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

IEP NEWSLETTER

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OF INTEREST TO MANAGERS

Randall Brown, DWR, rbrown@water.ca.gov

- **IEP Program and Budget**

  Chuck Armor (DFG, page 11) describes the results of the IEP Directors' October meeting at which the proposed 2000 program and budget were approved.

- **Fall Midwater Trawl Indices**

  Russ Gartz (DFG, page 5) presents the results of the 1999 fall midwater trawl surveys. The fall delta smelt index of 864 was the eighth highest of record. On the other hand, the striped bass index of 541 was among the lowest of record.

- **Mitten Crab**

  Tanya Veldhuizen (DWR, page 14) describes the results of a visit to the Bay-Delta by a chinese mitten crab expert, including his observations on what we might expect from this asian interloper.

- **Freshwater Flows and Salinity**

  Noah Knowles (Scripps, page 15) reports on the use of a numerical salinity model to examine the effects of Delta diversions and upstream impoundments on Delta salinity and location of X2, He found that, on average, human impacts were greatest in May but there was considerable interannual variation.

- **Abundance Trends of Introduced Centrarchids and a Native Perch**

  On page 23, Matt Nobriga (DWR) and Mike Chotkowski (USBR) discuss preliminary results of their analyses of historical fish salvage data and beach seine data sets. Indications are that the abundance of several introduced centrarchids (blackbass and sunfish) is increasing while the native Tule perch is decreasing in abundance.

- **Thoughts on a New Delta Smelt Summer Abundance Index**

  Lee Miller (DFG, page 37) recommends use of a new delta smelt summer index based on delta smelt catch in the summer townet survey and the timing of striped bass indexing as a surrogate for seasonal variation in spawning conditions. A weak correlation between the new index and fall midwater trawl index suggests it may be a better estimate of summer smelt abundance.

- **Delta Smelt Culture**

  Joan Lindberg, Brad Baskerville-Bridges, and Serge Doroshov (UC Davis, page 45) provide an update on delta smelt culture and larval feeding behavior. They have found that successful culture through the larval stage was the largest challenge due to the delicate nature of the larvae and the long larval stage. Although it has some problems (disease for example), use of Delta water in a circulating system seems to be critical for early larval development. The researchers also found that turbidity (either planktonic algae or inorganic particles) and adequate levels of zooplankton were necessary for first feeding.

REAL TIME MONITORING

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The RTM project work team (PWT) met in September and December to discuss the first and second drafts of the "Programmatic Review of the 1996–1999 Spring Real Time Monitoring Program in the Sacramento/San Joaquin Delta." A final draft will be reviewed by the PWT at its January meeting with the goal of having the program ready for April. There has been a large turnover in core staff for the RTM program at DFG's Central Valley Bay-Delta Branch. Kevan Urquhart transferred from the Delta Fish facilities Operations and Monitoring Program to supervise the Estuarine Monitoring Program that includes RTM. Kevin Fleming, formerly in the position of RTM and Bay Study Associate Biologist, transferred to the Associate Fishery Biologist position with the Delta Smelt Project, and Range B Biologist Doug Killam left for a position in DFG Region 1 in August. Both the latter positions are still vacant, but should be filled in January.

1999 FISH TREADMILL PROJECT FIELD COLLECTIONS

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Field collections for delta smelt used in fish performance experiments at the UC Davis Fish Treadmill began in late September and ceased in early December 1999. A small purse seine was the primary method of collecting delta smelt. This was the same method used in previous collections in 1997 and 1998. A small number (23 of 175) of sets was made with a Lampara net. UCD Fish Physiology staff provided staff training and oversight on fish handling, fish transport, and laboratory acclimation.

More delta smelt were collected in 1999 than in 1997 and 1998 combined. More than 3,500 delta smelt were caught in 1999 compared to 1,700 in 1997 and 1,500 in 1998. Mean catch per unit effort in 1999 (23 fish/set) was more than five times that in 1998 (4 fish/set). Most of the delta smelt were collected in the Sacramento River near Sherman Island. Due to the fishing success this year, sampling was suspended early when the target number of fish was obtained.

YOLO BYPASS STUDY

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In November 1999, we began testing a large cylindrical fyke trap in the Yolo Bypass Toe Drain with the main objective to test the feasibility of catching adult fish. In addition, we hope to examine adult species composition and the timing and duration of fish migration into the Yolo Bypass relative to different physical conditions. To the extent possible, we will also compare the timing and duration of species captured in the Yolo Bypass to those captured in other Sacramento Valley tributaries. The focus will be on anadromous fish species; however, data will be collected on other fish.

The fyke trap is about seven meters long, three meters in diameter, and is constructed of chain-link fence material stretched around a steel frame. The terminal chamber of the trap is lined with 20-mm square plastic mesh. The trap is anchored and accessed using a series of cables and a truck-mounted winch. One trap was installed at the lower end of the Yolo Bypass Toe Drain and will be operated through March 2000. The DFG's Central Valley Bay-Delta Branch office loaned the trap. This season, fyke trap sampling in the Yolo Bypass will be completed in conjunction with rotary screw trap and beach seine sampling.

So far the fyke trap has proven easy to use, and no fish mortality has been observed. Native fish catch in November and early December included five adult chinook salmon (mean fork length 697 mm), two Sacramento suckers (mean fork length 506 mm), and two Sacramento blackfish (mean fork length 410 mm). Somewhat surprising was the number and size of adult striped bass: 77 striped bass (mean fork length 584 mm) were captured. Other species captured include black crappie, carp, threadfin shad, and white and channel catfish. With appropriate hydrologic conditions, we expect to catch splittail and sturgeon as well.

UPDATE ON CHINESE MITTEN CRAB ULTRASONIC TELEMETRY STUDY

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Field trials of ultrasonic tagged mitten crabs were carried out in three phases starting in mid-October and continuing in November.

For Phase I, tagged crabs (five males and five females) were released October 14 in Old River (at the Tracy Blvd. Bridge) and monitored using mobile monitoring equipment. One day after release, six crabs were found within Old River relatively close to the release site. The Tracy Fish Collection Facility (TFCF) recovered two male crabs four days after release. Seven crabs from the original ten crabs released were tracked at one time or another during nine mobile monitoring attempts between October 14 and 28.

The second phase started with four male crabs being released in Old River at the Tracy Blvd. Bridge on November 8. For approximately 11 hours, beginning the evening of November 9, a night mobile monitoring session was conducted using five crabs released in Grantline Canal at the Tracy Blvd. Bridge.

Starting November 10, fixed monitoring stations were installed at TFCF near the far end of the trash deflector and at the Clifton Court Forebay (CCF) radial gates. On November 12 and 15, two additional fixed stations were installed at the CCF public dock just outside of the radial gates and at the Head of Old River (HOR). A total of six hydrophones and four receivers (two multiplexing) were used for the fixed station.

For the third and final phase, two female and three male crabs were released on November 15 just above Mossdale Marina on the San Joaquin River to evaluate the crabs' response to the channel split at HOR. All five crabs passed the HOR fixed monitoring station by November 16.

Crabs tagged with dummy tags to determine mortality due to tag placement were held from early October through December. Five 9-hour video recordings of these crabs' behavior have been made.

The data are currently being analyzed and a draft report will be released by the end of February.

NEOMYSIS/ZOOPLANKTON STUDY

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In October and November, *Limnoithona tetraspina* was the most abundant copepod and was ten times more abundant than the next most abundant species. Its peak abundance exceeded 80,000/m^3 in October in the San Joaquin River at Antioch. Adult densities >30,000/m^3 were common during both months in Suisun Bay and the Delta and nauplii were present in concentrations of several hundred thousand per cubic meter. *Eurytemora affinis* began to reappear in small numbers in the Suisun Marsh sloughs and Suisun Bay during October and became more abundant in November. *Pseudodiaptomus forbesi* was at typical fall abundance levels of 1,000 to 2,000/m^3 at a maximum. No other copepods were abundant. Cladocerans were absent at most stations and exceeded densities of 1000/m^3 only in the San Joaquin River at Stockton. The rotifer, *Synchaeta bicornis*, was fairly abundant in Suisun Bay and the western Delta in October.

Neomysis mercedis was absent this fall as it has been for several years. The introduced mysid, *Acanthomysis bowmani*, was fairly abundant in October and November and reached a maximum concentration of 61/m^3 in Suisun Slough.

DELTA SMELT HATCH DATA ANALYSIS

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We are examining the feasibility of aging adult delta smelt through otolith microstructural analysis. The purpose of this project, if aging techniques are successful, is to determine the days or weeks when delta smelt hatched in 1998. The temporal distribution of hatch dates will be examined along with environmental variables (for example, exports, food availability, temperature, among others) to retrace delta smelt rearing during contemporaneous environmental conditions. To date, the otoliths from 100 adult delta smelt (collected during the 1998 DFG Fall Midwater Trawl Survey) have been sectioned and polished. The next step is for two readers to independently determine ages by counting the daily increments on the otoliths.

Delta Flow Measurement

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No major operational problems occurred throughout the quarter at any of the UVM or side-looking ADCP (SL-ADCP) continuous flow monitoring stations that resulted in missing data for an extended period.

Several 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 will be used to flow calibrate the SL-ADCP measured index velocity. Flow calibration and the calculation of tidal flows from the time when the SL-ADCP was installed up to the present is scheduled to be completed next quarter.

Flow calibration was successful for three of the five upward-looking ADCPs (UL-ADCP) that were deployed in the Delta during last spring. Three-month long tidal-flow time series were computed for Turner Cut, Middle River south of Columbia Cut, and Connection Slough. This was the first time that flows have been continuously monitored in Connection Slough (north side of Bacon Island). What we learned is that the tidally averaged net flow for Connection Slough is generally from east to west, with the magnitude of the westerly net flow decreasing as the SWP and CVP export rate increases. The flow data from these three sites will be presented in a future article. Flow calibration was not successful at the False River and Old River at San Joaquin River at Webb Tract sites due to the extreme tidal-flow asymmetry that exists at these two sites.

Several flow calibration measurements made during the quarter at several of the Grizzly Bay UL-ADCP sites were described in the previous quarterly report. The UL-ADCPs were just recently retrieved, the velocity data downloaded, and then the unit re-deployed at the same location. The re-deployed UL-ADCPs will again be deployed for three months. Flow calibration for the first three-month UL-ADCP deployment will begin during the next couple of months.

Splittail Investigations

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Final database corrections and a draft report for 1999 fieldwork were completed. Study design revisions for field sampling in 2000 were made. The 1999 report is being revised for a future article. With this work completed, biologist Gayle Garman accepted an ES III timber harvest review position in Eureka.

1999 Fall Midwater Trawl Survey

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The California Department of Fish and Game completed the 1999 Fall Midwater Trawl Survey (FMWT) on December 9; completing our thirty-first fall survey since 1967 (no surveys were done in 1974 or 1979). During this season the FMWT assisted in data collection for the following projects: CALFED’s “Assessment of the Impacts of Selenium (Se) on Restoration of the San Francisco Bay-Delta Ecosystem” (USGS) and a histological study of longfin smelt (*Spirinchus thaleichthys*) and delta smelt (*Hypomesus transpacificus*) (UCD).

The FMWT samples 116 stations monthly, from September through December and uses data from 100 stations to calculate indices of abundance (the extra 16 stations are for monitoring delta smelt). These 100 stations are divided into 14 areas with the mean catch calculated for each area and multiplied by a water volume weighting factor. The monthly index of abundance (or index) is the sum of the weighted mean catches and the fall index of abundance is the sum of the monthly indices.

Originally tasked with monitoring and reporting on the distribution and abundance of young-of-the-year (YOY) striped bass (*Morone saxatilis*) the FMWT has expanded its reporting to include delta smelt, longfin smelt, Sacramento splittail (*Pogonichthys macrolepidotus*), and American shad (*Alosa sapidissima*). Below are brief descriptions concerning distribution of the above species in 1999.

YOY striped bass distribution began to concentrate in Suisun Bay from September through December increasing from 44% in September to 92% in December (Table 1).

The distribution of delta smelt shifted from Suisun Bay in September to the lower Sacramento River in December. The percentage of the index in Suisun Bay in September was 68% while in December it was 20%. However, the percentage of the index set in the lower Sacramento River was 13% in September and 79% in December.

Table 1 1998 and 1999 monthly and FMWT abundance indices for selected species with record high and low FMWT abundance indices

Year	*Sep*	*Oct*	*Nov*	*Dec*	*Fall Index*
Young-of-the-year striped bass					
1999	154	68	134	185	541
1998	234	290	126	574	1,224
Record Low Fall Index: 392 (1996)					
Record High Fall Index: 20,038 (1967)					
Delta smelt					
1999	198	380	114	172	864
1998	239	97	15	70	421
Record Low Fall Index: 102 (1994)					
Record High Fall Index: 1,673 (1970)					
Longfin smelt					
1999	1,953	2,736	330	223	5,242
1998	149	1,578	2,032	2,895	6,654
Record Low Fall Index: 76 (1992)					
Record High Fall Index: 81,790 (1967)					
Sacramento splittail					
1999	24	3	12	0	39
1998	127	92	45	17	281
Record Low Fall Index: 0 (1977)					
Record High Fall Index: 281 (1998)					
American shad					
1999	346	155	145	69	715
1998	1,318	2,093	515	214	4,140
Record Low Fall Index: 338 (1972)					
Record High Fall Index: 6,912 (1995)					

The distribution of longfin smelt spanned from San Pablo Bay to Suisun Bay (including the Carquinez Strait) between September and December. However, the distribution shifted from 61% of the index being set in San Pablo Bay to 15% in October and November to 32% in December.

The low numbers of splittail caught in the 1999 FMWT preclude describing the changes in splittail distribution.

The distribution of American shad spread westward over time. The percentage of the index in San Pablo Bay increased from 1% in September to 19% in December.

The Department of Fish and Game will continue the Midwater Trawl Survey from January through March primarily to monitor the distribution and movement of delta smelt.

JUVENILE SALMON MONITORING

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The US Fish and Wildlife Service, Sacramento-San Joaquin Estuary Fishery Resource Office Delta monitoring efforts increased on October 4 for the fall sampling period. Lower Sacramento River seining caught three winter-run-sized chinook (43–99 mm) between November 5 and December 22, and two fall-run chinook (32 to 36 mm) on December 22. A more intensive Sacramento area beach seine effort was started October 19 to better detect the presence of spring-run and winter-run chinook emigrating into the Delta. Two winter-run-sized chinook (78–83 mm) were captured between December 6 and 12. Four late-fall run (99–121 mm) and three fall-run chinook (32–37 mm) were captured between December 3 and 22. No juvenile chinook were detected at the South Delta or San Francisco Bay seine sites. San Joaquin River beach seining efforts increased from three sites sampled every other week, to nine sites once per week. Due to low flows, the upper three sites remained inaccessible. No juvenile chinook have been captured since June 2.

Kodiak trawling replaced midwater trawling at Sacramento on October 4. Two late-fall-run chinook (119 to 126 mm) were captured between November 8 and

December 4 and one 360 mm steelhead was caught on November 12.

Mossdale Kodiak trawling started on October 18. No chinook have been captured to date.

Between October 13 and December 21, the Chipps Island trawl captured 28 late-fall run chinook (117 to 167 mm), and 28 fall run chinook (121 to 194 mm). No chinook in the spring-run or winter-run size range have been captured so far this fall. Delta smelt catches have sporadically curtailed sampling since October 4.

Late-fall-run coded wire tag survival experiments began with releases in Georgiana Slough and Isleton on December 10 and 11, respectively. A second experiment was also initiated with releases on December 20 and 21. The intent was to provide more data on the effects of Delta exports on the survival of fish in the interior Delta (Georgiana Slough) relative to those migrating down the mainstream Sacramento River (Isleton) at low to moderate export conditions. Water quality concerns in the Delta have resulted in fluctuations in exports over the duration of the tagged fish recovery period. Tagged fish recoveries will extend into January.

In conjunction with regular monitoring activities, fish supplied to ongoing studies include an otolith study (Rob Titus, DFG) and a genetic race discrimination analysis (Sheila Greene, DWR).

Since late November and continuing through February, fish monitoring data from rotary screw traps at the Tisdale Weir and Knights Landing (DFG), Sacramento River and Delta beach seines, Sacramento and Chipps Island trawls, and the fish salvage facilities at the CVP and SWP are being made available on a real time basis to the Data Assessment Team (DAT) and the “No Name Group.” These data provide the information to consider, develop, and implement protection measures for listed salmon such as Delta Cross Channel closures and export reductions at the CVP and SWP.

Salmon Passage at the Suisun Marsh Salinity Control Gates

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The second year of the Suisun Marsh Salinity Control Gates (SMSCG) adult salmon passage study has been completed. Salmon passage was monitored during the normal operations and a modified gate configuration in which two 3-foot by 40-foot slots were placed in the flashboard portion of the structure. The Department of Fish and Game staff, with the assistance of DWR staff, evaluated the effects of the modification. Previous studies in 1993 and 1994, indicated the SMSCG could potentially block and delay the upstream migration of adult salmon. The objectives of the current evaluation were to compare chinook salmon passage numbers with and without the flashboard modifications and chinook salmon passage times with and without the modification in place.

One hundred and ninety-eight adult fall-run chinook salmon were tagged with regular and depth-sensitive ultrasonic telemetry tags during the three operational configurations of the SMSCG (66 fish per configuration). Table 1 shows the schedule of the 1999 evaluation.

Table 1 Schedule for the 1999 salmon passage evaluation at the SMSCG

Dates	*SMSCG Configuration*
September 15 to 26	Modified flashboards installed, gates operating, boat lock operating
September 27 to October 13	Regular flashboards installed, gates operating, boat lock operating
October 14 to November 4	Flashboards and gates out of the water, boat lock operating

Nine stationary monitoring sites and some mobile monitoring by boat were used during each of the configuration monitored the movements of these fish.

Preliminary analysis of the 1998 and 1999 adult salmon passage data indicates the modification in the flashboard structure did not improve salmon passage numbers or passage time. In some cases, the passage numbers decreased in comparison to the normal flashboard configuration. Additionally, the fish passage times increased for the modified flashboard configuration. The data are still being analyzed for fish passage numbers by tidal condition for each gate configuration.

For the second year in a row, noise problems with monitoring stations on the structure suggest these locations should not be used for stationary monitoring sites in the future. This equipment should be used at locations just upstream and downstream of the structure to confirm fish passage or non-passage.

HYDRODYNAMICS OF NORTH BAY

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Two major field efforts were conducted this fall. The first involved deploying a large network of self-contained oceanographic equipment in the Grizzly Bay area to study shallow-channel exchange processes. This equipment was put in the water mid-September, and will continuously monitor water level changes, current speeds, temperature, salinity, and turbidity until June. Seventeen velocity sensors were deployed; six of which are profilers (able to measure the vertical current distribution). Eighteen Conductivity-Temperature-Depth (CTD) sensors were also deployed. Of these, 12 were fitted with turbidity sensors. Although the primary objectives of this study are to monitor the exchange of water, salt, and suspended sediment between Grizzly Bay and the channels of Suisun Bay, secondary objectives include (1) quantifying the impact on the flows in Grizzly Bay from the Suisun Marsh Salinity Control Gate operation and (2) documenting a possible bathymetrically controlled estuarine turbidity maximum (ETM) near the northern tip of Ryer Island (Garnet Point). This study is being conducted in direct collaboration with Dave Schoellhamer, USGS, and is funded through the IEP and the Department of Interior's Placed Based program. The hydrodynamic and sediment transport studies just described are part of a larger interdisciplinary Placed Based funded effort that includes both contaminant (Sam Luoma and Kathy Kuivila, USGS) and benthic ecology (Jan Thompson, USGS) components, among others.

A two-week shear-buoyancy-turbulence interaction study was also conducted in Suisun Cutoff in mid-October. This effort was aimed at studying the fundamental physics of density driven transport, such as gravitational circulation, which is controlled by the non-linear interaction between the tidal currents, bed-shear, vertical mixing (turbulence and dissipation), and the horizontal and vertical (stratification) salinity gradients. The difficulty in simultaneously measuring each of these quantities with sufficient temporal and spatial resolution has previously made studying the interactions among them impossible.

This October all of the equipment necessary to conduct such an experiment was assembled and deployed. The centerpiece of the study was a 'turbulence cluster' deployed in the center of Suisun Cutoff. The turbulence cluster consisted of (1) an autonomous CTD-turbidity profiler, (2) a pair of Acoustic Doppler Current Profilers that simultaneously measured the large scale near-bed and water column turbulence, and (3) a series of three high-frequency (25 Hz) Acoustic Doppler Velocimeters (ADVs) deployed in the near-bed region designed to capture the near-bed shear. A turbidity sensor was deployed adjacent to each ADV so that sediment deposition and re-suspension could be directly related to the near-bed shear. All of the equipment in the turbulence cluster was placed on the channel bottom and cabled to an anchored houseboat that was continuously operated for a two-week spring-neap cycle.

In addition to the houseboat, we deployed an autonomous CTD profiler (buoy) and an ADCP at each end of the Cutoff. The equipment at the ends of the Cutoff will allow us to compute the along-channel momentum balance and to address the combined affects of tidal straining, vertical mixing and density driven circulation on the observed salinity stratification. Dissipation measurements were also made near the turbulence cluster from the research vessel *Turning Tide*. Finally, lateral variability in the velocity and salt fields was measured on two different days during the two-week period using the research vessel *Compliance*. Collaborators in this study include Mark Stacey (UC Berkeley), Jessica Lacy and Matt Brennan (Stanford University), and Mike Gregg (University of Washington). Stephen Monismith (Stanford University) is the lead principal investigator. The Office of Naval Research and the IEP funded this study. A majority of the equipment used in this study was purchased through the Placed Based program.

ROCK SLOUGH MONITORING PROGRAM

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A sieve-net was used to sample fish entrainment once a week at the Rock Slough intake of the Contra Costa Canal in October, November, and December. Overall, few fish were captured in the sieve-net in October and November. Juvenile striped bass, *Morone saxatilis,* (mean: 108 mm FL) was the predominant fish species captured during these two months. No fish were captured in December. Once again, our equipment at the sampling site was vandalized and essential sampling equipment was stolen in late December. Fish entrainment sampling has been discontinued until the equipment can be replaced.

OLD RIVER FISH SCREEN FACILITY (LOS VAQUEROS) MONITORING PROGRAM

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A sieve-net was used to sample fish entrainment once a week behind the fish screens at the Old River Fish Screen Facility in October, November, and early December. Sampling was discontinued from December 9 to 31 because the facility was shut down due to high chloride levels in Old River. Inland silverside, *Menidia beryllina* (mean: 52 mm FL), was the predominant fish species captured in the sieve-net in October. Few fish were captured in the sieve-net in November and no fish were captured in December. Fish entrainment sampling frequency will be increased up to three times per week between January and June.

DELTA SMELT

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At the request of the IEP Coordinators, a delta smelt work group headed by Kevin Fleming and Zach Hymanson has been formed. The charge of this group is to develop a ten-year strategic plan for delta smelt research. Using prioritized "research needs" outlined from past delta smelt workshops, the group will produce a long-term plan that will serve as the guide for delta smelt monitoring, analysis research. Where possible, the group will identify key individuals or teams who will translate the research needs into testable hypotheses and study proposals.

SEASONAL COMPARISONS OF INTRODUCED GELATINOUS ZOOPLANKTON FROM SAN FRANCISCO BAY TO THE DELTA

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Systematic monitoring for jellyfish was conducted near six stations along a salinity gradient of 0.2 to about 30 ppt from Big Break near Antioch in the Delta to the Golden Gate, from May through December, supplemented with additional sampling.

Native jellyfish were found to be common primarily in the Central Bay, including areas near the Golden Gate and Alameda. In the San Pablo Bay area, populations of the small introduced hydromedusan jellyfish, *Blackfordia virginica*, occurred in August and September. These *B. virginica* were found mainly in the Napa River between the Kennedy Park Boat Launch and Cuttings Wharf (salinities about 7 ppt, or about 20% seawater). Population densities reached $>1/m^3$. In September, adult populations of *Maeotias inexspectata,* a larger (about 3 cm) introduced hydromedusan, had appeared near Chipps Island and Suisun Slough, at salinities of about 5 ppt (about 15% seawater). By October, *M. inexspectata* was common in the Delta at Brannon Island, north of Big Break, at salinities of about 3 ppt (<10% seawater). A third introduced hydromedusan, *Moerisia* sp., appeared near Martinez in August and September, at about 15 ppt salinity. Introduced jellyfish population densities were found to far outnumber larval fishes in these open water habitats, but jellyfish were far less common in marsh habitats. Preliminary laboratory experiments with *M. inexspectata* and small fishes show that these introduced jellyfish are capable of killing fishes such as juvenile sticklebacks, although they have not been reported to ingest fishes.

In the Central Bay, juvenile and adult populations of the native hydromedusan jellyfish *Polyorchis penicillatus* became numerous near Alameda Point in mid-November and was seen to feed on zooplankton, as has been noted in previous years. Population densities reached about $1/m^3$. The native ctenophore *Pleurobrachia bachei*, which appeared together with *Polyorchis*, also was observed feeding on shallow zooplankton. *Pleurobrachia bachei* densities reached about $4/m^3$ at Alameda in November. Both the above gelatinous predators plus two scyphozoan jellyfish (juvenile *Scrippsia pacifica* and adult *Aurelia labiata)* also were detected at Alameda in December. Salinities have been nearly oceanic (> 30 ppt) near Alameda since late June.

In summary, low-salinity areas of the Bay-Delta showed no native jellyfish but showed three introduced jellyfish species, which became very common during late summer through early fall.

Gear Type Selection for the Chinese Mitten Crab Habitat Use Study

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The Chinese mitten crab habitat use study is designed to determine the relative abundance of juvenile and adult mitten crabs among various habitats in the Sacramento-San Joaquin Delta. In 1999, we conducted a pilot study to develop sampling gear and methods. Due to the low abundance of mitten crabs in the Delta this past spring and summer, we conducted gear evaluations in Suisun Marsh and the Guadalupe River, a tributary to South Bay, which had higher densities of mitten crabs than the Delta. We evaluated a variety of sampling techniques, including blocknet enclosures, baited traps, artificial substrates, and snorkeling transects.

Gear types were evaluated based on capture effectiveness and usefulness regardless of water depth, vegetation density, and substrate type. For subtidal habitats, we selected two gear types: baited traps and “crab condos.” The baited trap consists of a mesh-covered wire-frame box with rectangular funnel entrances on either side. The funnels are designed so that the crabs must “push” through the mesh to enter the trap. With this design, escapement is very low. These traps are functional in high velocity habitats. We tried a variety of baits (cat food, herring, clams, shad, shrimp, mitten crab, among others) and selected frozen sardines, based on effectiveness, cost, and availability. Initially, we fished the traps for 24 hours. However, due to interference from river otters (that is, bait stealing), we will conduct additional tests to determine if a decreased soak time is equally effective at capturing crabs.

The “crab condo” is a baitless sampling gear, consisting of 12 tubes (6-in long, 2-in diameter ABS pipe) clustered in a honeycomb fashion and secured in a PVC rack. Crab condos appear to function as a source of cover. Crab condos were found to be effective for catching small crabs (16 to 42 mm carapace width) and are functional in all water velocities. Experimental treatments varying soak time (two, three, five, and nine days) showed no significant difference in catch per unit effort. Thus, we will fish the condos for two days.

Dissolved Oxygen Levels in the Stockton Ship Channel

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Dissolved oxygen concentrations in the Stockton Ship Channel are closely monitored during the late summer and early fall of each year because levels can drop below 5.0 mg/L, especially in the eastern portion of the channel. The dissolved oxygen decrease in this area is apparently due to low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow conditions in the San Joaquin River past Stockton. Low dissolved oxygen levels can cause physiological stress to fish and block upstream migration of salmon.

Monitoring of dissolved oxygen levels in the Stockton Ship Channel was conducted by vessel nine times between August 10 and December 7, 1999. (See the article in this issue on historical fall dissolved oxygen levels for information about methods.)

