Interagency Program Quarterly Highlights, July-September 1998

Delta Flow Measurement
July to September 1998
Richard N. Oltmann

The San Joaquin River at Jersey Point UVM site became inoperable on September 13 due to separation of the transducer track from the piling. The cause of this separation is unknown, and repairs will be made as soon as possible. The other UVM stations successfully collected data throughout the quarter.

The velocity measuring equipment (ADCPs and one S4), which were deployed at seven sites in the south Delta for three months during the spring and described in the previous quarterly report, were successfully retrieved on June 29. Unfortunately, the Turner Cut ADCP provided no velocity data, and battery problems resulted in shortened velocity records (~1.5 month) for Old River, between CCFB intake channel and Grant Line Canal, and San Joaquin River, between Turner and Columbia Cuts sites. The next step is to use the numerous flow measurements taken during the 3-month deployment period to develop velocity calibration curves that will be used to convert the ADCP/S4 measured velocities to mean cross-sectional velocities so that time series of tidal flows can be computed.

The USGS concluded testing of the new two-beam, side-looking ADCP, described in the last quarterly report. The ADCP was operated for 2 months at the Threemile Slough UVM site; the ADCP and UVM measured velocities compared quite well.

DWR and USGS began a cooperative hydrodynamic study of the confluence area of the Sacramento and San Joaquin Rivers by deploying 16 velocity monitoring stations on September 14 and 15. The ADCP and S4 velocity monitoring equipment will remain deployed until about mid December 1998. Nine flow monitoring sites were defined:

1. Sacramento River upstream of Point Sacramento
2. San Joaquin River upstream of Point Sacramento
3. Montezuma Slough at eastern end
4. Middle Slough
5. New York Slough
6. Sherman Lake at Sacramento River
7. Sherman Lake at Broad Slough
   (west side of Sherman Lake)
8. Mayberry Slough
9. Mayberry Cut

USGS and DWR will make numerous tidal-flow measurements throughout the tidal-flow range at each of nine flow monitoring sites by using downward-looking ADCP flow measuring systems. The flow measurements will be used to develop velocity ratings so that time-series of tidal-flows can be computed in the same manner as has been done in the south Delta. Velocity monitoring equipment was deployed at three locations within Sherman Lake to monitor flow patterns. Water-level and salinity data will also be continuously monitored at several of the sites.

Neomysis/Zooplankton Study
Jim Orsi

During July and August seven mysid species were caught from San Pablo Bay to the delta. The most abundant was the introduced Acanthomysis bowmani, which reached a maximum density of 56/m3 at station 28 in Grizzly Bay in July. Neomysis mercedis densities were always <1/m3. Other native species taken were Alienacanthomysis macropsis and N. kadiakensis but neither was abundant. The very rare and cryptic Deltamysis holmquistae was represented by a single specimen taken in the Suisun Marsh in July. This is the first one we have taken in a couple of years. A few specimens of the Japanese A. aspera were found in Carquinez Strait in July. The most interesting capture was three unidentified mysid juveniles in San Pablo Bay. This is the second unidentified mysid we have caught in the last two years.

The most abundant copepod was Limnoithona tetraspina, which was most abundant in Carquinez Strait. The second most abundant copepod was Pseudodiaptomus forbesi, which reached its highest abundance in the Suisun Marsh. No other copepod had abundance >1000/m3. Cladocerans were only abundant in the San Joaquin River at Stockton. Synchaeta bicornis was the most abundant rotifer and was found mainly in Carquinez Strait.

Summer Townet Survey

Stephen Foss

The young striped bass index for 1998 is 1.4, the record low annual index measured since the beginning of the Townet Survey in 1959. The previous low striped bass index was 1.6, measured in 1997. This year's striped bass index is lower than expected, based on water exports by State and federal water projects and river flow. Egg production of adults may now be severely limiting the production of young despite high outflow conditions. Thus, 1998 continues a trend of very low indices in recent years despite high flows and low water export impacts.

The final abundance indices for the Suisun and delta areas were 1.3 and 0.1, respectively, reflecting a much higher concentration of striped bass in the Suisun Bay area. Only about 5% of young striped bass were found in the delta this year. Although young striped bass are typically found in the downstream portion of the estuary in wet years, this year's distribution is extreme (compared with the previous low of 20% in 1980 and 1982), and mostly reflects the effect of very high flows from estuary tributaries.

The young striped bass index is set when the mean length of the sample is 38.1 mm, which typically occurs sometime in July. This year, however, the 38 mm mean length was not attained until August 30 (the last day of the fifth and final survey), the latest ever. The late 38 mm date resulted from a delay in striped bass spawning and probably slower growth due to abnormally cool spring and summer water temperatures.

Due to the high outflows and the resultant downstream location of striped bass, we added 4 extra stations in San Pablo Bay (for a total of 5 stations) to assess the possibility of striped bass distribution exceeding the usual sampling area. Only one striped bass was caught among the 5 stations in San Pablo Bay during the 5 surveys. Additionally, bottom conductivity in the San Pablo Bay stations ranged from 12.5 to 17.3 mS/cm during the first survey. Therefore, we think that we sampled the range of young striped bass distribution.

Fall Delta Smelt Abundance

Zach Hymanson

The Department of Fish and Game recently reported results from its September midwater trawl survey. This survey is completed monthly from September through December, and is the primary means used to determine the location and abundance of adult delta smelt. This information is also used to evaluate recovery of delta smelt relative to criteria established in the Native Species Recovery Plan.

Survey results from this September show a high abundance of delta smelt in the Suisun Bay area. The monthly abundance index was 238, which is the third highest September index since 1980. In years past, a high September index has been indicative of a high overall (four-month cumulative) index. This is welcome, but somewhat unexpected news. Low numbers of young delta smelt were captured in surveys completed this spring and summer. Additionally, extreme wet conditions as occurred last winter and spring are typically not beneficial to delta smelt. However, summer tow-net results revealed juvenile delta smelt occurred mainly downstream of Chipps Island, and were associated with high zooplankton concentrations. These conditions may have translated into improved survivorship. Contact Dale Sweetnam (dsweetnam@delta.dfg.ca.gov) for more information.

Juvenile Salmon Monitoring Program

Erin Sauls

Beach seining efforts were continued throughout the delta and Sacramento River from July through September. A few outmigrating salmon were seen in the beach seine during this period. Three fall run sized salmon were captured in July and August and 3 late-fall run sized salmon were captured in August. All of these salmon were seen in the upper Sacramento River above Knights Landing. Our first winter run sized salmon (38 mm) of the season was captured on September 22 at Clarksburg on the Sacramento River.

Trawling efforts were terminated on June 30, and resumed on September 2 at both Sacramento and Chipps Island. As of September

23, the following salmon have been captured at Chipps Island: 10 fall run, 12 late-fall run, and 5 adults. Chipps trawling was suspended the week of September 21 due to high delta smelt catches. Sacramento kodiak trawl has not yet captured any salmon for the quarter.

Most of the summer was spent processing coded wire tagged salmon that were collected this spring. A total of 5,083 tags were processed from July through September, including recoveries from Chipps Island midwater trawl, Jersey Point kodiak trawl, and the Fish Facilities. Although preliminary recovery numbers are now available for these sites, the final numbers will not be available until quality control checks are completed. Survival indices will be calculated based on the Chipps Island and Jersey Point recoveries in the near future.

Central Valley Salmonid Team

Randall Brown

The Central Valley Salmonid Team held its annual workshop on September 15, 1998 on the U.C. Davis campus. The workshop participants heard team reports from Up-River (Rich Johnson), Delta (Pat Brandis), and San Joaquin (Carl Mesick) about their efforts to develop conceptual models and recommendations for monitoring and research. These recommendations will be forwarded to CMARP staff for consideration in CALFED's comprehensive monitoring and research program.

The workshop participants also heard technical presentations about ocean salmon hooking mortality (Allen Grover, DFG), the use of the Yolo Bypass by juvenile chinook salmon (Ted Sommer, DWR), and the use of radio tags to follow movement of juvenile chinook salmon in the southern delta (Dave Vogel). Here are a couple of observations from the reports:

- Mooching, a way of catching ocean salmon by basically dangling the bait, can result in high mortality of sub-legal sized salmon. The high mortality, due to the bait being swallowed, can be reduced by using a different type of hook.
- During high flow years, the Yolo Bypass appears to provide good juvenile chinook salmon habitat.
- Radio tag studies conducted on behalf of the East Bay Municipal Utility District can be used to provide information on salmon movement at flow splits. Two limitations are short battery life and the relatively large sized salmon used in the studies.

Splittail Investigations - Summer 1998

Randall Baxter

Most fieldwork concluded in April. Data entry and correction were completed during the quarter, and data summarization and report writing were initiated. The paperwork needed to hire a biologist was sent to Sacramento and specified a start date of November 1. Early in the quarter, comments were made to the U.S. Fish and Wildlife Service on its proposal to list splittail as threatened. New information was gathered to prepare the comments; a little information related to river use is summarized below. In 1997 and 1998, splittail were again collected from a broad area within the Sacramento-San Joaquin River system, indicating a continued positive response to favorable flow conditions. In 1997, two adult splittail were captured at the Red Bluff Diversion Dam river kilometer (rkm) 391, one in April and one in August. Red Bluff is the most upstream location of capture for splittail in recent years, surpassing Hamilton City (rkm 331). The August capture at Red Bluff and another from Hamilton City indicate that some adult fish may spend the summer upstream in the main-stem Sacramento River rather than return to the estuary after spawning. On the San Joaquin River, beach seine sampling in 1998 again collected young-of-the-year splittail from Fremont Ford (rkm 201), until recently the most upstream location of splittail captures. On April 30, 232 young-of-the-year were collected in six seine hauls. On July 2, five were collected in a single seine haul; five additional hauls at three sites farther upstream failed to collect splittail. The farthest upstream collection occurred in mid June when a joint USFWS/CDFG crew using electrofishing gear collected young-of-the-year splittail from Salt Slough in San Luis National Wildlife Refuge. The collection site was about 10 km upstream of the confluence with the San Joaquin River at rkm 208.5. Additional fish were collected from Mud Slough about 8 km from its mouth. These collections indicate that during high flows adult splittail move extensively in search of spawning habitat. Initial indications suggest that 1998 abundance indices will be comparable to those of 1995.

Mitten Crabs

Randall Brown

Over the past few weeks, as many as 20,000-25,000 maturing adult mitten crabs have been entering the federal fish facilities at Tracy each day. These crabs, measuring 3-4 inches across the carapace (back) have caused up to 4 feet of headloss across the trashrack and have interfered with fish salvage operations. During much of this period, the nearby State facility was salvaging only a few hundred per day. However, as of September 29, the estimated number of crabs entering the federal facilities each day had dropped to about

10,000 and the State facility was encountering about the same number. The adult crabs are heading downstream to the bay for spawning and may be in the South Delta for another few weeks.

On September 30, a group of federal and State biologists and engineers met to discuss mitten crabs and begin the process of finding out more about the animal's life history, methods of controlling their abundance, and behavioral cues that may be used to minimize their impact at the fish protection facilities.

Rock Slough Fish Monitoring Program

Jerry Morinaka

Fish entrainment sampling was initiated at the Rock Slough intake of the Contra Costa Canal on August 21, 1998. Sampling was conducted once a week on the flood tide using a large-fyked sieve net. Threadfin shad (Dorosoma petenense), mean fork length 32 mm, and inland silversides (Menidia beryllina), mean fork length 53 mm, were the predominant species captured through the middle of September. Entrainment sampling is scheduled to continue on a weekly basis throughout the year.

Old River Fish Screen Facility (Los Vaqueros) Monitoring Program

Jerry Morinaka

We used a sieve net to sample fish entrainment once a week at the Old River Fish Screen Facility in July, August, and September. Twelve different fish species were captured during the sampling efforts on the downstream side of the fish screens. The majority of these fish measured less than 20 mm (fork length). Threadfin shad (Dorosoma petenense), mean fork length 17 mm, and white catfish (Ictaluras catus), mean fork length 17 mm, were the predominant species captured behind the fish screens. Entrainment sampling will continue once a week until January when the sampling will intensify to up to three times per week.

Mallard Slough Monitoring Program

Lee Mecum

Sampling for 1998 started on May 26 and ended on July 30. Sampling was conducted approximately once per week. The salinity level became too great for CCWD to operate the pumps in August. The most abundant species entrained were threadfin shad (2024, mean fork length 9 mm), striped bass (128, mean fork length 12 mm), and fathead minnow (37, mean fork length 66 mm). Inland silversides, American shad, largemouth bass, bigscale logperch, threespine stickleback, and prickly sculpin were also entrained.

No salmon or smelt were taken. Delta smelt were not seen this year because the high outflow located the population downstream from Mallard Slough.

Agricultural/Municipal Diversion Effects Project Work Team

Zachary Hymanson

During this quarter, IEP Technical Report 61: Delta Agricultural Diversion Evaluation Summary Report, 1993-1995 became available for distribution. This report, authored by Lizette Cook (DWR) and Lauren Buffaloe (DWR) presents results obtained from numerous samplings of several agricultural diversions and the adjacent channels. Results from day and night catch comparisons and seasonal entrainment trends are also presented. The report concludes with recommendations for future diversion effects studies needed to address outstanding issues. Copies of this report can be obtained by contacting Judi Sabella (Sabella@water.ca.gov) at DWR.

The Contaminant Effects PWT Makes Designated Action Recommendations to CALFED

Chris Foe

Last fall, CALFED identified a series of data gaps or designated actions where additional information was needed to help restore the biological health of the estuary. CALFED set aside $2.7 million and requested that the PWT develop study plan recommendations for three designated actions: Impacts of Insecticides on Aquatic Communities in the Sacramento-San Joaquin Delta Estuary, Baseline Pesticide Monitoring, and Chronic Fish Toxicity. The recommendations were developed by subgroups of the PWT, but extensively reviewed by the entire group. The recommendations were submitted to CALFED at the end of September. If approved, the recommendations will be included in the next CALFED Request For Proposal for competitive bidding. Call Chris Foe (916-255-3113) for a copy of the recommendations.

X2 Workshop Notes

Stephen Monismith, Stanford University

Introduction

On March 11, 1998 the Interagency Ecological Program (IEP) and the Bay-Delta Modeling Forum sponsored a day-long workshop on X2. Held at the Contra Costa Water District (CCWD) building in Concord, the workshop was attended by approximately 100 people from the IEP and related agencies, consulting firms, and stakeholders.

X2 is defined as the distance along the main channel (usually in km) from the Golden Gate Bridge to the point where the salinity on the bottom is 2 psu. Following a series of workshops led by Jerry Schubel and described in the report Managing freshwater discharge to the San Francisco Bay/ Sacramento-San Joaquin Delta Estuary: The Scientific Basis for an Estuarine Standard [1] , X2 was proposed by the Environmental Protection Agency (EPA) as a basis for regulating freshwater inflows to San Francisco Bay. While the EPA standards were never implemented, the 1994 Bay-Delta Accord explicitly includes X2 standards [2] .

As stated in an e-mail from the workshop's organizers, the background for the workshop is as follows:

"... It [X2] is being used to manage flow conditions in the estuary on the basis of relationships between X2 and abundance or survival of a number of estuarine-dependent species. The use of X2 for this purpose has engendered a good deal of confusion, particularly regarding the distinction between the 2-psu isohaline as it represents the habitat defined by the low-salinity zone (or Entrapment Zone) of the estuary, and the position of the 2-psu isohaline as an index of overall flow conditions.

Uncertainty also exists in the bay-delta community about whether recent changes in the estuarine food web have resulted in a deterioration of some of the X2 relationships. The purpose of this workshop is to define more clearly the nature of X2 (both as a description of habitat and as an index of estuarine condition), to identify likely causes of the relationships and fruitful avenues of research to ascertain those causes, and to describe the changes that have occurred in the relationships. We will also examine some of the policy implications of the X2 standard. The output of the workshop will be a consensus document on the above issues with accompanying technical discussions of the key issues."

With this background, the objectives of the meeting were to:

1. Refine our knowledge of X2 and its hydrodynamic and biological implications.
2. Provide stakeholders with a consensus statement about the value (or lack thereof) of X2 and the relevance and biological significance of the relationships of abundance to X2.
3. Clarify points of misunderstanding or technical disagreement.
4. Build on the Estuarine Ecology Team's discussion of probable mechanisms underlying the X2 relationships.

Presentations

The workshop began with a series of talks in the morning by Wim Kimmerer, Bruce Herbold, Jon Burau, Bill Bennett, and BJ Miller. Each of these presentations is reviewed below. The morning talks were followed after lunch by a sometimes lively, free-ranging question and answer session with questions from the audience directed to a panel consisting of all of the morning speakers, except BJ Miller who was replaced by Tom Mongan.

Wim Kimmerer: X2 review: Introduction and review of X2 and the Schubel workshops

Wim began his presentation by reviewing the genesis of X2 as a possible flow standard in the Bay/Delta system. He pointed out several important features of X2:

- It is a tidally averaged variable.
- It is an open-water concept, not necessarily applicable to marshes.
- It was selected to be an index of estuarine conditions.
- It is correlated with a number of variables and effects, including changing physical/chemical processes, habitat, and abundance of organisms at all trophic levels (but not all organisms).
- To date, there has not been much success at separating the effects of inflows from those of outflow, i.e., entrainment effects are weakened when X2 is downstream in Suisun Bay rather than in the delta.

Wim reminded the audience of how X2 came to be used during the Schubel workshops, which were originally convened to discuss positioning of the postulated Entrapment Zone (EZ). After very little discussion, Jim Arthur and Doug Ball's EZ concept was rejected as a basis for standards and instead attention was focused on the low salinity habitat (around 2 psu) that was thought to characterize the EZ. Although concomitant analysis of X2-abundance relationships showed many strong relationships between X2 and abundance/productivity, the Schubel group did not recommend standards but instead suggested that it was important to maintain the natural variability of the salinity field as indicated by the "natural" (historic) variability of X2.

Bruce Herbold: X2 standard development

Bruce introduced his presentation by remarking that it was in essence a summary of several presentations he had given over the past few years discussing the EPA's rationale for their proposed X2 standards. Bruce's talk included several salient points:

- Freshwater flows are difficult to connect to fish behavior, at least in the Western Delta and Suisun Bay, because tidal motions are generally (much) stronger. However, residual flow patterns that may lead to entrainment in the pumps are directly related to freshwater flows.
- The number of days X2 was at or downstream of Chipps Island within a given water year type has generally decreased over the last 50 years. 3
- Careful attention was given by the EPA as to how monitoring and compliance with an X2 standard should be done, i.e., the conversion of a standard requiring a sequence of monitoring stations to one using data from existing sites, as well as permitting several options for compliance (equivalent flow etc.).
- Year type, although often convenient, compresses real hydrological variability, e.g., '97 was classified as a "wet" year, yet the rain essentially stopped in January.
- X2 doesn't limit exports directly and so may not protect against entrainment, something the State Board is considering in its deliberations.

Bruce completed his presentation by noting that a triennial review of standards (and data?) is required. If we have implemented X2 standards and we continue to see declines, we will have to return to the drawing board, because the problem will not be one of habitat, but instead "something else like food limitation."

Jon Burau: Physical conditions in the low salinity zone - why flow has little direct effect during low flow

Jon's discussion of his work over the last few years on Suisun Bay and the Western Delta illustrated a blend of field observations and numerical modeling. He made the following important points:

- Contrary to a widely-held view, the Western Delta is not a river; transport there is the combined result of advection (residual currents) and dispersion mostly due to tides. The relative importance of residual flows and dispersion of course depend on flow rate.
- The density gradient that results from the longitudinal salinity gradient is important to hydrodynamics and thus to transport. The exact nature of the linkage depends on the interaction of turbulent mixing by the tides with the stratification that develops (see Monismith et al 1996 4). X2 is significant because it sets the strength of this gradient and the upstream limit of gravitational circulation.
- On a more direct level, ADCP data from Suisun Bay reveal a mean flow picture that is different from that hypothesized to maintain the ETM (Estuarine Turbidity Maximum), a better term for describing what has been known as the Entrapment Zone (this distinction was also made during the Schubel workshops). However, Jon (and Wim) prefer to refer to it as the LSZ (low-

salinity zone), since: (1) the turbidity maximum isn't always found there; and (2) there is no agreement as to the location, significance, and nature of the ETM 5 . A revised picture emphasizes the importance of local topographic features like the rapid shoaling of the main channel near Benicia as well as the connection of channels to shallow high turbidity regions like Grizzly Bay.

