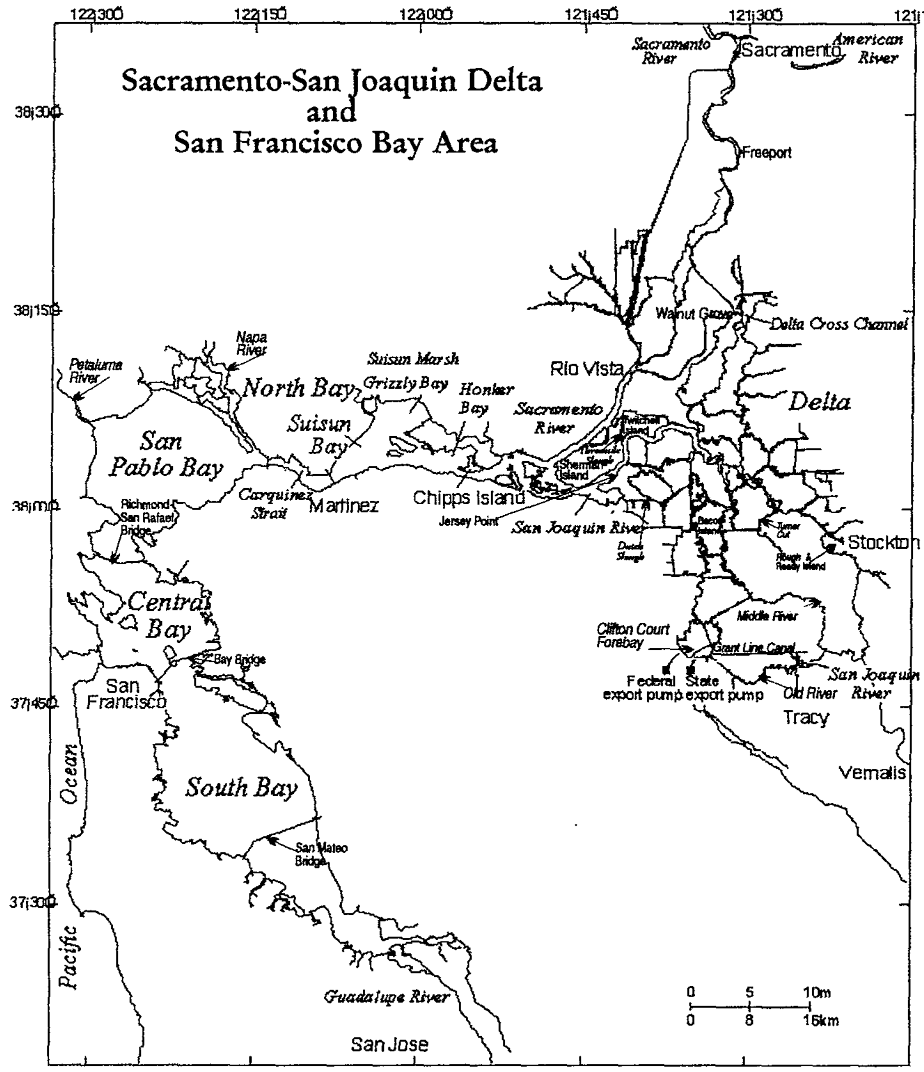
Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

Autumn 1995

Readers are encouraged to submit brief articles or ideas for articles. Correspondence, including requests for changes in the mailing list, should be addressed to Randy Brown, California Department of Water Resources, 3251 S Street, Sacramento, CA 95816-7017.



CONTENTS

Interagency Program Highlights

In the past, routine informal reporting of significant activities and results of Interagency Program elements has been accomplished through stand-alone quarterly reports. Beginning with this issue, program highlights will be a regular part of the *Newsletter* to call attention to significant findings and activities of the monitoring and special study elements. This will supplement more formal reporting provided by the annual reports, technical reports, and publications by individual agencies.

Program Revisions

Randy Brown

On October 17, the Directors approved a significant program revision. Pat Coulston, Program Manager, is preparing a report describing the revision in detail. The following are some of the highlights. One of the guidelines going into the revision process was that we would recommend a program that maintained a level budget. We also listed some studies or elements that should be funded if additional money were made available. The Directors stayed with the level budget, and Interagency Program staff and the water contractors will be working to bring in additional funds to cover some of the unfunded, but important, elements.

Before going into the program itself, it may be helpful to provide an idea of the origin of this year's funding and the total amount available. It is always difficult to lay out the actual program budget for the upcoming year, mainly because two fiscal years (federal and state) are involved. Federal budgets for FY 96 have not been established yet, so the following values for federal contributions are estimates.

Department of Water Resources	$ 6,000,000
U.S. Bureau of Reclamation	3,375,000
U.S. Geological Survey	966,000
U.S. Fish and Wildlife Service	220,500
Department of Fish and Game	1,345,000
CVPIA (U.S. Department of Interior)	100,000
Contra Costa Water District	35,000
Total	$12,041,500

Base Monitoring Program

- Midwater trawl survey.
- Chinook salmon monitoring from near Hamilton City through the delta and to include funding a portion of the ocean salmon tag recovery program.
- The bay fish and invertebrate surveys.
- Water quality monitoring surveys as modified from Decision 1485.
- Hydrodynamic monitoring.
- Resident fish monitoring.
- Suisun Marsh fish monitoring.
- Numbers of fish salvaged at the SWP and CVP intakes.

Special Studies

Following are some of the special studies planned for the next 12 months.

- An expanded version of the real-time monitoring. In May and June 1995 we showed it can be done; now we have to determine if the data can be used in a more typical water year to operate the projects to protect fish and provide for water supply reliability.
- A study at Knights Landing to determine if we can obtain reliable estimates of the numbers of chinook salmon entering the delta.
- Marking about 1 million fall-run salmon from Coleman Hatchery and releasing three groups of them upriver to determine if these fish can be used to obtain better estimates of through-delta salmon survival. The idea is that these salmon will have had a chance to become more like wild fish than salmon released directly into the delta from the hatchery trucks.
- A 20-millimeter fish survey to determine if a new gear type is better able to capture delta smelt and other fish in the range of 15-50 millimeters.
- A program to evaluate the benefits of including a more structured community monitoring program as part of the baseline monitoring program.

What is Not Included in the Revised Program

Following are some elements that are not part of the approved program.

- An evaluation of fish screen approach velocity criteria using a fish treadmill.
- Predator removal from Clifton Court Forebay. Indications are that striped bass freely exchange between the forebay and the delta, and removal would not be effective.
- The agricultural diversion fish entrainment study. We will analyze and publish results of the first 3 years of study before deciding where to go next.
- Almost all sampling of eggs and larvae. Again, we will analyze the data before doing any more of this work. (Exceptions will be small studies required in biological opinions, such as the one for the North Bay Aqueduct.)
- An evaluation of the fish barrier at the head of Old River. We are waiting for an acceptable study plan before beginning this important study. Much of the funding will come from DWR as part of its interim south delta program.

Significant Decisions About Program Structure

- Retain the Management Advisory Group and improve the way it is used.
- Retain the Science Advisory Group and improve the way it is used.

- Work with staff to develop a more effective means of keeping track of the interagency budget.
- Develop, publish, and use quality assurance/quality control, study design, and peer review processes to enhance the quality of our data and information.
- Establish a data users' project work team to help make data more readily available to program staff and others.
- Establish a contaminants project work team to help sort out the role of toxic materials in controlling the abundance and distribution of key populations and communities.
- Integrate representatives of the stakeholders into the project work teams.
- Coordinate the Interagency Program with other monitoring activities such as the San Francisco Estuary Institute, Category III, and the Central Valley Project Improvement Act. This should lead to better understanding of factors affecting fish and wildlife in the estuary.

We have a lot of work to do to convert the recommendations into actual field and analytical work. One of the first challenges will be to design and implement the expanded real-time monitoring program. Thanks to the management team, program staff, coordinators, and stakeholder representatives, we have made major strides in changing and improving the program over the past several months. We must continue to move forward.

Brackish Water Species Benefit from High 1995 Flows

Kathy Hieb

Preliminary catch data indicate that species that depend on brackish water (intermediate salinity) have benefited from the high winter/spring outflow. As of September 1995, young-of-the-year longfin smelt catches were the highest since 1982. In July, we also recorded the highest single-station catch of young-of-the-year longfin smelt since the study began: 3,593 at the Red Rock station, just downstream of the Richmond-San Rafael Bridge. Young-of-the-year longfin smelt were concentrated in Central Bay and lower San Pablo Bay, with fish collected upstream to Chipps Island. Pacific herring young-of-the-year catches were comparable to 1993 but remained below predrought levels. This year may be similar to 1983, when Pacific herring larvae were carried outside the bay by outflow, and a large portion of the year class apparently reared in the ocean. The May-September young-of-the-year starry flounder catch was the highest since 1983, when the long-term abundance decline started. Although the catch of 72 young-of-the-year starry flounder is low relative to many other estuarine species, it is well above the 1987-1994 mean of 13 for the same months. Young-of-the-year starry flounder were concentrated in San Pablo and Suisun bays, with a few collected in the lower Sacramento River.

Although near-shore ocean temperatures returned to normal in 1994 and 1995, species that respond positively to warm water, including California halibut and Pacific sardine, continue to be relatively abundant in the bay. In contrast, the 1995 year class of Dungeness crab, which responds positively to "normal" ocean temperature, is poor. Frequent, intense storms in 1995 produced a strong northward flow, which is not favorable for retention of Dungeness crab larvae and megalopae in the Gulf of the Farallones. Abundance of megalopae in the gulf has been positively correlated with subsequent abundance of 0+ crabs in the bay.

Tracking Introduced Crabs

Kathy Hieb

Although we have yet to collect any Chinese mitten crabs, a substantial number of juveniles have been collected this summer in the freshwater reaches of Guadalupe River, Alviso Slough, and the Alameda Creek flood control channel (all in South Bay) by Kathleen Halat, a University of California, Berkeley, graduate student. Her highest estimate of density was about 10 burrows/square meter, with more than one crab possibly occupying a burrow. Last winter, shrimp fishermen collected ovigerous mitten crabs in the channels of South and San Pablo bays.

In 1995, we planned to determine the depth distribution of the green crab by season, sex, and size, with the goal of designing a survey to monitor their relative abundance and distribution. As of September, we have designed, built, and field-tested crab traps and determined that they collect significantly more green crabs than do baited ring-nets. Green crabs are abundant in South Bay, especially south of the San Mateo Bridge. In fall 1994, they were abundant in San Pablo Bay, but their distribution apparently shifted in response to the high outflows in early 1995. We have not collected many juvenile crabs at any of the sampling locations except Redwood Shores Lagoon.

Tidal Marsh Pilot Fish Studies Capture Splittail

Kathy Hieb

Site selection and development of sampling methodology has been the focus of 1995 work. We have tested block-nets, cast-nets, minnow traps, and beach seines. Sample sites are in the lower Petaluma River, where mature, young, and restored marshes are within a short distance of each other. This year these marshes are brackish, with salinity at the Sonoma Land Trust Marsh ranging from 7 parts per thousand in April to 17 ppt in August.

Catches have been dominated by yellowfin goby, longjaw mudsucker, splittail, threespine stickleback, *Tridentiger* spp, and striped bass. With the exception of the Rush Creek Unit, which is a managed marsh, young-of-the-year splittail have been collected at all of the sites. This includes the Green Point Unit, Rush Creek just downstream of the Rush Creek Unit, the Petaluma River Unit, and various sites along the lower Petaluma River. Splittail have been collected by all gear types from a variety of habitats, ranging from small, first-order channels to shallow water over mudflats.

No Striped Bass 38-mm Index for 1995

Lee Miller

Every summer since 1959, juvenile fish surveys have provided an index of young striped bass abundance. Beginning usually in June, we sample the population every 2 weeks until the mean size of the catch exceeds 38 millimeters. Then we interpolate between the last two surveys to estimate abundance when the mean size is 38 mm. This year's high flows and cool weather prolonged striped bass spawning and resulted in recruitment over all five surveys. Hence, the mean size did not progress as expected. Mean size was 25.2 mm for the third survey, 32.6 mm for the fourth, and 33.4 mm for the fifth. Since only 56 fish were caught on the fifth survey, perhaps because of gear avoidance, we decided to quit sampling, even though the index size had not been reached.

Usually, the 38-mm index is attained in three or four surveys, although five have been required in some high-flow years. Although no 38-mm index was obtained, abundance appeared to be low, considering the high flows. The third survey index was only 22.2, the fourth was 10.6, and the fifth was only 1.8. The 38-mm index has historically ranged from 4.6 to 117.3

In 1966, we had no index because no boat was available for sampling. In 1983, high flows moved fish downstream of our sampling area, resulting in a severely biased, invalid index. The September midwater trawl survey crew observed few striped bass downstream of Carquinez Strait, suggesting that this bias did not occur this year.

Juvenile Sturgeon Set-Lining

Dave Kohlhorst

To develop an index of year-class strength for white sturgeon, in late August, we attempted to fish baited set-lines for juveniles at 20 sites from the western delta to San Pablo Bay. Because of a boat breakdown, only nine sites were sampled. A total of 67 white sturgeon were captured, which is similar to the number caught at the same sites in 1991, the last time enough bait was available to sample with set-lines. A major difference between 1991 and 1995 is that almost no fish less than 85 centimeters were caught this year; in 1991, 58 percent of the catch was less than 85 cm. Apparently, white sturgeon production has been poor for about 10 years, corresponding to the recent drought. This is consistent with other evidence that white sturgeon reproductive success is best in high-outflow years.

Low *Neomysis* Abundance in Recent Years

Jim Orsi

Abundance of *Neomysis* has been low since 1993, when an exotic species of *Acanthomysis* became abundant in Suisun Bay. Peak monthly abundance of *Neomysis* was 7 m^{-3} in Suisun Slough in May, 6 m^{-3} in the entrapment zone in June, and 1-3 m^{-3} in the entrapment zone in July. These values are 1-2 orders of magnitude lower than before the arrival of *Acanthomysis*.

Acanthomysis was an order of magnitude more abundant than *Neomysis* in these months and rose from May to July, instead of declining. Peak abundance was 10 m^{-3} in the entrapment zone in May, 21 to 25 m^{-3} in June, and 33 m^{-3} in July. *Acanthomysis* appears to carry more young at equivalent sizes than *Neomysis* does. Competition almost certainly occurs between them, and *Neomysis* abundance will likely be affected as long as this is the case.

A paper describing *Acanthomysis* as a new species was in progress when the senior author died. Dr. Tom Bowman, of the Smithsonian Institution, possessed an unrivaled knowledge of crustacea and will be difficult to replace.

Pseudodiaptomus forbesi was the dominant copepod in the estuary in June, the last month for which data are available. *Sinocalanus* abundance was low. *Bosmina* was displaced downstream from the eastern delta to the western end of Sherman Island.

Zooplankton abundance at Stockton was unusually low in June, probably because of the high outflow in the San Joaquin River.

No new introduced species have been detected this year, but the ballast water issue continues to attract interest. Three requests for information have been received this year, two by people writing reports or articles on the issue. The *Newsletter* published our article on introduced species, which was distributed at a meeting of the San Francisco Estuary Project. In July, the Freshwater Foundation started a newsletter devoted to aquatic nuisance species, and a report on the introduction to Chesapeake Bay of nonindigenous species via ballast water appeared in January. Support is growing for national and international control of ballast water releases.

Low Dissolved Oxygen Conditions in the Stockton Ship Channel

Harlan Proctor

Dissolved oxygen levels in the eastern portion of the Stockton Ship Channel historically drop to below 5.0 mg/L during late summer and early fall, mainly due to low flows (1,000 cfs at Vernalis is common) and high biochemical oxygen demand. In August and September of this year, however, Vernalis flows of 4,000-5,000 cfs have maintained positive net flows in the ship channel. Despite improved flows, dissolved oxygen at the bottom was 4.0-5.0 mg/L from Turner Cut to Rough and Ready Island. Surface dissolved oxygen remained above 5.0 mg/L except in the midreach of the bottom sag, where it dropped to 4.8 and 4.5 on two occasions in August. Conditions improved in September, with dissolved oxygen of at least 5.0 mg/L at all sites. Due to the high sustained flows, no temporary barrier will be installed at the mouth of Old River this fall.

Fall Sampling Planned for the Asian Clam, *Potamocorbula amurensis*

Harlan Proctor

In the fall of 1990 and 1993, we sampled 214 sites to estimate the spatial distribution of the accidentally introduced Asian clam, which was first discovered in 1986. The 1990 survey demonstrated a nearly solid distribution west of the delta; some Suisun Marsh sites had as high as 19,200 clams per m^2. Following the first year of high flow since the clam was introduced, the 1993 survey showed a westward shift in abundance and higher recruitment downstream relative to 1990.

In May 1995, a survey of 43 sites showed distribution patterns similar to those in 1993, with less dense populations (up to 3,700 clams per m^2 in Suisun Slough and Montezuma Slough). High densities of juvenile clams were still found in San Pablo Bay shoal areas. This fall's survey will document current density in response to the prolonged freshwater flows, as well as any changes in their distribution and population structure.

New Delta Channel Flow Measurement Capability

Rick Oltman

During August, we installed an ultrasonic velocity meter (UVM) flow monitoring station on the San Joaquin River at Stockton (0.5 mile north of Highway 4 crossing), with funding provided by the City of Stockton. The site is operational but has not yet been calibrated.

A UVM flow monitoring site is being installed on Dutch Slough, with funding provided by USGS. The instrument shelter and transducer piles were installed in September, and data collection should begin in October.

During the high flows of January and March, transducer mounting piles were destroyed at several UVM sites. During August, steel replacement piles were driven at three sites: San Joaquin River at Jersey Point, Sacramento River upstream of the Delta Cross Channel, and Sacramento River at Rio Vista. The Rio Vista site is new and consists of two UVMs, one on each bank of the ship channel. The right bank UVM has been operational since late April; the left bank UVM had a pile destroyed in March. Once the sites have been repaired and are again operational, the UVM flow monitoring network will consist of nine sites, four of which will monitor delta outflow.

