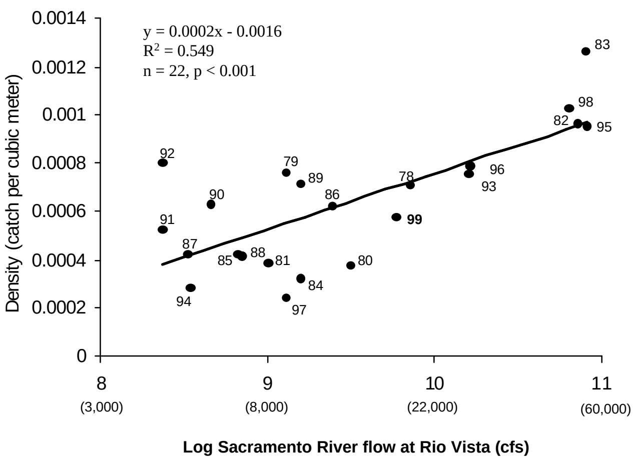

Figure 4 Mean catch of unmarked chinook salmon smolts per cubic meter in the midwater trawl at Chipps Island between April and June 1978 to 1999 versus log of mean daily Sacramento River flow (cfs) at Rio Vista between April and June

Density of juvenile salmon between January and March during 1999 in San Francisco Bay was below the average density obtained in previous years (Figure 5).

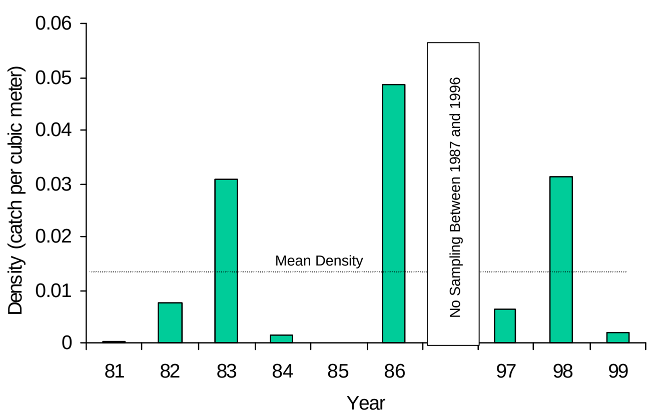

Figure 5 Mean catch of chinook salmon fry per cubic meter between January 1 and March 31, 1981–1986 and 1997 and 1999 in the bay beach seine. No sampling was conducted between 1987 and 1996.

Winter-run and Spring-run Yearling Chinook Protection

Sampling at Sacramento in the fall and winter months using the Kodiak trawl and beach seine was used to enhance capture of larger, less abundant winter-run and spring-run yearling salmon. The information gained was used to develop operational recommendations to protect these listed races from diversion into the Delta via the Delta Cross Channel where reduced survival has been shown to occur.

Identifying winter-run and spring-run yearlings in the Delta is challenging. The daily size criterion (Fisher 1992) is based on Sacramento River fall-run growth rates in the upper river and does not describe the alternate life history strategy of some tributary spring run that emigrate as yearlings. Thus, in addition to protection for winter run (described by the size criteria), chinook salmon between 70 and 200 mm were closely monitored between October and January and considered for protection as potential spring run yearlings. All chinook collected in the fall and early winter of 1998–1999 in the Sacramento area beach seine and the Kodiak trawl are shown in Figures 6 and 7, respectively. The size criteria model seems to define fall-run and spring-run fry well. Winter and late-fall populations are described but less clearly distinguished.Note that spring-run yearlings are not described by the size criteria, but would occur somewhere in the winter run and or late-fall run area of the graphs above the dashed line.

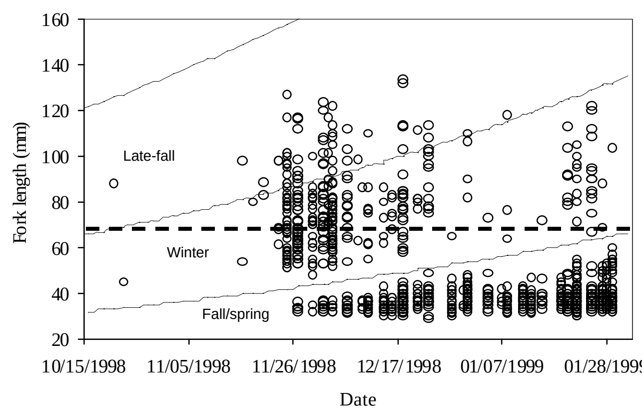

Figure 6 Fork lengths of chinook salmon observed in the Sacramento area beach seine (RM 43 to 80) during the 1999 field season between October 15, 1998, and January 31, 1999. Race discrimination criteria as designated by Fisher in 1992 are also included. The dashed line marks the minimum cutoff (70 mm) used to identify potential spring run yearlings.

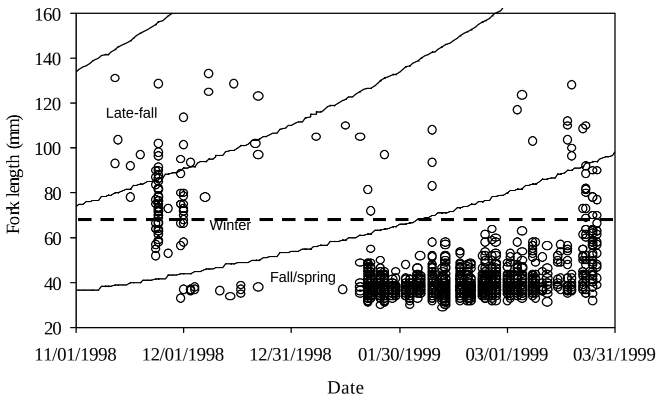

Figure 7 Fork lengths of chinook salmon observed in the Sacramento Kodiak trawl during the 1999 field season between November 1, 1998, and March 31, 1999. Race discrimination criteria as designated by Fisher in 1992 are also included. The dashed line marks the minimum cutoff (70 mm) used to identify potential spring run yearlings.

The USFWS monitoring program attempted to determine when these large yearlings were entering the Delta. When chinook yearling abundance was relatively high, export curtailments or Cross Channel Gate closures were considered to provide protection for the greatest number of fish. However, catches of these low abundant races are usually sparse and variable, making decisions for protection difficult.

Daily catch rates of 70 to 200 mm chinook salmon between October 1 and January 31 in the Kodiak trawl and beach seine at Sacramento obtained since fall 1994 are shown in Figure 8. Yearling spring run chinook are expected to emigrate within this size range. Peak seaward migration of these fish varied between years; however, most catches appear to correlate with flow spikes between early November and late January. The status of the Delta Cross Channel Gates is also described in Figure 8. The gates appear to have been closed (protective status) when most of the winter run and spring run yearlings were captured at Sacramento, with the exception of a large part of December 1994.

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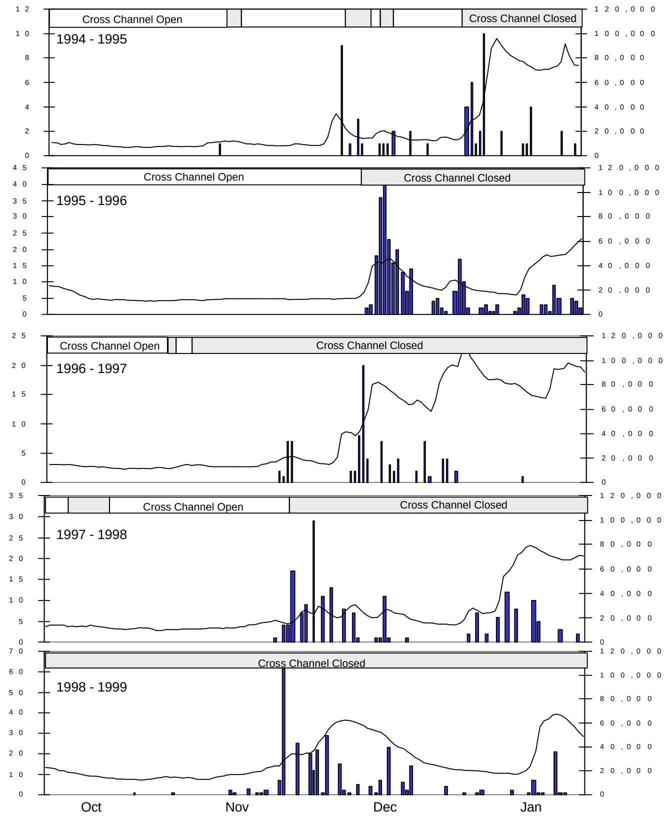

Figure 8 Daily catch of juvenile chinook (70 to 200 mm) per day in the Sacramento Kodiak trawl and beach seine and flow at Freeport (cfs) between October 1 and January 31, 1995 to 1999. Effort within and between years is not consistent. Status of gates (open, closed) is provided on each graph. Daily catch scale varies between years.

CHINOOK SALMON CATCH AND ESCAPEMENT

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The following information was taken from the February 2000 report *Review of the 1999 Ocean Salmon Fisheries* by the Pacific Fishery Management Council (PFMC). Copies of the report can be obtained by calling (503) 326-6352.

As in the past few years, in 1998 the PFMC took actions to reduce the ocean harvest of winter-run chinook salmon and Klamath River fall-run chinook salmon. These actions had the ancillary effect of reducing landings of non-target runs and increasing escapement to the spawning grounds of fall and late fall runs.

Figure One—Central Valley Chinook Salmon Annual Abundance Index

The index consists of estimated ocean harvest plus total Central Valley escapement. The index does not include inland harvest, which may be up to 25% of the salmon leaving the ocean. The 1999 abundance index of 644 was near the 1970–1998 average of 665.

The ocean recreational effort was estimated to be about 148,000 angler trips compared to a 1982–1997 average of 205,000 trips. Commercial fishermen fished an estimated 14,000 days in 1999 compared to an average of 41,000 days from 1982 through 1997.

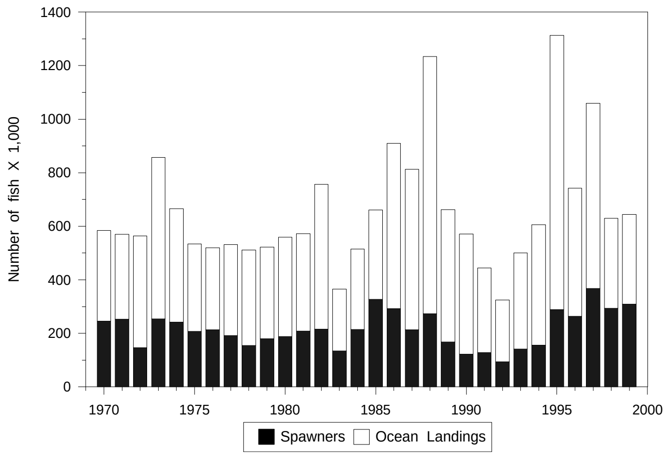

Figure 1 Central Valley chinook salmon annual abundance index, 1970–1999

Figure Two—Ocean Commercial and Recreational Catch

In 1998, commercial fishermen landed about 75% of the total number of chinook caught in the ocean, which is slightly higher than the 1970–1997 average of 71%. Ocean conditions and new regulations may have reduced recreational harvest.

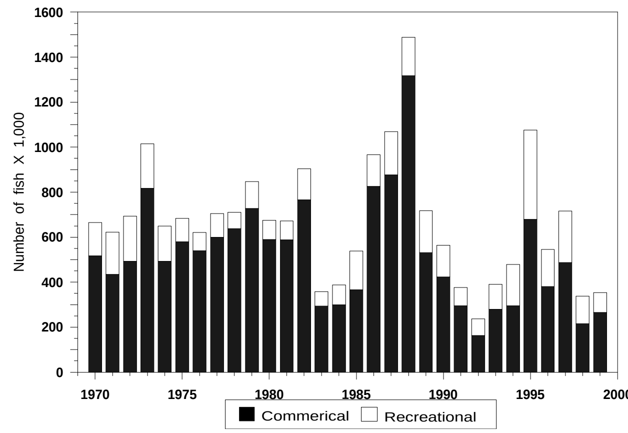

Figure 2 Annual California commercial and recreational chinook ocean catch

The estimated 1999 ocean harvest index of 52% is the second lowest during the period of record and is significantly lower than the indices in from about 74% to 79% seen from about 1985 through 1995.

Figure Three—Ocean Harvest Index

The ocean harvest index consists of the estimated ocean harvest divided by the sum of the ocean harvest and total Central Valley escapement. It does not include inland harvest.

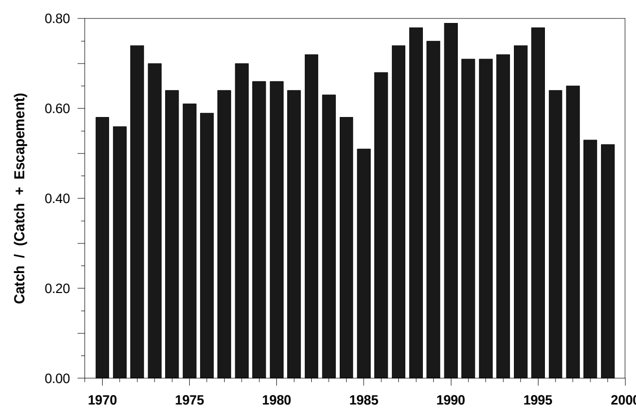

Figure 3 Central Valley chinook salmon Ocean Harvest Index, 1970–1999

As mentioned earlier, the lower ocean harvest is likely due to harvest regulations to protect winter-run chinook and Klamath fall-run chinook. Some economic factors may be coming into play as pen-reared Atlantic salmon make up a larger portion of the fresh salmon market.

Figures Four and Five—Sacramento Valley Escapement

The 1999 natural and hatchery chinook runs to Sacramento River mainstem and tributary streams and hatcheries were among the strongest seen since 1970.

The good escapement was at least in part due to the reduction in ocean catch. Most of the escapement was to the Feather and American rivers and Battle Creek—streams that have major fall-run hatcheries. The 1999 total escapement of over 300,000 spawners exceeded the PFMC's spawning escapement goal of between 122,000 and 180,000 adults. This estimate includes hatchery and naturally spawning fish.

The strength of the 1999 escapement is further demonstrated in Figure 5, which indicates that the natural escapement was the second highest for the period of record. Natural escapement includes adult salmon that were of direct hatchery origin but spawned in the streams instead of entering the hatchery.

Escapement (spawning ground) counts are essential indicators of the impacts of salmon management and effects of natural habitat variation. The counts generally have wide error bars. The IEP's Central Valley Salmonid Team is convening a June 2000 escapement workshop to evaluate existing estimating techniques and recommend improvements.

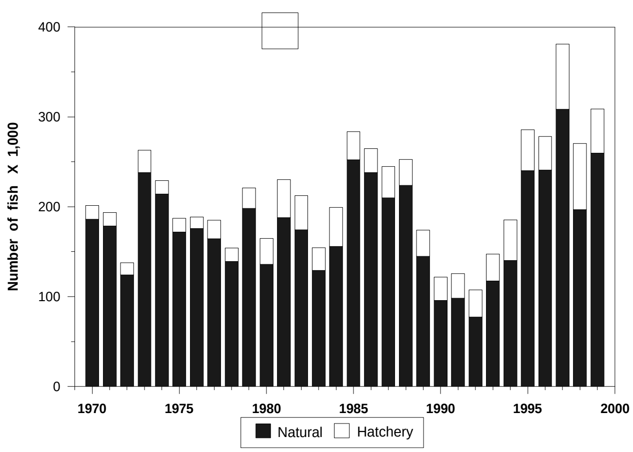

Figure 4 Annual fall-run escapement to Sacramento River and major tributaries, natural and hatchery contribution

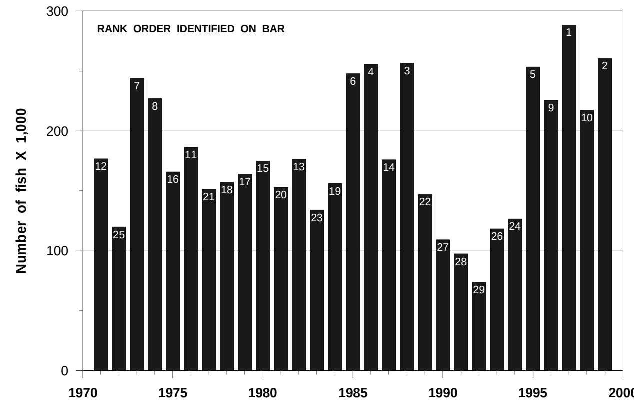

Figure 5 Annual natural fall-run cohort escapement to Sacramento River and major tributaries

Figure Six—American River Escapement

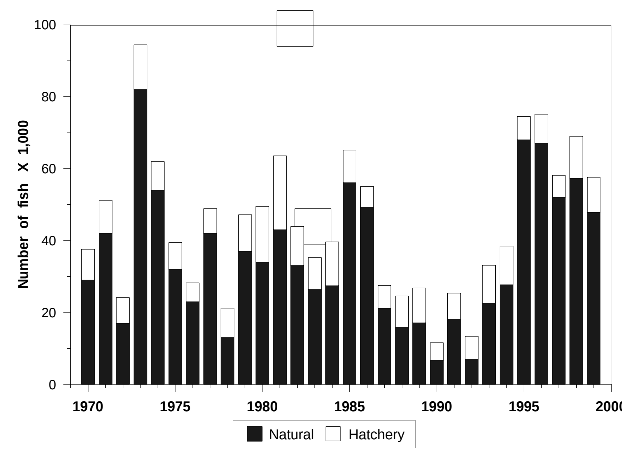

Figure 6 Annual fall-run escapement to American River, natural and hatchery contribution

The 1999 escapement to the American River was the fifth strong year in a row and the fourth highest year in the 1970–1998 period of record. Note that all production from the Nimbus Hatchery is trucked to near Carquinez Strait for release as smolts.

Figure Seven—Feather River Escapement

The 1999 escapement to the Feather River was good, but not exceptional. Similar to the American River's Nimbus Hatchery, the entire production from the Feather River Hatchery is trucked to near Carquinez Strait for release.

DWR continues to tag more than one million Feather River Hatchery spring-run and fall-run juveniles each year to help determine the hatchery's contribution to catch, spawning, and straying. This spring DWR has a target of tagging 200,000 naturally spawned juveniles as they emigrate the reaches below the fish barrier dam and it appears the target will be reached.