Wim Kimmerer: Fish-X2: Update and analysis of time trends 6

Besides reviewing some background to X2-fish relations (e.g., the near co-occurrence of X2 and the abundance of Eurytemora), Wim's presentation aimed at addressing three technical issues:

The statistical significance of some X2-abundance relations has decreased in the past few years. Mysids showed the largest change, with essentially no relation between X2 and abundance after 1987. This change may reflect changes in trophic dynamics resulting from the arrival of Potamocorbula and the subsequent decline of phytoplankton blooms in Suisun Bay. In contrast, significant relationships still exist for several of the species analyzed by Jassby et al (1995), including Crangon franciscorum and longfin smelt. Wim hypothesized that lower trophic levels responded directly to Potamocorbula, and hence may no longer exhibit X2 dependence, whereas higher trophic levels still depend on X2, albeit in some cases more weakly than before Potamocorbula's establishment.

1. The use of log transforms in formulating these relationships;

Several good reasons exist for using log rather than linear relationships: the variance is more homogeneous (presumably making for more robust statistical interpretation); there is concern for populations at low abundance levels where extinction may occur; and finally, biological populations (like the stock market?) grow in multiples (i.e., logistically).

1. The formulation of statistical relations based only on the range of flow rates than can be controlled by operation of the water projects;

There is some argument as to whether or not regulations should only be based on abundance variations occurring for flows that can be controlled, perhaps because different mechanisms might function at low and high flows. Wim argued that regressions can only be used to evaluate trends and not to make predictions. Moreover, tests of two-segment fits for existing X2 abundance relations did not show substantial differences between low and high flows. In any event, since we don't yet have specific causal relations to explain any observed X2 abundance relations, prudence (and possibly limited data) dictates that we choose the simplest relations.

Wim concluded by saying that the X2-fish relations have not changed sufficiently to warrant being scrapped; nonetheless, the uncertainties point to the need to understand the basis of those relationships

Bill Bennett: Causes of the X2-Fish Abundance relationships: How does freshwater flow regulate fish populations

The tone of Bill's talk was set by the following quote with which he prefaced his talk: "...the full details of the mechanism of regulation of population density have probably never been worked out even for one species..." 7 Nonetheless, in a very general way, Bill outlined an approach to working out what regulates the population of a given organism that includes:

- Monitoring the population (catch/unit effort, abundance)
- Identifying likely mechanisms (density dependence, stock-recruitment, environmental factors)
- Developing life history tables (e.g., what life stage contributes most to mortality)
- Using observation/experimentation to develop and test hypotheses

In his talk, Bill illustrated this approach as it applies to relating fish abundance to X2. As a starting point, one must recognize that the fish species of interest in the Bay-Delta system widely differ in their life histories; thus, it is clear that "X2 represents a single indicator for many factors averaged over many scales." To emphasize this point, Bill presented a table (figure 1 in a 1997 EET report 8 on X2-abundance relations) of species and mechanisms by which X2 might influence abundance to some degree.

Discussing Bay and X2/Delta species separately, Bill briefly reviewed some possible mechanisms of importance:

- For Crangon franciscorum, starry flounder, and Pacific herring their reproductive strategies require them to transit the Golden Gate, suggesting outflow and gravitational circulation (which has been hypothesized to depend on the longitudinal density gradient and hence outflow) should be important factors. Passage across Potato Patch Shoal may be problematic 9 . However, for C. franciscorum, "many believe" that habitat space may be limiting rather than recruitment rate.
- For X2/delta fish, there appear to be two pathways for effects: habitat/trophic effects (access/extent of shallow water, food, exotics, toxics); and hydrodynamic (retention, transport, entrainment).
- For short-lived X2/delta fish effects on early life history are more likely to drive population dynamics.

Bill's discussion of particular examples of these last two points illustrated the complexities involved in connecting a single variable, X2, to abundance:

1. It has been shown that Sacramento splittail has higher year class success when the Yolo Bypass is flooded, something that coincidentally is more likely in wet years when X2 is relatively farther downstream on average.
2. Gravitational circulation (the strength of which depends on X2, and on position relative to X2) has been hypothesized to transport organisms upstream against the mean flow driven by outflow, and so allow them to remain in the ETM. Recent data taken by Bill and Wim show that larval fish and zooplankton can use vertical migration to selectively use the vertically variable tidal currents to accomplish the same end 10 .

3. Bill's dissertation research 11 showed that even after the arrival of Potamocorbula, and the subsequent low standing stocks of phytoplankton and zooplankton, captured larval and juvenile striped bass were not starving. Although there was clear evidence of substantial liver damage associated with pesticide exposure in 1988-90, a big drop in pesticide use and a concomitant drop in liver damage in 1991 did not result in higher young of the year indices. Because a single factor like X2 "can alternate in importance between and among years," it can be difficult to distinguish the effects of changes in such a factor on target populations. Nonetheless, "...because X2 can represent the influences of many of these factors, it is an extremely useful index."

Focusing on delta smelt, Bill discussed how its life cycle and the timing of different life stages might be used to test more carefully for X2 effects by looking at mortality at each life stage. For example, egg-juvenile mortality accounts for 33% of the variability in the log of the Midwater Trawl Index (MWT) whereas the MWT Index is essentially independent of juvenile-adult mortality. Egg-juvenile mortality in turn is significantly correlated with the presence of X2 upstream of Collinsville (R2 = 0.55), the percent of inflow diverted (R2 = 0.39), and with the abundance of inland silversides (R2 = 0.20). More detailed analysis suggests that the effects of inland silversides are separate from those of X2. While diversions and X2 position also seem to have separate effects, the fact that the two variables are related suggest that further work is needed to look at this question.

Bill finished his talk by addressing the question, "Is X2 useful?" His answer had two parts:

1. "X2 is a useful indicator of population abundance for many species. Indeed, that so many constituents of [the] estuarine food web are associated with X2 is a unique and fortunate finding (i.e., this is why Jassby et al were published in Ecol. Applications.)"
2. The "actual mechanisms vary and currently we don't know all [of the] mechanisms or how they interrelate."

BJ Miller: Policy implications of the X2 standard.

BJ introduced his presentation by posing the question, "Why is X2 important to water users?" His gave two answers:

1. X2 affects water supplies. Most of the CALFED alternatives produce little water but cost lots of money, so potential reductions in supply due to X2 regulations are of concern.
2. While water users understand the importance of X2 to environmental protection and improvement, given point 1, water users have agreed that X2 needs critical re-examination.

BJ made the following arguments in support of the view that the formulation of X2-based regulations needs to be reexamined. Firstly, after 1986 most X2-abundance relationships, except those for C. franciscorum and splittail, have broken down or weakened. Secondly, those relations could originally have been expressed in terms of delta inflow, "which could have produced requirements that did not influence export much if at all." Thirdly, X2 must meet the "adult fish test," i.e., any actions taken must be aimed at improve stocks of adult fish, rather than larval and juvenile fish alone.

Rather than use log-log 12 or log-linear plots to test for changes in X2 (or flow) abundance relations, BJ plotted several abundances as functions of X2 and of delta inflow, and argued that by simple inspection of these plots, one can conclude that 13 :

- Crangon--the relationship still looks pretty good
- longfin smelt--used to be good, not so good anymore, much lower abundance for lower X2
- delta smelt--never had one, don't have one now
- splittail--still looks good
- striped bass 38 mm--never had one, don't have one now
- striped bass year 3--never had one, don't have one now
- striped bass MWT--used to be good, not so good anymore, much lower abundance for lower X2
- striped bass survival--still a relationship, but no data past 1993.

Supporting his second point, BJ redisplayed these data using Delta inflow rather than X2 as the independent variable. This lead him to pose the question, "How much do observed relations depend on large inflows vs. small inflows?" 14 , 15

His last point, that of adult fish, was predicated on three ideas: (1) The average person doesn't care out about larval fish, a point BJ reinforced with the entertaining image of a fisherman posing with a string of recently caught larval fish; (2) The connection between pre-adult and adult stages is not well established. Good juvenile-adult relationships are needed if we insist on focusing regulatory, research and monitoring energies on juveniles rather than adult fish; (3) "The CVPIA and other regulatory mandates call for increases in populations of adult fish."

Lastly BJ outlined a course of action that included the following:

- More workshops such as this one, including "outside experts" to help resolve the various biostatistics/fisheries issues that have been at the core of many of the X2/flow debates of recent years
- Determining for which species an "X2-like" relationship is valid (or not), as well as understanding the mechanisms that underlie that relationship (if one exists)
- Evaluating actions that could increase abundance of target species, in particular looking at both water project operational requirements and ecosystem improvements like requirements for flooded vegetation.

He concluded by stating that linked actions for ecosystem improvement are not possible with "surrogate requirements such as X2."

Panel Discussion

Following lunch, a panel consisting of the above speakers, with Tom Mongan substituting for BJ Miller, responded to a series of question posed by the audience. The principal issues that arose were:

1. X2 could serve as an example of "adaptive management" in the sense that CALFED uses the phrase to mean adjusting regulations in response to observed changes in the system (or the lack thereof). Among other things, this requires that we continue to track X2-fish relations (WK 16), and perhaps most importantly, that we recognize that X2 is an index of a variety of mechanisms affecting a variety of species (BH), something that may be taken to be the main point made in Jassby et al (1995). However, using an index like X2 will not necessarily be as efficient for single species like delta smelt or winter run salmon for which more specific actions like particular detailed regulations on pumping might be more efficient (BH).
2. The challenge of using X2 to help manage the flow is complicated due to continuing changes in the estuary like variations in contaminant distributions, or invasions by introduced species, particularly, P. amurensis. Taking this to one limiting view, one can argue - because of food web changes apparently driven by P. amurensis, X2 is no longer a good index for management of the Bay-Delta system (TM). In the parlance of "adaptive management" one would argue that the adaptive action should be not to continue setting flow standards using X2! Alternatively, one could argue that while X2 is currently the best indicator

(predictor) of ecosystem health, CALFED is free to consider other indicators (Gary Bobker), in which case we still need to understand the implications of the change from a pelagic/planktonic food web to one dominated by the benthos.

3. The viability of adaptive management seems to be predicated on having hypothesized (or understood) mechanisms by which the management actions might accomplish stated goals, e.g. increasing the abundance of delta smelt. One set of hypotheses for X2 has been developed by the IEP Estuarine Ecology Team, and it may prove useful to test it experimentally for some specific organisms like Crangon (which may not be important overall) for which the X2-abundance (or flow-abundance) relations are strong, or to look at an intercomparison of longfin and delta smelt (BH). This may require a substantial financial investment as well as a more substantial involvement of university researchers (BH, BB).

Summary and Comments

The morning presentations packaged together nicely data, analyses, points of view, and problems that give a fair view of the current status of X2 as a regulatory tool. In contrast, the afternoon Q&A session served to remind one of the degree to which the Bay-Delta community, as represented by those in attendance at the workshop, diverges in its understanding of the basis of X2 as well in its utility. For example, it was surprising to me to hear questions from the engineering community about specific features of the salt field that would be important if X2 regulations were strictly given in terms of X2. However, given that the EPA proposal provided three different ways of satisfying the standard, one of which involves flows directly, operational concern that X2 is different from X2 inferred from surface salinity measurements seems a waste of time.

More fundamentally, the tone of the questioning and discussion, well exemplified by BJ's presentation, highlights one of the major challenges of any policy formulation in the Bay-Delta system: Water is so valuable that the uncertainty/natural variability in aquatic population response to X2 makes X2 regulations a difficult pill to swallow. BJ's point that the cost of new facilities designed to increase water harvest essentially makes the marginal cost of water for environmental protection quite substantial is well taken. From an engineering standpoint, one always wants to optimize extraction of a resource or minimize cost to achieve a given goal like protection. Thus, if restoration/protection goals are articulated taking the X2-abundance relations given in Jassby et al. to be predictive in the same way that a stage-discharge relation (also empirically determined) is predictive, disputes will naturally arise. As Bill took great pains to point out, the difficulty with the expectation of predictability is that population dynamics generally don't work that way.

The primary issue is one of trying to manage broadly rather than specifically: X2 can be taken as an important measure of system hydrology (as can flows on the fortnightly or longer time scale). If hydrology is thought to be important biologically, one approach would be to try to make the behavior of X2 look as much as possible like it would do "naturally," with "natural" defined as some level of water development (a policy-based decision). Somewhat like the "Field of Dreams" philosophy - i.e., build it and they will come - this presumes that by restoring some aspect of the physical environment to some previous state which was better ecologically (e.g. which supported larger populations of native fishes), one will see ecological restoration (defined as some specific goals cf. CALFED). It should be pointed out that this is exactly the guiding rationale for increasing shallow water habitat in the Delta, notwithstanding the lack of anything like the X2-abundance relations to connect acres of shallow water habitat to (e.g.) abundance of Delta Smelt. If we adopt this approach with X2, we must be satisfied with the very loose level of control it accords. Specifically, the results may take a long time to manifest themselves. This point was made repeatedly during the shallow water habitat workshop in late June, particularly by Si Simensted, who was arguing for decades for the development of littoral/shallow water habitats in restored wetlands/marshes.

The alternative is to try to manipulate the system in detail, as one might operate a sewage treatment plant, or design an airplane. Certainly from an engineering standpoint, it is much more tractable to pursue the latter strategy, i.e., to consider pump operation strategies or the construction of facilities aimed at preventing specific problems like entrainment. The results are immediately measurable, i.e., fewer Delta Smelt entrained, and, adaptation of the design (facility or policy) more easily done to achieve an optimal solution. Which mode of operation provides a better return on resources (water, capital) invested seems to be a fundamental issue that was only tangentially addressed in the workshop.

Nonetheless, based on the workshop proceedings and on previously published work, I think some answers can be given to the questions posed for the afternoon workshop:

1. Is it possible to devise an experimental test of the success of X2? Yes, if one is willing to wait sufficiently long to see the results, and if one designs limited, focused experiments on hypothesized connections between X2 and abundance, e.g., X2 downstream means intensified gravitational circulation through the Golden Gate, which equates to better recruitment of things like Crangon

(or Dungeness crab) into the Bay. This approach means a continued focus by the IEP on "studies" (research) in addition to monitoring, and most likely an enhanced role for university researchers. It also means continuous, careful, biostatistical analysis of the data. We should not be debating log vs. linear plots. Perhaps one should say that we need consensus by a group of statisticians; it shouldn't really matter what BJ Miller or I think about the statistical significance of X2-striped bass relationships.

2. Is X2 any better as a standard than X1 or X3? From a statistical standpoint, there is no real difference given the self-similarity of the salinity distributions observed in Northern SF Bay. From a physics standpoint there is not much difference although if you were choosing between X2 and X6 or X0.5 there are real differences in flow structure. From a biological standpoint, Bill and Wim's X2 studies may show that X2 (like Ball and Arthur's earlier EZ work) is a good reference position for looking at the spatial structure of ETM (LSZ) populations. However, this all begs the question of why all the action at or around X2 given Jon's observations that show convincingly that the ETM (LSZ) does not function in the way hypothesized by Ball and Arthur (which, by the way, was a very useful hypothesis for guiding subsequent work).
3. Is X2 more or less useful than outflow for use as a standard or conceptual tool for understanding the estuary? Since X2 and flow are tightly linked at timescales of a fortnight or more, X2 has only proven to be more useful as a standard in the sense that it could be promulgated, and thus was useful in breaking the logjam that had developed over flow regulation. Conceptually, on the other hand, it is different since it determines the strength of the density gradient that drives gravitational circulation, it measures where one finds habitat at a given salinity, and it thus determines where that habitat is positioned relative to the pumps. Jon provided a useful view of the difference--X2 is good for describing things related to the salt field in Suisun Bay and the western delta whereas flow is good for describing things where the currents it drives are comparable to those driven by the tides, e.g. somewhat upstream of Suisun Bay at low flows and possibly down in San Pablo Bay at high flows. Other variables, like contaminant levels, the presence of exotic species, or even, one might argue, the operation of the Montezuma Slough tide gates might be found to be important at times and for particular species.
4. What needs to be done next? In terms of actions, there seems to be some interest in focusing some attention on species like Crangon or longfin smelt that exhibit a robust X2-abundance relation, and for which hypotheses exist as to possible mechanisms behind those relations. This might involve some workshop activity summarizing what is known, etc., but more likely requires designing new experiments and/or monitoring. From the standpoint of data analysis, careful examination of X2-abundance relations should be an ongoing activity, carried out by people who are skilled at the necessary biostatistics. I doubt that the X2-Q-time relationship needs re-evaluation, but it would not hurt, especially given the additional data that would be available for the high flows we have seen in the past few years 17 .

Finally, bluntly put, the workshop failed to accomplish the latter 3 of its 4 major objectives, which, in retrospect, were probably too ambitious. In particular, little progress was made on the second and fourth objectives, i.e., there was no consensus achieved about the current value of X2. This is hardly surprising given that the earlier Schubel workshops lasted 8 days in total, included a good deal of work outside the workshop, and, in the end reached a set of conclusions that were not unanimously adopted.

Owing to the large size of the meeting, and a lack of direction in the afternoon discussion, it is hard to argue that much was accomplished in the latter part of the workshop. To be successful, this type of discussion probably needs to be steered somewhat by the firm hand of the moderator, which can easily raise the collateral issue of whose agenda is subtly or not so subtly being put forward. To his credit, Randy Brown was suitably neutral in his moderation of the afternoon session. As a recommendation, I would think that a group of the size of the Estuarine Ecology Team might be better suited to carry on the real group work needed to address the stated objectives of the workshop, with a large town meeting like the X2 workshop used to inform the community as to what the smaller group was engaged in or about what conclusions to which they had arrived. In that respect, public presentation of the EET X2 matrix might have been a more useful activity after the morning talks.

Overall, I don't regret having attended the workshop. However, for myself, the exercise of preparing these notes has helped me to reflect upon what was presented and said. Although it would be expensive in terms of IEP staff time, I would recommend that anyone who attends a workshop like this be required to develop their own view of what was accomplished. This would serve two goals--first, the number of workshops and their total of attendees would drop, and secondly, those who do attend will better profit from their time spent listening to presentations and discussion. I note that this is not unlike the approach we employ in teaching university students!

Acknowledgments

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A Summary of the Current State of the X2 Relationships

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On March 11, 1998 the Interagency Ecological Program (IEP) and Bay-Delta Modeling Forum sponsored a workshop at the Contra Costa Water District (CCWD) to present and discuss several aspects of the X2 standards and relationships between abundance of aquatic organisms and X2 (the "fish-X2" relationships). This report is a summary of my presentation at the workshop, borrowing heavily from those of other presenters in an attempt to summarize the current state of these issues. I update the relationships with the most recent data, and discuss several of the salient issues that came up before and during the workshop.

The overall workshop is discussed in a separate report by Stephen Monismith (this issue).

X2 is defined as the distance in kilometers up the axis of the estuary to where the tidally-averaged near-bottom salinity is 2 psu (practical salinity units). It was developed as an indicator of the physical response of the estuarine ecosystem to changes in freshwater flow. For a concept that is relatively straightforward, X2 has engendered a surprising amount of disagreement and misunderstanding. The workshop was convened to increase the general level of understanding of these issues, discuss key areas of disagreement, and attempt to build on previous attempts by the Estuarine Ecology Team (EET) and others to identify probable mechanisms underlying the relationships.

X2 is now being used, in a somewhat altered form, to manage the estuarine ecosystem. The water costs of this management may be high in dry years. Furthermore, we do not know whether an "Isolated Transfer Facility" would improve conditions in the estuary enough to justify relaxing the X2 standard. Therefore, intense interest exists among stakeholders in ways to reduce the water costs of the X2 standard while providing adequate protection of the estuarine ecosystem and key species.

A Brief History of X2

Although the idea of using a 2 psu isohaline for ecosystem management arose in the late 1980's, it received its major impetus in a series of workshops from 1991 through 1992, organized by the San Francisco Estuary Project and moderated by Jerry Schubel (see Schubel 1993, Kimmerer and Schubel 1994). An important basis for these workshops was the recognition that freshwater flow had measurable effects on the abundance of estuarine-dependent species (Turner and Chadwick 1972, Stevens 1977, Armor and Herrgesell 1985, Hatfield 1985).