Hydrodynamic Model Development

Francis Chung

DWR continued development of a one-dimensional computer simulation model of the delta. The new model is composed of three major components: a hydrodynamics module (DSM2-HYDRO), a water quality module (DSM2-QUAL), and a particle-tracking module (DSM2-PTM). The DSM2 model will also include several pre- and post-processors, including a graphical user interface, a boundary tide and salinity predictor, a land use module for generating agricultural diversion and return volume estimates, and a trihalomethane formation potential module. The hydrodynamics and water quality modules are derived from the USGS FourPt and BLTM models, respectively. Through license agreements, it is DWR's goal to eventually make DSM2 available free to the public. DWR is working closely with the Interagency Program hydrodynamics project work team and will provide uncalibrated prerelease versions for testing and peer review. A prerelease version of DSM2-HYDRO will be released to the work team pending resolution of legal issues. Prerelease versions of DSM2-QUAL and DSM2-PTM are expected to be released before the end of the year.

New Juvenile American Shad Indices and Winter-Run Salmon Monitoring

Pat Brandes

Between July 1 and September 30, we have been midwater trawling 3 days a week at Sacramento and Chipps Island to document the movement of juvenile shad migrating into and out of the delta for the Central Valley Project Improvement Act's Anadromous Fish Restoration Program. The data will be used to evaluate whether annual juvenile indices could be obtained using the midwater trawls at Sacramento and Chipps Island. Numbers of juvenile shad were substantial, especially at Chipps Island. A report is scheduled for release by January 1996.

Beach seining continued every week or two in the lower river and northern, central, and southern delta.

The Central Valley Salmon Project work team has met several times this summer to finalize plans for the 1995-96 monitoring work, use of the 130,000 marked late-fall-run post-smolts, and identifying and integrating other valleywide salmon monitoring plans into delta efforts for next year. Next month will be dedicated to determining the use of 800,000 marked fall-run smolts for experiments in spring 1996.

Although the core monitoring program in the delta has been identified, two special studies have been proposed, pending funding:

- A pilot effort at Knights Landing using two rotary screw traps, fyke nets and kodiak trawl to estimate absolute abundance of juvenile winter run (as well as other races) entering the delta.
- Tagging 1 million Coleman fall run and recovering them at Sacramento, Chipps Island, and other monitoring sites associated with the real-time monitoring effort. Smolts of known origin and at large enough numbers will be helpful in determining distribution of juvenile salmon throughout the delta.

Other special studies may be further developed for project work team, management team, and coordinator approval throughout the year.

Evaluation of Splittail Investigation Techniques

Randy Baxter

Splittail investigation this spring and summer focused on two general objectives:

- Determining effectiveness of various types of gear in capturing juvenile splittail in different freshwater habitats.
- Collecting and rearing juvenile splittail to evaluate spray dying as a marking technique.

Gear evaluation in the Sacramento and San Joaquin rivers began in June and will continue through early October. Gear being evaluated includes boat and backpack electroshockers, 30-, 50-, and 100-foot beach seines, minnow traps, cast-nets, and hook-and-line. Most sampling was during the day, but night sampling was also included. Beach seining still appears to be the most effective gear for young-of-the-year splittail, but its effectiveness diminishes as the fish grow.

In late July, about 200 fish were transferred from Clifton Court Forebay to large grow-out tanks at Skinner Fish Facility. Temperature was 22-24°C for most of the holding period but spiked at 31°C on July 28. Even with moderate salting of the tanks, all fish died of columnaris disease within 4 days of introduction. This experiment will be repeated next spring. In the interim, personnel will help spray-dye juvenile striped bass to familiarize themselves with the equipment and technique.

Plans are being developed for a study during winter and spring of 1996 to track splittail and identify their spawning habitats through the use of radio tags and telemetry.

Delta Smelt Investigations

Dale Sweetnam

Partly due to the wet year and subsequent low tow-net index, we decided not to do any special field studies. However, we did the 20-mm survey and tow-net survey and are doing the midwater trawl. A subsample of fish collected in the November kodiak trawl survey will be subjected to electrophonetic work to distinguish delta smelt from wakasagi.

DFG-Stockton is analyzing factors that may be responsible for size and weight differences in fish caught in summer 1994 by kodiak trawl upstream and downstream of Chipps Island. We will examine otoliths and stomach contents and will examine gonads. Preliminary results should be available in December.

The project work team will also be reviewing studies and research initiated in response to the listing of delta smelt. The review should be completed by March 1996.

Real-Time Monitoring

Leo Winternitz

A draft report describing results of the 1995 Real-Time Monitoring Program should be available by the end of October.

We have started planning for the 1996 program. The goal has been to develop a "straw" proposal, which the newly formed project work team will use to develop the full program. The straw proposal embodies several flexible strategies to minimize sampling expense, including wet year/dry year sampling schemes and sampling triggered by the occurrence of target organisms at other stations or in other surveys. As with the 1995 program, the 1996 proposal will coordinate as much as possible with other programs and surveys.

Delta Agricultural Diversion Evaluation

Katie Wadsworth

The 1995 agricultural diversion study began May 30 and ended August 31. We sampled at three sites during dawn periods. One fall-run chinook salmon (97 mm TL) was collected off Twitchell Island on June 19. No delta smelt were collected during the 1995 sampling.

A draft summary report of the 1993 and 1994 Lakos-Plum Creek self-cleaning fish screen evaluation is available.

North Bay Aqueduct Entrainment Monitoring

Jenni Lott

Larval sampling at four sites in the North Bay Aqueduct region was completed July 15. In the 264 samples, only two delta smelt were collected, the first on April 18 and the second on July 7. Apparently due to the high outflows and reduced exports, density of larval delta smelt was low in Lindsey and Barker sloughs, and pumping restrictions were not imposed.

Contra Costa Canal Intake Entrainment Study

Jerry Morinaka

We used a sieve-net to sample fish entrainment every fourth day at the Contra Costa Canal (on the discharge side of Pumping Plant 1) during July and once a week during August and September. The predominant fish species captured in July was striped bass (30 mm mean fork length) and in August was white catfish (48 mm mean fork length). Considerably fewer juvenile splittail were captured in July and August than in June. No chinook salmon, delta smelt, or longfin smelt were captured during any of the sampling.

Mallard Slough Monitoring Program

Jerry Morinaka

Once in July and once in August, we monitored for larval fish at the intake channel of the Mallard Slough pumping plant and outside the channel in the Sacramento River. No larval delta smelt were captured in the intake channel during either effort. In August, Contra Costa Water District discontinued use of Mallard Slough pumping plant, so there will be no monitoring there until the facility is back in operation.

Fish/X2 Relationships

Wim Kimmerer

During the last quarter, the estuarine ecology team examined probable mechanisms underlying the "fish/X2" relationships, which form the basis of salinity standards for the bay and delta. These relationships probably occur through several mechanisms leading to the same result for most estuarine-dependent species: more flow means more fish. Given the wide variety of trophic levels and life histories of the species having positive relationships to flow, the mechanisms likely operate at different times and places, and on different life stages, for each species. The estuarine ecology team determined which mechanisms were most likely to operate for which species, based on experience of team members and knowledge of life histories, habitats, and details of the relationships. A summary report will describe the most probable mechanisms behind these relationships and the studies required to determine which mechanisms are actually operating.

San Luis Reservoir Survey

Lloyd Hess and Scott Siegfried

O'Neill Forebay and San Luis Reservoir were surveyed during August. The goals for the 1995 survey were to:

- Document survival of juvenile splittail in O'Neill Forebay.
- Document reproduction of wakasagi in San Luis Reservoir.

Both goals were accomplished. Large numbers of young-of-the-year splittail were observed in the complex this year. During 1994, when there was minimal splittail reproduction in the delta, splittail were not observed. Splittail reproduction was very successful in the delta during 1995, and large numbers of young-of-the-year splittail were observed in O'Neill Forebay. The question remains whether these young-of-the-year splittail will reside in the O'Neill Forebay/San Luis Reservoir complex or try to migrate from the system.

An abundant population of 80- 90-mm wakasagi was found in San Luis Reservoir. Scale analysis indicates these fish were young-of-the-year. Delta smelt were not observed.

Large numbers of both delta smelt and wakasagi young-of-the-year were observed at the SWP and CVP fish facilities in 1994 but they were not observed at the fish facilities in 1995. For more information on the San Luis, see page 15 of this issue.

Handling and Trucking Study at Skinner Fish Facility

Scott Barrow

The draft study plan is being reviewed. Preliminary experiments with splittail were stopped due to personnel constraints. Only one preliminary splittail experiment was completed, in which we measured about a 25% mortality rate due to trucking. The fairly high water temperature (mid-70°F) during the experiment could have caused the high mortality.

Clifton Court Forebay Plant Debris

Scott Barrow

Initial surveys of the area of Clifton Court Forebay treated with herbicide in May showed rapid regrowth of aquatic plants. In August, the herbicide Komeen was reapplied to about 600 acres — the original 300 acres in southern Clifton Court Forebay plus an adjoining 300 acres. The herbicide was applied with a helicopter by licensed applicators, and water exports were curtailed during the application period. Preliminary results indicate the treatment was successful. DWR Delta Field Division is preparing a report.

Clifton Court Forebay Striped Bass Sonic Tracking Program

Kevan Urquhart

Efforts to document the movement of adult striped bass into and out of Clifton Court Forebay using sonic tags, fixed tag-monitoring stations, and mobile tracking have been effective. Preliminary data analysis shows that 31 of 48 sonic-tagged striped bass originally tagged in the forebay were tracked across the radial gates. Of these, 20 were subsequently tracked in the forebay. Of interest, one fish was tracked inside Clifton Court Forebay with a "coded" tag, presumably one of the sonic-tagged splittail from Tracy Fish Facility. Eight fish tagged near the radial gates were later monitored at the Skinner Fish Facility trash racks. No fish have been located outside the forebay with mobile tracking.

The unattended monitoring site at the radial gates now consists of three stations and four hydrophones and is operated around the clock. Another station adjacent to the Skinner Fish Facility trash racks is also operated around the clock. Mobile tracking has been facilitated through use of a series of prototype hydrophone fairings, which allow monitoring at speeds to about 12 mph (a 1200% increase from an infrared hydrophone).

Several tags have been recovered from dead fish, and anglers have also returned tags. Early in the study, high water temperatures (>80°F at the surface) and subsequent stress from handling and tagging probably caused the known loss of several tagged fish. After those mortalities, sampling was limited to late evening and early morning, with no known mortality due to handling. High water temperature and poor water quality at Skinner Fish Facility have precluded maintaining a control group. Vigorous, untagged fish could not be maintained more than a few days.

Status and Trends

The winter issue of the Interagency *Newsletter* will be devoted to a review of the status and trends of some important organisms living in or moving through the estuary and some of the chemical and physical parameters that affect their distribution and abundance. The issue will be long on graphical displays of the data and short on text that attempts to tell us why the trends have occurred. Looking at "why" will be the subject of technical reports on the individual organisms and parameters. We hope this will be a useful exercise and, if it is, we will make it an annual feature of the *Newsletter*.

We welcome suggestions as to which organisms and parameters should be covered in the status and trends issue. Send suggestions to Randy Brown via fax (916/227-7554) or email (rbrown@water.ca.gov) or phone (916/227-7531).

Modeling and Predicting Intertidal Variations of the Salinity Field in the Bay/Delta

Noah Knowles, Scripps Institution of Oceanography, La Jolla, California; Dave Peterson, U.S. Geological Survey, Menlo Park, California; Reg Uncles, Plymouth Marine Laboratory, Plymouth, United Kingdom; Dan Cayan, Scripps Institution of Oceanography, La Jolla

San Francisco Bay and the Sacramento/San Joaquin Delta have challenged estuarine modelers for some years. Accurate, broad-scale models of this estuary have been in demand by those concerned with its ecological health and the development of sound management policies. A description and better understanding of the dynamics that govern the bay/delta are complicated by the system's complexity, requiring models that are sophisticated enough to capture the subtle physical processes involved.

One approach to simulating daily to monthly variability in the bay is the development of an intertidal model using tidally-averaged equations and a time step on the order of a day. An intertidal numerical model of the bay's physics, capable of portraying seasonal and interannual variability, would have several uses. Observations are limited in time and space, so simulation could help fill the gaps. Also, the ability to simulate multi-year episodes (eg, an extended drought) could provide insight into the response of the ecosystem to such events. Finally, such a model could be used in a forecast mode wherein predicted delta flow is used as model input, and predicted salinity distribution is output with estimates days and months in advance. This note briefly introduces such a tidally-averaged model (Uncles and Peterson, in press) and a corresponding predictive scheme for baywide salinity forecasting.

The Uncles/Peterson Model

This numerical model, developed by Uncles and Peterson, simulates tidally-averaged currents and salinities with a time step of one day. Bathymetry data are used to configure the model to the estuary. Daily forcing inputs are precipitation, evaporation, salinity at the mouth of the estuary, freshwater inflow rates, and tidal state that varies with the spring/neap cycle.

The intertidal equations employed by the model are derived by averaging the full equations of fluid motion over a tidal cycle, presumably resulting in equations that represent tidally-averaged motion. However, intertidal estuarine models typically suffer from difficulties in accounting for physical processes lost through this averaging process. The UP model addresses this limitation by building in results from a more detailed, high-resolution intratidal model (Cheng, Casulli, and Gartner 1993). This intratidal model was run through a series of tidal states, varying from a weak neap tide to a strong spring tide. A few important variables relating to the tides, including maximum tidal current speed, tidal energy dissipation, and stress on the bay's bed, were taken from these runs and tabulated according to five ranges of the tidal state. The UP model then accesses these tables with only the indication of each day's tidal state as its input. Thus, some of the crucial information usually lost in the tidal averaging process is recovered, and a great deal of computation is avoided.

The second means by which the UP model reduces its computational load is through its relatively coarse resolution. The model bay is composed of 50 two-layer segments (Figure 1). The upper layer is 5m thick and the lower layer extends to the deepest part of each segment's estuarine section (Figure 2). At each time step, the model calculates across-segment flows and volumetric mixing, which it uses along with the forcing inputs to set up the inverse problem for salinity conservation. This low-resolution, "box-model" approach, when combined with the intertidal method discussed above, allows a simulation of long-term dynamics without massive amounts of computing (the FORTRAN version runs on a work station, 1 minute compute time, about 2 years simulation time).

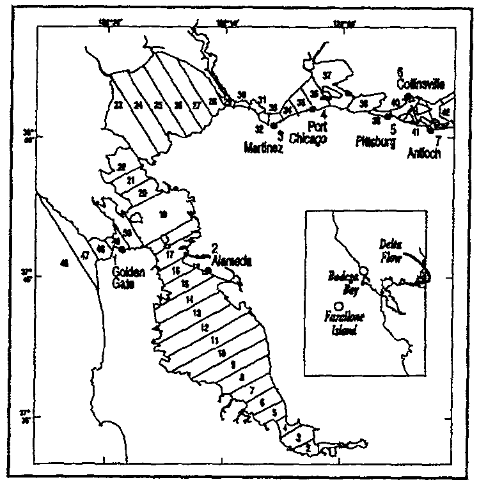


Figure 1
SEGMENTS COMPRISING BAY/DELTA IN THE UNCLES/PETERSON MODEL

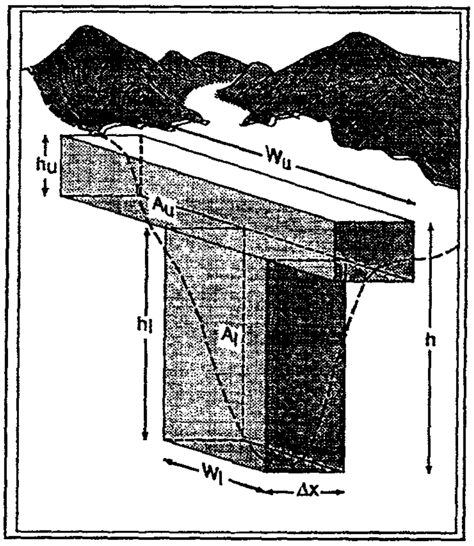


Figure 2
SAMPLE MODEL SEGMENT, UPPER AND LOWER LAYERS
The upper layer is 5 meters thick; the lower layer represents deeper channels.
Layer widths (Wu, Wl) are in the cross-estuary direction.

An example of the UP model output is shown in the series of images in Figure 3. These maps show the simulated evolution of the bay's salinity distribution for water years 1994 and 1995, with darker shading corresponding to saltier water. The upper map shows the high-salinity distribution that typically occurs in October. In the relatively dry water year of 1994, the freshwater/saltwater interface (FSI) was displaced slightly seaward from the delta in October to Carquinez Strait by April (Figure 3, middle). In subsequent months, delta flow diminished enough to allow tidal mixing effects to take over, and the FSI retreated, reaching the delta again by the water year's end (Figure 3, top). In the much wetter winter of 1995, in which sustained flows of over 2,000 m^3/s pushed the FSI as far as Point San Pablo, freshening the north bays and having a clear effect in the south bay (Figure 3, bottom). By the end of May, Sierra snowpack reserves began to diminish, and the FSI began its slow push up the estuary.

The UP model has not yet been fully tuned to optimally capture the bay salinity variability, but the initial version of the model agrees well with observations on a monthly and perhaps daily time scale. Figures 4 and 5 compare modeled and observed monthly-averaged surface salinities throughout the bay. These exhibit reasonable agreement at Golden Gate and Alameda, the closest stations to the coastal sea. The model and observations at Martinez show very similar trends but with an offset between them. The model consistently underestimated salinity at this station, indicating that the modeled FSI tended to be too far down-estuary (toward the Golden Gate), or possibly that lateral effects may be important at this station (see Figure 10 of Smith and Cheng 1987). Nearer the delta, three stations are grouped: Pittsburg, Collinsville, and Antioch. Figure 5 shows that the model replicates observations quite realistically at these stations, indicating that it may be a useful tool for predicting salinity intrusion and the location of the FSI and the associated turbidity maximum. A comparison of modeled and observed daily salinity at Pittsburg over 1967-1981 (Figure 6) demonstrates that it also captures the interannual changes in salinity over the broad range of conditions that occurred during this epoch.