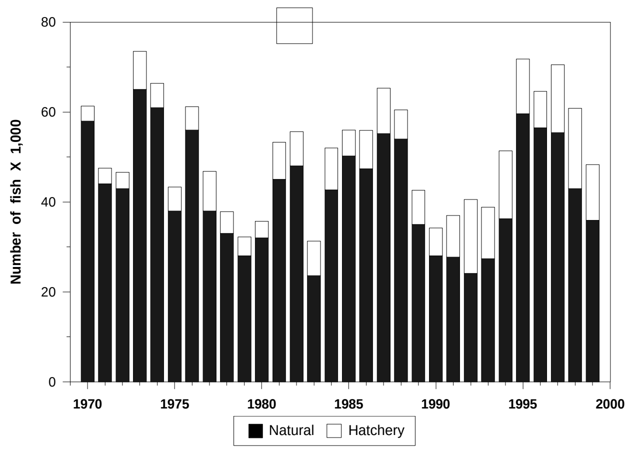

Figure 7 Annual fall-run escapement to Feather River, natural and hatchery contribution

Feather River escapement to the Feather River Hatchery includes what are now called spring-run chinook. Through the use of a new set of microsatellite markers, UC Davis geneticists will soon be able to determine if there is a genotypic spring run to the hatchery. Use of existing markers, which work best for winter run, indicates that hatchery fall and spring "runs" are genetically identical.

Figure Eight—Fall-run Chinook Salmon Escapement to the Yuba River

Earlier data have indicated that Yuba River fall-run chinook are a naturally spawning run with little input from Feather River Hatchery strays. The tagging program now underway on the Feather River and the recovery of tagged salmon on the spawning grounds will be used to help determine the source of fall-run chinook spawning in the Yuba River. Whatever the source of the fish, the 1999 escapement was again quite good.

State Water Resource Board hearings and potential restoration and other measures in the Yuba River watershed have increased the need for more information on Yuba River salmon and steelhead runs. Studies to be conducted over the next several years will lead to increased understanding of these runs.

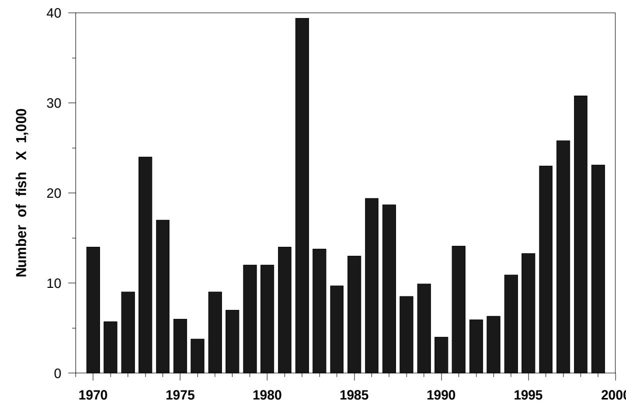

Figure 8 Annual natural fall-run escapement to Yuba River

Figure Nine—Escapement to the San Joaquin System

Although 1999 was the fourth consecutive year with reasonably good escapement to San Joaquin tributaries, it was not as good as might be expected based on flow: escapement data from past records (Figure 9). The relatively low numbers of returning adults are in spite of the lower ocean harvest.

Preliminary genetic information indicates that San Joaquin fall run cannot be distinguished from other Central Valley fall runs. DFG received a CALFED grant to further investigate the genetics of San Joaquin stocks spawning in the main tributaries. Dr. Bernie May of UC Davis will do the work.

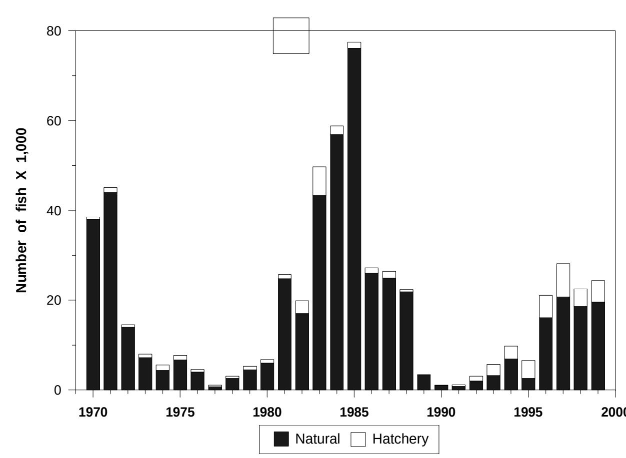

Figure 9 Annual fall-run escapement to the San Joaquin River system, natural and hatchery contribution

Figures Ten and Eleven—Spring-run Chinook Salmon Escapement

In 1998, the California Fish and Game Commission listed spring-run chinook as threatened. NMFS listed spring run as threatened in 1999.

Figure 10 includes those spring run estimated to have spawned in the mainstem Sacramento River. The trend of low, in-river spawning, which began in 1991, continues.

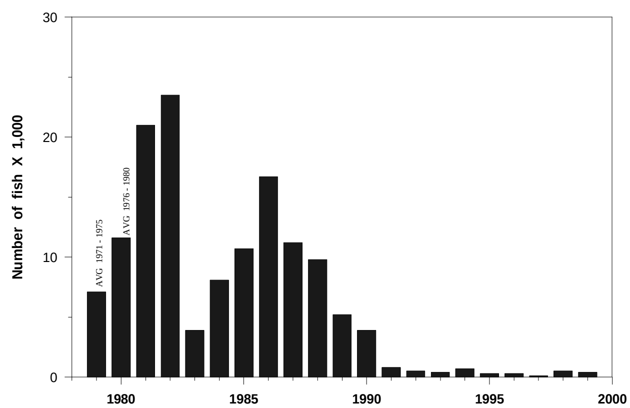

Figure 10 Annual spring-run escapement to upper Sacramento River

As shown in Figure 11, the 1999 spring run escapement to Butte Creek was relatively good at about 4,000 fish, the fifth best on record. Perhaps more importantly, there were about twice as many adults in 1999 than in the 1996 parent run that produced them. Although not shown, 1999 spring-run escapement to the other tributaries (mainly Deer and Mill creeks) totaled about 2,000 adults.

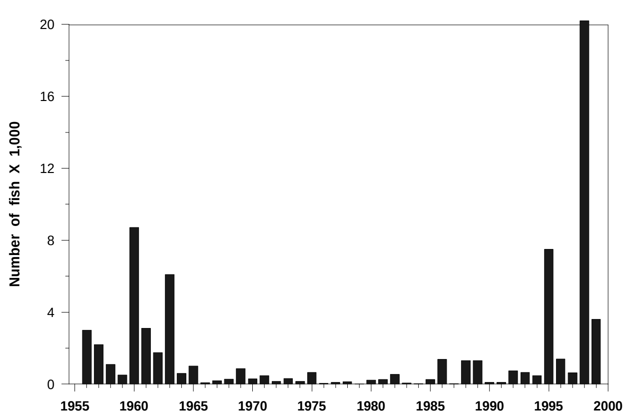

Figure 11 Annual spring-run escapement to Butte Creek

Figure Twelve—Winter-run Chinook Salmon Escapement

The 1999 spawning estimate was more than 3,200—the highest escapement in the past decade.

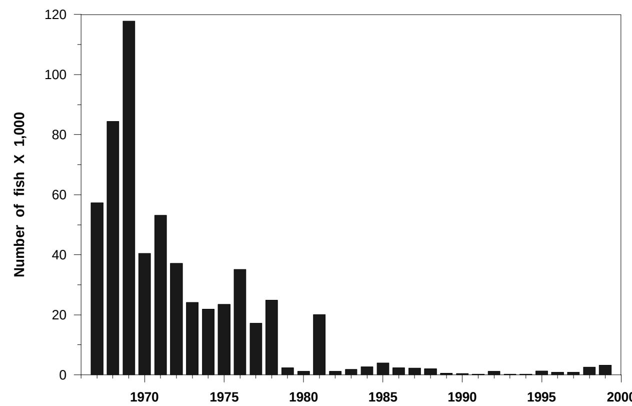

Figure 12 Annual winter-run escapement to upper Sacramento River

The cohort replacement rate for the 1999 escapement was 1.45, below the goal of 1.77, but slightly above the 1998 replacement rate of 1.38. (The cohort replacement rate is the number of spawners in a given year divided by the number of spawners that produced the run.)

The Pacific Fisheries Management Council conducted two ocean test fisheries in 1999 to determine the catch of winter-run chinook. One fishery did not attract enough boats. In the second fishery (between Pillar and Pigeon points), of the 617 tissue samples collected for genetic analysis, 31% were estimated to be Feather River spring chinook and less than 1% to be winter chinook.

Young-of-the-Year Striped Bass, American Shad, and Threadfin Shad Abundance and Distribution

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Striped Bass Abundance and Distribution

Two California Department of Fish and Game annual surveys measure the abundance of young-of-the-year (YOY) striped bass (*Morone saxatilis*) in the Sacramento-San Joaquin Estuary, the midsummer townet survey

(TNS) and the fall midwater trawl survey (FMWT). The TNS has been ongoing since 1959 (no survey was conducted in 1966) and the FMWT has been ongoing since 1967 (no surveys were conducted in 1974 or 1979). Both indices in 1999 continue to indicate that YOY striped bass abundance is considerably lower than in the 1970s and early 1980s. Before 1995, high TNS and FMWT indices were generally associated with "wet" years (wet or above normal) and low indices with "dry" years (below normal, dry, and critically dry). The mean TNS index was 26.7 (n = 19, standard deviation: 23.6) for dry years and was 63.0 (n = 15, standard deviation: 30.2) for wet years. The mean FMWT index was 2,004 (n = 13, standard deviation: 1,784) for dry years and was 6,781 (n = 13, standard deviation: 5,149) for wet years. After log transformation of these data, two sample t-tests indicate a significant difference between the two year types for both surveys (TNS: t = 3.89, df = 32, P = 0.0005) (FMWT: t = 4.10, df = 24, P = 0.0004). However, since 1995, TNS and FMWT indices have been the lowest of record even though these were favorably wet years.

Midsummer Townet Survey

The TNS index of striped bass abundance is set when the mean length of the catch is 38 mm. The 1999 TNS index of 2.2 was set on August 6, 1999, making the fifth consecutive year that the index has been below ten (Figure 1). The last series of low indices occurred during the drought years 1988 to 1991 (range: 4.3 to 5.5). However, the current series of low indices starting in 1995 (range: 1.4 to 7.2) have been in wet or above normal years. Before 1988, the index was below ten in 1985 (index = 6.3, dry year) and 1977 (index = 9.0, critically dry year).

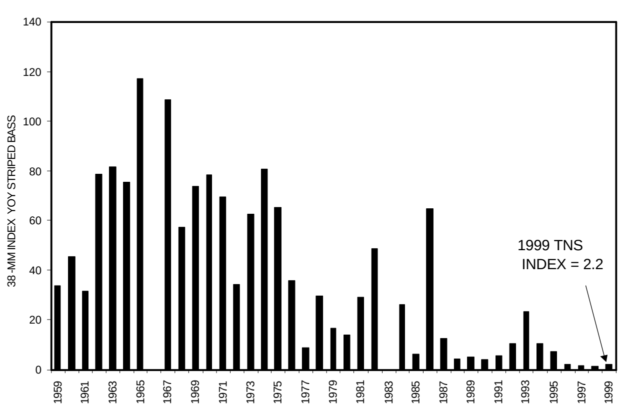

Figure 1 Midsummer townet 38-mm index of abundance for young-of-the-year striped bass, 1959–1999. No survey was conducted in 1966 and no index was calculated in 1983.

Fall Midwater Trawl

Monthly abundance indices for September through December and a fall index (the sum of the four monthly indices) are calculated for the FMWT. The 1999 fall index of 541 was only 44% of the 1998 index of 1,224, but similar to other recent years (1995–1997) when the index has varied from 392 to 568 (Figure 2). Before 1995 only five other years (all dry or critically dry) had FMWT fall indices below 1,000: 1976 (773), 1977 (883), 1988 (477), 1989 (442), and 1991 (944).

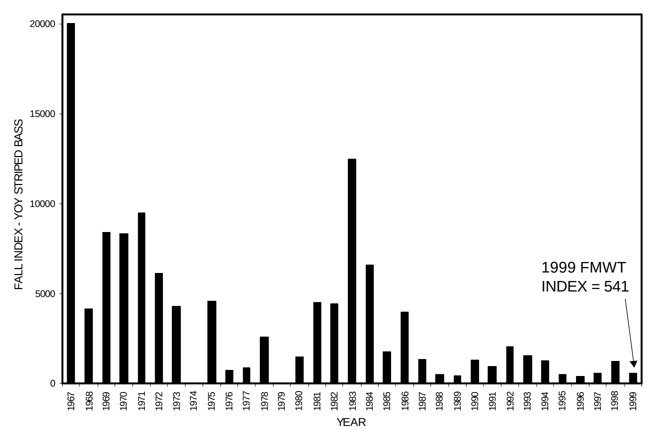

Figure 2 Fall midwater trawl indices of abundance for young-of-the-year striped bass, 1967–1999. No surveys were conducted in 1974 and 1979.

Given the greater number of stations sampled (100 are used in the FMWT index as opposed to 32 for the TNS), the FMWT is better able to describe the spatial distribution of YOY striped bass in the estuary. I partitioned the monthly indices into six areas and calculated the percentage of monthly index by area for September through December 1999. The six areas are (1) San Pablo Bay, (2) Carquinez Strait (including the lower Napa River), (3) Susiun Bay (including Montezuma Slough), (4) lower Sacramento River, (5) lower San Joaquin River, and (6) the eastern Delta. In 1999, Suisun Bay accounted for the largest percentage of the index in all months and steadily increased over time; whereas the percentages fluctuated or steadily declined in other areas (Figure 3).

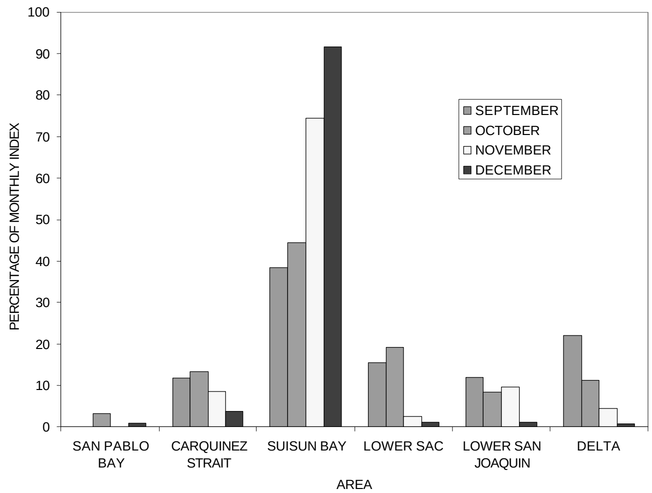

Figure 3 Percentage of monthly fall midwater trawl index by area for young-of-the-year striped bass in 1999. See text for area descriptions.

American Shad Abundance and Distribution

American shad (*Alosa sapidissima*) abundance is indexed from FMWT data using the same method as for YOY striped bass (see "Striped Bass Abundance and Distribution" section). Before 1999, the fall index for American shad was significantly different between wet and dry years (two-sample *t*-test for ln(fall index): t = 3.11, df = 28, P = 0.0042). The mean fall index was 1,547 (n = 13 standard deviation: 1,113) for dry years and 3,173 (n = 17, standard deviation: 1,721) for wet years.

The 1999 fall index of 715 was the fourth lowest of record and only 17% of the 1998 fall index of 4,140 and below 1,000 for the first time since 1988 (fall index 899, a critically dry year) (Figure 4). Before 1999, the overall trend in American shad abundance had been generally increasing (Gartz and others 1999).

As expected, the center of American shad distribution (analyzed in the same manner as distribution of YOY striped bass) in 1999 spread westward as they migrated (Figure 5) throughout the fall. However, the westward movement was not as pronounced as in 1998 (Gartz and others 1999).

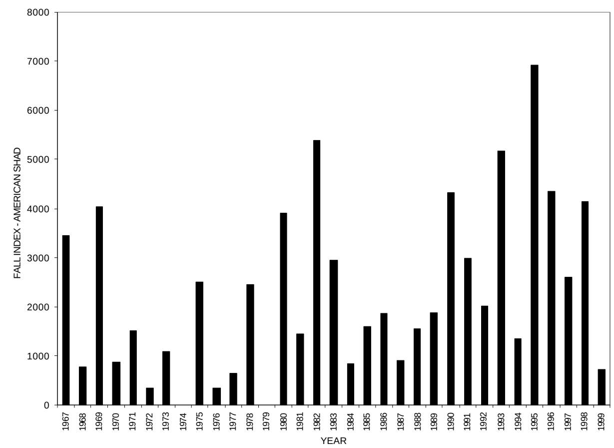

Figure 4 Fall midwater indices of abundance for American shad, 1967–1999. No surveys were conducted in 1974 and 1979.

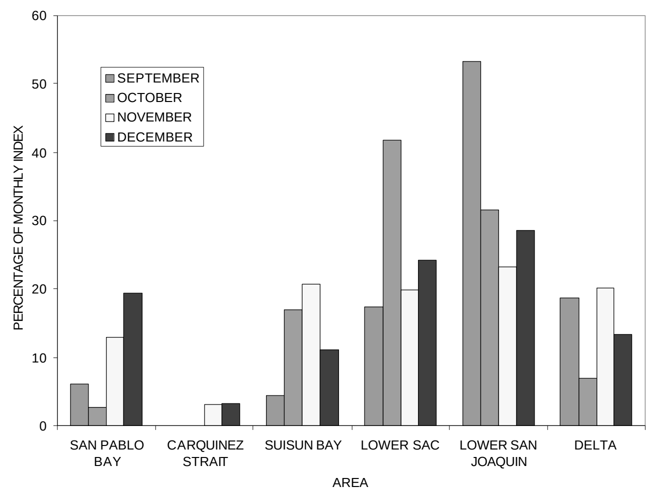

Figure 5 Percentage of monthly fall midwater trawl index by area for American shad in 1999. See text for area descriptions.