In the Schubel workshops the concept of X2 was defined as an alternative description of flow conditions in the estuary. The relationships between X2 and abundance of several estuarine species were developed (Jassby et al. 1995). The report of the workshops (Schubel 1993) made several recommendations, the principal one being that X2 be used as an index of estuarine condition.

The daily numerical value of X2 was determined by interpolation using data from continuous monitoring stations maintained by the U.S. Bureau of Reclamation and the Department of Water Resources (Jassby et al. 1995). These stations sample 1 meter below the surface, in about 10 meters of water between the shoreline and the ship channels; near-bottom sensors on some of these instruments had not provided enough data to use in interpolation. The measurements were converted to salinity and corrected to bottom salinity assuming a constant stratification of 0.24 psu determined from grab sample data for surface and bottom salinity. Stratification did not depend on outflow except at extremely high values. Gaps in the data were filled using a time-series regression that included the log of net delta outflow and the previous day's value of X2. For times when X2 was seaward of the Martinez sensor, values were calculated using the same equation; thus values for X2 in Carquinez Strait and seaward (<56 km) are merely estimates and based on recent field experience (Kimmerer 1998) these may be very inaccurate. The final time series consisted of daily values from 1968 to 1992. Values for earlier and later years have been filled in using the time-series regression model.

Estimates of X2 now being used in management are based on the same time-series regression developed in the Schubel workshops.

This analysis was never intended to be the underpinning of a system of legal requirements for California's water system, but as an exploration of what form a standard might take. To my knowledge the analysis has never been repeated by other researchers, nor has it been updated to reflect a longer series of data or more appropriate (i.e., near-bottom) data.

Participants in the Schubel workshops had expected to recommend particular values of X2 as standards based on analysis of the available data. This was not possible because the fish-X2 relationships were monotonic, with no optimum or leveling-off point. This meant that more flow should produce more fish, at least up to, and sometimes including, the extreme flows of 1983. Therefore particular values for X2 could not be selected using only scientific analyses, and societal factors had to be brought to bear. Workshop participants therefore left the selection of particular values of X2 to other forums.

It is worth noting that participants in the Schubel workshops agreed that whatever standard was developed on the basis of whatever relationships, these would apply only if the plumbing of the water projects remained the same. The participants expected that major changes in water project configuration would result in substantial but unpredictable changes in these relationships.

The next step in development of standards was made by the Environmental Protection Agency (EPA) on the basis of three principles: (1) the standard should account for water availability on a continuous basis rather than by discrete water year types; (2) the standard should be set by comparison with conditions existing at a time when the biological populations of the estuary were considered "healthy"; and (3) the standard should use salinity at existing monitoring stations rather than interpolated values of X2.

Using these principles, EPA developed a "sliding scale" by which X2 was dependent on the availability of flow to the watershed and the level of development in the watershed, represented by calendar year. This gave a relationship in which the value of X2 could be set based on precipitation including recent history, and on a selected year representing level of development. The year ultimately written into the standard was 1971.5. The sliding scale ensures that the amount of water used to control X2 is proportional to the amount available in the watershed.

In designing the new standard, EPA replaced the actual value of X2 with the frequency with which 2 psu salinity was exceeded at three control points where conductivity sensors had been in place: Collinsville, Chipps Island, and Roe Island. This modification eliminated the need for accurate estimates of X2, and therefore the recommendation of the Schubel workshops (that sensors be put in place to monitor X2), was not taken. Furthermore, this modification made the use of the "g model" of the Contra Costa Water District more suitable in management than the X2 equation, since the g model predicts salinity at a site rather than the movement of a salinity value.

The State Board adopted the X2 standard following the signing of the Bay-Delta Accord in 1994. A provision of the Accord was that there would be a triennial review of the standard, but to date no formal review has occurred. This may be partly due to the high flows that have occurred in all years since 1994, resulting in little impact of the standard on operations.

X2 and the Low Salinity Zone

I use X2 to mean the distance up the axis of the estuary to the 2 psu isohaline; I call the region of the estuary where the salinity is around 2 psu the "Low-salinity Zone" (LSZ). Several terms have been used to describe this region including "Entrapment Zone," "Null Zone," and "Estuarine Turbidity Maximum" (ETM). However, the region where salinity is around 2 (say, 1-6) psu is not always an Entrapment Zone (Burau 1998); since stratification is weak in Suisun Bay, it is not always a Null Zone (Burau 1998); and only sometimes is it an ETM. The term Low-Salinity Zone implies no mechanisms and is unequivocally related to a certain salinity range.

X2 is an index of estuarine conditions and it responds to flow (Figure 1). However, a large array of other variables are, or may be, correlated with flow (Table 1). The mutual relationships among these variables make it difficult or impossible to use statistical analyses of annual data to determine which is a better predictor of variation in fish abundance, or if any has a direct causal link. To unravel the relationships requires understanding of the biology of the individual species in the context of the physical conditions in the estuary. This is discussed further below. However, it is important to recognize that on statistical grounds, other variables may be just as good as X2 in predicting abundance.

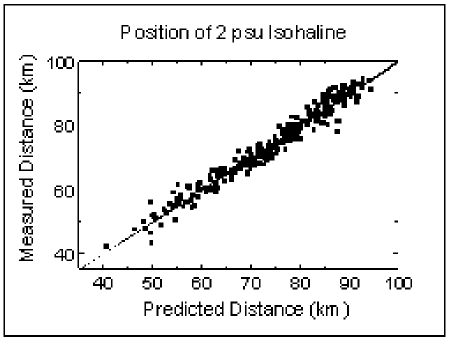

Figure 1. Relationship of X2 to net delta outflow (DWR Dayflow model output). The model is a time-series model containing the log of monthly mean outflow and X2 in the previous month.

Table 1. Variables Related to Freshwater Flow into the San Francisco Bay-Delta Estuary and River System. *

Flow Variables	
Sacramento River, San Joaquin River, tributary flow	Cause
Delta inflow and outflow	Cause
Inundation of flood plains and flood-control bypasses	Cause
Physical/chemical variables	
Nutrient and organic carbon supply rate	Data
Sectionally-averaged seaward residual circulation	Cause
Residence time	Inferred
Distance up estuary to 2 psu salinity "X *2*"	Data
Distance up estuary to any salinity	Inferred
Steepness of longitudinal density gradient	Data
Stratification seaward of LSZ	Inferred
Gravitational circulation seaward of LSZ	Inferred
Habitat Variables	
Area of inundated river-margin habitat	Inferred
Temperature (weak effect)	Data
Dilution or mobilization of river-borne contaminants	Suspected
Area or volume encompassed by two salinity values	Inferred
Location of low-salinity zone and associated species	Data
Biological Variables	
Abundance or survival of numerous species	Data
Transport of young anadromous fish into bay	Suspected
Entrainment of young into bay	Suspected
Proportional entrainment in export pumps	Inferred

** The table indicates whether the relationship is known from a clear causative link, known from data analysis, inferred from other information, or suspected.*

X2 is clearly useful in describing some physical characteristics of parts of the estuary unlikely to be affected directly by freshwater flow. Two factors are important here: the dispersive nature of the estuary, and the qualitative difference between fresh and brackish water regions of the estuary.

The further seaward one goes in the estuary, the more the hydrodynamics is influenced by tide and the less by flow. At Chipps Island in a low-flow period, tidal flows are about 50 times greater than net freshwater flow. Although the tidal flows are bidirectional, tidal trapping and asymmetry in tidal currents in different channels of the delta and Suisun Bay produce intense mixing that is the predominant mode for transport of some substances under these conditions. Generally tidal dispersion can be expected to dominate the net flux of substances that have a strong gradient (e.g., salt), while the net flow due to freshwater input would be expected to transport substances with little gradient (e.g., chlorophyll before 1987, Jassby and Powell 1994). As flow increases, the boundary between dominance by tidal mixing or by net flow moves seaward.

The LSZ also marks a boundary between the tidal-freshwater region of the estuary and the brackish region. In the freshwater region stratification is slight and ephemeral. Seaward of the LSZ, stratification and therefore gravitational circulation are possible, although they are common only in deep water, given the tidal energies and horizontal salinity gradients typical in this system (Burau 1998). Furthermore, at the LSZ the flora and fauna of the estuary change from a freshwater assemblage to an assemblage characteristic of brackish water, and further seaward to an assemblage characteristic of more saline water (Kimmerer and Orsi 1996).

An Update of the Fish-X2 Relationships

The fish-X2 relationships have been updated through March 1998 (Figure 2). Data for fish and bay shrimp are annual values, since these species reproduce on an annual basis. Data for chlorophyll, a measure of phytoplankton biomass, and for planktonic species, are monthly or survey means to reflect the shorter generation times of plankton. Below I discuss the features observed in each of the relationships, including results of exploratory data analysis done on some of the species. Regression statistics are given in Table 2.

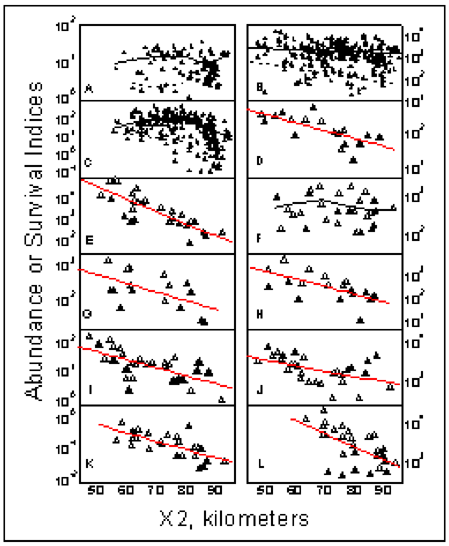

Figure 2. The fish-X2 relationships. Open symbols and solid lines, data before 1988; closed symbols and dashed lines, data from 1988 on; solid lines only include all the data. A, chlorophyll, monthly means; B, Eurytemora affinis abundance, survey means, with post-1988 data for March-June only; C, Mysid abundance (Neomysis mercedis until 1992, then also Acanthomysis spp.), survey means for May and later and for temperature over 18°C; D, Crangon franciscorum; E, Longfin smelt; F, Delta smelt; G, Pacific herring; H, Starry flounder; I, Sacramento splittail; J, American shad; K, striped bass survival index (ratio of summer young-of-the-year abundance index to egg abundance estimate); L, striped bass midwater trawl index. Data from IEP monitoring, provided as annual abundance indices except raw data were used for A-C. Curved lines in A and F are locally-weighted regressions drawn to capture the general trend in the data without fitting a chosen model; the curved line in C is a second-order polynomial regression. To account for zeros in the data, abundance indices for starry flounder were incremented by 10, and those for splittail by 1, before log-transformation.

All data were log-transformed before analysis (see below). Linear models were generally fit by ordinary least-squares methods, after examination of residuals for departures from assumptions. When apparent outliers were present I used generalized linear models with robust fitting procedures (Venables and Ripley 1994). Residuals from modeled relationships of the higher-frequency data (lower trophic levels) were autocorrelated over a time scale of a few months. Since the data are not evenly spaced in time and contain numerous gaps, they are not suitable for time series analysis or any of the available methods of correcting for autocorrelation. Therefore I calculated confidence intervals using a conservative value for the number of data points that was 10-fold lower than the actual number of points (Figure 2 B, C).

For most response variables I examined the relationships up to 1987 and for the entire time series. For lower trophic levels, which had clearly changed, I examined the relationships separately for data up to 1987 and for 1988 and later. Except for the three representatives of lower trophic levels, the models did not change much when the post-1988 data were added (Figure 2, Table 2). Apparent weakening in some of the relationships (longfin smelt, starry flounder, and striped bass MWT index) did not result in substantial changes in either the fitted slopes or their confidence limits (Table 2), mainly because the increased number of data points reduced the error variance.Chlorophyll in samples taken from 0.5-5.6 psu salinity (1-10 mS/cm specific conductance; Figure 2A) were taken as the geometric mean of data from the IEP water quality and zooplankton monitoring programs. Chlorophyll has never had a relationship with X2, and the mean value decreased by about 5-fold after 1987. The data taken before 1988 (solid line and open symbols) show a decline at low X2 values that may be a seasonal effect: low values occurred in spring before the annual phytoplankton bloom.

The abundance of the copepod Eurytemora affinis (Figure 2B) had a significant but very weak relationship to X2 before 1988, along with a large, continuous decline in abundance between 1972 and 1987. The relationship with X2 after 1988 was steeper and stronger, with mean abundance about 10-fold lower than before 1988. Note that the values for 1988 and later include March-May only, since this copepod is now found in few or no samples in summer to fall each year. A straight line provided a good fit to both data sets (Table 2).

Mysids (Figure 2C) include Neomysis mercedis as well as Acanthomysis spp, introduced in about 1992 (Odlin and Orsi 1997). Data were truncated to include months after April and temperature above 18°C, since mysids are uncommon when the water is cooler. Before 1988 N. mercedis had a complex relationship to X2 and also varied seasonally, decreasing from a peak in late spring to a low in the fall. This relationship was fitted with a linear term in date within year, and a quadratic term in X2. The curved line in Figure 2C is for mid-July. After 1988 the seasonal trend remained but the relationship to X2 appeared linear; the dashed line is for mid-July (Table 2).

The bay shrimp Crangon franciscorum had a significant relationship with X2 that did not appear to change since 1988 (Figure 2D). The lowest and highest residuals around the X2 trend line were both observed after 1988.

Longfin smelt (Figure 2E) had the strongest relationship with X2 which weakened somewhat after 1988, with a decrease in abundance of about 5-fold but little change in slope. Delta smelt (Figure 2F) has no relationship with X2, and did not appear to decrease in abundance beginning in 1988. The contrast between these related species may be useful in unraveling the mechanisms underlying the relationship of longfin smelt to X2.

Table 2. Summary of parameters of fish-X2 relationships. Slopes are given with estimated 95% confidence limits.

Taxonomic		*Averaging*	*Pre-1988*		*All Data*		*Post-1988*		
Group	*Variable*	*Period*	*N*	*Slope*	*N*	*Slope*	*N*	*Slope*	*Remarks*
Phytoplankton	Chlorophyll	Month	114	--			46	--	No relationship
Eurytemora	Abundance (0.5-6 psu)	Survey	257	-0.006 0.0035			37	-0.022 0.011	
Calanoid Copepods	Abundance (>6 psu)	Survey	223	-0.013 0.004			109	-0.029 0.012	
Mysids	Abundance	Survey	158	Nonlinear			74	-0.024 0.018	
C. franciscorum	Abundance index	Mar-May	8	-0.025 0.019	18	-0.025 0.012			
Longfin smelt	Abundance index	Jan-Jun	19	-0.062 0.016	29	-0.059 0.017			
Delta smelt	Abundance index	Feb-Jun							No relationship
Pacific herring	Abundance index	Jan-Apr	7	-0.035 0.039	16	-0.026 0.022			1983 omitted; see text
Starry flounder	Abundance index	Mar-Jun	8	-0.031 0.029	18	-0.031 0.021			
Sacramento splittail	Abundance index	Feb-May	19	-0.038 0.017	29	-0.028 0.013			
American shad	Abundance index	Feb-May	19	-0.025 0.011	29	-0.015 0.010			Slope declined: increased abundance at high X2
Striped bass	Survival index	Apr-Jun	18	-0.022 0.012	25	-0.027 0.012			
Striped bass	Abundance index	Jul-Nov	19	-0.037 0.015	29	-0.035 0.018			

Pacific herring (Figure 2G) had a weak relationship with X2 before 1988: the 95% confidence limits of the slope included 0, with only 7 data points. This analysis was done with 1983 excluded because of the unusually low abundance. The relationship for the entire period, again excluding 1983, better predicts abundance, although since 1990 it has been lower than predicted by the relationship. Including 1983 requires a nonlinear fit to the data that is forced entirely by that one point. Thus, the relationship for herring is not very strong and very high flow appears to result in a decrease in abundance index.

Starry flounder had a similar weakening of a significant relationship, with a flatter slope than before (Figure 2H).

Both splittail (Figure 2I) and American shad (Figure 2J) vary with X2 and for both species the slope has flattened apparently because of higher abundance at high values of X2. The cause of any increase in abundance with high X2 is unknown, although the mechanism for the X2 relationship is better understood for splittail than for any other species (Sommer et al. 1997).

Two different variables for striped bass tell a slightly different story. Survival index from egg to summer townet index (Figure 2K) is related to X2, and the relationship has not changed. The midwater trawl index (Figure 2L), also related to X2, has fallen below the prediction in every year since 1988 when X2 was at or below 85 km. The difference between these can be interpreted as due to declining egg production because of declining abundance of large adults (Kimmerer 1997, Bennett and Howard 1997). This decline is accounted for in the survival figure, but not in the figure for abundance.

Some technical details

Several key issues bear on the interpretation of the fish-X2 relationships. I discuss these below using longfin smelt as an example. This species has the strongest relationship with X2 and also one of the longer time series of data.

Interpretation of relationships

Each of the relationships depicted in Figure 2 can be interpreted as follows: "On average, the abundance of species x increases by y% for each kilometer seaward movement of X2." The percentage increase y per kilometer seaward movement can be calculated from the slope b as: percent increase = 100 (10-b - 1). Thus, for example, the expected abundance of longfin smelt increases by 15% and that of starry flounder by 7% on a 1-km seaward movement of X2.

The prediction inherent in the relationships only holds if future conditions will continue as in the past, so intervening changes may lessen their predictive value. The prediction is for the average condition only, rather than for a particular future year. It can be assumed to work within a year, such that if X2 were at, say, 70 km over the course of the relevant time period (Table 2), then longfin smelt would be 72% more abundant than it would have been with X2 at 74 km. Of course, there is no way to test this directly.

Use of log-transformed data

One of the topics for discussion at the X2 workshop was the use of raw vs. log-transformed abundance data (Figure 3). Log-transformed relationships are familiar from other fields: e.g., the Richter scale, the pH scale, and decibels all involve a log transform. Although some people are not comfortable with the concept of "log fish," I argue that log-transformed data are more appropriate than linear data for several reasons, some general and some specific to the fish-X2 relationships.

Ecologists log transform abundance data for four main reasons, two statistical and two ecological. Commonly-used statistical techniques require that variances be homogeneous; that is, variance of the response variable must not depend on its mean value. This is usually not the case for abundance data, for which the variance is often positively related to the mean value. Log transformation often removes this heterogeneity. Modern, computer-intensive statistical techniques do not require the constraint of homogeneous variances, so this use of log transforms is less necessary than before.

The other statistical reason for using log-transformed data is that often an underlying relationship can be more closely modeled as a straight line, which makes fitting the model much simpler and more straightforward.

One ecological reason for using log transforms is that biological populations change by multiples. This means that models fitted to log-transformed data have parameters with unambiguous meanings. For example, if we fit a straight line to the time course of log-transformed abundance of striped bass in the fall, the slope of the line is the mortality rate. Similarly, the slope of the time course of log-transformed annual abundance of winter-run salmon gives the annual proportional loss to the population on an instantaneous basis. The time trend of abundance data that have not been log-transformed has no clear meaning.

Finally, we are more concerned about the populations at low than at high abundance. This is because populations have a higher probability of extinction at low abundance. Thus from a species-protection perspective, this is the part of the curve we should be concerned about. At the high end of the curve, we would like to produce as many of each species as we can, but nobody knows what a suitable target abundance index should be. Thus our fitted curve should emphasize proportional change, not absolute abundance, and a log-transformed curve is preferable.

Figure 3 shows the relationship between longfin smelt abundance index and X2, plotted on linear and log scales. The linear plot appears to show a step change in abundance, such that at high flow/low X2, abundance is high and variable, while at low flow/high X2 it is always low. This implies that there is no relationship of abundance index to X2 at low flow, but as the log-transformed figure shows, this is misleading. In fact the relationship appears to be the same throughout the range of X2, such that a seaward movement of 10 km in X2 results in about a 4-fold increase in abundance index on average. This increase is not apparent in the linear graph because it starts from a baseline that is very low on the arithmetic scale.

