

# Newsletter

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BAY-DELTA FISHERY PROJECT

Spring 1995

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

## Field Identification of Delta Smelt and Wakasagi

Dale Sweetnam, DFG-Stockton

Wakasagi, *Hypomesus nipponensis*, was first introduced into California in 1959 as a forage to salmonids in six warmwater reservoirs (Wales 1962). At the time, both wakasagi and delta smelt, *H. transpacificus*, were thought to be pond smelt, *H. olidus* (Pallus 1814). The true "pond smelt" is not found in California so, to avoid confusion, the "wakasagi" should be used for *H. nipponensis* (Committee on Names of Fishes 1991).

The six reservoirs where wakasagi was first introduced are:

- Dodge Reservoir (Lassen County)
- Shastina Reservoir (Siskiyou County)
- Freshwater Lagoon (Humboldt County)
- Spaulding Reservoir (Nevada County)
- Jenkinson Lake (El Dorado County)
- Big Bear Lake (San Bernadino County)

A complete list of locations where wakasagi has been stocked is not available.

DFG data show that wakasagi has been seen occasionally in the bay/delta estuary for at least the last 13 years, and more were seen in 1994 than in the past. There are large populations of wakasagi in Lake Oroville and Lake Almanor on the Feather River

and in Folsom Lake on the American River. Oroville and Folsom lakes are major water storage and release facilities for the SWP and CVP, which transfer water from the estuary. Below these reservoirs, wakasagi has been seen in the lower American River (below Nimbus Dam), in Cache Slough (off the Sacramento River), in the Mokelumne River system, and at the CVP/SWP fish salvage facilities in the southern delta. With this invasion into the estuary, identifying juvenile and adult *Hypomesus* spp. has become increasingly difficult.

Species identification is difficult at larval stages (see Wang 1991) and can also be difficult at juvenile and adult stages unless specific guidelines are followed. This article is intended to aid in identification of delta smelt and wakasagi at standard lengths of 20mm and above.

Six species of osmerids are present in at least part of the estuary (Miller and Lea 1972; Moyle 1976). Whitebait smelt, *Allomerus elongatus* (Ayres 1854) and night smelt, *Spirinchus starksi* (Fisk 1913) are predominantly marine. Surf smelt, *Hypomesus pretiosus* (Girard 1855), is mainly marine but can be found in brackish to fresh

water. Longfin smelt, *S. thaleichthys* (Ayres 1860) and delta smelt, *H. transpacificus* (McAllister 1963) are more euryhaline, although longfin smelt has been seen from the Gulf of the Farallones to Sacramento, and delta smelt has been seen from San Pablo Bay to the mouth of the Feather River. Miller and Lea (1972) is a good reference for identifying the marine and brackish water species.

Wakasagi has been found only in fresh water, but it may become established in brackish water as it moves to lower parts of the estuary. The three species of osmerids found in brackish to fresh water portions of the estuary are longfin, delta, and wakasagi smelt. Longfin smelt can usually be differentiated from the other two using the following criteria (modified from Miller and Lea 1972, Wang 1991):

- Jaw extends beyond middle of eye, snout pointed upward.
- Pectoral fin extends 83-128% of distance to insertion of pelvic fin.
- Eye diameter is smaller than other osmerids.
- Air bladder is round and develops earlier than delta smelt.
- No chromatophores at isthmus.

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In McAllister's (1963) revision of the osmerid family, he used two main characteristics to differentiate delta smelt from wakasagi (at that time they were considered subspecies). These characteristics are fin ray counts and the number of chromatophores between the mandibles. In 1994, 283 smelt were collected from several reservoirs and the estuary and identified to species by electrophoretic analysis (Trenhan, Moyle, and Schaffer, unpub. data). These smelt were used for the meristic analyses presented here. Results are based on 177 smelt analyzed so far. When all 283 smelt have been analyzed, results will be updated.

### Dorsal Pigmentation

Dorsal pigmentation is a characteristic used in 1994 to aid in identification of osmerids; its use as a reliable tool had not been verified. Subsequent analyses of smelt of known species indicates that use of dorsal pigmentation is unreliable (Figure 1).

Of the fish analyzed so far, 50% of the delta smelt overlapped in pigment classes with wakasagi. In addition, some specimens of both delta smelt and wakasagi fall into every pigment category (DFG, unpub. data). Therefore, we suggest that dorsal pigmentation not be used as a basis for species identification.

### Fin Ray Counts

Fin ray counts on fish identified to species by electrophoretic analyses suggest that using only fin ray counts for species identification is ambiguous for about 90% of the *Hypomesus* species observed in 1994 (Figure 2). Thus, extreme care must be taken at getting accurate counts (see Strauss and Bond (1990) for a description). The count ranges are as follows, the values in parentheses are reported by McAllister (1963).

	Delta Smelt	Wakasagi
Dorsal Fin	8-11 (9-10)	8-11 (7-9)
Anal Fin	15-19 (15-17)	14-17 (13-15)
Pectoral Fin	10-12 (10-12)	11-14 (12-14)
Pelvic Fin	8-9 (8-9)	8 (8-9)

### Chromatophores at the Isthmus

Use of the number of chromatophores present on the isthmus between the mandibles appears to be the best method to differentiate delta smelt from wakasagi (Figure 3). Delta smelt had 0-1 chromatophore present on the isthmus, which is consistent with McAllister (1963). Wakasagi measured so far had from 1 to 60 chromatophores (Figure 4). One wakasagi (98mm SL) collected in December 1982 near Antioch and now in the historical collection at Stockton had 77

chromatophores. Only one wakasagi had less than 5 chromatophores; it was collected in Barker Slough. We are rechecking the identification of this fish.

When only the wakasagi from the reservoirs are plotted against standard length (Figure 5) the relationship becomes quite strong ( $r^2=0.87$ ), indicating that the number of chromatophores increases as wakasagi increase in size. However, the relationship does not appear to hold for wakasagi collected from the estuary (Figure 6).

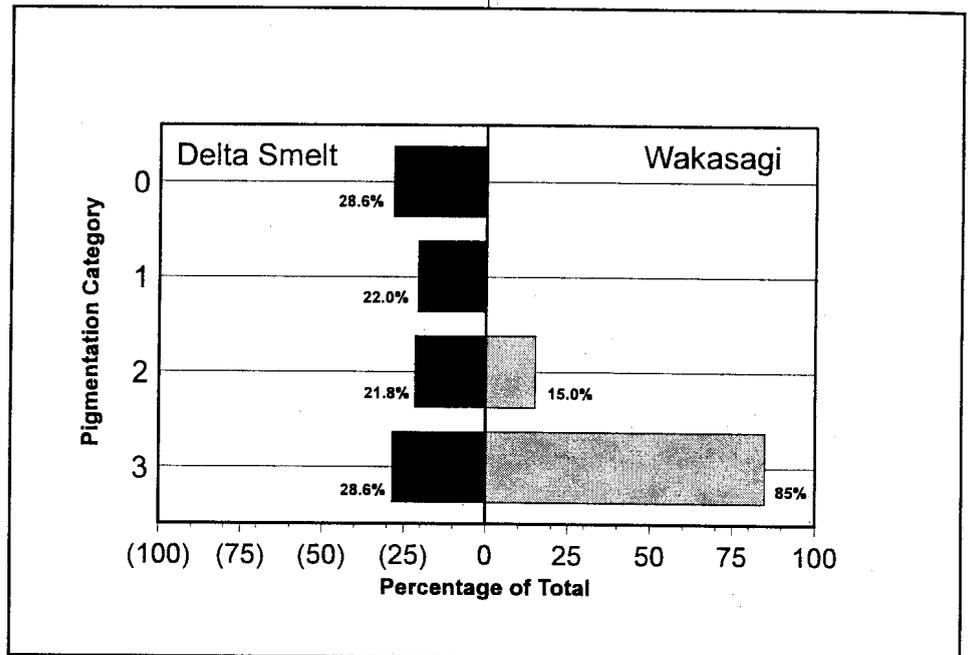


Figure 1  
AMOUNT OF DORSAL PIGMENT PRESENT IN DELTA SMELT AND WAKASAGI  
Pigment categories range from 0 (least pigmented; pigment present only from caudal fin to adipose fin) to 3 (most pigmented; pigment present from caudal fin to head).

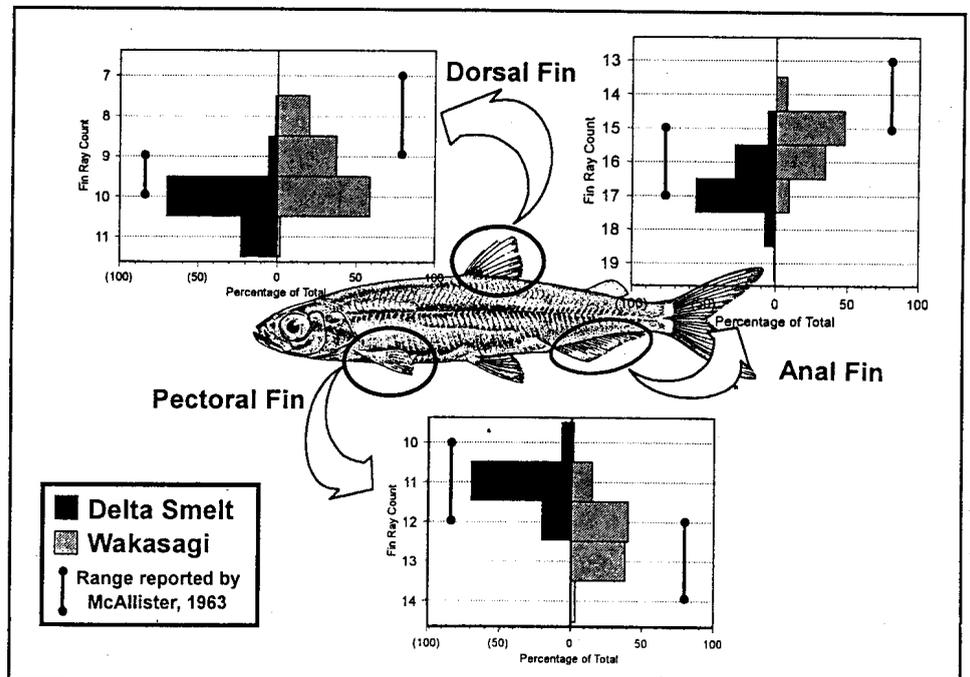
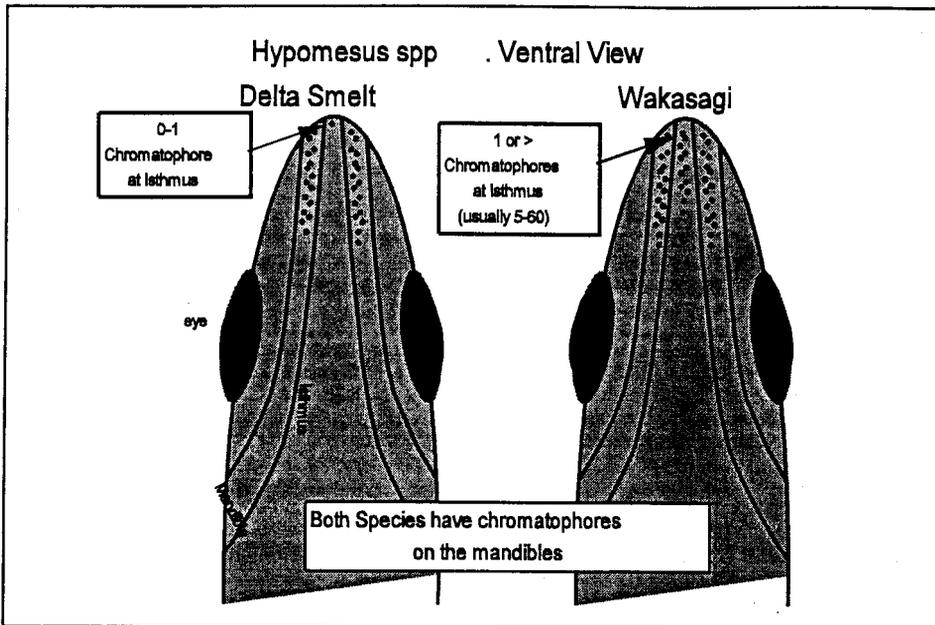


Figure 2  
FIN RAY COUNTS FOR DELTA SMELT AND WAKASAGI



We are trying to identify a mechanism as to how wakasagi are, in essence, "losing their spots".