Threadfin Shad Abundance

Threadfin shad (*Dorosoma petenense*) abundance is indexed from FMWT data using the same method as for YOY striped bass. With the exception of the 1997 fall index, the 1999 fall index of 7,527 (September = 2,670, October = 772, November = 2,392, and December = 1,639) continues a general increasing trend in abundance that began in 1994 (Figure 6). Threadfin shad fall indices ranged from a low of 718 in 1975 to a high of 15,268 in 1997 (Figure 6) with the majority of the distribution in the eastern Delta. However, in 1973, 1975, and 1984, the eastern Delta was only sampled in September and in 1985 only in September and October, which would lead to underestimates of the threadfin shad fall indices.

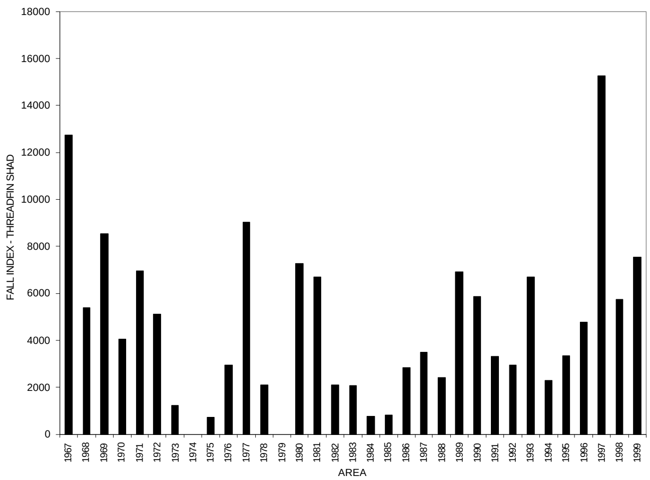

Figure 6 Fall midwater trawl indices of abundance for threadfin shad, 1967–1999. No surveys were conducted in 1974 and 1979.

More striped bass and American shad information may be viewed on our website. The URL for the site is http://www2.delta.dfg.ca.gov/data/mwt99/index.html.

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Gartz R, Foss S, Miller L. 1999. Striped bass and American shad abundance. IEP Newsletter 12(2):42–44.

FISH SALVAGE AT THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT FACILITIES

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In 1999, monthly water exports at the State Water Project (SWP) ranged from 52,309 acre-feet (AF) in February to 410,845 AF in August (Figure 1). This was higher than the 1998 range of 1,839 AF to 295,816 AF. SWP water exports totaled 2,707,517 AF in 1999, compared to 1,687,404 AF in 1998. Monthly exports of water at the Central Valley Project (CVP) ranged from a low of 100,716 AF in April to a high of 269,790 AF in August, compared to the 1998 range of 579 AF to 268,748 AF. CVP water exports totaled 2,533,967 AF in 1999 compared to 2,092,194 AF in 1998.

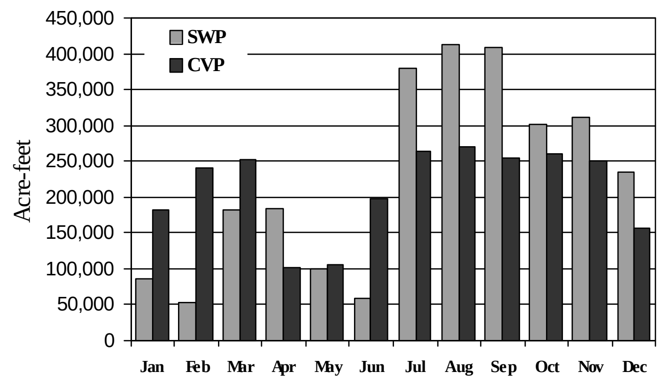

Figure 1 Monthly acre-feet of water exported in 1999 for CVP and SWP

The number of fish salvaged per acre-foot was highest at the SWP in July (4.4) and at the CVP in June (3.7) (Figure 2). Striped bass accounted for much of the salvage in July at the SWP (65%) and during June at the CVP (64%).

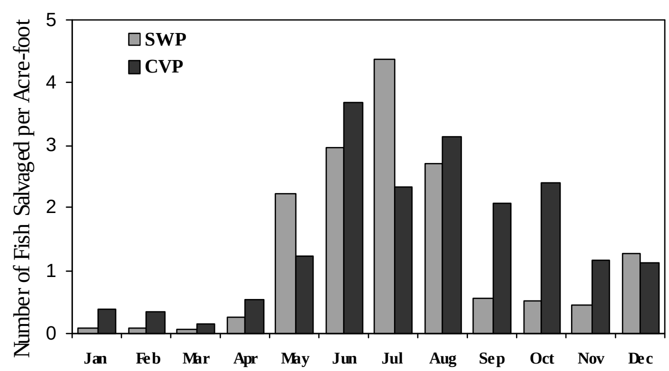

Figure 2 Number of fish salvaged per acre-foot of water exported in 1999

More delta smelt were salvaged at the SWP in 1999 than in any other year (Figure 3). More than 107,000 delta smelt were salvaged at the SWP, almost double the total in 1988, the previous high. At the CVP, about 47,000 delta smelt were salvaged, the most since 1981 (Figure 4). More than 99% of the delta smelt were salvaged during May, June, and July (Figure 5).

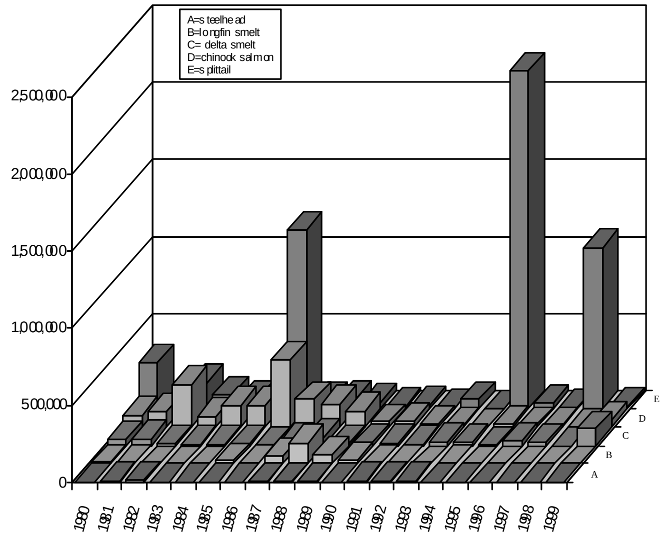

Figure 3 Number of fish of special concern salvaged at the SWP: (A) steelhead, (B) longfin smelt, (C) delta smelt, (D) chinook salmon, and (E) splittail

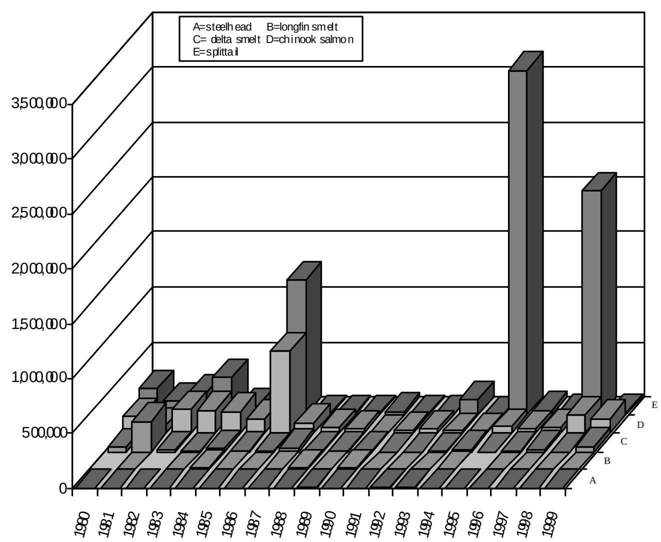

Figure 4 Number of fish of special concern salvaged at the CVP: (A) steelhead, (B) longfin smelt, (C) delta smelt, (D) chinook salmon, and (E) splittail

Salvage of chinook salmon at the SWP in 1999 was low compared to the CVP (Figures 3 and 4). Peak salmon salvage at the SWP exceeded 23,600 in both April and May, but at the CVP, salmon salvage was high in February, April, and May and ranged from 33,354 to 38,148 during those months (Figure 6). The majority of salmon salvaged in February were fall-run-sized fish, but in April and May, there was a mix of fall-run- and spring-run-sized fish.

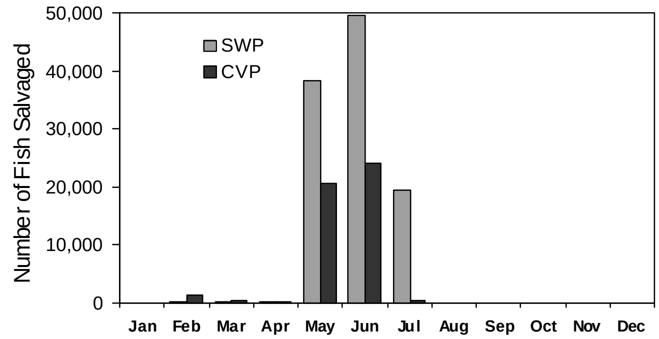

Figure 5 Number of delta smelt salvaged in 1999 by month and facility

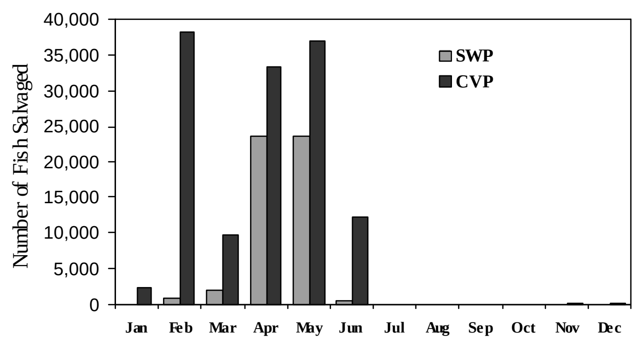

Figure 6 Number of chinook salmon salvaged in 1999 by month and facility

Steelhead salvage was higher at the CVP (1,556) than at the SWP (1,076) (Figures 3 and 4) and was highest in April at both facilities (Figure 7). Most of the steelhead salvaged at the SWP (89%) and CVP (95%) were wild, non-adipose-fin-clipped fish. The combined salvage from the two facilities was higher than the two previous years, but was only about 35% of the ten-year average (1990–1999).

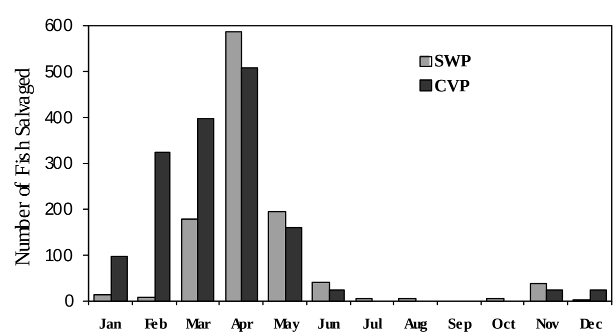

Figure 7 Number of steelhead salvaged in 1999 by month and facility

Striped bass salvage peaked in July at the SWP and in June at the CVP. Over 1 million striped bass were salvaged in July at the SWP and more than 464,000 were salvaged in June at the CVP (Figure 8). Young-of-the-year fish accounted for the high numbers salvaged at the facilities in June and July. In 1999, salvage of striped bass was the highest at the SWP since 1993 and highest at the CVP since 1994 (Figures 9 and 10). Since 1993, however, striped bass have been salvaged in lower numbers than between 1984 and 1989.

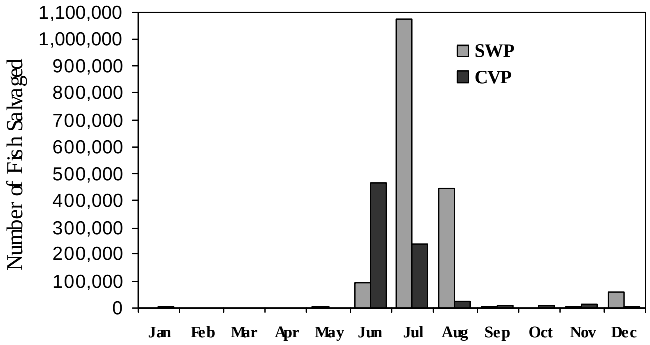

Figure 8 Number of striped bass salvaged in 1999 by month and facility

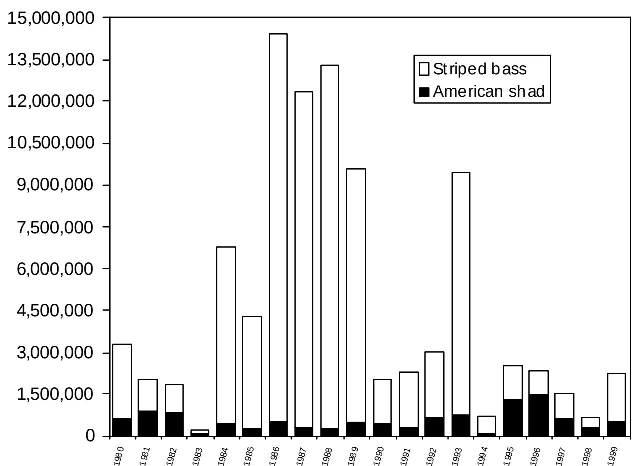

Figure 9 Number of striped bass and American shad salvaged at the SWP

Salvage of American shad peaked twice at the SWP in 1999: once in August, with more than 264,000 salvaged, and again in December (Figure 11). At the CVP, salvage of American shad reached 173,000 fish in August. Most American shad salvaged were age 0. American shad salvage in 1999 was lower than the highs of 1.5 million salvaged at the SWP and 972,000 salvaged at the CVP in 1996.

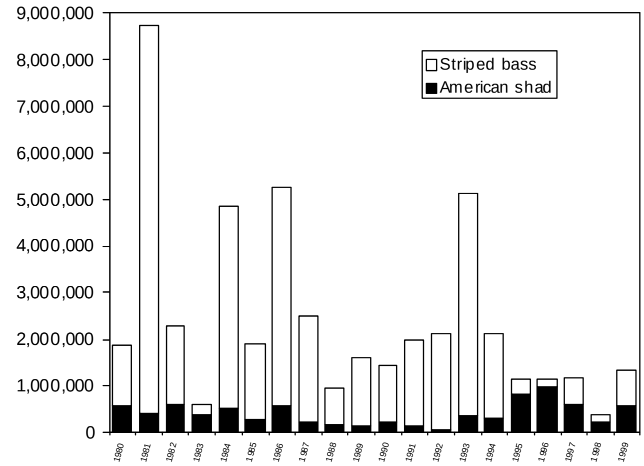

Figure 10 Number of striped bass and American shad salvaged at the CVP

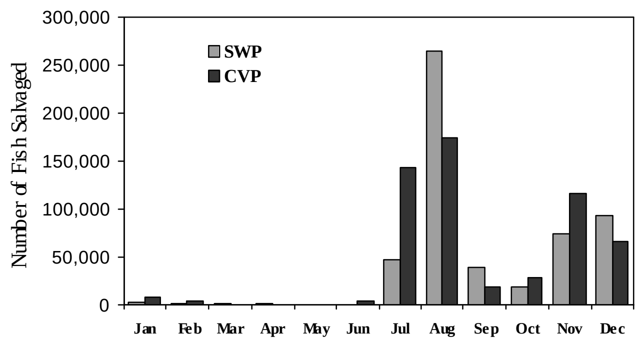

Figure 11 Number of American shad salvaged in 1999 by month and facility

Splittail salvage was highest in July at both facilities; about 10,000 were salvaged at each facility in that month (Figure 12). In 1999, splittail salvage at the SWP and CVP was only about 1% of last year's salvage (Figures 3 and 4). Few longfin smelt were salvaged at either facility: only 673 were salvaged at the SWP and 132 at the CVP (Figures 3 and 4).

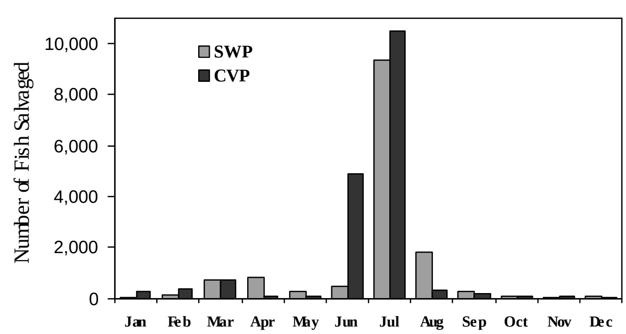

Figure 12 Number of splittail salvaged in 1999 by month and facility

A Plea for Standardized Terminology in IEP Communications

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One of the hallmarks of scientific writing is the use of standardized, consistent terminology. There are two areas in which inconsistent or non-standard terminology is commonly used in reports of the IEP and others, particularly in the *Newsletter,* and I believe this usage impedes communication.

The first issue is the name of the estuary we are all working in. We should all call it by the same name in our publications and reports. The name should be straightforward, easy to recognize, and informative to as many readers as possible. There is a general trend for people living and working in Sacramento and Stockton to call it the “Sacramento-San Joaquin Estuary” and for those west of the Central Valley to call it the “San Francisco Estuary,” although there are numerous variants. Perhaps the full name should be the “San Francisco Bay/Sacramento-San Joaquin Delta Estuary,” but that is a jawbreaker. I suggest that we all refer to the estuary as the “San Francisco Estuary” and call the Delta the “Sacramento-San Joaquin Delta.” Why not the “Sacramento-San Joaquin Estuary,” since those are the major rivers that feed the estuary? There are several reasons. First, place names generally should be informative to the outside world, and most people have heard of San Francisco (yet I suspect many people even in California could not pinpoint the Delta on a map). Second, there are precedents for an estuary to be named differently from its rivers: who has heard of the Susquehanna Estuary? Third, the San Francisco Estuary Project has established the name and given it some recognition and coherence.

The second issue is the use of non-standard units. The Interagency Ecological Program is a scientific organization. Most of the reports in the *Newsletter* and IEP Technical Report series are about scientific issues, communicated to scientists. The language of science includes a common system of units which is entirely metric. Most scientific journals require the use of metric units in all papers accepted for publication. The IEP should do the same in its reports and newsletters. The use of acre-feet as a unit of measure is a particular anomaly, as are fish per acre-foot and tons of sediment per acre-foot. Although the acre-foot is a convenient measure for irrigation, the IEP is in the business of providing scientific analysis, not irrigation water.