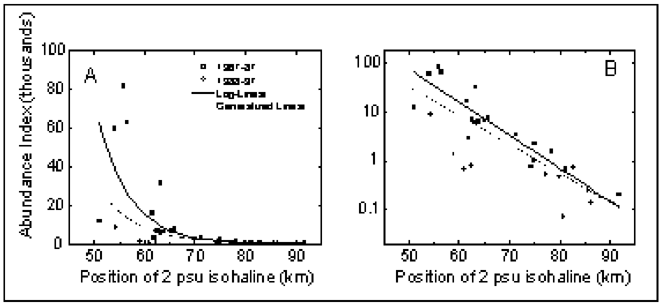

Figure 3. Longfin smelt. Comparison of relationships to X2 of raw (A) and log-transformed (B) data. Squares are pre-1988 and circles are post-1987 data. The darker line is calculated from a linear regression on log-transformed data, while the lighter line is from a generalized linear model with log link function, fit to the raw data.

In both plots of Figure 3, two lines have been drawn: one is the regression line based on log-transformed data, and the other is the fit of a generalized linear model (glm) with log link function and variance proportional to the mean squared (Jassby et al. 1995, Venables and Ripley 1994). The fitted lines have the same form but a somewhat different slope, with the log line having symmetrical residuals on the log scale, and the glm line having symmetrical residuals on the linear scale. However, both increase monotonically with decreasing X2, so both give the same information.

The only cases where we might be more interested in fitting a curve to the raw abundance indices are when the data contain a lot of zeros, or when the objective is an unbiased forecast of abundance under a specified set of conditions. This might be the case if, for example, the objective were to predict abundance in a fishery. However, that is not the objective for any of the fish-X2 relationships as they relate to setting standards for the estuary.

Using all or part of the data set

The fish-X2 relationships include a range of X2 values controllable by project operations, and a range that responds largely, but not entirely, to high flows during wet years. This has led to the "controllable range" shibboleth, which is this: we should use only the controllable range of X2 data in assessing the effect of project operations on fish abundance.

There are several arguments for using the entire set of data. First, relatively simple continuous functions are appropriate for data that do not contain step or other discontinuous functions. The fish-X2 relationships cannot contain discontinuous functions, as demonstrated by a simulation shown in Figure 4. I started with the assumption that the actual underlying response of a species such as Crangon franciscorum could be a step function, as shown by the line in Figure 4. Then I took the daily X2 values for March-May in each year and calculated a fraction of each day on which X2 would be seaward or landward of the assumed breakpoint of the step function. The tidal excursion in Suisun Bay is about 14 km, so the fraction seaward of the breakpoint was scaled linearly from 1 to 0 over 14 km, with a value of 0.5 at 68 km. Then I calculated the response based on the step, and averaged the values over the season.

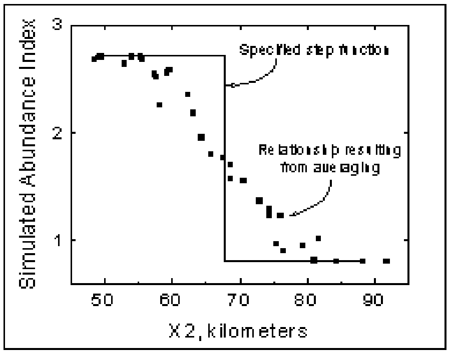

Figure 4. Results of a simulation illustrating the smoothing out of a postulated step function in response of a bay species (Crangon franciscorum used as an example) by temporal variability in X2 during the averaging period.

The average values calculated for each season (1967-1997) are plotted as points in Figure 4. The daily tidal excursion and seasonal variation in X2 have smoothed the step function into a continuous, nearly linear function. This suggests that either a straight line or some slowly-varying curved function would be most appropriate to fit to the fish-X2 relationships, irrespective of the shape of the underlying mechanism.

The second argument for using all the data is by analogy. Suppose we wanted to bet on a one-on-one game of basketball, and all we knew about the two players was that one had a larger shoe size than the other. The prudent gambler would always bet on the player with the larger shoe, reasoning that this person would probably be taller than the other player and therefore have an advantage in a game of basketball. However, this gambler would not expect to win this bet every time, and the closer the two shoe sizes are together, the smaller the odds in the gambler's favor.

This analogy has an exact parallel in understanding the meaning of the fish-X2 relationships. In neither case is it likely that the independent variable (shoe size or X2) exerts a direct influence on the outcome; both are surrogates for variables that probably do have an effect. In both cases, we use our knowledge of the overall relationship to make inferences about changes over a small range. In neither case do we expect to be able to predict the outcome of an individual event (game or year's abundance index), but we expect that on average, we will come out ahead by using the average relationship. In both cases, using all of the available data improves the ability to predict the likelihood of success in a given trial.

An additional argument is that, if somebody wants to use just part of the relationship to establish how abundance varies with X2, then that person should be obliged to demonstrate that the relationship is in fact different within that range than over the entire range. I have investigated this possibility by calculating piece-wise linear regressions for each of the significant fish-X2 relationships, assuming the "controllable range" to be landward of 68 km (corresponding to about 20,000 cfs delta outflow). In four cases the slopes of the two segments differed, but in three of those cases the slope was actually steeper in the low-flow range (Table 3).

Table 3. Statistics for Piece-wise Regressions Around the Controllable Range (68 km) for Annual Indices Except for delta smelt (no significant relationship) and Striped Bass Midwater Trawl Index (only one x2 value <68 km).

Taxonomic group	*Response Variable*	*Difference in Slopes**
C. franciscorum	Abundance index	-0.017 + 0.021
Longfin smelt	Abundance index	-0.002 + 0.03
Pacific herring	Abundance index	*-0.077 + 0.02*
Starry flounder	Abundance index	*-0.020 + 0.016*
Sacramento splittail	Abundance index	0.021 + 0.028
American shad	Abundance index	*0.050 + 0.043*
Striped bass	Survival index	*-0.024 + 0.009*

Difference in slopes is the slope of the controllable range minus the slope of the remaining range, given with 95% confidence limits.

The "Adult Fish" test

Concern has been expressed by some that the objective of restoration actions should be to restore populations of adult fish, not juveniles. About half of the fish-X2 relationships apply to juveniles. However, only for those species that are harvested are we concerned about adults; for other species (e.g., delta smelt) juvenile abundance is a more suitable and convenient measure of the status of the population than abundance of adults.

For those species that are harvested, the issue is whether density-dependent mortality occurs between the life stage measured and the life stage of interest. This is mortality that increases as the number of fish increases. Density dependence is very difficult to determine from field data, and for most species in the estuary it has not been detected. Survival of young striped bass from their first summer to the end of the first year of life appears to be density-dependent (Kimmerer 1997).

In the absence of a clear indication of density dependence, we can only assume that in any one year some fraction of the young fish will become adults, and that fraction will not change if there are more young fish. Therefore, if the fish-X2 relationship predicts more young fish with a seaward position of X2, then more adults are also expected. This assumption should be verified for those species with significant fisheries.

Investigating the Mechanisms

A great deal of interest was expressed by many participants at the X2 workshop in investigating the mechanisms underlying the fish-X2 relationships. I believe that there is now a general consensus that these relationships can be investigated only through a careful program of research. Although some investigators have pursued particular aspects of the relationships (e.g., Unger 1994, Kimmerer 1998) there is not now a comprehensive strategy for investigating them.

The motivation for pursuing these mechanisms varies, but an underlying theme among many stakeholders is that the X2 standard is too crude a tool for managing the estuary, and since it is so expensive in terms of water, it should be made more efficient. This could be done by limiting the time period over which X2 is adjusted, or by employing other, more efficient measures to accomplish the same ends.

It is somewhat ironic that, in this age of "ecosystem management," there is such strong interest in species-specific management. X2 is one of the few examples of ecosystem management in aquatic ecosystems. Perhaps the interest in management at higher than the species level is not as strong as the economic interest in protecting the estuarine system parsimoniously as to water.

The Estuarine Ecology Team wrote an essay on the likely mechanisms (EET 1996; text portion available at http://wwwiep.water.ca.gov/eet/x2fish.html), basing its conclusions on knowledge of the biology of the various species. Unfortunately, because of time constraints and a lack of funding or mandate to write a scientific paper on this topic, the EET chose not to attempt to back its consensus opinions with citations or evidence, so it remains merely a statement of consensus of the group.

The EET's report examined the likely mechanisms by which X2 or any of its covariates (Table 1) could influence species abundance, and then looked at each species to determine which of these causal linkages were likely to operate. Mechanisms were divided into those that were very likely, moderately likely, and unlikely, based on current knowledge about the location and seasonal patterns of movement and development of each species. For each species, several mechanisms were considered the most likely. Although these differed among species, several were labeled as important for more than one species. These included physical habitat space including spawning habitat, residence time, food production, and co-occurrence of the species with food.

The mechanisms selected as important can be used to develop hypotheses to be used in a research plan. These hypotheses would then be tested using an appropriate combination of data analyses, field and laboratory studies, and modeling. This will not be easy, and it will not be cheap, given the complexity of this ecosystem and the likelihood that different factors interact on different time scales to influence species abundance (Bennett and Moyle 1996).

Not all possible mechanisms should be investigated. For example, it is equally specious to look for a direct causal link between delta inflow and Pacific herring, as between X2 and splittail. We do know a few things, one of them being that causal mechanisms probably operate in the regions where the species are found.

The original motivation of the EET was to use its conclusions to devise a research program to investigate the mechanisms further. It has not done this yet. Given the interest in this topic, several members of EET and others are developing a research plan to address this need.

Conclusions

The deterioration of the X2 relationships for lower trophic levels is a concern. However, most of the fish and bay shrimp seem to have maintained their relationships with X2, although abundance of longfin smelt has declined. The lack of major changes in most of the fish and shrimp is a major ecological puzzle, since most of these fish and shrimp rely on the lower trophic levels for food. It suggests caution in predicting future abundance patterns from X2, but also suggests that the X2 relationships are fairly robust to significant perturbations to the system.

The next step should be to develop and implement a program of research into mechanisms. Future workshops can be convened to discuss results of such investigations.

Finally, I believe it is time for researchers and managers in the Bay-Delta arena either to accept the concept of X2 as an indicator of estuarine response to flow, or find and publish a legitimate reason not to use it. The fish-X2 relationships are robust, they are real, and they are generally consistent with one another. Arguments for amendment (in either direction) of the X2 standard should be based not on the relationships themselves, but on either the selection of a target year for use in the sliding scale, development of a standard that is as protective but more conducive to effective water management, or refinement of the standard through investigation of the mechanisms, their time and space dependence, and their probable response to CALFED rehabilitation activities.

Recommendations

1. The flow-X2 relationship should be recalculated using all available data. This calculation should be updated on an annual basis.
2. The fish-X2 relationships should continue to be updated annually, new ones should be identified, and any revisions to the overall trends should be announced.
3. A major effort should be undertaken to determine the mechanisms underlying the X2 relationships.

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Relative Efficiency of the Midwater and Kodiak Trawl at Capturing Juvenile Chinook Salmon in the Sacramento River

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Introduction

In order to increase capture of the larger chinook salmon that are believed to have evaded the midwater trawl net used in the past, the Kodiak, or pair trawl, was added to the Interagency Ecological Program (IEP) sampling regime near the city of Sacramento. Using one boat on each side of the net, the Kodiak trawl sends fish into the center of the net in a herding fashion (Noel, 1980). The additional power of an extra boat enables a larger net to be pulled creating an increased fishing area. In situations where fish are sparsely distributed (i.e., winter, late-fall, and yearling spring run), it is important to use a net with an enlarged mouth opening to improve the chance of capture (Sainsbury, 1996; McNeely, 1964). Salmon may not recognize they are trapped until they are unable to escape (McNeely, 1964). The small mesh size of the Kodiak trawl could increase salmon retainment as opposed to the midwater trawl net, which has considerably larger mesh towards the mouth. However, the effects of back pressure on the two nets are not known. The two-boat effect on herding might be significant and partially responsible for an increase in efficiency as discussed by Noel (1980).

This pilot study was done by the U.S. Fish and Wildlife Service (USFWS) to identify the relative efficiency of the Kodiak and midwater trawl nets used at Sacramento. The study was conducted to answer four questions:

- Does the Kodiak trawl catch larger salmon?
- Does the Kodiak trawl catch more salmon?
- Do the results of the Kodiak trawl show a higher density of salmon than the midwater trawl?
- Is the Kodiak trawl worth the additional effort?

The Kodiak trawl offers a much larger mouth opening (maximum of 1.8 X 7.6 m) than the midwater trawl net (maximum of 1.8 X 4.5 m). In addition, it has a leading footrope (Figure 1) to offset the downward flight of fish. Past studies indicate an increase in catch of pelagic species when changing from a midwater to a Kodiak trawl (Garner, 1978). Thompson (1978) found two boat trawls to produce four to ten times as much fish as single vessel trawls off the Ivory Coast in West Africa.

Historically, the IEP used catch per twenty minute tow on the Sacramento River near the city of Sacramento, and in Suisun Bay adjacent to Pittsburg, as a means of comparing relative abundance of chinook salmon. In recent years, trawling effort was reported more precisely by using the volume of water sampled rather than tow duration.

Theoretically, density could be compared between and within gears and used to analyze trends in abundance and distribution. Because the midwater and Kodiak trawl nets are designed differently, relative efficiencies needed to be analyzed to validate these comparisons.

Methods

Between April 1, 1996, and April 4, 1996, ten twenty-minute comparison tows were attempted daily on the Sacramento River at river mile 55 with the Kodiak and midwater trawl. Tows were conducted simultaneously, adjacent to each other in the main channel of the Sacramento River. Boats alternated locations in the river to avoid a position bias. All fish captured were identified and enumerated. A maximum of 50 of each race of chinook and 30 of all other species of fish were measured to the nearest millimeter fork length. Water temperature, time, and flow meter readings also were recorded after each tow. Water turbidity was recorded to the nearest centimeter with a secchi disk at the beginning of each tow.

The midwater trawl net (Figure 1) was a variable mesh net with a fully extended mouth size of 1.83 x 4.57 meters (6 x 15 feet) tapering to a cod end of 0.32 cm (1/8 inch) mesh (USFWS, 1987). One pair of metal bottom doors sink and spread the net at the lead line and one pair of aluminum top doors with floats spread the top of the net at the surface.

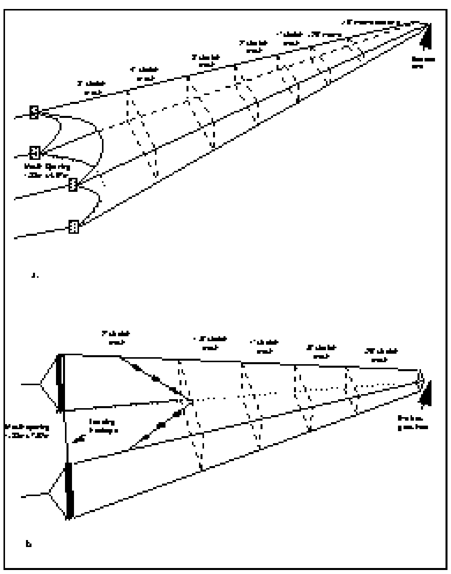

Figure 1. Schematic drawing of midwater (a) and Kodiak trawl (b) nets used in study at Sacramento.

The Kodiak trawl net (Figure 1) was constructed of variable mesh with a fully expanded mouth opening of 1.83 x 7.62 meters (6 x 25 feet). A weighted footrope and headrope with floats allow the net to fish the top 1.8 meters of the water column. The Kodiak trawl was fished with aluminum live box as a cod end to minimize chinook salmon mortality. Two boats pulled the Kodiak net through the water, one towing each wing. A 1.8-meter bar was attached to the front of each wing keeping the depth of the lead line constant. At the end of each tow, one of the boats retrieved the live box and removed the fish. Though the depth the net fished was relatively constant due to the spreader bars, the width of the mouth opening was affected by the boats pulling it and varied within and between tows.

Though the midwater trawl is called such due to its design, it fishes at the top of the water column. Actual fishing dimensions of the net vary and have been described in past reports (USFWS, 1993). The mean effective fishing mouth size of the net mouth was found to be 5.08 m2 based on these studies. The estimated fishing net mouth size of the Kodiak trawl was 12.54 m2. The catch per cubic meter and mean amount of water sampled reported in this paper were based on these preliminary fishing mouth dimension studies.

Meters of water sampled were measured with a General Oceanics mechanical flow meter (model 2030). Linear meters were calculated by multiplying meter rotations with the Standard Speed Rotor Constant (26,873) and dividing the result by a conversion factor (999999). Linear meters traveled per tow were multiplied by the mouth opening of the net to calculate the volume of water sampled. Dividing total catch by volume yielded a density measurement to be used for relative abundance.

Total chinook catch, density, and mean fork length per tow as well as linear and cubic meters fished were tested for normality using SYSTAT descriptive statistics function (SYSTAT for Windows version 7). Catch per tow and mean water sampled distributions were not normal and tested with the Mann-Whitney U test. Mean fork length and salmon density were tested with a t-test.

Results

The mean number of chinook captured per tow was 55.7 (standard error = 4.0) in the Kodiak trawl and 21.3 (standard error = 2.3) in the midwater trawl (Table 1, Figure 2). Catch of all salmon was found to be significantly higher in the Kodiak trawl (p = 0.000).

The mean fork length of salmon captured was 70.8 (standard error = 0.35) in the Kodiak trawl and 68.7 (standard error = 0.22) in the midwater trawl (Figure 3). Mean fork length was found to be significantly higher by 2.0 mm in the Kodiak trawl (p = 0.007).

The mean volume of water sampled per tow with the Kodiak trawl was 12,314 (standard error = 238.2 m3), while the mean for the midwater trawl was 5,438 (standard error = 63.9 m3), significantly less than the Kodiak trawl (Table 1).

The density of chinook salmon was 0.00469 (standard error = 0.00036 m3) in the Kodiak trawl and 0.00387 (standard error = 0.00039 m3) in the midwater trawl. A probability of 0.13 suggested there is no difference in efficiency.

Water clarity, as defined by secchi disk was comparable between the two gears and had an overall range of 0.30 to 0.56 meters in the Kodiak trawl and 0.27 to 0.49 in the midwater trawl.

Table 1. Mean and range per tow of water sampled (m3), chinook catch, fork length (mm), and chinook density in the Kodiak and midwater trawl as well as the probability level and sample size.

	Kodiak		Midwater					
	Mean	Range	Mean	Range	n	Test	p	Significant?
Salmon Catch	55.7	18 -103	21.3	4 - 62	34	Mann-Whitney	0.000	Yes
Fork Length	70.9	38 -112	68.9	32 - 100	34	T-test	0.000	Yes
Water Sampled (m3)	12,314	10,557 - 18,190	5,438	4,628 - 6,311	726	Mann-Whitney	0.000	Yes
Salmon Density (m3)	0.0047	0.0014 - 0.0088	0.0039	0.0008 - 0.0098	33*	T-test	0.13	No

** One tow deleted from cubic water sampled and density calculations because of a faulty flow meter reading.*

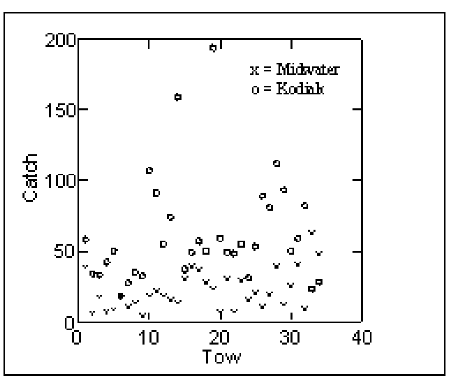

Figure 2. Plot of salmon catch per tow in the Kodiak/midwater trawl experiment conducted between April 1 and April 4, 1998, at Sacramento.

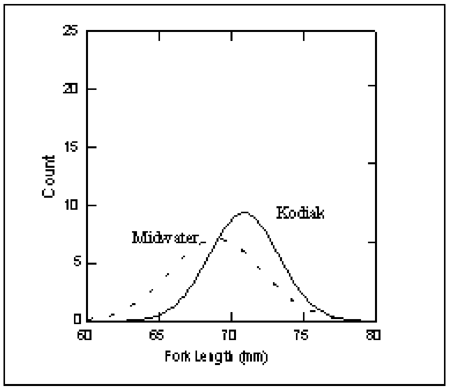

Figure 3. Density plot of mean fork length per tow in the Kodiak/midwater trawl comparison experiment between April 1 and April 4, 1998, at Sacramento.