A Predictive Scheme

The ability of the UP model to simulate the salinity distribution in the bay/delta on daily and seasonal time scales enables it to be used in a predictive scheme. To this end, we have developed a simple statistical flow prediction capability based on a 23-year history of recorded flow data and snowpack indicators in the Sierra. This historical record was partitioned into two subsets: those years with average flow rates above and those below the median, providing two sets of data with which separate predictors for wet and dry years were developed. Late-winter, spring, and summer flows were predicted based on current flow and snowpack values and used to force the model through future months, providing salinity predictions. When such predictions are applied to the 23-year record

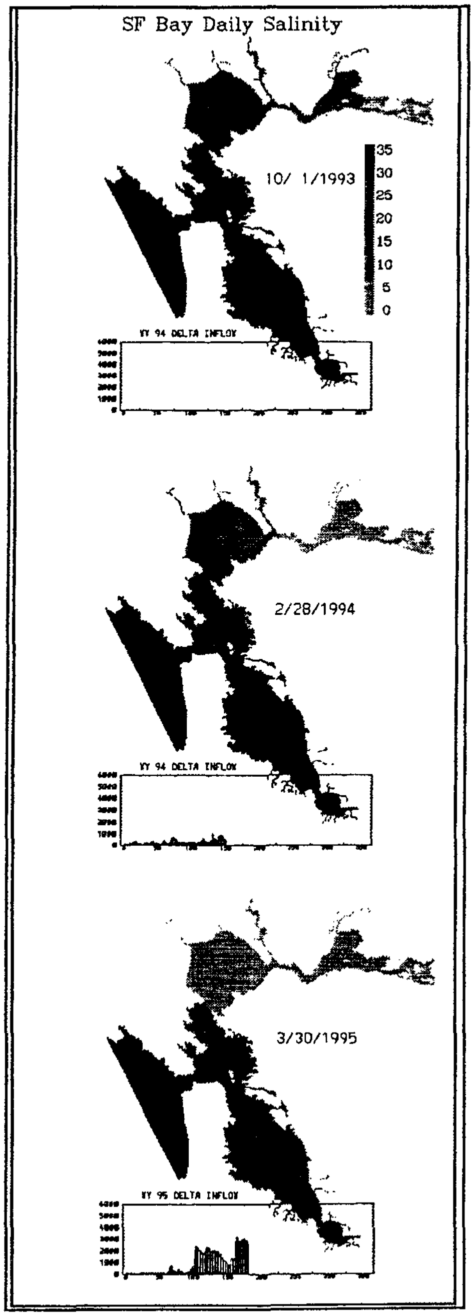


Figure 3
MAPS OF BAY SALINITY
Top: Typical saline October distribution.
Middle: Freshest distribution of dry year 1994.
Bottom: Freshest distribution of wet year 1995.

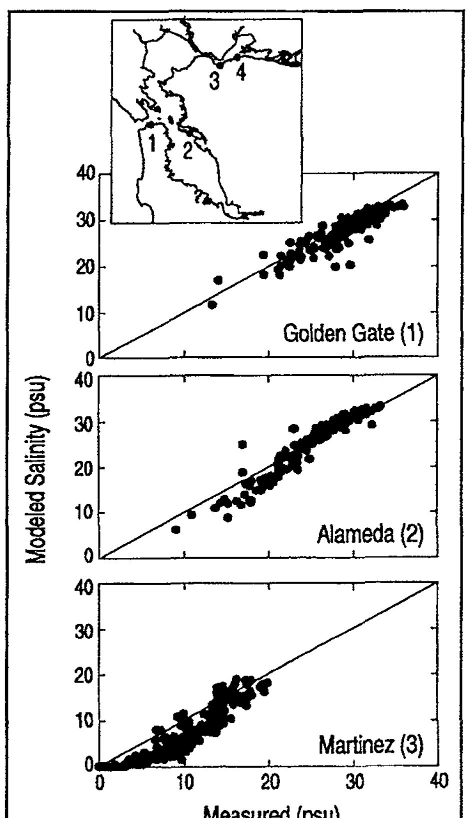


Figure 4
UNCLES/PETERSON MODEL PERFORMANCE AT HIGHER-SALINITY (SEAWARD) STATIONS

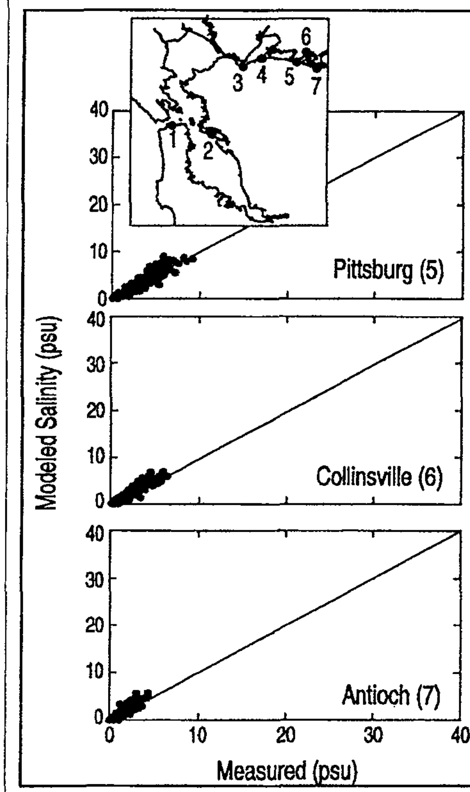


Figure 5
UNCLES/PETERSON MODEL PERFORMANCE AT LOWER-SALINITY (NEAREST DELTA) STATIONS

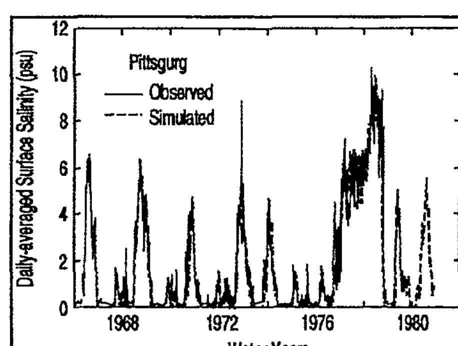


Figure 6
UNCLES/PETERSON MODEL PERFORMANCE (SIMULATED VERSUS OBSERVED) AT PITTSBURG, 1967-1981

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for which flow and snowpack records are available, the difference between observed and predicted flows is considered to be due to the effects of weather. In this way, two 23-year ensembles of weather effects are determined, associated with the wet-year and dry-year predictors. Then, when a new prediction is developed, these multiple realizations of weather can be added to it, and the resulting spread of salinity represents the distribution of the weather's potential influence on the bay/delta. To demonstrate, predictions of surface salinity at Martinez, in Carquinez Strait, have been developed for 1994 and 1995 (Figure 7).

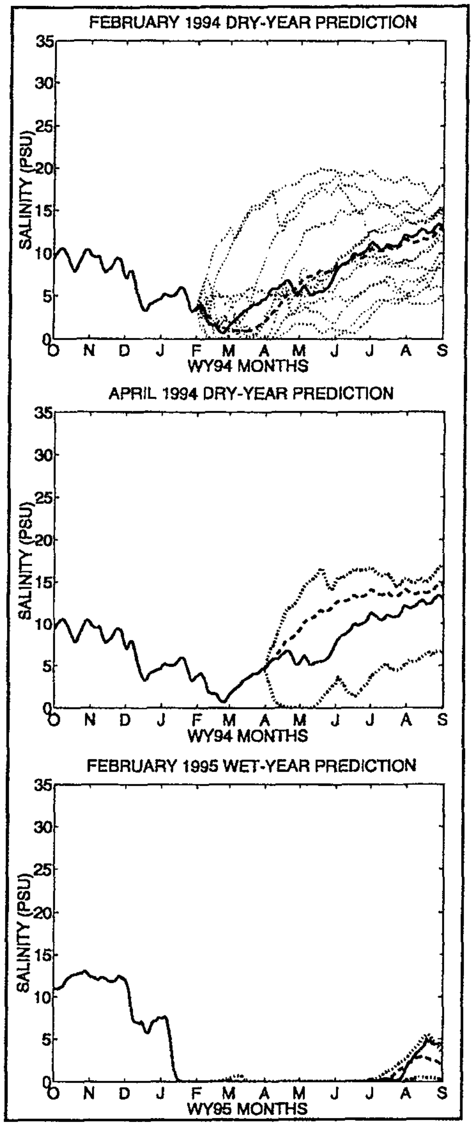

Figure 7
UNCLES/PETERSON MODEL PREDICTIONS OF SALINITY AT MARTINEZ

Top: For 1994 from February 1 conditions.
Middle: For 1994 from April 1 conditions.
Bottom: For 1995 from February 1 conditions
Hindcast salinity from observed flow (solid lines), predicted salinity (heavy-dashed lines), and distribution of weather effects (light-dashed lines).

The upper plot shows the dry-year prediction applied to information available on February 1, 1994. The predicted salinity agrees remarkably well with the hindcast salinity. This results because 1994 was very dry, and by late February, freshwater flows were already small enough that tidal mixing had begun to dominate the dynamics. This highlights the strength of the UP model as an accurate predictive tool in particularly dry years, when salinity forecasts tend to depend strongly on hydrodynamics of the bay. In the next two plots, the effects of the weather ensemble have been replaced with curves representing the 10^{th} and 90^{th} percentile of the prediction for clarity. The middle plot in Figure 7 shows the April 1 dry-year prediction for 1994. One would expect some improvement in the prediction, since most significant events affecting freshwater flow occur in winter and spring, but the April prediction is poorer than February's. Part of the reason for this is that 1994 was so dry, lowering the relative significance of the earlier months over the later ones. The final plot (Figure 7, bottom) shows the wet-year prediction for the current wet year. It is, of course, difficult to gauge the efficacy of the wet-year predictor in this case, because salinity was zero for most of the year and changes in predicted inflow would have little effect. Nonetheless, the dynamical accuracy of the UP model enables a reasonably accurate prediction of timing of the year-end rise in salinity.

Summary and Conclusions

The UP model provides a capability to simulate daily-interannual variability in salinity throughout San Francisco Bay. Although the UP model cannot account for lateral (cross-bay) salinity spatial variability, initial comparison with observed daily salinity records at selected stations between the Golden Gate and the delta shows that interannual salinity variations are very well captured over the 23-year history examined so far. The UP abilities in the south bay are not thoroughly illustrated here, but experiments at USGS in Menlo Park (D. Peterson and L. Schemel, personal communication) indicate usefulness there also.

The economy of the UP model in terms of computational requirements and its physically based baywide character make it a model forecast tool. The preliminary efforts shown here are aimed at developing an extended (few days to several months) forecasting capability. Because it is easy to run several predictions of a given water year case, the approach here is toward carrying out an ensemble of forecasts to establish a mean and the level of uncertainty. In the present case, we have used salinity as our predictand, but because the model contains fundamental physical properties (at least in approximate form), it is conceivable that other variables can also be predicted (*eg*, temperature, sediment load, nutrients, *etc*).

Several improvements are envisioned or underway. Developments planned for the UP model include a calibration of each segment's horizontal and vertical mixing coefficients to optimize model performance. Wind effects on evaporation and surface stress will be included, allowing the model to be coupled to a suitable model of the atmosphere. Knowledge of the temperature field would be useful to those studying the biology of the bay, so a thermal component will be added. Variables representing the chemistry such as nutrient content will also be incorporated. The predictive scheme will be improved by developing a more sophisticated predictor of delta flow, along the lines of the extended streamflow prediction procedure that combines historical data with hydrologic model output (Smith *et al* 1992).

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Petition to List Spring Chinook

Spring chinook is one of four races of chinook salmon inhabiting some of California's Sacramento Valley streams. Spring run are found in Butte, Mill and Deer creeks off the Sacramento River mainstem; in the Feather River; in the Sacramento River itself; and in a few other small tributaries. Although no spring chinook are presently found in the San Joaquin system, there was a large run to the upper San Joaquin drainage before construction of Friant Dam in the 1940s.

Adult spring chinook move through the delta during the spring toward their natal streams, where they hold in deep, cool pools before spawning in early fall. Not much is known about the juvenile outmigration. Some appear to move downstream as fry, some as smolts, and some as advanced smolts.

Extensive Feather River spring chinook hatchery production, with subsequent planting and straying to some Central Valley streams, has confused the issue as to what constitutes a "wild" spring run.

On August 30, 1995, Senator Tom Hayden submitted a petition to the California Fish and Game Commission to list the spring run of chinook as endangered under the California Endangered Species Act. On advice from staff, the petition was temporarily withdrawn for reformatting and inclusion of additional information then resubmitted to the Fish and Game Commission on October 16.

The next step is for the Fish and Game Commission to publish a notice of receipt in the California Regulatory Notice Register, which starts a Department of Fish and Game 90-day review period. The commission will then schedule the petition for hearing at its first available meeting after review is completed. It appears that the petition could be considered at its meeting in Redding on March 7 and 8, 1996.

At the meeting, the Fish and Game Commission can:

- Reject the petition.
- Conclude that the petition is warranted and make the spring run a candidate species.

If the Fish and Game Commission finds the petition to be warranted, it will solicit public comments during a 45-day review period and instruct the Department of Fish and Game to prepare a status review of the spring run. The status review will include an analysis of the best scientific information and a conclusion as to whether or not the petition is warranted. The review also includes information on critical habitat and management actions needed to recover the species.

If all goes according to schedule, the Fish and Game Commission will consider final disposition of the petition at its March 1997 meeting. The public will be able to comment at this meeting and will have access to the status report. If the commission finds that the petition is warranted, it will publish a notice of finding and proposed rule-making to list the spring chinook as threatened or endangered.

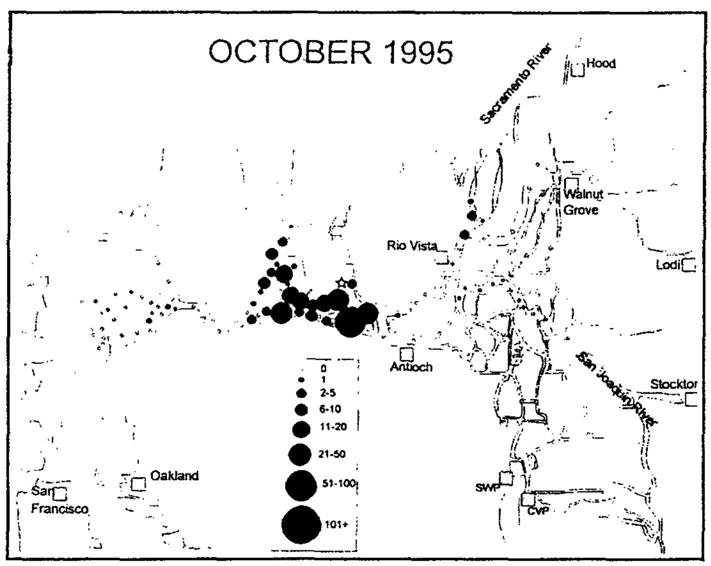
Delta Smelt October Midwater Trawl Survey Results

Leo Winternitz, Department of Water Resources

Results of the October midwater trawl survey indicate a delta smelt distribution centered around the Suisun Bay area, with a few fish found in San Pablo Bay and in the Sacramento River near Cache Slough. Results also indicate a fairly high abundance index for the month. A total of 326 delta smelt were collected, for an index of 349.6. Combined with the September index of 126, the 2-month index is 475.6. With November and December left, the year's abundance index could be around 600. The relatively high September and October index is surprising, given that delta smelt were coming off the lowest adult abundance index on record (1994 adult index of 101.2) into a very wet year. Wet years such as 1995 along with dry years such as 1994 have been considered stressor years for the species. Historically, delta smelt survival is poor in these types of years.

Not all species appeared to do well this year. Based on the summer and fall tow-net and midwater indices, striped bass survival appeared to have been low. Apparently, environmental factors that provided for relatively high delta smelt survival did not do the same for striped bass. What are these factors? Why is delta smelt survival up given they came off the lowest adult abundance index on record into a stressor year? Results from the midwater trawl survey continue to puzzle biologists working on the species. We continuously learn there is much we do not know about delta smelt.

Anybody with ideas, please contact the Resident Fish Project work team at 916/227-7548 or lwintern@water.ca.gov.



DELTA SMELT COLLECTED DURING OCTOBER IN THE FALL MIDWATER TRAWL
Delta Smelt Collected = 326
October Abundance Index = 349.6

The Department of Fish and Game, the lead agency for the midwater trawl, develops the delta smelt indices. Personnel from other agencies assist in the data collection.

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Preliminary Results from the Hydrodynamic Element of the 1994 Entrapment Zone Study

Jon Burau, USGS, California District; Mark Stacey, Stanford University; and Jeff Gartner, USGS, National Research Program

This article discusses preliminary results from analyses of USGS hydrodynamic data collected as part of the 1994 Interagency Ecological Program entrapment zone study. The USGS took part in three 30-hour cruises and deployed instruments for measuring currents and salinity from April to June. This article primarily focuses on the analysis of data from five Acoustic Doppler Current Profilers (ADCPs) deployed in Carquinez Strait, Suisun Bay, and the Western Delta. From these analyses a revised conceptual model of the hydrodynamics of the entrapment/null zone has evolved. The ideas discussed in this newsletter article are essentially working hypotheses, which are presented here to stimulate discussion and further analyses. In this article we discuss the currently-held conceptual model of entrapment and present data that are inconsistent with this conceptual model. Finally, we suggest a revised conceptual model that is consistent with all of the hydrodynamic data collected to date and describe how the 1995 study incorporates our revised conceptual model into its design.

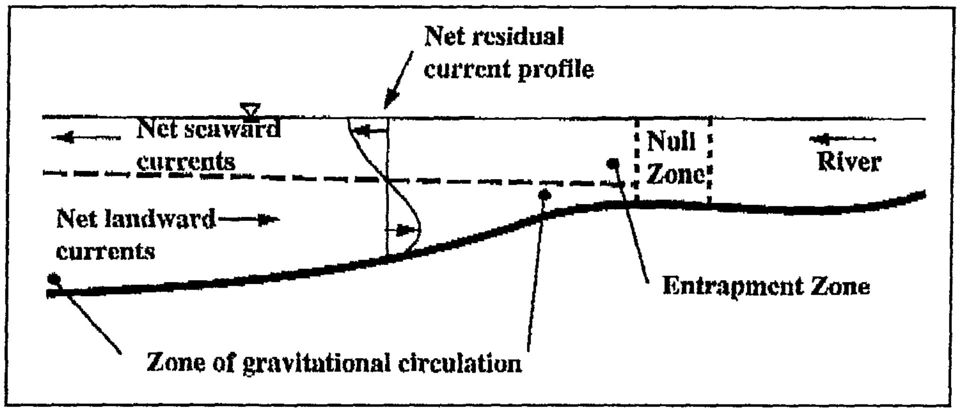

Figure 1
CONCEPTUAL MODEL OF THE ENTRAPMENT AND NULL ZONES

Existing Conceptual Model of Entrapment in the Northern Reach

The generally accepted conceptual model of the entrapment zone is that it is an area of the estuary where a flow convergence results in increased concentration of particulate matter; this usually occurs through the interaction of particle (or organism) sinking and net up-estuary flow at depth (Kimmerer 1992). For the purposes of this article, net, tidally-averaged, and residual all imply time scales whose periods are significantly longer than the diurnal tidal period of about 25 hours. The null zone, which is generally believed to coincide with the up-estuary limit of the entrapment zone, is a location in the estuary just down-estuary of where residual landward flow near the bottom ceases and where residual flow throughout the water column is seaward (Figure 1).