Although there is slight overlap in the number of chromatophores at the isthmus between species, with proper magnification, this characteristic appears to be the best avenue for quick identification in the field. A 10X hand-held magnifying lens (lupe) appears to give enough magnification to count the chromatophores on the isthmus. For easier viewing, open the mouth to separate the mandibles from the isthmus.

Values reported here are preliminary, but they are the most up-to-date information on identification of delta smelt from wakasagi. We are working on describing differences in body shape between the species.

If you have questions or want to report the presence of wakasagi, please contact Dale Sweetnam at 209/942-6112 or e-mail [dsweetna@delta.dfg.ca.gov](mailto:dsweetna@delta.dfg.ca.gov). An electronic version of this article can be found at world wide web site: <http://www.delta.dfg.ca.gov>.

## New USBR Technical Report Series

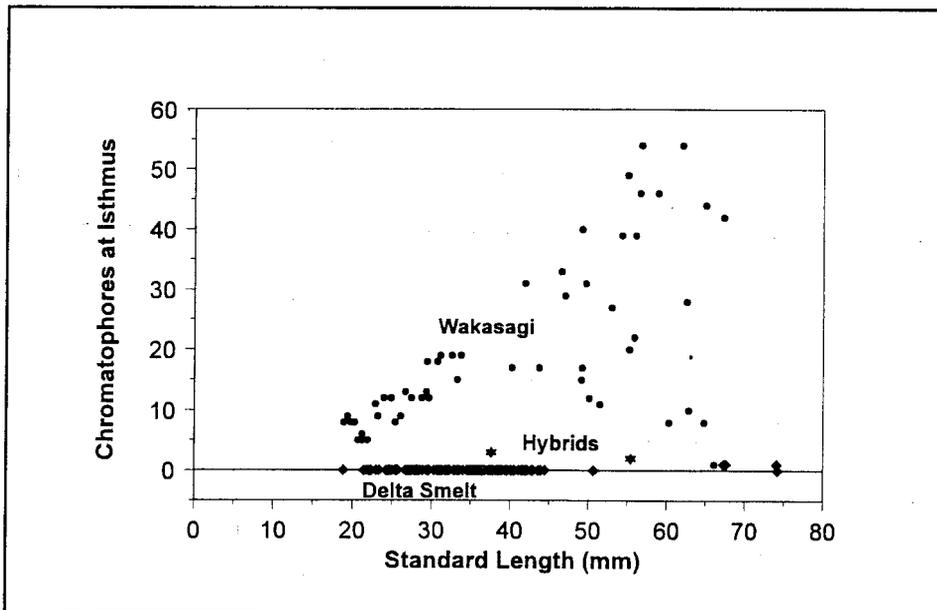
A technical report series for the USBR Tracy Fish Collection Facility Evaluation and Improvement Program has recently been established as a peer-reviewed volume series.

- Volume 1, "Predator Removal Activities Program and Intake Channel Studies, 1991-1992", has been printed.
- Volume 2, "Continuous Monitoring of Fish Eggs and Larvae, 1991-1992", is now being printed.
- Volume 3, "Re-evaluation of Louver Efficiencies for Juvenile Chinook Salmon and Striped Bass at the Tracy Fish Collection Facility, Tracy, California, 1993", is ready for peer review.

Many aspects of the Tracy Facility are undergoing evaluation, and we anticipate additional volumes.

Contact Lloyd Hess at the Tracy Fisheries Office (209/833-0340).

Figure 3  
NUMBER OF CHROMATOPHORES PRESENT ON THE ISTHMUS BETWEEN THE MANDIBLES FOR DELTA SMELT AND WAKASAGI



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## Interagency Workshop — Keeps Growing, and Growing, and Growing ...

In the late 1970s, the old 4-Agency Program held annual meetings in places such as Modesto and Stockton with attendance by some 30-50 people. In the mid-1980s, the 6-Agency Program held annual workshops at the Maritime Academy attended by about 100 people. More than 340 people attended the 1995 Interagency Program workshop at Asilomar. In addition to staff from the nine agencies comprising the modern Interagency Program, representatives of 6 institutions of higher education, 28 consulting firms, 11 water agencies, and 8 other groups (environmental plus local and state government) also attended the 2-1/2 day workshop. The Bay-Delta Modeling Forum, a recently organized group dedicated to review and development of hydrodynamic, biological, and other models held two sessions and its annual meeting concurrently with the workshop.

Topics at the 1995 Interagency Workshop were varied, but all related to bay/delta issues. Topics included technical discussions and findings on modeling issues, fish and clam species, and the 1994 entrapment zone study. General interest talks included information on epic droughts in California, perspectives on the December 15, 1994, water agreement, and revisions to the Endangered Species Act.

In 1996, the Interagency Workshop will be held February 28, 29, and March 1, again at Asilomar. If you have ideas for topics or comments on the 1995 workshop and modeling forum, contact Leo Winternitz (916/227-7548 or lwintern@water.ca.gov) or Chuck Armor (209/948-7800 or carmor@delta.dfg.ca.gov).

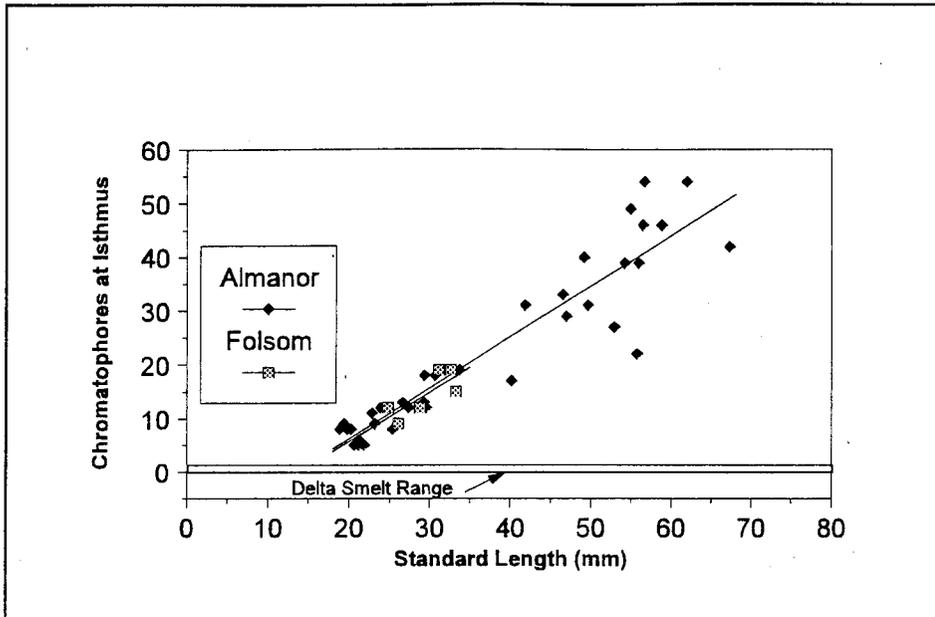


Figure 5  
RELATIONSHIP BETWEEN CHROMATOPHORES AT THE ISTHMUS AND STANDARD LENGTH FOR WAKASAGI COLLECTED IN RESERVOIRS

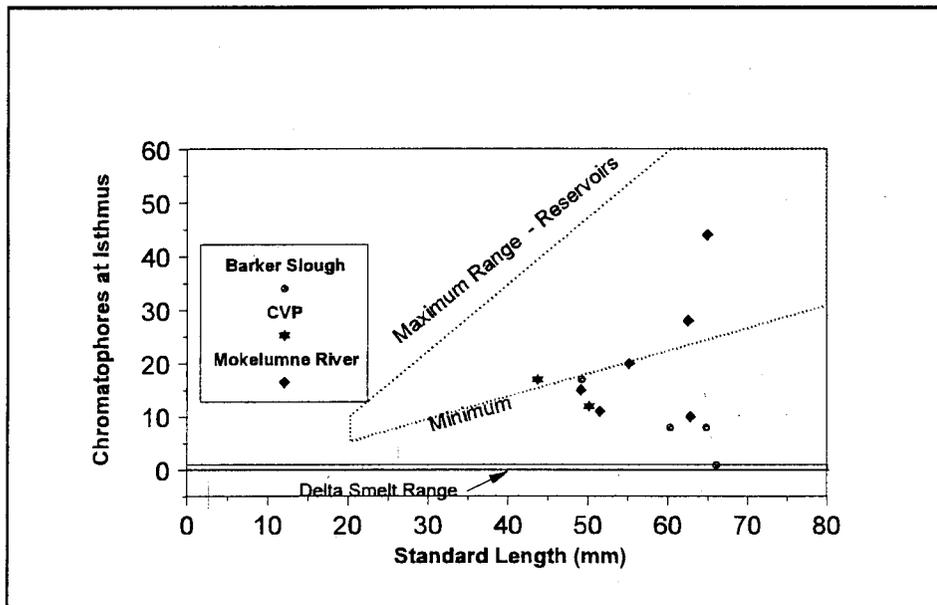


Figure 6  
RELATIONSHIP BETWEEN CHROMATOPHORES AT THE ISTHMUS AND STANDARD LENGTH FOR WAKASAGI COLLECTED IN THE ESTUARY

## National Marine Fisheries Service Joins the Interagency Program

Last fall, the National Marine Fisheries Service became the ninth member of the Interagency Ecological Program. Hilda Diaz-Soltero, Director of the Southwest Region in Long Beach, represented NMFS at the February 22 Directors' meeting. Jim Lecky, Chief of the Southwest Region's Division of Protected Species, will be the NMFS member of the Interagency Coordinators.

There is interest at the NMFS Tiburon Laboratory in getting involved in salmon-related questions. On April 26, some of the Coordinators will be meeting with Lab Director Alec MaCall, Jim Lecky, and Gary Stern to discuss possible areas of mutual interest.

## Comprehensive Bay/Delta Monitoring Program

Randy Bailey and Jud Munroe, Consultants to  
Metropolitan Water District of Southern California

The December 1994 "Principles for Agreement" created a significant change in management of the bay/delta and biological resources that depend on this diverse and heavily used resource. The policy-makers initiated a long-term adaptive management strategy to the ecosystem. This policy decision places responsibility for mending past abuses clearly on the shoulders of all who benefit from this magnificent body of water. The policy-makers also made three points.

- They want it to function, the best a highly altered system can, like a natural ecosystem, and it is up to us to tell them how to accomplish this goal.
- They want to know how the ecosystem functions and what causal relationships drive the biology.
- They want to know if the water quality standards are improving the overall health of the ecosystems, whether biological resources are improving and, if not, how we should proceed to reach our goal.

The data necessary to support adaptive management and ecosystem-based decision-making are considerably different from past efforts. To meet the challenge, a comprehensive monitoring and assessment program is needed with the following components.