Discussion

The results of this study indicate that the Kodiak trawl captured larger fish than the midwater trawl during the spring of 1996 at Sacramento. Though the Kodiak trawl selected chinook that were on average two millimeters larger, the fish in the Sacramento River during the spring were mostly composed of fall run hatchery smolts released from Coleman National Fish Hatchery which usually have a narrow size frequency. The results may have been different if a larger variation in size was present during our pilot study. The different design of the Kodiak net may increase the selection ability of larger sized salmon as shown by the results of fork length distributions.

To thoroughly test the size selectivity and relative efficiency of the two gears on larger chinook, comparison trawls should be done in the fall months during winter and late-fall run, as well as spring run yearling juvenile migration seasons. The fish composition during this time of the year would be composed of a mixture of yearling and fry sized salmon and present the experiment with a larger and potentially more variable fork length distribution to test.

The two trawls cover comparable linear distance during a tow, however, the effective fishing mouth opening of the Kodiak trawl is larger and is built differently than the midwater trawl net. As a result, the Kodiak trawl captured more salmon per tow than the midwater trawl, but density values were not found to be significantly different. The larger catches in the Kodiak trawl also enabled more of the larger, less abundant fish to be captured.

Because densities appeared similar in the Kodiak and midwater trawls, it will be feasible to use the two gears interchangeably for abundance and timing information for chinook density during the spring.

The Kodiak trawl should continue to be utilized to maximize effort at catching larger chinook salmon in the Sacramento River. Consideration should be given to using a larger Kodiak net if logistically possible. Further analysis should be done during the fall and winter seasons to take advantage of the fry, smolt, and yearling sized salmon in the system.

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Simulated Effects of Delta Outflow on the Bay -1998 Compared to Other Years

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Introduction

Water year 1998 was characterized by above average precipitation from January through June throughout the 400,000 km2 San Francisco Bay-Delta watershed. Cool temperatures delayed the peak snowmelt until early July, keeping streamflows above average well into the summer (DWR 1998a). This was similar to another strong El Niño in recent history, WY1983. These years stand in sharp contrast to 1997, in which an extremely wet, early winter was followed by one of the driest springs on record (Figure 1). These three water years are compared here to reveal how year-to-year differences in the timing and magnitude of the seasonal flow pulse can affect water quality in the Bay. For a more detailed look at the salinity dynamics in South Bay over the past four water years, (see Schemel in this issue).

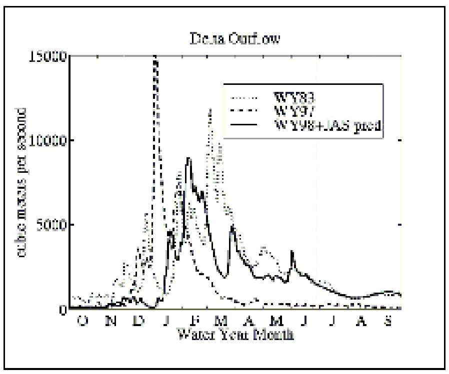

Figure 1. Delta outflow estimates for water years 1983, 1997, and 1998.

Data and Model

DAYFLOW estimates (DWR 1998b) of Delta outflow were used to drive a 32-year (WY67-98) run of the Uncles-Peterson water quality model. At the time of this writing, preliminary DAYFLOW data were available only through June of this year, so a statistical prediction of Delta outflow for the remaining 3 months based on historic June flow totals was used to drive the model through September.

The Uncles-Peterson Bay model uses coarse resolution and tidally-averaged physics to generate simulations of the laterally-averaged salinity field in two vertical layers. The model is also able to trace the movement of Delta outflow throughout the Bay and to estimate residence times. The model's dominant inputs are the tidal state and freshwater inflows. Due to lack of data, local inflows (South Bay streams and Napa River) have been assumed proportional to the Delta flow. The U-P model has been shown previously to produce reliable estimates of weekly to interannual salinity variability and water movement throughout the Bay under these assumptions (Uncles and Peterson 1996; Knowles et al. 1995, 1997). Still, the use of field data permits a more complete investigation of the response of South Bay to the timing and magnitude of local streams and Delta outflow (Schemel, this issue).

Results

The evolution of the salinity field for water year 1998 is very interesting and can be put in perspective by comparing it with two previous strong winters, 1983 and 1997. Salinity for WY83, WY97 and for 10/97 through 6/98 was simulated using Delta outflow estimates; 7/98-9/98 were based on the statistical flow prediction. WY 1998 (Figure 2) showed a strong freshwater signal beginning in January and reaching into South Bay by mid-February, when Delta outflow peaked. The peak flow in mid-February was about 9,000 m3/s, compared to the 1983 peak of nearly 12,000 m3/s in early March and the 1997 peak of over 16,500 m3/s at the start of January.

A convenient indicator of the effects of these flows on the Bay is the position of the lower layer 2 ppt isohaline, X2. Despite the very different flow peaks, the maximum seaward X2 displacement was nearly identical in all three cases, reaching Point San Pablo (Figure 3). The effects on average North Bay (Point San Pablo to the western Delta) residence time were also similar in all three cases, flushing older water and dropping the average to about 7 days.

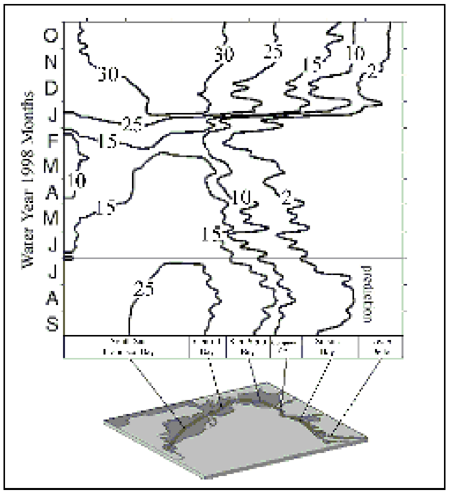

Figure 2. Isohaline movement for WY 1998, including predicted salinity for July-September.

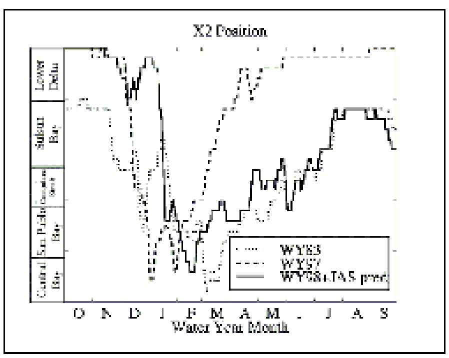

Figure 3. Evolution of X2 for three water years, including Water Year 1998 forecast.

After the peak flows subsided, the three water years evolved differently. In 1997, the flow receded sharply to well below average levels by March. In contrast, both WY98 and WY83 sustained above-average Delta outflow well into summer. This difference is reflected clearly in the movement of X2 (Figure 3). With the sharp flow recession in WY97, tidal mixing dominated the dynamics and ocean water was quickly mixed into the estuary, reaching above-average salinities by May. Water years 1983 and 1998 were marked by high flows that carried into summer, producing a much slower salinity recovery. By June, the simulated difference in X2 position between WY97 and the other years was at a maximum of over 30 km. The difference in residence times also peaked in June, when the average age of North Bay water reached 22 days in 1997 but only 11 days in the other two years. The dynamics of salinity recovery in South Bay, which differ significantly from North Bay but are still strongly regulated by Delta outflow, are discussed in Schemel (this issue).

Our forecast of X2 for WY98 closely parallels the X2 of 1983. With the large snowpack remaining in the Sierra, X2 is projected to creep landward slowly throughout the summer. In September, however, it will likely be pushed seaward somewhat as flood control requirements dictate an increase in Delta flow. Note that years with drier summers, such as 1997, do not typically require such drawdowns and do not exhibit the September freshening. By water year's end, the U-P model still estimates a 30 km difference in X2 position between the years, indicating that significant carryover can exist from one water year to the next in the managed estuary/watershed system.

Conclusions

Three recent water years provide a picture of how different freshwater inflows can affect the Bay. Surprisingly, very different flows can have similar effects as with the maximum X2 displacement. However, the timing of flows is of critical importance to the timing of the maximum displacement and the subsequent relaxation up-estuary. Further study should reveal which particular characteristics of the seasonal flow pulse most strongly affect Bay water quality. Also, a comprehensive examination of upstream hydrology and management constraints should provide more accurate water quality forecasts. These considerations point the direction for future work.

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Effects of Delta Outflow and Local Streamflow on Salinity in South San Francisco Bay: 1995-1998

Larry Schemel (USGS)

In their article on simulated salinity for 1998 and other years, Knowles and others (this issue) showed how variations in Delta outflow can control the position of X2 in the North San Francisco Bay and affect bay-wide salinity distributions (Figure 1). In this article, field measurements for 1995-1998 show the influence of Delta outflow on salinity in South San Francisco Bay, and also show the effects of discharge from local streams.

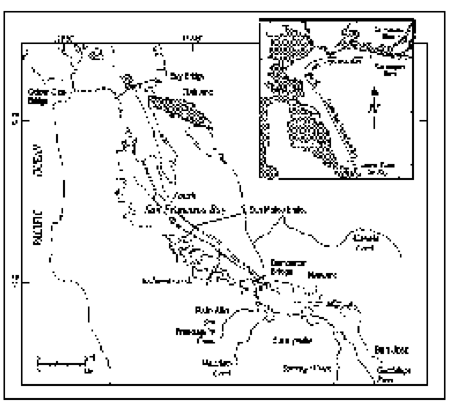

Figure 1. Map showing the San Francisco Bay estuarine system and selected features and locations in South San Francisco Bay.

Daily mean salinity at the Dumbarton Bridge and total (daily) discharge (note the inverted right-hand axis) from the local streams are presented in Figure 2. Peaks in discharge from the local streams coincided with immediate decreases in salinity at the Dumbarton Bridge. For example, record-breaking discharges from the Guadalupe River in March 1995 and San Francisquito Creek in February 1998 (flow values for 1998 are not shown) were largely responsible for abrupt decreases in salinity to the lowest values recorded in those years. However, discharges from local streams were typically short-lived, and subsequent mixing would have rapidly increased salinity at the Dumbarton Bridge without the bay-wide freshening caused by the more-persistent and higher-level Delta outflow.

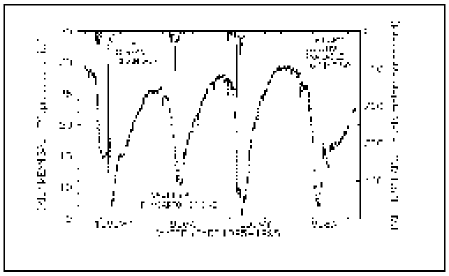

Figure 2. Daily mean values for salinity at the Dumbarton Bridge and the combined flow from local streams to South San Francisco Bay. Values for salinity were computed from measurements recorded at 15-minute intervals (1 m deep). Flow data are available from: URL http://waterdata.usgs.gov/nwis-w/CA. Information on the 1998 flood was obtained on 6/29/98 from: URL http://water.wr.usgs.gov/flood'98/11164500.html.

During all four winters, high Delta outflow caused lower salinities near the Bay Bridge compared to the summers when Delta outflow was lower (Figure 3). However, spring-summer patterns of Delta outflow were different among the years in this study. For example, a wet winter was followed by a very dry spring and summer in 1997, as pointed out by Knowles and others (this issue). Consequently, salinity near the Bay Bridge increased rapidly in early spring 1997, and it remained high much longer compared to 1995, 1996, and 1998.

The control of salinity near the Bay Bridge by Delta outflow also regulates the supply of sea salt to South San Francisco Bay. Low Delta outflow led to the rapid recovery of salinity to marine levels at the Dumbarton Bridge during spring and summer 1997. Highest salinity at the Dumbarton Bridge over the four-year record occurred in late summer 1997, which coincided with the longest period of high salinity near the Bay Bridge. In contrast, salinities in early September 1998 at the Dumbarton Bridge and near the Bay Bridge were very low compared to the late-summer values in 1995-1997. The low salinities at both locations in 1998 most likely resulted from the persistence of seasonally-high Delta outflows through the summer months.

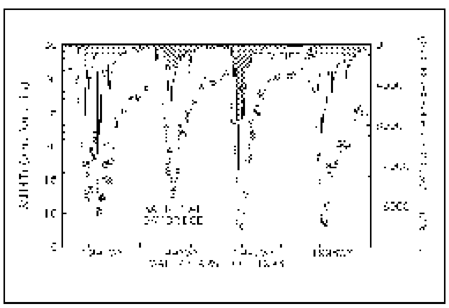

Figure 3. Salinity at the Bay Bridge and daily mean values for delta outflow. Salinity values (2 m deep) are available from: URL http://sfbay.wr.usgs.gov/access/wqdata/index.html. Delta outflow values computed by the DAYFLOW program for 1995-1997 water years were obtained on 2/18/98 from: URL: http://www.cd-eso.water.ca.gov/~dfriend/dayflow/doc.html. Delta outflow index values for 1998 are available from URL http://wwwoco.water.ca.gov/cmplmon/reports/hydro.html.

- ## Progress in Modeling Salinity Impacts of Suisun Marsh Levee Breaches

Chris Enright, Kate Le, Kamyar Guivetchi, DWR

Introduction

The DWR and USBR expended $1.1 million for emergency repair of private levees at 11 sites along Grizzly Bay, Honker Bay, Montezuma Slough, Suisun Slough, and Cutoff Slough that were breached during the February 1998 Suisun Marsh Flood. The DWR and USBR decided to participate in the levee repairs for three reasons: 1) to protect DWR/USBR infrastructure in the Marsh; 2) to meet Suisun Marsh water quality standards and, 3) to protect Suisun Marsh and delta water quality. The implicit assumption in reason 3, that breached Marsh levees will lead to higher Bay and delta salinity, is the topic of this article.

Background:
The February 1998
Suisun Marsh Flood

Spring tides, low barometric pressure, storm winds, and El Niño ocean conditions combined to breach or overtop levees at over 60 locations in the Suisun Marsh in February 1998. Exterior levees along Grizzly Bay, Honker Bay, and Lower Sacramento River sustained 11 major breaches of approximately 100 feet each. Over several days, about 22,000 of the 57,000 acres of the managed wetlands in Suisun Marsh were inundated. The tidal prism in the Marsh was expanded by about 85,000 acre feet, roughly 40% of the volume of Suisun Bay by comparison. DWR and USBR repaired the 11 exterior levee breaches at a cost of about $1.1 million to protect approximately $80 million program/infrastructure, maintain the ability to meet Suisun Marsh salinity standards and protect Suisun Marsh and Delta water quality.

The DWR Suisun Marsh Planning Section conducted a hydrodynamics and salinity modeling analysis to evaluate the potential impacts on the Marsh and delta if the Suisun Marsh levee breaches were not repaired. Our expectation was that the increased tidal prism created by the additional inundated lands would generally increase mixing of ocean salt into the Bay and delta. The actual response was more complex, if not surprising.

Approach for Modeling the
Impact of Suisun Marsh
Levee Breaches

Our approach to modeling this problem was guided by a goal to determine the long-term impacts of not repairing the exterior Marsh levees. We simulated historical hydrology, facilities configurations, and project operations for the four year period between October 1991 and September 1994. This approach provides enough time for the salinity response to propagate through the system, and affords the opportunity to examine impacts for three dry years and one wet year.

We also examined the sensitivity of the salinity response to breach size, location, and extent of inundated area because we recognized that the geometry of the levee breaches would influence the salinity response. If, for example, the eleven, 100-foot breaches had not been repaired, they would likely grow much larger over time. We therefore simulated two breach configurations:

- Run 1: Simulate the February 1998 Suisun Marsh flood as eleven breaches, each 100 feet wide, by 10 feet below MLLW.
- Run 2: Simulate expanded breaches comprising between 10% and 40% of the exterior levee perimeter (similar to Frank's Tract).

We conducted two additional four-year simulations using the same breach configuration approach for a hypothetical levee failure on the San Joaquin River side of Sherman Island. Run 3, simulates a single, 100-foot breach. Run 4 simulates a wide (15,000 feet) breach. Runs 3 and 4 were done to confirm that the model is providing similar results compared to Sherman Island flood simulations done in the past.

Preliminary Findings

Due to space limitations, only results at Jersey Point (Figure 1), Rio Vista (Figure 2), and Old River at Rock Slough (Figure 3) for water year 1992 are presented. Each plot contains four panels, A through D, depicting results for Runs 1 through 4.

Run 1: 1998 Suisun Marsh Flood

- Salinity is increased in western Suisun Bay, but reduced in eastern Suisun Bay and the delta (Figures 1A, 2A, 3A).
- The tidal range is reduced up to one-half foot along the axis of the estuary and the average water level is reduced in the delta

(these plots are not shown here).

Over half of the inundated area volume is exchanged through the levee breach on each tide (plots not shown).

Run 2: Extensive Suisun Marsh levee breaches

- Increasing levee breach width allows increased salinity intrusion in the Bay and West Delta. The north and South Delta still experience salinity reduction (Figures 1B, 2B, 3B). Therefore, the salinity response is dependent on the configuration of the hydraulic connection between Suisun Bay and inundated areas.
- The tidal range is reduced up to two-thirds foot along the axis of the estuary (plots not shown).

Run 3: 100-foot breach on the San Joaquin River side of Sherman Island

- Marginal reductions of salinity are observed west of Sherman Island (plots not shown)
- Significant increases in salinity are observed in the Delta (Figures 1C, 2C, 3C).

Run 4: 15,000-foot breach on the San Joaquin River side of Sherman Island

- Marginal (though larger than Run 3) reductions of salinity are observed west of Sherman Island (plots not shown).

Very large increases in salinity are observed in the Delta (Figures 1D, 2D, 3D).

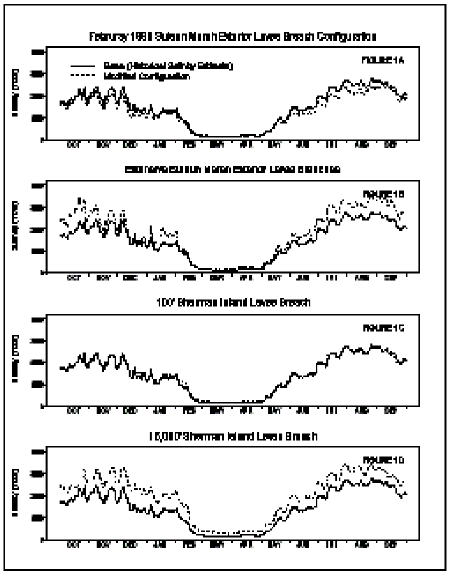

Figure 1. Jersey Point--1992. Historical Simulation of Mean Tidal Day Salinity.

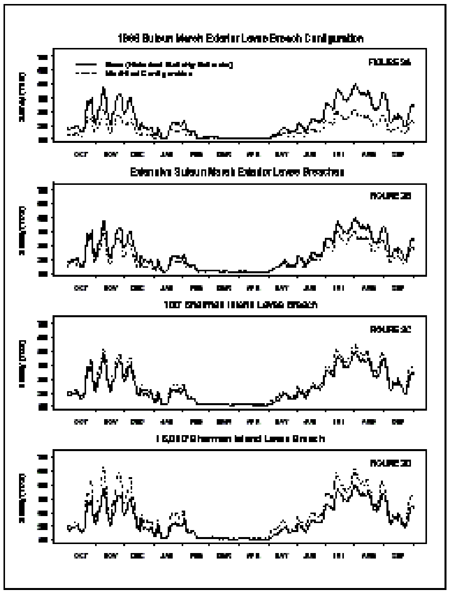

Figure 2. Rio Vista--1992. Historical Simulation of Mean Tidal Day Salinity.

Possible Mechanisms

We believe that the observed salinity response reflects a complex (nonlinear) balancing between friction, bathymetry, tidal prism, and tidal range/tidal excursion. There are two competing tendencies acting on upstream advancing tidal waves: First, tide heights tend to be reduced by shallow water and constriction friction losses. At the same time, tide height can be amplified when the tide is forced up through constrictions or shallow water.

For example, Carquinez Straight and the levee breeches themselves tend to force up water levels, but energy is dissipated in the process. The importance of each tendency at a particular location is a function of bathymetry, friction, and water levels everywhere else. Amplified wave height at one location may result in dissipated wave height elsewhere.