Dissolved oxygen levels in the Stockton Ship Channel followed a unique pattern in late fall 1999. Usually dissolved oxygen levels in the eastern portion of the channel recover from the relatively low late summer and early fall (August through October) levels of 3.0 to 5.0 mg/L to levels greater than 5.0 mg/L by late fall (November) due to cooler water temperatures and improved San Joaquin River inflows to the eastern channel. In some years, late fall levels in the eastern channel improve sufficiently to approach the 7.0 to 9.0 mg/L typically measured in the western channel. In 1999, however, low dissolved oxygen levels persisted in the central and eastern channel from November through December in spite of cooler water temperatures and improved inflows.

During the late fall, field staff observed activities that could have increased the BOD and subsequently contributed to the persistence of low late fall dissolved oxygen levels in the central and eastern channel. The crew observed dredging and re-suspension of sediments in the area from Light 28 (immediately west of Fourteen Mile Slough) to Light 34 (adjacent to Fourteen Mile Slough) on November 23 and near the middle of Rough and Ready Island on December 7. In addition, they observed that the aerators operated by the US Army Corps of Engineers near the eastern end of Rough and Ready Island were not operating during the same period as the dredging activity. These and other factors could have contributed to the anomalous 1999 fall dissolved oxygen values.

As in previous years, dissolved oxygen levels in the western channel from Prisoner's Point to Disappointment Slough were relatively high and stable throughout the study period, ranging from 7.7 to 10.0 mg/L from August 10 to December 7. The robustness of dissolved oxygen levels in this portion of the channel is apparently due to the greater tidal mixing and the absence of conditions creating BOD. In the central portion of the channel from Columbia Cut to Fourteen Mile Slough, dissolved oxygen levels dropped from the consistently high levels in the western channel to levels approaching or below 5.0 mg/L throughout the monitoring period. In the eastern channel from Buckley Cove to the eastern end of Rough and Ready Island, the dissolved oxygen results were more variable, but in general, approached or fell below 5.0 mg/L throughout much of the monitoring period.

CALFED Science Conference

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CALFED's Comprehensive Monitoring, Assessment and Research Program (CMARP) is organizing the first CALFED Science Conference to be held October 3–5, 2000, at the Sacramento Convention Center. Fred Nichols (fnichols@usgs.gov) and Randy Brown are co-chairing the conference steering committee. Larry Brown and Bill Bennett (lbrown@usgs.gov and wabennett@ucdavis.edu) are technical program chairs. Several local scientists have been asked to prepare recommendations for specific technical sessions. Peggy Lehman (plehman@water.ca.gov) and Bruce Thompson (brucet@sfei.org) will organize the poster session.

The Science Conference will be an annual or semi-annual forum for scientists and engineers who are conducting scientific investigations that address technical issues pertinent to CALFED programs (ecosystem restoration, levee system integrity, water quality, etc.). The conference program will be developed around technical themes, and will feature a mix of invited and contributed talks and poster presentations that describe recent study results, models, and syntheses that are relevant to the accomplishment of CALFED's goals and objectives in the San Francisco Bay-Delta watershed. Talks and posters are not limited to CALFED funded projects but are open to all projects with significant findings relevant to CALFED goals.

The conference is intended specifically for sharing information among scientists and engineers working on studies relevant to CALFED technical issues. A comprehensive summary of the management implications of the information presented at the conference will be prepared for later distribution to interested individuals and groups by mail or on our conference web site (see below).

A call for abstracts will be distributed in early March. The deadline for the submittal of abstracts is June 2.

Program details, with abstract submittal and registration information, will be available soon at the web site (http://www.iep.water.ca.gov/calfed/sciconf1/).

Questions about the conference can be directed to Fred, Randy, Larry, or Bill.

Summary of IEP Activities for 2000

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On November 5, 1999, the IEP Directors or their designees approved the IEP 2000 program and associated budget. The 2000 program contains 68 separate monitoring and special study elements covering a broad spectrum of physical and biological subjects with an estimated cost of almost 14 million dollars.

Development of the 2000 Program began in January 1999 with the revision of the previously developed Long-term Planning Considerations and Actions. This document details what strategic areas IEP needs to emphasize in the current and future year's work. During the spring and summer, interagency Project Work Teams (PWTs) reviewed past program accomplishments, long-term planning considerations and actions, information gaps and known monitoring and special study activity improvements. Based on these factors, PWT members and other individuals prepared and submitted proposals. The appropriate PWT reviewed each proposal, worked with the authors to correct any deficiencies, and finally ranked all of the proposals reviewed. The Management Team compiled and reviewed the PWTs recommendations and rankings. Then based on program budget considerations, long-term planning considerations, and perceived program information priorities, the Management Team developed an integrated, overall program for the Coordinator's review. The Coordinators reviewed the recommended program and directed the Management Team to revise the program to meet agency information needs, priorities, and budgets. The program was then presented to the Management Level Advisory Group (MLAG) for their input and recommendations, after which it was finalized by the Coordinators. This final draft was presented and approved by the Directors in November.

2000 Program

Eighty-seven proposals were processed through the review process. Seventeen were for monitoring efforts, fourteen for on-going program elements in their second or third year, four for fish facilities work, fifty for new special studies, and two were other non-IEP projects that sought IEP review or coverage under IEP Biological Opinions. The program as approved by the Directors contains eighteen monitoring, thirty-two ongoing, three fish facility, and fifteen new special study elements. In terms of budget $6,179,000 is allocated for monitoring programs, $6,725,000 for special studies and $1,003,000 for management related activities, all totalling $13,748,000. Special studies consist of new programs and ongoing multi-year programs. Table 1 highlights the agencies contributing to the program and the agencies that are carrying out the work.

The 2000 Program continues IEP's historic emphasis on long-term monitoring efforts. This year those monitoring activities that directly support or provide information to CVP and SWP operations were placed in the "Operations Monitoring" category. These included real-time monitoring, delta smelt 20-mm survey, portions of Delta juvenile salmon and Knights Landing salmon monitoring, the portion of the compliance water quality monitoring covering telemetered sites, and enhanced salvage reporting. Similar to the past year, the 2000 Program continues support for investigations of listed species ecology and effects of exotic species. Expanded this year are shallow water related investigations, including the development and evaluation of shallow water sampling methods, studies of the predator-prey relationships of fish in shallow water habitats, basic studies of the food web in shallow water areas, and a broad spectrum of efforts in the Yolo Bypass. These shallow water investigations will be critical for future CALFED shallow water habitat restoration planning and evaluation.

Fish facilities work for next year includes the continued evaluation of the effects of handling and transport on delta smelt and splittail at the SWP, and investigations of the effects of the Suisun Marsh Salinity Control Structure on fish passage. A study to determine whether significant mortality occurs to juvenile salmon from standard collection and trucking operations at the SWP is a new program element this year.

QA/QC

In 1996 and 1997, the IEP, in response to comments by stakeholders and internal groups, developed a formal QA/QC program that consists of two parts: (1) a Quality Assurance Management Plan and (2) a Quality Assurance Project Plan. This QA/QC program contains everything from guidelines on what should be addressed in study proposals, details on sample and data quality control and a formalized structure for peer review of all products of each program element. This document was used to guide principal investigators in their preparation of proposals and will be used to prepare their workplans. Workplans for all approved program elements will be completed and turned into the IEP Management Team by January 2000.

Table 1 Interagency funding transfers and approximate agency self-funding levels associated with the completion of proposed 2000 Interagency Ecological Program Monitoring and Special Study Activities [a]

	Agency (From)											
Agency (To)	*DWR*	*DFG*	*SWRCB*	*USBR*	*USFWS*	*USGS*	*USEPA*	*NMFS*	*USACE*	*CVPIA*	*Other [b]*	*Total*
DWR	$2,068	$0	$0	$358	$0	$0	$0	$0	$0	$0	$150	$2,576
DFG	$2,214	$1,653	$0	$1,712	$0	$0	$0	$0	$0	$167	$291	$6,037
SWRCB	$0	$0	$10	$0	$0	$0	$0	$0	$0	$0	$0	$10
USBR	$0	$0	$0	$433	$0	$0	$0	$0	$0	$0	$0	$433
USFWS	$515	$0	$0	$514	$181	$0	$0	$0	$0	$130	$0	$1,340
USGS	$407	$0	$0	$639	$0	$715	$0	$0	$0	$0	$46	$1,807
USEPA	$0	$0	$0	$0	$0	$0	$20	$0	$0	$0	$0	$20
NMFS	$0	$0	$0	$0	$0	$0	$0	$305	$0	$0	$0	$305
USACE	$0	$0	$0	$0	$0	$0	$0	$0	$5	$0	$0	$5
Other	$396	$0	$0	$619	$0	$0	$0	$0	$0	$200	$0	$1,215
Total	$5,600	$1,653	$10	$4,275	$181	$715	$20	$305	$5	$497	$487	$13,748

[a] Values expressed in thousands of dollars.
b Includes CALFED.

CMARP

The IEP has expended considerable personnel resources towards the CALFED CMARP process during the past two years and this commitment will continue. The IEP Coordinators and Management Team view this participation in CALFED as a high priority. This participation will be accomplished via re-direction of existing personnel and suspending or re-evaluating existing elements or element products. Where work on existing program elements is affected by these activities, due dates for various products will be adjusted by the amount of time spent on the CMARP activity.

Vessel Replacement and Safety

Two items began last year were the IEP Research Vessel Replacement Plan and safety training of IEP field personnel. The Research Vessel Replacement Plan is being implemented, as funding becomes available with the refurbishment of existing vessels, the retirement of obsolete vessels, and the purchase of new vessels. In 1999 the *Beowulf II* was repowered, the *Scrutiny* was transferred to DFG and its engines were replaced, two new 24-foot skiffs were purchased and a new 28-foot research vessel was ordered. Four old vessels were removed from service and disposed of. This year we hope to purchase a new 42-foot research vessel, a new electrofishing boat, a specially designed shallow water skiff and two general purpose skiffs. All permanent boat operators who operate IEP vessels have passed the Department of Interior's Boat Operator Safety Certification course. All other individuals who operate IEP vessels on a short-term basis must pass a thorough safety review by a permanent IEP boat operator before operating a vessel or skiff.

Database Development and Implementation

The IEP has made significant progress in 1999 in developing and implementing a relational database for IEP, CAMP, AFRP, Category III monitoring, fish salvaged at the CVP and SWP and HEC/DSS (Hydrologic Engineering Center Data Storage System). This new relational database allows principal investigators to automatically upload their data via a customized data-editing program provided by IEP, while allowing the user to maintain control of their data on their own system. A new spatial data engine has been added to the system to allow GIS users to generate data files directly from the relational database. Users, via the Internet, can view data stored in the database and easily download subsets of the data to their own computer. Because the data uploading and downloading process is now automated, field data can be made available to decision makers via the Internet in just days after collection.

Predictions and Predications from a Visiting Chinese Mitten Crab Expert

Tanya Veldhuizen, DWR

During May 1999, DWR staff and a consultant traveled to China to investigate the Chinese mitten crab in its native range. (See Hymanson and others [1999] for an account of this trip). Professor Zhao Nai-gang, a leading mitten crab researcher and aquaculturist, was their local host. In August, Professor Zhao traveled to California to learn about California and provide insight on the mitten crabs now occurring in the San Francisco Estuary and its watershed. During his week-long visit, Professor Zhao toured the Sacramento-San Joaquin Delta and Suisun Marsh to view habitats available to the mitten crab, the DWR's Delta Field Division office and pumping facility, and the DWR and USBR fish facilities to view and discuss the mitten crab exclusion devices. His trip concluded with a meeting of the Chinese Mitten Crab Project Work Team, which provided an opportunity to exchange information and a forum for Professor Zhao to brief us on his opinion of the mitten crab in California. Professor Zhao's visit allowed him to provide some general information about the biology and ecology of the mitten crab population. New information about the mitten crab is summarized below.

Professor Zhao believes the Delta is good habitat for juvenile mitten crabs. Optimal rearing habitats for juvenile mitten crabs are areas with still or low velocity water, a stable water depth, low turbidity, and warm temperatures (ranging from 20° to 30° C, with optimum growth occurring at 24° to 28° C). In China, mitten crabs are commonly found in lacusterine (lake) to riverine habitat. The river is a passageway for the crab, not a nursery area. Submerged aquatic vegetation (SAV) is an important component to the habitat. Areas with SAV provide cover and high concentrations of epiphytic invertebrates, which the crabs consume. Mitten crabs inhabit areas with an average depth of 2 m (which corresponds to the distribution of SAV). They do not rear in deep water areas, which lack SAV.

Professor Zhao noted the Delta water quality is much better than that of the Yangtze River, which suffers from high siltation due to deforestation. Overall, the Delta is good habitat for crabs: suitable temperature, areas of slack water, and abundant vegetation to provide refuge and food resources.

Small crabs consume small epibenthic and epiphytic invertebrates, tender plant shoots, and SAV (not emergent vegetation). Professor Zhao said water hyacinth is also edible (the crabs eat the roots and organisms living on the underside of the plant). Larger crabs eat benthic invertebrates, such as shrimp, mysids, amphipods, snails, clams (including *Corbicula*), and all types of SAV. As observed under aquaculture conditions, the crabs can be cannibalistic. Megalopae consume mostly algae and some plankton.

During the first year, juvenile crabs migrate upstream along shallow water corridors seeking lacusterine areas with clear water, SAV, and abundant food to rear in. The crabs stop migrating when good habitat is found. Older crabs that continue to migrate upstream during their second year are continuing the search for suitable habitat. Dam releases or high winter flows may affect habitat suitability by changing water velocity or temperature or both. This may explain the occurrence of large numbers of age-1 juvenile crabs migrating upstream to areas above the Delta from January through March 1998 (Hieb and Veldhuizen 1998). This migration followed the flood events of January 1998.

In China, there are two "types" of the Chinese mitten crab, a river form and a coastal form. It is unclear whether these types are genotypic or phenotypic variations. The river form is characterized by crabs that rear in freshwater areas of large river systems and that mature later and at a larger size relative to the coastal form. The coastal form is characterized by crabs that mature within one year and at a relatively small size. The small size and accelerated maturation of the coastal form may be the result of the close proximity to brackish water, limited rearing area, and/or high water temperatures. Both types of crabs occur in the San Francisco Estuary. Crabs that rear in South Bay tributaries mature at half the size of crabs that rear in the Delta and Central Valley.

Due to the large numbers of crabs entering the fish facilities during the fall of 1998, there was much interest amongst members of the PWT to learn more about migratory cues. Professor Zhao said the downstream spawning migration commences after the crab passes through its last molting stage. Environmental cues trigger the migration. The first cue is a drop in water temperature. The crabs follow the flow downstream. When they reach brackish water, the crabs then follow the salinity gradient.

Upon viewing the width of the Delta levees, Professor Zhao expressed doubt that the crabs will cause significant damage to levees and banks. In areas with SAV, the crabs seek refuge in SAV before expending energy to construct a burrow. Given the extent of SAV in the Delta, burrowing should be minimal. This is reflected in data from the IEP Mitten Crab Monitoring surveys conducted by DFG in 1997 and 1998 (Veldhuizen 1997, Holmes and Osmondson 1999). These surveys found densities of burrowing mitten crabs were higher in Suisun Marsh, an area lacking SAV, compared to the Delta.

Professor Zhao toured the DWR and USBR fish facilities and viewed the mitten crab exclusion devices. Professor Zhao thought that DWR's K-rail would work (perhaps he was just being polite), but he offered to send us drawings of a better design. He was unable to comment on USBR's traveling screen, because it was undergoing modifications and was non-operational at the time.

The exchange of information with Professor Zhao continues. He is interested in learning more about California's mitten crab population and requested periodic updates. He is currently translating his mitten crab publications to English and will notify us when these documents become available.

Acknowledgements

Special thanks to our interpreter, Johnson Wang.

References

Hieb K, Veldhuizen T. 1998. Mitten crabs on the move. IEP Newsletter 11(2):3–4.

Holmes A, Osmondson J. 1999. The second annual IEP monitoring survey of the Chinese mitten crab in the Sacramento-San Joaquin Delta and Suisun Marsh. IEP Newsletter 12(1):24–7.

Hymanson Z, Wang J, Sasaki T. 1999. Lessons from the home of the Chinese mitten crab. IEP Newsletter 12(3):25–32.

Veldhuizen T. 1997. First annual IEP monitoring survey of the Chinese mitten crab in the Delta and Suisun Marsh. IEP Newsletter 10(4):21–2.

Natural and Human Influences on Freshwater Flows and Salinity in the San Francisco Bay-Delta Estuary and Watershed

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Abstract

Understanding the processes controlling the physics, chemistry, and biology of the San Francisco Bay-Delta estuary is complicated by both natural and human effects on freshwater inflows. To investigate implications for the estuary, changes in inflows due to major reservoirs and freshwater diversions (including Delta exports) in the watershed were inferred from available data. Effects on Bay-Delta salinity were estimated by using the reconstructed Delta outflows to drive a numerical salinity model. Both natural and human-induced signals show strong interannual variability. Though reservoir effects are negatively correlated with both natural variability and Delta exports overall, relative effects vary strongly within the average year. Human effects combine to raise salinities during the wet season, with maximum impacts occurring in spring. On average, May is the time when human impacts are greatest and human and natural effects are least correlated. While year-to-year variations in all signals are very large, natural interannual variability can greatly exceed the range of human effects on water quality in the estuary.

Figure 1 1999 LandSat-7 image of the bay and surroundings. Most of the bay's freshwater arrives through the Delta (upper right).

INTRODUCTION

The San Francisco Bay-Delta estuary has been the subject of intense scientific scrutiny in recent decades, stimulated largely by concerns about destruction of natural habitat, contamination of the rivers and estuary, and declines in aquatic species populations. Like all estuaries, behavior of the Bay-Delta is linked to the coastal ocean and to the inland rivers, resulting in high variability at many scales. Also, the estuary has undergone extensive human development over the past 150 years, as has its upstream watershed. Current attempts to understand and restore the Bay-Delta's valuable ecosystems are complicated by both natural and human effects on freshwater inflows. Freshwater flow through the Delta of the Sacramento and San Joaquin rivers (Figure 1) is the most significant single factor affecting water quality in the estuary (Uncles and Peterson 1995). These inflows flush seawater from the Bay-Delta, determining levels of salinity throughout the estuary. Salinity levels in turn determine water density and flow patterns, which affect nutrient concentrations and so on. Salinity conditions are also directly related to the survival of some plants and animals in the estuarine ecosystem (Nichols 1985). The freshwater inflows which drive these processes have a well-known seasonal cycle, but seasonal to interannual deviations from the climatological pattern can be immense. Understanding this variability in flow patterns is essential to a comprehensive understanding of the estuary.

Freshwater inflows link the Bay-Delta to its upstream watershed, the area of land which stretches from the eastern slopes of the coastal range to the Sierra Nevada, and from the Cascades to the Kings river basin in the south, covering an area of about 400,000 km^2 (Figure 2). Processes in and over the watershed determine the timing and amount of inflow to the bay. Annually, about 30 km^3 of freshwater enter the bay from the watershed, with peak flows coming in early March, on average. Interannual variation in both timing and amount of these flows can be large and is due to both natural and human-induced effects.

Figure 2 shows locations in the watershed where human effects significantly impact flow patterns. Reservoirs with a combined capacity of over 35 km^3 (roughly equal to the bay's total annual inflow) substantially alter the magnitude and timing of river flows throughout the watershed (DWR 1998). Also, freshwater is diverted above and in the Delta region for municipal, industrial, and agricultural uses. The combined effect of reservoirs and diversions constitute the bulk of human-induced changes in bay freshwater inflows (other effects include return flows, groundwater pumping, river confinement, and land use changes). Subsequent use of the term "human effects" in this paper refers to the effects of reservoirs and diversions on freshwater flows into the bay, and the resulting effects on salinity in the estuary. These effects take place in the shadow of the watershed's large natural hydrologic variability, resulting in a complex managed watershed-estuary system. The present study is an attempt to quantify the implications of human effects on bay freshwater inflows, in the context of natural variability, for water quality in the estuary.

DELTA OUTFLOW VARIABILITY AND HUMAN EFFECTS

Data

The first step in exploring the estuarine impacts of reservoirs and diversions is to quantify their effects on the rate of freshwater input to the bay through the Delta. To this end, daily time series of estimated data provided by two agencies proved invaluable. First, the DAYFLOW data program (DWR 1999) offers, among other values, estimates of flows into ("Delta inflow") and out of ("Delta outflow") the Delta region. Subtracting outflows from inflows gives an estimate of losses, primarily due to freshwater exports, in the Delta region. These losses (Figure 3, bottom panel) are hereafter referred to as the "Delta export effect." Next, the California-Nevada River Forecast Center (CNRFC) provided estimates of "unimpaired" river flows below nine major reservoirs throughout the watershed. These data were calculated using reservoir storage data and out-of-basin diversion rates above the reservoir outflow point to infer what the flows would have been without these impairments. Subtracting the unimpaired flow data from observed flow rates at the same locations, and summing the differences to yield one time series, yields daily estimates of the "reservoir effect" on Delta outflow rates (Figure 3, middle panel). Finally, the observed flows just below the major reservoirs were subtracted from the DAYFLOW Delta inflow values to estimate flow contributions from the foothills and valleys. These contributions were then added to the total of the CNRFC "unimpaired" flow time series to yield estimates of unimpaired Delta outflow (Figure 3, top panel). This quantity is intended to represent what freshwater inflows to the San Francisco Bay estuary would have been without shifts in flow timing and magnitude caused by reservoir effects and Delta exports. Though this estimate does not account for such effects as increased in-basin losses due to irrigation, it is nonetheless an approximation to the watershed's outflow in its undeveloped state.

A cursory examination of the flow component time series (Figure 3) reveals that year-to-year variability of both the natural signal and the human effects is large, with extreme events providing notable examples. The signature of the 1976–77 drought is evident in all three signals, while the wet years, such as water year 1983, are reflected most clearly in the unimpaired and reservoir signals. The Delta export effect, consistently negative (other than occasional positive spikes representing in-Delta storm runoff), became noticeably stronger over the period of record. It is also apparent that each of these signals has a strong annual cycle (Figure 3), though the exact timing is not clear. However, a plot of the mean annual cycles (with smoothed versions for clarity) of the flow contribution time series from Figure 3 clearly illustrates the average yearly timing of natural and human effects (Figure 4).

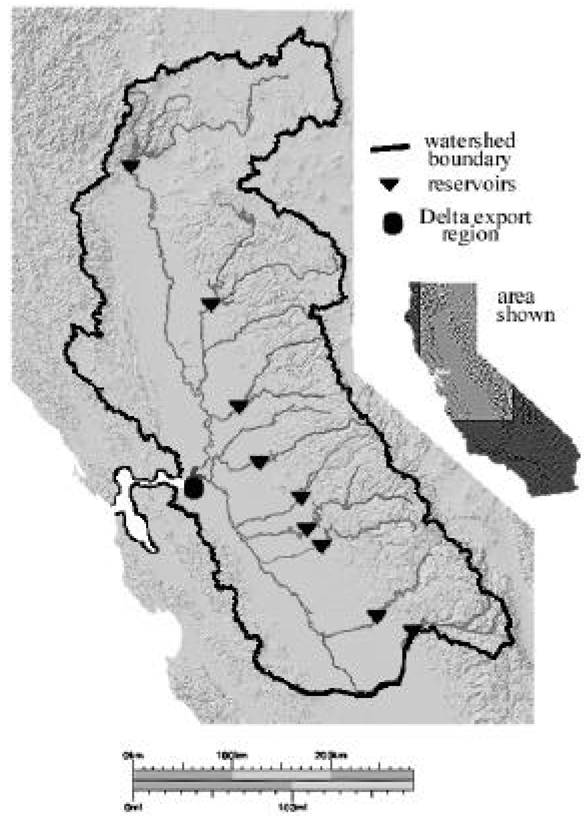

Figure 2 Map of the San Francisco Bay-Delta estuary and watershed, showing locations of major human influences on freshwater flows.

Analysis of Delta Outflow Components

Natural flows reach a peak in February and March, with the low flows of the dry season extending from July through October. On average, reservoirs effectively remove water from Delta outflow from February through early June, returning it during the dry season. The sharp peak in the negative reservoir effect in May is due primarily to reservoirs in the southern Sierra capturing snowmelt runoff. Figure 4 also shows Delta exports to be at their maximum during June, July, and August, with the lowest diversions occurring from November through May. Though these human effects are clearly related to natural variability, the year-to-year character of these connections is not apparent from Figure 4. An empirical orthogonal function analysis (EOF) of standardized versions (with zero mean and standard deviation equal to one) of these time series provides a more quantified representation (Figure 5) of the relationships between human effects and natural variability.

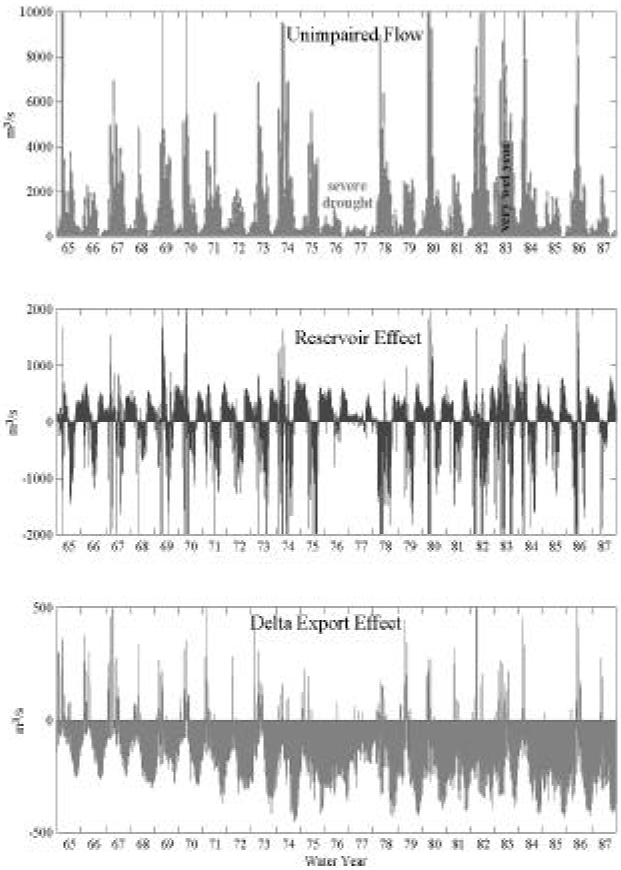

Figure 3 Estimates of unimpaired flows and effects of reservoirs and Delta exports on bay freshwater inputs through the Delta. Adding the three series yields estimates of Delta outflow. Water year spans from October 1 through September 30.

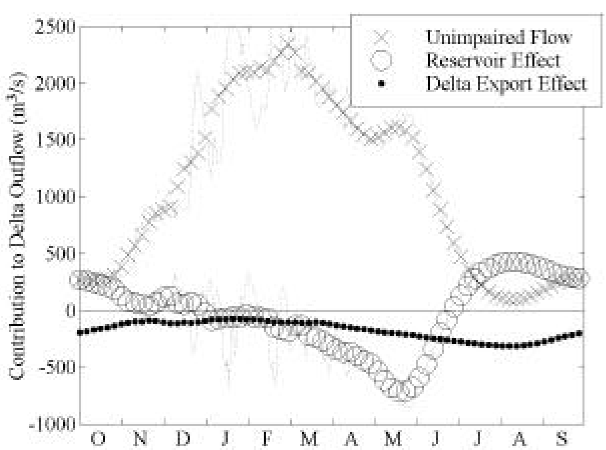

Figure 4 Mean annual cycles of unimpaired, reservoir, and Delta export flow contributions with 30-day smoothed versions

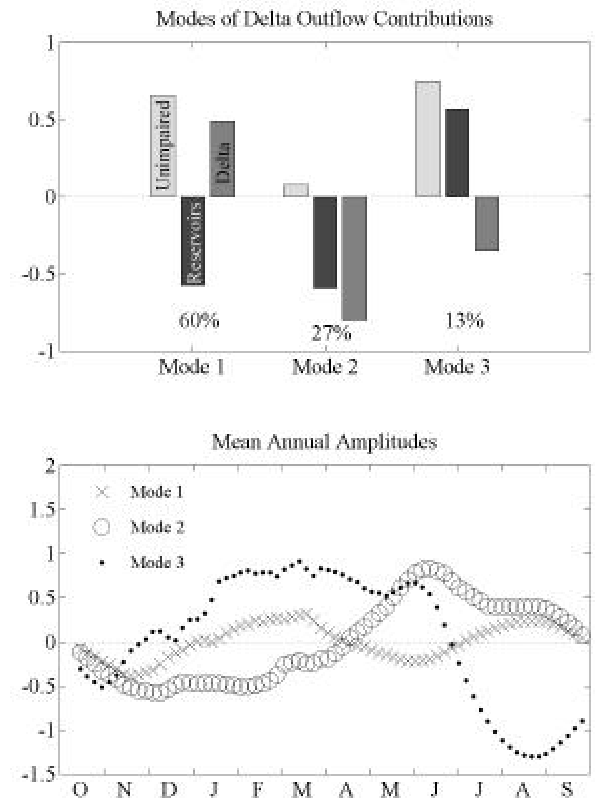

Figure 5 EOF Modes and their mean annual cycle amplitudes for daily Delta outflow contributions

The EOF analysis breaks down the variability of the three standardized flow components into portions that are perfectly correlated with one another, called "modes." Thus, if all natural variability were perfectly correlated with both human effects, only one mode would result, which would capture all of the Delta outflow variability. Conversely, if the three components were completely uncorrelated, the EOF analysis would yield three modes, each representing one of the original series. Here, the analysis yields three modes which explain 60%, 27%, and 13% of the total variance of the standardized data. The first and third modes represent flow variability which is directly due to, or results from a management action correlated with, concurrent (at the daily scale) natural variability. These "nature-correlated" modes capture a total 73% the variance. The dominant mode shows that reservoir effects and Delta export effects tend to be negatively correlated. This is no surprise as non-flood related reservoir releases are primarily scheduled to meet export demands. The remaining 27% of variance captured by the second mode represents human effects that are either unrelated to natural variations, or that are correlated, but with a time lag. This may represent, for example, changes in demand unrelated to natural variability or management actions based on the flow history or on runoff forecasts.