CONTRIBUTED PAPERS

RECENT RESEARCH ON THE HYDRODYNAMICS OF THE SACRAMENTO-SAN JOAQUIN RIVER DELTA AND NORTH SAN FRANCISCO BAY

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INTRODUCTION

This article presents an overview of recent findings from hydrodynamic research on circulation and mixing in the Sacramento-San Joaquin Delta (Delta) (Figure 1) and North San Francisco Bay (North Bay) (Figure 2). For the purposes of this article, North Bay includes San Pablo Bay, Carquinez Strait, and Suisun Bay. The findings presented are those gained from field studies carried out by the U.S. Geological Survey (USGS), as part of the Interagency Ecological Program (IEP), and Stanford University beginning about 1993. The premise behind these studies was that a basic understanding of circulation and mixing patterns in the Bay and Delta is an essential part of understanding how biota and water quality are affected by natural hydrologic variability, water appropriation, and development activities.

Data collected for the field studies described in this article have significantly improved our understanding of Bay and Delta hydrodynamics. Measured flows in the Delta have provided valuable information on how water moves through the Delta's network of channels and how export pumping affects flows. Studies of the shallows and shallow-channel exchange processes conducted in Honker Bay have shown that the water residence time in Honker Bay is much shorter than previously reported (on the order of hours to several tidal cycles instead of weeks). Suisun Bay studies have provided data on hydrodynamic transport and accumulation mechanisms that operate primarily in the channels. The Suisun Bay studies have caused us to revise our understanding of residual circulation in the channels of North Bay and of "entrapment" mechanisms in the low salinity zone. Finally, detailed tidal and residual (tidally averaged) time-scale studies of the mechanisms that control gravitational circulation in the estuary show that density-driven transport in the channels is governed by turbulence time-scale (seconds) interactions between the mean flow and stratification. The hydrodynamic research summarized in this article spans a range of estuarine environments (deep water channels to shallow water habitats and brackish water to freshwater) at time scales that range from seconds to years.

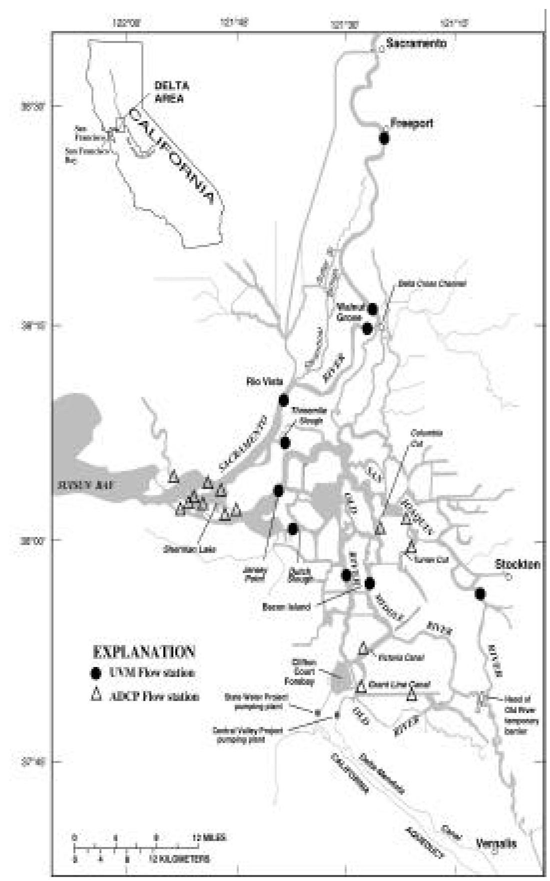

Figure 1 Map of the Delta showing the location of the current network of 10 UVM flow monitoring stations (solid circles). In situ acoustic Doppler current profilers (ADCP) have also been deployed for three month periods during the spring of 1996, 1997, and 1998 and the fall of 1998 (open triangles).

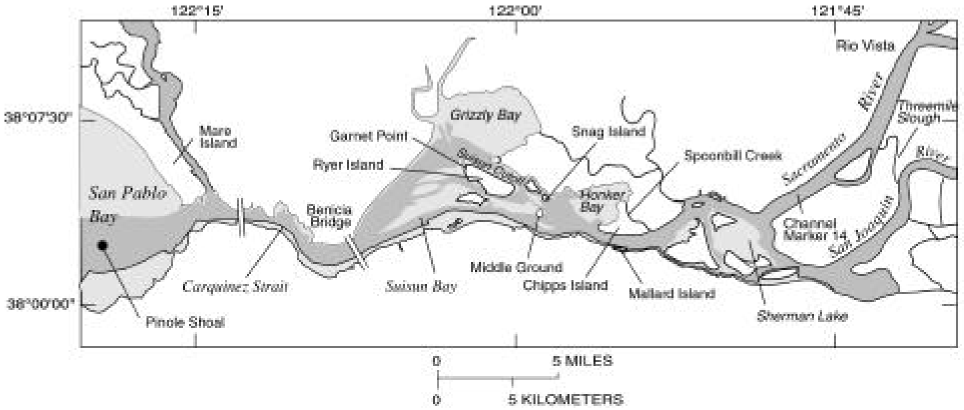

Figure 2 Map of North Bay, which, for the purposes of this article, includes San Pablo Bay, Carquinez Strait, and the western Delta

Funding for these studies was provided by the IEP, the USGS Federal-State Cooperative program, the U.S. Department of Interior Place-Based Program, the San Francisco Regional Water Quality Control Board, CALFED, the National Science Foundation, the Office of Naval Research, the city of Stockton, and the Contra Costa Water District.

Each finding is presented briefly in a “highlight reel” format. Additional details can be obtained through the reference list, which include several websites, and from the principal investigators (e-mail addresses are provided). Where possible, each finding is presented as an observation followed by its implications. The article discusses the Delta then North Bay.

DELTA

Between 1987 and 1996 the USGS installed a network of ten tidal-flow monitoring stations in the Delta (Figure 1). Ultrasonic velocity meters (UVMs) are used to continuously monitor the tidal flows at these permanent installations. The net or tidally averaged flow at each station is calculated using a digital filter. Because the net flows are usually ten percent or less of the tidal flows (depending on proximity to the ocean) the tidal flows must be measured very accurately to keep the error in the estimated net flow reasonably small. For example, the net flows in very dry years could be on the order of the error in the tidal flow measurements. An error analysis using data from the Threemile Slough flow station suggests that the net flows at this station are accurate to within 0.5% of the peak tidal flows (Simpson and Bland 1999). Although error estimates have not been made at the other flow stations, the error estimate at Threemile Slough is likely lower than at stations that have longer acoustic path lengths and more complicated channel geometries, such as Rio Vista and Jersey Point. More information on the error analysis is available from Michael R. Simpson at the USGS (mrsimpson@usgs.gov).

In addition to the continuous flow monitoring stations, acoustic Doppler current profilers (ADCPs) also have been deployed in the Delta during spring 1996, 1997, and 1998 and fall 1998 to measure tidal flows over three-month periods at several additional locations. Both the UVM and ADCP measured flow data are being used to calibrate and validate several flow models being applied in the Delta. Some of what has been learned about the hydrodynamics of the Delta using these measured flow data is described here.

Delta Outflow

Daily indirect measurements of Delta outflow have been made by combining the data from four UVM stations; Sacramento River at Rio Vista, Threemile Slough, San Joaquin River at Jersey Point, and Dutch Slough (Figure 1). Data from this combination of stations are available, beginning February 13, 1996, to the present, from the USGS hydrodynamics data base and the IEP file server. The measured Delta outflow generally compares well with the mass-balance calculated Delta outflow (DAYFLOW, DWR 1986) during high-flow periods, except that the measured data are lagged by several days because DAYFLOW does not account for travel time through the Delta. During low-flow periods, however, Delta outflow calculated using the two methods can be different primarily because DAYFLOW does not account for the spring neap cycle filling and draining of the Delta (see below) and DAYFLOW uses imprecise estimates of consumptive use (Oltmann 1998a). The UVM computed outflow is generally greater than DAYFLOW during low-flow periods, although the opposite occurred in 1998.

Spring Neap Cycle Effects

The tidally averaged water-surface elevation in the Delta can vary by as much as one foot during the fortnightly (14-day) spring neap tidal cycle. A uniform one-foot change in the water-surface elevation in the Delta equates to a change in storage of about 50,000 acre-feet. Therefore, the spring neap cycle water level oscillation in the Delta can produce a significant oscillation in the net flows (filling and draining) and also in the position of the salt field. As a direct result of the Delta filling and draining, net flows can occur in a landward direction during late summer and fall in the lower reaches of the San Joaquin River at Jersey Point (Oltmann 1995; Oltmann and Simpson 1997). The ability of the “G” model (Denton 1993) to predict daily variations in salinity in the western Delta was significantly improved during the solstices of each year (a time when the difference between spring and neap tides is greatest) after the “G” model was modified to include spring neap cycle effects (computed by the Fischer Delta Model, Fischer 1982).

Effects of Barriers

Delta Cross-Channel Gates

Although the Delta cross-channel gates originally were installed in the 1950s to improve water quality in the central Delta, the gates now are used to keep fish in the Sacramento River from entering the central Delta. The flow data collected at the Sacramento River upstream and downstream of the gates near Walnut Grove show the effects of gate operation on local hydrodynamics. For example, net flow from the Sacramento River into Sutter and Steamboat Sloughs increases by about 1,800 cubic feet per second when the gates are closed, compared to periods when the gates are open (Oltmann 1995).

South Delta Hydrodynamics

Flow data (ADCP and UVM) from spring 1997 and 1998 document the combined effects on south Delta hydrodynamics of the barrier installed at the head of Old River, a 30-day pulse flow on the San Joaquin River, and high overall inflows from the San Joaquin River. The barrier at the head of Old River is installed to prevent emigrating salmon from being drawn into the export facilities through Old River. One purpose for the San Joaquin River pulse flow is to help salmon bypass the export facilities by moving them north through the Delta (Oltmann 1998b). The flow data showed that during low-flow periods, the hydrodynamics of the south Delta are influenced primarily by the tides, rather than by inflows and exports. Tracer-dye studies also were conducted in the south Delta during spring 1997 and 1998. The dye studies showed that the dynamic tidal flows in this area rapidly dispersed (mixed) the dye (Oltmann 1998b, 1999). See also the Honker Bay section that discusses the mixing that occurs in channel bends.

Effects of the Confluence (Including Sherman Lake)

Tidal flows were measured using ADCPs at nine sites in the confluence area for a three-month period during fall 1998. These data showed that the net flow through Sherman Lake was from the Sacramento River to the San Joaquin River. The net flows through Threemile Slough, which were measured by a UVM during the same time period, also were from the Sacramento River to the San Joaquin River. Surprisingly, the magnitude of the net flow through Sherman Lake, a shallow water habitat that also provides an important hydraulic connection between the Sacramento and San Joaquin rivers, was about 1.5 times that of Threemile Slough (R. N. Oltmann unpublished data).

Effects of Meteorology

Variations in atmospheric pressure and wind can significantly affect water-surface elevations and flows in the Delta (Oltmann 1998a). An increase in atmospheric pressure results in a lowering of water levels and a “draining” of the Delta; a decrease in atmospheric pressure results in raising water levels and a “filling” of the Delta. Changes in atmospheric pressure are often accompanied by increased wind speeds that also can alter water levels and flows in Delta channels. For example, a drop in atmospheric pressure and sustained westerly winds on December 12, 1995, resulted in the elimination of the daily low-high tide and the associated ebb flow throughout the Delta.

More information is available from Richard N. Oltmann at the USGS (rnoltmann@usgs.gov).

NORTH BAY

Although the Bay and Delta are often considered separately, they are intimately connected by the tides. Tidal forcing varies spatially throughout North Bay and the Delta in direct proportion to proximity with the Pacific Ocean. The tides and tidal discharges reach their peak at the Golden Gate Bridge and gradually diminish until, on the eastern fringes of the Delta, tidal flows completely give way to riverine influences (Walters and Gartner 1985). Computer-model-generated residual current plots often show a deceptively simple one-way exchange from the Delta to the Bay even though the daily tidal flows in the western Delta are often 50 to 60 times the net flows (Oltmann 1998b). The large tidal exchanges can introduce large net landward directed fluxes of water, salt, and suspended particulate matter by lateral mixing, or dispersive processes, that can far exceed the fluxes of these quantities from the net flows (Fischer and Dudley 1975). Therefore, the net exchange of salt, suspended particulate matter, biota, etc., past a given location, which includes advective (net flow) and dispersive components (tidal correlations), can be (during low flow periods, in particular) from the Bay to the Delta. Salinity intrusion into the Delta from the Bay during late fall is a good example of up-estuary dispersive transport in opposition to Delta outflow.

The flows in the Delta and in the Bay, where saltwater is present, are fundamentally different. The flows in the Delta, for example, are simply driven by water-surface slopes (gradients). Tidal flows are caused by water-surface slopes that result from the propagation of the tide wave and net flows are driven by tidally averaged water surface slopes that are created by riverine inputs, exports, and by tidal nonlinearities (for example, spring neap cycle “filling and draining”) and changes in the local meteorology.

All of the water-surface-slope-derived flow patterns described above in the context of the Delta also operate in the Bay. However, the physics of the flows in the Bay are relatively more complicated than the flows in the Delta because of the presence of higher concentrations of salt, and, as a consequence, the underlying physics of the flows in the Bay are relatively less well understood. Salinity affects the density of the water and, therefore, spatial differences (gradients) in salinity can drive density-driven (baroclinic) flows such as gravitational circulation; a circulation pattern wholly absent throughout most of the Delta because water is fresh in the Delta. The location where flows change from being fundamentally riverine (barotropic) to flows that include both barotropic and baroclinic components is based on the presence or absence of salinity, not geography (for example, Bay versus Delta). For practical purposes, this change occurs at X2; only water surface slope-driven flows exist landward of X2, whereas, seaward of X2, a combination of water surface slope and density driven flows prevail. X2 is the distance, in kilometers from the Golden Gate Bridge, of the near-bed tidally averaged salinity of 2.

The remainder of this article focuses on physical insights we have gained over the last few years in North Bay, the area of the estuary where saltwater and freshwater mix.

HONKER BAY

Since most of the hydrodynamic research before 1995 focused on channel dynamics, little was known about the transport and mixing within shallow areas until this time, despite the fact that as early as 1975 Hugo Fischer (Fischer and Dudley 1975) suggested that approximately 70% of the upstream migration of salt is due to lateral shear and shallow-channel exchange processes. Lateral shear is the change in current speed that occurs between the side of the channel where the current speeds are slower and the center of the channel where the current speeds are greatest. The primary reason for the lack of field studies aimed at quantifying the shallows-channel exchange contribution to transport, in general, and to salinity intrusion specifically, is that these processes evolve from the storage and release of waters from the shallows into the channels that occurs over a large area. The amount of equipment needed to cover the spatial scale of these exchanges was simply not available to researchers in this estuary before 1995.

CALFED’s general interest in shallow water habitats and the unknown, although suspected, important role the shallows of Suisun Bay play in the Bay-Delta ecosystem prompted the USGS and Stanford University to carry out two experiments in Honker Bay (December 1996 through March 1997 and April through August 1997). Although previous work suggested that the water residence times in Honker Bay were on the order of weeks, these studies found that the exchange between Honker Bay and its bounding channel was relatively rapid (hours to several tidal cycles) (Lacy 2000). In contrast, sediment transport measurements conducted as part of the hydrodynamic studies suggest that sediment residence times are on the order of months (Ruhl and Schoellhamer 1999). The marked difference between the water versus sediment residence times could have important implications to the exposure pathways of organisms to contaminants. For example, direct exposures of organisms to pulses of contaminants in solution (for example, dissolved forms of pesticides) will be limited in Honker Bay because of the relatively short water residence times (Lacy 2000). However, exposure to contaminants via ingestion of particulate materials may be enhanced by the longer residence times of the suspended particulate matter. Brown and Luoma (1995) reported higher concentrations of metals (cadmium, chromium, vanadium, and nickel) in bivalves in Honker Bay than anywhere else in Suisun Bay. Moreover, disruption of the reproductive capabilities in the Asian clam, *Potamocorbula amurensis*, also was found in Honker Bay (Brown and Luoma 1998). At the same time, this highly opportunistic clam, which is found in large numbers throughout North Bay (Figure 2) and serves as a primary food source for bottom-feeding ducks and sturgeon, has virtually disappeared from Honker Bay (J. Thompson, personal communication, see "Notes"). The longer residence time of suspended particulate matter is a possible explanation for the higher metals concentrations in bivalves in Honker Bay and one feasible explanation (among others) for their subsequent population decline in this area.

Finally, the hydrodynamic and suspended-sediment transport studies also highlight the importance of seemingly innocuous (small) hydraulic pathways. Significant tidally driven [not residual (net) current driven] transport of water mass, salinity, suspended sediment, and by extension biota, can occur in small channels, such as Spoonbill Creek, which connects Honker Bay with the Sacramento River (Warner and others 1997), or Threemile Slough, which connects the Sacramento River with the San Joaquin River.

Water Residence Times

To examine large-scale circulation patterns in Honker Bay, a series of drifter experiments was conducted as part of the hydrodynamic studies. In regions with complex shape and variable depth, techniques such as drifters, which track masses of water over the tidal cycle, can provide a better estimate of the tidal excursion than can measurements of velocities at a single point. The tidal excursion is the distance a parcel of water (a drifter) travels over a tidal cycle (ebb + flood). The drifter studies demonstrated that tidal excursions in Honker Bay are the same order of magnitude as the length of Honker Bay, and that water residence times in Honker Bay range from several hours to several tidal cycles. The relatively short water residence time in Honker Bay may limit its importance as a distinct shallow water habitat (Lacy 2000).

In summer, tidally averaged (residual) currents throughout Honker Bay are directed landward (into Honker Bay toward the Delta), producing upstream transport of salt and neutrally buoyant particles (Lacy 2000). This is in contrast to conventional wisdom regarding the circulation in the shallows where the residual currents, in the absence of gravitational circulation, are assumed to flow seaward in concert with net Delta outflow. The flood-directed residual currents in Honker Bay are due to the mixing of waters that flow into Honker Bay from Suisun Cutoff (where the phase of tidal currents is later than in the main channel) with waters that flow into the Honker Bay from the main channel. The flood tide starts in Honker Bay when the main channel starts to flood, but the beginning of the ebb is tied to the ebb in Suisun Cutoff. As a result, salt and particulate matter in Honker Bay is more likely to leave Honker Bay by Chipps Island to the east or through Spoonbill Creek, than to the west. Thus, the shallows of Honker Bay serve to lengthen the residence time of Suisun Bay as a whole (Lacy 2000).