Both the entrapment and null zones have been associated with X2, the position of the near-bed 2 psu isohaline. This model of the entrapment zone assumes a landward flowing residual current along the bottom of the estuary known as gravitational circulation. Gravitational circulation is a residual two-layer flow in which low salinity water flows seaward in the surface layer, while denser, more saline water flows landward in the bottom layer; this two-layer flow results from the balance between the free surface slope acting in a down-estuary direction, and the longitudinal density (salinity) gradient acting in the up-estuary direction (Officer 1976). The commonly held conceptual model of entrapment is based on gravitational circulation, a tidally averaged or residual concept. Yet most (if not all) of the data previously used to substantiate this model are of short duration (transects), which are not suitable for studying residual or net processes.

In contrast, time series data from deployments of ADCPs and Conductivity, Temperature, Depth (CTD) sensors can be low-pass filtered to remove the tidal signal so that residual processes can be directly estimated. The approximately 2 months of continuous hydrodynamic time series data collected in the spring of 1994 can be used to evaluate the conceptual model of the entrapment zone based on gravitational circulation. Specifically, is gravitational circulation the major contributor to the salt balance in Suisun Bay and is it the principal mechanism responsible for accumulation of particles and organisms in the low salinity zone (~2 psu)?

Discussion of the Data

Figure 2 shows the approximate ADCP positions of the 1994 entrapment zone study. The ADCP data from the instruments located in the southern channel of Suisun Bay and the Western Delta show no evidence of upstream flow at the estuary bed even though the mean position of the 2 psu near-bed isohaline was near Mallard Island (Figure 3). Specifically, the ADCP data collected in Carquinez Strait near Martinez from April 22 to June 15 show strong residual near-bed currents of 15-20 cm/s directed up-estuary (Figure 4). In contrast, ADCP data from Concord (Figure 5), Mallard Island, the Sacramento River near channel marker 10, and the San Joaquin River near Antioch show near-bed residual currents that were directed down-estuary, indicating a lack of gravitational circulation. ADCP data collected by NOAA in Carquinez Strait and at Concord from April 22 to May 22, 1992, are consistent with the data collected in 1994 in that near-bed, residual currents in Carquinez Strait were up-estuary, and near-bed residual currents were down-estuary at Concord. X2 was again landward of Mallard Island during the 1992 NOAA deployments as shown in Figure 3.

The observed magnitude of up-estuary near-bed residual currents in the Carquinez Strait ADCP data, coupled with the down-estuary near-bed residual currents in Suisun Bay, suggests the possibility of a topographic control of the gravitational circulation at the Benicia

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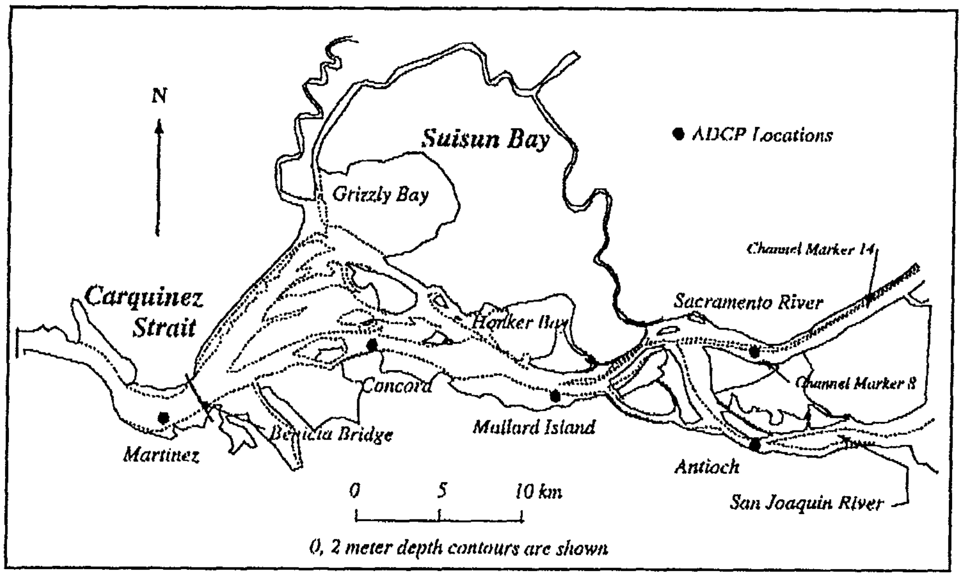

Figure 2
1994 ADCP POSITIONS

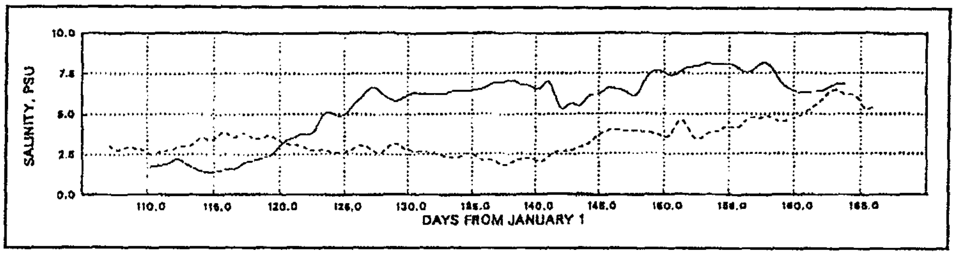

Figure 3
LOW-PASS FILTERED SALINITIES AT MALLARD ISLAND

Solid Line = 1992 near-surface sensor
Dashed Line = 1994 near-surface sensor
The near-bed sensor was not available in 1992

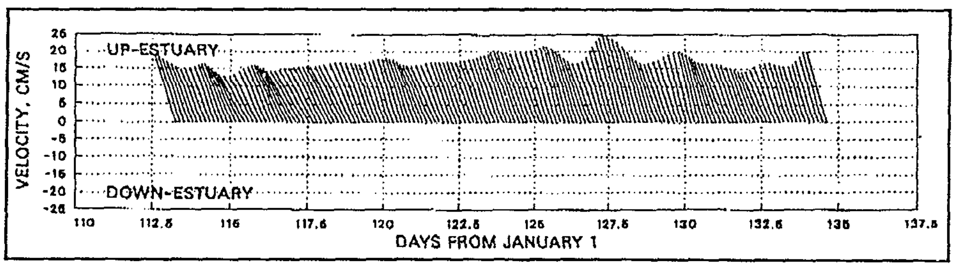

Figure 4
NEAR-BED RESIDUAL CURRENTS IN CARQUINEZ STRAIT NEAR MARTINEZ
In this stick diagram, currents are rotated into a local principal direction of 75 degrees determined by harmonic analysis.

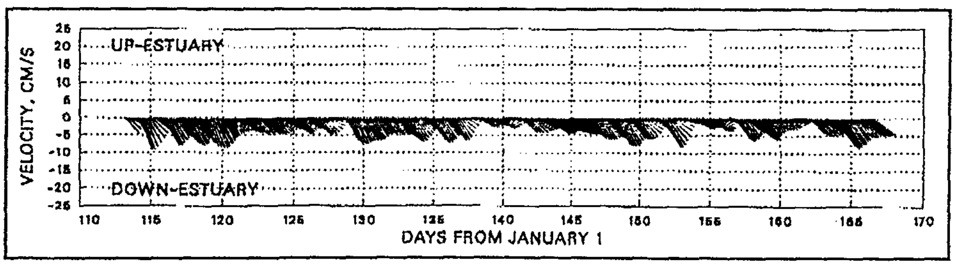

Figure 5
NEAR-BED EULERIAN RESIDUAL CURRENTS IN SUISUN BAY NEAR CONCORD
In this stick diagram, currents are rotated into a local principal direction of 82 degrees determined by harmonic analysis.

Bridge, where the depths change from about 19 meters in Carquinez Strait to about 11 meters in Suisun Bay. The concept of topographic control is well known (Armi 1986; Farmer and Armi 1986), and we believe the rapid decrease in depth just landward of the Benicia Bridge may be responsible for the change in near-bed residual currents from 15-20 cm/s up-estuary in Carquinez Strait to 5-10 cm/s down-estuary at Concord in both the 1992 and 1994 data sets. It is, therefore, likely that a null zone (location where the near-bed residual current changes from up-estuary to down-estuary) was geographically fixed to an area near the Benicia Bridge in the spring of 1992 and 1994 even though the mean position of the 2 psu near-bed isohaline was near or up-estuary of Mallard Island during these periods.

A complete review of all of the historical near-bed current meter data collected in Suisun Bay (Cheng and Gartner 1984; Mortenson 1987) and in the Sacramento River (George Nichol, 1990, personal communication) suggests the following spatial and temporal characteristics of gravitational circulation in the northern reach:

(1) Gravitational circulation dominates residual transport in Carquinez Strait unless freshwater inflows are so high that no salt water is present.
(2) Gravitational circulation has not been measured in Suisun Bay in the spring but has been consistently measured in the fall (Figure 6).
(3) Gravitational circulation has been measured in the Sacramento River at channel marker 14 when the near-bed salinities have locally exceeded about 2 psu.

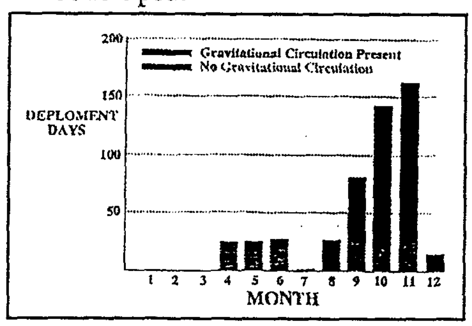

Figure 6
OCCURRENCE OF NET UP-ESTUARY NEAR-BED CURRENTS
Data collected by Cheng and Gartner, NOAA, and Mortenson.

(4) When gravitational circulation is present in the northern reach, its magnitude is modulated by the fortnightly (14-day period) spring/neap cycle: gravitational circulation is weakest during spring tides and strongest during neap tides.

In summary, the available data suggest a seasonal variability in the strength of the gravitational circulation in Suisun Bay which is tied, through the salt field (horizontal density gradient), to winter fresh water flows. In the spring, gravitational circulation appears to be weak or absent in the southernmost channel of Suisun Bay. However, as salinities increase in Suisun Bay as the summer progresses, the strength of the gravitational circulation increases until winter runoff flushes salinity out of the northern reach. In the following sections we suggest a revised conceptual model of how gravitational circulation works in Suisun Bay that at least qualitatively explains the depth, fortnightly and seasonal variability observed in the gravitational circulation.

Revised Conceptual Model of Entrapment in the Northern Reach

Officer (1976) developed a simplified model of gravitational circulation for a uniform channel that assumes a balance between the tidally averaged horizontal pressure gradient (which can be split into a density gradient component $\frac{\partial\rho}{\partial x}$ that drives the gravitational circulation and a water surface gradient component, essentially the tides, $\frac{\partial\zeta}{\partial x}$ and shear induced vertical mixing from the density current profile itself. On the basis of this balance he presented the following equation for the residual current profile.

$$u_z = \frac{g}{N_z}\cdot\left[\frac{1}{2}(H^2 - z^2)\frac{\partial\zeta}{\partial x} - \frac{1}{6\rho_o}(H^3 - z^3)\frac{\partial\rho}{\partial x}\right] \quad (1)$$

where u_z is the longitudinal residual velocity as a function of z, g is gravity, N_z is a vertical eddy viscosity (a vertical mixing parameterization), H is the mean depth, z is distance in the vertical direction measured positive from the bed, ζ is sea level, ρ is density, ρ_o is a reference density (usually taken to be that of fresh water), and x is distance in the horizontal (or along channel) direction. Officer's relation (Equation 1) describes the three principal factors we now believe control the strength of the gravitational circulation: the horizontal density gradient ($\frac{\partial\rho}{\partial x}$), depth ($H$), and vertical mixing ($N_z \sim \frac{U^2}{H}$). Although Officer's relation has the correct essential ingredients, it is based on a balance that is limited to the vertical mixing created by the density current profile itself and ignores vertical mixing by the tides.

Based on one-dimensional modeling of stratified water columns, we can construct (see Monismith *et al* 1995) an alternate parameterization of gravitational circulation strength based on a horizontal Richardson Number, Ri_x, whose formulation relies on a balance between the mixing energy of the tides ($\sim \frac{U^2}{T}$, which, when using a straining time scale, [$T \sim \frac{H}{U}$), gives $\sim \frac{U^3}{H}$] and the potential energy from the gravitational circulation induced stratification [$\sim (\frac{\Delta\rho}{\rho_o}\frac{gH}{T})$ where $\Delta\rho$ can be scaled assuming an advective balance as ($UT\frac{\partial\rho}{\partial x}$), which gives $(\frac{g}{\rho_o})UH\frac{\partial\rho}{\partial x}$, where U, H, T are appropriate velocity, depth, and time scales. This balance becomes:

$$\frac{U^3}{H} \sim \frac{g}{\rho_o}UH\frac{\partial\rho}{\partial x}, \quad (2)$$

which can be rewritten as a nondimensional ratio:

$$Ri_x = \frac{g}{\rho_o}\frac{H^2}{U^2}\frac{\partial\rho}{\partial x} \quad (3)$$

The horizontal Richardson number, Ri_x, involves the same dependent variables as does Officer's relation [proportional to the horizontal density gradient, depth (squared), and inversely proportional to the tidal energy (U^2)] yet includes tidal mixing directly in its formulation and is, therefore, at least theoretically, more appropriately applied to macrotidal systems like Suisun Bay. A more intuitive form of Equation 3 is:

$$Ri_x = \frac{(\frac{g}{\rho_o})\frac{\partial\rho}{\partial x}}{(\frac{U}{H})^2} \quad (4)$$

where U is the near-surface velocity. In this form, Ri_x can be thought of as representing a ratio between the horizontal density gradient ($\frac{\partial\rho}{\partial x}$) that *drives* the gravitational circulation (which also stratifies and thereby stabilizes the water column) *balanced against* the (water column average) vertical shear ($(\frac{U}{H})$) squared, which tends to *reduce* the strength of the gravitational circulation through vertical mixing.

When the numerator in Equation 4 is large relative to the denominator, we expect a strong gravitational circulation cell. Conversely, if the numerator is small and the denominator is large, we expect no gravitational circulation to develop. In between these extremes, a critical condition exists where the destratifying influence of the vertical shear is perfectly balanced by the density gradient induced stratification. Above this critical value, gravitational circulation exists; below it, vertical mixing by the tides inhibits its development. We refer to this condition as the critical horizontal Richardson number, $Ri_{x(crit)}$.

If we assume the horizontal Richardson number is a good predictor of the occurrence of gravitational circulation and that its critical value, $Ri_{x(crit)}$, is independent of position, then we can estimate, from data, the difference in the relative magnitude of the horizontal density gradient required for gravitational circulation to exist in Carquinez Strait and in Suisun Bay. For gravitational circulation to occur in Carquinez Strait we have,

$$\frac{g}{\rho_o}\frac{H_{car}^2}{U_{car}^2}\frac{\partial\rho}{\partial x}\Big|_{car} \geq Ri_{x(crit)} \quad (5)$$

and for gravitational circulation to occur in Suisun Bay,

$$\frac{g}{\rho_o}\frac{H_{sus}^2}{U_{sus}^2}\frac{\partial\rho}{\partial x}\Big|_{sus} \geq Ri_{x(crit)} \quad (6)$$

Equating the two Richardson numbers at criticality and rearranging,

$$\left(\frac{\partial\rho}{\partial x}\right)_{sus} = \left(\frac{H_{car}}{H_{sus}}\right)^2\left(\frac{U_{sus}}{U_{car}}\right)^2\left(\frac{\partial\rho}{\partial x}\right)_{car} \quad (7)$$

From the ADCP data collected last spring, we know that $H_{car} = 15m$, $U_{car} = 85cm/s$, and $H_{sus} = 8m$, $U_{sus} = 78\,cm/s$ (data collected near the naval weapons station, the velocity scale in both cases is the near-surface RMS current) so that Equation 7 becomes

$$\left(\frac{\partial\rho}{\partial x}\right)_{sus} \approx 3\left(\frac{\partial\rho}{\partial x}\right)_{car} \quad (8)$$

which suggests that for gravitational circulation to exist in Suisun Bay, it requires three times the horizontal density gradient required in Carquinez Strait.

Even though very little data have been collected that can be used to compute horizontal salinity (density) gradients (spring 1995 entrapment zone data will

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change this), the filtered ADCP data collected last spring are qualitatively consistent with the above discussion and suggest that in the relatively shallow channels (≈11m) of Suisun Bay, the magnitude of the horizontal salinity gradient is generally too weak in the spring to overcome the energy available from the tidal currents for vertical mixing. Conversely, deep waters like Carquinez Strait (≥18m) can sustain a gravitational circulation cell in the spring because:

(1) Deeper waters require a smaller horizontal density gradient to exceed a critical horizontal Richardson number, and
(2) Salinities "pile up" (topographically controlled) behind the change in depth that occurs near the Benicia Bridge, which locally confines and increases the horizontal salinity gradient in Carquinez Strait during the spring.

On the basis of the historical current meter data (Figure 6), it appears that gravitational circulation begins in the southern channel in Suisun Bay in late summer or early fall depending on fresh water inputs to the bay. Because the depths and the tidal energy generally available for vertical mixing in Suisun Bay are not markedly different between spring and fall (both of these time periods are during the equinoxes when the tidal energy is weak, Figure 7), we hypothesize, based on Equation 3, that the lack of gravitational circulation in Suisun Bay in the spring and its occurrence in the fall are due to an increase in the horizontal salinity gradient in the fall over that in the spring.

Long-Term Variations in Tidal Energy

The dynamics that control the magnitude of the net near-bed currents are among the most complicated in surface water physics since they involve shear-buoyancy interaction at turbulence time and space scales. The study of vertical mixing through turbulent interactions in a stratified water column is not only fundamental to understanding long-term transport processes in the estuary, but is essential to produce realistic long-term 3D model results (*eg*, the problem of turbulence closure). In this article, however, we skip over the complexities that occur at the turbulence and intertidal time scales (primarily because they are poorly understood) and provide instead a heuristic discussion of how the tidal currents affect density-driven residual transport. Moreover, an important goal of this research is to develop a relatively simple, easily measurable parameterization, like Ri_x, that predicts the occurrence of gravitational circulation, which could be related to ecosystem parameters and could easily be applied as a management tool.