Two key results of this analysis of influences on Delta outflow are that human effects are strongly dependent on the large natural variability, and reservoir effects tend to be negatively correlated with both natural variability and Delta export effects. These will be shown to have significant implications for the Bay-Delta estuary.

SIMULATING THE ESTUARINE RESPONSE

The next step in evaluating human impacts is to develop simulations of the salinity field's response to the reconstructed flows. The model used here is the Uncles-Peterson model (Uncles and Peterson 1995), an advective-diffusive intertidal box model whose dominant inputs are tidal state (a measure of the spring-neap tidal status) and freshwater inflows. Other data used to force the model are coastal ocean salinity and local precipitation and evaporation. The model divides the Bay horizontally into 50 segments (Figure 6) and vertically into two layers (not shown).

This model simulates San Francisco Bay's daily- and laterally-averaged salinity and current fields with a very low computation load, making it ideal for applications requiring long-term, multiple simulations such as this study. It has been applied in several previous studies of the Bay and has been shown to accurately reproduce salinities at weekly to interannual time scales over a wide range of flow regimes (Peterson and others 1995; Knowles and others 1997; Knowles and others 1998).

To explore the effects of human-induced flow changes on the estuary, three versions of reconstructed Delta outflow were used to drive the model. The flow components (Figure 3) were summed sequentially to generate three hypothetical time series (Figure 7): unimpaired Delta outflow, Delta outflow with reservoir effects only and the estimated real Delta outflow, which includes both reservoir effects and Delta exports.

These three time series were used to force the U-P model over 21 water years from October 1966 through September 1987 to provide estimates of salinity under the three reconstructed levels of impairment.

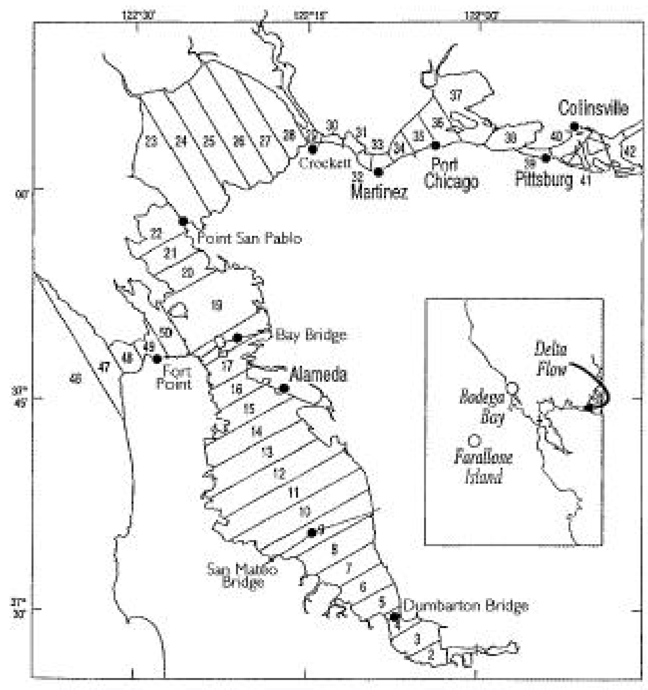

Figure 6 Segmentation of the UP estuary model used to simulate salinity

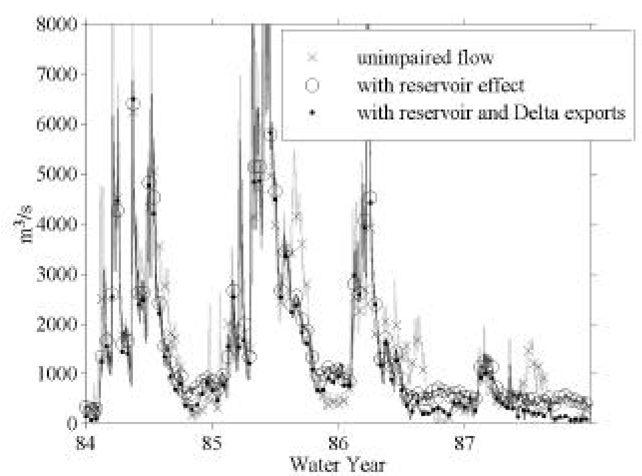

Figure 7 Sample time series for reconstructed flows with differing levels of human effects

IMPACTS ON SALINITY

Long-term Statistics

A plot of two simple measures of the influence of reservoirs and Delta pumping on salinity throughout the estuary—the mean and standard deviation of the daily salinity field (Figure 8)—reveals that though the effects on the mean salinity field might seem small, the final result of all human impacts is to raise mean salinity 1 to 2 psu throughout the estuary.

Reservoir effects alone tend to lower average salinity by up to 2 psu in the northern part of the Bay-Delta (from San Pablo Bay through the lower Delta), an indication of the practice of releasing water to repel salt from the export region during the dry season. Reservoir effects also reduce the variability of salinity, lowering the standard deviation by 1 to 2 psu from unimpaired levels. Delta exports have the opposite effect, restoring variability to well within 1 psu of unimpaired levels throughout the bay. The competing effects of reservoirs and Delta exports on the statistics of the salinity field are a result of their negative correlation, as discussed in the results of the modal analysis (Figure 5). It is also worth noting that since the North Bay is near zero psu in most wet seasons, human effects on salinity there are largely restricted to the dry-season months. In South Bay, on the other hand, salinity tends to reach a maximum in the dry season, and is relatively unaffected by human effects on Delta outflow, except during the wet season. It is also pertinent to remember that the relatively small South Bay inflows remain unchanged in these simulations; only impacts on Delta outflow are represented.

Mean Annual Cycle and Interannual Variability

Though human effects on the long-term statistics are small, changes in the mean annual cycle are much more significant. Human impacts on the monthly mean annual cycle of the salinity field's position are clearly indicated by X2 (Figure 9), the commonly used salinity index which is defined as the distance of the near-bottom 2 psu isohaline from the Golden Gate (Jassby and others 1995). High values of X2 correspond to saline conditions, while low values signify fresh conditions and higher inflows.

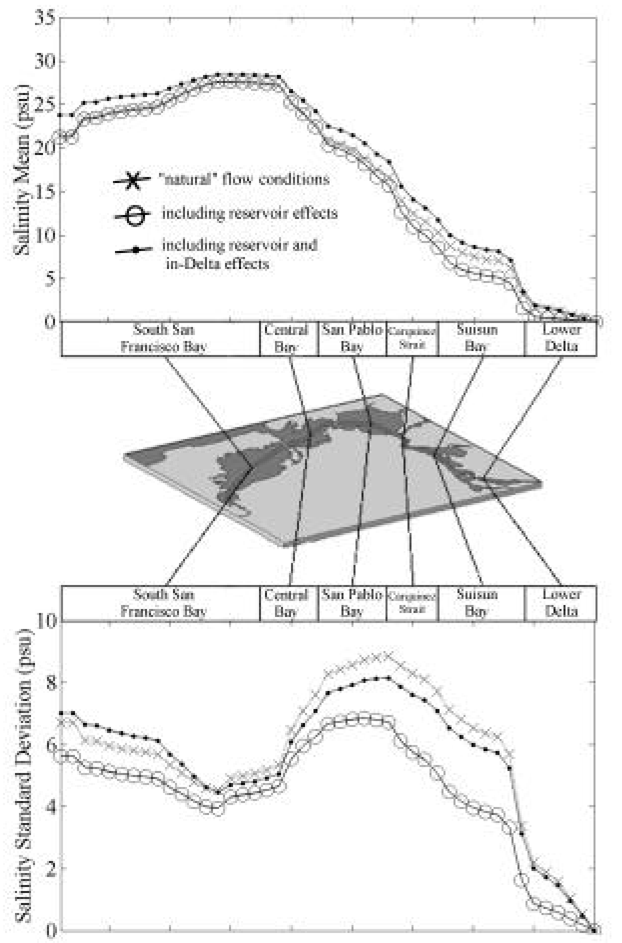

Figure 8 Mean (upper panel) and standard deviation (lower panel) of modeled Bay-Delta salinities over a 21-year period (October 1966 to September 1987)

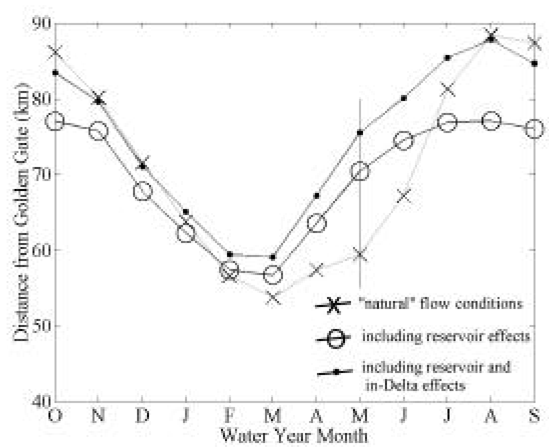

Figure 9 Average annual cycle of human effects on salinity. The maximum difference between "natural" and actual X2 is in May, as indicated. See Figure 10 for interannual variability of May effects.

Although in the long-term, reservoir and Delta export effects are negatively correlated and have competing effects on salinity relative to unimpaired conditions, Figure 9 shows that this is not true year-round. From February through mid-June, the two effects combine to increase monthly mean salinity levels, shifting X2 by a maximum of over 15 km up the estuary in May. During the dry season, on the other hand, reservoir effects move X2 as much as 10 km downstream relative to unimpaired conditions, while competing Delta exports increase the salinity, pushing X2 to near unimpaired levels.

Considering the large average human effects in spring, it is useful to examine the year-to-year variability of these effects. Figure 10 shows the relative May effects for each year of the record. X2 displacements due to reservoir and Delta export effects vary greatly, particularly at five- to ten-year intervals. Reservoir effects displace May X2 anywhere from 0 km to 22 km landward of unimpaired values. Delta export effects increase this displacement as much as 10 km. Despite the wide variability of these effects over the record, reservoirs and Delta exports consistently act in concert during this time of year. Both displace X2 landward in every year of the record, the only exception being the slight seaward displacement due to reservoirs in May 1977, the second year of an extreme two-year drought.

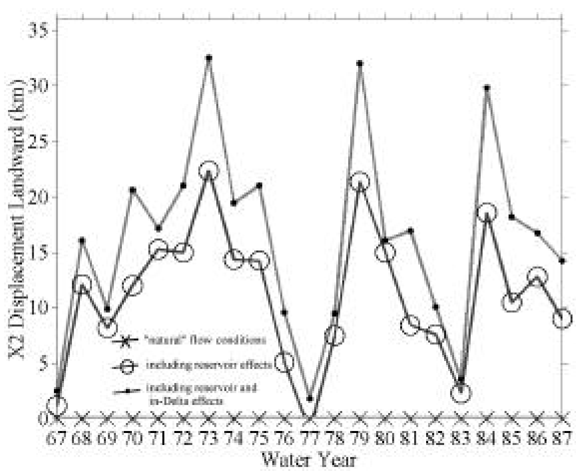

Figure 10 May residual management effects on salinity intrusion. See Figure 9.

A comparison of the X2 displacement data (Figure 10) and average "unimpaired" inflow rates (Figure 11) reveals no clear correlation at the annual scale between May management effects and natural variability. Also, May is the time when the second mode, representing human effects not correlated with natural variability, reaches its largest amplitude. It appears that in May, human effects on Delta outflow and bay salinities reach not only their highest level, but also their greatest independence from concurrent natural variability.

Extreme Years

Having examined the long-term and year-to-year effects of humans on salinity in the Bay-Delta, it is now interesting to consider the average effects in particular types of water years. After selecting the five wettest and driest years with respect to average annual "unimpaired" flow rates (Figure 11), composite mean annual cycles of X2 were generated for the different human impact levels (Figure 12).

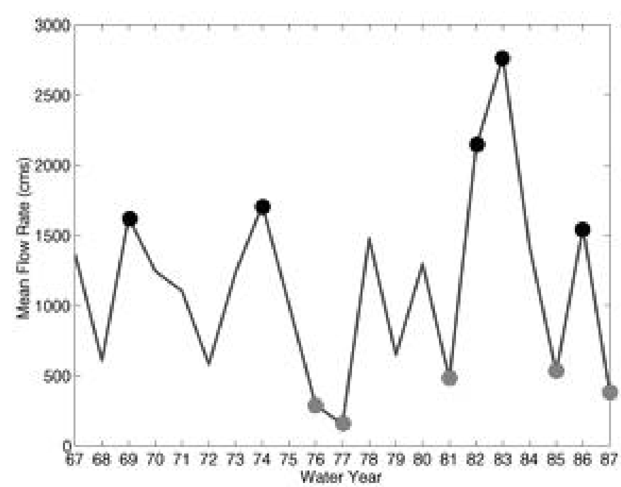

Figure 11 Annual average "unimpaired" Delta outflow rates with five wettest and driest years indicated

Several interesting facts emerge from a comparison of these two plots. First, with the exception of late summer, human effects on X2 (the spread between the simulated "natural" and "actual" values) are much stronger in dry years. Though this is partially due to the greater proximity of the 2-psu isohaline to the Delta during dry conditions, it is largely a result of increased human effects on flow during such years. Also, though spring effects are still the largest, during dry years, the maximum human effect comes in April, one month earlier than in the mean annual cycle (Figure 9). Conversely, in wet years this maximum occurs later, in June. Note also that though it may not be obvious, the maximum human effect on X2 is slightly larger in wet years than in dry years. In both composites, it is still true that reservoir and Delta effects counter one another during the dry season. This is particularly evident during dry years and during August and September of wet years, when releases for flood control storage generate a large reservoir effect.

Perhaps the most noteworthy aspect of the information in Figure 12 is that human effects in the estuary are dwarfed during the wet season by natural differences between the wet and dry composites. Clearly, the overwhelming difference in spring X2 values between relatively wet and dry years suggests natural variability will often effect the estuary in ways that are not, and likely cannot be, affected by upstream freshwater management.

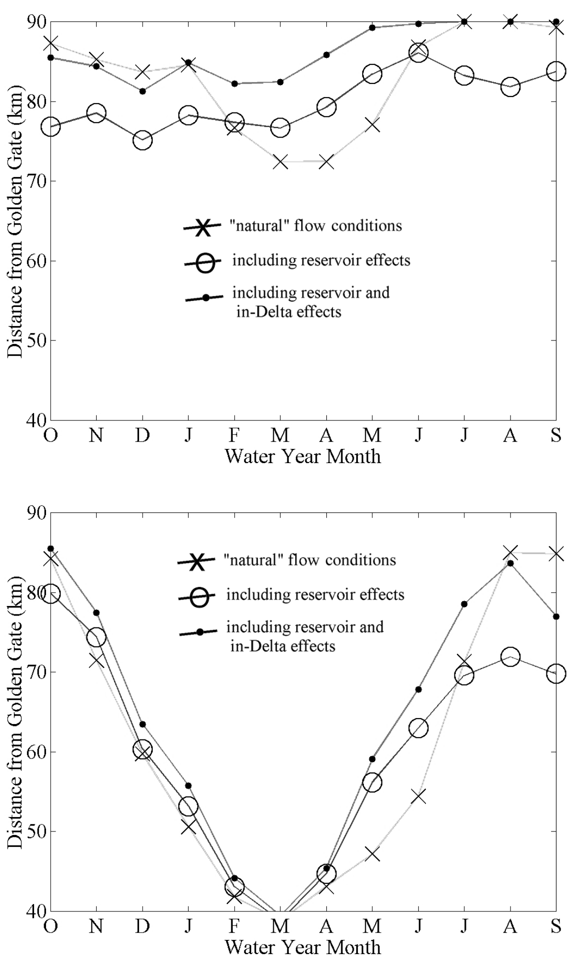

Figure 12 Dry and wet year composite annual cycle of human effects on salinity

Conclusions

In this study, effects of reservoirs and Delta exports on Bay-Delta salinity were estimated by using reconstructed Delta outflows to drive a numerical salinity model. Both natural and human effects exhibited large seasonal and interannual variability. The long-term mean annual cycles and a modal analysis of contributions to Delta outflow showed human effects to be strongly related to concurrent natural variability. Reservoir effects were largely negatively correlated with both natural variability and Delta export effects. This leads to competing effects from the two human influences on the mean and variance of baywide salinities. Within a water year, the relative effects of Delta exports and reservoirs are, on average, opposite during the wet versus the dry parts of the year. During the wet season, both effects serve to raise salinities, while they tend to offset one another during the dry season. While some of these results may seem obvious considering the operating procedures of the reservoirs and the Delta export facilities, understanding the magnitude and timing of these effects could have important implications for the health of estuarine ecosystems.

Spring was shown to be the period of largest human effects in the estuary in terms of X2. This is a critical time of year for many species in the estuary (Jassby and others 1995), though the implications of particular changes caused by altered flows are still poorly understood. The importance of spring is further emphasized by recent research, which suggests there is usually a snowmelt-driven runoff surge from Sierra watersheds that marks the transition from winter to spring (Cayan 1999). This phenomenon spans western North America and is driven by hemispheric atmospheric patterns. The large scale of these patterns suggests the spring snowmelt surge may be a predictable event, possibly allowing the timing and magnitude of the estuarine effects to be more accurately forecast.

Compositing mean annual X2 cycles for wet and dry years revealed several interesting differences in effects between water year types. For instance, maximum human effects occur earlier in dry years. The most interesting result, however, was that natural variability in the freshwater supply can cause large year-to-year shifts in salinity patterns which are not significantly altered by human effects. This has important implications for understanding ecosystem health. In the case of several consecutive dry years followed by several wet years, as has occurred since 1987, native and restored estuarine ecosystems must be capable of adapting to the accompanying shift in salinity regimes. Much attention has rightfully been given to the concept that "the volume and timing of freshwater flows to the Bay should reflect historical or natural conditions under which the bayland habitats and animals developed" (Goals Project 1999). Clearly, it is also important to consider the existing large natural variability when studying surviving and restored ecosystems, which are but remnants of the original ecosystem and must be able to adapt to inevitable natural variability.

Future work will include the development and application of a macroscale model of the Bay-Delta watershed's hydrology, including a more explicit accounting of the effects of irrigation, groundwater exchange, and land use change. This will permit the study of more subtle human impacts in the watershed and a better understanding of their implications for the estuary.

ACKNOWLEDGEMENTS

This work was supported by the California Department of Water Resources, Environmental Services Office, administered by Randy Brown. I am also grateful to Dan Cayan, Mike Dettinger, Fred Nichols and Dave Peterson for their helpful comments and advice and to Reg Uncles for providing the estuarine model. Thanks also to Scott Staggs of the CNRFC for providing natural flow estimates.

REFERENCES

Cayan D. 1999. The spring runoff pulse from the Sierra-Nevada. In: preprint volume. 14th Conference on Hydrology; 10-15 Jan 1999; Dallas, Texas. American Meteorological Society 77–9.

[DWR] California Department of Water Resources. 1998. Water Conditions in California. Sacramento (CA): California Department of Water Resources. 3 p.

[DWR] California Department of Water Resources. 1999. DAYFLOW Data, California Department of Water Resources. Available via the Internet at: http://iep.water.ca.gov/dayflow/data/.

[Goals Project] San Francisco Bay Area Wetlands Ecosystems Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project, US Environmental Protection Agency, San Francisco, California, and San Francisco Bay Regional Water Quality Control Board, Oakland, California. 169 p.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell T, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5(1):272–89.

Knowles N, Cayan D, Uncles R, Ingram L, Peterson D. 1997. Diagnosing the flood of 1997 in San Francisco Bay with observations and model Results. IEP Newsletter 10(3):28–31.

Knowles N, Cayan D, Peterson D, Uncles R. 1998. Simulated effects of Delta outflow on the Bay: 1998 compared to other years. IEP Newsletter 11(4):29–32.

Nichols FH. 1985. Increased benthic grazing: an alternative explanation for low phytoplankton biomass during the 1976-1977 drought. Estuarine Coastal Shelf Science 21:379–88.

Peterson D, Cayan D, DiLeo J, Noble M, Dettinger M. 1995. The role of climate in estuarine variability. American Scientist 83(1):58–67.

Uncles RJ, Peterson DH. 1995. A computer model of long-term salinity in San Francisco Bay—sensitivity to mixing and inflows. Environment International 21(5):647–56.

RECENT HISTORICAL EVIDENCE OF CENTRARCHID INCREASES AND TULE PERCH DECREASE IN THE DELTA

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BACKGROUND AND MOTIVATION

Recent preliminary results presented by Simenstad and others (1999) suggested native emergent vegetation would quickly colonize intertidal areas at intertidal elevation, but that exotic submerged and floating vegetation would dominate subtidal habitats like breached levee flooded islands in the Delta. The rates of sediment accretion they measured (10 to 43 mm/year) indicate that many years would be required to naturally return these flooded islands to intertidal elevations. This has potentially serious implications for fish restoration. Significantly higher densities of exotic centrarchid and ictalurid fishes were found in these subsided habitats with submerged and floating vegetation than in open habitats or habitats with emergent vegetation, which contained significantly higher densities of larval delta smelt and juvenile chinook salmon, respectively. Tule perch, *Hysterocarpus traski*, was the only native species reported by Simenstad and others (1999) to occur at significantly higher densities in submerged or floating vegetation.

We were curious about the co-occurrence of tule perch with a suite of exotic fishes. We were especially interested in comparing trends in abundance of centrarchids to tule perch. While the species are morphologically similar, they have different ecologies and very different reproductive life histories and intrinsic rates of increase. Recent evidence suggests embiotocids are in general decline in the bay (Baxter and others 1999) and in some cases, along the coast. This has been attributed to the small intrinsic rates of increase characteristic of embiotocids, which produce small numbers of nearly mature young (Moyle 1976). We wondered: are tule perch also declining, and what is simultaneously happening to the egg-laying and widely successful centrarchid species?

We decided to examine the salvage data for these taxa (an undertaking that has since expanded to all Delta resident fish species) to see whether any evidence of time trend is apparent. A preliminary analysis was presented by one of us (MN) at the October meeting of the Estuarine Ecology Project Work Team and by both of us at the November meeting of the Shallow Water Habitat PWT. This paper presents a more advanced, but still preliminary (and emphatically partial) analysis of the abundance of tule perch and centrarchid fishes in the Delta and Sacramento River. The work is ongoing and is being incorporated into manuscripts for peer-reviewed publication that explore changes in the Delta's shallow water fish community.

Sources of Information and Methods of Analysis

The CVP and SWP salvage databases and the USFWS beach seine database were examined to see whether centrarchid or tule perch time trends may exist. These species are routinely reported at low CPUE abundances in all three data sets. Although the data clearly provide a weaker basis than a focused monitoring program would have provided, we believe they provide a sufficient basis for estimating long-term trends. They are also among the only data sources with sufficient historical length to be useful for this analysis.

We fitted generalized linear models to species variables in all three data sets. Use of actual date rather than year of collection offered no advantage, so time was represented by year. Besides Year, we incorporated month of sample to explain seasonal variation, and a hydrologic variable to explain the effect of variation in Delta flow volume on CPUE. The Delta flow variable we used ("Total Delta Inflow") was the daily value of the DAYFLOW variable QTOT. In the beach seine analysis, we also incorporated collecting station to explain assemblage differences among the sites.

USFWS Beach Seine (1976–1998)

For examining beach seine data, counts from each of 6,520 seine hauls at a "core" subset of 28 Delta and Sacramento River stations were used for this analysis (Table 1). Because the seine program was active mainly during the winter and early spring months during the 1980s, we only used data obtained during January through April of each year for the period of record. In addition to tule perch, eight centrarchid species were examined (Table 2).

The counts were overdispersed relative to the Poisson distribution with equal mean, most likely because station means were influenced by unobserved habitat variables. To accommodate this, we fitted a general linear model that assumes a negative binomial distribution in the response (species) variable, using a computational routine written for S-Plus by Venables and Ripley (1999). The routine incorporates maximum likelihood estimation of the dispersion parameter associated with an unobserved variable having an assumed form likely to be appropriate in this case. The model ultimately adopted included terms for Year, Station, Month, and Total Delta Inflow.

Table 1 List of USFWS beach seine stations used in "core" station list [a]

			Latitude		Longitude	
USFWS Code	*Location*	*N*	*Degrees*	*Minutes*	*Degrees*	*Minutes*
AM001S	American River	274	38	36.17	121	29.39
DS002S	King's Island	278	38	3.52	121	27.45
GS010E	Georgiana Slough	227	38	13.55	121	31.56
LP003E	Terminous	285	38	6.73	121	29.82
MK004W	B&W Marina	285	38	7.65	121	34.76
MR010W	Woodward Island	169	37	55.30	121	31.65
MS001N	Sherman Island	242	38	3.36	121	47.09
SF014E	Wimpy's	277	38	13.63	121	29.44
SJ001S	Antioch Dunes	210	38	0.90	121	46.91
SJ005N	Eddo's	267	38	3.05	121	41.90
SJ026N	Venice Island	189	38	3.14	121	30.30
SJ041N	Dad's Point	229	37	57.45	121	20.95
SR012E	Stump Beach	249	38	8.01	121	41.14
SR014W	Rio Vista	206	38	11.19	121	39.69
SR017E	Isleton	254	38	9.77	121	36.71
SR024E	Koket	286	38	14.42	121	33.23
SR043W	Clarksburg	268	38	22.98	121	31.21
SR049E	Garcia Bend	338	38	28.65	121	32.51
SR060E	Discovery Park	304	38	36.05	121	30.49
SR071E	Elkhorn	244	38	40.37	121	37.42
SR080E	Verona	268	38	47.05	121	37.06
SR090W	Knights Landing	172	38	48.07	121	43.37
SR094E	Reels Beach	126	38	51.19	121	43.59
SR130E	South Meridian	119	39	6.93	121	54.30
SR138E	Wards Landing	144	39	11.66	121	56.16
SR144W	Colusa State Park	142	39	13.21	122	0.83
TM001N	Brannan Island	287	38	7.01	121	40.97
XC001N	Delta Cross Channel	181	38	14.74	121	30.18

[a] The project's station maps are available on the IEP web site: iep.water.ca.gov/juv_mig/beach/map.html. N represents the number of observations (seine hauls) in the dataset used in this analysis.