Suspended Solids Concentrations

The highest suspended solids concentrations in Honker Bay occur from late April through early May (Ruhl and Schoellhamer 1999)—when the shallows of Suisun Bay are a host to the critical life stages of several species of concern—not during large runoff events. If toxic substances are associated with suspended particulate matter, then higher suspended-solids concentrations during this period could lead to increased organism exposure during this time. Elevated suspended solids during this period are caused by wind-wave resuspension of fluvial inputs deposited during large runoff events. The cycle of deposition and wind-wave resuspension of bed sediments suggests that the sediment residence times in Honker Bay are on the order of months (Ruhl and Schoellhamer 1999).

The general observation that residence times for negatively buoyant particles (sediment) are higher in the shallows has important implications for the residence times of other suspended particles, such as phytoplankton cells, which also can be negatively buoyant. Therefore, the buoyancy of phytoplankton cells is important in determining their residence time in the shallows (Arthur and Ball 1979; Ball and Arthur 1981). The shallow waters of Grizzly and Honker bays are zones of net phytoplankton production, while the adjacent deep channels are net sinks for phytoplankton biomass (Cloern and others 1985). Therefore, residence time of phytoplankton in the shallows is an important factor in determining the rate at which shoal-derived organic matter (food) is transported to consumers living in the deep regions of Suisun Bay.

Effects of Geography

Geography can have a dramatic effect on transport of salt, sediment, and biota. Geographic effects are intrinsically site specific, depending on both structural and hydrodynamic influences, and the interaction between them (although armored levees, by design, significantly constrain this interaction). For example, the interaction between the physical configuration of an individual channel—its capacity in terms of its cross-sectional area and roughness, its length and sinuosity—with the local tidal and riverine forcing determine its tidal and residual transport characteristics. Yet, characterizing the tidal and residual transport characteristics of each channel individually, in isolation, provides an incomplete picture. It is the interactions among the flows in the channels and between the channels and the shoals in the Bay and Delta that controls where things (salt, sediment, biota, etc.) ultimately go and how they get there. Not only must the physical configuration of the shoal (aerial extent, volume, tidal prism, fetch, etc.) be considered when trying to understand the role it plays in transport, but also its connection with the main channel(s), as well as the characteristics of the channel itself also must be considered. This section describes several specific examples of the effects of geography on transport. In each case, the connections between channels and between channels and shoals (at least within a tidal excursion) are emphasized.

Channel Length—Spoonbill Creek

Drifter studies indicate that during neap tides, exchange between Honker Bay and the Sacramento River through Spoonbill Creek is limited to the easternmost part of Honker Bay. During spring tides, exchange through Spoonbill Creek can influence most of Honker Bay, due to greater tidal excursions. In summer, there is a persistent tidally averaged salinity gradient across Honker Bay with the fresher water in the eastern part of the Bay towards Spoonbill Creek. This suggests Spoonbill creek provides a direct connection between Honker Bay and the Sacramento River (Lacy 2000).

Spoonbill Creek also provides a steady flux (mostly dispersive, involving tidal correlations) of suspended solids from Honker Bay to the Sacramento River (Warner and others 1997). This dispersive transport occurs because the length of Spoonbill Creek is significantly less than the tidal excursion through the creek. Sediment-laden water, that originates in Honker Bay, leaves Spoonbill Creek with each ebb and is almost completely mixed with Sacramento River water, which contains less sediment. The concentration of suspended sediments in the water returning through Spoonbill Creek on the flood is much lower than was present on the ebb. This process of "ebb-mixing-flood" results in a net transport of sediment from Honker Bay to the Sacramento River. The dispersive transport in Spoonbill Creek is an example of tidal pumping (Fischer and Dudley 1975); an often overlooked, yet extremely efficient transport mechanism that has nothing to do with the local residual currents (net flows).

That channels with tidal excursions greater than their lengths can produce significant net dispersive transports is a general finding that has important implications in the Delta. For example, the tidal excursions in Threemile Slough and Sherman Lake are often greater than their respective lengths. Therefore, dispersive transport in Threemile Slough and in Sherman Lake probably far exceeds the transports computed based on the fixed site net flows alone. Drifter studies conducted in Sherman Lake in fall 1998 confirm this conclusion because the tidal excursion from the Sacramento River through Sherman Lake to the San Joaquin River is 3.6 miles longer than the tidal excursion in the opposite direction (J. Cuetara, personal communication, see "Notes"). This implies that during low-flow periods, the measured net flows underestimate the actual exchange between the Sacramento and San Joaquin rivers through Sherman Lake and through Threemile Slough because most of the water originally from the Sacramento River that exits both Sherman Lake and Threemile Slough into the San Joaquin does not return when the tidal current reverses. This is a classic case of tidal pumping (Fischer and Dudley 1975)

Channel Curvature—Snag Island Channel

In the channel flowing west from Honker Bay behind Snag Island, episodic cross-channel circulation is strong enough to mix the entire cross section in less than one hour. The cross-channel circulation is caused by centrifugal acceleration around the bend in Snag Island Channel and, at times, by lateral gradients in salinity. These observations suggest that channel curvature can be a very important mixing mechanism. Many channels in the estuary and Delta are curved, and the mixing caused by transverse currents is poorly understood and likely not well represented in most numerical models of the estuary (Lacy 2000).

For more information on the hydrodynamics of Honker Bay, contact Jessica Lacy (jlacy@leland.stanford.edu), Stephen G. Monismith (monismith@cive.stanford.edu), or Jon R. Burau (jrburau@usgs.gov). For information on sediment transport contact, John C. Warner (jcwarner@ucdavis.edu), Catherine A. Ruhl (caruhl@usgs.gov), or David H. Schoellhamer (dschoell@usgs.gov). For information regarding drifter studies in Suisun Bay and the Delta, contact Jay I. Cuetara (jcuetara@usgs.gov).

Suisun Bay and Carquinez Strait

Over the years there has been considerable interest in the effect of gravitational circulation on transport and on the accumulation of particles and biota in North Bay. Therefore, a considerable amount of research has been directed towards a better understanding of the basic physics in this area. Primarily through IEP support, the USGS has deployed large numbers of acoustic Doppler velocity profilers (ADCPs) and salinity-measuring equipment since 1993. Although much research needs to be done, particularly at the shorter (tidal and turbulence) timescales, our increased knowledge of the basic physics has allowed a better understanding of the observed temporal and spatial variability in gravitational circulation. For more information, contact Jon R. Burau (jrburau@usgs.gov), Stephen G. Monismith (monismith@cive.stanford.edu), or Mark T. Stacey (mstacey@socrates.berkeley.edu).

Gravitational Circulation

The horizontal salinity gradient (saltwater near the ocean to freshwater in the Delta), not salinity itself, drives gravitational circulation (Hansen and Rattray 1965). Gravitational circulation increases with water depth and is suppressed by increased vertical mixing that occurs during spring tides when the tidal currents are stronger (Walters and Gartner 1985; Burau and others 1998). Therefore, a combination of factors controls gravitational circulation strength—the horizontal salinity gradient, current speed, and depth (Smith and others 1991; Monismith and others 1996; Burau and others 1998; and Stacey and others 1999). These three factors have geographic consequences, which are described below.

Geographic Consequences

Rapid reductions in depth along the axis of the estuary can act as internal hydraulic controls (Armi 1986). This means, in effect, that significant reductions in depth (shoals or sills) can severely reduce or completely eliminate gravitational circulation. Because North Bay has several shallow areas that occur in the channels (such as Pinole Shoal and the reduction in depth near the Benicia Bridge), this depth dependence suggests that gravitation circulation in the North Bay and the western Delta operates as a series of independent cells bounded by sills (or shoals) at either end.

Gravitational circulation dominates residual transport in Carquinez Strait unless the waters in the strait are completely fresh (Burau and others 1993; Smith and others 1995; Monismith and others 1996). Gravitational circulation is likely stronger and a more persistent feature in Carquinez Strait than anywhere else in the Bay (Burau and others 1998) because a persistent horizontal salinity gradient exists along the axis of the strait for most of the year, and it is deep (approximately 50 ft, mean lower low water [MLLW]).

Gravitational circulation is rare in Suisun Bay's southern (ship) channel during the spring because the tidal currents are relatively strong [M2 tidal amplitude of approximately 90 cm/s] at this location and the ship channel is relatively shallow (approximately 30 ft MLLW) (Burau and others 1998). The M2 tidal amplitude is a single number that is often used to characterize the strength of the tides and tidal currents. The M2 tidal amplitude is the largest "partial tide" in San Francisco Bay (by approximately a factor of two) and is computed by harmonic analysis) (Burau and others 1998). Harmonic analysis decomposes the tides and tidal currents into a series of sinusoidal components of astronomically known frequencies. The M2 partial tide has a period of 12.42 hours.

Gravitational circulation has been measured during the fall in Suisun Cutoff because the tidal currents there are relatively weak (M2 tidal amplitude of approximately 60 cm/s) (Mortenson 1987; Stacey 1996; Burau and others 1998). Sills at either end of Suisun Cutoff reduce its tidal currents, and most likely define the end points of an independent gravitational circulation cell within the Cutoff.

Gravitational circulation has been measured in the lower Sacramento River (Nichol 1996) because the tidal currents in the river also are relatively weak (M2 amplitude of approximately 50 cm/s). This observation has implications for salt transport in the western Delta in dry years. Because the amplitude of the tide wave is greatly reduced as it passes through Suisun Bay on its way to the Delta, vertical mixing generally is significantly weaker in the Delta compared to the Bay. The reduction in vertical mixing, coupled with the relatively deep channels of the western Delta (> 30 ft), suggests that gravitational circulation could contribute significantly to the upstream migration of salt in the western Delta in dry years (this needs to be confirmed with additional data) (Burau and others 1998).

Relation to X2

The linkage between gravitational circulation and salt flux may have important consequences for the relation between flow and X2. The more than 20-year salinity data set of the U.S. Bureau of Reclamation, used by Jassby and others (1995) to develop X2-organism abundance relations, shows that the dependence of X2 and, hence, salinity intrusion in the Bay-Delta system on flow is much weaker than would be expected. One explanation for this is that there is a feedback mechanism—increased flow pushes the salt field down estuary—thus, intensifying the salinity gradient (Monismith and others 1996). However, when the salt gradient is stronger (compressed), strong gravitational circulation is more likely, as is strong upstream salt flux, which resists the downstream progression of X2. Thus, the seasonal-scale response of the salinity field to flow variations may be attributed to physical processes, such as gravitational circulation, which take place at the tidal time scale. For more information, contact Stephen G. Monismith (monismith@cive.stanford.edu).

Estuarine Turbidity Maxima

Because gravitational circulation ceases or becomes weaker over sills that separate deeper sections of the channels, this suggests the sills create geographically fixed null zones (Burau and others 1998). A null zone is a region in the estuary where the net current flowing landward along the bottom reverses direction. In most estuaries, a null zone also is associated with a region of high turbidity known as estuarine turbidity maxima (ETM) (Burau and others 1998). An ETM and null zone often are found immediately seaward of a sill. Suspended-solids data have confirmed the existence of a strong and persistent ETM seaward of the sill near the Benicia Bridge and west of the sill near Garnet Point on Ryer Island in Suisun Bay (Figure 2) (Schoellhamer and Burau 1998). An ETM also may exist at Pinole Shoal and at the sill north of Middle Ground (Figure 2).

Analysis of data collected in Suisun Cutoff during summer 1995 suggests that sediment and salt are transported differently (Schoellhamer and Burau 1998). This contrasts with the conceptual model offered by Arthur and Ball (1979) who suggest that entrapment of suspended material evolves directly from gravitational circulation (salt transport). Specifically, analyses of these data found that the salt flux through Suisun Cutoff was greater during neap tides than during spring tides. Suspended-solids fluxes, on the other hand, had the opposite temporal trend; lower fluxes occurred during neap tides and greater fluxes occurred during spring tides (Schoellhamer and Burau 1998). For more information, contact David H. Schoellhamer (dschoell@usgs.gov) or Jon R. Burau (jrburau@usgs.gov).

Turbulence

During November 1994, Stanford University and the USGS made a series of turbulence measurements (Stacey 1996; and Stacey and others 1999). The results from these studies that link the high frequency (seconds) turbulent motions to the tidal and residual time-scale transports of interest to the biologists are described here.

Residual circulation is created in an unsteady fashion as a time average of a series of density-driven current pulses at the tidal timescale. The interaction between stratification, shear, and turbulent mixing is fundamental in establishing the magnitude and timing of these pulses. The timing of these pulses, relative to other processes such as the resuspension of sediment, is critical in determining the net transport in the system. For example, if suspended-sediment concentration is low during the density-current pulses, the net transport will be low. On the other hand, if the pulses occur simultaneously with higher suspended-sediment concentrations, the net transport will be greater than predicted by computations based on a simple time average (Stacey 1996). Tobin and others (1995) observed density-current pulses concurrent with high suspended-sediment concentrations at Mallard Island that resulted in a net landward suspended-sediment flux, despite seaward net flow. It is possible that the tidal-timescale correlation between the density-current pulses and elevated suspended-solids concentration could provide the mechanism for ETM formation near X2 in the absence of residual gravitational circulation because the necessary gradient in salinity that drives the pulses ends near X2.

Turbulence in the Bay, which sets the level of shear and strongly influences the timing and magnitude of the residual flows, is largely produced at the bed by the interaction of the tidal flows with the bottom. There is, therefore, a high-energy region of active turbulent production near the bed. The upward transport of turbulence from the bed is limited from above by the presence of stratification. The degree to which this turbulence is able to "erode" the stratification (mix the near-bed waters with the overlying water) is critical to setting the net circulation and transport (Stacey 1996).

Common turbulence models, especially the simple models, poorly predict the extent of mixing away from the bed. Thus, the predictive ability of a three-dimensional model, which is needed to simulate the density-driven current pulses described above, will depend upon the turbulence model (Stacey 1996; Stacey and others 1999).

There is a strong asymmetry between ebb and flood tides in the structure of the turbulence—with more intense turbulence occurring on flood tides. This asymmetry may have implications for sediment transport (more sediment is suspended on flood tides than on ebb tides) and for biological migration (organisms may be able to distinguish flood tides from ebb tides by the energy in the turbulence), as well as for the creation of residual flows (Stacey 1996; Burau and others 1998; Stacey and others 1999).

For more information contact Mark T. Stacey (mstacey@socrates.berkeley.edu) or Stephen G. Monismith (monismith@cive.stanford.edu).

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ENVIRONMENTAL FACTORS INFLUENCING THE DISTRIBUTION AND SALVAGE OF YOUNG DELTA SMELT: A COMPARISON OF FACTORS OCCURRING IN 1996 AND 1999

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INTRODUCTION

The delta smelt (*Hypomesus transpacificus*) is listed as a threatened species under both the Federal Endangered Species Act (FESA) and the California Endangered Species Act. Through formal consultation under Section 7 of the FESA, USBR and DWR received a Biological Opinion from the USFWS, which allows for the incidental take of delta smelt arising through operation of the Central Valley Project and the State Water Project. The incidental take of delta smelt is estimated as part of the ongoing CVP and SWP fish salvage operations. Salvage levels of young delta smelt have exceeded incidental take levels every spring and summer since 1994, except in the high spring outflow years of 1995 and 1998 (Nobriga and others 1999). These high salvage levels have resulted in changes to project operations, often leading to the curtailment of water exports. An extended period of high salvage and export curtailment in 1999 raised substantial concerns and numerous questions that remain unanswered.

Previously, Nobriga and others (1999) described the high numbers of delta smelt salvaged at the State and federal Delta fish facilities in spring 1999 as “surprising since [the 1999 Delta inflow] hydrograph showed a similar pattern to 1996,” a year of lower delta smelt salvage. However, additional work presented here shows this characterization was too general. In this article we provide a more thorough analysis of differences between 1996 and 1999 to help explain the differences in delta smelt salvage between these moderately high outflow years. We examined information from a variety of sources (Table 1) to assist with the interpretation of observed patterns. Overall, we found the differences in delta smelt salvage between spring 1996 and 1999 were due to differences in the smelt recruitment patterns and central and south Delta hydrodynamics.

Table 1 Data sources

Type of Assessment	*Agency*	*Data Source*
Delta smelt distribution	DFG	20-mm Survey
Delta smelt recruitment pattern	DFG	20-mm Survey
Water temperature	DFG	20-mm Survey
Specific conductance	DFG	20-mm Survey
Delta hydrodynamics	USGS	UVM flow data
Delta export and delta smelt salvage	DWR/DFG/ USBR	Delta fish salvage facilities

METHODS

Many of the conclusions we draw in this article are based on data from the IEP's 20-mm Survey. The 20-mm Survey has been conducted annually by DFG during the spring and summer since 1995. This survey samples for delta smelt at fixed stations throughout the upper estuary using a towed net. The net is designed to collect late larval and early juvenile stage delta smelt. See the DFG 20-mm website at http://www2.delta.dfg.ca.gov/data/20mm/2000/ for additional details regarding survey methods.

The USGS collected detailed flow measurements in Old and Middle rivers using ultrasonic velocity meters (UVM). These measurements, along with daily San Joaquin River inflow and export flows are used to describe Delta hydrodynamics during spring 1996 and 1999. Fifteen-minute interval time-series of tidal flow data are produced for each UVM station, but only tidally averaged (net flow) data are presented in this article. The tidally averaged flows for Old and Middle rivers are referred to as central Delta flows throughout this article. For a description of the use of UVMs to measure tidal flow refer to Oltmann (1998).

Distribution of Adult Delta Smelt

The distribution of adult delta smelt at the time of spawning directly affects the subsequent distribution of young delta smelt. Thus, understanding the factors affecting adult delta smelt distribution during the spawning period can help us to understand the patterns in young delta smelt recruitment and distribution. An examination of DFG spring midwater trawl data shows adult delta smelt distribution during the probable spawning period (February to May) does vary among years. In particular, the occurrence and spawning of adult delta smelt in the central and south Delta seems to vary considerably among years.