The previous sections have discussed the dependence of the gravitational circulation on the depth, H, and on the horizontal density gradient, $\frac{\partial \rho}{\partial x}$. From Equation 3, we see that the magnitude of the tidal currents, U, also play a role (*eg*, inversely proportional to the tidal current squared). In fact, variations in the current, U, change Ri_x substantially more than do the horizontal density gradient, $\frac{\partial \rho}{\partial x}$, variations. When the overall magnitude of the currents are higher, during spring tides, we see reductions in the strength of the gravitational circulation. Conversely, during periods of generally weak tidal currents (neap tides), when vertical mixing is less, increased gravitational circulation is observed. Figure 7 shows the variation in tidal energy (proportional to $\langle u^2 \rangle$ where the $\langle \; \rangle$ represent a tidal filter) throughout the year for 1991, 1992, and 1994. Although this plot looks deceptively like a tidal record, each local maximum on this plot represents a spring tide and each local minimum a neap tide. From Figure 7, one can see that the tidal energy available for vertical mixing changes significantly within the year and between years. The solstices are periods of maximum tidal range and weakest neaps. Conversely, the vernal and autumnal equinoxes are periods of *minimal* tidal range and energetic neap tides. The 1992 and 1994 ADCP data were collected near the vernal equinox during a period of energetic neap tides. The energetic neap tides in combination with what we believe were relatively weak horizontal density gradients (the density gradients were not actually measured) likely account for the observed lack of net upstream bottom currents in Suisun Bay during the spring of 1992 and 1994.

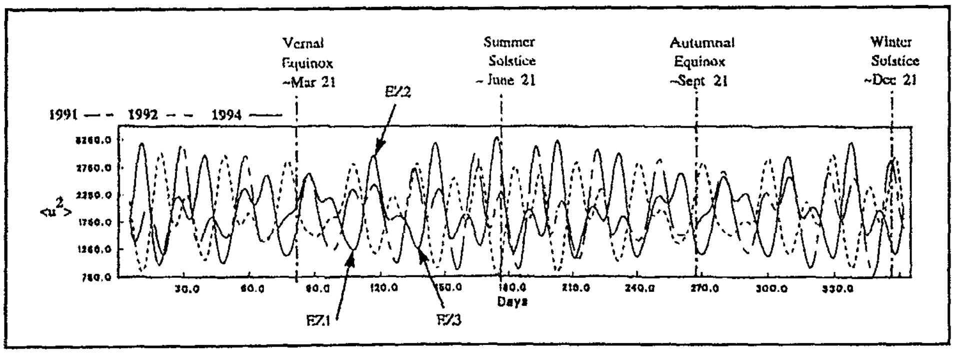

Figure 7
FILTERED PREDICTED CURRENT SPEED SQUARED AT MALLARD ISLAND FOR CALENDAR YEARS 1991, 1992, AND 1994
The labels EZ1, EZ2, and EZ3 represent the times when the biological synoptic sampling occurred.

In summary, our revised conceptual model of the northern reach based on Eulerian measurements is as follows:

(1) The depth dependence in Equation 3 explains, in part, why we see strong gravitational circulation in Carquinez Strait (H≥19m) and none in Suisun Bay (H≈11m) in the spring.
(2) The inverse relation to velocity squared, U^2, in Equation 3, accounts for the spring/neap modulations in gravitational circulation strength. The velocity squared is an index of the tidal energy available for vertical mixing. Increased vertical mixing from the increased tidal energy available during spring tides breaks down stratification, which effectively short circuits the gravitational circulation induced two-layer flow.
(3) The horizontal density gradient, $\frac{\partial \rho}{\partial x}$, drives the gravitational circulation; without it, gravitational circulation does not exist. The strength of the horizontal density gradient in proportion to the depth squared and in inverse proportion to the velocity

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squared (eg, the horizontal Richardson number) provides a possible explanation for the absence of gravitational circulation in the spring in Suisun Bay and its occurrence in the fall. Although there have been very few data collected in Suisun Bay from which horizontal salinity (density) gradients can be calculated, we hypothesize that the density gradient in the spring may be too weak to drive the gravitational circulation (*eg*, the horizontal Richardson number is less than its critical value in the spring). During the summer, salinities and the horizontal salinity gradient increase until the horizontal Richardson number exceeds its critical value, and gravitational circulation occurs.

(4) A semi-permanent null zone (and possibly a turbidity maximum) is probably located near the Benicia Bridge in the spring. At the very least, net near-bed currents are significantly reduced in the channels of western Suisun Bay from what they are in Carquinez Strait. A null zone probably moves from near the Benicia Bridge into Suisun Bay and possibly as far as the Western Delta sometime during the late summer when the horizontal density gradients become strong enough to overcome tidal mixing.

Management Implications

This revised conceptual model has significant implications to proposed dredging in Suisun Bay and to the generally accepted hydrodynamic explanation for the turbidity maximum and the entrapment zone.

If the depths near the Benicia Bridge are significantly lowered (dredged from 11m deep and 92m wide to 14m deep and 183m wide) as part of the John F. Baldwin and Stockton ship channel dredging projects (USACOE 1989), the bathymetric control that reduces the strength of the gravitational circulation in Suisun Bay from what it is in Carquinez Strait will be moved from the vicinity of the Bridge into the interior of Suisun Bay (Point Edith). This change in bathymetry could result in elevated salinities in Suisun Bay and the Western Delta. A detailed hydrodynamic study in the area adjacent to the Benicia Bridge is needed, however, to verify the importance and extent of this topographic control.

Given that gravitational circulation was not measured in Suisun Bay in the spring of 1992 and 1994, what does this imply about the existence of a turbidity maximum or entrapment zone based on existing conceptual models? Numerous publications (Arthur and Ball 1979; Peterson *et al* 1975; and others) have explained the turbidity maximum and entrapment zone as resulting from a hydrodynamic null zone. The lack of measured net up-estuary bottom currents in Suisun Bay in the spring suggests that if a turbidity maximum or entrapment zone does exist in the spring, a mechanism other than gravitational circulation must be responsible for it.

Conclusions and Ongoing Research

It is not surprising that a gravitational circulation/null zone based model of entrapment persisted; because much of the hydrodynamic data were collected in the fall when gravitational circulation has been observed in Suisun Bay (Figure 6). The horizontal Richardson number accounts, at least qualitatively, for the observed spatial and temporal variations in the gravitational circulation. However, before the revised conceptual model presented in this article can be accepted, a long-term (spring through fall) study is needed in which all of the parameters in the horizontal Richardson number are directly measured. This study is now under way. Seven ADCP-CTDs were deployed in Suisun Bay in late May 1995. The location of other *in situ* hydrodynamic instrumentation (Figure 8) was carefully chosen to measure all of the relevant parameters in the horizontal Richardson number along the axis of the northern reach. Moreover, because gravitational circulation does not appear to dominate spring-summer residual transport in the southern reach of Suisun Bay, shallows/channel exchange is likely to play a significant role. Therefore, six current meters with CTDs were deployed in the shallows of both Grizzly and Honker Bays in early July 1995 to address shallows residence times and shallows/channel exchange processes. Most of the instruments in this study were recovered in mid-September; the rest were recovered in mid-October 1995.

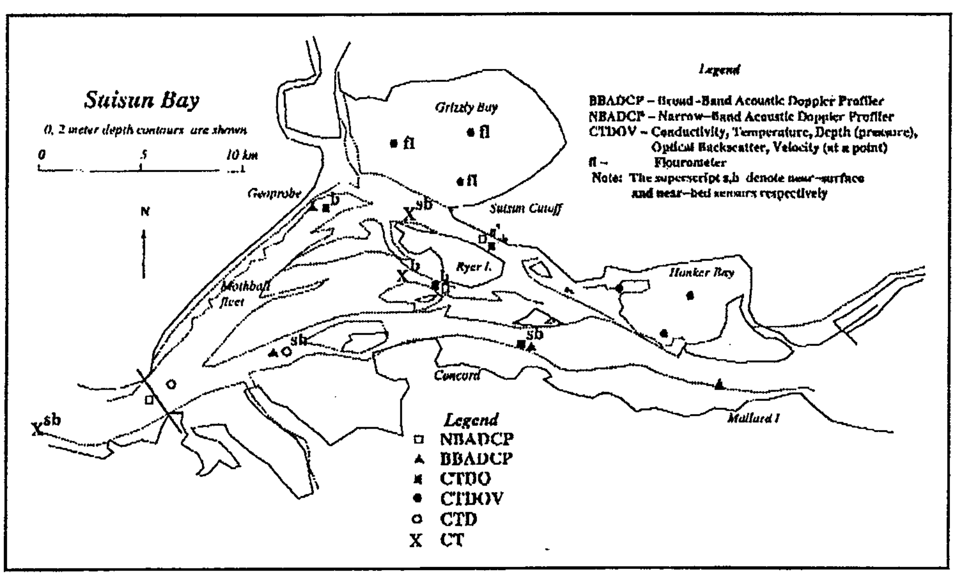

Figure 8
POSITIONS OF *IN SITU* INSTRUMENTS IN 1995
Channel stations were deployed the first week of June; shallows stations were deployed the first week in July.

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Acknowledgments

Collaborators in this year's 1995 entrapment zone study include: Dave Shoellhamer, California District, USGS, who is looking at suspended solids exchanges from Optical BackScatter instruments; Ralph Cheng, USGS, National Research Program, who assisted in study design; Dave Cacchione, USGS, Pacific Marine Geology, who deployed his sediment resuspension equipment (Geoprobe) within our existing network; and Peggy Lehman, Ted Sommer, and Hank Gebhard, DWR, who are interested in chlorophyll concentrations in Grizzly Bay. Stanford University deployed a 600 Khz ADCP at Chipps Island to address turbulence and tidal time-scale dynamics. Special thanks to Tim Hollibaugh for the loan of four OS100 CTDs; Rich Bourgerie, NOAA, for the loan of four Seacat CTs; and Francis Chung, DWR, who supplied an S4 current meter.

Finally, the authors wish to acknowledge that many of the ideas described in this article were distilled from numerous discussions with colleagues at Stanford University (Stephen Monismith, Jeff Koseff), USGS-NRP (Ralph Cheng), and within the California District's hydrodynamic group (Pete Smith, Dave Shoellhamer, Rick Oltmann, Larry Smith). Funding for the shallows instrumentation came from the Geological Survey's San Francisco Bay-Delta Ecosystem Initiative. The Interagency Program's continued support of this program is also gratefully acknowledged. Mark Stacey is supported by National Science Foundation grant OCE 94-16604 to Stanford University.

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Sacramento Coordinated Water Quality Program Includes Interagency Program Representative

Harlan Proctor, Department of Water Resources

A description of the Interagency Program's comprehensive monitoring plan was presented at an October 16 of the Sacramento Coordinated Water Quality Program. The coordinated monitoring program was organized by a coalition of the Sacramento Regional County Sanitation District, City of Sacramento, and Sacramento County Water Agency. Its initial goal was to determine ambient concentrations of trace elements in the American and Sacramento rivers so reasonable limits on NPDES permit requirements could be developed. Biweekly sampling at four sites has been conducted for the past 3 years. In addition to a general discussion of program results, the committee was seeking areas for collaboration with other ongoing monitoring. Since coordinating resources is also one of the primary objectives of the revised Interagency Program, we will have a representative on the technical review subcommittee to comment on water quality management goals, exchange data, and propose mutually beneficial program modifications.

Sacramento Perch, Wakasagi, Splittail, Sacramento Blackfish, and Shimofuri Goby in San Luis Reservoir and O'Neill Forebay

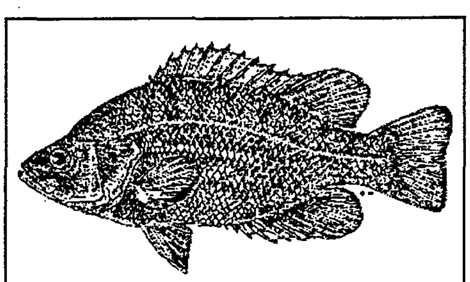
Lloyd Hess and Cathy Karp, U.S. Bureau of Reclamation, Denver, and Johnson Wang, National Environmental Sciences, Inc.

Fish sampling activities in San Luis Reservoir have supplemented USBR research in the Delta. Objectives of the San Luis research are to:

- Help us understand the effectiveness of Tracy Fish Collection Facility in protecting fish from entrainment to Central Valley Project facilities leading to San Luis Reservoir.
- Examine potential survival of fish species passing the fish facilities and arriving at the reservoir through the Delta-Mendota Canal, particularly the ecologically sensitive smelt and native cyprinids.
- Determine the ecological significance of fish species capable of self-reproduction in the reservoir.

Two trips were made to San Luis Reservoir to sample the fish community: April 20-21, 1994, and August 22-23, 1995. Areas sampled represented most of O'Neill Forebay and the Portuguese Cove arm of San Luis Reservoir (Figure 1). On the first trip, sampling gear included a half-meter plankton net, a 3-foot plankton (net) beach seine, a 10-foot (1/8-inch mesh) beach seine, and experimental gill-nets. A total of 11 fish species were captured (Table 1). On the second trip, 10-foot and 50-foot beach seines (both 1/8-inch mesh) were used to sample inshore fish fauna. A total of 21 fish species were captured in 1995. During the two field trips, 24 fish species were observed.

The most abundant fish species were inland silverside and threadfin shad. Five species of special interest are discussed below.



SACRAMENTO PERCH
From *Fishes of California* (Moyle 1976, U.C. Press.)

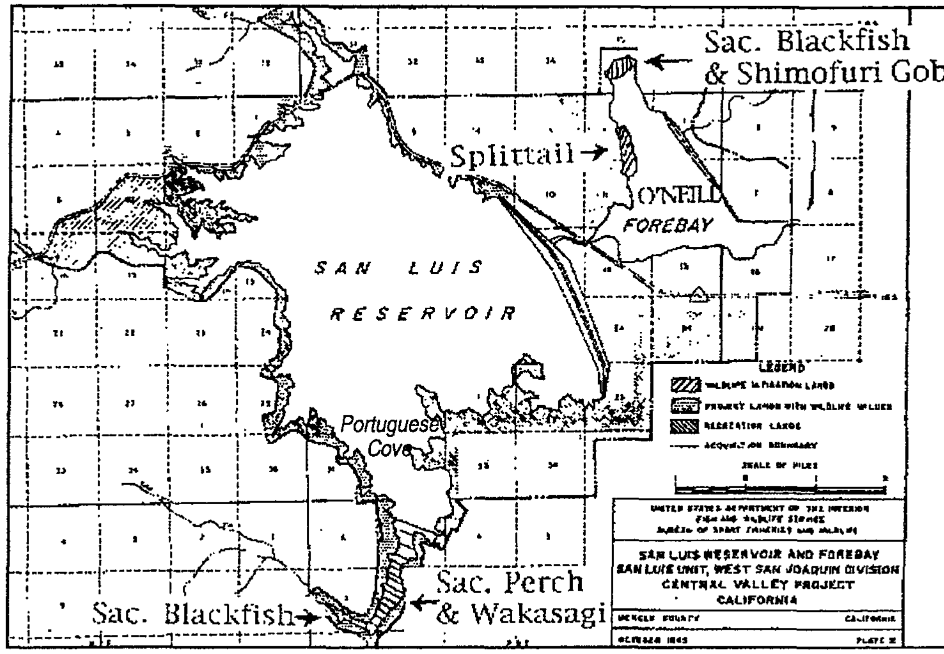


Figure 1
COLLECTION AREAS FOR SPECIAL INTEREST FISHES IN
SAN LUIS RESERVOIR AND O'NEILL FOREBAY

Table 1
FISH SPECIES OBSERVED AT
SAN LUIS RESERVOIR AND O'NEILL FOREBAY,
1994 and 1995.

Common Name	Scientific Name	1994	1995
American shad	*Alosa sapidissima*	+	+
Threadfin shad	*Dorosoma petenense*		+
Wakasagi	*Hypomesus nipponensis*	+	+
Goldfish	*Carassius auratus*	+	
Common Carp	*Cyprinus carpio*		+
Sacramento blackfish	*Orthodon microlepidotus*		+
Splitttail	*Pogonichthys macrolepidotus*		+
Sacramento sucker	*Catostomus occidentalis*	+	+
White catfish	*Ameiurus catus*	+	+
Channel catfish	*Ictalurus punctatus*		+
Western mosquitofish	*Gambusia affinis*		+
Inland silverside	*Menidia beryllina*	+	+
Threespine stickleback	*Gasterosteus aculeatus*		+
Striped bass	*Morone saxatilis*		+
Sacramento perch	*Archoplites interruptus*		+
Green sunfish	*Lepomis cyanellus*	+	
Warmouth	*Lepomis gulosus*	+	
Bluegill	*Lepomis macrochirus*	+	+
Largemouth bass	*Micropterus salmoides*		+
Black crappie	*Pomoxis nigromaculatus*		+
Bigscale logperch	*Percina macrolepida*		+
Tule perch	*Hysterocarpus traski*	+	+
Shimofuri goby	*Tritentiger bifasciatus*	+	
Prickly sculpin	*Cottus asper*	+	+
Total		11	21

Sacramento Perch

Sacramento perch (*Archoplites interruptus*) is the only North American native centrarchid found west of the Rocky Mountains. It is considered extirpated from its original habitat (the Sacramento and San Joaquin rivers) and has not been seen in the delta for at least a decade (Peter Moyle and Scott Mattern, personal communication). It is found in ponds in and around the delta and in a few lakes where it was introduced. The Sacramento perch's decline is attributed to the introduction of other centrarchids (sunfish and bass), which out compete it in its native habitat.

Sacramento perch was extremely abundant in beach seine collections. We preserved 77 Sacramento perch ranging from 20 to 43 mm total length, which were captured on August 23, 1995, in Portuguese Cove Arm. All specimens were young-of-the-year from the 1995 year-class and represented only a small portion of perch observed. Apparently, Sacramento perch has existed and reproduced in San Luis Reservoir for quite sometime. Since there are presently no Sacramento perch in the delta, it must have been introduced into San Luis Reservoir when the reservoir began filling in the late 1960s. At that time a small delta population still existed.

We believe successful reproduction in 1995 may have been related to the wet winter, which allowed high stable water levels in San Luis Reservoir during May and June, the perch spawning season. Drawing down the reservoir in late spring for agricultural and municipal purposes probably strands many Sacramento perch spawning nests, leaving them exposed to predation — and even out of water in drier years.