CVP and SWP Salvage (1979–1998)

For the salvage databases, data representing CPUE (individuals per acre-foot of water exported) for 7,025 days at the CVP facility and 6,710 days at the SWP facility were used for the analysis. All months were retained, and the data were averaged by month. Because the species CPUE variables were scaled sums of counts, we expected them to be gamma-distributed. The model ultimately adopted included terms for Year, Month, and Total Delta Inflow. For estimation of the model, the log link function was used. Because the CVP and SWP salvage facilities are operated differently, we chose to treat the data sets separately. The model in both full and reduced forms (with terms dropped) failed altogether to converge for a few less abundant species (see Table 2 notes). It was reduced to <fish var> about Year for tule perch in the SWP data; consequently the coefficient of Year is not comparable to those estimated for the other models, and is less likely to represent an actual trend.

INITIAL FINDINGS

With only a few exceptions, the inclusion of Year in the models substantially reduced the unexplained variation (= "deviance"), and, with only the exception of white crappie in CVP data and green sunfish in beach seine data, all the centrarchids for which a model could be estimated had coefficients to the Year variable that were significantly different from zero (see Table 2). Furthermore, all of the abundant centrarchids had a positive coefficient, which probably indicates an increase in abundance through time. The exceptions were green sunfish and warmouth in CVP data, which appear to be decreasing, but account for only 0.8% and 1.2% of centrarchids, respectively. The relative abundances of various centrarchid species varied substantially between the facilities, but we will leave that discussion for a future article. Tule perch had significant, negative time variable coefficients in all three data sets, suggesting decreasing abundance through time.

It should be observed that none of the models fitted here provide more than a partial explanation of the variation in the data. Residual deviance (analogous to residual sums of squares in ANOVA) was often a substantially larger proportion of null deviance than the total deviance accounted for by the model (more than 80% in a few cases). Consequently, although we believe we have fit the best possible models to these data, a great deal of deviance is unexplained. Much of it may be "pure error" or noise. However, it is possible that future models incorporating other variables may better fit these data, altering both the estimated coefficients and our interpretation of them.

Table 2 Apparent time trends in centrarchid and tule perch CPUE in salvage and USFWS beach seine databases, 1979 to September 1998 [a]

Taxon	*Overall Mean (AF^{-3}) [b]*	*Average % within Family [c]*	*Time Var. Coef.*	*Approx. Pr(Coef. = 0)*	*Notes*
CVP Salvage, 1979 – 1998 (Data for All Months)					
Centrarchidae					
green sunfish	1.91E-04	0.8	–0.2694	< 0.0001	
warmouth	3.06E-04	1.2	–0.0437	< 0.0001	
bluegill	1.74E-02	70.6	0.1220	< 0.0001	
redear sunfish	3.64E-04	1.5	0.3728	< 0.0001	
smallmouth bass	9.22E-05	0.4	0.1438	< 0.0001	
largemouth bass	4.02E-03	16.4	0.2632	< 0.0001	
white crappie	1.79E-04	0.7	0.0022	0.8241	
black crappie	2.07E-03	8.4	0.0812	< 0.0001	
Embiotocidae					
tule perch	2.80E-03	100%	–0.1998	< 0.0001	
SWP Salvage, 1979 – 1998 (Data for All Months)					
Centrarchidae					
green sunfish	1.25E-04	0.8	0.1195	< 0.0001	
warmouth	9.39E-05	0.6	0.1328	0.0145	
bluegill	3.99E-03	26.0	0.0826	< 0.0001	
redear sunfish	1.50E-05	0.1			1
smallmouth bass	3.58E-05	0.2			1
largemouth bass	8.93E-03	58.2	0.3093	< 0.0001	
white crappie	7.94E-05	0.5	0.2300	< 0.0001	
black crappie	2.08E-03	13.6	0.0198	0.0040	
Embiotocidae					
tule perch	1.30E-03	100	–0.0920	< 0.0001	2
USFWS Beach Seine, 1979 – 1998 (Core Stations, Data for January through April)					
Centrarchidae					
green sunfish	0.0064	2.2	–0.0565	0.5465	
warmouth	0.0008	0.3			1
bluegill	0.0972	33.1	0.0666	< 0.0001	
redear sunfish	0.0298	10.1	0.1583	< 0.0001	
smallmouth bass	0.0057	1.9	0.0611	0.0341	
largemouth bass	0.0411	14.0	0.0387	< 0.0001	
white crappie	0.1008	34.3	0.0396	< 0.0001	
black crappie	0.0120	4.1	0.0125	0.0177	
Embiotocidae					
tule perch	0.0434	100	–0.0867	< 0.0001	

[a] CVP and SWP salvage: A generalized linear model assuming a gamma distribution of the fish variables was used (log link = log). Salvage data were averaged by month and treated separately. The model for fish CPUE in salvage included terms for Year, Month, and Total Delta Inflow. USFWS beach seine: A generalized linear model assuming a negative binomial distribution of the fish variables was used (link function = log). Original counts were used. The model for fish species in the seine included terms for Year, Sampling Station, Month, and Total Delta Inflow. Partial results presented here include the coefficient of the variable Year in the fitted linear predictor for each model and probability (by C2) that it is zero. Notes: (1) Model could not be fitted because of convergence problems. (2) A reduced model, tule perch about Year, was used. Time variable coefficients are not directly proportional to rates of change.

[b] For USFWS Beach Seine, 1979–1998 (Core Stations, Data for January through April), Overall Mean ($haul^{-1}$) was calculated.

[c] Average percentages are calculated based on the family members represented in this table.

COMMENTS

Extending the qualification above, we add that these results are preliminary for two primary reasons (and several lesser ones). First, we have not taken account of the population size-structures we believe are being sampled. Variation in the strength and especially timing of recruitment of young-of-the-year fishes to the seine may, given the seasonal (January through April) truncation of the data set, have influenced the outcome of the analysis. This concern does not apply to the salvage data because data from all months were included in the analysis. Second, the use of instantaneous Total Delta Inflow as an explanatory variable is probably not the best choice for a hydrologic variable. Besides other variables, we are exploring other forms of this variable, especially forms summarizing outflow during some period immediately before each seine observation and will update our findings accordingly.

We believe that centrarchids are becoming more abundant in the Delta, and tule perch are declining, but these data provide only incidental evidence of the trends. If there had been a long-term monitoring program for vegetation-associated fishes, the findings might have been more striking. Consequently, we have resisted developing quantitative estimates of the rates of change using these data, though we may do so in the future.

It is unclear whether centrarchid abundance increases and the tule perch decrease are directly related. They were included in this initial analysis because of their morphological similarity, and their dissimilarity in potential reproductive rate. The habitat overlap indicated by Simenstad and others (1999) could set the stage for competition or predation-derived effects to tule perch, although direct resource competition between tule perch and centrarchids seems less likely. These possibilities will be explored further as our analysis progresses and will also be explored over the next two years during the predator-prey dynamics element of the Shallow Water Monitoring Methodology study.

The general increase in a suite of exotic species known to use vegetated shallow water habitats in the Delta indicates a substantial habitat change may be occurring (for instance, an increase in *Egeria densa* abundance, see Grimaldo and Hymanson 1999). The finding of Simenstad and others (1999) that breached levee restoration would likely result in more of this habitat type suggests we have a lot to learn about the physical and biological processes structuring the Delta's shallow water fish community before large-scale restoration projects are initiated.

REFERENCES

Baxter R, Hieb K, DeLeon S, Fleming K, Orsi J. 1999. Report on the 1980–1995 fish, shrimp, and crab sampling in the San Francisco Estuary, California. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 63. 503 p.

Grimaldo L, Hymanson Z. 1999. What is the impact of the introduced Brazilian waterweed *Egeria densa* to the Delta ecosystem? IEP Newsletter 12(1):43–5.

Moyle PB. 1976. Inland fishes of California. Berkeley (CA): University of California Press. 405 p.

Simenstad C, Toft J, Higgins H, Cordell J, Orr M, Williams P, Grimaldo L, Hymanson Z, Reed D. 1999. Preliminary results from the Sacramento-San Joaquin Delta breached levee wetland study (BREACH). IEP Newsletter 12(4):15–21.

Venables WN, Ripley BD. 1999. Modern applied statistics with S-Plus. 3rd ed. New York: Springer-Verlag.

SURVIVAL OF JUVENILE CHINOOK SALMON TAGGED WITH BIOTELEMETRY TRANSMITTERS

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INTRODUCTION

Biotelemetry systems have been used for many years to monitor fish activities (Winter 1983). Most of the studies have been conducted on large fish to minimize or eliminate the effect of the transmitter's weight on the fish's physiology and behavior. Current research on the West Coast has focused on describing the migration and movements of juvenile chinook salmon, but the size and weight of available transmitters limit telemetry studies of juvenile salmon. Winter (1983) recommended against using transmitters that weigh more than 2% of a fish's weight in air.

Advances in transmitter miniaturization have allowed the construction of biotelemetry transmitters (tags) which are of suitable size for juvenile chinook salmon >150 mm fork length (FL). Fisheries telemetry systems use either radio or ultrasonic transmitters, depending on the habitat of the species being tracked. Winter (1996) recommended ultrasonic telemetry for studies in saltwater or in freshwater with high conductivity, and in deep water, since these conditions cause little reduction in signal strength.

Unpublished California Department of Fish and Game (DFG) telemetry research on juvenile salmon concluded that ultrasonic tags are better suited than radio tags for the depth and salinity conditions found in the Sacramento-San Joaquin Delta (George Edwards, personal communication, see "Notes"). External attachment of ultrasonic tags resulted in greater mortality than internal surgical implantation, but the size of the tags (8 by 22 mm) prevented gastric insertion.

I conducted two experiments using nonfunctional or dummy tags to test the latest miniature ultrasonic tags on juvenile salmon. The objectives for the experiments were (1) to determine the survival and behavior of juvenile chinook salmon after tagging; (2) to select the most suitable type of tag attachment method based on survival and behavioral observations; and (3) to determine the minimum size of juvenile salmon that can be tagged without subsequent behavioral changes.

METHODS

First Experiment

I obtained 150 yearling late-fall-run chinook salmon from Coleman National Fish Hatchery and held them at a California Department of Water Resources (DWR) facility in Hood, California on the Sacramento River. The fish were subsampled from a larger group released on December 30, 1998 for a coded wire tag study conducted by the US Fish and Wildlife Service (USFWS). The holding facility consisted of four covered 568-liter stock tanks and a single 1136-liter tank. The tanks were located in a fenced enclosure maintained by DWR for the water quality station at Hood. Water was continuously pumped from the Sacramento River into the holding tanks. A supplemental air supply system aerated each tank.

Fish were held for one week prior to tagging. Tag insertion was conducted on January 6, 1999. Eighty fish were tagged using similar handling procedures. Fish were divided into three treatments and observed for a 14-day period. Treatments included gastric implant (tag inserted into stomach), internal tag (surgically implanted in body cavity), and surgery only (same as internal tag but without tag implantation). A control group (no manipulation) was also included. After tagging, each of the four, 568-liter tanks held 20 fish of each treatment plus the control group. Extra fish were held in the larger 1136-liter tank. Fish were held for a total of 38 days (7 days pre-tagging + 14 days survival analysis + 17 days observational period). The smallest transmitter available at this time (7 by 19 mm, 1.6 g) had an effective battery life of 14 days. Hence, a 14-day period was used as the end point for the survival analysis since fish released into the river would not be able to be located after 14 days. Daily observations were conducted to document any behavioral changes that occurred after the tagging procedures. Observation records included the number of dead fish and fish exhibiting abnormal swimming behavior. Other observations included water quality (dissolved oxygen, water temperature, specific conductance, and pH), water and air supply checks, feeding behavior, and disease incidence.

A fisheries pathologist examined the fish at the beginning and end of the 14-day survival study. He recommended treatment of healthy fish and removal of any fish exhibiting symptoms of disease before beginning the extended study. All fish observed with fungus, fin rot, or body discoloration were removed. Fish were held after the 14-day test to document any longer term survival and behavioral changes.

Second Experiment

A second dummy tag experiment was conducted shortly before a planned field tracking release study in early June. I obtained 40 juvenile fall-run chinook salmon from the Nimbus Fish Hatchery. These fish were tagged on May 25, 1999 and held at the Nimbus Fish Health Laboratory in Rancho Cordova. Based on the results of the first experiment these salmon were divided into two groups: control and gastric implant (treatment). Each group consisted of 20 fish. The fish were held in two, 76-liter aquaria with continuous air and water flow through each aquarium. A new type of miniature transmitter became available in spring 1999 (Sonotronics IBT-97-0). This transmitter was slightly heavier than the tag available in the first experiment (1.85 g), but it could be coded to identify individual fish. The battery life of this tag was adjustable up to 21 days, depending on the power output requested at the time of purchase. Observations were conducted daily over a 22-day period. A videotape was made of this experiment to document these observations and is available for viewing. Observation records were similar to those procedures described in the first experiment.

RESULTS

First Experiment

After 14 days, internally tagged fish suffered the largest (30%) mortality, followed by surgery only and gastrically implanted fish, both with 20% mortality. The control fish had 10% mortality (Table 1). Pre-tagging mortality as a result of transport from Coleman Hatchery and handling stress was four fish or 2.7% of the fish obtained.

Table 1 Survival against time in the first experiment[a]

Time	Control	Gastric	Internal	Surgery	Extra
Start	20	20	20	20	55
7 days	19 (95%)	18 (90%)	18 (90%)	20 (100%)	54 (98%)
14 days	18 (90%)	16 (80%)	14 (70%)	16 (80%)	52 (95%)

[a] Values in parentheses are percent survival from start of tagging period.

A chi-square analysis of the 14-day survival rates showed no statistically significant difference between the observed and expected survival rates among the four groups ($P^2 = 3$, $df = 3$, $a = 0.05$). However, the low number of fish in each group produced a low statistical power to detect a significant difference.

Two of the fish in the study clearly died from tagging complications. One, an internally tagged fish, was sluggish and had a darker coloration pattern from day 2 until it died on day 4. A second gastric tagged fish died suddenly on day 5. It had a swollen belly and a necropsy revealed the stomach was filled with water. The rest of the fish mortality was due to disease that affected the extra and control fish, as well as the tagged fish.

Disease affected all tanks of the fish being held at the facility during the experiment. Pathologists from the Department of Fish and Game's Fish Health Laboratory visited the facility twice. The first visit was conducted six days after the fish arrived, the second was done two weeks later. The initial pathology report indicated that the fish were in good general health and that a light *Epistylus* (protozoan) infection was present but of no health significance. A small *Saprolegnia* (fungus) lesion was found on one of four observed fish and was attributed to an early maturing condition found in the one-year old fish. The pathologist stated that some yearling late-fall salmon exhibit sexual maturation and soon perish naturally.

A second pathology report two weeks later described a variety of problems mostly due to handling, poor river water quality, and overfeeding. Caudal and dorsal fins were eroded and *Flexibacter psychrophilus* and fungus (*Saprolegnia* sp.) were present. Gills were infected with mixed motile bacteria (species unknown) and *Flavobacteria* sp. (fusiform bacterial gill disease). Excessive motile bacteria were also present on the skin, as well as moderate levels of *Epistylus*. Complications from the fungus and bacterial infections began shortly after the second week (day 6 of the study) of holding the fish.

Diseased fish often exhibited a progressive pattern of sickness that eventually resulted in death. A discoloration usually on the posterior dorsal portion of the body would first appear. On the second day, the fish would exhibit sluggish behavior and little flight response. By the third day, the fish would have eroded fins (primarily caudal) which would soon be covered in fungus. Death would result soon after. This pattern of symptoms occurred in all tanks. Fish placed in the extra tank also succumbed to this disease at similar rates. The disease did not affect all fish simultaneously, but slowly claimed fish in each tank over the study period. Fish that were held after the 14-day survival experiment to document longer-term behavioral changes continued to die of disease complications despite oxytetracycline treatments and daily salt baths.

The average fork length (FL) of the first experiment fish was 147 mm, (range: 121 to 178 mm) and the average weight was 32 g, (range: 19 to 56 g). The weight of the transmitter was 1.6 g, resulting in an average fish to tag weight ratio of 20:1 or 5% of the body weight. Except for the two fish that died from tagging complications and diseased fish, no differences were noted on swimming behavior for any of the tagged fish compared to the control fish. Healthy fish from all treatments responded with rapid flight movements from perceived threats, (hands waved above tanks during feeding).

Second Experiment

In the second experiment fish were held for a total of 23 days (1 day pre-tagging + 22 days post-tagging). Most mortality of the tagged fish (5) occurred within 48 hours after tagging (Table 2).

Table 2 Survival against time in the second experiment[a]

Time	*Control*	*Gastric*
Start	20	20
1 day	20	16 (80%)
2 days	20	15 (75%)
7 days	20	14 (70%)
14 days	20	13 (65%)
21 days	20 (100%)	12 (60%)

[a] Values in parentheses are percent survival from start of tagging period

Mortality rates of the tagged fish slowed after the first day of the study. Some mortality continued to occur, however, as some fish were unable to adjust to the tag. At the conclusion of the study (21 days) 12 tagged fish (60%) remained. Behavioral changes in the tagged fish occurred throughout the study.

Tagged fish exhibited two types of abnormal swimming patterns. Many fish were unable to swim and rested on the bottom of the tank while showing minimal flight response. Other tagged fish would swim upright in the water column with heads pointed at the water surface.

Feeding responses were non-existent in the tagged fish until day 4 when several fish ate a few pellets of their usual hatchery feed. Feeding response of the control fish was excellent, and their swimming behavior was judged normal. They exhibited rapid flight responses when threatened by hands waving above aquarium lid.

By the end of the 14-day period, the 13 tagged fish remaining seemed to have adjusted to the tag. Ten of the 13 fish were swimming and feeding normally.

The average fork length of the gastric-tagged fish was 108 mm, (range: 100 to 117 mm), and average weight was 14.6 g, (range: 11 to 20 g). The newer, coded tag weighed 1.85 g, resulting in an average fish to tag weight ratio of 7.9:1 or 12.7% of body weight.

One tagged fish was observed with a fungal infection on day 17 of the study, but disease was not a problem during this experiment.

Discussion

First Experiment

Results of the first experiment proved somewhat encouraging for the use of ultrasonic tags on juvenile chinook salmon in the Sacramento-San Joaquin Delta. Disease affected the test fish, but it also affected the fish in the control tank. Survival comparisons should remain valid between treatments because disease affected each treatment similarly. If disease is a naturally occurring problem with all hatchery fish released in the Delta, then future tagging studies could be designed to statistically accommodate fish killed by disease by increasing the number of tagged fish. Based on survival rates (Table 1), the best tagging methodology for ultrasonic tagging of juvenile salmon is a gastric implant.

Gastric implantation was also superior to internal surgery due to lower costs in materials, less handling during tagging, and the absence of performance or behavioral changes in gastrically tagged fish. The time required to perform a surgical implantation varied depending on the skill of the technician, but on average took two to four minutes of out-of-water handling. A gastric insertion requires no out-of-water handling and requires less than a minute to perform. Training for the gastric insertion is simple and can be learned after a few practice attempts. Fish tagged with gastric inserts in this experiment showed no behavioral changes compared to control fish.

During the extended holding period after the 14-day experiment, fish of all groups continued to die of disease complications. I intended to document long-term behavioral changes to the fish as they adjusted to the tags but the disease problems rendered these results meaningless.

Second Experiment

Results of the second experiment indicate that the smallest ultrasonic transmitters are not light enough to successfully tag juvenile chinook salmon much smaller than 120 mm FL. On the first day after tagging, 20% of the fish (4) had died and another 40% to 60% (8 to 12) were unable to swim normally. These results raised concerns that the fish in the planned field tracking study would be heavily preyed upon in the Delta. The planned fish release study was subsequently postponed, as no larger juvenile salmon were available until later in the year. Other researchers working on the Stanislaus River have released juvenile chinook salmon implanted with radio tags and have successfully tracked and captured striped bass which consumed the released salmon. (Craig Fleming, personal communication, see "Notes").

It was observed that ten of the tagged fish adjusted to the tag and displayed similar feeding and swimming behavior to that of control fish after 14 days. These fish, if released into the Delta, might have behaved similar to hatchery released fish. Unfortunately, the 14-day period required to adjust to the transmitter would have drained the battery. If the technology to activate a tag after it is inside a fish can be adapted to miniature tags or if longer life batteries are developed, it may be possible to release salmon of 100 to 120 mm FL and successfully track them. Until this occurs, I recommend against tagging juvenile salmon whose weight results in a tag-to-fish weight ratio of greater than 20:1 or that exceeds 5% of a fish's body weight.

CONCLUSIONS

I recommend using a gastric implant for ultrasonic transmitters on larger juvenile chinook salmon (>120 mm) in the Sacramento-San Joaquin Delta. Adams and others (1998) recommended surgical implantation over gastric implantation in a similar study using radio tags. They found that surgically implanted fish grew significantly more than gastrically implanted fish, but the external antenna of radio tags was shown to cause behavioral problems (coughing) in gastrically implanted fish. Ultrasonic tags lack an antenna and no behavioral differences between surgical and gastric fish were observed in this study.

Gastric tags allow for rapid implantation and minimal handling stress on the fish. Survival in the first 14 days following tagging was not significantly different from fish tagged using surgical implantation in the first experiment. I found that transmitter weights not exceeding 5% of a fish's weight did not noticeably affect swimming performance. Preferably, a tag should not be greater than 2% of a fish's weight. The smallest currently available ultrasonic transmitters weigh between 1.6 g and 1.85 g depending on specifications. As a general estimate, hatchery late-fall chinook salmon weighing 32 g (140 to 145 mm) and 37 g (155 to 165 mm) would meet a 5% criterion for these two tag weights.

Some smaller (100 to 117 mm, 11 to 20 g) fish might adjust to proportionately heavier tags in an aquarium given a suitable length of time (14 days). The battery life of current miniature tags ranges from 7 to 21 days, depending on signal power and programming settings. Unlike for larger transmitters, there is presently no method to implant a miniature tag and determine if a fish will be able to adjust to the tag without activating the tag. Unfortunately, miniature transmitter technology at this time does not allow researchers to remotely turn on a transmitter once it is placed within a fish. If this were possible, I believe that fish of this size could be tagged and released to accurately track their movements throughout the Delta with the types of transmitters presently available.

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REFERENCES

Adams SM, Rondorf DW, Evans SD, Kelly JE. 1998. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile chinook salmon. Trans Am Fish Soc 127:128–36.

Winter JD. 1983. Underwater biotelemetry. In: Nielsen LA, Johnson DL, editors. Fisheries techniques. Bethesda, (MD): American Fisheries Society. p 371–95.

Winter JD. 1996. Advances in Underwater biotelemetry. In: Murphy, BR, Willis DW, editors. Fisheries techniques. Bethesda, (MD): American Fisheries Society. p 555–90.

NOTES

Edwards, George. 1998. California Department of Fish and Game. Fish Facilities Research Unit. Stockton, California.

Fleming, Craig. 1999. United States Fish and Wildlife Service. Stockton, California.

TIDAL MARSH STUDY

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INTRODUCTION

We conducted an IEP funded Tidal Marsh Study from 1995 to 1999, sampling a variety of San Francisco Bay tidal marsh habitats in the lower Petaluma River and northern Napa-Sonoma Marsh for fishes, shrimps, and crabs. Adjacent deep water habitats, such as the Petaluma River and Napa Slough, were also periodically sampled. In 1999, we sampled several tidal marsh habitats in Browns Island (western Delta) and completed a series of mark-recapture experiments to determine the efficiency of several gear types. Previous *IEP Newsletter* articles have briefly described gear types used by habitat and summarized interim results (most recently, winter 1999 and fall 1999). Results from sampling several habitats for the entire study, the 1999 Browns Island sampling, and the mark-recapture experiments are summarized in this article.

METHODS

In the lower Petaluma River, we sampled a marsh plain, emergent vegetation, the larger third-order channels, and shallow open water over mudflat. Sampling locations included the Green Point Unit of Petaluma River Wildlife Area on the west side of the the Petaluma River, the Sonoma Land Trust Marsh on the east side of the river, and near the Black Point boat ramp. We also sporadically sampled tidal marsh habitats in the Rush Creek, Blackjohn Slough, and Petaluma River units of the Wildlife Area. These units are somewhat upstream of the lower river stations and the results are not included in this article.

In the northern Napa Marsh, we sampled similar habitats to those in the lower Petaluma River. The shallow open water area was tidally muted, as the water level is managed with a tide gate. Most of the stations were within or adjacent to the Huichica Creek Unit of the Napa-Sonoma Marshes Wildlife Area, although we also sampled the nearby Coon Creek Unit.

No one gear type was used to sample all habitats: we used modified minnow traps ("minifykes") and block traps in the first-, second-, and smaller third-order channels of the marsh plain, cast nets and block nets and a beach seine in the larger third-order channels, a bottomless lift net, throw cage, fyke trap, and experimental gill nets in emergent vegetation, and cast nets, throw cage, and beach seine in open water. To compare catches from the marshes with adjacent deeper water areas, a beam trawl, otter trawl, purse seine, and cast net were used to sample the fourth- and fifth-order channels and rivers.

Species composition by year is presented for several habitats and locations: marsh plain channels and emergent vegetation in lower Petaluma River and northern Napa Marsh and shallow open water (muted tidal) in northern Napa Marsh. Data for the larger third-order channels and shallow open water in the lower Petaluma River were not summarized for this article. Catches from adjacent deeper water areas are summarized in the text, but were not tabulated. Mean catch-per-unit-effort (CPUE), as catch/m^2 for demersal species or catch/m^3 for pelagic species, was calculated for the fyke, lift nets, throw cage, and block nets-beach seine. For the minifykes and block traps (used to sample the marsh plain channels), calculating CPUE was problematic, as many of the channels did not completely dewater during ebb tides.

We conducted mark-recapture experiments for the minifykes and block traps used in the marsh plain channels at our Petaluma River and Napa Marsh stations. We also conducted mark-recapture experiments for the fyke and throw cage at our standard Napa Marsh stations. Twenty-four hours before the mark-recapture tests, fish were collected, marked with a clip, and kept in a holding pen in the same body of water to be sampled. We attempted to use species that were representative of the communities sampled with each gear type for the mark-recapture tests. These tests were conducted late in the season when some species were no longer abundant; therefore some species were substituted for like species. For example, we used shimofuri gobies instead of yellowfin gobies and longjaw mudsucker.

For the minifykes and block traps tests, fish were placed in the channels during the flooding tide so they could acclimate to the area before the channels dewatered during the ebb tide. Fish were added to the fyke during high slack, just after the net was set. For the throw cage and block nets-beach seine, fish were added just after the nets were deployed and allowed to acclimate for five minutes before fishing began.

RESULTS

Marsh Plain

In the lower Petaluma River marsh plain channels, the threespine stickleback (*Gasterosteus aculeatus*), longjaw mudsucker (*Gillicthys mirabilis*), and yellowfin goby (*Acanthogobius flavimanus*) were the most common species collected (Table 1). The threespine stickleback and longjaw mudsucker are native species, resident to marsh habitats, while the yellowfin goby is introduced. The remaining species collected were a mix of native resident and transient species, including splittail (*Pogonicthys macrolepidotus*), and a few introduced species, shimofuri goby (*Tridentiger bifasciatus*), rainwater killifish (*Lucania parva*), and western mosquitofish (*Gambusia affinis*). Of note, 1999 catches were very low, with only a few longjaw mudsucker and yellowfin goby collected.

Our catches in northern Napa Marsh marsh plain channels were dominated by the native prickly sculpin (*Cottus asper*), shimofuri goby, and threespine stickleback (Table 2). Additional native species collected included Pacific staghorn sculpin (*Leptocottus armatus*), longjaw mudsucker, splittail, and tule perch (*Hysterocarpus traski*), while introduced species included all those collected in the lower Petaluma River marsh plain plus the inland silverside (*Menidia beryllina*). As for the lower Petaluma River marsh plain, our Napa Marsh catches were lower in 1999 than in previous years. Also, all the staghorn sculpin, but no prickly sculpin, were collected in 1999. This change in species composition was possibly due to slightly higher salinities in 1999.