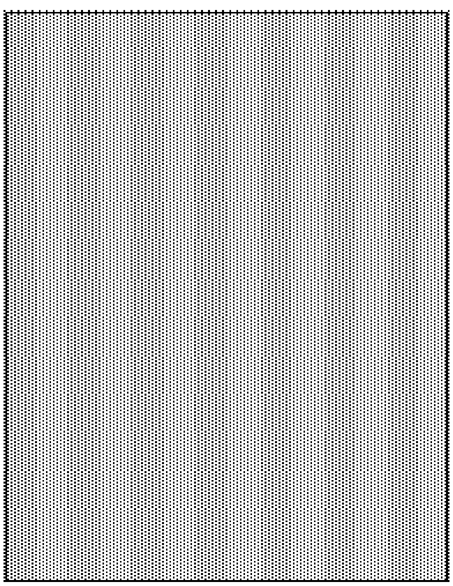

Figure 3. Old River at Rock Slough--1992. Historical Simulation of Mean Tidal Day Salinity.

The large inundated area behind Suisun Marsh levee breaches may be absorbing some of the finite tidal energy propagating from the Golden Gate. The Marsh "captures" some of this energy and dissipates it in the new shallow baylands. Consequently, the tidal energy that remains to propagate into the Delta is lower which results in reduced tidal range and diminished tidal excursion of particles and salt. The net outcome is reduced tidal dispersion of salt in the delta.

Modeling Analysis In Progress

The one-dimensional model that we used for our analysis (DWRDSM1 Suisun Marsh Version) is likely inadequate for accurate estimates of the magnitude of the salinity response observed. However, we believe the model is simulating the direction of the response properly. We are collaborating with hydrodynamics/modeling experts from the USGS, DWR, and UC Davis to verify our results. We are also pursuing analysis with higher dimensional models. Our preliminary results have been shared with the CALFED Levees and Channels committee, and a report summarizing our results will be submitted to the CALFED Bay-Delta Program in October 1998.

UC Davis Fish Treadmill Investigations Update

Ted Frink and Shawn Mayr, DWR
Christina Swanson, Paciencia S. Young, and Joseph J. Cech, Jr., Department of Wildlife, Fish, and Conservation Biology, UC Davis
Bob Fujimura, DFG
M. Levent Kavvas, Department of Civil and Environmental Engineering, UC Davis

A comprehensive investigation of juvenile and small-size delta fishes' swimming ability and behavior during exposure to complex flow regimes in front of a simulated large screened diversion is being conducted at the UC Davis Hydraulics Laboratory. The experimental apparatus, designed and constructed to simulate a delta or on-river screened diversion, is referred to as the "fish treadmill." Interagency personnel from DWR Environmental Services Office and DFG Bay-Delta Special Water Projects Division, and the UC Davis Fish Physiology research group and the UC Davis Hydraulics Laboratory engineering staff conduct the cooperative studies. NMFS, USBR, and outside consultants from the Washington State Department of Fisheries and Alden Research Lab in Massachusetts provide consultation on the project.

The Fish Treadmill is a large diameter (20 ft) circular flume with a 13-ft diameter annular swimming channel created by a rotating 5/32 inch perforated plate screen. A 9-ft diameter fixed stainless steel vertical wedge wire inner screen (3/32 inch) simulates a diversion facility in a delta or riverine system. The swimming channel created between the rotating outer and fixed inner screens is 2 ft wide and 1.1-1.5 ft deep, providing enough room for fish to escape from close encounters with the screen surface if they choose to do so. The fish treadmill's design can impart various sweeping flows and approach velocities at the screen surface that mimic flow conditions at screened diversions constructed with the flat-plate vertical wedge wire screen. More details of the fish treadmill configuration can be found in an earlier IEP Newsletter by D. Hayes (Winter 1997, Vol. 10(1):16-18).

The fish treadmill is designed to provide controlled flow, temperature, and light conditions in clear water to allow continuous detailed observation and videotape recording of fish behavior and performance during the experiments. Within the swimming channel, approach (i.e., the flow perpendicular to the fish screen) and sweeping (i.e., the flow parallel to the fish screen) flows can be established and controlled independently. Experiments are being conducted at combinations of three approach flows, 0.2, 0.33, and 0.5 ft/s, and three sweeping flows, 0, 1.0, and 2.0 ft/s, and at a control flow condition (0 ft/s). For all the flow regimes, experiments are conducted at two seasonal temperatures (12C in the winter and spring, and 19C in the summer and fall), and during the day under lighted conditions, and during the night under dark conditions. In night/dark experiments, fish are observed and video recorded using infra-red sensitive goggles and cameras. More details regarding the experimental objectives, design, methods, and potential applications of the results for development of fish screen criteria are described in the accompanying article by Swanson et al. in this issue.

Biological tests using the fish treadmill have been ongoing since late 1997 with no unresolved problems in equipment or, until recently, fish availability. To date, more than 160, 2-hour long experiments using delta smelt (day/light conditions, 12 and 19C), splittail (day/light and night/dark, 12 and 19C), and chinook salmon (day/light and night/dark,12 and 19C) have been completed. In some experiments with large fish (species to date, chinook salmon and splittail, 6-8 cm SL), blood chemistry analyses are being conducted to evaluate stress responses of fishes tested in different flow regimes. Presently experiments with delta smelt (night/dark, 19C) and juvenile American shad (day/light, 19C) are being conducted, although field collection of adequate numbers of these species has been difficult. Experiments with large splittail (6-8 cm SL, day/light, 19C, with blood samples taken for measurement of stress) are also currently in progress.

In January 1998, UC Davis prepared and distributed for review a progress and status report of the previous year's research efforts and preliminary results of the 1997 fish treadmill experiments. It also included a preliminary schedule for continuing research beyond June 30, 1998, when the original contract expired. The report was distributed to interested agency personnel, cooperating agencies, and the program consultants. Some copies are still available through DWR's Environmental Services Office (contact Ted Frink at tfrink@water.ca.gov).

Earlier this year, the Technical Advisory Group for the fish treadmill project submitted a draft proposal, developed by the UC Davis researchers, to DWR to fund continued research. The proposal was distributed for review to Interagency personnel and program consultants. On June 17, 1998, DWR convened an annual review meeting with program consults, Mr. Ken Bates (Washington State Department of Fisheries), Mr. Ned Taft (Alden Research Lab), and Mr. Rick Wantuck (NMFS) to review the program and discuss current and future research directions of the fish treadmill project. The California Department of Fish and Game, which has provided continued review, guidance, and hands-on assistance during the program, contributed additional review and comments to the proposal. In conjunction with this meeting, comments were solicited from the consultants on the draft proposal for continued research. Based on comments and suggestions offered during this meeting and by other interested Interagency personnel, the proposal was revised and resubmitted to DWR late this summer. In August, funding was approved for an additional year of research.

Ultimately, results of this comprehensive research effort examining the effects of exposure to complex flows and a fish screen on the behavior, swimming performance, sublethal physiological responses, and survival of delta fishes will provide guidance in the design and operation of fish screens that are more "fish friendly."

- ## Swimming Performance, Behavior, and Physiology of Delta Fishes in Complex Flows Near a Fish Screen: Biological Studies Using the Fish Treadmill

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UC Davis Fish Physiology and Hydraulics Engineering Groups and collaborating biologists from DWR and DFG are currently conducting research on the swimming performance, and behavioral and physiological responses of juvenile and small-size delta fishes exposed to complex flow regimes in front of a fish screen using the fish treadmill. In this article we describe the objectives, experimental design, and methods used in these biological studies, and discuss potential applications of the results for development of flow and operational criteria for large diversion fish screens. The present status of ongoing fish treadmill experiments is described in the accompanying article by Frink et al. in this issue. In subsequent issues of the IEP Newsletter, we will present and discuss preliminary results from our fish treadmill experiments, as well as results of complementary biological studies using other systems.

The Fish Treadmill

The fish treadmill, located at the UC Davis Hydraulics Laboratory, is designed to simulate a large delta or on-river screened diversion and to allow collection of detailed quantitative data on fish performance, behavior, physiological responses, and survival under controlled flow and environmental conditions. This complex apparatus is described in an earlier IEP Newsletter article (Hayes, 1997). For the biological studies, the test section of the fish treadmill is a screened annular swimming channel, 13 ft (4 m) in outside diameter, 2 ft (0.6 m) wide, and 1.1-1.5 ft (0.3-0.4 m) deep. Figure 1 shows a top view of a portion of the swimming channel. The inner screen (9 ft or 2.8 m diameter) is the simulated fish screen. To small fishes in the apparatus, the large radius, round design simulates a "flat" fish screen of indeterminate length. Within the swimming channel, two flow vectors, the approach flow (perpendicular to the inner screen) and the sweeping flow (parallel to the screen), can be controlled independently.

Objectives and Experimental Design

The objectives of the fish treadmill studies are to quantitatively evaluate and compare the performance (e.g., survival, impingement), behavior (e.g., swimming velocity and orientation, distance traveled), and physiological responses (e.g., sublethal stress) of small delta fishes exposed to two-vector flows, including those representing present fish screen criteria, near a fish screen under a variety of environmental conditions. Results will be compared with those from other fish screen studies (e.g., Kano, 1982) and used to further refine design, flow, and operational criteria for existing and proposed large screened facilities.

While a number of delta fish species are thought to be adversely affected by screened barriers, priority for the fish treadmill experiments is: (1) delta smelt juveniles and adults, (2) splittail young-of-the-year, and (3) chinook salmon parr and smolts. Depending on season and availability of adequate numbers of fish, alternate test species include steelhead parr and smolts, American shad young-of-the-year, striped bass young-of-the-year, and longfin smelt. For each of the species, experimental priority is for the small sizes thought to be most vulnerable to entrainment. Table 1 outlines the experimental variables and protocols under which these species are being or will be tested in the fish treadmill.

Measurements

Fish performance and behavior are measured during the experiments by visual observation, after the experiments (e.g., post-experimental survival), and from video taped records of each experiment. In some experiments with larger fish, blood will be collected from randomly selected fish at several post-experimental times to assess sublethal physiological responses to exposure to the flow treatment and fish screen. Table 2 outlines the different types of measurements made for each experiment.

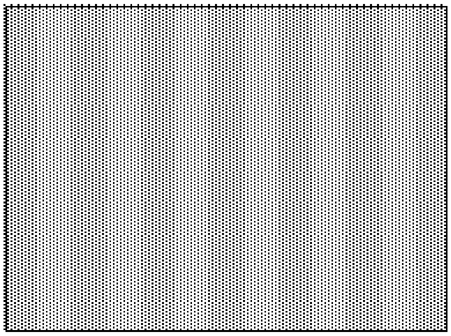

Figure 1. Top view of the fish treadmill swimming channel as seen through one of the video cameras. The outer rotating screen is at top, the inner fixed screen simulating the fish screen is at bottom. Arrows indicate the directions of the approach, sweeping, and resultant flow vectors.

Potential Applications of Results

Fish screen design, flow, and operational criteria have been developed from a variety of data types, most commonly swimming endurance (Bates, 1988; Clay, 1995), screen retention rates (Margraf et al., 1985; Young and Cech, 1997), and survival following exposure in screened flumes (Kano, 1982). We suggest that the utility of these types of data for developing effective screen criteria is limited, particularly for small, less active fishes like delta smelt (Swanson et al., 1998). For example, swimming endurance results have been used to test the ability of the fish to escape entrainment, but they cannot reliably predict the actual performance or behavior of the fish in the complex flow regimes typical near fish screens. Survival studies may provide an easily interpreted result but, in the absence of concurrent observations on behavior, they offer few insights into the causes or timing of mortality and thus provide little information to suggest design or operational changes that might improve fish protection.

Table 1. Experimental Variables and Protocol Used in the Fish Treadmill Experiments

Flow (ft/s)	*Approach*	*Sweeping*
	0 (control)	0 (control)
	0.2 (6 cm/s)	0
(10 flow treatments, one control and nine experimental)	0.33 (10 cm/s)	0
	0.5 (15 cm/s)	0
	0.2	1.0 (31 cm/s)
	0.33	1.0
	0.5	1.0
	0.2	2.0 (62 cm/s)
	0.33	2.0
	0.5	2.0
Temperature	12°C: winter and spring	
	19°C: summer and fall	
Time of Day/ Light Level	Day, light level: 200-300 lux Night, light level: 0-1 lux	
Fish Size	small: <6.0 cm SL	
	medium: 6.0-8.0 cm SL	
Number of Fish per Experiment	20	
Experiment Duration	2 hours	(All fish used only one time in the fish treadmill experiments)
Post-Experimental	48 hours	(Some fish sampled for stress responses during the post-experimental period)
Replicates per Treatment	3 replicates	

The experimental design and suite of biological measurements made during each fish treadmill experiment are intended to help build a comprehensive understanding of how fishes perform and behave during and after exposure to realistic multi-vector flows near a screened barrier. The results will provide multiple and complementary types of data that have direct application to several aspects of fish screen design and operation, including approach velocity criteria, sweeping velocity criteria, spacing between fish bypasses, differential design and/or operation for different species, and differential operation under different environmental conditions (e.g., day vs. night operation). With these data, we are developing general linear statistical models to quantitatively relate aspects of fish performance (e.g., survival) and behavior (e.g., screen passage times) in the fish treadmill to approach and sweeping flow, environmental conditions (e.g., temperature, light level) and other behavioral and physiological response variables (e.g., screen contact rates, swimming velocities, rheotaxis, plasma cortisol concentrations). Unlike many earlier studies, these experiments will provide information useful to improve both fish protection and fish passage. Some examples of potential applications of fish treadmill results are described below.

Data on survival will provide immediate information on tolerable and intolerable flow conditions. Concurrent measurements of impingement, screen contact, and injury rates will provide complementary information on the proximate causes and timing of screen-related mortality, yielding information potentially applicable to design features like screen length, spacing between fish bypasses, and maximum allowable screen exposure duration. However, tolerable flow conditions with 100% survival may not necessarily be equally effective for either fish protection or passage (e.g., if anti-predator behavioral responses are compromised). Optimal screen flow criteria should minimize screen contacts and sublethal stress, and maximize passage efficiency. Even temporary contact with the screen or prolonged exposure to the diversion-induced flow regime may be injurious or stressful to fishes. Sublethal stress can affect the short-term performance of fishes (e.g., swimming capacity, ability to avoid impingement; Strange and Cech, 1992) and, over a longer period, can impair growth, resistance to infectious diseases, and reproductive success and survival (Wedemeyer et al. 1990; Schreck, 1991) and adversely affect fish populations. The relationships (including statistical interactions) among impingement and screen contact rates, stress, and approach and sweeping velocities can be used to determine the flow combination that minimizes contact between the fish and screen and/or fish stress. Information on fish swimming velocities, rheotaxis, and swimming location relative to the screen can be used to determine the velocity combination that facilitates screen passage, predict passage times at specific flow combinations and/or under specific conditions (e.g., day vs. night), and provide additional information on screen lengths and distances between fish bypasses. For example, fish swimming rheotactically (i.e., into the resultant water current from the approach and sweeping current vectors) while being swept past the screen at 1.2 ft/min (37 cm/min) may show fatigue after 1.2 hours (72 min) exposure to the flows. Fatigue may be evi-

Table 2. Measurements Made During Each Fish Treadmill Experiment

Measurement Type	Definition	Method
Performance		
Impingement	prolonged (>5 mim) contact with screen	measured visually throughout experiment
Screen Contact	temporary contact with screen	measured visually throughout experiment
Survival	-----------------	measured at 0 and 48 h post-experimental
Injury	damage to skin, scales, fins, eyes	measured 48 h post-experimental
Behavior		
Swimming velocity		
over the ground	cm/s, velocity past screen	measured using computer-assisted motion analysis of video tapes
through the water	cm/s, swimming velocity	measured using computer-assisted motion analysis of video tapes
Orientation (rheotaxis)	orientation relative to resultant current	measured using computer-assisted motion analysis of video tapes
Distance from screen	distance (cm) from inner fish screen	measured using computer-assisted motion analysis of video tapes
Schooling	distribution of fish in swimming channel	measured visually throughout experiment
Physiological Responses		
Plasma cortisol concentration		
Plasma pH		
Plasma lactate concentration		measured from pooled blood samples collected from randomly selected fish at selected times post-experimental
Plasma glucose concentration		
Plasma chloride ion concentration (or osmolality)		
Hematocrit		

dent from numerous screen contacts or impingements (fish treadmill visual observations), changes in swimming gait from continuous swimming to intermittent bursts (fish treadmill motion analysis from video tapes), or elevated post-experimental plasma lactate concentrations (fish treadmill physiological responses). During this 1.2 hour period, the fish is swept 86.4 ft (27 m) along the screen. If effective fish bypass structures for this species (and size class) can be incorporated into this screen design, then they should be placed at <86.4 ft intervals. Incapacitated fish (e.g., subjected to fatigue or injury) are more susceptible to predation (Gadomski and Hall-Griswold, 1992).

Fish treadmill experiments are ongoing. We encourage interested people to contact us, visit the facility, and observe experiments in progress.

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- ## Salmon Stock Origin as Determined by Otolith Geochemistry

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Introduction

In California, chinook salmon (or king salmon) mature in the Pacific Ocean and migrate through San Francisco Bay estuary to spawn in the streambed gravels of the Sacramento and San Joaquin river systems. Chinook salmon are native to the estuary and have been fished by native Americans in San Francisco Bay for thousands of years. Over the past 150 years, hydraulic mining, dam construction, water diversion, and land-use changes in the Central Valley have significantly reduced the salmon spawning habitat (Gilbert, 1917; Nichols et al., 1986). These alterations of the estuary and its watershed (which is 60% of the area of California), have caused a dramatic decline (up to 70% decrease) in the migration of adult salmon to streams for spawning (Fisher, 1994). As a result, the winter run salmon population is critically low and listed as both a State and federal endangered species (Kope and Botsford, 1994). The spring run salmon is listed as a State threatened species (DFG, 1987; USFWS, 1987). Only the fall run is abundant, possibly because it is supported by five hatcheries, which were established to offset the decline in the number of naturally-spawning salmon in the Sacramento-San Joaquin watershed. Knowledge of the geographic distribution of threatened and endangered salmon species within the watershed is critical for implementing policy to offset their decline. For example, to decrease the impact of delta pump mortality on endangered salmon, pumps in the delta are turned-off after entrainment of a certain number of individuals.

There are four genetically distinct runs designated by the season in which they enter fresh water to spawn: a fall run that enters fresh water during July through November, a late-fall run that moves upstream during October through February, a winter run that moves upstream during January through June, and a spring run in the Sacramento River that moves upstream during March through July. These salmon runs also appear to migrate to distinct streams to spawn. After hatching, the young salmon (smolt) move downstream and through the delta and estuary to the Pacific Ocean. The four salmon races are currently distinguished using their size, and timing of out-migration. These criteria are considered relatively inaccurate. Genetic characteristics are also being explored for distinguishing between salmon races.

Here, we report a new technique for evaluating the origin and movement of juvenile salmon stocks by examining the geochemical and Strontium (Sr) isotopic compositions of their otoliths (aragonitic ear bones). The approach used in this study relies on the natural geographic variation of trace elements and Sr isotopes as markers for salmon stock that migrate through the San Francisco Estuary and Delta.

Background

Otoliths are stone-like (not bone, not vascularized) carbonate structures that are located in the inner ear of teleost fish. During the first months of development, diurnal changes in carbonate deposition make daily bands visible. Later, daily bands are no longer visible, but annual bands develop, allowing for accurate aging of fish. Chemical analysis of individual bands of an otolith can potentially reveal information on a fish's life history, including movement and habitat use. Previous studies have shown the Sr concentrations in adult otoliths vary systematically, with lower concentrations in the center, reflecting lower Sr concentrations in river waters (~30-120 ppb), and higher concentrations around the outer surface, reflecting higher Sr concentrations in seawater (8 ppm). These results suggest that the otoliths retain their original chemical and isotopic composition (Gauldie et al., 1991; Koch et al., 1992; Kennedy et al., 1997) rather than being affected by replacement during the life of the salmon. In this study, we are testing the feasibility of using Sr isotopic compositions and trace element concentrations of juvenile salmon otoliths and waters from the San Francisco Bay watershed to determine salmon stock origin.