Wakasagi

Wakasagi (*Hypomesus nipponensis*) is an exotic osmerid introduced from Japan into several California reservoirs in the late 1950s. At that time it was considered to be the same species as delta smelt, but the two species have now been separated. Wakasagi is thought to have reached the Delta through an introduction into Sly Park Reservoir in the 1980s (Dennis Lee, personal communication). Wakasagi migrated through the American River drainage to Folsom Lake, where it has become abundant. Extensive dike repairs at Folsom Dam required major reservoir draw-downs, which probably enhanced the invasion of wakasagi to the American and Sacramento rivers. Wakasagi has been positively identified at the CVP/SWP fish facilities in recent years.

In April 1994, three prejuvenile and juvenile specimens (18.5 to 23.0 mm total length) were captured by plankton-net beach seining in a small retention pond on the Portuguese Cove Arm. This pond floods when San Luis Reservoir is full. On August 23, 1995, 29 larger juvenile wakasagi (64.0 to 90.3 mm total length) were collected in the retention pond and beach seine stations in Portuguese Cove. All wakasagi captured during both trips were young-of-the-year.

We believe wakasagi has established a reproducing population at San Luis Reservoir in recent years because of an apparent large wakasagi population in San Luis Reservoir, while virtually no young-of-the-year smelt were collected at the fish facilities in 1995. Reproduction in San Luis Reservoir is a more plausible explanation, rather than Delta export, for the observed wakasagi distribution and abundance.

No delta smelt or longfin smelt were collected at San Luis Reservoir during either of the two sampling trips. We believe wakasagi were successfully introduced into San Luis Reservoir, while delta smelt were not, because of wakasagi's preference for fresh water. Delta and longfin smelts seem to require more brackish water.

We expect the wakasagi population in San Luis Reservoir to continue to expand. We have not collected any wakasagi in O'Neill Forebay.

Splittail

Splittail (*Pogonichthys macrolepidotus*) is a large native minnow that is being considered for protection under the federal Endangered Species Act. During the drought years of the late 1980s and early 1990s, splittail became scarce in the CVP fish facility salvage; about 1 million juvenile splittail were salvaged in 1993 and 3 million in 1995, both wet years.

During the 1994 survey of San Luis Reservoir, we were looking for splittail reproduction, but found none. In 1995, we wanted to document survival in O'Neill Forebay of juvenile splittail being transplanted down the Delta-Mendota Canal from the abundant splittail year class in the delta. On August 22, 1995, 26 juvenile splittail (72 to 135 mm total length) were captured near San Luis Creek boat ramp in O'Neill Forebay. We believe these came from the Delta and not from natural reproduction in the San Luis/O'Neill complex. We based this conclusion on the fact that in 1994, when splittail reproduction in the delta was low, we could not find splittail in either San Luis or O'Neill, but in 1995, when splittail reproduction was very successful in the delta, we found juvenile splittail in O'Neill Forebay. The question remains whether these juvenile splittail will stay in the reservoir or try to migrate from the system.

Sacramento Blackfish

Sacramento blackfish (*Orthodon microlepidotus*) is a native minnow that has declined substantially in the delta. Blackfish has been abundant in the San Luis/O'Neill complex and supported a commercial fishery in San Luis Reservoir.

In 1995, we collected two size classes of Sacramento blackfish in the San Luis complex. We collected several blackfish in O'Neill Forebay and preserved a single specimen (107 mm TL). We believe these fish were transported from the delta, since similar-sized blackfish were seen at the fish facilities. In addition, two small juvenile blackfish (33.1 and 47.0 mm) were collected in the uppermost section of Portuguese Cove. We believe these smaller fish were spawned in the cooler water in San Luis Reservoir and grew more slowly than delta fish.

Shimofuri Goby

Shimofuri goby (*Tritentiger bifasciatus*) is an exotic fish species introduced from Japan. It likely came into San Francisco Bay via ballast water in a freighter. There is a question whether this species can survive and successfully reproduce in fresh water.

Three juvenile Shimofuri goby (18.6 to 33.5 mm total length) were observed at the Delta-Mendota Canal's entrance to O'Neill Forebay on August 22, 1995 — the first observation of this species in the San Luis/O'Neill complex. It is not known whether these juveniles represent reproduction in O'Neill Forebay or transport from the Delta. Because of their collection location, we suspect the latter.

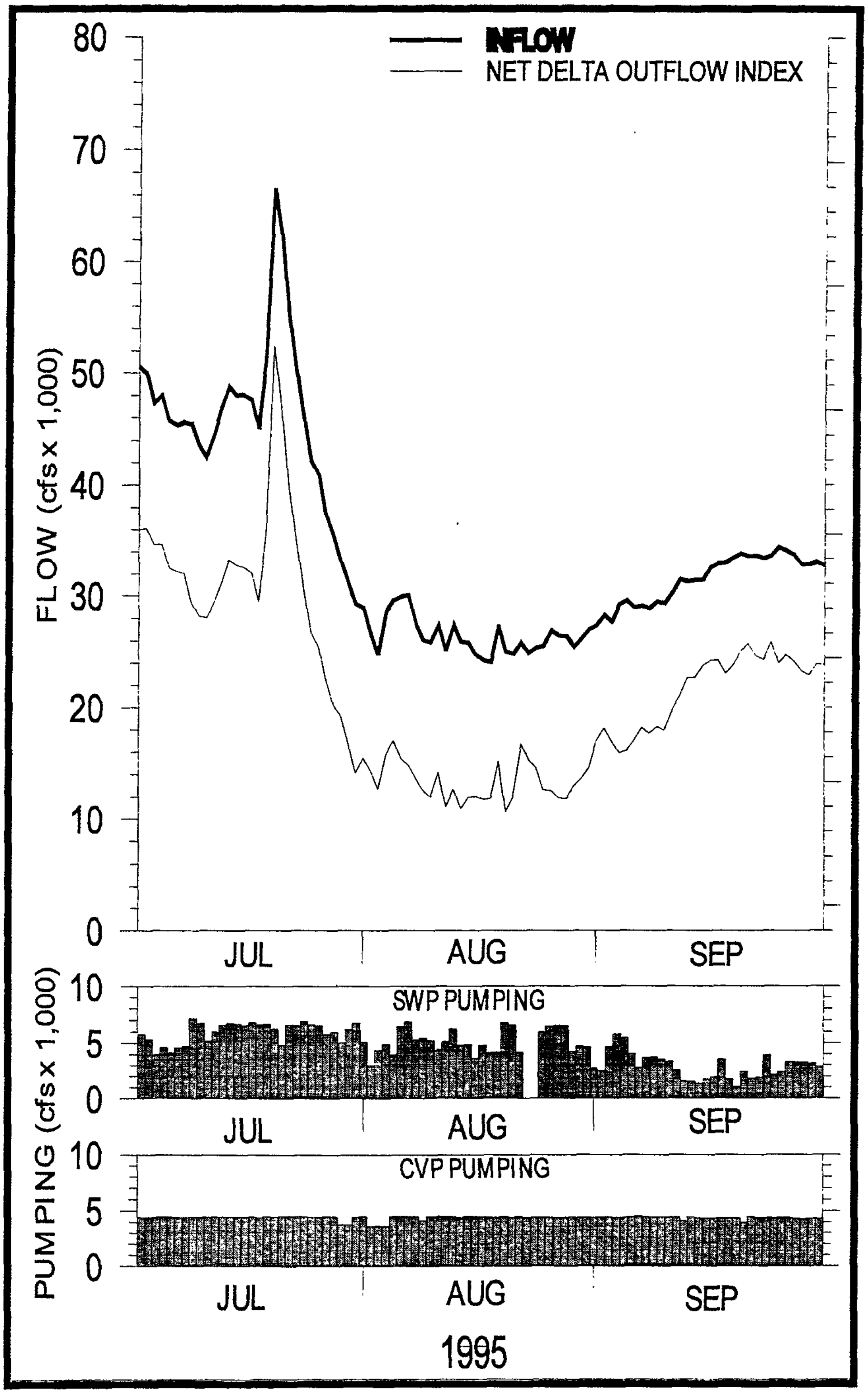
Conclusions

Fish whose native habitat has declined — and whose abundance has declined as a result — have colonized the habitat in at least part of the San Luis/O'Neill complex. Sacramento perch found suitable habitat in San Luis Reservoir and is an example of a native fish that expanded its range to newly created habitat. Wakasagi, a recently arrived exotic species, seems to be dramatically expanding its range and exploiting new habitat. For both fishery and water delivery managers, management implications are associated with development and potential use of new fish habitat. Additional research on the fish communities of CVP canals and reservoirs is being considered.

Delta Flows

Kate Le, Department of Water Resources

The July-September Delta Outflow Index averaged about 22,000 cfs. During the latter part of July, peak inflow was about 67,000 cfs and peak outflow was about 52,000 cfs. These peaks are results of high flows due to the Folsom Dam gate failure. Combined SWP and CVP pumping from July through September averaged about 8,900 cfs. Since the CVP was pumping at full capacity, SWP pumping was increased to accommodate the high releases through the failed gate. SWP pumping ceased for 2 days in late August because of maintenance work.



Laboratory Culture of Delta Smelt

Serge Doroshov and Randy Mager, University of California, Davis

Wild juvenile delta smelt captured in fall 1994 were raised to maturity in laboratory tanks. They spawned in May 1995. Eggs were collected and incubated in conical glass jars with upwelling flow. Although spawning results were not entirely satisfactory (most spawnings produced infertile or low fertility eggs), we obtained several batches of eggs of high fertility and hatchability. Mortalities during rearing from juvenile to mature stage were minor, and there was no incidence of *Mycobacterium* disease. Full screen metal content analysis of rearing water was conducted to elucidate potential effect of contaminants on spawning: all metals were below detection limit, except for barium (100 ppb in rearing tank and 120 ppb in the water source, a newly built well at Institute of Ecology. There was no evidence of any toxic effect of barium at this concentration on adult broodstock, but elevated concentration of barium are known to negatively affect the fertilization success in marine invertebrates (Dr. Gary Cherr, Bodega Bay Marine Laboratory, personal communication).

Hatched larvae were raised for the first 3 weeks in static-renewal aquaria at water salinity 5-6 parts per thousand and high stocking density. The continuous culture and production of *Nanochloropsis* oculata (alga) and *Brachionus plicatilis* (rotifer) was established to maintain concentration of algae at about 250,000 cell/ mL and rotifers 10/mL in rearing containers. It was observed that phytoplankton in rearing tanks is required to stimulate feeding activity of larvae. This phase of larval rearing was highly successful: estimated survival was about 80%, and total length of larvae increased from 5 to 12 mm. At 3 weeks after hatching, larvae retained continuous finfold and did not exhibit lumenal dilation of the swim bladders.

At 3-4 weeks after hatching, larvae were transferred to larger tanks with a partial water exchange. Algae, rotifers, and brine shrimp nauplii were added daily. At this age, larvae exhibit strong preference for larger prey, consuming only brine shrimp nauplii. Despite the significant feeding activity and consumption, mortality increased, most likely due to inadequate nutritional value of brine shrimp nauplii. Attempts to use artificial diets at this stage of development failed. The available larval diets are ingested, but they leach rapidly in the water column, resulting in poor water quality. At about 4-5 weeks after hatching, larvae were about 14-15 mm tail length, had differentiated caudal and dorsal fins, and differentiated but not inflated swim bladders. At 6 weeks after hatching, larval survival in rearing tanks was 30-40%.

Larvae were sampled at about 10-day intervals, and data on growth and development will be presented. Preliminary observations suggest larval development of delta smelt from hatching to metamorphosis is generally similar to that of *Osmerus eperlanus* (Urho 1992, Baltic Sea) and likely to *Osmerus mordax* (Cooper 1978) — hatching at 5-6 mm TL; yolk resorption and first feeding at 5 days after hatching; sparse pigmentation with ventral melanophores; differentiation of dorsal, caudal, anal, and pelvic fins at 12-18 mm TL; and swim bladder filling at 17 mm.

There is an overall similarity, with regard to problems and techniques in rearing smelt larvae to metamorphosis, with larval culture of clupeoid fish reviewed by Blaxter and Hunter (1982).

This year, work suggests that laboratory culture of delta smelt is technically feasible but labor-intensive. Broodfish can be raised and spawned in captivity to obtain adequate supplies of fertilized eggs and larvae. Normal growth, development, and high survival of larvae can be maintained during the first 3 weeks of feeding. Further rearing to metamorphosis requires improvement, mainly in larval feeding techniques. Use of new larval diets with enhanced stability in water may be appropriate to pursue.

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DAYFLOW Hydrologic Data

A semiannual DAYFLOW update for October 1994 through June 1995 is now available in electronic or paper copy.
The 1995 water year annual DAYFLOW update is scheduled to be available in December 1995.
Contact Sheila Greene (916/227-7538).

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Continuous Flow Measurements Using Ultrasonic Velocity Meters: An Update

Rick Oltmann, U.S. Geological Survey

An article in the summer 1993 *Newsletter* described USGS work to continuously monitor tidal flows in the delta using ultrasonic velocity meters. This article updates progress since 1993, including new installations, results of data analysis, damage during this year's high flows, and the status of each site.

UVMs operate by sending acoustic signals between two fixed transducers positioned on opposite sides of a channel; the acoustic path between transducers is oriented at about a 45-degree angle to the primary direction of flow. The UVM itself generally is placed in an instrument shelter on shore and connected to the transducers by transmission cables that lie on the channel bottom. Acoustic signals are transmitted in both directions across the channel, and signal travel times are measured precisely. The difference in time-of-travel for an upstream- and a downstream-transmitted signal provides a measure of the average velocity across the channel at the depth of the transducers. This velocity measurement is an index velocity (not mean cross-sectional velocity) and generally is referred to as a "line velocity". The line velocity is converted to total discharge by multiplying it by a coefficient and the channel cross-sectional area. The velocity coefficient is determined by calibration with measured discharges; the cross-sectional area is obtained using measured stage and channel geometry data. Generally, the UVM is programmed to provide a time series of tidal flow at a 15-minute interval; these data can be tidally averaged to estimate daily net flow. An acoustic Doppler discharge measuring system (Simpson and Oltmann 1992) is being used to make fast and accurate flow measurements for use in calibrating and validating the UVMs; the system uses an acoustic Doppler current profiler. Laenen (1985) provides details on operation of a UVM flow measurement station.

USGS has ten UVM flow monitoring stations in the delta that are either operational or in some phase of repair or installation. The oldest stations are the Sacramento River at Freeport (operational since 1979) and the Old River and Middle River sites adjacent to Bacon Island (operational since 1987). The 1993 *Newsletter* article described the installation or planned installation of four additional UVM stations: Sacramento River upstream of the Delta Cross Channel, Sacramento River downstream of Georgiana Slough, San Joaquin River at Jersey Point, and Sacramento River downstream of Decker Island. All except the Decker Island station have been installed, and that station has been relocated upstream, at Rio Vista. Three additional stations have been or are being installed: Threemile Slough, Dutch Slough, and San Joaquin River at Stockton. Following is a discussion of the status of all these sites except Sacramento River at Freeport, along with available data analyses.

Old River and Middle River

UVM stations on Old River and Middle River are on two of the three flow paths through which water is drawn to the SWP and CVP export facilities; the third route is from the San Joaquin River through Old River and Grant Line Canal. During low export periods, maximum tidal flow during both flood and ebb tides generally is about 10,000 cubic feet per second at both sites. Daily net flow data produced by the two stations for 1987-1992 indicate that about 80% of the combined SWP/CVP export rate is drawn from the north down Old and Middle rivers, and the other 20% is drawn from the east from the San Joaquin River.

Percentages of flow drawn through the three paths vary depending on the export rate, whether daily net flow of the San Joaquin River at Stockton is positive (to the north) or negative (to the south), and whether a temporary rock barrier is installed across Old River at the confluence with the San Joaquin River. When a temporary barrier is not installed and daily net San Joaquin flow at Stockton is positive, about 33% of the export water is drawn down Old River, 45% is drawn down Middle River, and 22% is drawn west from the San Joaquin River. Flow percentages for Old River and Middle River at the UVM sites increase by about 3% when daily net San Joaquin River flow is negative, resulting in about a 6% decrease in the flow drawn west from the San Joaquin.

The data also show that flow percentages for Old River and Middle River decrease by 1-3% as the export rate increases throughout its range, indicating that the percentage of San Joaquin River water increases as the export rate increases. Installing a temporary notched, rock barrier at the head of Old River results in about a 64% reduction in flow of San Joaquin River water through Old River and Grant Line Canal; Old River flow increases to about 40%, and Middle River flow increases to about 52%.

This year is the only time since data collection at these stations began (in 1987) that net flows have been measured flowing to the north — away from the export facilities. From March 9 until June 14, 1995, San Joaquin River flow at Vernalis was high (over 10,000 cfs, with a maximum of about 26,000 cfs) and the combined SWP/CVP export rate was fairly low (less than 4,000 cubic feet per second). Maximum northerly net flows at the Old River and Middle River UVM sites were about 6,000 cfs on March 24, 1995.

Sacramento River near Walnut Grove

The UVM station on the Sacramento River upstream of the Delta Cross Channel was operational from December 1992 until January 1995, when a rock barge destroyed a transducer pile. The Sacramento River station downstream of Georgiana Slough has been operational since January 1993.

The difference in flow records for these two stations provides an indirect measure of the flow passing through the Delta Cross Channel and Georgiana Slough when the cross channel gates are open and the flow through Georgiana Slough when the gates are closed. At the upstream site, tidal flows during low streamflow conditions range from ebb flows of about 13,000 cfs to flood flows of about 2,500 cfs; at the downstream site, ebb flows are about 10,000 cfs and flood flows are about 7,000 cfs.

Figure 1 shows how the tidal and tidally averaged flows vary at the two stations on the Sacramento River near Walnut Grove when the cross channel gates are alternately opened and closed. When the gates are open (days 295-301, 312-319), minimum tidal flows for the upstream site are ebb flows of about 4,000 cubic feet per second. When the gates are closed (days 302-304, 306-311), minimum tidal flows are slight flood flows of about 1,000 cfs. Opening and closing the gates has the opposite effect on tidal flows at the downstream site. When the gates are open, flood flows are at a maximum of about 7,000 cfs, and when the gates are closed flood flows decrease to about 4,000 cubic feet per second.