Table 1 Number of fish collected and percent total in the lower Petaluma River marsh plain channels, 1995–1999

Species	*1995*	*1996*	*1997*	*1998*	*1999*	*Totals*	*%*
threespine stickleback	33	42		15		90	41.3
longjaw mudsucker	31	3	1	16	3	54	24.8
yellowfin goby	11	14	17	6	3	51	23.4
splittail	8					8	3.7
shimofuri goby		1	1	3		5	2.3
staghorn sculpin		1		2		3	1.4
rainwater killifish		3				3	1.4
prickly sculpin		1		1		2	0.9
western mosquitofish		1				1	0.5
goby species					1	1	0.5
Totals	83	66	19	43	7	218	
Sample Number	23	52	12	29	18		

Table 2 Number of fish collected and percent total in the northern Napa Marsh marsh plain channels, 1997–1999

Species	*1997*	*1998*	*1999*	*Totals*	*%*
prickly sculpin	71	3		74	35.6
shimofuri goby	10	30	2	42	20.2
threespine stickleback	3	31	1	35	16.8
staghorn sculpin			17	17	8.2
yellowfin goby	7	6	1	14	6.7
western mosquitofish	13			13	6.3
inland silverside	2	5		7	3.4
longjaw mudsucker	3			3	1.4
splittail		1		1	0.5
rainwater killifish	1			1	0.5
tule perch		1		1	0.5
Totals	110	77	21	208	
Sample Number	13	20	12		

Emergent Vegetation

Emergent vegetation (*Spartina* and *Scirpus* spp.) was a time-consuming habitat to sample, and sample numbers were relatively low each year (Table 3). In the lower Petaluma River, the yellowfin goby accounted for just over half of all fishes collected, with threespine stickleback, and Pacific staghorn sculpin also common. However, species composition changed in 1999, as staghorn sculpin was the most common species and no yellowfin goby were collected. Prickly sculpin, longjaw mudsucker, splittail, and the introduced shrimp *Palaemon macrodactylus* (not in the table) were also relatively common in this habitat. CPUE in emergent vegetation was lower in 1999 than in previous years. In 1998, mean CPUE was 1.5/m^2 for yellowfin goby, 2.0/m^3 for threespine stickleback, 0.55/m^3 for splittail, and 0.8/m^2 for *Palaemon* while in 1999, the mean staghorn sculpin CPUE was 0.2 m^2.

In northern Napa Marsh, shimofuri and yellowfin gobies were the most common species collected in emergent vegetation, followed by prickly sculpin, inland silverside, and splittail (Table 4). All of the splittail were collected in 1998, while all of the prickly sculpin were collected in 1999. We also collected longjaw mudsucker, rainwater killifish, and tule perch. As for the lower Petaluma River, CPUE was lower in 1999 than 1998: shimofuri goby CPUE was 0.05/m^2 in 1999, compared to 0.32/m^2 in 1998, while yellowfin goby CPUE was 0.01/m^2 in 1999 compared to 0.27/m^2 in 1998.

Table 3 Number of fish collected and percent total in the lower Petaluma River emergent vegetation, 1996–1999

Species	*1996*	*1997*	*1998*	*1999*	*Totals*	*%*
yellowfin goby	46	42	312		400	53.5
threespine stickleback	4		103		107	14.3
Pacific staghorn sculpin			15	62	77	10.3
prickly sculpin			38		38	5.1
longjaw mudsucker	23	2	4	7	36	4.8
splittail			25		25	3.3
inland silverside			21		21	2.8
western mosquitofish	19		1		20	2.7
shimofuri goby		4	6	8	18	2.4
rainwater killifish		2	3		5	0.7
striped bass			1		1	0.1
Totals	92	50	529	77	748	
Sample Number	2	2	11	8		

Shallow Open Water

We also sampled a tidally muted shallow pond in northern Napa Marsh (there was no comparable habitat in the lower Petaluma River). Our catches were dominated by inland silverside and rainwater killifish (Table 5); prickly sculpin, western mosquitofish, threespine stickleback, and shimofuri goby were also common. This was one of the most intensively sampled habitats, as the throw cage and cast nets are easily deployed. In spite of the relatively high effort, we collected only ten species, five of which were native. These five species accounted for only 9% of our total catch. This habitat had the highest mean CPUEs for the study: for 1996–1998, CPUE was 12.3/m^3 for inland silverside and 11.2/m^3 for rainwater killifish, and in 1999, CPUE was 14.3 m^3 for inland silverside and 17.0/m^3 for rainwater killifish.

Table 4 Number of fish collected and percent total in the northern Napa Marsh emergent vegetation, 1997–1999

Species	*1997*	*1998*	*1999*	*Totals*	*%*
shimofuri goby	3	34	24	61	43.0
yellowfin goby	4	29	6	39	27.5
prickly sculpin			13	13	9.2
inland silverside	10		1	11	7.7
splittail		9		9	6.3
longjaw mudsucker			3	3	2.1
rainwater killifish		2	1	3	2.1
tule perch	1	1	1	3	2.1
Totals	18	75	49	142	
Sample Number	3	4	12		

Table 5 Number of fish collected and percent total in a northern Napa Marsh tidally muted pond, 1996–1999

Species	*1996*	*1997*	*1998*	*1999*	*Total s*	*%*
inland silverside	170	108	226	115	619	47.9
rainwater killifish	122	51	187	129	489	37.9
prickly sculpin	20		58	11	89	6.9
western mosquitofish	1	36	1		38	2.9
threespine stickleback	4		11	10	25	1.9
shimofuri goby	2	4	11	6	23	1.8
staghorn sculpin				4	4	0.3
yellowfin goby			1	1	2	0.2
longjaw mudsucker				1	1	0.1
Sacramento sucker			1		1	0.1
Totals	319	199	496	277	1291	
Sample Number	44	45	42	41		

Deep Water

Species composition in the adjacent deeper water habitats differed from the marsh habitats, as transient species were more common in the deeper habitats. In the lower Petaluma River and adjacent larger sloughs, such as Blackjohn Slough, striped bass (*Morone saxatilis*), American shad (*Alosa sapidissima*), splittail, and the shrimp *Crangon franciscorum* dominated our catches. In 1999, topsmelt and northern anchovy were also common and we collected several Dungeness crab (*Cancer magister*). Although we collected no marsh resident species (longjaw mudsucker, threespine stickleback, rainwater killifish, western mosquitofish) from deeper water, we did collect species that were also common in the marshes, including yellowfin goby, prickly sculpin, staghorn sculpin, and inland silverside. Species composition in deeper water habitats adjacent to our Napa-Sonoma Marshes sampling sites was similar to Petaluma River. The major difference was that in 1999 we collected no topsmelt in Napa-Sonoma Marshes sloughs, but did collect three delta smelt.

Browns Island

We sampled several tidal marsh habitats in Browns Island sporadically with a variety of gear types in 1999 (Table 6). Although salinities were very low (0.3‰ to 3.5‰) at Browns Island, we collected many of the same species as in the higher salinity tidal marshes. Introduced species accounted for 8 of the 12 species and 91% of our total catch in this area. Splittail, Sacramento pikeminnow (*Ptychocheilus grandis*), tule perch, and threespine stickleback were the only native species we collected.

Mark and Recapture

The percent of marked fish recaptured in the mini-fykes and block traps (marsh plain channels) was very low for all species, ranging from 0% to 56% (Table 7). Recapture percentages were lowest for demersal species, such as the gobies and prickly sculpin and highest for inland silverside, a pelagic species. Recapture percentages were slightly higher in the block nets-beach seine, although a large number of demersal species were not available for testing. The fyke had consistently higher recapture percentages than either the mini fykes or block nets-beach seine, ranging from 33% to 57%. The highest recapture percentages were from the throw cage, with 67% to 93% of all fish recaptured. In this gear, the lowest recapture percentage was for prickly sculpin, the highest for inland silverside.

Table 6 Number of fish collected with each gear type at Browns Island, 1999

Species	*Cast net*	*Mini-fykes*	*Otter trawl*	*Blocknets-beach seine*	*Gill net*	*Total*
western mosquitofish	1	2		12		15
inland silverside	14					14
yellowfin goby				11		11
striped bass			8		1	9
rainwater killifish	1			4		5
threadfin shad	1		3			4
largemouth bass	2					2
splittail	2					2
tule perch			1	1		2
Sacramento pikeminnow					1	1
shimofuri goby	1					1
threespine stickleback				1		1
Totals	22	2	12	29	2	67
Sample Number	27	2	5	5	4	

Table 7 Number of fish marked, number recaptured, and percent recaptured with each gear type, 1999

	Minifyke and Block Trap			*Block Nets and Beach Seine*			*Fyke*			*Throw Cage*		
Species	*Marked*	*Recaptured*	*%*	*Marked*	*Recaptured*	*%*	*Marked*	*Recaptured*	*%*	*Marked*	*Recaptured*	*%*
inland silverside	9	5	55.6	37	22	59.5	155	89	57.4	75	70	93.3
longjaw mudsucker	2	0	0.0	1	0	0.0	6	3	50.0			
Pacific staghorn sculpin							2	1	50.0			
prickly sculpin	2	0	0.0	1	0	0.0	8	4	50.0	6	4	66.7
rainwater killifish	57	5	8.8	1	0	0.0	141	75	53.2	71	52	73.2
shimofuri goby	50	1	2.0	3	2	66.7	71	37	52.1	38	30	78.9
threespine stickleback	41	1	2.4	1	0	0.0				50	42	84.0
yellowfin goby				1	0	0.0	12	4	33.3			
Sample Number		6			3			4			5	

SUMMARY

In general, resident native species dominated our catches in the marsh plain channels, with a gradation to transient species, many introduced, as we moved to deeper open water habitats. Two introduced gobies, the yellowfin goby and the shimofuri goby, were collected in all habitats sampled in the lower Petaluma River and the northern Napa Marsh. The inland silverside was collected in all habitats sampled in Napa Marsh and all but one habitat, the marsh plain, in the lower Petaluma River. Splittail were also collected in all but one habitat (the tidally muted pond), but catches were limited to years of high abundance (as in 1995 and 1998).

The tidally muted pond in northern Napa Marsh had the highest fish densities, although our catches were dominated by introduced species. The water level in this area varied little over a tidal cycle and slowly decreased over the sampling season; it was also the only sampling area we routinely witnessed birds (primarily terns) foraging while we sampled. We also noted large numbers of egrets foraging in another area managed with a tidal gate that we did not routinely sample.

The mark-recapture experiments indicated that we are very unsuccessful in capturing demersal species, especially in the marsh plain channels. Surprisingly, recapture percentages were approximately 50% for all species in the fyke, which is also a passive gear. Capture rates were highest in the throw cage, which is sampled by sweeping the cage at least five times with a sweep net and dip nets.

The data presented in this article are preliminary. In 2000 we plan to complete a methods report for all sampling gear used in the Tidal Marsh Study and a more comprehensive report of results. Future results will include data from the larger third-order channels and the sporadic sampling of locations upstream of our lower Petaluma River stations. We also plan to complete more rigorous community analyses where feasible and compare our marsh data to other deeper water data sets, including the CDFG Napa Marsh study from the 1970s and Napa River data from IEP monitoring surveys.

ACKNOWLEDGMENTS

Tom Greiner worked on many aspects of the 1999 Tidal Marsh Study. Tom helped plan the sampling, was the field crew leader, identified fish in the laboratory, proofed data sheets, and summarized data. Ken Flowers, Zane Harris, Emily Kolkemo, Lisa Konyecsni, Spencer Lewis, Paul Macias, Andy Rockriver, Ramiro Soto, Gregg Schmidt, and Rakhal Turcotte conducted the field sampling. Emily Kolkemo, Lisa Konyecsni, and Spencer Lewis identified many small fish in the laboratory. Sally Skelton and Lisa Konyecsni entered and edited the 1999 data. Special thanks to Andy Rockriver, who designed the Access® data base and served as a tutor.

The Tow-Net Survey Abundance Index for Delta Smelt Revisited

Lee W. Miller, DFG

Introduction

The delta smelt, *Hypomesus transpacificus*, is listed as threatened and has consequently become a key species affecting water management in the Sacramento-San Joaquin estuary (Moyle and others 1996). This paper reexamines the methods used for summer indexing of delta smelt abundance.

The Summer Tow-Net Survey (TNS) has been used to index striped bass (*Morone saxatilis*) abundance in the Sacramento-San Joaquin Delta since 1959 (Chadwick 1964; Turner and Chadwick 1972) and more recently delta smelt abundance (Stevens and others 1990; Moyle and others 1992). The method currently used to index delta smelt abundance differs from that used for indexing young-of-the-year striped bass. For striped bass, abundance is interpolated at a catch length of 38 mm from a regression of the $\log_{10}$ abundance on mean length of the catch for the two surveys that bracket the mean catch length of 38 mm (Turner and Chadwick 1972). This approach accounts for variability in spawning time and growth to set an index at a size that reflects these effects. This was not done for delta smelt because length data were inadequate, and in some years only two surveys were conducted (Stevens and others 1990; Sweetnam and Stevens 1993).

Wadsworth and Sommer (1996) attempted to develop a size-standardized index for delta smelt similar to the one used for striped bass, but found that abundance had no consistent relationship to the mean length. Another problem with this approach is that no delta smelt were measured before 1973. Therefore a length-based delta smelt index would be limited to the post-1973 period, even if feasible. This paper describes an evaluation of a new mid-summer TNS delta smelt index based on the timing of the striped bass index, which reflects the synchrony of striped bass size with environmental conditions. Using the striped bass index period as a surrogate for the spawning and recruitment of delta smelt to the TNS gear could provide a more accurate index of abundance for delta smelt than the arbitrary use of the first two surveys to calculate the index. The young of both species have similar spatio-temporal distributions which make this approach plausible.

The new index was evaluated to determine if it would better reflect delta smelt abundance than the index currently used by comparing both indices to the Fall Mid-Water Trawl Survey (FMWT) delta smelt abundance index. Factors affecting the spawner-recruit relationship and summer-to-fall survival based on the new index are also explored.

Methods

Calculation of the New Delta Smelt Tow-Net Index

Tow-net surveys are conducted every other week beginning in mid-June or early July. To calculate the new delta smelt index, only the two surveys that determine the striped bass 38-mm index are used. The surveys can vary annually in tandem combinations from the first and second to the fourth and fifth. To calculate each survey's index, the sum of the catch in three tows at each station is weighted by the estimated water volume in acre-feet at the station. These products are summed over all stations and divided by 106 for reporting convenience. The mean of the two indices is the annual index. The old delta smelt index was calculated using the same methods, except only the first two surveys are used. The percent increase or decrease in the new index relative to the old index was calculated to evaluate changes in the two indices. The new annual index was also calculated for the six areas of the estuary reported by Stevens and others (1990): Montezuma Slough, Suisun Bay, Lower Sacramento River, Lower San Joaquin River, South Delta, and East Delta. In 1966, no survey was conducted, and in 1967 and 1968 delta smelt catches were not recorded.

Factors Affecting the Timing of the Striped Bass Abundance Index

The first step in justifying the new index was to demonstrate the relationship between the timing of the striped bass index and environmental conditions. The Julian calendar date (days past January 1) when the striped bass mean size reaches 38 mm was correlated with mean flows and temperatures. These Julian dates ranged from day 173 to day 242. Flow data were used from the California Department of Water Resources (DWR) DAYFLOW data base. Temperatures used were those of record for April to June 1983–1998 from DWR's continuous recorder data collections made on the Sacramento River (station RSAC101) at Rio Vista and on the San Joaquin River (station RSAN007) at Antioch.

Survey mean lengths of delta smelt were regressed on striped bass mean lengths to determine if both increased together indicative of a similar period of recruitment to the gear. Delta smelt 61 to 126 mm fork length (FL) were assumed to be from the previous year class based on a plot of length frequencies (Figure 1). These comprised 1.9% of all delta smelt measured and were excluded from length analyses. However, because not all fish counted were measured, no attempt was made to account for their small contribution to the abundance index.

Spawner-Recruit Relationship

The new index was evaluated for a spawner-recruit relationship using a Beverton-Holt model (Beverton and Holt 1957, as cited in Ricker 1975):

$$\text{Recruits} = 1/(\text{Alpha} + (\text{Beta}/\text{Spawners}))$$

The previous year's (FMWT) delta smelt abundance was used as an estimate of spawners and the new TNS index as a measure of recruits. The FMWT abundance index is based on sampling 100 stations in the estuary monthly from September to December. An abundance index is calculated monthly by summing the products of mean catch per tow and water volume for 17 subareas of the estuary. The total fall index is the sum of the four monthly indices (Stevens and others 1990). Regression relationships between log transformed spawner and recruit data were calculated for both the old and new indices to compare them.

Residuals from the spawner-recruit model were correlated with several environmental and prey variables. For example, copepods have been identified as the major prey of delta smelt (Nobriga and Lott, submitted; Lott and Nobriga, submitted). To estimate prey abundance where delta smelt occur, mean zooplankton densities were calculated from the California Department of Fish and Game's (DFG) zooplankton survey data for the specific conductance range where 95% of delta smelt abundance was sampled. For methods and distribution of sampling stations, see Orsi and Mecum (1986).

Survival between Summer and Fall

Summer-to-fall survival for both the new and old indices was evaluated for the period between the TNS and the FMWT. The survival index was calculated by adjusting both the FMWT index and the TNS index to their full volume weighted size and dividing the FMWT index by the TNS index. The FMWT index was divided by four to compute an average index value and multiplied by 104. The TNS index was multiplied by 106 to restore the index to its original size. Differences between decline and predecline periods in mean survival were tested using the Wilcoxon two sample test. Statistical analyses were done with SAS (1988) software. A significance criterion of " = 0.05 was used for all tests.

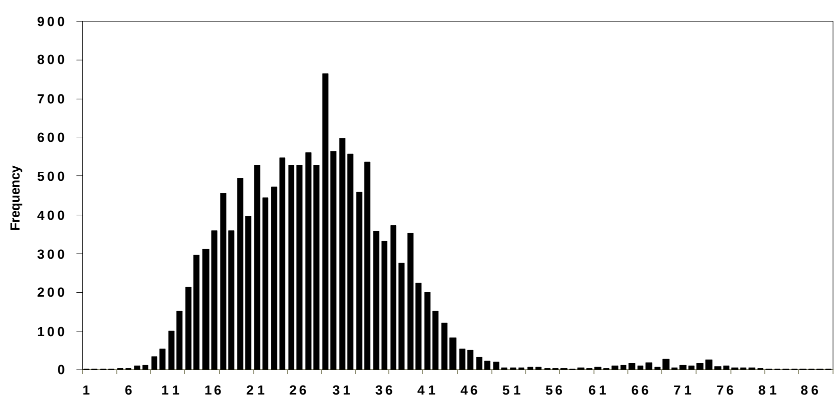

Figure 1 Length-frequency distribution of all delta smelt caught in the midsummer tow-net surveys. Fork lengths greater than 86 mm were omitted for clarity.

RESULTS

Factors Affecting the Timing of the Striped Bass Abundance Index

The striped bass index is set later in years of low temperature and high flows. The striped bass index date showed a significant negative correlation with both the Antioch and Rio Vista water temperatures for April, May, and June and was positively correlated with San Joaquin River and Sacramento River flows for the same months (Table 1). The relationship of the index date to San Joaquin River flows was weaker than the relationship with Sacramento River flows. Sacramento River flow and temperature at Rio Vista are strongly correlated (r = –0.84 for April, r = –0.76 for May, and r = –0.90 for June); mainly because in wetter years with spring storm events, water temperatures tend to be cooler than in dry, non-stormy springs. Therefore, the striped bass index date varies over a range of calendar dates in response to these conditions.

Table 1 Correlations of the 38-mm striped bass index set date with temperature (1983–1999) and with river flow (1959–1998)

April	*May*	*June*	*April*	*May*	*June*
Temperature at Rio Vista			**Temperature at Antioch**		
–0.687	–0.8245	–0.8098	–0.70260	–0.68364	–0.74820
P = 0.046	P < 0.0001	P < 0.0001	P = 0.0051	P = 0.0050	P = 0.0013
n = 15	n = 16	n = 16	n = 14	n = 15	n = 15
Sacramento River flow at Sacramento			**San Joaquin River flow at Jersey Pt.**		
–0.582	–0.673	–0.676	–0.562	–0.597	–0.630
P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0002	P < 0.0001	P < 0.0001
n = 39	n = 39	n = 39	n = 39	n = 39	n = 39

New Delta Smelt Index

The new delta smelt index was higher than the old index in 21 years, lower in only six and the same in ten years (years when surveys 1 and 2 were used). In 1959, 1965, 1972, 1977, 1987, 1988, and 1991, the new index was more than double the old index (Table 2). The new and old indices were strongly correlated (r = 0.801, P < 0.0001, n = 37). The delta smelt is most abundant in Suisun Bay and the Lower Sacramento River. The decline in abundance is evident in all areas (Table 3). The new index was significantly though weakly correlated with the FMWT survey indices except for November, whereas the old index was significantly correlated only with the December FMWT index (Table 4).

The relationship between the survey mean lengths of delta smelt and striped bass was significant and positive (R^2 = 0.329, P < 0.0001) (mean delta smelt length: 29.5 + 0.318 mean striped bass length) (s.e. = 1.72 and 0.049) with means increasing over time (Figure 2). However, the average survey mean size of delta smelt for all surveys was about half as variable as that of striped bass (c.v. = 2.1 for delta smelt compared to 27.7 for striped bass). The rate of increase in the mean length over the surveys was about three times greater for striped bass than for delta smelt. The mean delta smelt lengths were greater than those of striped bass in the early surveys but this difference decreased with later surveys (Figure 3). This convergence of mean lengths and the progressive changes in length frequencies for the two species, as well as the change in the delta smelt abundance, are illustrated using the four 1975 surveys (Figure 4).

Spawner-Recruit Relationship

The spawner-recruit relationship for the new index was not strong (Figure 5). The standard errors of the estimates for Alpha (0.026, s.e. = 0.0145) and Beta (12.4, s.e. = 9.92) were large relative to the estimates. A linear regression of the $\log_{10}$ recruits (new TNS index) to $\log_{10}$ spawners was significant (r^2 = 0.326, P = 0.003) and explained more of the variation than a similar regression using the old TNS index (r^2 = 0.189, P = 0.02). The regression relationship between the $\log_{10}$ FMWT index (spawners) and the $\log_{10}$ FMWT of the previous year's index (recruits) was not significant (r^2 = 0.022, P = 0.47). Therefore, the new TNS index provides a better, although weak spawner-recruit relationship than the relationship between the fall indices lagged by one year.

Eurytemora affinis density was the only variable significantly correlated with the residuals of the new index spawner-recruit relationship (Table 5). This relationship was driven by the high residual variation in four years which were associated with high *E. affinis* densities (Figure 6). The residuals from a spawner-recruit relationship based on the years before 1988, before the collapse of the *E. affinis* population, are also significantly correlated with *E. affinis* density ($r = 0.64$, $P = 0.013$). Hence, the residual abundance relationship with *E. affinis* is driven by the trends in the population before 1988 and not by the low *E. affinis* abundance after 1987. The residual variation in the spawner-recruit index for the old TNS index was also significantly correlated only with *E. affinis* abundance ($r = 0.48$, $P = 0.014$).

Survival Between Summer and Fall

The survival of delta smelt was higher for the post-decline years (after 1982) compared to pre-decline years (Figure 7). The mean survival index was 0.101 for the pre-decline years and 0.237 for post decline years and these means were significantly different (Wilcoxon $Z = -2.576$, $P = 0.01$). Survival was significantly but negatively correlated with *E. affinis* density (Table 6), a relationship inconsistent with the positive correlation expected between survival and food supply. This result likely reflects the time trends in both survival and *E. affinis* abundance. Survival was not significantly correlated with flows or other food variables, but the correlation with water transparency (Secchi disc) was nearly significant. Using the old index, the differences in mean survival between the two time periods was also significant (Wilcoxon $Z = -2.344$, $P = 0.02$).

Table 2 Relationship between the new and old delta smelt abundance indices [a]

Year	*Old Index*	*New Index*	*Difference*	*Percent Change*
1959	12.1	39.6	27.5	227.3
1960	25.4	24.7	–0.7	–2.8
1961	21.3	12.9	–8.4	–39.4
1962	24.9	24.9	0.0	0.0
1963	1.8	2.1	0.3	16.7
1964	24.6	42.4	17.8	72.4
1965	6.0	12.2	6.2	103.3
1969	2.5	4.2	1.7	68.0
1970	32.5	44.9	12.4	38.2
1971	12.5	24.2	11.7	93.6
1972	11.1	70.7	59.6	536.9
1973	21.3	23.4	2.1	9.9
1974	13.0	16.2	3.2	24.6
1975	12.2	14.7	2.5	20.5
1976	50.6	50.6	0.0	0.0
1977	25.8	52.0	26.2	101.6
1978	62.5	75.6	13.1	21.0
1979	13.3	15.7	2.4	18.0
1980	15.8	13.1	–2.7	–17.1
1981	19.8	19.8	0.0	0.0
1982	10.7	9.2	–1.5	–14.0
1983	2.9	2.9	0.0	0.0
1984	1.2	1.2	0.0	0.0
1985	0.9	1.0	0.1	11.1
1986	7.9	7.9	0.0	0.0
1987	1.4	3.2	1.8	128.6
1988	1.2	3.2	2.0	166.7
1989	2.2	2.2	0.0	0.0
1990	2.2	1.5	–0.7	–31.8
1991	2.0	7.9	5.9	295.0
1992	2.6	2.6	0.0	0.0
1993	8.2	12.1	3.9	47.6
1994	13.0	8.5	–4.5	–34.6
1995	3.2	4.4	1.2	37.5
1996	11.1	11.1	0.0	0.0
1997	4.0	4.0	0.0	0.0
1998	3.3	4.3	1.0	30.3

[a] No delta smelt were enumerated in 1967 and 1968, and no survey was conducted in 1966.

Table 3 Delta smelt new tow-net survey abundance index by area [a]

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
1959	0.0	3.5	34.5	1.6	0.1	0.1
1960	0.3	3.4	20.1	0.6	0.2	0.3
1961	0.0	0.3	10.5	1.0	0.1	1.1
1962	0.3	4.8	18.6	1.2	0.0	0.0
1963	0.0	1.0	1.0	0.2	0.0	0.0
1964	0.0	3.6	36.2	1.8	0.1	0.8
1965	0.1	2.8	8.6	0.6	0.2	0.2
1969	0.0	2.3	1.7	0.3	0.0	0.0
1970	0.0	3.8	39.2	1.3	0.2	0.4
1971	0.5	19.7	1.6	1.4	0.0	1.1
1972	0.0	1.0	68.7	0.8	0.1	0.2
1973	0.0	15.2	6.1	2.0	0.0	0.1
1974	0.1	14.3	0.2	1.5	0.0	0.1
1975	0.7	12.6	0.8	0.5	0.1	0.1
1976	0.1	4.8	41.2	4.1	0.1	0.4
1977	0.0	0.7	48.3	3.0	0.0	0.0
1978	1.3	27.2	46.9	0.2	0.0	0.0
1979	0.0	0.9	14.6	0.1	0.0	0.0
1980	0.3	8.5	3.2	1.3	0.0	0.0
1981	0.2	2.3	16.3	1.1	0.1	0.0
1982	0.4	7.7	1.0	0.2	0.0	0.0
1983	0.2	2.8	0.0	0.0	0.0	0.0
1984	0.0	0.9	0.3	0.1	0.0	0.0
1985	0.0	0.1	0.8	0.1	0.0	0.0
1986	0.1	1.0	6.6	0.1	0.1	0.0
1987	0.0	0.0	2.5	0.7	0.1	0.0
1988	0.0	0.2	2.9	0.2	0.0	0.0
1989	0.1	0.2	1.7	0.1	0.0	0.1
1990	0.0	0.3	1.1	0.2	0.0	0.0
1991	0.0	0.2	7.5	0.3	0.0	0.0
1992	0.0	0.3	1.8	0.5	0.0	0.0
1993	0.0	5.5	5.7	0.9	0.0	0.0
1994	0.0	1.4	6.3	0.8	0.0	0.0
1995	0.0	3.6	0.6	0.2	0.0	0.0
1996	0.1	7.1	3.4	0.6	0.0	0.0
1997	0.0	1.7	2.3	0.2	0.0	0.0
1998	0.0	4.3	0.0	0.0	0.0	0.0

[a] Areas: (1) Montezuma Slough, (2) Suisun Bay, (3) Sacramento River, (4) San Joaquin River, (5) South Delta, and (6) East Delta.