Examination of San Joaquin River hydrographs for the January through July period between 1994 and 1999 shows considerable variation among years (Figure 1). However, the San Joaquin River hydrographs for 1996 and 1999 were unlike the other years examined. In these years, San Joaquin River inflow to the Delta generally ranged over intermediate values (about 140 to 425 m^3/s or about 4,940 to 15,000 cfs) from late January through late May. In both of these years, DFG spring midwater trawl surveys found many adult delta smelt in the San Joaquin River system but relatively few in the Sacramento River system. We hypothesize the occurrence of intermediate flows on the San Joaquin River in late winter provided attractive conditions for adult delta smelt moving upstream to spawn. Maintenance of moderate flow levels through spring then provided favorable spawning and juvenile rearing conditions for delta smelt in the central and south Delta.

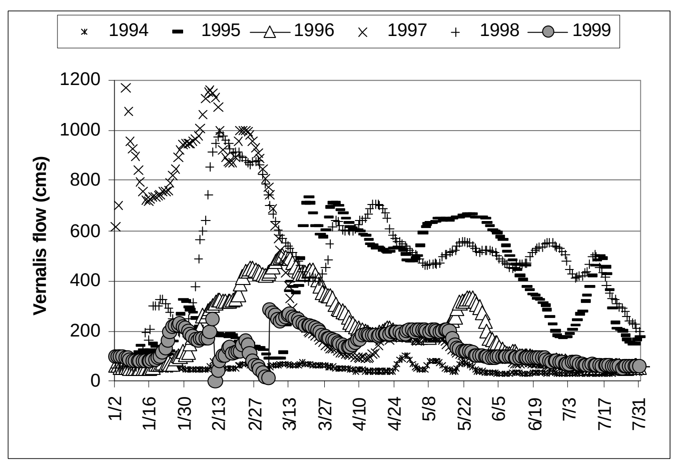


Figure 1 San Joaquin River flows at Vernalis, January 1 through July 31, 1994–1999

Overview of 1996 and 1999 Salvage Patterns

Salvage of young delta smelt at the SWP and CVP Delta fish facilities begins to be quantified each spring when the smelt reach a salvageable length of about 25 mm. Salvage continues into the summer until delta smelt residing in the Delta either: (1) move downstream away from the influence of the Delta export facilities; (2) maintain a position in an area of negative net flow thereby avoiding adverse environmental in the south Delta; or (3) are eventually entrained into the facilities. Obviously, natural mortality also affects the abundance of young delta smelt, but the three outcomes listed here are inferred from the observation that salvage eventually declined during the summer in 1996 and 1999 (Table 2) despite high values of negative central Delta flow (Figures 2B, 2D). Overall, delta smelt salvage at the SWP and CVP fish facilities was much lower and occurred for a shorter period in 1996 than in 1999.

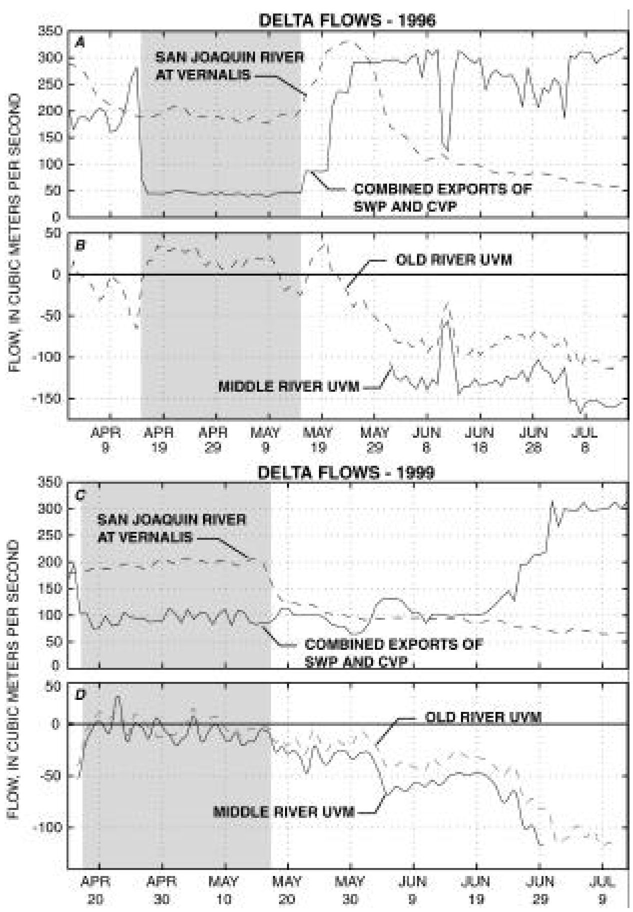


Figure 2 Delta daily and tidally averaged flows and VAMP periods (shaded in gray) for spring 1996 and 1999.

Table 2 Expanded combined monthly delta smelt salvage at the Delta facilities, May through August, 1996 and 1999

Month	*1996*	*1999*
May	30,099	58,943
June	9,465	73,368
July	148	20,272
August	0	48

Pattern of Apparent Delta Smelt Recruitment and Rearing

Delta smelt recruitment from egg to juvenile stages is not monitored in a rigorous manner. The best information we have to track recruitment patterns is length frequency data from the 20-mm Survey. Delta smelt length is a good proxy for age, at least up to 30 mm (Grimaldo and others 1998). However, the survey length frequencies are subject to severe gear bias. As its name implies, the 20-mm Survey is most effective at capturing delta smelt around 20 mm TL. The gear also collects smaller and larger smelt, but it does not provide accurate estimates of abundance relative to 20-mm smelt. Therefore the discussion below should be considered a description of “apparent” patterns of delta smelt recruitment to a size where they are susceptible to the 20-mm gear.

One of the major differences between the 1996 and 1999 salvage patterns was the length of time delta smelt salvage remained at high levels (see Table 2). This was obviously due in part to the extended delta smelt recruitment period described in more detail below. Specific factors that influence delta smelt recruitment have not been thoroughly examined. More research emphasis has been placed on understanding surrogate variables like X2 (Jassby and others 1995). Here we attempt to provide some new insight into these subjects by discussing the 1996 and 1999 recruitment and rearing patterns relative to X2, the interplay of salinity and water temperature, and Delta hydrodynamics.

In 1996 the 20-mm Survey revealed a conspicuous large recruitment of delta smelt, particularly during surveys 3 and 4 (Figure 3A). Smaller peaks during surveys 4 and 5 are noticeable, but relatively few fish less than 20 mm were collected by survey 6, suggesting a cessation of spawning or recruitment through the early larval stage sometime before that survey.

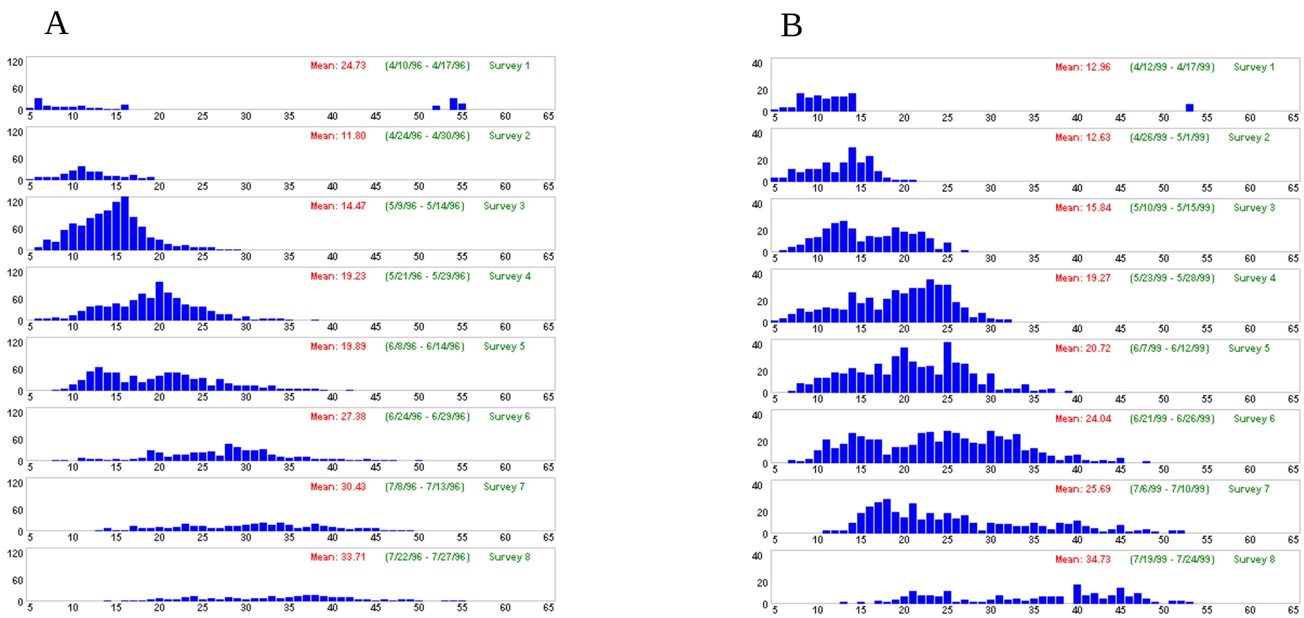


Figure 3 Delta smelt length frequency distributions from 20-mm surveys 1 through 8; (A) 1996 and (B) 1999

The apparent recruitment pattern was noticeably different in 1999 (Figure 3B, note the change in y-axis scale). There were multiple small peaks that are difficult to differentiate among surveys. Peaks in the number of fish less than 20 mm of comparable magnitude to the earlier surveys continued through surveys 6 and 7, suggesting modest levels of successful recruitment occurred through spring and into early summer in 1999. This protracted period of apparent recruitment resulted in a longer period of susceptibility to export entrainment for delta smelt in 1999 compared to 1996.

Delta Smelt Distribution Patterns Relative to X2 in 1996 and 1999

Delta smelt survival is weakly related to the position of X2, the distance upstream from the Golden Gate of the 2 psu isohaline (Moyle and others 1992; Sweetnam 1999). X2 is thought to be a surrogate for several factors important to delta smelt survival, including increased freshwater habitat area, increased transport to favorable habitat, decreased influence of water diversions, and at least historically, increased food availability (Bennett and Moyle 1996). Conditions are thought to be more favorable for delta smelt as X2 assumes a location farther downstream in Suisun Bay. Generally, X2 was farther downstream in 1996 than 1999 between April and July (Figure 4). However, most of the time the differences were fairly small. For example, during the VAMP periods in 1996 and 1999 (approximately mid-April through mid-May each year), the maximum differences in X2 position were about 2 km, a distance equal to about 10% of the length of Suisun Bay.

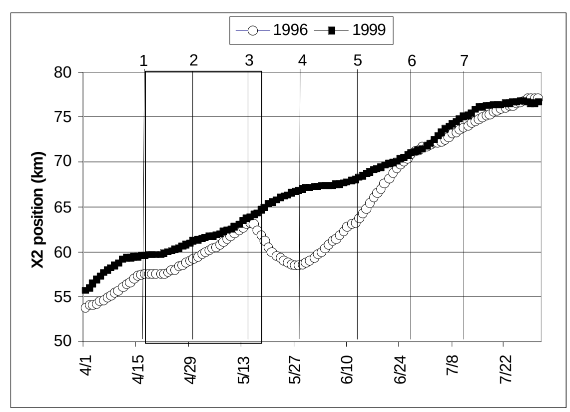


Figure 4 Daily X2 position, April 1 through July 31, 1996 and 1999. VAMP period shaded in gray.

More substantial differences in X2 position (up to 8.4 km) occurred during the month following the VAMP periods in 1996 and 1999 (Figure 4). The 1996 and 1999 20-mm Survey results from surveys 4 and 5 (Figures 5D, 5E and 6D, 6E, respectively) correspond to the period of these larger differences in X2 position between 1996 and 1999.

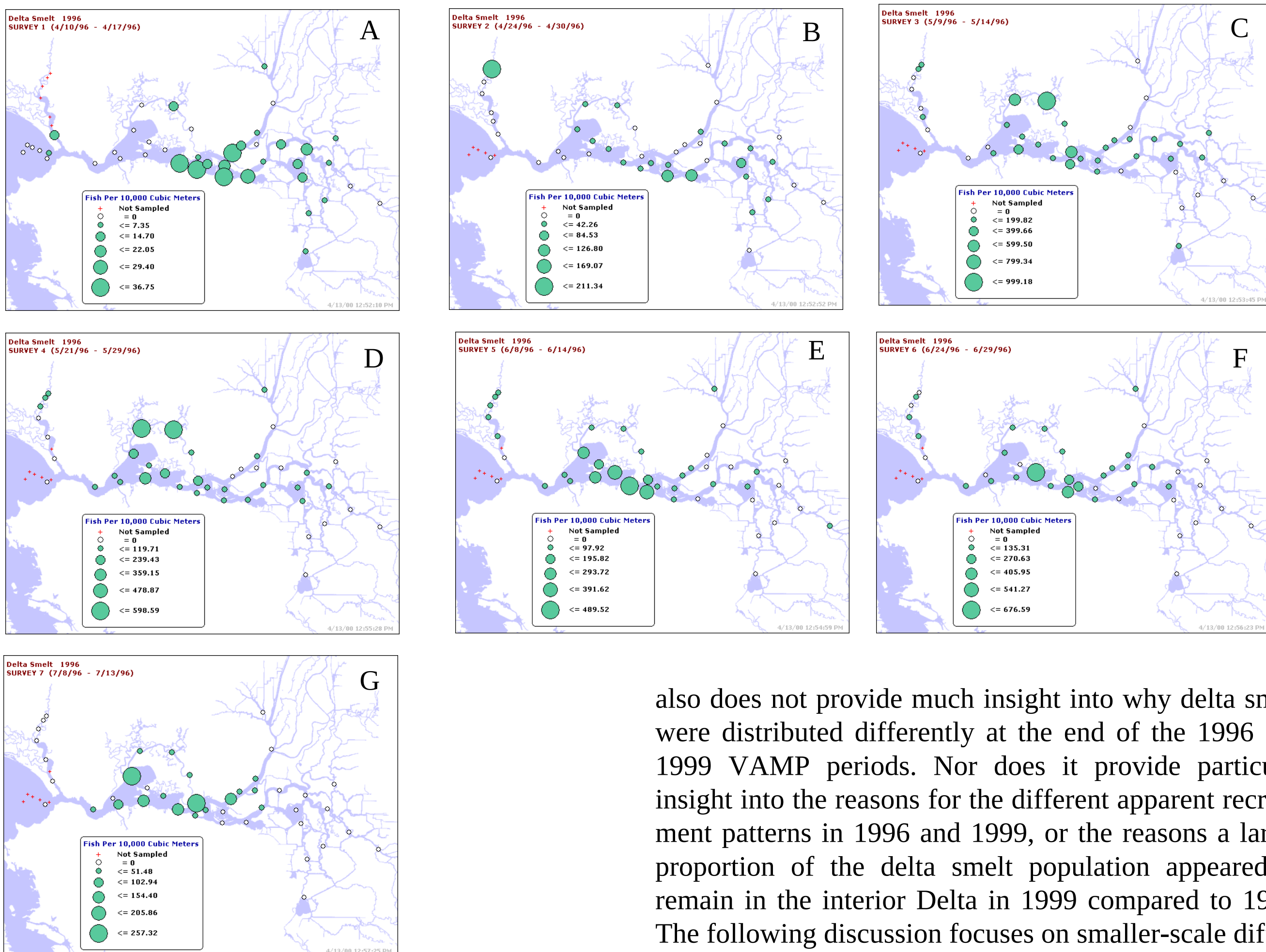


Figure 5 Delta smelt distribution from 1996 20-mm Surveys 1 through 7 (A through G)

The differences in the delta smelt distribution between surveys 4 and 5 in 1996 and 1999 reflect the differences in isohaline position; more delta smelt were distributed somewhat farther downstream in 1996 as was X2.

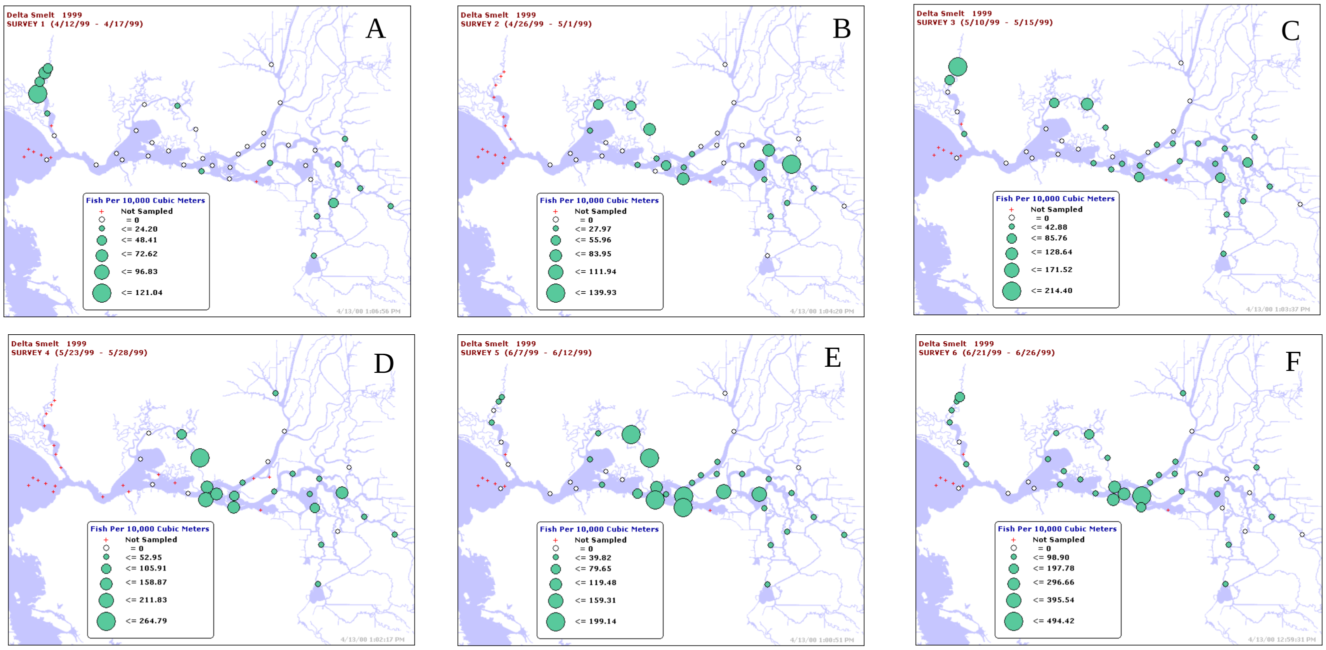
In 1996 and 1999 X2 position was very similar in late June and early July (Figure 4) during 20-mm Surveys 6 and 7 (Figures 5F, 5G, 6F, and 6G), corresponding to a position in the vicinity of Chipps Island. Not surprisingly, the distribution of the delta smelt covered similar ranges during this time. Peak abundance occurred at different stations during 20-mm surveys 6 and 7 in 1996 and 1999, but some interannual variation is expected.