**Broad Geographic Coverage** — Any ecosystem-based monitoring program should include all of those places that influence the system. In this case, the geographic coverage should include those waters tributary to the estuary, including tributaries to the Sacramento and San Joaquin rivers.

**Compliance Monitoring** — This component will determine if the water quality standards are being complied with and will encompass such activities as determining the location of X2, documenting whether the Delta Cross Channel was open or closed, etc.

**Operations Support Group** — This segment of monitoring would provide the CALFED Operations Group with data to assist them in making the adaptive management decisions outlined in the agreement based on some understanding of the current water quality and biological situations in the vicinity of the CVP and SWP pumping plants. These data would facilitate such decisions as changes in export/inflow ratios, Cross Channel gate openings or closings, pump switching, etc. This

component will require near-real-time monitoring, which will necessitate quick turn-around of information so it will be available to the Operations Group in a timely manner.

**Effectiveness of the Standards** — This component is required to determine if the standards are having the desired or hypothesized effects. These data will tend to support or refute assumptions behind the standards, such as: Do pulse flows transport salmon smolts? Does the location of X2 result in more delta smelt? Are the export/inflow ratios having the desired effects on distribution and reduced mortality at the pumping plants?

**Long-Term Trends in Aquatic Resources** — This segment would be designed to determine long-term trends in various species and parameters. Although an ecosystem approach to management may not place as much emphasis on an individual species as in the past, the realities of listed species will necessitate careful trend monitoring. These data are really intended to answer the longer-term question of whether things are getting better or worse.

**Ecological Relationships** — This component would be used to determine the basic relationships between various physical and chemical parameters and the biological responses in the system. These data would be used to assess the causal interrelationships and provide the basic science from which future management strategies could be developed.

**Monitoring of Non-Flow Projects (Category III)** — This segment would be designed to assess effects of implementing the various Category III projects. These data would help determine which measures are providing significant benefit and which should be modified or eliminated.

Implementing this program will not be easy or cheap. The focus will be problem-solving and providing answers from which management strategies can be developed. Monitoring will require exacting coordination of projects scattered over a wide geographic area; development and application of new gear and technology that will provide better and more cost-effective data; and integrated sampling that must include the physical, chemical, and biological factors stratified by habi-

tats. The level of data management, assessment, analysis, integration, and synthesis will exceed anything done in the past. Peer-reviewed publications from this effort will advance the science to a new level of understanding about how this ecosystem functions. This is essential to restore and conserve this ecosystem.

### BROWN BAG SEMINAR

Role of  
Introduced Fish Species  
in the  
San Francisco Bay/Delta  
Estuary

Dr. Peter Moyle,  
University of California,  
Davis

Tuesday, April 25, 12 to 1:30  
DWR Cafeteria  
3251 S Street, Sacramento

This is the second in a series of  
informal technical discussions  
over lunch to be held about  
every other month.

If you have questions or  
suggestions, contact  
Leo Winternitz  
(916/227-7548).

### Georgiana Slough Acoustical Barrier

Oral agreement has been reached for all permits required for an April 1995 installation of the test acoustical barrier at the head of Georgiana Slough. High Sacramento River flows have delayed barrier deployment somewhat, and it is now scheduled to be operational sometime during the week of April 17. The final report documenting results of last year's testing has been received from the contractors and will be published this summer as an Interagency Technical Report.

# Pathway Models Could Aid Management of Contaminants

S. N. Luoma, USGS-Menlo Park

## Introduction:

### Identifying Effects of Pollutants

Heavy metal and trace organic contaminants are often cited as factors that could affect the richness of the biological community of San Francisco Bay as well as the health of resident organisms. Silver (Ag), selenium (Se), mercury (Hg), copper (Cu), nickel (Ni), chromium (Cr), and cadmium (Cd) are among the trace elements of current regulatory interest. All these elements can be toxic to estuarine organisms in minute quantities. However, understanding their toxicity in nature has proven a difficult challenge.

In general, it is difficult to prove how pollutants are affecting ecosystems. The undisturbed "baseline" condition in San Francisco Bay is not always well enough understood to identify whether certain processes are affected or unaffected by contamination. Sources of disturbance (flow diversions, drought, invasion of exotic species, etc.) occur in addition to chemical contamination. Responses to contamination in individual organisms, populations, and communities are seldom pollutant-specific, and the complex responses to moderate levels of contamination are not well known.

### Challenges in Managing Pollutants

Although the problems with identifying toxicity are important, even more basic uncertainties exist with regard to identifying the mechanisms or routes by which organisms are exposed to pollutants. It is uncertain what compartments in nature (water, suspended particulates, sediments, prey organisms) are the most important sources of toxicity. It is also unclear which of these compartments should be monitored, and what compartments should be included in the next generation of regulatory guidelines. Resolving these uncertainties could aid greatly in better attempts to understand toxicity in nature.

At present, pollutants are managed by estimating concentrations that cause toxicity from simplistic laboratory bioassays, then comparing these toxicity levels to concentrations of the pollutant in whole (unfiltered) water samples from the bay. Although this approach employed the best tech-

nologies available when it was established, it has many limitations. One of the most important is the assumption that the only route of toxicant exposure is via water or pore water. Other exposure pathways (ingestion of contaminated food, for example) occur in nature, but they are ignored in the toxicity estimates.

### Understanding Pathways of Bioaccumulation

In recent studies, partially supported by the Interagency/EPA San Francisco Bay Research Enhancement Program, a multi-investigator group from the Marine Science Research Center, SUNY, Stony Brook, NY, and USGS in Menlo Park, CA,\* developed a combined experimental, field and modeling approach that defined exposure of key benthic species from San Francisco Bay to trace element contaminants via multiple pathways.

These studies allow projections of what environmental media (dissolved metal, total metal in water, or metal in sediments) should be monitored or regulated, when upper trophic level organisms (including commercially important species) might be threatened and how exposures might change with changes in regulations.

A simple, one-compartment model of exponential metal bioaccumulation provided the basis for field and laboratory experiments (Figure 1). The model was developed to facilitate understanding of how contaminant exposures might change as trace elements inputs and fates change in the complex, dynamic biogeochemical environment of the bay. Experiments determined physiological coefficients appropriate for the model. Gross influx rate from solution was studied directly with radionuclides to estimate concentration dependence and salinity dependence of uptake from water. Assimilation efficiency from food was determined using radionuclides in pulse-chase experiments. Assimilation was compared among a variety of individual types of food as well as natural mixtures of food types. Field studies indicated the types of food that were used.

Efflux rates were also determined experimentally. Results from long-term field studies were incorporated into

the models, including the dissolved and particulate element concentrations observed under different geochemical conditions typical of the estuary and feeding rates typical of local species. Steady-state bioaccumulation was from the sum of dissolved and particulate sources (Figure 1a) under varying conditions. To validate the model results, predicted bioaccumulation was compared to concentrations in animal tissues found in field studies. Results from two trace elements with different chemistries and dynamics are contrasted below.

### Selenium Pathways

Studies of Se in San Francisco Bay first began after reproductive toxicity in birds from Kesterson Reservoir was related to Se in agricultural runoff. Initial studies were designed to determine if Se-enriched San Joaquin River waters reached San Francisco Bay. The California Fish and Game Selenium Verification study showed that diving ducks in Suisun Marsh had Se concentrations nearly equivalent to those in birds that suffered reproductive damage in Kesterson. Three lines of evidence indicated that the Se contamination originated from local industries.

- Concentrations in water, suspended sediments and resident clams in Suisun Bay were highest around industrial discharges near Carquinez Strait (Johns and Luoma 1989; Cutter 1989).
- The predominant form of the element in the San Joaquin River (selenate or Se(VI)) was different from the form discharged by industry (selenite or Se(IV)) (Cutter 1989). The form in the bay was more consistent with industrial than with riverine inputs.
- The mass of Se discharged by industries accounted for a substantial fraction of the element in the bay (Cutter 1991).

A perplexing aspect of the observations was that the concentrations of Se in Suisun Bay water were well below those predicted to be problematic or toxic. Luoma *et al* (1992) showed that selenite uptake from solution was very slow. But when local clams (*Macoma balthica*) were

\* Co-investigators include Nicholas Fisher and the author, who are co-PIs, along with Alan Decho, Wenxiong Wang, Sarah Griscom, Byeong-Gweon Lee, Cynthia Brown, John Reinfelder and Alexander van Geen.

fed phytoplankton contaminated by selenite, assimilation of Se was highly efficient (>85%). If the clams ate sediments contaminated by microbially reduced selenate, selenium was assimilated, but less efficiently (22%). Thus speciation in solution and nature of incorporation into particulate form were important in assimilation. The physiological coefficients describing uptake from water and food, along with the concentrations of Se in suspended particles and solution in Suisun Bay, were used to calculate

bioaccumulation by the clam. The model predicted Se concentrations in clams similar to those found in the estuary. More than 95% of the Se in clams originated from food. Calculations also showed that bioassays with dissolved Se were irrelevant, because organisms absorbed very little Se from solution at concentrations that occur in the bay. Regulations derived from toxicity tests with Se in water would underestimate actual Se exposures of the clams by more than twentyfold.

It was deduced that the birds and fish accumulated high concentrations of Se because the form of the element in industrial wastes (selenite) was concentrated by phytoplankton, converted to organoselenium (Figure 2), and passed efficiently to clams. The birds most contaminated in Suisun Bay (migratory scoter and scaup) eat clams, as do fish with the highest selenium concentrations (sturgeon).

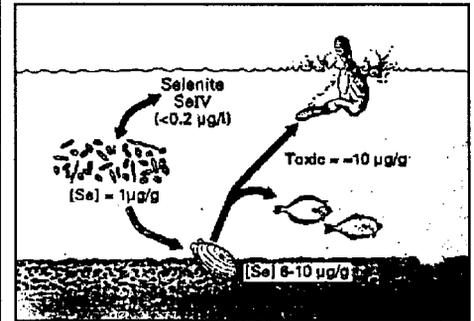
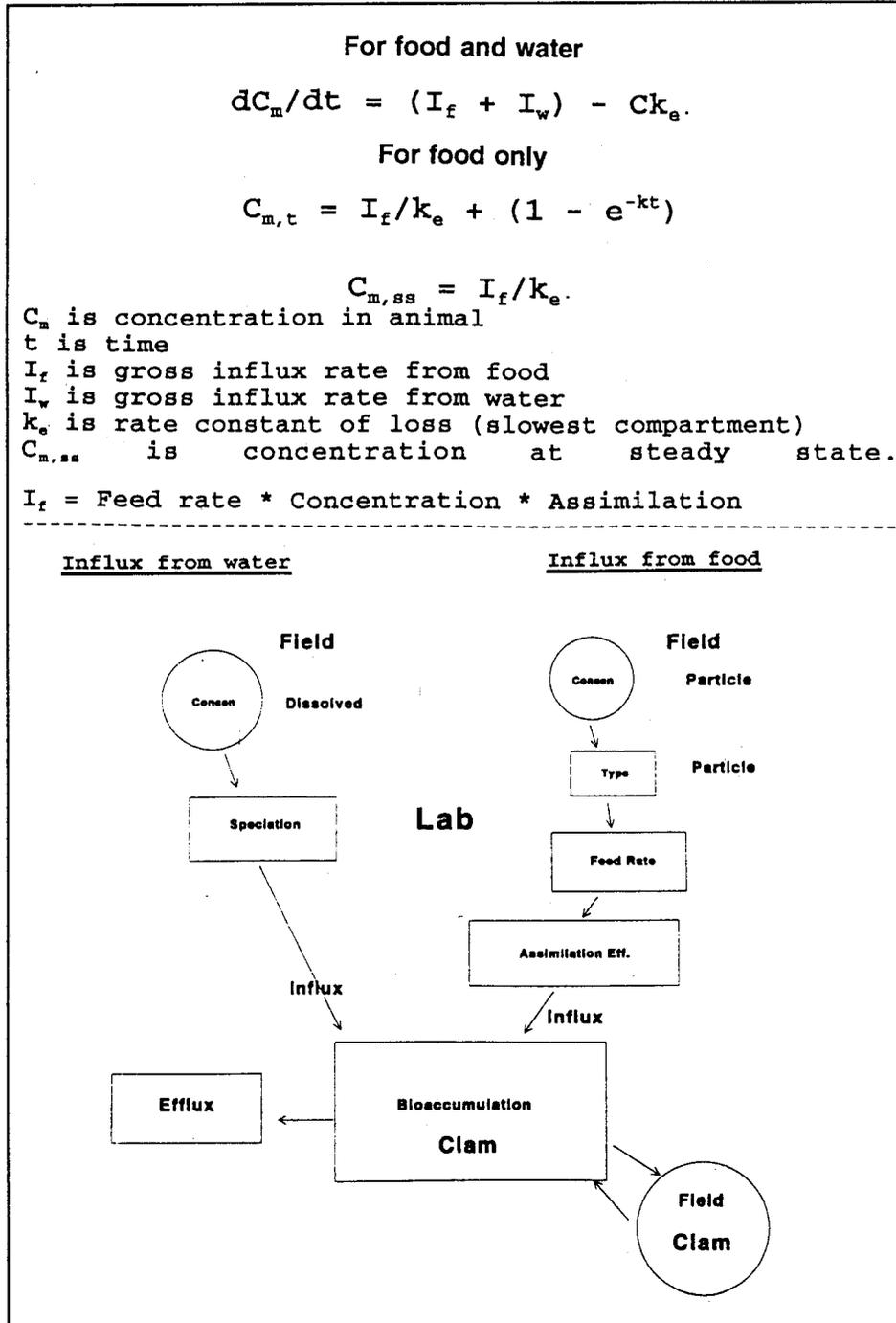