Table 4 Correlation of old and new tow-net delta smelt abundance indices with the fall midwater trawl delta smelt abundance index for 28 years of record

Tow-Net Delta Smelt Abundance Index	FMWT Delta Smelt Abundance Index				
	Total	Sep	Oct	Nov	Dec
Old	0.267	0.263	0.074	–0.037	0.589 [b]
New	0.425 [a]	0.492 [b]	0.373 [a]	–0.056	0.516 [b]

[a] significant at P = 0.05 to 0.01.
[b] significant at P < 0.01.

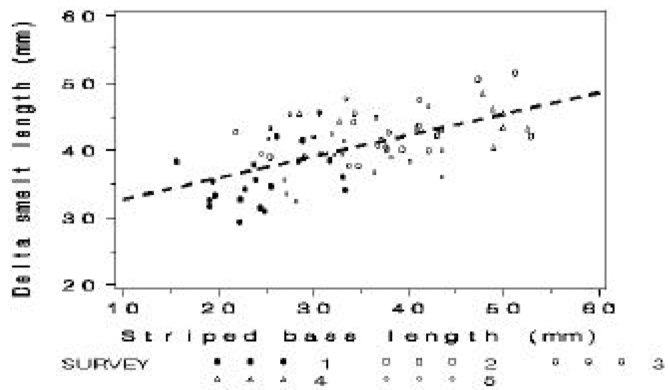

Figure 2 Relationship of delta smelt mean length to striped bass mean length for the midsummer tow-net surveys where the samples size of delta smelt was >30 fish per survey

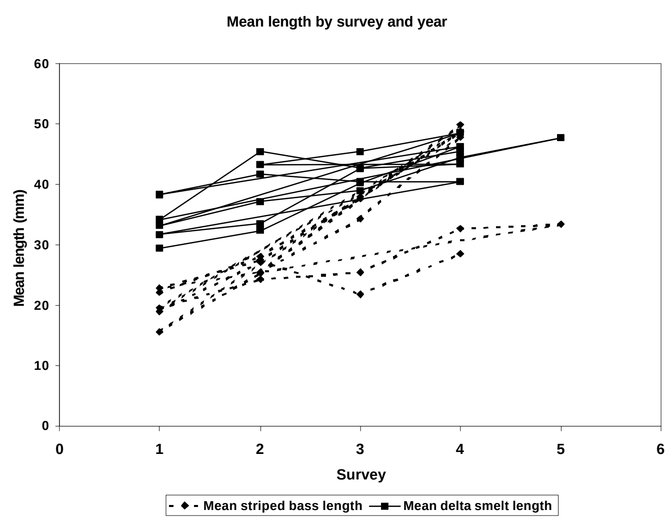

Figure 3 Annual plots of the mean lengths of delta smelt and striped bass over survey for those years when at least four or five surveys were conducted

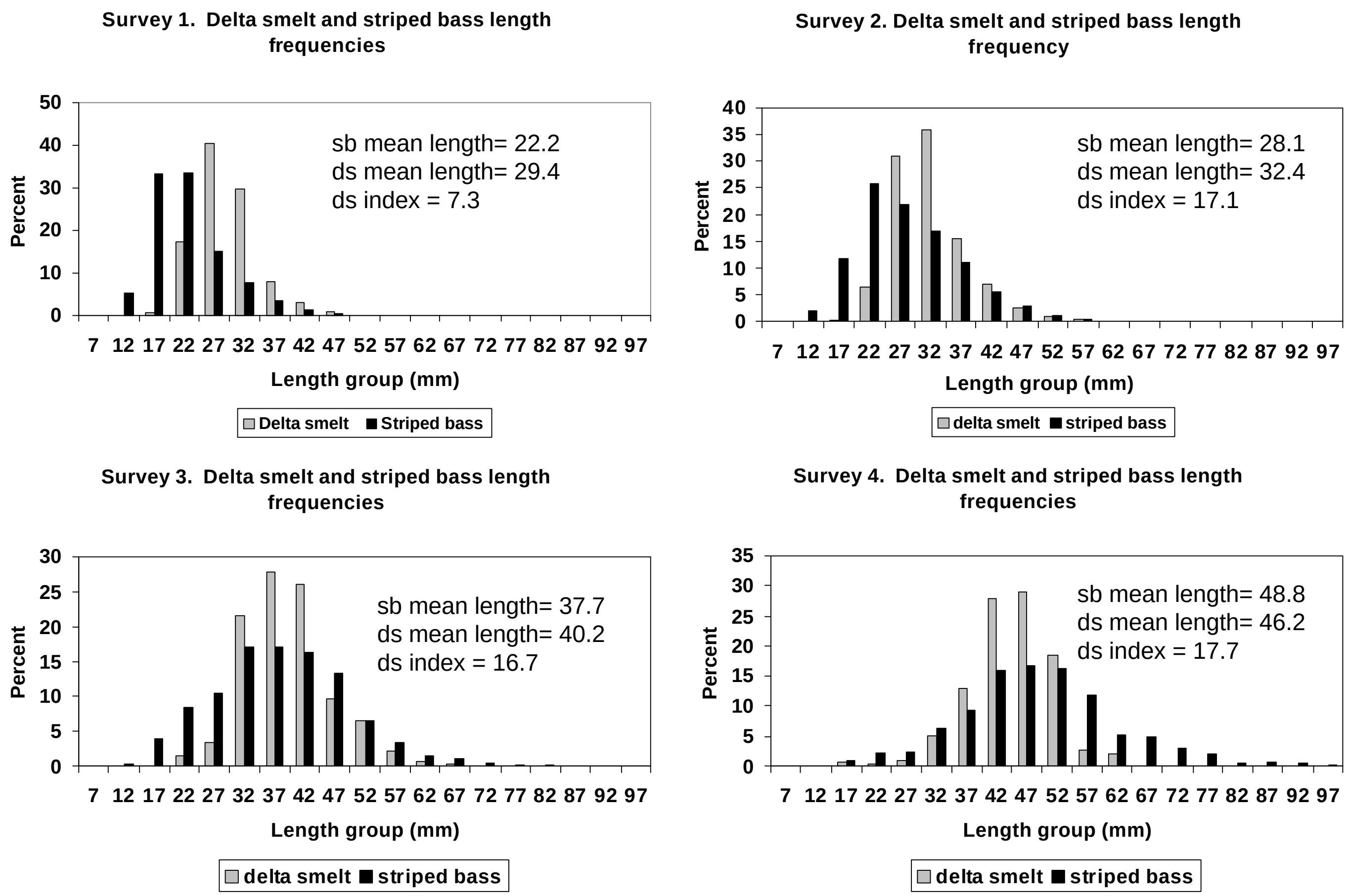

Figure 4 Length frequency distributions for striped bass and delta smelt for summer tow-net surveys conducted in 1975

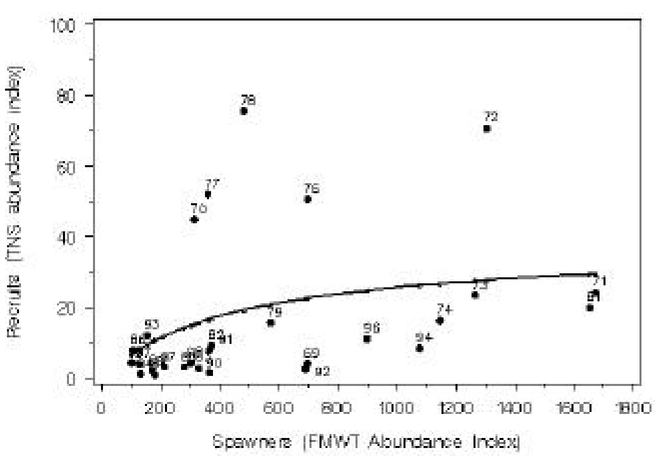

Figure 5 Beverton-Holt Spawner-Recruit model fit for delta smelt based on the new tow-net index as a measure of recruits and the previous FMWT abundance index as a measure of spawning stock

Table 5 Correlations of residual variation of recruit abundance for the new delta smelt index with annual means of environmental variables from April to June

Variable	*Correlation Coefficient*
Delta water exports	–0.091
Mean flow at Jersey Point on the San Joaquin River (Qwest)	–0.106
Log_{10} Delta outflow	–0.165
Water transparency (Secchi disc)	–0.390
Eurytemora affinis density at <6000 : S/cm EC	0.677 [a]
Calanoid copepod density at <6000 : S/cm EC	0.139
Cyclopoid copepod density at <6000 : S/cm EC	–0.101

[a] significant at $P < 0.01$.

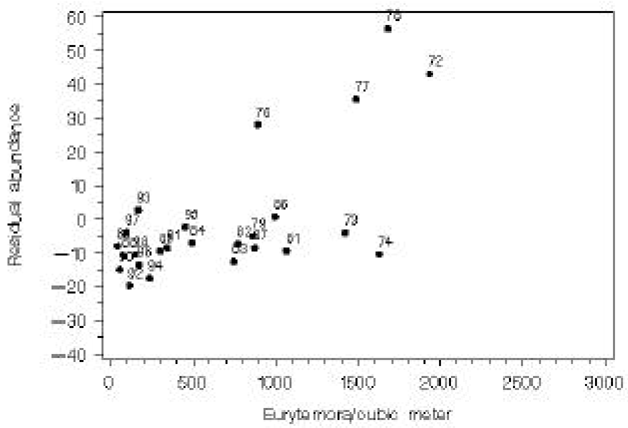

Figure 6 Relationship of residual abundance variation in recruits with *Eurytemora affinis* density

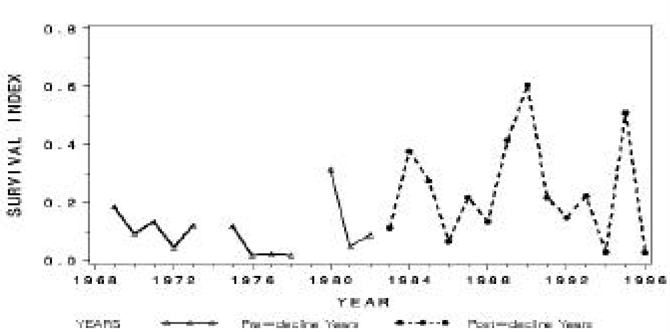

Figure 7 Trends in annual survival indices for delta smelt based on the midsummer tow-net survey and the FMWT abundance indices.

Table 6 Correlations of survival indices with mean environmental conditions for July through October

Variable	*Correlation Coefficient*
Delta water exports	0.249
Mean San Joaquin flow at Jersey Point (Qwest)	–0.076
Log_{10} Delta outflow	0.058
Water transparency (Secchi disc)	0.390
mean *Eurytemora affinis* density at # 12 mS/cm EC [a]	–0.402 [b]
mean calanoid copepod density at # 12 mS/cm EC	0.235
mean cyclopoid copepod density at # 12 mS/cm EC	–0.006

[a] Over 95% of all FMWT delta smelt were captured at # 12 mS/cm EC.
[b] Asterisk indicates an inconsistent relationship. See text for details.

DISCUSSION

Population parameters, such as spawning time and growth that determine the striped bass index date are likely affected by temperature. Therefore, the new delta smelt index more likely reflects seasonal timing by using the time of striped bass indexing as a surrogate for seasonal variation. Delta smelt mean lengths tend to be larger than those of striped bass in the first two surveys but converge in later surveys. This pattern suggests delta smelt may have a more prolonged spawning period or spawn earlier than striped bass. Delta smelt apparently spawn at lower temperature than striped bass. Delta smelt larva have been captured at temperatures as low as 11 °C, whereas striped bass eggs are first captured at temperatures of 14 to 15 °C (unpublished DFG Egg and Larva Survey data).

The conclusion that the new index is better is based on several findings. The new index tends to be higher than the old one because delta smelt tend to be more abundant when later surveys can be included. The positive correlations, albeit weak to moderate, between the new TNS index and the FMWT indices suggest the new index better reflects the relative abundance at midsummer than the old index which was weakly correlated with the FMWT in only one month. The new index when used in a spawner-recruit regression produces a stronger relationship than the old index.

The positive correlation of Beverton-Holt residuals with *E. affinis* may not be cause and effect but reflect coincident time trends. However, further research on this relationship is merited because *E. affinis* was the major delta smelt food item before its abrupt decline in abundance in 1988 (Lott and Nobriga) following the invasion of an Asian clam *Potamocorbula amurensis* (Kimmerer and others 1994). Before the sharp decline in *E. affinis* in 1988, there was a long-term decline in abundance (Obrebski and others 1992). Delta smelt feed mainly on calanoid copepods, including the introduced *Pseudodiaptomus forbesi*, which has become abundant since *E. affinis* declined. However, residual recruit abundance was not significantly correlated with total calanoid density (*E. affinis* plus *P. forbesi*). Total calanoid density did not decline after 1987 due to the increase in *P. forbesi*.

Average summer to fall survival increased significantly in the post-decline years, but the reason is not clear.

One possibility is that survival is higher because density has declined. Correlation of survival with food abundance and flow conditions were not significant and revealed no potential mechanisms for the change in summer to fall survival.

Abundance changes in the new index relative to the old one would not affect previous conclusions regarding the general decline in delta smelt abundance in all areas of the estuary or the timing of the decline as both become marked after 1982. Although the new index may not be as accurate as a size-standardized index, it is likely the most rational index possible with the data limitations. The new index and methods for calculating it should be used in future consultations and data analysis. Although the new indexing method is an apparent improvement, the new index sheds little new light on environmental conditions controlling delta smelt abundance or survival.

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REFERENCES

Beverton RJH, Holt SJ. 1957. On the dynamics of exploited fish populations. Fisheries Investigations (Ser. 2) 19. U. K. Ministry of Agriculture Fisheries. 533 p.

Chadwick HK. 1964 Annual abundance of young striped bass, *Roccus saxatilis*, in the Sacramento-San Joaquin Delta, California. California Fish and Game 50(2):69–99.

Kimmerer WJ, Gartside E, Orsi JJ. 1994. Predation by an introduced clam as the possible cause of substantial declines in zooplankton in San Francisco Bay. Marine Ecology-Progress Series 113:81–93.

Lott JL, Nobriga ML. The diet of delta smelt in the Sacramento-San Joaquin Estuary. Manuscript submitted to the Transactions of the American Fisheries Society.

Moyle PB, Herbold B, Stevens DE, Miller LW. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Trans Am Fish Soc 121:67–77.

Moyle PB, Pine R, Brown LR, Hanson CH, Herbold B, Lentz KM, Meng L, Smith JJ, Sweetnam DA, Winternitz L. 1996. Recovery plan for the Sacramento/San Joaquin Delta native fishes. Portland, Oregon: USFWS.

Nobriga ML, Lott JL. Feeding ecology of larval delta smelt. Manuscript submitted to the Transactions of the American Fisheries Society.

Obrebski S, Orsi JJ, Kimmerer W. 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin Estuary. Technical Report 32. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary.

Orsi JJ, Mecum WL. 1986. Zooplankton distribution and abundance in the Sacramento-San Joaquin Delta in relation to certain environmental factors. Estuaries 9(4B):326–39.

Ricker WE. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada. 382 p.

Stevens DE, Miller LW, Bolster BC. 1990. Report to the Fish and Game Commission: a status review of the status of delta smelt (*Hypomesus transpacificus*) in California. Candidate Species Status Report 90-2.

Sweetnam DA, Stevens DE. 1993. Report to the Fish and Game Commission: A status review of the status of delta smelt (*Hypomesus transpacificus*) in California. Candidate Species Status Report 93-DS.

Turner JL, Chadwick HK. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. Trans Am Fish Soc 101(3):442–52.

Wadsworth K, Sommer T. 1996. Should the delta smelt summer tow-net index be size-standardized? Interagency Ecological Program for the Sacramento-San Joaquin Estuary. Newsletter 8(2):24–6.

Update on Delta Smelt Culture with an Emphasis on Larval Feeding Behavior

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Introduction

This article gives a brief update on delta smelt culture and factors influencing larval feeding behavior. The detailed information is available in our recent report to the California Department of Water Resources (DWR) (Lindberg and others 1999). Our studies on delta smelt culture were supported by DWR, CALFED Bay-Delta Program, US Bureau of Reclamation, and Interagency Ecological Program for the Sacramento-San Joaquin Estuary. The California Department of Fish and Game provided assistance in obtaining delta smelt broodstock.

Our culture project was previously conducted at two facilities (Aquatic Center at UC Davis and State Water Project facility in the Delta at Byron), but has been consolidated at the Delta site since 1998. This decision stemmed from our observations on better spawning performance of smelt in the Delta water, compared to well water at UC Davis. The effect of water quality on smelt spawning was not investigated. The high hardness and alkalinity of the water at UC Davis may have adversely affected spawning. It is also possible that Delta water provides physical or chemical spawning cues absent in well water. However, Delta water at the SWP cite appears to carry disease vectors that severely affected larval survival in 1998 and 1999 (Lindberg and others 1998b; Lindberg and others 1999).

Recent (1998–1999) expansion of the SWP delta smelt facility and the installation of water purifying equipment (settlement tanks and ozone generator) improved culture conditions and enabled expansion of egg, larval and live food production, including the addition of a water-recirculating system with biological filtration. With these production systems in place, we were able to test larval rearing methods in two separate water systems, two sizes of larval tanks, and two stocking densities. Emphasis was placed on rearing the larvae from the onset of feeding to viable stages, as the larval stage of smelt is the most challenging life stage in culture.

We also extended our work on elucidating the environmental factors influencing larval feeding behavior (Lindberg and others 1998b). In particular, we tested for an effect of physical and chemical components of algal particles on larval feeding behavior. General methods of delta smelt culture have been described in previous reports (Lindberg 1996; Mager and others 1996; Lindberg and others 1998a, 1998b, 1999).

Summary of Smelt Culture in 1999

Broodstock Rearing and Spawning

Immature delta smelt were collected in fall 1998 and reared in circular flow-through tanks under a natural cycle of photoperiod and temperature (Lindberg and others 1999). As in previous years, the fish began to spawn in the spring when the water temperature rose above 14 °C. Nearly 115,000 eggs were collected in spring 1999, yielding more than 36,000 yolk sac larvae. This yield is substantially higher than obtained last year. Twice as many eggs were produced yielding 10,000 more larvae (Table 1).

Table 1 Captive delta smelt spawning summary for 1997–1999 at the SWP site near Byron[a]

	1997	*1998*	*1999*
Broodfish Number on 4/1/99	256	322	256
Spawning Events	55	71	146
Number of Eggs	34,709	53,776	114,895
Percent Fertility (%)	44	58	NA
Number Hatched	8,851	25,995	36,773
Percent Hatched (%)	26	48	32

[a] Spawning events (number of tanks/day that eggs were collected), egg fertility, and hatch of delta smelt. Fertility (%) is the number of live/total eggs on day 2 post spawn; not available in 1999. Overall hatch is the number of hatched larvae/total eggs collected, expressed as percent.

Larval Rearing

The reliable culture of larval delta smelt has not yet been achieved on a large scale. Rearing of larvae to juveniles is the major limiting factor, due to the length of the larval life-stage and high mortality during this period. We conducted experiments to compare survival in different water systems (flow-through compared to recirculating) and to investigate the effects of tank size and stocking density on larval survival and growth. Larvae were stocked at densities of 40 and 80 larvae/L in two replicate clear-tubular-acrylic tanks (20 L) covered with black plastic (except for a small vertical observation window). Two larger (80 L) black plastic tanks, were stocked with 40 larvae/L. These rearing experiments were performed in the flow-through and recirculating water systems. Each water system was equipped with mechanical and chemical filters and an ultraviolet sterilizer.

Each treatment was randomly assigned to two tanks ($n = 2$). All statistical procedures used SAS/STAT® software (SAS Institute 1985). Data expressed as percentages (survival) were transformed (arcsin square root) before conducting analysis of variance (ANOVA). Treatments were compared at each sampling time. Differences were considered significant at P # 0.05. When the ANOVA was significant, mean separation was determined using Duncan's multiple range test (Snedecor and Cochran 1993).

Cultured rotifers (*Brachionus plicatilis*) and brine shrimp (*Artemia*) nauplii, enriched with Super Selco® (Inve Aquaculture, Inc., Grantsville, UT) were added to the tanks four times a day (0800, 1200, 1600, and 2000 h) to maintain sufficient prey densities (about five rotifers and three nauplii per ml). Algae paste, prepared from *Nannochloropsis oculata* (Reed Mariculture Inc., Santa Cruz CA), was added to the tanks at each feeding at 3 million cells/ml to create a "green-water effect" and promote feeding (Mager and others 1996; Lindberg and others 1998b). All tanks had up-welling aeration and were maintained at 16 to 18 °C. Twenty larvae per tank were randomly sampled for total length at 20, 30, 40, 50, and 60 days after hatching. The survival was evaluated by counting larvae at 30 and 60 days.

Larvae reared in the ozonated flow-through system did not survive beyond 20 to 25 days of age. The survival in the recirculation system to 60 days was significantly higher ($P < 0.05$) in the large black tanks (31.6%) compared to the small tank (5.6%). Larvae grew faster in the larger tanks, reaching average total length of 16.6 mm compared to 12.9 mm in the smaller tanks. High stocking density (80 larvae/L) had no adverse effects on growth and survival. While the results of rearing trials can be affected by inadequate replications (due to space constraints), they suggest a more reliable production of juveniles can be achieved in larger tanks and at high stocking densities. The ability to culture larval smelt at high densities would reduce total production cost and required effort, by reducing the number of rearing units. In the next season we will continue larval rearing trials in the large tanks. We also are extending our larval culture facility to investigate the effect of rearing temperature on growth and survival of delta smelt larvae.

LARVAL FEEDING EXPERIMENTS

Methods

Larval delta smelt are about 5 mm in length and six to eight days old when they switch from endogenous to exogenous feeding. They are visual feeders, recoiling into an "S" shape and thrusting forward to ingest their prey. In previous years, we observed that larvae do not ingest rotifers in clear water, but they start to ingest rotifers within minutes after addition of an algal suspension to the tanks (Mager and others 1996). The results of our preliminary studies in 1998 showed that larvae feed well on rotifers if the algal cell density is higher than 3 to 4 million/ml (Lindberg and others 1998b). We were then interested to determine whether the algae played a physical or chemical role in promoting feeding behavior.

In 1999 we tested several related factors for their influence on feeding behavior of larvae, including algal cell density, filtered algal water, water turbidity (suspension of algal or clay particles), and light intensity. Four experiments were conducted using the method developed earlier (Lindberg and others 1998b). The sides and bottom of 2-L glass beakers were covered with black plastic except for a 5-cm vertical window. Larvae (age 7 d) were distributed at 20 per beaker with aeration and allowed to acclimate overnight. Treatments and live prey (rotifers at 10 per ml) were administered the following day. After allowing feeding for two hours, the contents of beakers were quickly passed through a sieve (600 µm) to collect and then fix the larvae in 5% buffered formalin. Preserved larvae were observed under the microscope to determine the percentage of fish with rotifers in the gut and the number of rotifers consumed per individual.

Four experiments were conducted, with the following treatments:

1. Algal cell density was tested with 6 replications per treatment: no algae; low density (1.5 million

cells/ml); medium density (3 million cells/ml); and high density (6 million cells/ml).

2. Filtered algal water was tested, with six replications per treatment: clear water (no algae, 0 nephelometric turbidity units, NTU); filtered algal water (0 cells/ml, 0 NTU); high cell density (6 million cells/ml, 25 NTU). The experiment was performed twice and the results were pooled. The “filtered algal water” treatment was prepared as follows. Fish were randomly distributed to 3 beakers (2 L), filled to one liter. Three additional beakers were placed in the water bath without larvae. All water was filtered using a 0.22-mm filter. The following day algae were added to the three beakers without larvae to achieve a concentration of 12 million cells/ml. The beakers were aerated for two hours, to simulate a typical feeding period. They were then filtered (0.22 mm) to remove algal cells, but collected exudates secreted by the algae. One liter of the filtered algal water was added to the three beakers, bringing the total volume to two liters.

3. Turbidity level was tested using a suspension of clay particles (bentonite), with three replications per treatment: clear water (0 NTU); algae at 6 million cells/ml (25 NTU); low density bentonite (25 NTU); medium density bentonite (50 NTU); high density bentonite (100 NTU). Turbidity levels were chosen based on the turbidity measurements at our Delta site during the smelt spawning season.

4. Light intensity compared to algal density were tested using a 3 by 3 factorial design, in two experiments:

First experiment (3 replications per treatment):

A. Light intensity:	B. Algal density:
1. Low (0.01 mmole/m^2/s)	1. Absent (0 million cells/ml)
2. Medium (0.3 mmole/m^2/s)	2. Medium (0.5 million cells/ml)
3. High (1.9 mmole/m^2/s)	3. High (2 million cells/ml)

Second experiment (3 replications per treatment):

A. Light intensity:	B. Algae concentration:
1. Low (0.1 mmole/m^2/s)	1. Absent (0 million cells/ml)
2. Medium (0.3 mmole/m^2/s)	2. Medium (3 million cells/ml)
3. High (2.3 mmole/m^2/s)	3. High (6 million cells/ml)

A completely random design was used to investigate the effect of algal concentration, turbidity, and light intensity x algal concentration (3 x 3 factorial) on the first feeding response of smelt larvae. A randomized complete block design was used in the algal filtrate study (block by experiment). All statistical procedures were conducted as described previously. Data expressed as percentages (percent of larvae eating) were transformed (arcsin square root) before conducting analysis of variance (ANOVA).

Results

Smelt larvae appear to require “green water” in the rearing unit to elicit a feeding response. In the first experiment, the density of algae significantly influenced the incidence of feeding and intestinal fullness (Figure 1A), confirming our preliminary observations (Lindberg and others 1998b). A higher percentage of the larvae initiated feeding and consumed more rotifers at algal concentrations of 3 and 6 million cells/ml. Eighty percent of the larvae in these treatments were observed with >4 rotifers in their intestine. In contrast, only 12.5% of the larvae were eating in clear water (no algae), with an average of 0.25 rotifers in their gut. Larvae held at the low algal concentration (1.5 million cells/ml) exhibited an intermediate response (38% eating, 1 rotifer/larva). We concluded that the algae promote a feeding response by either providing a chemical stimulant or a higher visual contrast with the prey.

The potential role of chemical stimulation was tested in the second experiment. The algal water (filtrate) did not significantly enhance the larvae’s feeding response (20.4%) compared to the clear water control treatment (6%), while the majority of the larvae (66.4%) in the positive control group, with algae (6 million cells/ml), were feeding well (Figure 1B). Gut fullness data show an even clearer response: only a few rotifer were consumed in algal filtrate and clear water treatments (0.36 and 0.15 per larva, respectively), whereas 2.9 rotifers per larvae were consumed when algae were added. This finding suggests the algal cell density acts as a physical, rather than chemical, factor in promoting feeding response.

The effect of turbidity on feeding behavior was investigated in the third experiment, using clay particles (bentonite) or algae. The majority of larvae (64% to 81%) were feeding when the turbidity level was at or above 25 NTU, whereas none of the larvae exhibited feeding in clear water at 0 NTU (Figure 1C). There was no significant difference in feeding between treatments with clay or algae at 25 NTU. This finding supports the hypothesis that the suspension of particles in the water is a critical factor for larval feeding. Turbid conditions may provide better contrast between the prey and their background, enabling the larval predator to better locate its prey (Boehloert and Morgan 1985). Larvae consumed 2.6 to 4.9 rotifers/larva in turbid conditions (25 to 100 NTU), and 0 rotifers/larva in clear water (0 NTU).

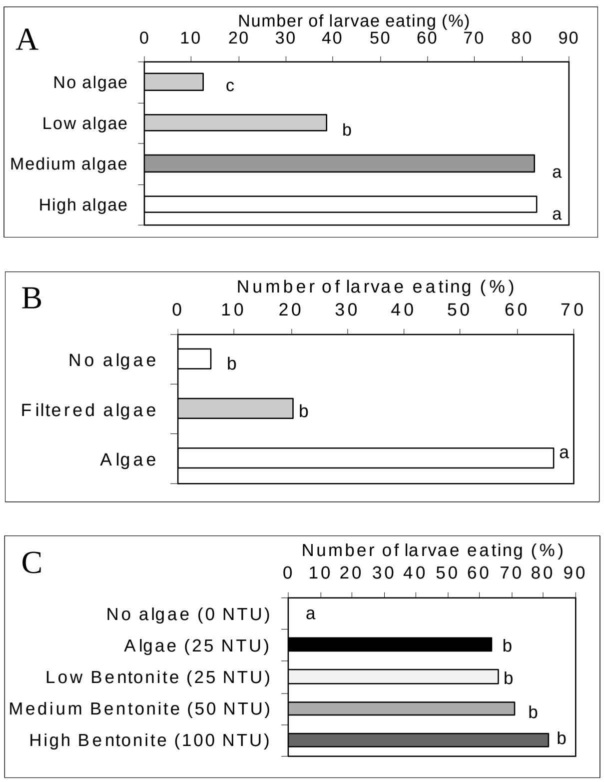

Figure 1 The effect of algal density (A), algal filtrate (B), and turbidity (C) on the first feeding response of delta smelt larvae. Bars with different letters were significantly different ($P < 0.05$). NTU: nepholometric turbidity units.