These data suggest that when the gates are open, flood flows moving up the Sacramento River past the downstream site encounter less resistance from the flow coming downriver past the upstream site relative to when the gates are closed. Thus, when the gates are open, flows past the sites are able to come together and move through the gates into the Delta Cross Channel. When the gates are closed, flood flow past the downstream site cannot enter the cross channel and, thus, exerts resistance to the ebb flow past the upstream site. This increased flow resistance decreases the magnitude of the flood flows at the downstream UVM site and decreases the magnitude of the ebb flows at the upstream site (at times, it even causes flood flows).

The two tidally averaged flow plots in Figure 1 indicate that when the Delta Cross Channel gates are closed, daily net Sacramento River flow past the upstream site decreases and daily net Sacramento River flow past the downstream site increases compared with when the gates are open. The decrease in net flow at the upstream site when the gates are closed results in increased flow from the Sacramento River into Sutter and Steamboat sloughs of about 1,800 cfs. This increase, along with the increase in net flow at the downstream site by about 2,000 cfs, results in an increased net flow of the Sacramento River at Rio Vista by about 3,800 cfs.

Replacement transducer mounting piles were driven at the damaged upstream site during August, and we hope to have the site operational in October.

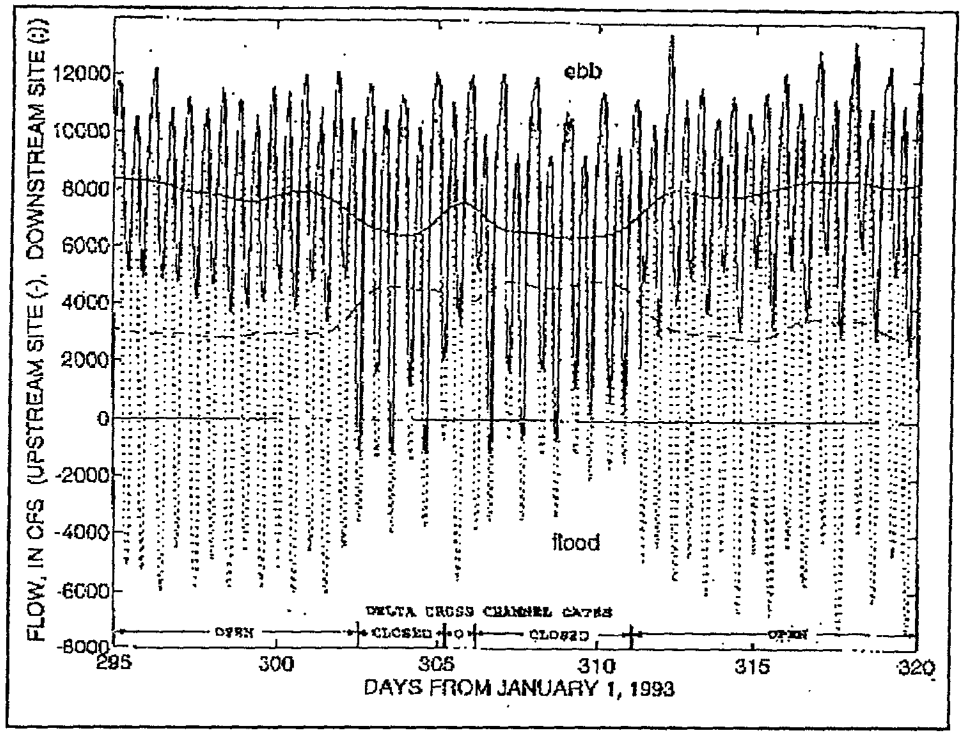

Figure 1
TIDAL AND TIDALLY AVERAGED FLOWS FROM UVM STATIONS IN THE SACRAMENTO RIVER NEAR WALNUT GROVE

San Joaquin River at Jersey Point

The Jersey Point UVM station was installed in May 1993, but because of instrumentation problems, it did not provide usable data until May 1994. At Jersey Point, the San Joaquin River is part of the deep water ship channel to the Port of Stockton. Depth is maintained by dredging — a hazard to transducer communication cables on the channel bottom. Therefore, a system of four transducers, one standard UVM, and a modified UVM called a "responder" was first used to create an acoustic link across the channel. The installation consisted of two transducers on one side of the channel connected by cable to a UVM and two transducers on the opposite side of the channel connected by cable to a responder. The UVM transmits an acoustic signal across the channel, and the signal is received by one of the transducers connected to the responder. The responder then initiates a return signal from the other transducer connected to the responder, which is received by the other transducer that is connected to the UVM. The time-of-travel of the acoustic signals is measured precisely and used as for a standard UVM installation.

Early operational problems of the Jersey Point system were thought to be related to the responder. To test this hypothesis, a temporary cable was laid across the channel bottom connecting one transducer from each side of the channel and eliminating the use of the responder. Use of the temporary cable resulted in good data from the UVM. Conversations with the Corps of Engineers revealed that dredging seldom occurs at this site. Therefore, an upgraded cable was deployed on May 11, 1994, and the site was operational until a passing vessel destroyed the transducer mounting piles on April 9, 1995. Replacement piles were driven in August, and the site should again be operational in October.

Flow data collected at Jersey Point before the transducer piles were destroyed showed that maximum tidal flow during both flood and ebb is about 150,000 cfs. Analysis of the tidally averaged net flow data demonstrates the filling and draining of the delta that occurs throughout the spring/neap tidal cycle. Figure 2 shows tidally averaged stage (top plot) and flow (bottom plot) for May 10 to October 26, 1994. Maximum combined Sacramento/San Joaquin inflow to the delta during this period was about 18,000 cfs. The vertical lines connecting the two

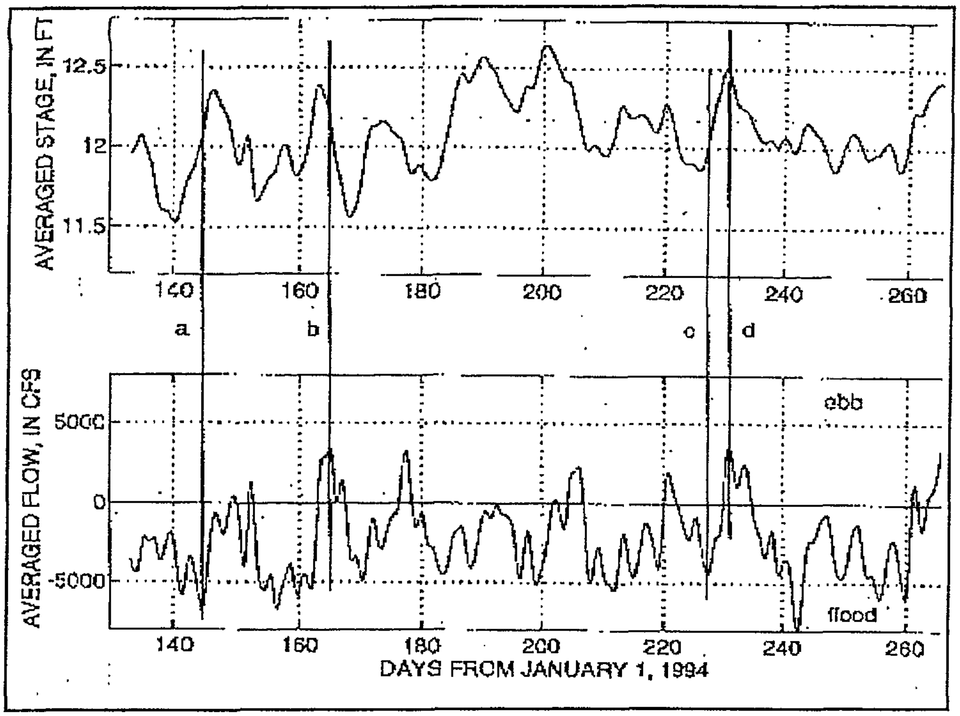

Figure 2
TIDALLY AVERAGED STAGE (top) AND FLOW (bottom) FROM SAN JOAQUIN RIVER AT JERSEY POINT UVM

plots show that during spring tides, when the net elevation of the delta is rising (lines a and c), net flows into the delta (negative flow; delta is filling) are largest, and during neap tides, when the net elevation is decreasing (lines b and d), net flows out of the delta (positive flow; delta is draining) are largest. Figure 2 also shows that the average net flow during this predominantly summer period was about 2,000 cfs upriver.

Threemile Slough

The Threemile Slough UVM station has been operational since February 1994. Maximum ebb and flood tidal flows are about 30,000 cfs. Net flow during conditions other than high flow is generally about 1,500 cfs from the Sacramento River to the San Joaquin River. The magnitude of this net flow varies with the spring/neap tidal cycle, with net flow being reduced as the delta drains and increased as the delta is filling. During the high flows of March 1995, maximum net flow was 22,300 cfs flowing from the Sacramento River to the San Joaquin River. For about 60 days following the peak, the net flow direction through the slough was periodically from the San Joaquin River to the Sacramento River, with a maximum net flow of about 2,000 cfs. The reversal of net flow direction appears to result from high flows entering the delta from the San Joaquin River; San Joaquin River inflow to the delta during the 60-day period never was less than 17,000 cfs.

Sacramento River at Rio Vista and Dutch Slough

Initially, a UVM installation was planned for the Sacramento River just downstream of Decker Island. The plan was to add flow from the Decker Island site to San Joaquin River flow at the Jersey Point site and to estimated flow through Dutch Slough to provide an estimate of delta outflow. The acoustic path length at the proposed Decker Island site was 3,000 feet, which exceeds the capability of the UVM equipment. Therefore, two complete UVM systems with responders (Sacramento Ship Channel), similar to the Jersey Point system, were initially planned for monitoring flow at this site. However, once funding was obtained for installation of the Threemile Slough UVM, we decided that the Decker Island station could be relocated upstream to the Rio Vista Bridge area and still provide the flow data necessary to estimate delta outflow. Three reasons for moving the Decker Island site upstream to Rio Vista were:

- To lessen the chance of obtaining erroneous line-velocity data due to bending of the acoustic signal because of salinity gradients within the acoustic path,
- To simplify installation and operation of the station by making use of the bridge structure, and
- To make use of a DWR compliance monitoring instrument shelter and stilling well.

During March 1995, installation began of two UVMs at the Rio Vista site. One is now operational; the acoustic path is on the northwest side of the channel. The acoustic path for the second UVM will be on the southeast side of the channel. The pile installed for the southeast acoustic path was lost during the March 1995 high flows; a steel replacement pile in addition to a support pile were installed during August. The two line velocities from the two UVMs will be used to compute the flow record. Because there will be two separate UVMs operating at this site, a radio link between the two will be required so that one UVM will be disabled while the other is measuring velocity.

The national ecosystem initiative program of the USGS funded installation of a UVM on Dutch Slough. This UVM station is needed to measure a small fraction of delta outflow. The equipment shelter has been installed, and the transducer mounting piles were driven during August. The site should be operational in November.

San Joaquin River at Stockton

A UVM flow monitoring station was installed on the San Joaquin River near Stockton in July 1995, with funding provided by the City of Stockton. The site is about a half-mile north of the Highway 4 bridge crossing near the city waste water treatment plant. The National Pollutant Discharge Elimination System permit requires the city to obtain flow data at the location where treated effluent is discharged into the river. This site will monitor the periods and magnitude of net southerly San Joaquin River flow due to operation of the SWP and CVP export facilities and consumptive use in the southern delta. The instrument is recording line velocity and stage data, but it has not yet been calibrated.

Supplemental Flow Data

The UVM network provides a valuable flow database for use in calibrating and validating delta flow and transport models. This database will be supplemented with ADDMS measurements collected periodically at critical flow splits to assess the accuracy of flow magnitude and phasing provided by models. An adequate number of measurements can be made with the ADDMS to simultaneously characterize tidal variations at three or four sites using one boat and a crew of two. The ADDMS is used to make a few measurements at each of the three or four sites in turn. Then the measuring cycle repeated for as long as desired; for example, during half or a complete tidal cycle.

Acknowledgments

The USGS greatly appreciates the funding provided by DWR, USBR, Contra Costa Water District, and the City of Stockton to install and operate the network of UVM flow monitoring stations. The author acknowledges Mike Simpson, Steve Gallanthine (no longer with the project), Rick Adorador, and Scott Posey of the USGS for their dedicated effort in installing, troubleshooting, and operating the UVM network. Without their efforts, these valuable flow data would not have been collected.

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Feather River Fisheries Studies

Ted Sommer and Debbie McEwan, Department of Water Resources

The lower Feather River extends from Oroville to its confluence with the Sacramento River at Verona. Fall-run and spring-run chinook salmon spawn on two reaches of the river: the low-flow channel from Oroville to Thermalito Afterbay outlet, and the lower reach from Thermalito Afterbay outlet to Honcut Creek, near the town of Live Oak. The lower reach also provides important habitat for other migratory species such as American shad, splittail, striped bass, and green sturgeon.

Flow into the system is controlled by the Oroville complex, including Oroville Dam, Thermalito Diversion, and Thermalito Afterbay. Recently, Water Resources has initiated several fisheries studies in cooperation with Fish and Game. Major issues to be addressed include chinook salmon spawning, outmigration gravel quality, and the role of Feather River Fish Hatchery.

Flow conditions for salmon spawning were recently examined during development of an instream flow model for the Feather River. A key issue is whether the model, which was based on measurements of spawning preferences during the 6-year drought, is applicable to higher flows. The present study will attempt to resolve this issue empirically by operating the low-flow channel at two different flow levels during the next 4 years. Beginning this fall, a combination of aerial photography and ground-based measurements will be used each year to determine spawning density, location, and conditions.

In early 1996, as part of efforts to provide comprehensive salmon monitoring in the Central Valley, Water Resources will install and operate screw traps below the low-flow channel and lower reach. We plan to operate the traps during winter and spring for at least the next 4 years to provide information about the timing and magnitude of juvenile salmon outmigration. We will also collect data on species such as splittail, green sturgeon, and steelhead.

Feather River Fish Hatchery plays a major role in the management of salmon and steelhead in the system. The hatchery program is being evaluated by marking young salmon produced in the hatchery and in the river. The goals of this study are to determine:

- Distribution of adult Feather River salmon throughout the Sacramento Valley and the Pacific Ocean,
- Hatchery versus in-channel production,
- Conditions affecting juvenile survival.

In 1995, a total of 550,000 fish were tagged and released in the estuary. An additional 400,000 tagged juveniles have been released in the Feather River (200,000 fingerlings, 200,000 smolts). Some of the young salmon collected in the screw traps will also be tagged for comparison with hatchery-produced fish. The tagging program will continue at near the 1 million fish/year level through 1998. Fish and Game will recover the tags from the ocean fishery, returning adults in hatcheries, and carcasses in the Feather River and other streams.

Critical Dissolved Oxygen Minima in Splittail

Paciencia S. Young and Joseph J. Cech, Jr., University of California, Davis

Because the splittail population had declined dramatically and its original range has decreased by two-thirds (Herbold *et al* 1992; Moyle and Yoshiyama 1992; Meng and Moyle 1995) we conducted the study on "Environmental Tolerances and Requirements of the Sacramento Splittail, *Pogonichthys macrolepidotus* (Ayres)" to assist in effective water and habitat management and restoration of this species. This report on the critical dissolved oxygen minima (CDOMin) of splittail is part the study.

CDOMin were measured in young-of-the-year (1-4 g), juveniles (19-48 g), and subadults (72-187 g) using a modified method of Cox (1974) and Becker and Genoway (1979) defined by a loss of equilibrium (endpoint). As dissolved oxygen level decreased to the endpoint, splittail increased activity (turning, swimming, or darting around) then decreased activity but increased ventilatory frequency and gasping. Post-CDOMin recovery (restoration of equilibrium) generally took ≤3 minutes. Mean CDOMin values were low (9-18 torr oxygen partial pressure (PO_2) or 0.6-1.2 mgO_2/L) for all size groups of splittail (Figure 1).

The splittail's preferred habitat (slow-moving sections of rivers and sloughs) can have very low dissolved oxygen levels. For example, in Buckley Cove (in the Stockton Ship Channel part of the San Joaquin River), at midday at 92 cm below the surface, the dissolved oxygen level can drop to 0.4 mgO_2/L (DWR 1992). Fish generally avoid hypoxic conditions by moving away from them. However, when food abundance is low, fish (especially benthic foragers) readily forage in hypoxic waters (Rahel and Nutzman 1994). Splittail are benthic foragers (Caywood 1974; Daniels and Moyle 1983), and their short-term low dissolved oxygen tolerance may increase survival by permitting foraging in hypoxic benthic areas at times of low food availability.

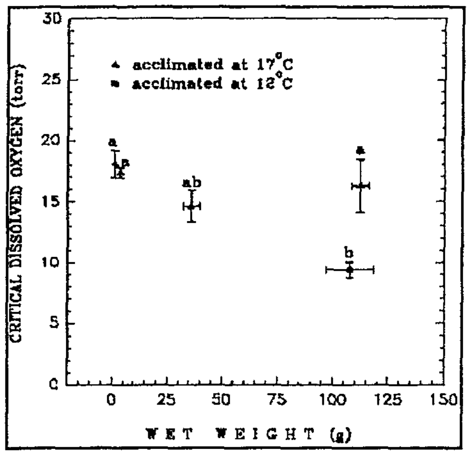

Figure 1
MEAN (± SEM) CRITICAL DISSOLVED OXYGEN MINIMA (TORR PO_2) OF DIFFERENT SIZE GROUPS OF SPLITTAIL
Subadults acclimated at 17 and 12 degrees Centigrade; Symbols with different letters are significantly different from each other; n = 4-10

Difference in size (1-187 g) had no significant effect on the CDOMin of splittail acclimated at 17°C. However, an increase in temperature increased the CDOMin. Subadult splittail acclimated at 17°C had a significantly higher ($P < 0.05$) mean CDOMin (16 torr PO_2 or 1.1 mgO_2/L) than those acclimated at 12°C (9 torr PO_2 or 0.6 mgO_2/L). This is probably because at higher temperature, fish have higher oxygen consumption rates than those at lower temperature (reviewed by Fry 1970) and, thus, require higher dissolved oxygen levels in the water. Davis (1975) explained that at higher temperatures, fish blood oxygen dissociation curves relating blood percentage saturation to the PO_2 typically shift to the right (indicating a higher oxygen requirement to fully saturate the blood), increasing the PO_2 threshold for hypoxia responses.