Figure 2  
 PATHWAY OF SELENIUM CYCLING IN  
 SUISUN BAY  
 Values are observed concentrations.

Adverse effects on reproduction in both birds and fish are observed in experimental studies when selenium in food approaches 7-10  $\mu\text{g}/\text{g}$ . The highest concentration of selenium in clams from North Bay was 9  $\mu\text{g}/\text{g}$ ; the long-term average at the site closest to the refineries was 5.2  $\mu\text{g}/\text{g}$ . In 1977, concentrations in mussels (*Mytilus edulis*) in this area were as high as 11.4  $\mu\text{g}/\text{g}$  (Johns *et al* 1988). Reproductive damage or other adverse effects in the local birds have been difficult to demonstrate directly. Exposures may be just below thresholds of toxicity; on the other hand scoter and scaup leave the bay before they reproduce, so reproductive anomalies are difficult to identify.

The above study was conducted between 1986 and 1991. Sources, concentrations, and conditions of Se exposure may change if more Se is added to the bay from either the San Joaquin River (as a result of the recent water agreement) or direct agricultural discharge. The studies indicated that particulate Se concentrations, relationships between particulate and dissolved Se, and concentrations in the tissues of prey species should be monitored to assess effects of these changes. Regulations based solely on toxicity tests with total dissolved Se could be inadequate to protect biological resources in the bay. The bioaccumulation modeling approach could improve the basis for estimating food web exposures as circumstances change.

Figure 1  
 (Top) SIMPLE BIOACCUMULATION MODEL  
 (Bottom) EXPERIMENTAL AND FIELD APPROACH EMPLOYED TO MODEL BIOACCUMULATION

## Cadmium Pathways

Field, laboratory, and modeling experiments have also been conducted with Cd and three species of benthic bivalves: *Macoma balthica*, *Potamocorbula amurensis* (a filter feeder that recently invaded San Francisco Bay), and the mussel *Mytilus edulis*. Experiments showed that food type and salinity were critical variables affecting Cd uptake via different pathways. *M. balthica*, for example, assimilated 80% of the Cd from pure cultures of diatom cells, but only 10-20% from sediments or humic substances extracted from sediments. Uptake differed less among food types for *P. amurensis*. Uptake from solution in both species was slow at salinities greater than 10‰, but increased tenfold between 10‰ and 2‰ (as Cd speciation in solution changed).

The bioaccumulation model was employed to simulate Cd uptake by *M. balthica* and *P. amurensis* during bloom conditions in South Bay, when Cd concentrations in solution decline, but concentrations in particles (and presumably phytoplankton) increase (van Geen, Lee, Brown, Luoma, and Cloern, USGS, unpublished data). The model predicted the greatest changes if *M. balthica* switched from ingestion of sediment to ingestion of diatoms during the bloom. Cadmium concentrations in the clam would increase tenfold just from changing diet (Figure 3). Changing diet had less effect on uptake by *P. amurensis*. Nevertheless, concentrations increased in *P. amurensis* despite the fact that dissolved concentrations of Cd decreased twofold. Thus phytoplankton blooms might be a time when at least some estuarine filter or deposit feeders are especially vulnerable to cadmium in contaminated estuaries. These simulations are being field tested in 1995.

Similarly, estuarine biota would be especially vulnerable if Cd contamination occurred in conjunction with freshwater inputs. For example, if salinities for clams at a site were 5‰ and dissolved Cd concentrations were 1nM/Kg (the upper end of concentrations we have observed in a number of years in the bay); and if

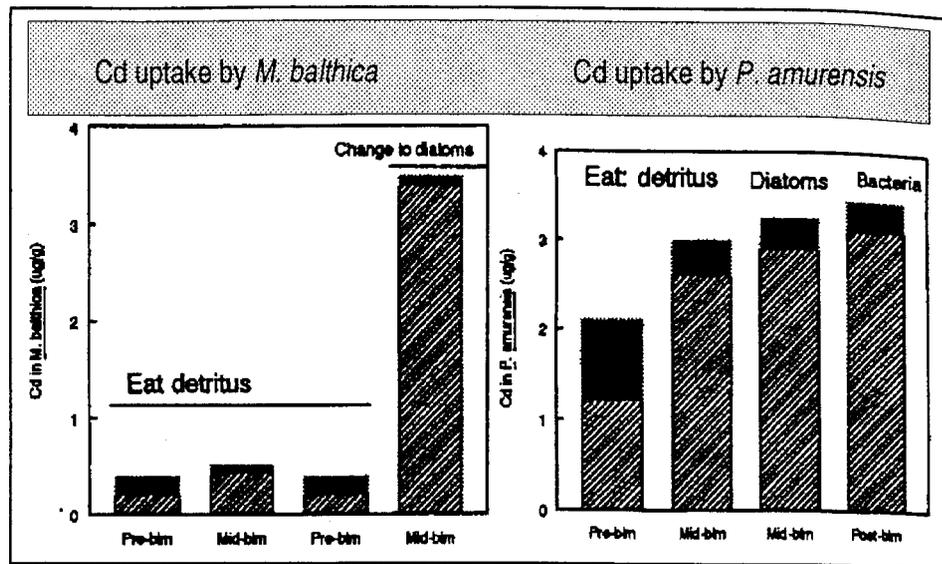


Figure 3  
MODEL SIMULATIONS OF THE EFFECT OF CHANGING Cd CONCENTRATIONS AND CHANGING FOOD SOURCES ON UPTAKE BY TWO CLAMS DURING A PHYTOPLANKTON BLOOM IN SOUTH BAY

Black bars indicate uptake from water; shaded bars show uptake from food.

particle concentrations ingested by the clam were 3 µg/g (not unrealistic at low salinities), concentrations in clams could rise to 16 µg/g. This is a very high concentration for this species. Most uptake would come from solution as a result of enhanced Cd bioavailability from the low salinities. In contrast, during periods of strong upwelling in coastal waters, naturally-derived Cd concentrations of 1nM/Kg enter the bay with high-salinity waters. Particles can contain 0.4 µg/g (less particle contamination occurs because of the higher ionic strength of the high-salinity waters). Only 2 µg/g Cd would be accumulated by clams under these conditions, even if their diet is half diatoms. Concentrations of dissolved Cd may not be greatly different between high river inflow and strong upwelling conditions, but Cd exposures of bivalves and their vulnerability to the contaminant are greatly different because of the effects of salinity on bioavailability and adsorption.

These studies indicate that the next generation of Cd regulations and monitoring must consider particulate Cd, dissolved Cd, and ancillary variables such as salinity and primary production. Again, experi-

ments and field studies designed to help solve simple bioaccumulation models might provide an improved basis for evaluating possible interactions among such factors in a complex estuary.

## Interagency Directors' Meeting

The Interagency Directors met on February 22 to review progress in implementing changes proposed at the 1994 annual meeting. Staff outlined significant changes, including convening the project work teams, forming the Management Committee and Science Advisory Committee. Staff also indicated that the "Delta Agreement" may result in the need for additional modifications.

The Directors asked staff to provide a detailed summary of the existing program by May 1 and recommendations for a revised program by September 15. The Coordinators and the Science Advisory Committee will be working with other parties to convene one or more workshops this summer to help design a comprehensive monitoring and special studies program.

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## Searching the Origins of the Delta Smelt

Peter B. Moyle, Department of Wildlife, Fish, and Conservation Biology, University of California, Davis

In recent weeks there has been considerable discussion about the relationship between delta smelt and wakasagi. I am taking this opportunity to present a description of delta smelt taxonomy, the origins of delta smelt, and the relationship between delta smelt and other species of smelt in the Sacramento/San Joaquin estuary.

With the support of an Interagency Ecological Program contract, we used biochemical (electrophoretic) techniques to demonstrate that the delta smelt (*Hypomesus transpacificus*) is only distantly related to introduced wakasagi (*H. nipponensis*) (Stanley *et al* 1995). Genetic distance, the quantitative measure of relatedness used, showed that these two species are more distantly related to one another than most species of fish that are placed together in a genus such as *Hypomesus*. In our study involving five smelt species, the species most closely related to the delta smelt proved to be the surf smelt (*H. pretiosus*), an abundant marine species found along the California coast. This result was not surprising in that similar species living in the same geographic area are generally more closely related to one another than those from distant areas.

There is no question that surf smelt and delta smelt are distinct species. For example, the most popular field guide (Eschmeyer *et al* 1983) to fishes of the Pacific coast provides many characteristics that make it easy to tell the two species apart.

A close look at distribution patterns alone indicates that the pond smelt (*H. olidus*, a species plentiful throughout the Pacific rim) and delta smelt are distinct species. The pond smelt is a freshwater species found mainly in arctic and subarctic Alaska, Canada,

and Russia; the closest population is more than 2,000 miles from San Francisco Bay. Despite this distance, all freshwater populations of *Hypomesus* were lumped together under *H. olidus* until 1963 — simply because no one had taken a close look at fish from different areas. McAllister (1963) analyzed smelt from various areas and concluded that freshwater populations from Japan, the Arctic, and California were distinct. McAllister chose to recognize the Japanese and California populations as subspecies of a "species", with populations of the subspecies found on opposite sides of the ocean (hence the name *transpacificus*); nevertheless, his work did recognize them as distinct forms. He also showed conclusively that both these populations were very different from the pond smelt, *H. olidus*.

It is worth noting that McAllister's work also demonstrated that the longfin smelt (*Spirinchus thaleichthys*) of San Francisco Bay was not distinct, at the species level, from longfin smelt populations elsewhere on the coast. Prior to his work, the local population was recognized as a separate species, the Sacramento smelt. The same biochemical studies that demonstrated that the delta smelt was clearly a distinct species confirmed McAllister's conclusions that the San Francisco Bay population of longfin smelt was not a distinct species. This evidence was a major factor in the FWS decision not to list the bay population of longfin smelt as endangered, even though its population has declined more than that of delta smelt.