Despite, the potential utility of X2 as an indicator for delta smelt distribution, it does not correlate well to delta smelt abundance (Jassby and others 1995). X2 by itself also does not provide much insight into why delta smelt were distributed differently at the end of the 1996 and 1999 VAMP periods. Nor does it provide particular insight into the reasons for the different apparent recruitment patterns in 1996 and 1999, or the reasons a larger proportion of the delta smelt population appeared to remain in the interior Delta in 1999 compared to 1996. The following discussion focuses on smaller-scale differences between 1996 and 1999 regarding the interplay of salinity, temperature, and Delta hydrodynamics to provide more insight into the factors affecting young delta smelt recruitment and rearing.

Recruitment Patterns Relative to Smaller-scale Physical Conditions in 1996 and 1999

Several studies examining larval fish recruitment through cohort analysis have found water temperature is a major determinant of cohort survival (Betsill and Van den Avyle 1997; Michaletz 1997; Secor and Houde 1995). Cohort analyses for delta smelt are underway (Dr. Bill Bennett personal communication, see "Note"), but here we look for evidence of temperature relationships using the DFG 20-mm Survey data.

We emphasize this is a less satisfactory method to the more direct cohort analysis approach.



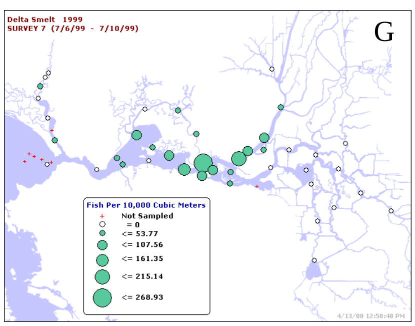


Figure 6 Delta smelt distribution from 1999 20-mm Surveys 1 through 7 (A through G)

With the exception of the Napa River, water temperatures were warmer in all survey areas during the first 20-mm survey in 1996, suggesting an earlier warming of the Delta relative to 1999 (Table 3). Appropriate temperatures system-wide could have prompted spawning over a wide area early on in 1996 (Figure 5A), potentially contributing to the large early season spawning peak (see Figure 3A). In 1999, comparably warm temperatures were only recorded in the Napa River, where the highest densities of smelt larvae were observed during the first 20-mm survey (Figure 6A). These findings suggest a potential relationship between water temperature and delta smelt recruitment past the larval stage. The critical temperature appears to be about 15 °C, even though larvae have been reported at considerably lower water temperatures (Wang 1986). A similar result was reported for threadfin shad (Betsill and Van den Avyle 1997). Larvae were first observed in Missouri reservoirs at temperatures as low as 15 °C, but cohort survival was poor until temperatures reached about 22 °C.

Table 3 Comparison of 1996 and 1999 mean water temperatures and standard deviations by region [a]

Region	*April 10–17, 1996*	*April 12–17, 1999*
Napa River	15.5 (*n* = 1)	16.3 " 0.8
Suisun Bay	16.9 " 1.2	14.8 " 0.6
Confluence	15.5 " 0.5	13.8 " 0.8
Central Delta	16.1 " 0.3	12.2 " 0.3
South Delta	17.9 " 0.2	13.2 " 1.1

[a] Data taken from 20-mm Survey 1.

The extended recruitment period in 1999 may have also been temperature-related. Larval threadfin shad survival (Betsill and Van den Avyle 1997) and larval striped bass mortality (Secor and Houde 1995) were both described as quadratic functions of temperature, where survival was lower (or mortality higher) on either side of an optimum temperature range. Average water temperature data collected during the 20-mm Survey indicate 1996 and 1999 went back and forth regarding which year had the cooler temperatures (Table 4). However, the rapid warming of Delta waters between surveys 4 and 5 in 1996 may have been sufficient to cause the cessation of spawning (or may have substantially reduced egg and larval survival). This relationship between recruitment and water temperature is speculative and should be researched further. Other factors, like food availability, may also have contributed to the recruitment differences between 1996 and 1999; however, sufficient comparative data on other environmental factors were not available.

Table 4 Average surface water temperatures and standard deviations from all stations sampled during the 20-mm Surveys 3 through 6, 1996 and 1999

Survey Number (Month)	*1996*	*1999*
3 (May)	19.1 " 1.1	16.5 " 0.7
4 (May)	16.9 " 1.4	18.7 " 1.4
5 (June)	22.0 " 1.5	18.5 " 1.1
6 (June)	20.4 " 1.7	21.5 " 1.6

Young Delta Smelt Rearing Relative to Smaller-scale Physical Conditions in 1996 and 1999

Grimaldo and others (1998) found a significant positive relationship among the age, size, and location of young delta smelt collected in 1996. Older, larger individuals were found in greater proportions in Suisun Bay, while size and age declined among delta smelt collected farther upstream. These results suggest rearing delta smelt actively seek specific habitat conditions as they grow. Grimaldo and others (1998) hypothesized the older smelt were seeking a particular salinity range. As discussed in the X2 section, the position of the low salinity zone is thought to be a major environmental factor affecting juvenile and pre-spawning adult delta smelt distribution (Moyle and others 1992; Sweetnam 1999). However, the possibility of ontogenetic changes in delta smelt's response to factors influencing distribution has not been explicitly studied.

Like all osmerids, the delta smelt is a cool water fish. Moyle and others (1992) reported that it was not collected in the field at temperatures over 23 °C. Its critical thermal maxima are lower than that of chinook salmon and are affected by salinity (Swanson and Cech 1995). Delta smelt tolerated slightly higher water temperatures at 4 ppt than at zero salinity. It would be worthwhile to study the interplay between salinity and temperature further, especially as they relate to conditions occurring in the Delta.

In an initial attempt to investigate the interplay between salinity and temperature, we used delta smelt relative abundance anomalies calculated from 20-mm Surveys 3 through 6 in 1996 and 1999. We used surveys 3 through 6 because these were the surveys that had average delta smelt lengths closest to 20 mm, hopefully reducing size bias due to gear selection. The anomalies were calculated by subtracting the average delta smelt density (number of fish per 10,000 m^3 of water) at all stations sampled for each survey, from the density at each individual station (similar to Obrebski and others 1992). Values greater than zero indicate above average relative abundance and provide a means of assessing the environmental conditions present where higher than average delta smelt abundance was recorded.

The delta smelt abundance anomalies relative to log-transformed specific conductance are shown in Figure 7. Although higher than average relative abundance of delta smelt was occasionally found where surface specific conductance corresponded to salinity greater than 6 ppt (log specific conductance > 4) (Napa River), almost 90% of the positive anomalies were recorded from stations where the surface specific conductance corresponded to a salinity of less than 1 ppt (<3.2 log specific conductance). It is very likely that surface and bottom specific conductance (which was not measured) were different at many of these sites. However, this principally freshwater distribution suggests the possibility that delta smelt may not require, or even be seeking, brackish water habitat this early in their life cycle.

The anomalies also show an interesting pattern in relation to water temperature (Figure 8). In all but one survey in 1996 and 1999, the distribution of positive anomalies is "bounded" between 16 °C and 24 °C (60.8 °F and 75.2 °F), with evidence of a time trend in 1999. In 1999, positive anomalies from the earliest survey (3) are skewed toward the warmer temperatures sampled, while positive anomalies from survey 6 are skewed toward the cooler temperatures sampled. Positive anomalies from the middle two surveys all fall within the range defined by surveys 3 and 6. The trend is less evident in 1996 because water temperatures were cooler during survey 4 than survey 3. Nonetheless, the positive anomalies are still generally bounded as described for 1999. This suggests delta smelt may seek a fairly narrow temperature range.

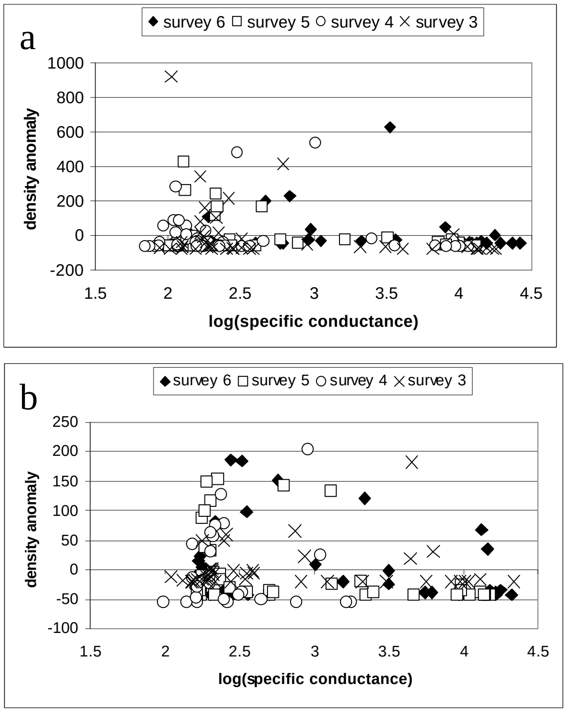


Figure 7 Log_{10}(surface specific conductance) versus anomalies of delta smelt relative abundance from 20-mm Surveys 3 through 6, (a) 1996 and (b) 1999

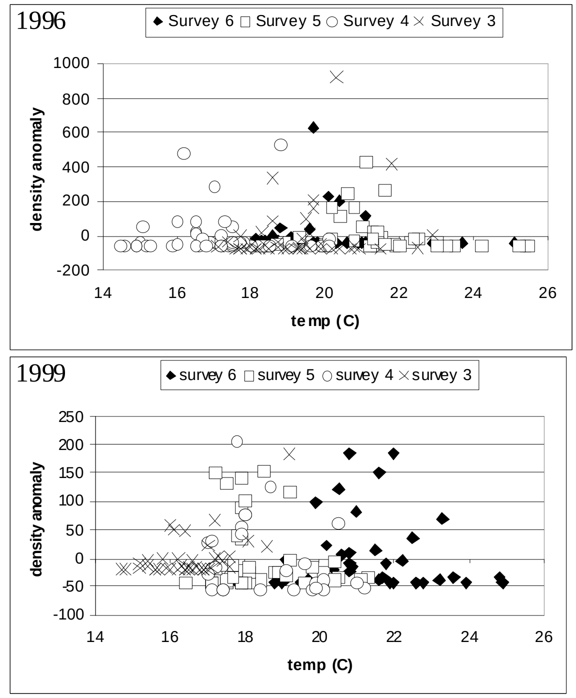


Figure 8 Surface water temperatures versus anomalies of delta smelt relative abundance from 20-mm Surveys 3 through 6, 1996 and 1999

This analysis could be biased by project operations since the warmest temperatures were usually recorded in the south Delta. Nonetheless, Swanson and Cech's (1995) research suggests a limit should be expected near the mid-20s (°C), since it is reasonable to expect fish leave areas near lethal temperatures.

Delta Hydrodynamics

We also think the differences in 1996 and 1999 salvage patterns were partly due to differences in Delta hydrodynamics, particularly differences associated with the VAMP. There are three remarkable hydrodynamics-salvage phenomena. First, there were clear differences in central Delta flows during the 1996 and 1999 VAMP periods. Second, there were clear differences in the export ramp-up following the VAMP pulse flow periods that resulted in relatively rapid increases in negative central Delta flow in 1996 compared to 1999. Again, this occurred despite an X2 position that was farther downstream in 1996 compared to the equivalent period in 1999. Third, peaks in salvage density corresponded to abrupt changes in central Delta flows.

As stated above, San Joaquin River inflow was slightly higher during much of winter and spring 1996 compared to 1999, and 1996 had a late May pulse flow which did not occur in 1999. However, potentially important details of how inflow to the Delta translates into Delta outflow can be clouded by the proportion of flow coming from the Sacramento and San Joaquin basins and by the level of water project exports. The tidally-averaged UVM central Delta flow data (Figures 2B, 2D) are a direct measure of flow at the Old and Middle river stations adjacent to Bacon Island and, therefore, provide an unambiguous measure of Delta hydrodynamics.

The USGS UVM data show an interesting contrast between the VAMP periods in 1996 and 1999. Central Delta flow (only data from Old River UVM available for 1996) was typically positive during the VAMP period in 1996 (Figure 2B), but fluctuated around zero during the 1999 VAMP period in Old River, to slightly negative values in Middle River in 1999 (Figure 2D). These differences were primarily due to lower export levels during the VAMP period in 1996 compared to 1999 (Figures 2A, 2C). The proportion of larvae successfully spawned in different regions of the estuary is unknown, but presumably positive Delta flow in 1996 would have helped move larvae spawned in the central and south Delta farther downstream. The 20-mm survey data from 1996 and 1999 appear to support this hypothesis. The timing of 20-mm Survey 3 approximately corresponded to the end of the VAMP periods in both 1996 and 1999. The results from the third survey for each year (Figures 5C, 6C) show a substantially greater proportion of the delta smelt population was located at or downstream of the confluence in 1996 (93%) than in 1999 (68%).

There is a second important hydrodynamic contrast illustrated in the central Delta flow data. The increase in San Joaquin River flow following the 1996 VAMP only briefly maintained positive values of central Delta flow because of the relatively rapid export ramp-up (Figures 2A, 2B). By the first week of June, negative central Delta flows were at levels not observed in 1999 until July (Figure 2D). Thus, if larvae hatched in the interior Delta after the 1996 VAMP period, they would have likely been entrained to the facilities before reaching a size they would be counted (25 mm). This may not have been the case in 1999. The lower magnitude of negative central Delta flow (Figure 2D) combined with a protracted period of recruitment are thought to have allowed more delta smelt to rear in the central and south Delta up to and beyond 25 mm TL. The net result was an extended period of high delta smelt salvage.

Additional evidence to support our hypothesis is provided by the work of Grimaldo and others (1998), who calculated the ages of delta smelt collected during 20-mm Surveys 7 and 8 in 1996. A re-analysis of these data indicates 62% of delta smelt collected in these surveys were born during the VAMP period when Delta exports were low (Figure 9). Keep in mind that by surveys 7 and 8 most delta smelt had grown too large to be sampled effectively by the 20-mm gear; thus the proportion of fish born before and during VAMP is seriously underrepresented in this analysis.

Comparison of salvage and flow data also shows peaks in delta smelt salvage density coincided with abrupt changes in central Delta flow. In 1996, salvage density (Figure 10A) showed one distinct peak during mid-May that coincided with the installation and removal of the head of Old River barrier. Installing the barrier changed the flow direction in Old River. Most of the time however, salvage density was #1 smelt/10,000 m^3 because most of the young smelt were located in downstream habitats by this time (Figure 5C).

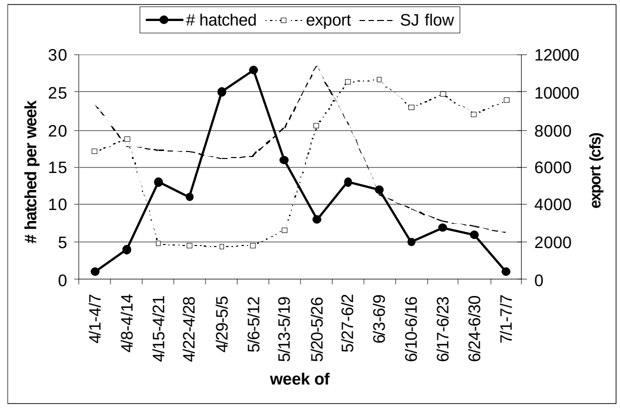


Figure 9 Estimated number of delta smelt hatched per week, San Joaquin River flow at Vernalis, and combined Delta exports, April 1 through July 7, 1996

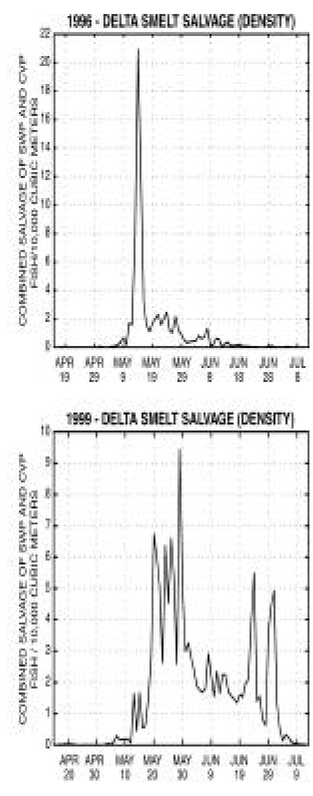


Figure 10 Expanded combined SWP and CVP salvage of delta smelt per 10,000 cubic meters of water exported from April through July in 1996 and 1999

This contrasts with 1999 when salvage density remained $2 smelt/10,000 m^3 for most of a 50-day period from mid-May to early July (Figure 10B). As in 1996, the peaks in salvage density in 1999 were associated with changes in Delta hydrodynamics. The first large peak in salvage density occurred after the VAMP period, when central Delta flow became consistently negative as a result of the decrease in San Joaquin River flow (Figures 2C, 2D). Salvage density actually declined during the next increase in negative central Delta flow, but increased again when exports were quickly ramped up at the end of June.

An estimated 48,780 delta smelt were salvaged during the last week of June and first week of July 1999. This was the last large young delta smelt salvage event of the season and it primarily occurred in between 20-mm Surveys 6 (June 21 to 26) and 7 (July 6 to 11). As stated above, increasingly negative central Delta flow during summer means there are basically two kinds of young delta smelt —those that move (or stay) downstream away from the influence of the export facilities, and those that will eventually be entrained to the facilities (the minority in both years).

During Survey 6 in 1999, some delta smelt were collected from Franks Tract and stations 915 and 910 in the south and east Delta respectively (see Figure 6F). By Survey 7 (see Figure 6G), no delta smelt were collected from the San Joaquin system upstream of Sherman Island. The UVM velocity data were used to estimate that during this period, water could travel from Frank's Tract to the export facilities in about two days. We think the late June and early July 1999 salvage event represented the removal of delta smelt that remained in the interior Delta beyond survey 6.