Finally, we investigated the influence of light intensity and algal concentration on first feeding of smelt larvae. There was a significant interaction, as the response to one factor varied over the levels of the other factor (Figure 2). There was a general trend of increased feeding activity with increased algal density, as observed in previous experiments. However, the response to light varied depending on the concentration of algae present. At high light intensity, low algae concentrations did not elicit a strong feeding response. Higher feeding activity was observed at high light intensity when the algal densities were above 2 million cells/ml.

Conclusions

Significant progress was made in 1999 for developing a method for culturing all life stages of delta smelt. Successful culture through the larval period is the biggest challenge due to the delicate nature of the larvae and their length of dependence on live prey. Only larvae reared in the recirculation water system (not the ozonated flow through delta water system) survived past 25 days post hatch. Data from rearing trials indicate that growing larvae in larger tanks and at higher densities improves their growth and survival. Adopting methods in our culture practices should improve production while reducing labor requirements.

Several experiments were conducted this past season to investigate the role of "green water," a suspension of algal cells, in eliciting a feeding response to rotifers in larval smelt. The physical components of the green water appear to be important. The chemical filtrate of algae did not significantly influence feeding, but abiotic clay particles could replace the algal cells and produced an equivalent feeding response. We also found that light level and algal density act together to enhance the feeding response in larvae. This information is being applied in the culture facility to promote optimal rearing conditions and may also be useful for the ecological studies on larval delta smelt. Turbidity in Suisun Bay in 1999 ranged from 13.5 to 90.6 NTU (G. Marsh, personal communication, see "Notes"), consistent with our test levels. The level of turbidity increased during April and continued to remain high until September. These conditions appear to be beneficial for first feeding smelt larvae, providing the adequate abundance of microzooplankton.

To achieve further progress in smelt culture, we will continue to test factors important to larval development, survival, growth, and feeding. We have expanded our broodfish facility to accommodate twice as many tanks. We are also expanding the larval facility to include a new recirculation system. This will enable us to test two rearing temperatures simultaneously. With these new systems in place we are in a good position to produce fish in higher numbers in the coming year.

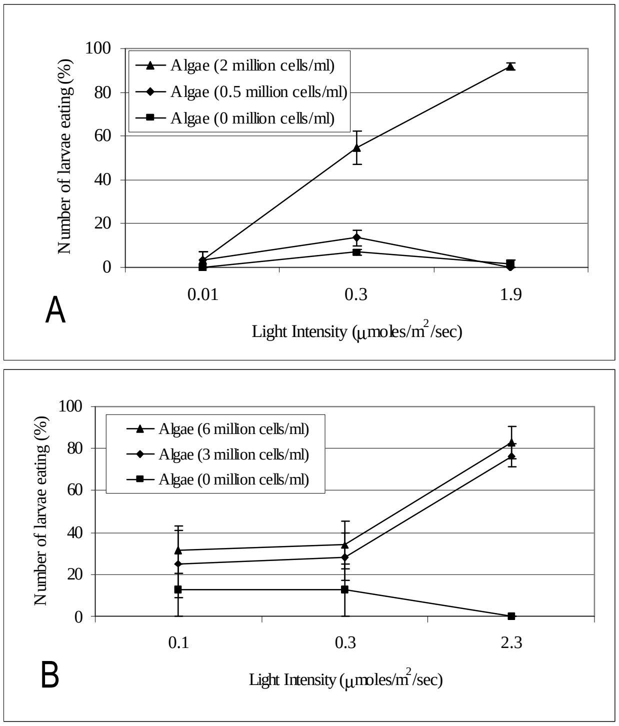

Figure 2 The effect of algae density and light intensity on feeding incidence of delta smelt larvae from experiment 1 (A) and experiment 2 (B). The simple effects are presented, due to a significant interaction between algal concentration and light intensity ($P < 0.05$). Values represent the mean " standard error of three replicates.

REFERENCES

Boehlert GW, Morgan JB. 1985. Turbidity enhances feeding abilities of larval Pacific herring, *Clupea harengus pallasi*. Hydrobiologia 123:161–70.

Lindberg JC. 1996. Delta smelt culture, state water site, 1995. Sacramento (CA): California Department of Water Resources.

Lindberg JC, Mager R, Baskerville-Bridges B, Kulczyk J, Van Eenennaam J, Doroshov S. 1998a. Delta smelt culture, 1997. Sacramento (CA): California Department of Water Resources. DWR B–80999.

Lindberg JC, Baskerville-Bridges B, Van Eenennaam J, Doroshov S. 1998b. Delta smelt culture, year-end report 1998. Sacramento (CA): California Department of Water Resources. DWR B–81355.

Lindberg JC, Baskerville-Bridges B, Van Eenennaam J, Doroshov S. 1999. Development of delta smelt culture techniques, year-end report 1999. Sacramento (CA): California Department of Water Resources. DWR B–81581.

Mager RC, Doroshov SI, Van Eenennaam JP. 1996. Development of laboratory culture of delta smelt, *Hypomesus transpacificus*. Sacramento (CA): California Department of Water Resources. DWR B–59306. 65 p.

SAS Institute. 1985. SAS user's guide: statistics. Version 5 edition. Cary (NC): SAS Institute.

Snedecor GW, Cochran WG. 1993. Statistical methods. 8th ed. Ames (Iowa): Iowa State University Press.

NOTES

Glenda Marsh (Department of Water Resources Monitoring and Analysis Branch). Phone conversation and e-mail with the author on December 17, 1999.

SIMILARITIES BETWEEN HATCHERY REARED DELTA SMELT AND WILD WAKASAGI FROM THE SACRAMENTO-SAN JOAQUIN DELTA

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INTRODUCTION

For a number of years the first investigator has been trying to develop a key to separate larval and juvenile delta smelt, *Hypomesus transpacificus*, from the morphologically similar wakasagi, *Hypomesus nipponensis*. Delta smelt are endemic to the San Francisco Estuary and Delta, while the wakasagi was introduced from Japan in 1959 (Wales 1962). Trying to develop this key has been complicated by the fact that these two species are morphologically similar. One example of these taxonomic problems occurs when the wakasagi leave Folsom Lake and move into the American and Sacramento rivers where their physical appearance changes and they become much more like the delta smelt.

The main way of distinguishing between the two species as juveniles and adults is through pigmentation under the lower jaw. In their natural environment, delta smelt start developing melanophores around and below the mandible of the lower jaw, in a horseshoe-like shape pigmentation pattern when fish reach approximately 20.0 mm. These fish have 0 to 1 melanophore located in the upper middle of the lower jaw, and there is no pigmentation present at the isthmus (Sweetnam 1995). For wakasagi, isthmus pigmentation appears when the fish reach approximately 15 to 20 mm in the lake population and approximately 25 to 30 mm for the estuary population. Isthmus pigmentation in wakasagi is typically more than two but less than 50 (but can be as high as 150) melanophores located in the middle of the lower jaw. The lake population has heavier pigmentation on the head, body, and fins; while the estuary wakasagi has much lighter pigmentation in these areas with some fish resembling the no pigmentation characteristics of the delta smelt. Isthmus pigmentation is the key characteristic used to separate wakasagi from delta smelt (Sweetnam 1995).

This article reports on the opposite phenomenon, namely adult delta smelt being taken from the estuary and reared in the fresh water hatchery tanks where they take on the physical appearance of wakasagi found in lakes.

METHODS

Captive delta smelt were obtained in July 1998, from Dr. Joan Lindberg. One hundred and eighty-five subadult and adult delta smelt (41 to 70 mm total length [TL]) were examined. In addition, in September 1999, Dr. Brad Baskerville-Bridges supplied another 88 delta smelt (58 to 80 mm TL). All fish had been preserved in 10% formalin. Fish were from the delta smelt culture program (see previous article), and represent mortalities during the rearing and spawning of the captive delta smelt. These fish originated from wild stock captured in fall 1997 and 1998 from the Chipps Island area near the confluence of the Sacramento and San Joaquin rivers.

A control group consisting of 64 subadult and adult wild delta smelt was collected at Tracy Fish Collection Facility from October through December 1997 and February through March 1999. An additional control group of approximately 70 wild wakasagi specimens was collected from Folsom Lake, Lake Oroville, and San Luis Reservoir between 1992 and 1999.

RESULTS

Approximately 21% of the wild delta smelt that were reared under hatchery conditions (40 of the 185) had the isthmus pigmentation similar to the wild caught wakasagi in 1998, and approximately 37% (33 of 85) in 1999. The density of melanophores ranged from a few melanophores to a full pigmentation covering the isthmus and adjacent areas. Stellate type (star shaped) melanophores were observed in the hatchery reared delta smelt, while the wild wakasagi typically had stellate, dashed, and block types of melanophores. Morphological measurements and fin ray counts obtained from hatchery reared delta smelt and control wild delta smelt were similar.

DISCUSSION

We do not know why some hatchery reared delta smelt exhibit the isthmus pigmentation typical of the wild caught wakasagi, while others do not. We believe this was a physical change in the delta smelt, brought about by environmental changes that occurred as a result of changing rearing habitats. Some of the delta smelt probably responded more strongly than others to the changes in their environment, from the estuary to the culture facility. The following environmental factors may have contributed to this phenotype change in the captive delta smelt:

1. Physical and chemical parameters of the rearing water.
2. Confinement in small fiberglass tanks in low light conditions.
3. Stress associated with the captive environment.
4. Body injury and other health problems.
5. Food differences.
6. Spawning stress in tanks lacking suitable spawning habitat.

For wakasagi, the identification problem is different. Wakasagi have successfully established a reproductive population in the estuary after descending from freshwater lakes in recent years (Wang 1995). These estuary wakasagi look different from the lake population, and look more like delta smelt with much lighter body pigmentation and a broad silvery band on the side. This indicates that the wakasagi phenotype is also strongly influenced by the environmental conditions found in the estuary.

Conclusion

To achieve accurate fish identification the fish biologist must use all resources available. In this case the biologist had to work with the geneticist to verify identification, because morphological characteristics proved inadequate to separate these two closely related species. During this study we cooperated with researchers at the University of California, Davis for allozyme analysis (May 1996).

References

May B. 1996. Identification of smelt species and their inter-specific hybrids in the Sacramento-San Joaquin Estuary by allozyme analysis. IEP Newsletter 9(3):9–16.

Sweetnam D. 1995. Field observation of delta smelt and wakasagi. IEP Newsletter spring:1–3.

Wales JH. 1962. Introduction of pond smelt from Japan into California. California Fish and Game 48(2):141–2.

Wang JCS. 1995. Field observation of possible larval and pre-juvenile wakasagi/delta smelt hybrids in the Delta and tributary streams. IEP Newsletter summer:18–9.

A Comparison of Fall Stockton Ship Channel Dissolved Oxygen Levels in Years with Low, Moderate, and High Inflows

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Introduction

Since 1968, Bay-Delta and Monitoring Section staff and supporting IEP staff have measured dissolved oxygen levels in the Stockton Ship Channel in late summer and early fall. Dissolved oxygen is monitored to determine if placement of the Old River closure is necessary and to monitor conditions during and after placement. This article compares the monitoring results obtained during years with low (1994), moderate (1997), and high (1998) fall inflows into the channel to determine if high inflows significantly improve dissolved oxygen levels within the channel.

Dissolved oxygen monitoring was conducted twice a month by vessel (the *San Carlos*) from August through November of each year. During each of the monitoring runs, 14 sites were sampled from Prisoner's Point in the central Delta (Station 1) to the Stockton Turning Basin (Station 14) (Figure 1). Dissolved oxygen and water temperature data were collected for each site at the top and bottom of the water column during ebb slack tide using traditional discrete (Van Dorn sampler and Winkler titration) and continuous monitoring (Hydrolab model DS-3 multiparameter surveyor) instrumentation.

Typically, dissolved oxygen levels in the eastern Stockton Ship Channel drop below 6.0 mg/L during the late summer and early fall because of low San Joaquin River inflows, warm water temperatures, high BOD, reduced tidal circulation, intermittent reverse flow conditions, and other factors. These low dissolved oxygen levels have been known to cause physiological stress to fish and block upstream migration of salmon in the San Joaquin River. Despite the distinctly different inflows into the eastern channel during the fall of 1994, 1997, and 1998, these conditions persisted. A brief description of the findings for different inflow conditions of each year follows.

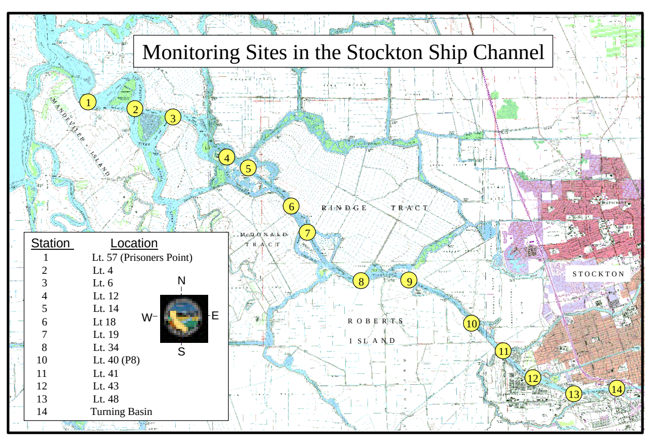

Figure 1 Dissolved oxygen monitoring sites in the Stockton Ship Channel

1994: A Dry Year with Low Fall San Joaquin River Flows

In 1994, average daily flows in the San Joaquin River past Vernalis approached 1,000 cfs in August and September and 1,300 cfs in October and November. Because of the low late summer and early fall San Joaquin River flows, the Old River closure was in place from September 7 through November 30. However, reverse flow conditions in the San Joaquin River past Stockton persisted throughout the late summer and early fall, as average net daily flows past Stockton ranged from –717 cfs to +168 cfs in August and September, and –308 to +301 cfs in October and November. These conditions apparently reduced any improvements attributable to placement of the closure.

Because of low inflows into the eastern channel, warm late summer water temperatures (24 to 28 °C), persistent reverse flow conditions past Stockton, and other factors, a dissolved oxygen sag (an area within the channel where levels were 5.0 mg/L or less) developed in the eastern channel in and immediately west of Rough and Ready Island (the Station 9 to 13 area) in August and persisted through early October (Figure 2). The lowest surface and bottom dissolved oxygen levels of 4.0 mg/L and 3.8 mg/L, respectively, were measured at the eastern end of Rough and Ready Island (Station 13) on August 22.

Cooler water temperatures in the channel on October 18 (16 to 19 °C) and November 18 (10 to 12 °C) and slightly improved flow conditions eliminated the sag area by October 18. Dissolved oxygen levels in the eastern channel fully recovered to levels similar to those in the western channel by November 15.

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 (the average daily flows past Vernalis briefly exceeded 3,000 cfs in mid-October). 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.

1998: A Wet Year with High Fall San Joaquin River Flows

In 1998, average daily flows in the San Joaquin River past Vernalis ranged from 4,753 to 6,708 cfs from August through October and average daily flows past Vernalis ranged from 1,020 to 2,011 cfs due to the exceptionally wet winter of 1997–1998 and the following cool, wet spring. Because of the exceptionally high flows and the absence of reverse flow conditions past Stockton, a closure across the mouth of Old River was not constructed in fall 1998.

In spite of exceptionally high San Joaquin River inflows into the eastern Stockton Ship Channel, a dissolved oxygen depression occurred in the central channel from Columbia Cut (Station 5) to Fourteen Mile Slough (Station 9) in August and early September (Figure 4). This area of depression is considerably west of the Rough and Ready Island area in the eastern channel where the sag area has historically occurred.

Relatively warm late summer water temperatures measured within the channel in August and early September (22 to 26 °C) appear to have contributed to the establishment of the dissolved oxygen depression in the channel in the late summer of 1998. However, at the range of water temperature values experienced in the late summer of 1998, dissolved oxygen levels have been lower (less than 5.0 mg/L) in the eastern channel in previous years.

The high San Joaquin River inflows into the eastern channel immediately east of Rough and Ready Island appear to have been sufficient to push the area of depressed dissolved oxygen levels westward from the historical sag area in the eastern channel to the central portion of the channel. Tidal fluctuations and greater water column mixing within the central portion of the channel may have contributed to the improved dissolved oxygen levels.

By September 18, 1998, the late summer dissolved oxygen depression in the channel was eliminated and by October 20, 1998, full recovery of dissolved oxygen levels to greater than 8.0 mg/L was accomplished throughout the channel due to cooler water temperatures (15 to 18 °C in October) and sustained high San Joaquin River inflows into the channel.

CONCLUSIONS

From August through October of 1998, average daily San Joaquin River flows past Vernalis (approximately 6,000 cfs) were six times the flows past Vernalis during the same period in 1994, and three times the flow past Vernalis during the same period in 1997. The significantly higher flows in 1998 did eliminate the dissolved oxygen sag normally present in the eastern channel. However, a dissolved oxygen depression developed within the Stockton Ship Channel in August and early September, when water temperatures were warmest, in spite of the significantly higher flows in 1998. Thus, the 1998 flow conditions apparently contributed to only partial improvement in late summer dissolved oxygen conditions within the channel.

Based on the 1998 dissolved oxygen monitoring results, placement of the closure at the head of Old River may produce marginal results in years with low to moderate fall San Joaquin River inflows. At no time during years with low to average fall flows in the San Joaquin River (such as 1994 and 1997, respectively) would placement of the Old River closure have improved flows sufficiently to duplicate the flow conditions and partial improvement on channel dissolved oxygen levels achieved in fall 1998.

POSTSCRIPT: THE STOCKTON TURNING BASIN IN 1994, 1997, AND 1998

Exceptionally high surface and low bottom dissolved oxygen levels were periodically measured in the Stockton Turning Basin throughout the fall in 1994, 1997, and 1998. During these periods, surface dissolved oxygen levels ranged from 9.6 to 15.4 mg/L and bottom dissolved oxygen levels ranged from 1.5 to 5.6 mg/L. Occasionally, the distinct dissolved oxygen stratification subsided, and surface and bottom dissolved oxygen levels became similar (within 2 to 3 mg/L of each other). These results are typical of all years.

The highly stratified dissolved oxygen conditions periodically detected in the basin during the late summer and early fall of each year appear to be the result of localized biological and water quality conditions occurring in the basin. The basin is at the eastern dead-end terminus of the channel and is subject to reduced tidal activity, restricted water circulation, and increased residence times when compared to the remainder of the channel. As a result, water quality and biological conditions within the basin have historically differed from those within the main channel downstream, and have led to extensive late summer and fall algal blooms and dieoffs. Usually a series of intense algal blooms composed primarily of crytomonads, diatoms, flagellates, and blue-green and green algae are detected. Stratified dissolved oxygen conditions appear to be produced in the water column of the basin by blooms in the following manner: (1) high algal productivity at the surface of the basin produces elevated surface dissolved oxygen levels and (2) dead or dying bloom algae settle out of the water column and sink to the bottom to contribute to high BOD. Bottom dissolved oxygen levels in the basin are further degraded by additional BOD loadings in the area such as regulated discharges into the San Joaquin River and from recreational activities adjacent to the basin. When bloom activity subsides, the dissolved oxygen stratification is reduced, and basin surface and bottom dissolved oxygen levels become less diverse.

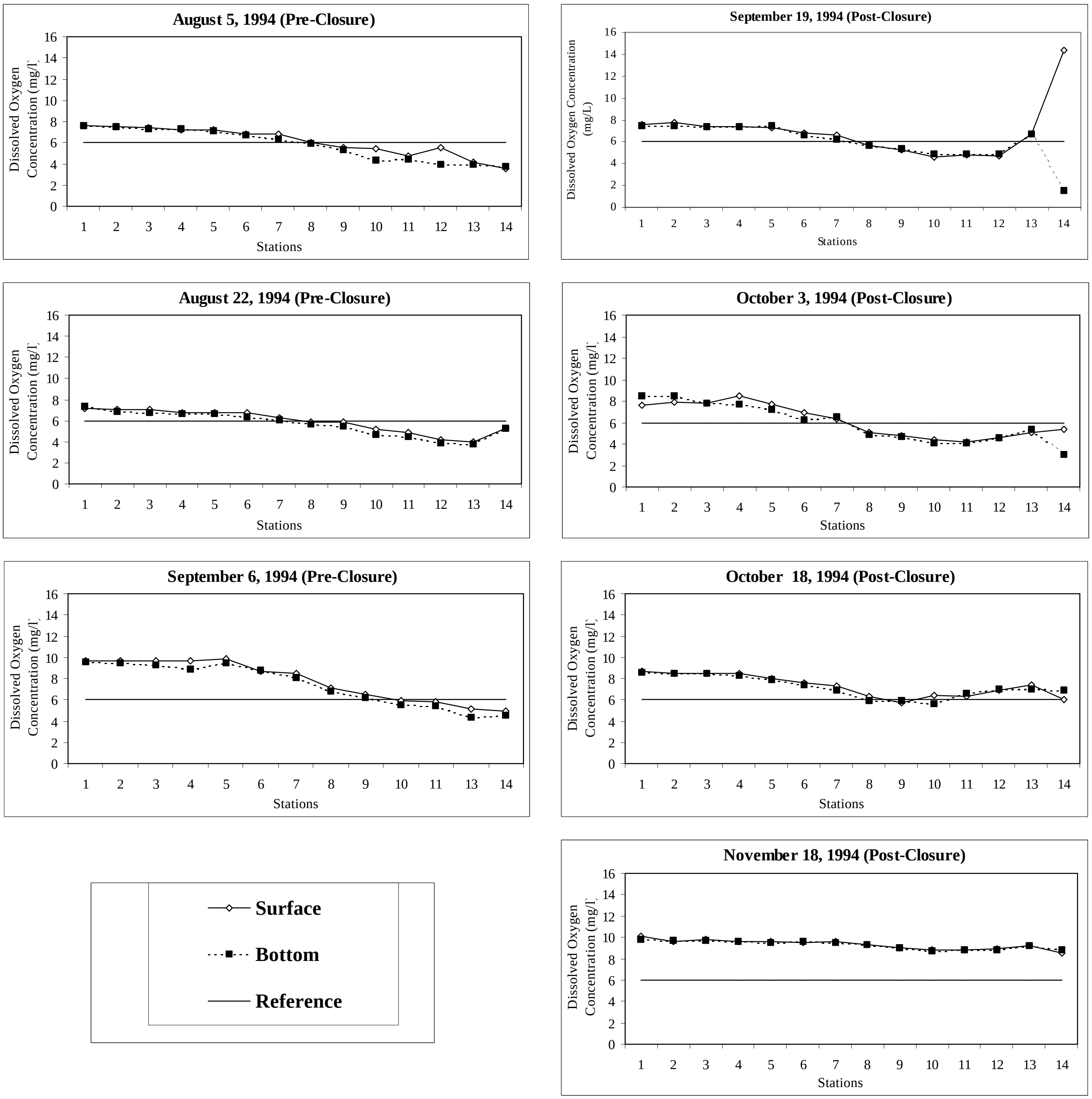

Figure 2 Dissolved oxygen concentrations in the Stockton Ship Channel in 1994

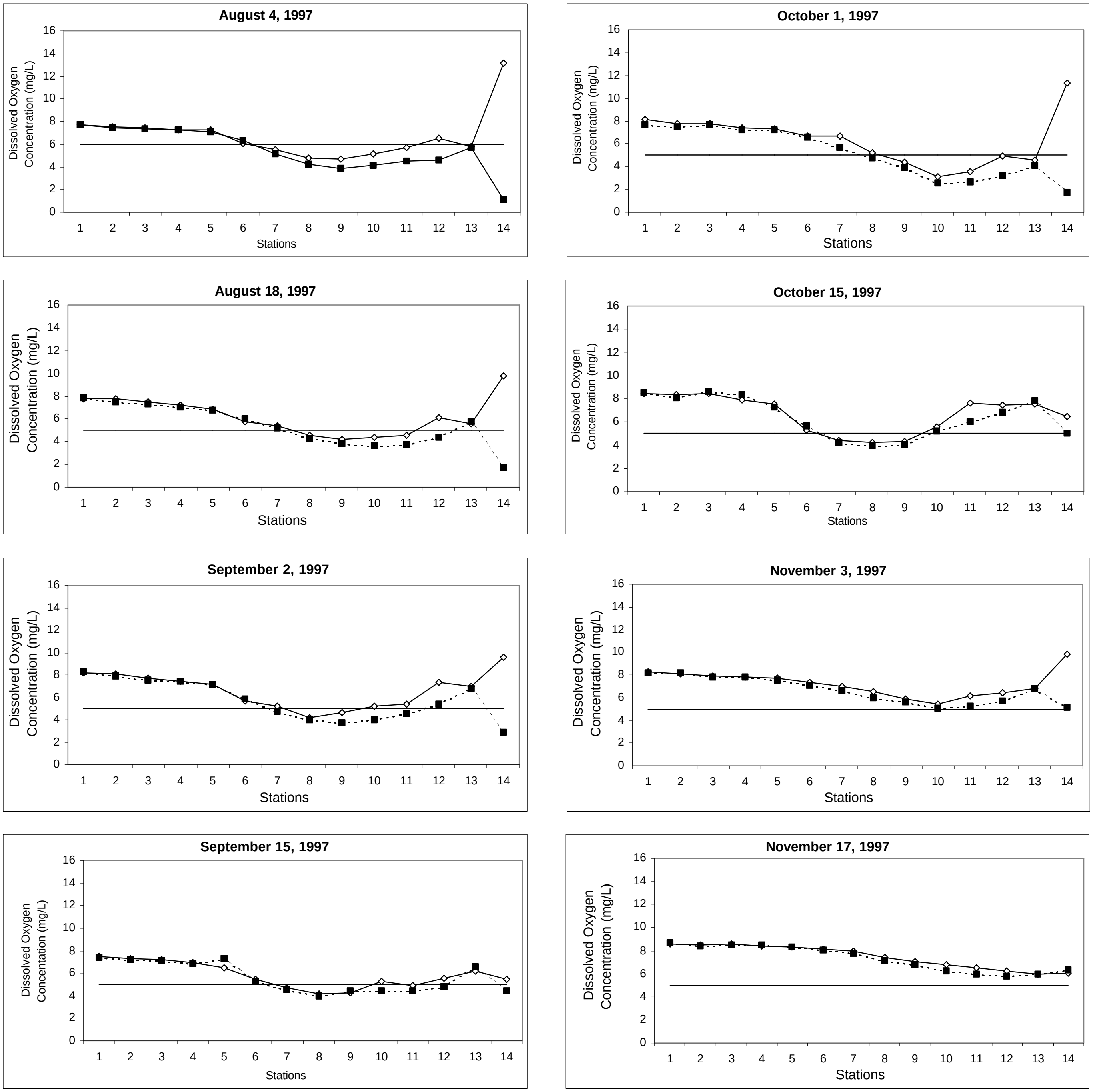

Figure 3 Dissolved oxygen concentrations in the Stockton Ship Channel in 1997

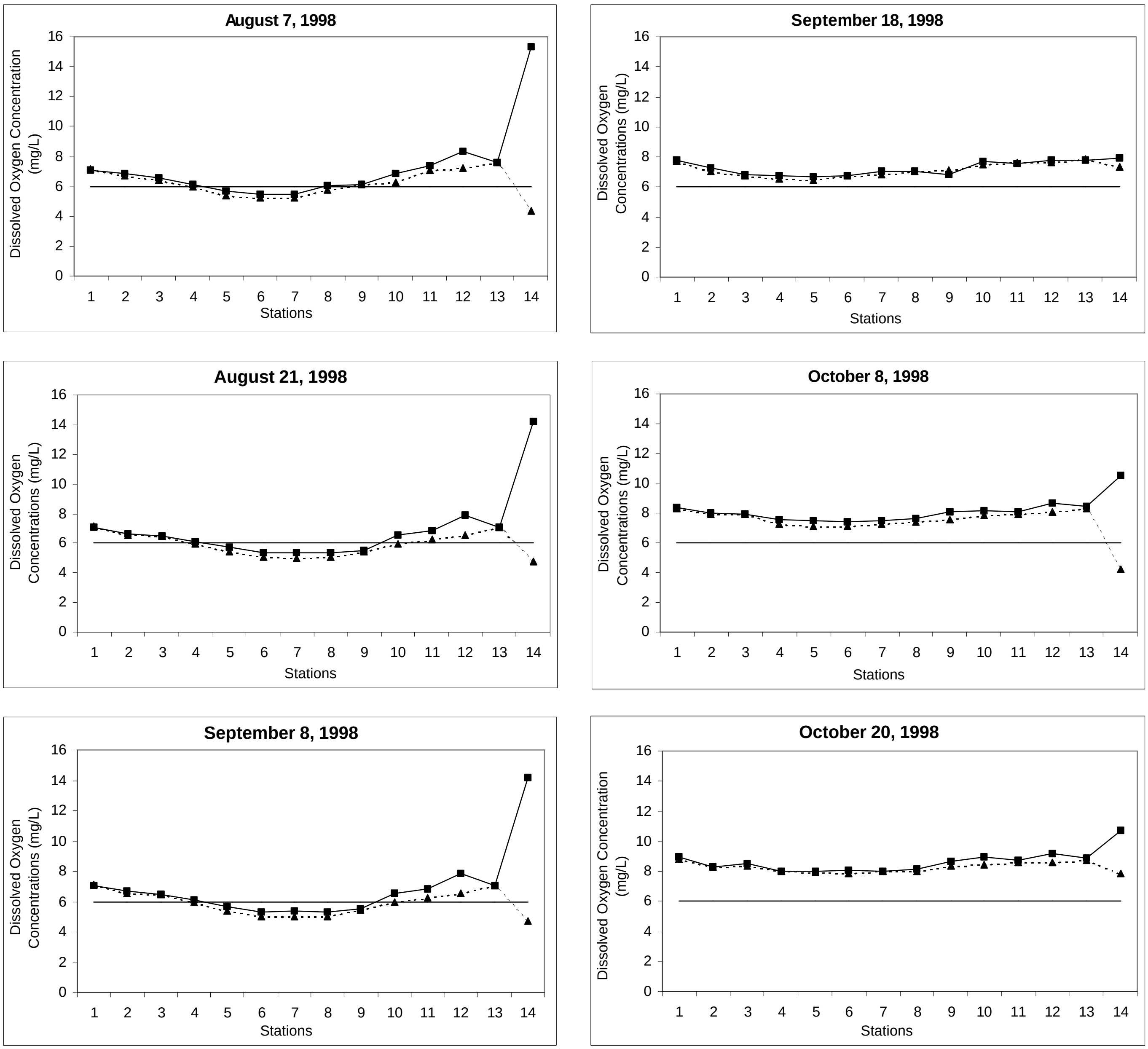

Figure 4 Dissolved oxygen concentrations in the Stockton Ship Channel in 1998

Examining the Relative Predation Risks of Juvenile Chinook Salmon in Shallow Water Habitat: The Effect of Submerged Aquatic Vegetation

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Introduction

Habitats with submerged aquatic vegetation (SAV) support large numbers of juvenile fishes and invertebrates (Kilgore and others 1989; Weaver and others 1997). SAV increases spatial complexity (Weaver and others 1997), support high numbers of invertebrate prey for fishes (Kilgore and others 1989), and provide cover for juvenile and small fishes, thereby reducing visibility and access by large piscivores (Heck and Thoman 1981; Brazner and Beals 1997; Kilgore and others 1989).