The biochemical study that confirmed the delta smelt as a species has been accepted for publication in *Copeia*, the journal of the American Society of Ichthyologists and Herpetologists (Stanley *et al* 1995). In addi-

tion, an independent panel of fish taxonomists has agreed that both the delta smelt and the wakasagi are separate species and accepted the two species for the American Fisheries Society list of fishes of the United States and Canada (Robins *et al* 1991).

A question often arises as to the likelihood of delta smelt and wakasagi interbreeding. The criterion that "valid" species cannot interbreed and produce fertile offspring is usually true under natural conditions, but reproductive isolation is often broken down by humans. Fish breeders know this, and many exotic varieties of aquarium fish have been produced by crossing species that would never interbreed in the wild. Hybrids among even distantly related fish species in the wild are encountered often enough so that there is a large literature on the subject. What is very rare is finding hybrids that interbreed with the parent species, even if they are interfertile. In the case of the smelt genus *Hypomesus*, the only hybrids among species known are those between wakasagi and delta smelt that we discovered in the delta in 1994. These hybrids occur in a situation where they might be expected — a few individuals of an invading species encounter spawning aggregations of a more abundant native species in a highly disturbed environment. Even so, the hybrids are rare and show no evidence of interbreeding with the parent species. Our biochemical studies indicate that the two species are so different that it is highly likely that the hybrids will be sterile (much like the mule) or will be unable to interbreed for other reasons. It would be worthwhile and interesting to determine if delta smelt/wakasagi hybrids are, in fact, sterile.

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# Ecosystem Responses to Phytoplankton Blooms — Examples from South San Francisco Bay

Jim Cloern, USGS- Menlo Park

In 1968, USGS began a program of basic research in San Francisco Bay that has complemented the research and monitoring elements of the Inter-agency Program. Although the USGS program changes its focus of study from year to year, it has elements of continuity because some measurements have been made routinely for decades. One of these elements has been a study of the spring phytoplankton bloom in South San Francisco Bay. Here I present data from multiple sources to explain why such emphasis has been placed on this biological phenomenon.

Figure 1 shows some of the linkages between phytoplankton and the geochemical/biological components of estuarine ecosystems. Like other chlorophyll-containing plants, phytoplankton produce new biomass through photosynthesis when they are exposed to sunlight. In the process, they assimilate dissolved inorganic substances such as carbon dioxide, nitrate, ammonium, phosphate, silicate, sulfate, and trace elements including iron, magnesium, selenium, zinc, etc. The net effect of phytoplankton primary production is to take these inorganic substances from solution and incorporate them into new phytoplankton biomass. This newly produced organic matter is a food resource for consumer organisms (heterotrophs) living in the water column and in the sediments.

Figure 1 shows three pools of reactive matter (dissolved inorganic substances, particulate organic matter, and populations of heterotrophs) and arrows to indicate exchanges between the three pools. In many circumstances the sizes of the pools remain approximately static — there is a quasi-equilibrium between all processes of uptake/consumption and regeneration. However, episodic events occur in which this quasi-equilibrium is disturbed and the pool size (biomass) of phytoplankton increases rapidly — sometimes tenfold within a week or two. These events are traditionally called “blooms”, and they occur when the balance between the production and consumption of phytoplankton is altered. One goal of the

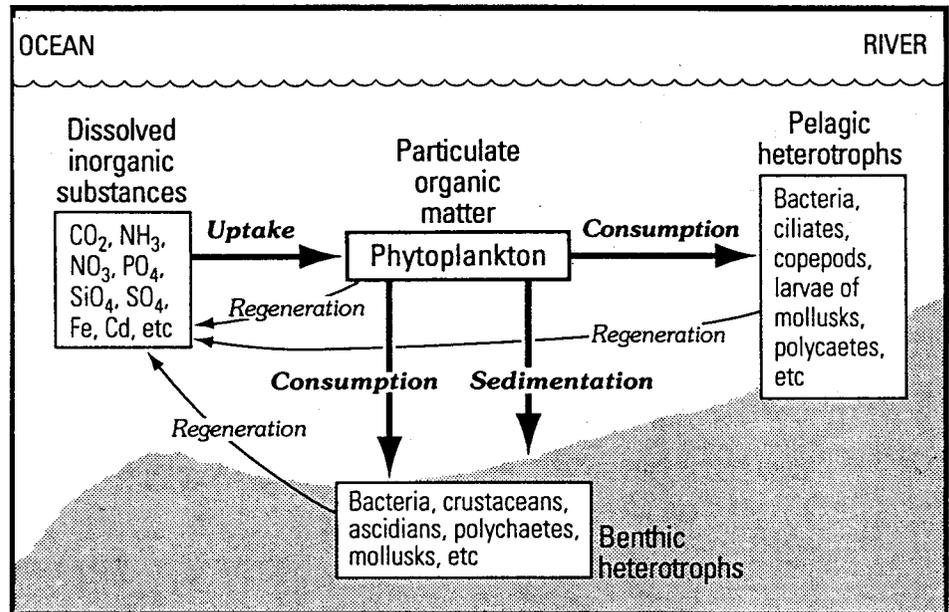


Figure 1  
SIMPLE CONCEPTUAL MODEL TO ILLUSTRATE THE ROLE OF PHYTOPLANKTON AS  
TRANSFORMERS OF MATERIAL WITHIN ESTUARINE SYSTEMS

USGS research program has been to unravel the mechanisms that give rise to these biological events (eg, Cloern 1991; Koseff *et al* 1993). The net effect of blooms is to change:

- The concentrations of dissolved inorganic substances (DIS),
- The abundance and composition of the particulate organic matter (POM),
- The abundance and metabolism of the heterotrophs, and
- The rates of material exchange between these constituents.

Figures 2-5 show the monthly distributions of diverse measurements in the channel of South San Francisco Bay.

## Spring Bloom and Rates of Material Flow in South San Francisco Bay (Figure 2)

Figure 2, Panel A shows the monthly distributions of phytoplankton biomass (as chlorophyll concentration) from samples taken during 1990 to 1994. Most measurements fall in the range 1-5 µg/L; exceptions occur in

the spring, usually in March-April, when chlorophyll concentration exceeds 10 µg/L and reaches peaks above 50 µg/L. Although the exact timing and intensity of these blooms change from year to year, this panel illustrates that the blooms are confined to spring months.

Figure 2, Panels B, C, and D show the monthly distributions of three components of system metabolism in the South Bay: primary productivity by phytoplankton; production rate by suspended bacteria; and pelagic respiration, the rate of oxygen consumption by the entire assemblage of microorganisms living in the water column. Primary productivity is a measure of the rate at which new organic matter is produced from inorganic constituents; bacterial production and pelagic respiration are measures of the rate at which organic matter is consumed and metabolized by heterotrophs. Rates of these processes are greatly accelerated during the spring as direct responses to enhanced phytoplankton biomass.

## Particulate Organic Matter (Figure 4)

The suspended POM in estuaries is a complex mixture that includes organic substances bound to sediment particles, detritus, and microorganisms including algae and bacteria. All components of the POM have unique origins and chemical character, and they differ in their availability and quality as food resources for heterotrophs. Figure 4, Panel A shows that the total pool size of particulate carbon is highest during spring, in association with the peak chlorophyll concentrations. Panels B, C, D show how the chemical character of the POM changes during spring. The ratio Chl:PC (Panel B) is an index of the percentage of POM composed of phytoplankton; the maximum ratio here of 0.4 is close to the ratio expected in a suspension of pure algae. The C:N ratio (Panel C) is an indicator of the nutritional quality of the POM, with small C:N ratios (6-7) indicative of protein-rich algae. In addition, geochemists use the relative proportions of the two stable isotopes of carbon,  $^{12}\text{C}$  and  $^{13}\text{C}$ , to deduce the origin of POM. The ratios shown in panel D indicate that POM in the water typically has a composition similar to that in the bottom sediments. Exceptions occur during spring blooms, when these ratios approach values expected of marine algae (del  $^{13}\text{C}$  of about -17). So, the abundance and the nutritional quality of POM both change markedly during phytoplankton blooms.

## Responses of Consumer Organisms (Figure 5)

Even in productive environments such as estuaries, heterotrophic organisms often live in a medium that is food limiting. Increases in the abundance or quality of POM, such as those shown above, provide opportunities for these organisms to optimize food intake and accelerate their rates of metabolism, growth, or reproduction. In South San Francisco Bay, the abundance (biomass) of bacteria is highest in spring (Figure 5, Panel A), suggesting a connection between bacterial population dynamics and phytoplankton primary production. Populations of some microzooplankton, such as tintinnid ciliates, increase in response to the spring bloom (Panel B). Some invertebrates begin seasonal cycles of spawning in response to increases in food supply; this may partly explain the maximum abundances of larval copepods (*Acartia clausi*) and spionid polychaetes

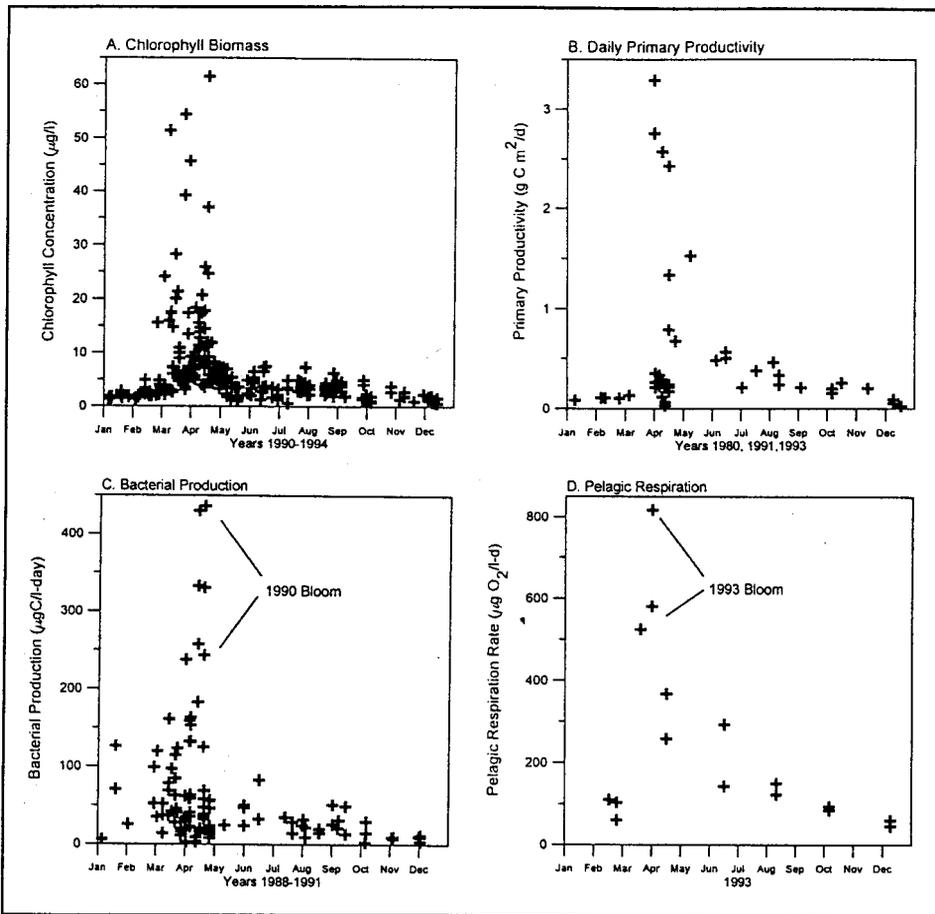


Figure 2  
SEASONAL DISTRIBUTIONS OF:

- A. PHYTOPLANKTON BIOMASS (CHLOROPHYLL CONCENTRATION) IN SOUTH BAY SURFACE WATERS BETWEEN THE SAN MATEO AND DUMBARTON BRIDGES, 1990-1994  
 B. PHYTOPLANKTON PRIMARY PRODUCTIVITY MEASURED IN 1980, 1991, AND 1993 (data from B.E. Cole)  
 C. BACTERIAL PRODUCTION FROM MEASUREMENTS DURING 1988-1991 (data from J.T. Hollibaugh)  
 D. PELAGIC RESPIRATION FROM MEASUREMENTS IN 1993 (data from J. Rudek)

## Dissolved Inorganic Substances (Figure 3)

Photosynthesis is a biochemical reduction of  $\text{CO}_2$  that yields oxygen as a byproduct, so the concentrations of dissolved oxygen (DO) and  $\text{CO}_2$  can change when the rate of phytoplankton photosynthesis (primary productivity) changes. Figure 3, Panel A shows seasonal distributions of DO in the South Bay for 1993 and 1994; Panel B shows the seasonal distributions of total  $\text{CO}_2$  concentration during 1990-1992. As expected, DO concentrations are maximum in spring, reaching levels that are 50% higher than concentrations at equilibrium with atmospheric oxygen (the water becomes supersaturated with oxygen). Carbon dioxide content of the water declines during the spring bloom, and this was particularly evident during the large bloom in April 1990.