Moving south from the Lassen area, along the western slope of the Sierra Nevada, the surficial geology varies from younger volcanic rocks, to a mixture of volcanic, sedimentary, and batholithic rocks, to primarily batholithic rocks in the Yosemite region. These rock types differ in both the chemical composition and also the rate at which they erode. Agriculture also appears to increasingly alter water chemistry approaching the Sacramento-San Joaquin Delta. Mining and other industrial activities may also have localized effects. To use trace elements and Sr isotopes in tracing salmon origin and migration, several criteria must be met: 1) freshwater sources in different drainages and tributaries have distinct geochemical signatures, 2) the geochemical signatures of the salmon otoliths reflect the ambient water, and 3) these geochemical signatures remain fixed in the otolith.

Starting in July 1997, we began a collaborative project with the California Department of Water Resources (DWR) to determine if otolith chemistry can be used to reconstruct the origin and movement of juvenile chinook salmon through the Sacramento and San Joaquin river systems during their out-migration. Better understanding of the patterns of movement of individual runs could be used to improve the management of threatened and endangered runs.

Water and Salmon Sampling

River waters were sampled from the primary spawning streams within the Sacramento and San Joaquin drainages, including the Merced River, American River, Feather River, Mokelumne River, the mainstem of the Sacramento River, Tuolumne River, Deer Creek, Battle Creek, and Mill Creek (Figure 1). Waters from five hatcheries were also sampled to allow direct comparison with the juvenile salmon otoliths taken from hatchery fish. The delta was sampled at two sites. All waters were collected in acid-washed 0.5 or 1.0-liter bottles, by DWR. Water sampling began October 1997 on a monthly basis to assess the potential effect of seasonality on the 87Sr/86Sr ratio and trace elements in the waters.

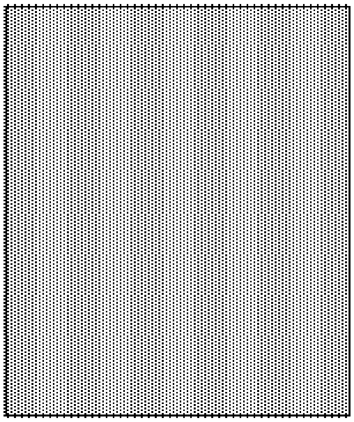

Figure 1. Map of Central and Northern California showing drainage area for San Francisco Estuary, major salmon spawning rivers, and reservoirs. Collection sites of river and hatchery waters and juvenile salmon are also shown.

Juvenile salmon were initially selected from hatcheries located along the Merced River, American River (Nimbus Hatchery), Feather River, Mokelumne River, and Battle Creek (Coleman Hatchery). Multiple otoliths from the same hatchery were provided by DWR for analysis (3-10 otoliths per hatchery), to test the homogeneity of their isotopic ratios. Additional otoliths are being analyzed as available.

Water Analysis for Trace Elements

Water samples are being analyzed with an inductively coupled plasma mass spectrometer (ICP- MS) for trace elements, and an inductively coupled plasma atomic emission spectrometer (ICP-AES) for major elements, both located at the Lawrence Berkeley National Laboratory. Twenty-two elements have been detected in the water samples, nineteen of which are in measurable quantities for at least one site. The initial results indicate that there is sufficient difference between the rivers and confluences of interest to be able to differentiate based on water chemistry. The elements of particular interest are those that can substitute for calcium in the otolith structure and are present in relatively high concentrations: Sr, Ba, Mn, and Mg (Figures 2, 3, 4 & 5). For example, the Tuolumne and Merced rivers have similar trace element signatures, but the Merced River has twice the concentration of Ba. These two rivers are differentiated from the other sampling locations in this study by their very low levels of Sr. The delta sites have generally higher levels of trace elements, but the southern sampling site, where the San Joaquin River enters the delta, has higher levels of Mn, associated with the levels seen in the Tuolumne and Merced rivers. In the North, Butte, Mill and Deer creeks each have distinct signatures, with Mill Creek displaying the highest levels for Sr and Mn in particular, and Butte having the lowest Ba concentrations. These data show that there are seasonal trends. These trends will be studied to determine if they can be used to differentiate between juveniles hatched at the same location but at different times of the year.

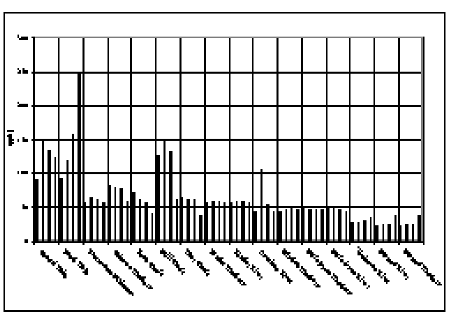

Figure 2. Strontium, Oct. 1997 - Jan. 1998

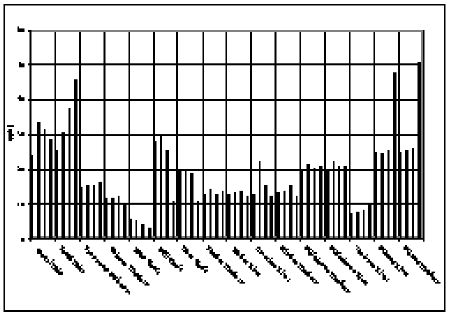

Figure 3. Barium, Oct. 1997 - Jan. 1998

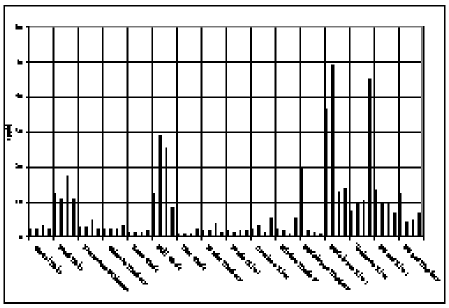

Figure 4. Manganese, Oct. 1997 - Jan. 1998

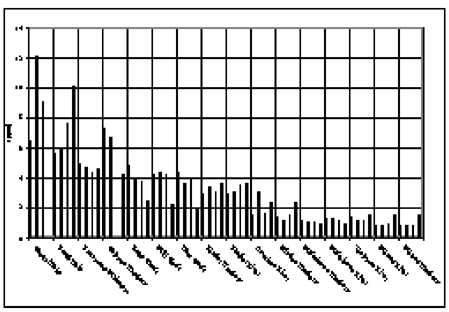

Figure 5. Magnesium, Oct. 1997 - Jan. 1998

Otolith Analysis for Trace Elements

Juvenile otoliths were mounted in epoxy and sectioned longitudinally to expose the nucleus and daily growth bands. The daily bands have been between 10 and 20 microns wide in the otoliths so far examined.

In situ trace element analysis is being performed with an ion microprobe located at the Lawrence Livermore National Laboratory. The beam can be narrowed down to 1 to 2 microns, allowing subsampling of daily growth bands. The ion microprobe has been successfully tested on several otoliths, showing variations across otoliths and between otoliths. These analyzes, however, are too preliminary to be present here because we are still in the process of developing standards for these samples. Initial calibration curves have been developed using calcite samples from the Geology Department at UC Berkeley.

Strontium Isotopic Analyses: Waters

Waters and otoliths were analyzed for 87Sr/86Sr ratios using mass spectrometry at the Center for Isotope Geochemistry at UC Berkeley.

River waters exhibit a large range of 87Sr/86Sr ratios and Sr concentrations. In general, the Sacramento drainage waters display lower 87Sr/86Sr ratios (0.7039 to 0.7066) than the San Joaquin River basin waters (0.7070 - 0.7085). In addition, streams are isotopically distinct within each drainage system. In the Sacramento drainage, the 87Sr/86Sr ratio of Feather River waters is between 0.70566 and 0.70662 (average = 0.70609). The Feather River Hatchery water had a 87Sr/86Sr ratio of 0.70602, very close to average Feather River water. Deer Creek and Mill Creek, both important spawning streams for the spring run salmon (Fig. 2), had the lowest river water 87Sr/86Sr ratios (0.70394 and 0.70423, respectively). The mainstem of the Sacramento River varied along is course, with lower values north of Shasta Dam (average = 0.70478) than south of Shasta Dam (average = 0.70640).

Within the San Joaquin River basin, 87Sr/86Sr ratios varied from high values in the lower Merced River (0.7085), to low values in the Mokelumne River (0.7067). The Tuolumne River had an average 87Sr/86Sr ratio of 0.70772, whereas the San Joaquin River had an average 87Sr/86Sr ratio of 0.70724, and didn't show significant variation along the course of the river. The Merced River showed the greatest variability in 87Sr/86Sr ratios, ranging from 0.7074 to 0.7085.

Sr concentrations were also distinct between the Sacramento and San Joaquin basins. The average Sr concentrations in the Sacramento basin were 59 ppb for the mainstem of the Sacramento River, 49 ppb for the Feather River. Within the San Joaquin Basin, Sr concentrations were 11 ppb for the mainstem San Joaquin, 15 ppb for the Tuolumne River, and 31 ppb for the Merced River. These results indicate that Sr concentrations and isotopic compositions are diagnostic for the Sacramento and San Joaquin river basins, and individual streams within these basins. The 87Sr/86Sr ratio can routinely be measured to 1 in 10-5. The variations between rivers range between several parts in 10-3, to several parts in 10-4.

River waters collected from the south and central delta showed elevated Sr concentrations (81 to 229 ppb), possibly due to the high input of irrigated waters from farms in the delta and central valley. This result suggests that delta water may have distinct chemical characteristics that may also be useful in determining the length of time the salmon inhabit the delta, which is important for assessing the effects other anthropogenic pollutants may have on the juvenile salmon prior to their passage to the ocean.

Strontium Isotopic Analyses: Otoliths

The 87Sr/86Sr ratios of juvenile salmon otoliths closely resemble the waters in which they were reared (Fig. 6). In addition, the five major hatchery salmon and waters have distinct Sr isotopic ratios, confirming that this technique will be particularly applicable to the Sacramento-San Joaquin drainage system. From the Sacramento River basin, otoliths from the Feather River Hatchery had 87Sr/86Sr ratios ranging between 0.70629 and 0.70640 (average = 0.70634). Coleman hatchery otoliths 87Sr/86Sr ratios ranging between 0.70511 and 0.70569 (average = 0.70545). From the Merced Hatchery, 87Sr/86Sr ratios ranged between 0.70851 to 0.70883 (average = 0.70866). Mokelumne River otoliths had 87Sr/86Sr ratios of 0.70640 to 0.70778 (average = 0.70759). Nimbus Hatchery fish had 87Sr/86Sr ratios ranging between 0.70975 and 0.70995 (average = 0.70986). From each hatchery, the 87Sr/86Sr ratio varied by several parts in 10-4. The 87Sr/86Sr ratios from two hatcheries (Battle Creek and Merced River) are lower than those of the ambient waters, by 0.0007 to 0.001. Also, a large spread in the otolith 87Sr/86Sr ratios from the Mokelumne River is apparent. The cause of these discrepancies may be due to the food and mineral supplements fed to the hatchery-reared fish, containing Sr with a different 87Sr/86Sr ratio than the ambient water. The effects of food source on the isotopic and chemical composition of salmon otoliths is presently being explored.

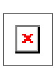

Figure 6. 87Sr/86Sr ratios of otoliths of juvenile salmon plotted against 87Sr/86Sr ratios of river and hatchery waters from five salmon hatcheries in the Sacramento-San Joaquin drainage.

These preliminary results suggest that the use of trace elements and Sr isotopes in the Sacramento-San Joaquin drainage may prove to be a promising new method for differentiating juvenile salmon races (and geographic origin of juvenile salmon) in the delta. Differentiating juvenile salmon races (particularly the wild salmon population) is important for understanding which environmental factors are impacting the salmon, which have suffered significant declines over the past decades in California.

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CALFED Comprehensive Monitoring, Assessment, and Research Program

Leo Winternitz and Collette Zemitis, DWR

The Comprehensive Monitoring, Assessment, and Research Program

The CALFED Bay-Delta program is proposing substantial changes to many aspects of the Bay-Delta/Central Valley environment and water management system. In order to monitor and assess the results of CALFED actions as well as identify and fund areas of needed research, CALFED has approved the development of a Comprehensive, Monitoring, Assessment, and Research Program (CMARP) (see article by Randy Brown in the IEP Newsletter, summer 1998). This monitoring and research program is critical to the CALFED adaptive management strategy, whereby CALFED resource managers and decision-makers will use information from CMARP to implement CALFED actions. This article provides an overview of the CMARP goals and tasks, as well as an update of the program's status.

CMARP Goals

The CMARP Stage 1 Report, developed by IEP, USGS, and the San Francisco Estuary Institute, lists CMARP goals and outlines a process for developing a monitoring and research plan by February 1999.

The goals of the Monitoring and Assessment Program are to:

1. Provide information to management on a continuing basis necessary to evaluate the effectiveness of program actions and to support ongoing adaptive management actions.
2. Describe conditions in the Bay-Delta and its watershed on appropriate temporal and spatial scales.
3. Evaluate trends in the measures of environmental conditions.
4. Identify the major factors that may explain the observed trends.
5. Analyze data and report results to stakeholders and agencies on a timely basis.

The goals of the Research Program are to:

1. Build an understanding of physical, chemical, and biological processes in the Bay-Delta and its watershed that are relevant to CALFED program actions.
2. Provide information useful in evaluating the effectiveness of existing monitoring protocols and the appropriateness of environmental attributes.
3. Test causal relationships among environmental variables identified in conceptual models.
4. Reduce areas of scientific uncertainty regarding management actions.
5. Incorporate relevant new information from all areas of research.
6. Revise conceptual models as our understanding increases.

CMARP Tasks

The CMARP Stage 1 Report also identified five major tasks needed to accomplish these goals.

Task 1: Identify Goals and Objectives

Identify the goals, objectives and needs of the CALFED Common Programs, (Ecosystem Restoration, Water Quality, Water Transfers, Water Use Efficiency, Watershed Management and Delta Levees) and related programs (Category III, Conservation Strategy and Indicators). Compile agency major program goals and objectives. Develop CMARP monitoring elements and a research program based on identified goals and objectives. This will be a continuing and iterative process.

Task 2: Develop a Conceptual Framework

Focus the development of explicit conceptual models for use in designing monitoring and research programs. Such conceptual modes are also useful for documenting the basis of earlier decisions on program design. This task is being accomplished in coordination with monitoring and research programs from Puget Sound, Chesapeake Bay, and South Florida.

Task 3: Monitoring Program Design

Comprised of five sub-tasks:

1. Inventory Existing Monitoring Programs
2. Develop Monitoring Elements (There are 6 elements and 13 sub-elements).
3. Develop a Process for Data Management
4. Develop a Process for Data Analysis and Monitoring
5. Develop and implement Category III Monitoring Institutional Process

Task 4: Design a CALFED Focused Research Program

This program will be designed to investigate causes and trends; reduce areas of scientific uncertainty and corroborate relationships in conceptual models.

Task 5: Develop an Institutional Structure for Monitoring, Assessment and Research

Identify functions of a CMARP predecessor; recommend how it should operate; how it should be funded; who it should be accountable to, and how it is related to CALFED.

CMARP Work Teams

In July and August 1998, the CMARP Steering Committee formed work teams to address the tasks. Participants on the work teams were chosen based on expertise in each of the subject areas. The work teams were charged with preparing draft conceptual models and monitoring and research proposals by September 30, 1998. Work was initiated with a CMARP Workshop on July 21, 1998. At the workshop, work team leaders and participants developed a "road map" for producing a comprehensive monitoring, assessment, and research plan.

As work on the monitoring plans progressed, participants were added to the work teams, and more and more work teams were formed. To date, there are thirty work teams with over two hundred participants. Some of the work teams and their objectives are listed below.

Bay-Delta Shallow Water Habitats and Watersheds Sub-Work Team

Objective: To identify the most valuable conceptual models, research questions, and field parameters to monitor the health of Bay-Delta shallow water habitats and watersheds.

River Resident Fish Work Team

Objective: To describe a long-term "ambient" monitoring program, to assess the distribution and relative abundance of river resident fishes, and to detect new introductions of exotic species. The program will be designed to identify presence/absence of all species and the relative abundance of a substantial subset of species.

Bay-Delta Salmon Work Team

Objective: To identify population and habitat use parameters for all races of Central Valley chinook salmon and steelhead in the delta, lower Sacramento River and tributaries, East side tributaries and bay for purposes of documenting life stage-specific responses (abundance, survival, growth, and distribution) to habitat restoration and management actions taken as part of CALFED.

Category III Monitoring Institutional Process Work Team

Objective: To determine if projects funded by CALFED have met their stated objectives and to provide guidance for assessing future rehabilitation needs.

Data Management Work Team

Objective: To develop an integrated database system that permits broad access to biological, water quality, and hydrodynamic and physical data from the Bay-Delta and its watershed. The intent of the CMARP database project is not to duplicate or replace the efforts of any entity involved, but to provide a comprehensive, integrated source of data for scientists and decision-makers.

Data Analysis and Reporting Work Team

Objective: To develop a process for data assessment and reporting, such that the all-important feedback about monitoring results is provided in technically sound, understandable reports released in a timely manner to managers, regulators, and the public.

Institutional Structure Development Work Team

Objective: To determine the attributes that clients, participants, and stakeholders of CMARP desire to have in the institutional structure that will manage the program, examine an array of potential structures based on examples both within the region and from other regions, and to make recommendations on what actions will be needed to achieve the desired institutional attributes.

This is a just a small subset of the complete list of work teams. There are also work teams developing water quality, water transfers, water use efficiency, delta levees, and watershed management monitoring plans, for example. Most of the work teams are using the participants' expertise. Other work teams, such as the data analysis and reporting work team and the institutional structure development work team, are also interviewing other ecosystem-level programs to get ideas for the California program.

CMARP Status

Draft monitoring plans are currently being submitted to the CMARP Steering Committee. CMARP staff and the Steering Committee are beginning the process of fitting the plans into a single, cohesive plan. At a facilitated workshop on October 20 and 21, team leaders were asked to assist the Steering Committee in the integration process. The Steering Committee will finish writing the plan, and public review will take place from late November to mid-December. Simultaneously, the Steering Committee will be holding informational public forums on the CMARP process with the first one scheduled on October 28 in Sacramento. This ambitious schedule is necessary to produce a final comprehensive monitoring, assessment, and research plan by the end of January 1999.

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Results from a Review of the IEP Project Work Teams

Zach Hymanson (DWR) and Chuck Armor (DFG)

The Interagency Ecological Program (IEP) Management Team (MT) initiated a programmatic review of the existing Project Work Teams (PWT) in December 1997 at the request of the IEP Coordinators. The MT recently completed its review, which will result in the cessation of two PWTs, rearrangement of three PWTs, and addition of three PWTs. This article summarizes the programmatic review completed by the MT and provides information on each of the PWTs currently within the IEP.

The concept and role of the IEP Project Work Team originated as one of several "structural solutions" identified in the 1993 review of the IEP (Herrgesell et al., 1993). The establishment of Project Work Teams within IEP was intended to improve cross-agency involvement at the project element level and provide a focused forum for detailed input and involvement of knowledgeable individuals. As stated in Herrgesell et al. (1993):

> Project Work Teams are established by the Management Team to implement one or more IESP [Interagency Ecological Study Program] elements. The teams are small, typically 3 to 6 people, working level groups consisting of members from agencies having a specific interest in the products of the team. Project Work Teams are intended to be "issue specific" groups which are established in response to specific information needs and their dissolution is planned for as part of their initiation... The interagency Project Work Teams will be actively and closely involved in element planning and the preparation and review of element products. The Project Work Teams are the source of proposed element work plans and budgets. Typically, individual IESP staff people will be assigned to more than one Project Work Team. Each Project Work Team will have a representative on the Management Team.

Prior to Management Team review and revision, the IEP organizational structure included 12 PWTs and one proposed PWT (Figure 1). Although not shown in Figure 1, the Central Valley Salmon Team served as the "parent" PWT to several "satellite" teams.

Figure 1. 1997 Organization of the Interagency Ecological Program for the Sacramento-San Joaquin Estuary.

For its review, the Management Team developed a questionnaire intended to evaluate the status and function of the existing PWTs (Figure 2). The questionnaire was sent to each PWT chairperson. Responses to the questionnaire along with input from PWT members and the MT representative to each PWT (summarized in Table 1) were all reviewed and discussed by the MT over several meetings. The MT used all of this information to evaluate the current PWTs and identify the following changes:

Figure 2. Questionnaire for PWT chairpersons and members.