SUMMARY AND CONCLUSIONS

Moderate winter and spring San Joaquin River flow may provide attractive conditions for spawning adult delta smelt. The presence of high numbers of adults in the DFG spring midwater trawl surveys in 1996 and 1999 relative to other years suggests this is the case. So far in 2000, San Joaquin River flows have been similar to 1996 and 1999, and we expect to see that substantial delta smelt spawning in the central and south Delta.

Our re-analysis of the 1996 and 1999 delta smelt salvage patterns suggests differences in salvage were due to the interaction of two main factors: (1) a relatively long apparent recruitment period in 1999 relative to 1996; and (2) differences in VAMP and post-VAMP hydrodynamics within the interior Delta, which probably facilitated the retention of a larger proportion of the smelt population in 1999.

We are not certain what factors contributed to differences in the apparent recruitment patterns of delta smelt observed between 1996 and 1999; however, we think water temperature differences and central Delta flow differences were important factors. Water temperature and environmental factors other than flow cannot be effectively managed. However, Delta hydrodynamics can be managed. San Joaquin River flow forecasts for 2000 are very similar to both 1996 and 1999, about 200 m^3/s. As stated above, the differences in central Delta flows between 1996 and 1999 were primarily due to different levels of project exports. Preliminary modeling results from the DWR Technical Modeling Group (not shown) predict the central Delta flow pattern for the 2000 VAMP period will resemble the 1999 pattern. In other words, the tidally-averaged central Delta flows are forecast to be near zero to slightly negative. We recommend maintaining project exports during the VAMP to achieve sustained positive central Delta flows. Positive central Delta flows should help move larvae that hatch in the central and south Delta downstream away from the influence of the export facilities once pumping resumes at the end of the VAMP period.

Comprehensive analyses like the one presented in this paper are limited by the available data. These limitations could be substantially reduced with a more comprehensive monitoring program and new research elements designed to improve our understanding of delta smelt recruitment dynamics (some of which is underway). Despite the large differences in salvage between 1996 and 1999, both years had similar summer tow-net indices, which were among the highest post-decline values. This further emphasizes the need to put research effort into understanding the factors influencing delta smelt recruitment. We suggest the following:

- Cohort analysis based on comparisons of delta smelt otolith microstructure from various surveys. Ideally, this would involve an egg and larval survey as well.
- Annual monitoring of feeding success.
- Studies to determine whether ontogenetic shifts exist in the delta smelt's response to factors influ-

encing distribution patterns. The interplay of salinity and temperature should be emphasized.

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NOTE

Dr. Bill Bennett. Bodega Marine Laboratory, University of California, Davis. E-mail communication with Matt Nobriga on April 5, 2000.

ERRATA

1999 FALL MIDWATER TRAWL SURVEY

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Two errors were discovered in the above-named article. This article was published in the winter 2000 issue of the *IEP Newsletter* (volume 13, number 1) and begins on page X. The correct paragraphs are provided below.

> YOY striped bass distribution began to concentrate in Suisun Bay from September through December increasing from 38% [incorrectly reported as 44%] to 92% in December.
>
> The distribution of American shad spread westward over time. The percentage of the index in San Pablo Bay increased from 6% [incorrectly reported as 1%] to 19% in December.

I apologize for any inconvenience that these errors may have caused.

A COMPARISON OF FALL STOCKTON SHIP CHANNEL DISSOLVED OXYGEN LEVELS IN YEARS WITH LOW, MODERATE, AND HIGH INFLOWS

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An error was discovered regarding the order of paragraphs within the above-named article. This article was published in the winter 2000 issue of the *IEP Newsletter* (volume 13, number 1) and begins on page 51. The incorrect sequence of paragraphs occurs in the section, "1997: A Wet Year with Moderate Fall San Joaquin River Flows." The correct paragraph sequence for this section follows. (This error has been also corrected in the on-line version of the *IEP Newsletter:* see the addendum at http://www.iep.ca.gov/report/newsletter/.)

1997: A Wet Year with Moderate Fall San Joaquin River Flows

> In 1997, average daily flows in the San Joaquin River past Vernalis approached 2,000 cfs in August and September and exceeded 2,000 cfs in October and November. Because of the relatively high average daily flows, the Old River closure was not installed due to overtopping, bank erosion, and other concerns. In spite of the relatively high flows in the San Joaquin River, average daily net flows past Stockton ranged from –466 cfs to +198 cfs in August and September, and reverse flows were not eliminated until early October when flood control related reservoir releases within the drainage basin of the San Joaquin River were initiated.
>
> Because of the relatively low inflows into the eastern channel, warm late summer and early fall water temperatures (22 to 27 °C), late summer and early fall reverse flow conditions past Stockton, and other factors, a dissolved oxygen sag also developed in the eastern channel in and immediately west of the Rough and Ready Island area (Stations 8 through 13) in August and persisted through early October (Figure 3). The lowest surface (3.1 mg/L) and bottom (2.6 mg/L) levels were measured at Buckley Cove (Station 10) on October 1, 1997.
>
> Cooler water temperatures in the channel on October 15 (17 to 19 °C) and in November (14 to 18 °C), improved fall flow conditions in the San Joaquin River, and the elimination of reverse flow conditions past Stockton on October 10 displaced the sag area westward on October 15 and gradually eliminated it in November. The lack of late fall rain in the San Joaquin River drainage basin delayed the full recovery of dissolved oxygen levels in the eastern channel to those historically measured in the western channel during November in previous years.

ANNOUNCEMENTS

IEP TECHNICAL REPORT 66 PUBLISHED IN APRIL 2000

Water, Salt and Nutrient Exchanges in San Francisco Bay by Steven V. Smith and James T. Hollibaugh was published as IEP Technical Report 66 in early April. The abstract of the report follows.

We constructed water, salt, and nutrient budgets for San Francisco Bay and used them to analyze the net biogeochemical performance of the bay. The bay was subdivided into three sectors, North Bay, Central Bay, and South Bay, with the Central Bay serving as a proxy for the "oceanic end-member." Separate budgets were constructed for the wet (October to March) and dry (April to October) seasons of each year for six years (1990–1995). This period of record contained two years of above normal runoff (1993 and 1995) and four years of below average runoff.

Sewage accounts for approximately 50% of the nutrient loading to the bay in winter and 80% of the summer loading. We conclude that overall the bay is slightly net autotrophic (production of new organic matter in the bay by plant growth exceeds respiratory demands); however, this varies seasonally (strongest in summer) and is complicated by abiotic P absorption in the North Bay. Both arms of the bay were apparently net heterotrophic during the winter, with this signal being strongest during the wet winters of 1993 and 1995.

We found the San Francisco Bay nutrient data set to be surprisingly sparse for the sort of biogeochemical mass balance analyses we performed. It would be highly desirable for future mass balance analyses and other geochemical modeling efforts to have better horizontal, vertical, and temporal resolution of bay water properties. The data that are available are minimal for defining the nutrient and salinity composition in the North Bay and for resolving weak horizontal gradients in the South Bay. Somewhat more detailed data on composition of freshwater reaching the bay (sewage, river, and possibly other sources) would be desirable, but better knowledge of the distribution in the bay is the critical weak point in the data.

Copies of the report may be obtained by contacting Randy Brown by phone or e-mail: (916) 227-7531 or rbrown@water.ca.gov.

A RECENT STUDY DISCOVERS A MORE EFFICIENT TRANSFER OF ENERGY WITHIN SUISUN BAY'S MICROBIAL LOOP

A study by James T. Hollibaugh and Patricia S. Wong titled, "Microbial Processes in the San Francisco Bay Estuarine Turbidity Maximum" was recently published in *Estuaries.* They found that the quality of material delivered to Suisun Bay by freshwater inflow is important. In particular, organic material delivered to Suisun Bay by freshwater inflow is significant in terms of the nutrition (as distinct from the carbon budget) of Suisun Bay. In this regard, their results complement the budget constructed by Jassby and others (1993).

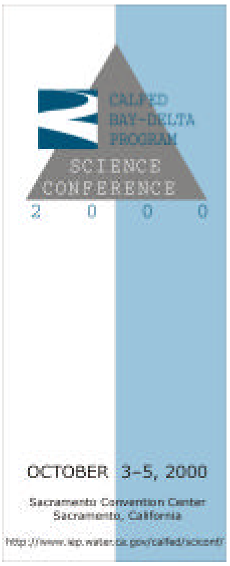
Bacterioplankton production was more closely related to the chlorophyll distribution than to salinity or particulate organic material concentrations, and the proportion of bacteria associated with particles in the estuarine turbidity maximum is much higher than earlier estimates (Hollibaugh and Wong 1996).

Since particle-associated bacteria are more readily available to grazers than free-living bacteria, metazoan grazers can directly consume a greater portion of the bacterial production, which results in a more efficient transfer of energy than would be expected from standard models of the microbial loop (Pomeroy 1974, 1980; Azam and others 1983; Dolan and Gallegos 1991; Davidson 1996).

Reprints of the journal article may be obtained by contacting Randy Brown by phone or e-mail: (916) 227-7531 or rbrown@water.ca.gov.

CALFED SCIENCE CONFERENCE UPDATE

Randy Brown, DWR
rbrown@water.ca.gov



The CALFED Bay-Delta Science Conference is a forum for presenting scientific information and ideas relevant to CALFED's goals and objectives in the San Francisco Bay, Delta, and watershed pertaining to ecosystem restoration, levee system integrity, and water quality.

The conference program will feature a mix of plenary and contributed talks and poster presentations on topical themes (listed in a recently published brochure, pictured at left) and on other relevant and timely subjects. The speakers will be scientists and engineers conducting technical studies that address CALFED topics of concern, regardless of funding source.

The primary goal of the conference is to make new information (results, models, syntheses) available to the broad community of scientists, engineers, and managers working on CALFED-related issues.

Session Titles and Session Chairs

Session Titles	*Session Chairs*
Bay-Delta Hydrodynamics	Jon Burau, USGS
Drinking Water Quality	Elaine Archibald, Consultant
Organic Carbon and Lower Trophic Level Processes	Jim Cloern, USGS Tim Hollibaugh, Univ. of Georgia
Fluvial Processes	Matt Kondolf, UC Berkeley
Invasive Species	Kim Webb, USFWS
Contaminants and Other Chemical Stressors	Val Connor, Regional Water Quality Control Board
Levee System Integrity	Lauren Hastings, CALFED
Salmonids	Randy Brown, DWR
Species of Special Concern	Bill Bennett, UC Davis Peter Stine, USGS

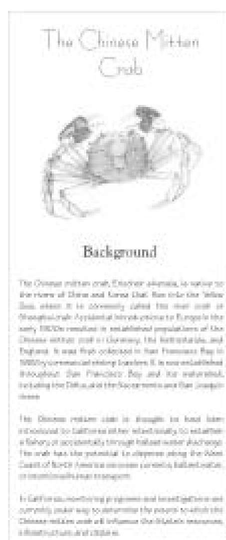
Please consider submitting an abstract through the website for oral or poster presentation (see address and specific information below.

A plenary session is being planned to include a presentation (or presentations) by members of CALFED's Interim Science Board (which includes Peter Moyle, Matt Kondolf, Bob Spies, and Wim Kimmerer from the local area) and a keynote talk by Marc Mangel (UC Santa Cruz) along the lines of "Why CALFED needs Ecological Detectives."

For registration and abstract information access the website at http://www.iep.water.ca.gov/calfed/sciconf/. For updates, please check the website. A second brochure with program details will be available in early August. For questions about the technical program contact Bill Bennett at UC Davis (smelt@monitor.net) or Larry Brown at the USGS (lrbrown@usgs.gov). For registration and other questions contact Heather Bowman at the San Francisco Estuary Project (510) 622-2465.

CHINESE MITTEN CRAB INFORMATION PAMPHLET

Tanya Veldhuizen, DWR
tanyav@water.ca.gov



The IEP published a public information pamphlet on the Chinese mitten crab in March 2000.

The pamphlet contains basic information on the crab's introduction to California, its life history, identifying characteristics, and current and potential effects in California.

In particular, effects on public health, agriculture, infrastructure, the ecosystem, and fisheries are presented. The same information will be available on the IEP website.

For copies of the pamphlet, please contact Tanya Veldhuizen by e-mail at tanyav@water.ca.gov.

To the Managing Editor: A Man for All Seasons

California's representative to the western regional panel for aquatic nuisance species. Member of the scientific oversight team for CALFED. Have you figured out who we are talking about to yet? No. Okay, a couple more hints…Chief Biologist and Interagency Ecological Program Coordinator. Have you got it yet? Okay, one final hint: Chief of the Environmental Services Office. You've got it figured out now, right? Yes, we're talking about Dr. Randall Brown. If you haven't heard yet, Randy is retiring soon. This issue of the *IEP Newsletter* will be his last one as managing editor. However, we hope that he will contribute more articles for future issues.

Below we express our sincere thanks and best wishes to Randy and his family—we will miss him and his steadfast leadership. In the following pages you'll be sure to find some thoughts (and pictures) that paint a more vivid picture of Randy, a man for all seasons.

To Randy:

"So long...and thanks for all the fish"

From

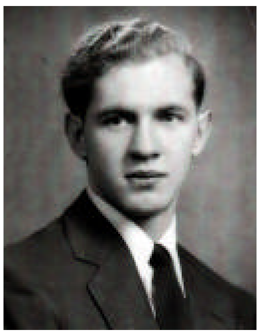
The Environmental Services Office

(and many others)

Odes to Randy Brown

What should be said about the person who has led IEP and much of the fisheries community of the estuary and Central Valley for more than 30 years? The following are a few, heavily plagiarized verses read at the environmental specialists' retreat at Fallen Leaf Lake in 1999: the young "pelicans" in attendance gave Randy quite an ovation. Although these lines only characterize Randy Brown as boss and mentor, they also describe other aspects of his personality that influence his other activities and hint at some qualities of his leadership. Randy demanded a lot from his staff and could always find value in everyone. We and the "water buffaloes" will miss his leadership, at least until he agrees to assume a new role. Meanwhile... Randy, thank you.

Larry Smith



Brownsong

If I were as wise
as many have said,
I would be more nice.
I'd be in my bed.

But I'm not in my bed;
I'm prowling the hall.
So staff be aware,
I'm not *that* wise after all.

Oh Please Take Me Fishing

Oh please take me fishing,
oh please, pretty please,
insisted my ES the pest.
He drives me bananas
when he's at his worst;
he bugs me when he's at his best.

He wouldn't give up
so I've brought him along,
but I've not decided his fate.
Maybe I'll patiently teach him to fish;
maybe I'll use him for bait.

Of course, Randy has spent many extra hours at the office and thus not enough hours fishing. What the verses don't say is how much more he demands of himself than of his staff.

Randy is a frugal person, a trait born of the realities faced by many families during and after the depression. This trait is unusual in the herd of water buffaloes with whom Randy has so often dealt. One rude remark about biological brotherhoods notwithstanding, Randy enjoys singular respect and recognition within the herd.

Randy B.

I'm so partial to Randy B.
who emanates no vanity.
He works amongst
charging buffaloes
but hasn't a single enemy.

Finally is a verse about his mentorship, the bird species being *Pelecanus occidentalis californicus*, of course.

A Pelican

A pelican uses
its steam-shovel bill
to gather more fish
than can possibly fill
its own hunger wish.

It's not out of greed.
That bill is a trough in
wheresoever often
young pelicans feed.

Some Musings on the Brown

Who is this Dr. Randall Brown, the Chief Biologist for the Department of Water Resources? Do I know him? Probably not very well; but this is what I know *of* him:

- He is a simple person; unpretentious. What you see is what you get. I have never seen him in fancy clothes (only in his wedding picture—even then, that was a tie and white shirt only). I have only seen him twice with a tie—once at a State Board hearing (and never again did he do that) and the second time when he received an award from UC Davis.

- However, be careful not to underestimate him. You only do it once—if you're smart. If you are intelligent, you don't do it at all.
- He enjoys simple pleasures; spicy food, poker, pool, wine (he thinks Merlot is trendy and over-rated) and beer (never offer him a flavored beer. It might be reflected on your A&D).
- He is successful because he is curious; wants to understand why things work the way they do, and is not afraid to ask questions. He is apt to pull groups of people together to search for practical answers to vexing questions.
- He is successful because he sticks to it. It's almost like he dabs a bunch of glue on his chair and on the seat of his pants and stays working until he is done with the job.
- He's not a pussycat. I have seen him get mad; it's not a nice sight. Face gets red, room gets warm, your adrenaline starts pumping. The flee instinct overrides any other instinct. Unfortunately, the door is narrow and his windows don't open.
- He doesn't like big words or complicated answers. I've tried it…that's when he gets mad.
- He is comfortable to be around with. You can share ideas with him—or ask his advice. I have not been steered wrong.
- For an old guy (sorry Randy), he is quite young. Likes new ideas; is receptive to change; listens well—even if you don't think he has heard you. Willing to eat many different kinds of foreign and exotic foods—even stuff I wouldn't touch. (Just don't offer him honey-flavored beer.)
- He is well respected in the science and water community, including those who don't agree with him. He is not afraid to speak the truth as he sees it—to his staff or to the Director—as he has done frequently.

There are many other things I could say about the Brown, but for his sake and because he always stressed brevity, I will keep this brief. Suffice it to say his family will be glad to have him back again. I, on the other hand, will miss him—his guidance and presence. I know the Department will also. Take care, Dr. Brown.

Leo Winternitz

■ Interagency Ecological Program for the Sacramento–San Joaquin Estuary ■

IEP NEWSLETTER

3251 S Street
Sacramento, CA 95816-7017

For information about the Interagency Ecological Program, visit our Internet site (http://www.iep.water.ca.gov). Readers are encouraged to submit brief articles or ideas for articles. Correspondence, including submissions for publication, should be addressed to Dr. Randall L. Brown, California Department of Water Resources, 3251 S Street, Sacramento, California, 95816-7017.

■ Interagency Ecological Program for the Sacramento–San Joaquin Estuary ■

IEP NEWSLETTER

The Interagency Ecological Program for the Sacramento–San Joaquin Estuary
is a cooperative effort of the following agencies:

California Department of Water Resources
State Water Resources Control Board
US Bureau of Reclamation
US Army Corps of Engineers
California Department of Fish and Game
US Fish and Wildlife Service
US Geological Survey
US Environmental Protection Agency

National Marine Fisheries Service

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