Photosynthetic assimilation of  $\text{CO}_2$  provides algal cells with the energy and building blocks required for the biosynthesis of new cellular biomass, and this process involves the uptake of elements required to synthesize proteins (N, S), nucleotides (N, P), diatom cell walls (Si), pigments (N, Mg), enzymes (Zn), etc. Figure 3, Panels C, D, E, and F show that concentrations of such reactive inorganic materials are highly variable in the South Bay and that minimum concentrations are observed in spring. Nutrient concentrations are very high in the South Bay, but phytoplankton primary production can remove the entire pools of dissolved inorganic N and Si and significantly reduce the pool of dissolved inorganic P during spring blooms. In the process, inorganic forms of these elements are converted into particulate organic matter. (Recent evidence shows that phytoplankton similarly transform trace elements such as cadmium, nickel, and zinc.)

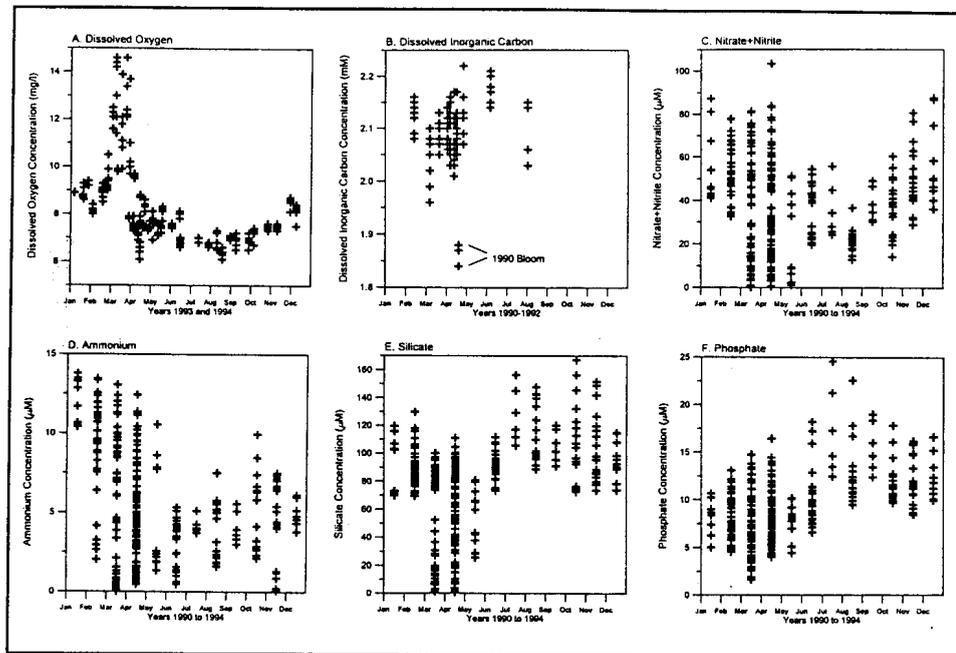


Figure 3  
 SEASONAL DISTRIBUTIONS OF SIX DISSOLVED INORGANIC SUBSTANCES IN SURFACE WATERS OF THE SOUTH BAY:  
 A. DISSOLVED OXYGEN; B. DISSOLVED INORGANIC CARBON (TOTAL CO<sub>2</sub>) (data from M. Huebner);  
 C. NITRATE PLUS NITRITE; D. AMMONIUM; E. SILICATE;  
 F. PHOSPHATE (nutrient data from S.W. Hager)

in the South Bay during spring (Panels C, D). The chemical composition of clams changes during spring blooms as well. The <sup>12</sup>C/<sup>13</sup>C ratio of *Potamocorbula* approaches that of phytoplankton during spring (Panel E), and lipids that can only be synthesized by algae are abundant in clam tissues following the spring bloom (Panel F). These observations are direct proof that phytoplankton biomass produced during spring blooms is incorporated into the tissues of consumer organisms.

### Conclusions

Sustained and multi-faceted investigation of South San Francisco Bay has given us an opportunity to illustrate the central role that phytoplankton play in estuarine ecosystems. Phytoplankton primary production is a large biological engine that acts to transform raw inorganic materials into organic matter that sustains production at other levels of the food web. Blooms are events in which the power of this engine is greatly amplified, with resulting large changes in the geochemical system and in the rate of production by some consumer organisms. It will be difficult, then, for the geochemists to understand variability of reactive substances, such as oxygen, nitrate, and cadmium, without measures of phytoplankton productivity. Fluctuations of populations at the lower trophic levels (including zooplankton and clams) will be difficult to interpret without measures of the production rate of labile POM. Finally, programs designed to understand the fate and effects of toxic substances must consider the role of phytoplankton primary production as a mechanism that transforms reactive contaminants into forms that are readily incorporated into food webs.

One of our largest gaps in knowledge, particularly with respect to the interests of Interagency Program, is the degree to which fluctuations at lower trophic levels propagate to the upper trophic levels — smelt, shad, juvenile salmon, sturgeon. A persistent scientific challenge that we face together is to understand the coupled mechanisms that give rise to variability in fish stocks. Results from study of South San Francisco Bay illustrate why we need to consider phytoplankton production as one potential mechanism of this variability.

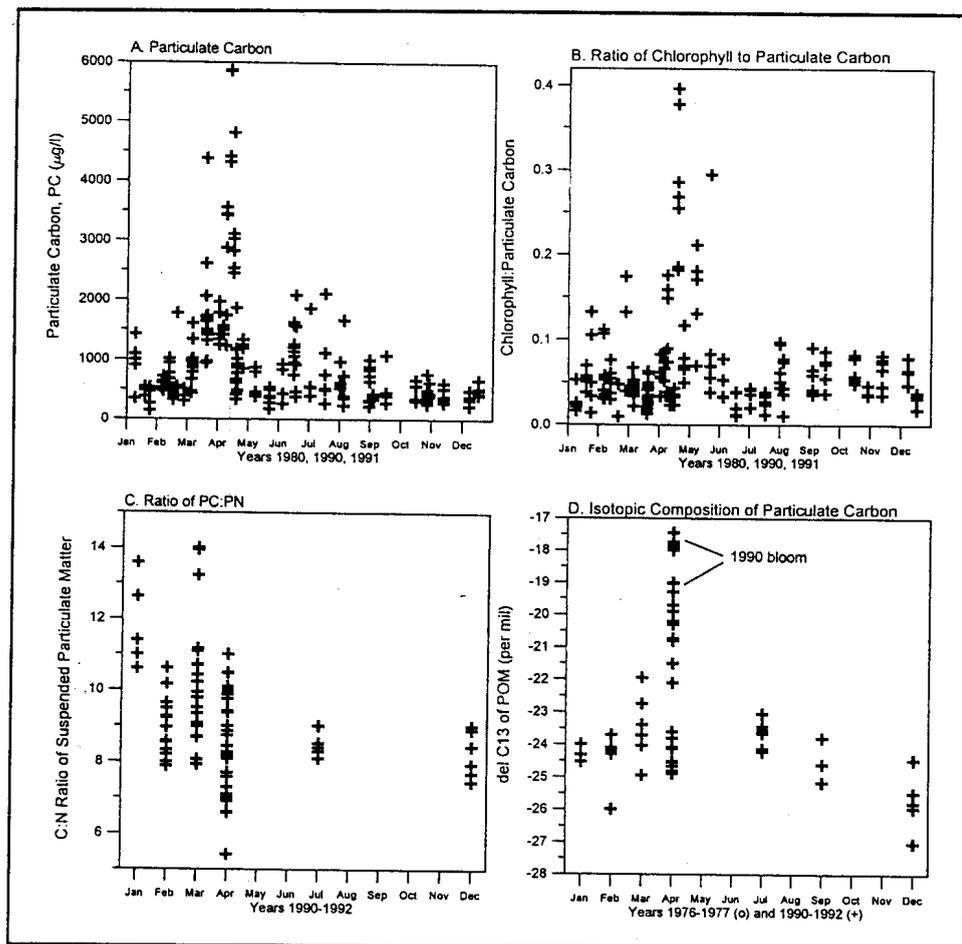


Figure 4  
 SEASONAL DISTRIBUTIONS OF FOUR INDICES OF PARTICULATE ORGANIC MATTER IN SURFACE WATERS OF THE SOUTH BAY:  
 A. CONCENTRATION OF PARTICULATE CARBON  
 B. RATIO OF CHLOROPHYLL TO PARTICULATE CARBON  
 C. C:N RATIO OF POM  
 D. ISOTOPIC COMPOSITION OF CARBON IN THE POM, EXPRESSED AS δ<sup>13</sup>C (data from G. Rau)

## Acknowledgments

Some data presented here were collected in special studies funded by the USGS Toxic Substances Hydrology Program; the San Francisco Estuary Project, Gaps in Knowledge Program; and a pilot study for the San Francisco Estuary Institute, Regional Monitoring Program for Toxic Substances. I thank my colleagues who shared data for this article: Elizabeth Canuel, Brian Cole, Steve Hager, Tim Hollibaugh (Romberg Tiburon Center), Mark Huebner, Anne Hutchinson, Greg Rau (UC-Santa Cruz), and Joe Rudek.

## Recent Interagency Technical Reports

Copies of these Technical Reports can be obtained from Lisa Batiste (916/227-7541; FAX 916/227-7554).

Available Now:

- IATR 41. *Food Habits of Several Abundant Zooplankton Species in the Sacramento-San Joaquin Estuary* (James J. Orsi, DFG).

Available in May:

- IATR 40. *Proceedings of the Eleventh Annual Pacific Climate (PACLIM) Workshop, April 19-22, 1994* (C.M. Isaacs and V.L. Tharp, editors).
- IATR 42. *Working Conceptual Model for the Food Web of the San Francisco Bay/Delta Estuary* (Estuary Ecology Team).