One must be cautioned in using the CDOMin for establishing criteria for dissolved oxygen levels. These values should be considered as extreme endpoints, approximating lethal limits. Complete loss of equilibrium in fish (endpoint) indicates the detrimental effects of the experimental variable so the fish becomes physically disorganized and loses its ability to escape from the harmful conditions, leading to its death (Becker and Genoway 1979). The International Joint Commission (1979) and the U.S. Environmental Protection Agency (1986) recommended that the effects of low dissolved oxygen level on growth be studied to determine minimum dissolved oxygen criteria. EPA (1986) reported that mortality or loss of equilibrium in salmonid and salmonid-like species occurred at the 1-3 mgO_2/L level. However, based on growth studies, the EPA established dissolved oxygen minimum levels of 9.5 mgO_2/L for early life stages, and 6.5 mgO_2/L in other life stages in salmonid and salmonid-like species, higher than the 1976 criterion of 5.0 mgO_2/L.

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Temperature and Salinity Tolerances of Delta Smelt

Christina Swanson and Joseph J. Cech, Jr., University of California, Davis

In 1992, we began a study of the environmental tolerances and habitat requirements of the delta smelt, *Hypomesus transpacificus*, at that time a candidate species for listing under the State and Federal Endangered Species Acts. The objective of our research was to provide information useful for defining delta smelt critical habitat and developing management guidelines for the species. In this report we describe results of our studies on temperature and salinity tolerances of the delta smelt and implications of these results for management and protection of this fish.

Delta smelt spawn seasonally and complete their life cycle in a single year; life history stages tend to be strongly correlated with seasonal temperature regimes. Therefore, we conducted our experiments using juvenile (<4.5 cm standard length), subadult (4.5-6.0 cm SL), and adult fish (>6.0 cm SL) acclimated to seasonally appropriate ranges of temperatures that represented, for each life history stage, a low and high temperature level (juveniles and subadults in summer and fall, 17 and 21°C; subadults and adults in winter and spring, 12 and 17°C). Delta smelt may also exhibit seasonal preferences in salinity. Juveniles and subadults are most abundant in the brackish entrapment zone; adults move upstream to fresh water prior to spawning. Therefore, we measured temperature tolerances in fish acclimated to both fresh (0 ppt) and brackish (4 ppt) water.

Temperature Tolerance

Temperature tolerance limits were measured in terms of critical thermal maxima (CT_{max}) and minima (CT_{min}), a protocol in which the fish were subjected to relatively rapid change in temperature (6°C/h increase or 5°C/h decrease). The tolerance limit was defined by a sublethal response, loss of equilibrium, although in the wild such a response would probably be lethal.

Delta smelt tolerated moderate acute changes in temperature (Figure 1). CT_{max} was significantly affected by acclimation temperature; fish acclimated to warmer temperatures tolerated higher temperatures. However, the magnitude of the tolerated temperature increase was similar (5-7°C) for all three acclimation groups. An increase in salinity to 4 ppt significantly increased the delta smelt's tolerance to temperature increases. CT_{min} was less dependent on acclimation temperature and independent of salinity. Fish size (or life history stage) did not affect either CT_{max} or CT_{min}. These results show that delta smelt are

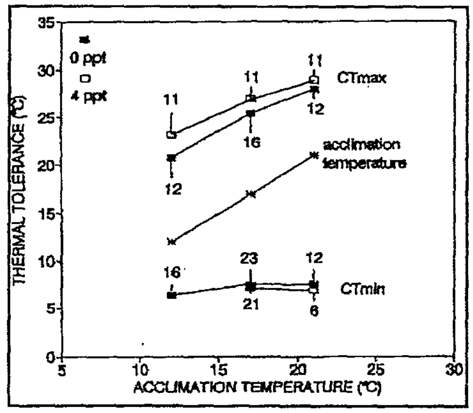

Figure 1
MEAN (±SD) CRITICAL THERMAL MAXIMA (CT_{max}) AND MINIMA (CT_{min}) OF DELTA SMELT ACCLIMATED TO 12, 17, and 21°C IN 0 AND 4 PPT

Sample sizes for each temperature/salinity combination are above or below the points. CT_{min} in 12°C was only measured in 0 ppt.

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eurythermal; they acclimated successfully to a relatively wide range of temperatures (12-21°C) and generally survived short-term exposure to acute temperature increases and decreases that are probably greater than the fish would normally encounter in the wild. However, in some areas within their range, delta smelt may be exposed to heated effluents and/or entrained in power plant cooling system water diversions where temperatures may reach 30°C (R. Pine, FWS, pers. comm.); our results strongly suggest that such exposure would be lethal to delta smelt. Furthermore, compared to a number of other delta fishes, delta smelt are more sensitive to acute temperature increases. Table 1 compares the CT_{max} of delta smelt to values measured for other fishes using the same methods and similar rates of temperature change. Splittail and inland silverside tolerated substantially greater increases in temperature. Even chinook salmon smolts acclimated to a slightly lower temperature had higher CT_{max}.

Table 1
COMPARISON OF CT_{max} OF DELTA SMELT AND OTHER DELTA FISHES

Species	Acclimation Temperature (°C)	CT_{max} (°C)	Source
Delta smelt	12	21	Swanson & Cech (1995)
	17	25	
	21	28	
Inland silverside	17	31	Swanson & Cech (1995)
Chinook salmon	16.5	26-27	Swanson & Cech (1995)
Splittail			
Young-of-Year	17	31	Cech & Young (1995)
	20	32-33	
Juvenile	12	21	
	17	29	
Subadult	12	22	
	17	29	

Table 2
CHRONIC UPPER SALINITY TOLERANCE LIMITS OF DELTA SMELT
(Mean ± SD)

Temperature (°C)	Life History Stage SL (cm)	Upper Salinity Limit (ppt)
17	Juvenile 3.7 ± 0.3	18.7 ± 1.8 (n=15)
17	Subadult/Adult 5.9 ± 0.3	19.1 ± 2.1 (n=14)
21	Juvenile 3.7 ± 0.4	19.2 ± 1.9 (n=10)

Salinity Tolerance

Chronic salinity tolerance of delta smelt was measured for juveniles, subadults, and adults in 17°C and for juveniles in 21°C. In these experiments, individual fish were subjected to a gradual increase in salinity (2 ppt/12 h), and the tolerance limit was defined as the maximum salinity the fish survived for 12 hours. The slow increase in salinity allowed the fish to physiologically adapt to the changing osmoregulatory demands; therefore the tolerance limit represents the maximum osmoregulatory capacity of the fish for salinity increase.

Delta smelt tolerated chronic exposure to salinity from 0 ppt (fresh water) to 19 ppt (about 55% sea water) (Table 2). Neither acclimation temperature (17 and 21°C) nor fish size affected salinity tolerance.

The results show that delta smelt are euryhaline and that their osmoregulatory capacity is fully developed by 3 months post-hatch when the juveniles were tested. Furthermore, delta smelt are able to tolerate higher salinities than those in which they have been collected to date, suggesting that salinity is not the factor that limits their distribution to fresh and slightly brackish waters. The chronic salinity tolerances of delta smelt measured in these studies were similar to those measured for young-of-the-year and juvenile splittail (Cech and Young 1995).

Implications for Management

Moyle *et al* (1992) reported that delta smelt are apparently extremely sensitive to estuarine conditions, but the relationships between specific environmental conditions in the estuary and delta smelt abundance have not been well defined. The results of these and other ongoing studies in our laboratory can be used to define how temperature and salinity may limit delta smelt distribution and how, within the fish's range, these factors affect survival, physiology, and behavior. As an example, results of the CT_{max} experiments show how anthropogenic temperature fluctuations may adversely and disproportionately impact delta smelt. This type of information contributes to definition and management of dellta smelt critical habitat and improved protection of this threatened fish.

Acknowledgments

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Suisun Marsh Diversion Screening Program

Frank Wernette, Department of Fish and Game

Suisun Marsh entrainment studies in 1981 and 1982 identified 34 fish species in Montezuma Slough that were vulnerable to entrainment into unscreened diversions serving managed wetlands in the marsh. Species included chinook salmon, striped bass, and delta smelt. Based on those data, the Fish and Wildlife Service and Marine Fisheries Service incorporated related conditions in a Corps of Engineers regional maintenance permit for Suisun Resource Conservation District and the Department of Fish and Game. The primary goal was to reduce entrainment of winter-run chinook salmon and delta smelt. The Suisun Marsh Diversion Screening Program was begun to help fulfill those permit conditions, which were developed through formal consultation under Section 7 of the Federal Endangered Species Act with the Marine Fisheries Service and Fish and Wildlife Service.

The screening program consists of an extensive diversion assessment element and a fish screen installation element. The assessment element consists of an evaluation to determine whether diversions can be eliminated, downsized, or consolidated; a fyke-net study of fish entrainment into 15 diversions (selected annually); and a mark/recapture evaluation using coded-wire-tagged chinook salmon.

Implementation of this screening program will also help address mitigation needs described in a DWR/DFG agreement to offset impacts associated with the State Water Project, and meet objectives outlined in the State Water Resources Control Board's May 1995 Water Quality Control Plan for the San Francisco/Sacramento-San Joaquin Estuary and the Central Valley Project Improvement Act to reduce impacts to anadromous and special-status fish by screening unscreened diversions. Program implementation will also facilitate addressing mitigation needs associated with the Tracy Fish Agreement and help guide screening funded through Category III.

The program, and the environmental documentation associated with it, will help expedite the permitting process so that screen installations funded from any of the above sources can proceed as rapidly as possible.

The SWRCB 1995 Water Quality Control Plan lists the reduction of losses of all life stages of fishes to unscreened water diversions as a high priority action. The proposed screening program is consistent with that level of emphasis. One goal of the Water Quality Control Plan is to increase transport of fish, such as delta smelt, into Suisun Bay. Screening diversions will help protect fish transported into this area. The screening program will work synergistically with the Water Quality Control Plan to begin the recovery of fish populations.

Significant efforts were already underway through the DWR/DFG agreement and the CVPIA to install screens to prevent entrainment of fish in the estuary, particularly chinook salmon. The screen recently installed on Fish and Game's Grizzly Slough intakes is an example of that effort.

In the long term, screening will assist in recovery of winter-run chinook salmon, delta smelt, and splittail populations, assist in reducing impacts to other salmonids, and may help avoid future listings. Screening will ensure the long-term maintenance of seasonal wetlands in Suisun Marsh and ensure that habitat is maintained for a diverse assemblage of wildlife, including listed species such as salt marsh harvest mouse. Consistent with the ecosystem approach, the long-term viability of these important wetlands (at no serious risk to fish) will ensure that habitat is available for waterfowl and the numerous other water-dependent species.

A key to the success of the program will be the interagency involvement in various phases of the program such as selection of diversions for sampling, development of sampling protocol, and selection of high-priority diversions for screening.

In October 1995, an interagency team, along with stakeholder representatives and their biological consultants, will inspect diversions in the Suisun Marsh to select those for future sampling and to recommend 5-10 diversions for immediate screening.

New Interagency Program Home Page

Karl Jacobs, Department of Water Resources

Looking for data? The Interagency Program Home Page is now on-line! The Interagency Program file server uses the World-Wide Web to provide bay/delta information to researchers. Besides providing field data, the file server uses the versatility of hypertext to provide:

- A bibliography of current and historical documents (digital copies of some will eventually be available);
- Lists of Interagency Program personnel;
- Background on the organization and how it is structured.

Major sections of the home page are still under construction. We are adding: more background information on bay/delta biology, data summaries and analysis results from the monitoring programs, and data needed to more fully understand the estuary.

Field data are organized by program element; metadata are also provided. The field data are in a comma-delimitered text format, and format files are included to provide data users with the structure of the text files. The first five fields of the data files are: (1) RKI number, (2) station ID, (3) date, (4) time, (5) depth. Maps showing sampled locations and general information are also included.

Although not all our data have been placed on the server, most should be available by the end of November. Current work on the data portion includes placing data on the server, helping staff format data, developing a Wide Area Information Server interface, and upgrading communications to the server. Work is also underway to develop telephone modem access to the server.

We want your comments. Pass your recommendations on to the Webmaster or your representative on the new Data Utilization work team. Select the "Webmaster" button (mdng@water.ca.gov) on the home page or call Murray Ng at 916/227-1309.

The home page is accessed on the Internet using World-Wide Web browsers such as Mosaic, Netscape, or Lynx. The address is http://wwwiep.water.ca.gov.

Science Advisory Group Lauds Interagency Monitoring

Leo Winternitz, Department of Water Resources

As part of our efforts to adapt to changing priorities, increase our efficiency, and organize our diverse data sets into formats more easily accessible, the Coordinators, management group members, and water contractor representatives met with the Science Advisory Group for 2 days of workshops on July 27 and 28. The specific purpose was to review the Long-Term Trend Monitoring program.

The Science Advisory Group is composed of seven scientists representing agency (USGS) and academic institutions (University of Maryland, University of California, University of Arizona, and Stanford University). At the conclusion of the workshop, the Advisory Group presented a report discussing six recommendations for the Long-Term Trend Monitoring:

- Expand the resources allocated to data analysis, synthesis, and dissemination.
- Maintain sufficient comparability in its measurement methods that trend analyses can take advantage of the entire historical record.
- Consider expansion of its present geographical boundaries.
- Begin to consider changes necessary to move toward a more community-based monitoring program.
- Consider "ecological health" of the bay/delta in use of Interagency Program data, but be aware that substantial effort has been expended by other programs in developing such indices, generally with little in the way of useful results.
- Be aware that communication, coordination, and collaboration will be keys to the future success and viability of long-term Interagency Program monitoring.

In addition, the Science Advisory Group commented that although many complex ecological questions remain unresolved, the bay/delta ecosystem is one of the best understood and most comprehensively studied estuarine ecosystems in the United States and that this is a result of Interagency Program monitoring and special studies. The advisory group also recognized that Interagency Program data are the basis for the public's growing awareness of bay/delta resources, that the Interagency Program has been critical in detecting the arrival of exotic species and understanding their effects on the ecosystem, and that the Interagency Program is the basis for environmental standards to protect the ecosystem.

For more information, contact:
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Winter-Run Chinook Salmon Captive Broodstock Program 1995 Progress Report

Nat Bingham, Pacific Coast Federation of Fishermen's Associations; Kristen Arkush and Paul Siri, U.C. Davis Bodega Marine Laboratory; and Randy Brown, Department of Water Resources

In response to critically low levels of winter-run chinook salmon in the Sacramento River during 1991, the Winter-Run Chinook Salmon Captive Broodstock Committee was initiated. Once numbering more than a hundred thousand spawning adults, returns had plummeted to 191 fish. To help save this unique and important salmon stock from possible extinction, several state and federal fishery agencies joined with commercial and recreational fishing interests, water users, and the academic research community to develop and implement a captive broodstock program. This coalition worked, by consensus, to develop its goals.

The primary goal of the captive broodstock program is to prevent the loss of the genetic resource contained in the winter run genome should the wild run become extinct. A secondary goal is to help prevent extinction by producing gametes that can be fertilized by wild fish gametes collected as part of the Coleman National Fish Hatchery winter run propagation program. The goals are to be met by rearing winter-run chinook salmon under controlled conditions until they become mature adults. Mature salmon would then be used as hatchery broodstock for continued propagation of the race.

The captive breeding program provides insurance against extinction and loss of genetic material, a source of eggs and sperm for the Coleman winter-run propagation program, a source to supplement naturally the remaining spawning salmon, a means to "buy time" until habitat conditions improve in the Sacramento River, an egg and fry source for experimental studies, and a way to maximize options for the recovery of the species.

The captive broodstock program plans to assist in winter-run salmon recovery by:

- Holding up to 1,000 juvenile winter-run salmon propagated at Coleman Hatchery in captivity each year;
- Transferring those juvenile salmon to fresh and salt water rearing facilities at Bodega Marine Laboratory and Steinhart Aquarium at the California Academy of Sciences, San Francisco;
- Raising the fish for 2-5 years (until maturity);
- Returning the adult salmon to Coleman Hatchery to be spawned;
- Using the resulting gametes to increase the winter-run population.

A genetic research and management plan was developed to:

- Ensure that the effective population size of the winter-run was not reduced by artificial propagation, and
- Manage the Captive Broodstock Program to conserve genetic resources.

To achieve these goals, the committee had to respond to several challenges. One of the most difficult was disease control. In addition to expected problems such as bacterial kidney disease, a previously undescribed pathogen in the winter run termed rosette agent — a systemic protist — appeared in the 1991 broodyear. Infection with this parasite resulted in substantial mortality in the 1991 cohort. Long-term treatment methods for these pathogens required development of new care and feeding strategies in addition to new disease detection methods.

The program was put under a year-long quarantine while field investigations in the Sacramento River were initiated. In 1994, the rosette agent was found in wild fall-run chinook. This discovery lifted the quarantine on the captive broodstock gametes, and about 30,000 eggs were delivered to Coleman Hatchery in 1995. Current research focuses on nutrition and maturation to increase fertilization rates.

Funding for the broodstock program has been provided by: U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, National Marine Fisheries Service, Department of Water Resources, Department of Fish and Game salmon stamp program, and the National Fish and Wildlife Foundation. Category III, resulting from the 1994 Bay/Delta Agreement, will provide funding in 1996. Implementing agencies are: U.S. Fish and Wildlife Service, Coleman National Fish Hatchery, California Academy of Sciences, Steinhart Aquarium, University of California-Davis, Bodega Marine Laboratory. In 1993, Congress authorized the winter-run captive broodstock program at a level of $1 million annually.

After 4 years, the broodstock program has:

- Rapidly established interagency/project coordination;
- Built rearing facilities at Bodega Marine Laboratory and Steinhart Aquarium literally around the juvenile salmon as they were being raised;
- Developed long-term feeding and rearing strategies;
- Developed pathogen detection methods and fish health management protocols to improve survivorship;
- Provided original genetic research resulting in a method using existing technology to identify the gender of a juvenile salmon and provision of genetic management direction to the broodstock;
- Provided about 30,000 salmon eggs to Coleman National Fish Hatchery.

The broodstock program is holding in captivity:

Bodega Marine Laboratory	
Brood year 1991	52 adult salmon
Brood year 1992	25 maturing salmon
Brood year 1993	249 year-2 salmon
Steinhart Aquarium:	
Brood year 1993	256 year-2 salmon
Brood year 1994	619 yearling salmon

As it approaches the half-way mark, the 10-year Winter-Run Chinook Salmon Captive Broodstock Program has overcome many developmental problems, has established the infrastructure necessary to continue at full production status, and can do so until the program is no longer necessary. Most importantly, this program will contribute to the recovery of this unique salmon stock.

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

Newsletter

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The Interagency Ecological Program is a Cooperative Effort of the:

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California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey
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