Simenstad and others (1999) investigated the distribution and abundance of fishes in SAV habitats of the Delta and found the ichthyofauna within shallow water habitats was segregated into two distinct assemblages based on the presence of SAV. One assemblage, primarily consisting of deep-bodied fishes, occurred in higher densities in SAV. The majority of these fishes were introduced species, characterized as year-round residents. The other assemblage, found mainly in areas without SAV, consisted of many pelagic species. The majority of these fishes were transient or migratory species, including juvenile chinook salmon.

Of interest in the Sacramento-San Joaquin Delta, is how presence of SAV influences predator-prey interactions between native and introduced fishes. This is of particular concern given the proliferation of Brazilian waterweed (*Egeria densa*) in the Delta (Grimaldo and Hymanson 1999) and the positive correlation between SAV and densities of introduced fish (Chotkowski 1999; Simenstad and others 1999). In this study we examined the relative predation risk of juvenile salmon in habitats with and without SAV to assess the role of SAV as refuge habitat for emigrating smolts.

Methods

Study Area

The study sites were located at three flooded islands (previously leveed) in the central Delta: Lower Mandeville Tip, Venice Cut Island, and Mildred Island. (See Simenstad and others (1999) for more details about these sites.) These sites were selected because Simenstad and others (1999) were conducting a study on fish and invertebrate habitat usage in SAV habitats at the same sites concurrent with this study.

Risk of Predation

Fish tethering is used to assess and quantify predation risk between various habitat types (Rozas and Odum 1988; Gregory and Levings 1998), under an array of environmental variables (Heck and Thoman 1981), and throughout seasonal and diel cycles (Curran and Able 1998; Post and others 1998). Tethering does not measure an absolute predation rate; rather, it measures a relative predation rate. Predation rates are measured as the number of restricted prey removed from a habitat over a specified time period. The major assumptions with tethering are (1) the tethered prey acts the same across experimental treatments and (2) predators do not become habituated to tethered prey, thereby resulting in either increased or decreased predation (Gregory and Levings 1998).

We conducted fish tethering experiments May through June 1999, coincident with the end of the fall-run chinook salmon emigration through the Delta. Juvenile fall run chinook salmon (mean = 74.4 mm FL, sd = 6.4 mm FL) were obtained from the Feather River Hatchery. The size range of salmon used in this study (58 to 96 mm FL) overlapped with wild salmon (70 to 116 mm FL) observed at the SWP and CVP salvage facilities during the same period. The tether consisted of three lines joined by a clasping swivel (Figure 1). The float line was anchored with a 142-g weight and suspended at the top with a seine float. A 16-lb dry fly hook was tied to the free end. Fish were anesthetized in tricaine methanesulfonate (MS-222), measured to the nearest mm fork length, and secured to the hook through the dorsal fin musculature. This method of prey attachment was shown to be 100% effective (no mortality or fish loss) for securing live tethered prey by Gregory and Levings (1998).

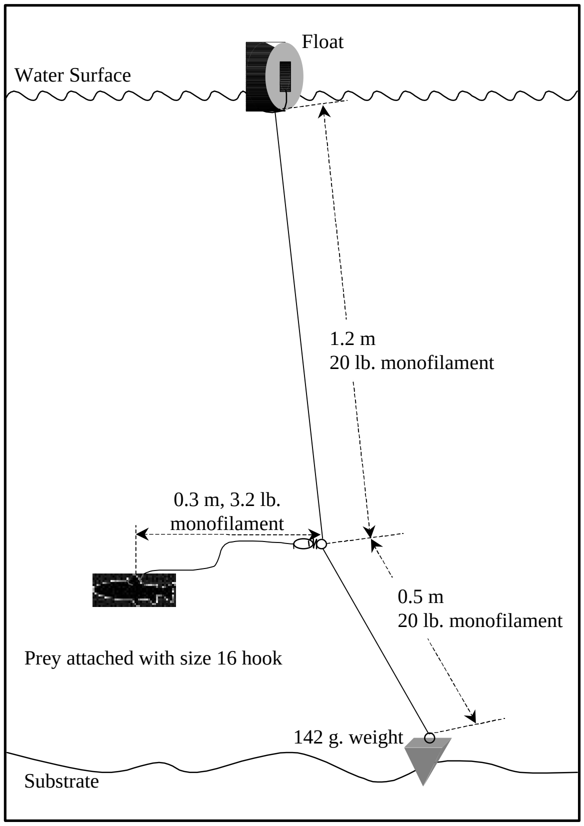

Figure 1 Graphic representation of a tethered salmon. Tethering technique modified from Gregory and Levings (1998).

Tethers in SAV treatments and no SAV treatments were “fished” for 120 minutes. In each treatment, five individually tethered salmon per set were placed approximately four to five meters from each other. A total of 90 tethers was deployed during the morning and early afternoon over the six days of this study. All tethers were deployed in water less then two meters deep. Water clarity and water temperature were measured before each set was deployed. Upon retrieval of the tethers, hooked predators were measured to the nearest mm FL. The predators were euthanized and processed for stomach content analysis to determine if they had consumed more than one tethered salmon. A predation event was confirmed by one of two criteria: (1) absence of tethered prey or (2) direct evidence of predatory attack (tether line snapped, hook bent, or predator on hook). Significant differences between the number of predation events in SAV and no SAV treatments were statistically tested using a Mann-Whitney U test.

Chinook Salmon and Predator Densities

Chinook salmon and predator densities were obtained from data collected by Simenstad and others (1999). Fish abundance was plotted against three classes of SAV percent cover: none, low, and high density. For more information on methods see Grimaldo and others (1998) and Simenstad and others (1999).

RESULTS

There was no significant difference (Mann-Whitney: $U = 19.5$, $P > 0.2$, $n = 6,6$) between secchi depth (cm) in SAV treatments (mean secchi depth = 60.3 " 13.2 [s.d.]) and no SAV treatments (mean secchi depth = 64.1 " 13.6 cm [s.d.]). Water temperature (°C) did not significantly differ (Mann-Whitney: $U = 22.0$, $P > 0.2$, $n = 6,6$) between SAV treatments (18.3 " 1.1 [s.d.]) and no SAV treatments (18.0 " 0.9 [s.d.]).

A majority of tethered prey was consumed. Thirty-seven of the tethering hooks were broken off and two were bent. Twenty-six salmon were missing from the leader lines (with leader lines and hooks in tact), and twelve salmon were present. The relative risk of predation was significantly lower in SAV treatments (Mann-Whitney: $U = 32.00$, $P = 0.035$, $n = 6,6$) (Figure 2). Tethered salmon in SAV treatments experienced 79% predation (Table 1). In comparison, salmon tethered in habitats without SAV experienced 95% predation. The average risk of predation between all study sites was 87%. In total, of the 90 tethers set, 13 predators were hooked; the predators were Sacramento squawfish (11), white catfish (2) and black crappie (1). Only one predator had a tethered salmon in its stomach contents. The stomachs of all other predators were empty, suggesting they regurgitated their stomach contents upon capture.

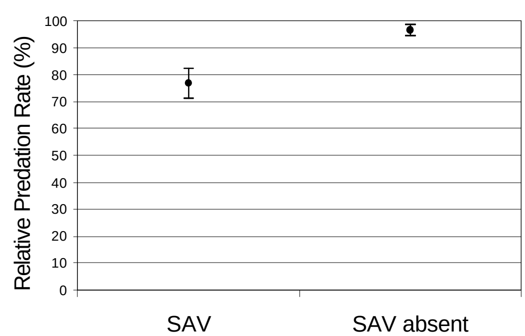

Figure 2 Relative predation rate for tethered salmon in vegetated and unvegetated habitats

Table 1 Summary of physical variables and results for each set of tethers by site and date

Date	SAV Present	Temperature (°C)	Secchi (cm)	Number of Tethers Set	Predation Event: Prey Absent [a]	Predation Event: Evidence of Predator [b]	Predation Event: Percent Predation [c]	Predators Captured [d]
Lower Mandeville Tip								
13 May	No	17.6	73	10	3	6	90	5 ss: 250, 280, and 120 (measured); 350 and 250 (estimated)
13 May	Yes	17.7	60	10	3	5	80	1 ss: 240 and 1 bc: 231
14 May	No	17.7	77	10	3	6	90	2 ss: 212, 258
14 May	Yes	17.3	64	10	3	4	70	1 wc: 297 and 1 ss: 300 (estimated)
17 May	No	17.8	75	3		3	100	
17 May	Yes	18.4	73	7	2	3	71	1 ss: 237
Total	No	17.6	75	23	6	15	91	
Total	Yes	17.7	64	27	8	12	74	
Venice Cut Island								
21 May	No	18.4	53	5		5	100	
21 May	Yes	18.5	52	5	2	2	80	
24 May	No	18.2	48	10	3	7	100	
24 May	Yes	18.6	46	10	4	6	100	
Total	No	18.2	49	15	3	12	100	
Total	Yes	18.5	48	15	6	8	93	
Mildred Island								
9 Jun	No	20.0	55	5	2	3	100	1 ss: 230
9 Jun	Yes	21.0	80	5	1	2	60	
Venice Cut, Lower Mandeville, and Mildred Island combined								
	No	18.1	64	43	11	30	95	
	Yes	18.3	60	47	15	22	79	

[a] Tethered prey not present at end of set.
[b] Predator caught, hook bent, or line snapped (hook missing).
[c] 100 H (predation events/number of sets).
[d] ss = Sacramento squawfish, bc = black crappie, wc = white catfish. Sizes are in mm FL.

DISCUSSION

The relative predation risk was significantly lower for juvenile salmon in SAV habitats compared to habitats without SAV. This suggests salmon would benefit from using SAV during their emigration through the Delta. However, Simenstad and others (1999) observed no salmon (Figure 3) in dense stands of SAV despite high invertebrate prey densities. Emigrating juvenile salmonids are visual predators, which generally forage on insects and zooplankton in the epibenthos or in the water column (Shreffler and others 1992; Johnson and others 1996) and in areas with medium to high velocities (Nislow and others 1997). This strategy might not fare well in dense beds of SAV, where access to prey items can be restricted (Brazner and Beals 1997; Weaver and others 1997) and where water velocity can be extremely low or zero (Janauer 1998). This suggests there may be a trade-off for salmon in open water areas. Although predation risk is higher, forage success may be higher as well. The actual trade-off, not examined in this study, may be observed during the diel cycle. Ruggles (1980) found most smolts migrate at night. It is possible salmon smolts can reduce predation risk in open areas by foraging at night when visibility to predators is lower. We believe this deserves further attention in future predator-prey studies of salmon in the Delta.

The colonization of shallow water habitats by SAV may also act to displace salmon and prevent access to suitable habitat. In 1999 we observed the majority of subtidal, shallow water habitats in the central Delta were colonized by extremely dense stands of *Egeria densa* (introduced SAV). The dense canopies formed a "wall" throughout much of the subtidal region and blocked access to intertidal habitats without SAV. Restricted access to preferred habitats may force salmon to inhabit deep water or channel habitats where prey densities may be lower and predation risk may be higher (as suggested by this study).

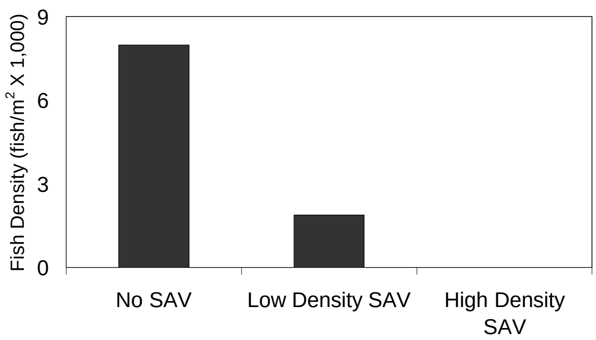

Figure 3 Abundance of chinook salmon by vegetation density. Data collected by Simenstad and others (1999).

Tethering experiments are criticized because many researchers neglect to report sampling artifacts associated with different treatments (Peterson and Black 1994; Curran and Able 1998). For example, Peterson and Black (1994) note many researchers who conduct tethering studies fail to address the possibility of opportunistic predators taking tethered prey that would not be able to do so if the prey was untethered. We addressed this potential sampling artifact by attaching the salmon with hooks, thereby increasing the potential to identify the predators. All predators hooked in this study were viable predators of juvenile salmon in the wild. In addition, because the tethered leader lines were able to hold squawfish and white catfish up to about 300 mm FL, we think larger predators (such as largemouth bass and striped bass) were responsible for the cases when bent hooks or snapped leaders were observed. Another potential bias with tethering can occur if predators are attracted by the tethered prey into an area they would not normally forage. The salmon tethered in SAV were consumed by predators associated with SAV (Figure 4). Likewise, the salmon tethered in habitats without SAV were consumed by predators associated with open water habitats. Although Sacramento squawfish comprised the majority of predators hooked in areas without SAV, we think its representation in the catch is biased high because they have small mouths and are more likely to be hooked in comparison to predators with larger mouths (such as striped bass). In addition, because we had success hooking the squawfish, a small-mouthed predator, we believe the cases where salmon were missing from the tethered hook and the hook was neither bent nor snapped (29%) was due to predation by larger predators (largemouth or striped bass) rather than small opportunistic predators (bluegill).

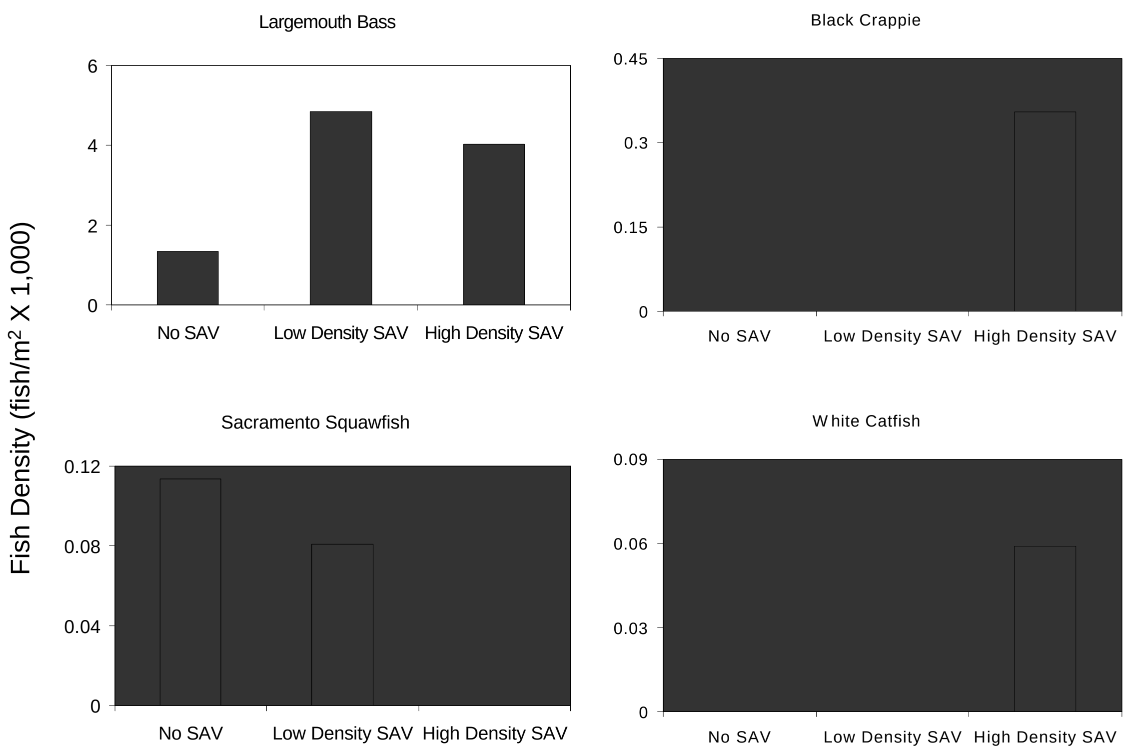

Figure 4 Abundance of predators by vegetation density. Data collected by Simenstad and others (1999).

References

Brazner BC, Beals EW. 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. Can Journ Fish Aquat Sci 54:1743–61.

Chotkowski M. 1999. List of fishes found in San Francisco Bay-Delta shallow water habitat. IEP Newsletter 12(3):12–8.

Curran MC, Able KW. 1998. The value of tethering fishes (winter flounder and tautog) as a tool for assessing predation rates. Marine Ecology Progress Series 163:45–51.

Gregory RS, Levings CD. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Trans Am Fish Soc 127:275–85.

Grimaldo LF, Harrell BC, Miller RE, Hymanson Z. 1998. Determining the importance of shallow water habitat in the Delta to resident and migratory fishes: a new challenge for IEP. IEP Newsletter 11(3):32–4.

Grimaldo LF, Hymanson Z. 1999. What is the impact of the introduced Brazilian waterweed *Egeria densa* to the Delta ecosystem. IEP Newsletter 12(1):43–5.

Heck KL, Thoman TA. 1981. Experiments on predator-prey interactions in vegetated aquatic habitats. Experimental Marine Biology and Ecology 53:125–34.

Janauer JB. 1998. Macrophytes, hydrology and aquatic ecotones: a GIS supported ecological survey. Aquatic Botany 58:379–91.

Johnson JH, Mckeon JF, Dropkin DS. 1996. Comparative diets of hatchery and wild Atlantic salmon smolts in the Merrimack River. North American Journal of Fisheries Management 46:440–4.

Kilgore KJ, Morgan RP, Rybicki NB. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North American Journal of Fisheries Management 9:101–11.

Nislow KH, Folt C, Seandel M. 1997. Food and foraging behavior in relation to microhabitat use and survival of age-0 Atlantic salmon. Can Journ Fish Aquat Sci 55:116–27.

Peterson CH, Black R. 1994. An experimentalist's challenge: when artifacts of intervention interact with treatments. Marine Ecology Progress Series 111:289–97.

Post JR, Parkinson EA, Johnston NT. 1998. Spatial and temporal variation in risk to piscivory of age-0 rainbow trout: patterns and population level consequences. Trans Am Fish Soc 127:932–42.

Rozas LP, Odum WE. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia 77:101–6.

Ruggles CP. 1980. A review of the downstream migration of Atlantic salmon. Canada Fisheries and Marine Service Technical Report 952.

Shreffler, DK, Simenstad CA, Thom RM. 1992. Foraging by juvenile salmon in a restored estuarine wetland. Estuaries 15:204–13.

Simenstad C, Toft J, Higgins H, Cordell J, Orr M, Williams P, Grimaldo L, Hymanson Z. 1999. Preliminary results from the Sacramento-San Joaquin Delta breached-levee wetland study (BREACH). IEP Newsletter 12(4):15–21.

Weaver MJ, Magnuson JJ, Clayton MK. 1997. Distribution of littoral fishes in structurally complex macrophytes. Can Journ Fish Aquat Sci 54:2277–89.

ANNOUNCEMENTS

FEATHER RIVER STUDY SALMON EMIGRATION REPORTS NOW AVAILABLE

The Feather River Study Salmon Emigration reports ("Feather River Study: Highlights of the Salmon Emigration Surveys, 1996–1998," in the fall 1999 issue of the *IEP Newsletter*) are now available for distribution. The three separate reports provide results of the salmon emigration surveys for March through June 1996, October through December 1996, and December 1997 through June 1998. The reports are available in hard or electronic (Adobe® Portable Document Format) copy.

For more information about the Feather River Study in general, or to request copies of the reports, contact Debbie McEwan at dmcewan@water.ca.gov or (916) 227-7624.

ASILOMAR 2000: THE IEP ANNUAL WORKSHOP AND BAY-DELTA MODELING FORUM

The IEP Annual Workshop will be held March 1–3, 2000 at the Asilomar Conference Center in Pacific Grove, California. The IEP workshop will provide information on a number of projects via talks, posters, and panel discussions. As in years past, the IEP workshop will overlap with the Bay-Delta Modeling Forum, held from February 29 through March 1. The final agenda can be accessed via the IEP web site (**http://www.iep.ca.gov**).

For information about the IEP Annual Workshop, please contact Zach Hymanson (zachary@water.ca.gov). For information about the Bay-Delta Modeling Forum, contact John Williams (jgwill@dcn.davis.ca.us).

DELTA INFLOW, OUTFLOW AND PUMPING

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Figure 1 (see page 63) contains plots of some important flow and pumping measurements for the fourth quarter of calendar year 1999 (October 1 through December 31). The sharp decrease in pumping during mid-December was in response to water quality issues throughout the Delta.

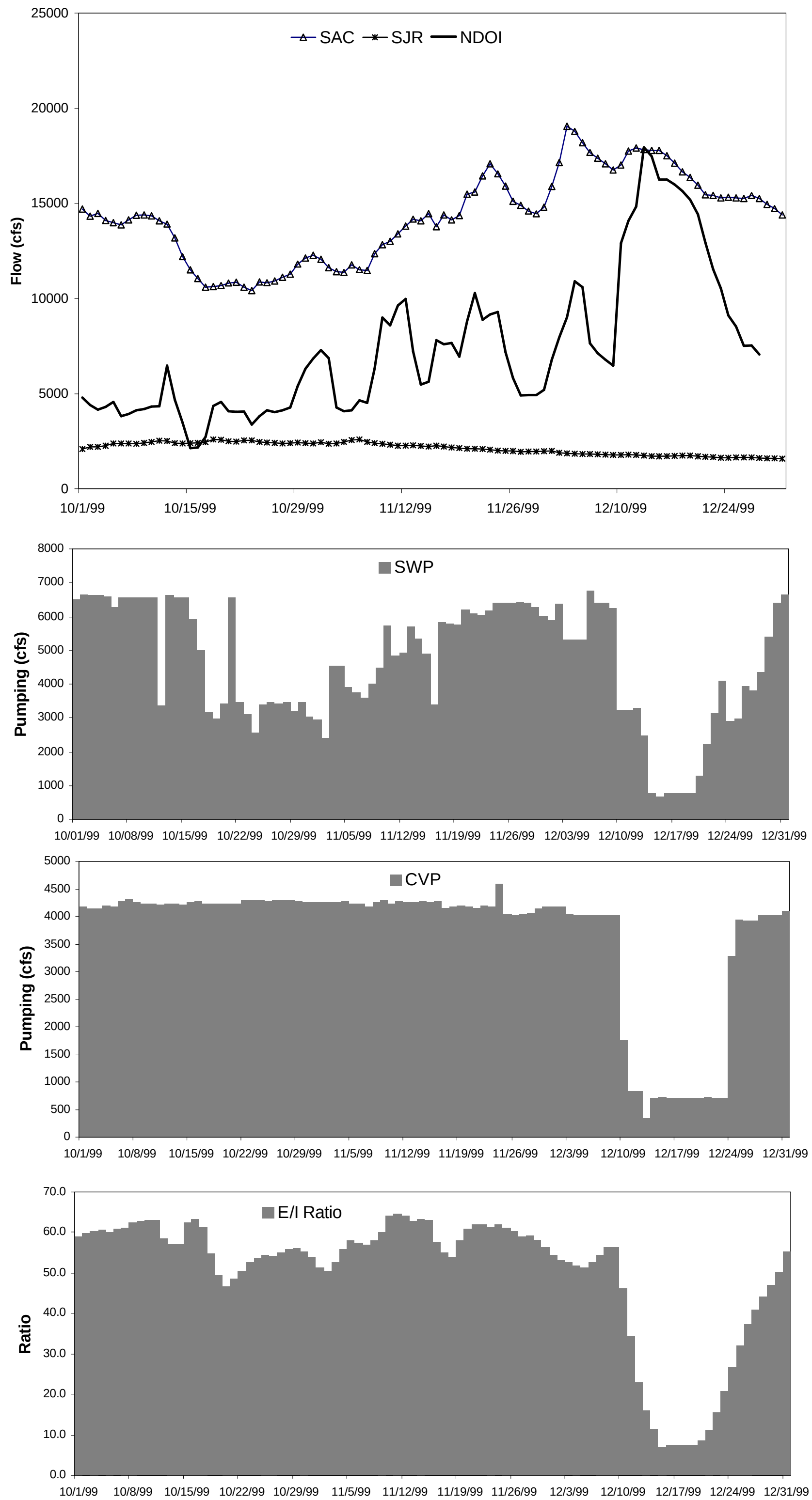

Figure 1 Delta inflow, outflow and pumping measurements, October 1 through December 31, 1999. Sacramento (SAC) and San Joaquin River (SJR) flows are measured. Delta Outflow (NDOI) and 14-day running average export-to-inflow ratios are calculated by DWR's Division of Operations and Maintenance.

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

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