## Literature

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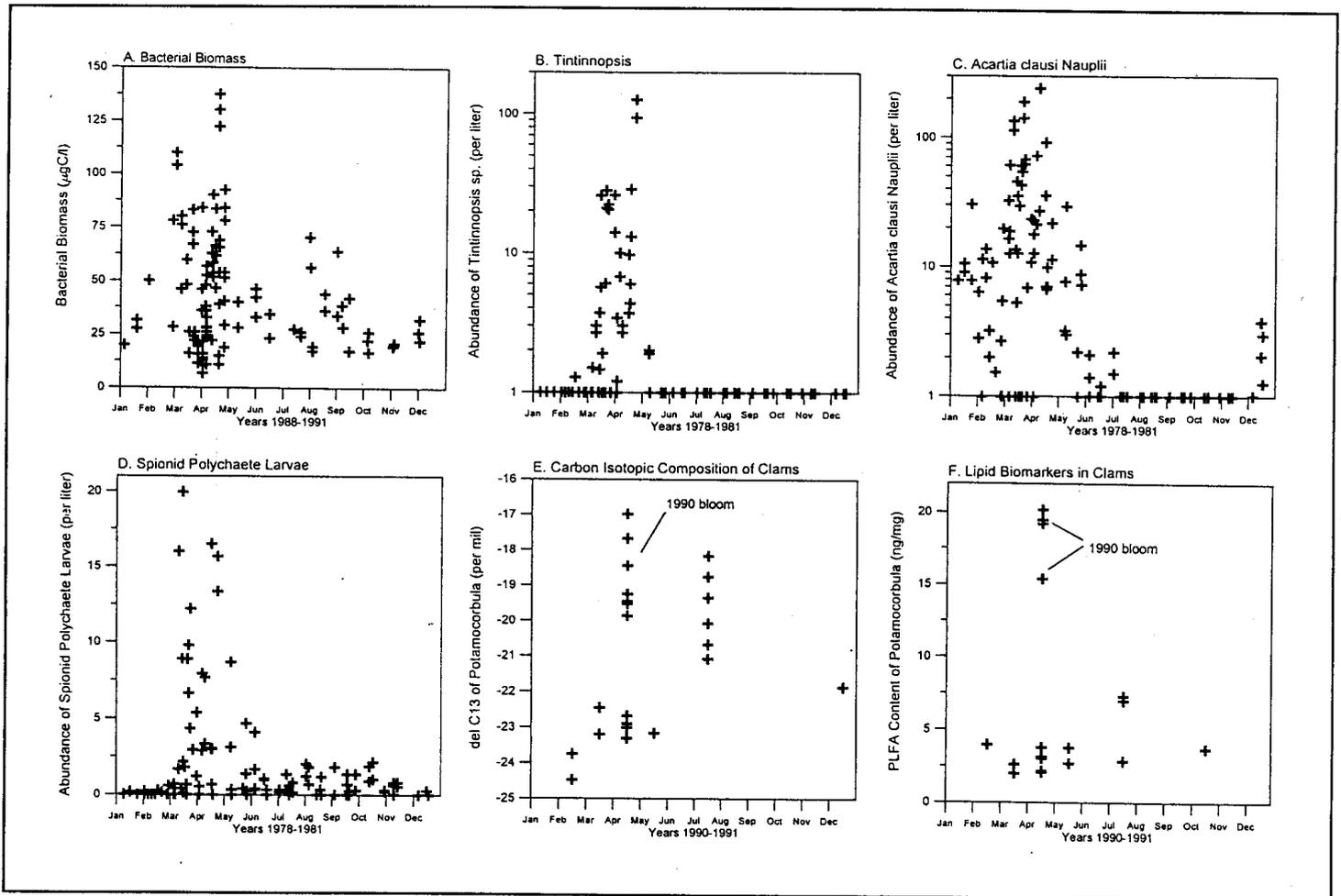


Figure 5

- SEASONAL DISTRIBUTIONS OF SIX INDICATORS OF CONSUMER ORGANISM RESPONSES TO THE SPRING PHYTOPLANKTON BLOOM IN SOUTH BAY:
- A. BIOMASS OF SUSPENDED BACTERIA (data from J.T. Hollibaugh)
- B. ABUNDANCE OF ONE MICROZOOPLANKTON SPECIES (THE CILIATE *TINTINNOPSIS* sp.)
- C. ABUNDANCE OF NAUPLIAR STAGES OF THE COPEPOD *ACARTIA CLAUDI*
- D. ABUNDANCE OF LARVAL STAGES OF SPIONID POLYCHAETES (zooplankton data from A. Hutchinson)
- E. ISOTOPIC COMPOSITION OF CARBON IN THE TISSUES OF THE CLAM *POTAMOCORBULA AMURENSIS* (data from G. Rau)
- F. CONCENTRATIONS OF LIPIDS (PLFA = PHOSPHOLIPID ESTER-LINKED FATTY ACIDS) INDICATIVE OF AN ALGAL ORIGIN IN THE TISSUES OF *P. AMURENSIS* (data from D. Ringelberg and E.A. Canuel)

## Category III Process Underway

The December 15 Bay-Delta Principles committed water users to conduct an open and collaborative process to develop a plan for implementing the "Category III" program. The term was originally used by water users to describe a set of non-flow-related factors that affect bay/delta fish and their habitats. The factors include unscreened diversions; municipal, industrial, and agricultural discharges; over-fishing and illegal fishing; introduced species; channel alteration; and loss of habitat.

The water users convened an ad-hoc work group, which has been meeting weekly to develop the implementation plan. The work group, with representatives designated by CALFED, the environmental community, the fishing community, and water users, includes 14 members:

Laura King ..... East Bay Municipal Utility District  
 B.J. Miller ..... Consulting Engineer  
 Jamie Roberts ..... MWD of Southern California  
 Cliff Schulz ..... Kronick, Moskovitz, Tiedemann & Girard  
 Ed Huntley ..... DWR, Division of Planning  
 Randy Brown ..... DWR, Environmental Services Office  
 Perry Herrgesell ..... Department of Fish and Game  
 Lowell Ploss ..... U.S. Bureau of Reclamation  
 Cynthia Koehler ..... Natural Heritage Institute  
 Gary Bobker ..... The Bay Institute  
 Nat Bingham .. Pacific Coast Federation of Fishermen's Assns.  
 Jim Crenshaw ..... California Sportfishing Protection Alliance  
 Dick Butler ..... National Marine Fisheries Service  
 Bob Pine ..... U.S. Fish and Wildlife Service

Walt Wadlow, Santa Clara Valley Water District, serves as staff to the work group. Representatives from other interests have attended and participated in the meetings.

The work group's efforts should be completed in April. The primary responsibility of the group is to draft an implementation plan that describes how the Category III program will be implemented over the next 3 years. The plan will include recommendations on the process for developing and selecting measures to address Category III factors and on developing an institutional structure to carry out the program. Anticipating that it will take time to implement the institutional structure, the work group developed a Memorandum of Understanding to establish a steering committee and technical advisory committees to continue implementing a program until the longer-term institution can be established. Finally, based on interviews with about 50 people, information from 16 reports and more than 400 measures submitted or developed so far, the work group will recommend a short list of measures for implementation in water year 1996. These measures are not presumed to be the "very best" of the measures but, instead, represent measures that can provide biological benefit and be implemented relatively quickly.

Topics still under discussion include additional financing beyond the original \$10 million per year guaranteed by MWD and the legal form of the longer-term institutional structure. There is no "closing date" for submitting proposed Category III measures. It is expected that new measures will be submitted continually throughout implementation of the program.

To submit a proposed measure, obtain an application from Steve Hirsch at MWD (213/217-6165). For additional information, contact any work group member or Walt Wadlow (408/265-2607 Ext. 2722).

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Sat, May 6, 8:30am - 5pm at the	12:00pm, Oakland Museum,
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& Sat, May 13, 8:30am - 5pm	<b>EVERYONE WELCOME!</b>
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# UPDATE ON STUDIES OF THE BIOLOGY OF THE ENTRAPMENT ZONE

Wim Kimmerer, Romberg Tiburon Center, San Francisco State University

Interagency and university scientists collaborated in spring 1994 on a study of the interaction of biology and physics of the entrapment zone. This study was designed to take advantage of knowledge gained in the USGS study, led by Jon Burau, of circulation patterns in the upper estuary.

The field portion of the project was a joint effort of USBR, USGS, and DWR. Key scientists on the biological study were Jim Arthur, Bill Bennett, Tim Hollibaugh, and Peggy Lehman. In related studies, Kathy Kuivila analyzed the transport of pollutants in sediments, and Dave Schoellhamer examined the movement of sediments within the entrapment zone.

## Background

Studies of entrapment processes in the bay/delta estuary began with the work of Jim Arthur, Doug Ball, and Dave Peterson in the late 1960s-70s. That work, together with related work from this and other estuaries, provided a conceptual model of the function of the entrapment zone. Briefly, that model describes the entrapment zone as a region, near the upstream limit of two-layer flow or null zone, where particles are trapped through the interaction of their sinking and the net, or tidally-averaged, upstream bottom current. This model was extended by Jim Cloern and colleagues to include the growth of phytoplankton: net growth occurs over shoals such as in Suisun Bay, while net respiration occurs in channels, and the proximity of the entrapment zone to shoals enhances biomass. Some zooplankton such as *Neomysis* may migrate vertically in synchrony with the tides, as shown by Jim Orsi.

The physics of estuaries is now known to be more complex than this simple model would suggest. Tidal processes are much more important than previously believed. Upstream flow at the bottom occurs only for brief periods during neap tides. Tides alone can produce turbidity maxima, and lateral processes across the estuary may be as important as vertical processes. Ebb/flood asymmetries in the vertical structure of tidal transport are driven partly by longitudinal density gradients, and partly through nonlinear characteristics of tidal propagation up the estuary. These asymmetries may be capable of net

upstream or downstream transport of particles and organisms.

Thus, the entrapment zone can be characterized as a dynamic and variable physical environment. Yet, maxima in turbidity and in abundance peaks of zooplankton and larval fish persist under most conditions of tide and freshwater inflow. How do these maxima persist, and what are the implications for population regulation in the estuary? Revisions in the conceptual model of the physics of the entrapment zone seem to demand parallel revisions for biology. Furthermore, we would like to know more about the biological and chemical characteristics of the entrapment zone to try to understand what advantage organisms might gain by concentrating there.

## Problem Statement

I include as "particles" all non-living particles as well as living particles with a swimming speed much lower than current velocities; *ie*, plankton and larval fish. Since they cannot swim very fast, their only control over longitudinal or lateral position is through vertical movement. The longitudinal transport or flux of particles through a section across the estuarine channel can be described simply by the equation:

$$\text{Flux} = \overline{UCA}$$

where  $U$  is velocity along the channel,  $C$  is the concentration of particles (or abundance of organisms), and  $A$  is cross-sectional area. The overbar indicates averaging over the cross-sectional area and time. The tidally-averaged value of this flux is the net transport; if this is positive, then on average the material will be washed downstream of this section.

If the velocity  $U$  were always positive, as in a river, the flux would always be outward. However, in San Francisco Bay and the delta,  $U$  reverses tidally and is typically much larger than the net, river-derived water velocity.

The velocity and concentration  $U$  and  $C$  above can each be described as a mean value plus a component that fluctuates in space and time. Then the above equation (simplified by ignoring fluctuations in  $A$  with tide) becomes:

$$\text{Flux} = (\bar{U} \bar{C} + \overline{U_x C_x}) A$$

where  $U_x$  and  $C_x$  are the fluctuating parts of  $U$  and  $C$  respectively. These fluctuating parts, by definition, have an average value of zero.

Typically the mean velocity is positive (downstream) and much smaller than the fluctuating velocity. The fluctuating velocity  $U_x$  varies in time and also in position within the cross section. It can be asymmetrical on ebb and flood so that it is stronger in a downstream direction in one part of the cross section and stronger upstream in another. Estuarine circulation is an extreme case of this, in which the time-averaged velocity near the bottom is negative (upstream) even though the cross-sectionally averaged velocity is downstream.