- Suisun Bay Team. This team will no longer be considered a formal Project Work Team. This team was formed to oversee the entrapment zone studies completed between 1994 and 1996. The 1994 report is in final production and the 1995-96 report is in progress. Team members continue to meet as necessary to discuss/review the 1995-96 results.
- Delta Agriculture/Municipal Diversion Evaluation Team. This team will continue its work as one of the Project Work Teams under the newly formed Fish Facilities Coordination Branch of IEP (see Figure 3). Team membership will largely remain the same, although the team's scope and mission may change somewhat.

- Suisun Marsh Ecological Workgroup (SEW). The State Water Resources Control Board recommended DWR convene a technical workgroup, SEW, to develop recommended numerical salinity standards for the Suisun Marsh as a means to implement the Suisun Marsh narrative objective. A majority of the workgroup members are not involved in the IEP. The Management Team concluded it is not appropriate to consider this workgroup an IEP Project Work Team, given this workgroup's charge and composition. However, the IEP recognizes the importance of the SEW's work. A Management Team member will continue to serve as a liaison between IEP and SEW, and existing PWTs and individuals within IEP will continue to assist this workgroup as requested.
- Addition of new Project Work Teams. The Management Team reviewed and approved the formation of three new PWTs: 1) the Water Quality PWT; 2) the Hydrodynamics PWT; and 3) the Shallow-water Habitat PWT. Each of these new PWTs is briefly described below.

As a result of the changes made by the Management Team and approved by the IEP Coordinators, the IEP organization (excluding the Fish Facilities branch) currently includes ten Project Work Teams (two with satellite teams) (Figure 3). Each of the PWTs is briefly described below.

Central Valley Salmonid PWT. Chairperson: Randy Brown, DWR (rbrown@water.ca.gov). The mission of this PWT is to encourage, facilitate and coordinate: 1) development and implementation of monitoring programs that can be used to determine trends in abundance and distribution of key salmonid races and stocks as well as associated physical, chemical, and biological habitat variables; 2) development and implementation of special studies designed to help understand salmon life history strategies and to help determine causes of any significant changes in abundance and distribution; 3) establishment and maintenance of an electronic storage and retrieval system for monitoring and special studies data using a format that makes the data readily available to scientists, resource managers, and other interested parties; and 4) conversion of monitoring and special studies data into information and dissemination of this information in the form of journal articles, technical reports and presentations.

This PWT also serves as the "parent" team to nine satellite teams: 1) Delta Salmon Team, Pat Brandes, FWS (pbrandes@delta.dfg.ca.gov) chairperson; 2) Salmon DNA Team, Sheila Greene, DWR (sgreene@water.ca.gov) chairperson; 3) San Joaquin River Salmon Team, Tim Ford, TID (tjford@ainet.com) chairperson; 4) Upper Sacramento River Salmon Team, Jim Smith, FWS (Jim_smith@fws.mail) chairperson; 5) Steelhead Team, Dennis McEwan, DFG (102264.3050@compuserve.com) chairperson; 6); Winter Run Salmon Team, Gary Stern, NMFS (gary.stern@noaa.gov), and Ken Lentz, USBR (klentz@mp.usbr.gov), co-chairpersons; 7) Spring Run Team, Alan Baracco, DFG (abaracco@hq.dfg.ca.gov) chairperson; 8) Winter Run Captive Broodstock Team, Randy Brown, chairperson; and 9) Vernalis Adaptive Management Program (VAMP) Team, Pat Brandes, and Chuck Hanson, Hanson Environmental (chansonenv@aol.com) co-chairpersons.

Estuarine Monitoring PWT. Chairperson: Jeff McLain, FWS (jmclain@delta.dfg.ca.gov). The mission of this PWT is to: 1) develop, evaluate, implement and maintain a comprehensive estuarine and lower river monitoring program that will allow determination of trends in abundance of aquatic organisms; 2) ensure that compliance with established water quality standards is determined, all monitoring mandates are achieved and meaningful changes in water quality and population trends are identified; and 3) coordinate monitoring activities with other monitoring programs in the estuary.

Estuarine Ecology PWT. Chairperson: Wim Kimmerer, SFSU (kimmerer@mercury.sfsu.edu). The mission of this PWT is to improve the understanding of the ecosystem of the Bay-Delta estuary with emphasis on the mechanisms controlling the production, growth, and survival of estuarine fishes. The Estuarine Ecology PWT investigates these issues in two ways: 1) through individual study projects; and 2) through activities designed to foster collaboration among IEP and outside scientists, including peer review of IEP activities and reports and information exchange between IEP and the broader scientific community. The goal of these activities is to insure that the best possible science is being applied to management problems in the estuary.

Real Time Monitoring PWT. Chairperson: Kevin Fleming, DFG (kfleming@delta.dfg.ca.gov). The mission of this PWT is to provide information on delta fish distribution and abundance necessary to facilitate decision making regarding water project flexibility. In addition the information collected will be used to: 1) refine the logistics of collecting and processing data in a real time mode; 2) determine if the movement of chinook salmon smolts, delta smelt and splittail through the delta can be followed and predicted; 3) determine if the movement of fish and water are related and what factors may affect this relationship; and 4) determine if predictable relationships exist between catch in the sampling program and the salvage of fish at the CVP and SWP facilities.

Table 1. Summary of responses to PWT Questionnaire and Management Team Review

Project Work Team	*Is the PWT aware of the IEP mission and objectives?*	*Does the PWT have a mission statement & objectives?*	*Does the PWT hold regular meetings?*	*Does the PWT produce meeting notes? Are notes posted on the IEP Home Page?*	*Is PWT membership listed on the IEP Home Page?*	*Are PWT members satisfied with the group? Is the team relevant?*	*Does the PWT have a MT Representative?*	*Is continuance as an IEP PWT recommended?*	*Comments*
Central Valley Salmonid	Y	Y	Y	Y/N	Y	Y/Y	N	Y	1. Better communication between parent team and Management team is needed. 2. Management Team needs more information about satellite teams.
Estuarine Monitoring	N	Y	Y	Y/N	N	N/Y	Y	Y	1. Team members need dedicated time for participation. 2. PWT should produce a triennial report of monitoring programs. 3. PWT should become involved in CMARP conceptual modeling effort. 4. PWT should consider implications of an adaptive management strategy on monitoring programs. 5. Formation of a separate water quality PWT is recommended.
Estuarine Ecology	Y	Y	Y	Y/Y	Y	Y/Y	Y	Y	1. Need to increase fish biologist representation. 2. Need to improve project recommendation process.

Real Time Monitoring	N	Y	Y	N/N	N	Y/Y	Y	Y	1. Need to increase stakeholder involvement. 2. Completion of programmatic review may alter real-time monitoring program.
Contaminant Effects	N	Y	Y	N/N	N	Y/Y	Y	Y	1. Need additional ecologists/fishery biologists. 2. Contracting process is difficult. 3. Need to complete long-range plan.
Yolo Bypass	Y	Y	Y	Y/N	N	Y/Y	Y	Y	1. This is a single purpose team that will dissolve upon completion of Yolo Bypass studies.
Resident Fishes	N	Y	Y	Y/Y	Y	Y/Y	Y	Y	1. Improve Management Team feedback for project planning.
Delta Hydrodynamics Modeling	N	N	N	Y/N	N	Y/Y	Y	Y	1. Team could do more for IEP. 2. Team needs a Management Team representative. 3. Team should continue to increase interactions among biologists and hydrodynamisists.
Particle Transport Modeling	N	Y	N	Y/Y	Y	Y/Y	Y	Y	1. Team needs to develop long-term goals. 2. PWT should work more closely with Resident Fishes PWT. 3. Team should continue to increase interactions among biologists

									and hydrodynamisists.
Suisun Bay	N	N	N	N/N	N	Y/Y	N	N	1. Team is in final stages of completing its work. 2. A formal PWT is no longer needed.
Suisun Marsh Ecological Workgroup	N	Y	Y	Y/N	N	Y/Y	N	N	1. Team needs MT liaison. 2. Group will continue irrespective of IEP involvement.
Delta Ag/Muni Diversion Evaluation	N	Y	N	Y/N	N	Y/Y	Y	Y	1. PWT objectives need to be updated. 2. Membership change is needed. 3. Future of team to be determined based on fish facilities re-organization.
Hydrodynamics	n/a	Y	n/a	n/a	n/a	n/a	n/a	n/a	1. PWT is newly formed. 2. PWT will serve as "parent" to Delta Hydrodynamics and Particle Tracking teams.
Shallow-water Habitat	n/a	Y	n/a	n/a	n/a	n/a	n/a	n/a	1. PWT is newly formed.
Water Quality	n/a	Y	n/a	n/a	n/a	n/a	n/a	n/a	1. PWT is newly formed. 2. Will allow more focus on water quality monitoring and special studies.

Contaminant Effects PWT. Chairperson: Chris Foe, CVRWQCB (FoeC@rb5s.swrcb.ca.gov). The primary mission of this PWT is to acquire and disseminate information on the effects of contaminants on aquatic resources in the Central Valley and Estuary. In addition, the PWT provides comments and recommendations to decision-makers aimed at minimizing contaminant related effects on populations of aquatic organisms.

Yolo Bypass PWT. Chairperson: Ted Sommer, DWR (tsommer@water.ca.gov). The mission of this PWT is to examine the relationship between the Yolo Bypass and the rest of the estuary and to develop recommendations for restoration actions that would improve bypass habitat for fishes and other aquatic organisms. Specific questions this PWT hopes to address, include: 1) Does the bypass provide net benefits to fish; 2) if so, does the bypass provide native species with a competitive advantage over exotics; 3) is the bypass a net sink or source of zooplankton to the estuary; 4) what are the sources of organic carbon to the bypass and how much does it contribute to the estuary; and 5) what is the hydrology of the bypass?

Resident Fishes PWT. Chairperson: Larry Brown, USBR (lbrown@mp.usbr.gov). The mission of this PWT is to acquire biological and life history information on selected species of resident fish of the Bay-Delta estuary, and to disseminate that information to the public by way of PWT reports and publications in peer-review journals. In addition, the PWT provides services to decision makers that will result in minimizing impacts to selected resident fish as a result of water, land or channel projects in the estuary, and to maximize the effectiveness of any ecological restoration efforts undertaken in the delta on behalf of resident species.

Figure 3. Interagency Ecological Program.

Hydrodynamics PWT. Chairperson: Pete Smith, USGS (pesmith@usgs.gov). This is a new PWT formed to provide better overall planning and coordination of hydrodynamic studies of the estuary. The mission of this PWT is to develop a better understanding of the hydrodynamics of the San Francisco Bay-Delta Estuary to meet the needs of the IEP agencies. This PWT also serves as the parent team to two satellite teams: 1) the Delta Hydrodynamics Modeling Team, Rick Oltmann, USGS (rnoltman@usgs.gov) and Chris Enright, DWR (cenright@water.ca.gov) co-chairpersons; and 2) the Particle Transport Modeling Team, Tara Smith, DWR (tara@water.ca.gov) and Zach Hymanson, DWR (zachary@water.ca.gov) co-chairpersons.

Shallow-water Habitat PWT. Chairperson: Mike Chotkowski, DFG (mchotkow@delta.dfg.ca.gov). This is a newly formed PWT. The need for such a PWT was clearly demonstrated at a recent workshop on shallow-water habitat. Numerous studies, both inside and outside IEP, are currently underway to gather needed information. Further, restoration of shallow-water habitat is a cornerstone of the CALFED Ecosystem Restoration Program. The mission of this PWT is to develop and communicate a comprehensive understanding of shallow-water habitat ecology in the Sacramento-San Joaquin Estuary to meet the needs of IEP and its member agencies.

Water Quality PWT. Chairperson: Leo Winternitz, DWR (lwintern@water.ca.gov). This is a newly formed PWT. Previously water quality issues were mostly dealt with in the Estuarine Monitoring PWT, although some of the issues are periodically discussed in several different PWTs. The Management Team concluded that a more specific PWT was needed where water quality staff of the IEP agencies can focus on program planning and implementation of water quality monitoring and research. The mission of this PWT is to ensure that monitoring and research of water quality variables are efficient, timely, and meet the needs of the IEP agencies. Data collected are to be available on the WEB via the IEP Homepage in a timely manner and periodically disseminated as technical reports, journal articles, and presentations.

As evidenced by the information presented in Table 1, additional changes aimed at improving the function of the PWTs are required beyond the reorganization and other initial changes completed by the Management Team. Over the next year all PWTs will need to work to improve the dissemination of information generated during PWT meetings, both among the PWTs and to individuals outside the IEP. Improving the PWT section of the IEP Home Page and ensuring meeting notes are regularly up-loaded to the Home Page are two important steps to improving information dissemination. The Management Team also intends to increase the role of the PWTs in IEP planning. For example, the Contaminant Effects PWT is developing a long-range plan for contaminant monitoring and special studies. Further, prioritizing elements of a long-term research strategy is one of the initial tasks of the Shallow Water Habitat PWT. Both the plan and the research strategy will be very useful in developing the annual IEP work plan. The IEP continues to improve its ability to respond to new and emerging issues in the estuary. Fully functioning PWTs having good communication within and outside the IEP are key to further improvements in IEP responsiveness.

Overall, the Project Work Teams continue to serve as the backbone to the IEP. The PWTs serve as IEP's main forum for the ongoing development and discussion of data and information generated through monitoring and special studies. The suite of PWTs will provide IEP with the capability to provide information on current and emerging issues in the estuary. You are encouraged to contact the chairperson of any PWT to learn more about issues of interest to you.

References

Herrgesell PL, Kjelson MA, Arthur J, Winternitz L, Coulston P. 1993. A Review of the Interagency Ecological Study Program and Recommendations for its Revision. A report prepared for the Coordinators of the Interagency Ecological Study Program.

Steelhead Satellite Project Work Team

Dennis McEwan, CDFG

On July 9, 1998 the newly-formed Steelhead Satellite Project Work Team held its first meeting. Since then, a mission statement and objectives have been developed.

Mission Statement

To encourage, facilitate, and coordinate steelhead monitoring, research, and information dissemination, and provide a technical forum on Central Valley steelhead.

Objectives

1. Encourage, facilitate, and assist development of research on life history, distribution, population dynamics, abundance, and ecology of Central Valley steelhead.
2. Encourage, facilitate, and assist development of monitoring and research to evaluate the effects of water development/management and other stressors on Central Valley steelhead.
3. Provide technical review on steelhead research, monitoring, and restoration proposals.
4. Encourage information exchange and standardized methods of data collection and reporting among agencies and individuals.
5. Promote dissemination of project updates, research results, and current literature among scientists, resource managers, restoration specialists, and constituent organizations.

The Team is currently working on several important issues.

- Life stage assessment protocol. A protocol to assess steelhead life stage is currently in development and should be available soon. It is our intent that all Central Valley monitoring projects begin using this protocol. This will allow us to document the occurrence of steelhead smolts, and to gain a better understanding of temporal and spatial aspects of smoltification.
- Differentiation of natural and hatchery steelhead. With the initiation of a statewide mass-marking program for all hatchery steelhead, we now have a means to determine gross origin of both juvenile and adult steelhead. The team is working on standardizing collection of this information.
- CALFED Monitoring and Research needs. We are currently developing a conceptual model for Central Valley steelhead and an assessment of existing monitoring and research projects for the Comprehensive Monitoring, Assessment, and Research Program (CMARP) of CALFED (see article on CMARP in this issue). This document will identify future needs for additional monitoring and research. A draft should be available by mid-October.

Visitor Statistics of the IEP World Wide Web Site

Willie Chang, PhD, DWR
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A common practice for analyzing the significance and work load of World Wide Web sites is to obtain the statistics of web page access activities on the host computer (or computers).

The visitor statistics for the IEP web site has been fully developed.

The statistics, dated from July 13, are being updated automatically everyday and shown as web pages linked to the IEP home page (www.iep.ca.gov).

The computer programs I created illustrate the information using pie charts and bar charts. Each daily, monthly, yearly, or all-time compilation, shows:

1. The pages visited (the most/least).
2. The names of the computers visiting (the most/least).
3. The countries of the computers visiting (the most/least).
4. The access frequencies of each year, month, day, and hour (peaks/lows).
5. The access detail (date, time, host name, page).

The following figures illustrate yearly summaries. For aily and monthly summaries and details, please visit www.iep.ca.gov with your favorite web browser.

Figure 1. Summary of web page access for 1998.

Figure 2. Monthly, daily, and hourly web page access for 1998.

Figure 3. Percentage of web page access for 1998, by country (continued in Figure 4).

Figure 4. Percentage of web page access for 1998, by country (continued form Figure 3.)

Annual Interagency Program Workshop

Zach Hymanson, DWR

The 1999 workshop will be February 24-26, at Asilomar Conference Center in Pacific Grove. As in years past, the workshop will provide information on a number of projects via oral and poster presentations and panel discussions. The Bay-Delta Modeling Forum will hold its spring meeting and workshop February 23-24 at Asilomar, so you can attend all or part of both workshops.

The planning committee is now formulating an agenda for the IEP workshop, with the intent of having a final agenda in December. However, due to processing changes at Asilomar, registration forms will go out prior to completion of the agenda. Check the IEP Home Page (www.iep.ca.gov) for the latest updates on the annual workshop agenda. The planning committee intends to include the titles of poster presentations in the 1999 workshop agenda. If you plan to present a poster at the workshop please contact Peggy Lehman (Plehman@water.ca.gov) with the title for your poster. Please contact Zach Hymanson (Zachary@water.ca.gov) or Heather McIntire (Hmcintir@delta.dfg.ca.gov) for additional information about the workshop.

Delta Outflow

Kate Le, DWR

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1. This report was published in 1993 by the EPA San Francisco Estuary Project. See also: Jassby AD, and others. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications. 5:273-289.

2. See http://calfed.ca.gov/historical/delta_accord.html

3. The statistical certainty of this conclusion was not given. That is, it is conceivable that this result may arise simply because the few years in a given decade that fell in a given water year type were slightly drier in the later decades than in the earlier decades.

4. Monismith SG, Burau J, Stacey M. 1996. Stratification dynamics and gravitational circulation in northern San Francisco Bay. In: Hollibaugh JT, editor. San Francisco Bay: The Ecosystem. Pacific Division: American Association for the Advancement of Science. p 123-153.

5. Wim Kimmerer, personal communication after the workshop.

6. Also see a separate report of Wim's analysis and discussion in this issue.

7. Charlesworth B. 1984. Evolution in age-structured populations. Cambridge UK: Cambridge University Press.

8. Estuarine Ecology Team. 1992 Jan. An assessment of the likely mechanisms underlying the fish-X2 relationships. Interagency Ecological Program Technical Report 52.

9. Consider that little is known about flows in the Central Bay or in the adjacent coastal ocean. Limited data suggest that exchange rates do increase with outflow, something that would be consistent with increases in density stratification that occur for large outflows. The physical basis for this is that both topographic and frictional controls on exchange are reduced by increased stratification.

10. Such behavior was documented in the St. Lawrence ETM by Laprise and Dodson in 1989 in an article in Mar. Ecol. Prog. Ser. 55:101-11.

11. 1995. Ecological Applications. 5:680-692.

12. Wim took a counter view, both in his presentation and in his article found in this issue.

13. These phrases were taken from my notes and from BJ's comments to me concerning a first draft of this report.

14. That is, the question that Wim discussed of restricting attention to controllable flows.

15. In reviewing a draft of my notes, BJ preferred that this be stated as follows: The statistical analyses of the abundance-inflow relationships produced essentially the same correlations as those for the abundance-X2 relationships and that, from statistical analysis, one could not tell which was better, X2 or inflow.

16. In this section I use the initials of the panelists in my attempt to attribute various comments and ideas to their originators.

17. Wim counters my view by stating, "The existing X2 time series is based on our interpolation and the `Jassby equation' is used to fill in the gaps including years since 1992." There are several potential problems with this: 1) the relationship could have changed; 2) the interpolation could be done differently; 3) the conversion from conductance to salinity could be different. I don't think the difference would be much, but the basis for this seems a bit thin given all that has been layered on top of it. At the time, who knew?