If the concentration  $C$  is constant or fluctuates randomly, the average value of the right-hand term above will be zero, and the flux of particles will be downstream. Any mechanism that causes the fluctuating parts of  $U$  and  $C$  to covary can cause upstream transport. This can happen in three ways:

1. The concentration of particles in the water column is highest where flow is flood-dominated; this can occur if the particles sink or swim downward, and there is either two-layer estuarine circulation or a pronounced flood dominance in the deeper parts of the water column, and ebb dominance in the shallower locations.
2. The concentration of particles in the water column increases on the flood, either by resuspension of sediments from the bottom or off shoals, or by the migration of demersal organisms off the bottom.
3. The concentration of particles is the same throughout the tide, but the particles are higher in the water column on the flood than on the ebb; this will put the highest concentration at a higher velocity on the flood than on the ebb.

Development of the acoustic doppler current profiler (ADCP) has provided a means of obtaining enough information on the vertical distribution of velocity to resolve the transport of particles. The greatest limitation on such a study is getting adequate resolution of the distribution of particles.

## Study Objectives

The main objective of this study was to take advantage of the effort by USGS on the entrapment zone in spring 1994, and to determine the relationship between vertical and longitudinal positions of common entrapment zone species and the velocity field under various conditions of tide and outflow. Entrapment zone species examined included phytoplankton, bacteria, microzooplankton, *Eurytemora*, *Neomysis*, and larval fish that are sufficiently abundant in the entrapment zone, including delta and longfin smelt and gobies.

Additional objectives were:

- To examine the vertical distribution and longitudinal transport of sediments.
- To determine the importance of particle-bound bacteria to bacterial community metabolism in and out of the entrapment zone.
- To determine the importance of losses from populations through exchange and advection relative to *in situ* mortality.
- To obtain information on small-scale spatial (particularly vertical) distribution of larval fish and zooplankton.

## Study Design

The sampling program had two major elements: continuous monitoring at fixed stations, and short, intensive sampling from a vessel. Continuous monitoring stations were established at four locations. These stations included ADCPs and in some cases CTDs equipped with optical backscatter detectors for determining particulate concentrations.

Intensive sampling was done on two neap tides and one spring tide in April and May from R/V *San Carlos*. Stations were fixed not in space but in salinity: we sampled at 1, 3, and 6 mS/cm surface specific conductance (roughly 0.7, 2, and 4 psu salinity) to approximate the entrapment zone and locations upstream and downstream of it. We used paired 60-cm diameter, 500  $\mu$ m mesh Bongo nets to sample for larval fish and larger zooplankton such as *Neomysis*. These nets, which are capable of being opened and closed at depth, were used to sample near bottom, at mid-depth, and at the surface to determine the vertical distribution of organisms. Although we had some difficulties

with the mechanisms, we obtained enough samples for our analysis.

We used a high-volume pump sampler for smaller zooplankton and phytoplankton. This sampler, assembled by Doug Ball (USBR), was used to sample the same depths as the net, plus intermediate depths as time on station permitted.

These kinds of samples have been taken before, but not in such large numbers nor with such a large volume sampled. Taking large samples improves the statistical utility of the data, and should make it possible to discern any patterns in the data.

The biggest improvement over previous such sampling, however, was the ancillary data collected on the *San Carlos* and other platforms. In addition to a GPS receiver recording precise locations of samples, and a Sea-Bird CTD used to obtain vertical profiles of temperature, salinity, and optical backscatter (OBS), we had a downward-looking ADCP on board. This instrument gave us instantaneous readouts of velocity profiles that were invaluable in timing our samples to the turn of the tide. In addition, we obtained backscattering intensity for particles in a size range about 1 mm, which includes large zooplankton to small fish. Using this instrument we were able to "see" layers of *Neomysis* and amphipods move off the bottom in the evening and disperse into the water column in the early hours of the night. We could also "see" dense bands of reflection indicating schools of fish.

At the same time, USGS had vessels in the estuary taking velocity and CTD (temperature, salinity, optical backscatter) profiles. Tim Hollibaugh was out in R/V *Questuary* by day to sample for bacteria and microzooplankton, and several DFG vessels were out sampling for larval and juvenile fish.

## Results to Date

The hydrodynamic analysis indicates that, contrary to our historical model of the entrapment zone, estuarine circulation is rare in the region of 2 psu salinity in springtime. This is apparently because of the shallow water depth in eastern Suisun Bay and the western delta. Tidal currents in shallow water break down stratification, greatly reducing estuarine circulation. The only exception to this was in brief bursts of upstream bottom currents that occurred around

some of the slack tides. We do not believe these are sufficient to overcome the net downstream transport of the entire water column that is the more common condition.

The ebb/flood asymmetry in velocity profiles, determined using the shipboard doppler, showed no net reversal of bottom currents at 3 mS/cm (Figure 1; note that this is based only on grab samples, not continuous monitoring). At 6 mS/cm, the asymmetry is much more pronounced, so the net seaward current goes to nearly zero near the bottom. This may be due to increased longitudinal density gradients at 6 mS/cm, although it could also be an artifact of the timing of the samples.

Dave Schoellhamer estimated sediment transport based on OBS measurements at the surface and at mid-depth. Surface sediment transport was generally downstream as expected. At mid-depth, there were pulses of net upstream transport; presumably this would have been the case at the bottom as well. These were due not to gravitational circulation, but to an increase in sediment concentration that occurred during flood tides (mechanism 2 above). The source of this sediment is believed to be the shoals of Suisun Bay.

Sampling for phytoplankton, zooplankton, and larval fish typically results in several hundred hours of sample analysis for every hour spent sampling. Thus, sample analysis will continue for 1-2 more months.

Analysis of bacterial samples indicates that the proportion of bacteria that are attached to particles is higher than previously believed. This means that the dynamics of particle movement in the entrapment zone should affect the movement of bacterial biomass. In addition, it means that the higher concentration of particulate matter in the entrapment zone (by whatever mechanism) results in higher bacterial activity. Thus, this may be an important site for conversion of organic matter, and may be a location where bacterial production is important to higher trophic levels through their consumption of non-living particles.

Phytoplankton samples indicate some variability among samples, with slightly higher chlorophyll concentration near the bottom. Longitudinal gradients were large: chlorophyll decreased sharply from the 3 mS/cm station to the 6 mS/cm station.

We expect to sample in the estuary again in 1995, using a design revised based on what we have learned to date. We expect to sample on a shorter time scale to provide better resolution of the movements of organisms. In addition, we will attempt to solve the problems with use of the ADCP for detecting layers of organisms. If we can do that, it will provide us with a way of filling in the data between sampling events.

We anticipate the following results from this program:

- A description of the vertical and longitudinal distributions of all of the biota sampled.
- A description of the nutritional environment of all heterotrophs (bacteria through fish larvae) in and adjacent to the entrapment zone.
- An assessment of the degree to which fish larvae and zooplankton may be food limited, based on the food environment at their actual locations (*ie*, not integrated over the water column). Conditions of some fish larvae in areas of low food concentration may be examined for morphological evidence of food limitation.
- A determination of the importance of hydrodynamic forcing and vertical positioning behavior in maintaining populations within the entrapment zone.
- A determination of the relative importance of the three mechanisms outlined above, and some idea of the way these may change as flow increases.
- Some data on the changes in function of the entrapment zone with flow, possibly suggesting mechanisms for the increase in abundance of certain species as flow increases.

### SWP Delta Pumping

The heavy rains in early March damaged sections of the California Aqueduct below San Luis Reservoir and in the east branch. The damage, coupled with abundant rainfall and a full San Luis Reservoir, resulted in very little SWP Delta pumping. DWR operations staff say pumping will increase slightly in mid-April but will remain much lower than normal — perhaps in the 3,000-cfs range — at least through June.

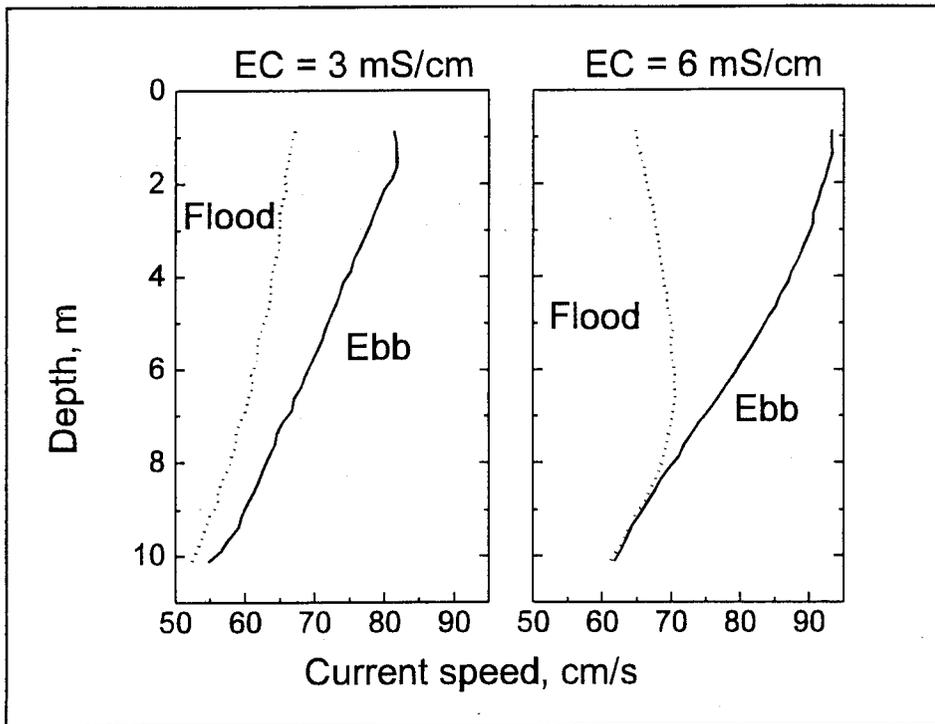


Figure 1  
 EBB/FLOOD ASYMMETRY IN CURRENT SPEEDS DURING THREE CRUISES IN SPRING 1994  
 Left figure shows current speeds at the 3 mS/cm station.  
 Right figure shows speeds at the 6 mS/cm station.

Zooplankton analysis so far indicates pronounced diurnal vertical migration in the larger zooplankton, comprising the mysids *Neomysis* and *Acanthomysis* and amphipods. On all three cruises these taxa were more abundant near the surface at night than by day. In addition, on all three cruises they were more abundant near the surface during the flood than during the ebb. If this reflects the behavior of these organisms, it corresponds to mechanism 3 above.

Smaller zooplankton also underwent tidal migration but to a lesser extent. In addition, the diurnal component of their migration was nearly absent. This is in contrast to results obtained for *Eurytemora affinis* and *Pseudodiaptomus* species in many other estuaries; in some locations these species remain on the bottom by day. The difference could be due to the low light levels at depth in the entrapment zone, which would reduce vulnerability to visual predation.

Larval fish analysis to date indicates that gobies, mainly yellowfin with some "double-banded" (formerly chameleon) gobies, were most abundant. Smelt larvae were abundant as well, mainly on the surface at night; about 90% of these were longfin, and the rest delta smelt. There were some striped bass larvae and a few other

taxa. Longfin smelt larvae remained near the surface, while juveniles were deeper in the water column, and migrated tidally so that they were higher on the flood than on the ebb (mechanism 3). Striped bass larvae were generally higher in the water column than previously shown, and were closer to the surface on floods than on ebbs (mechanism 3).

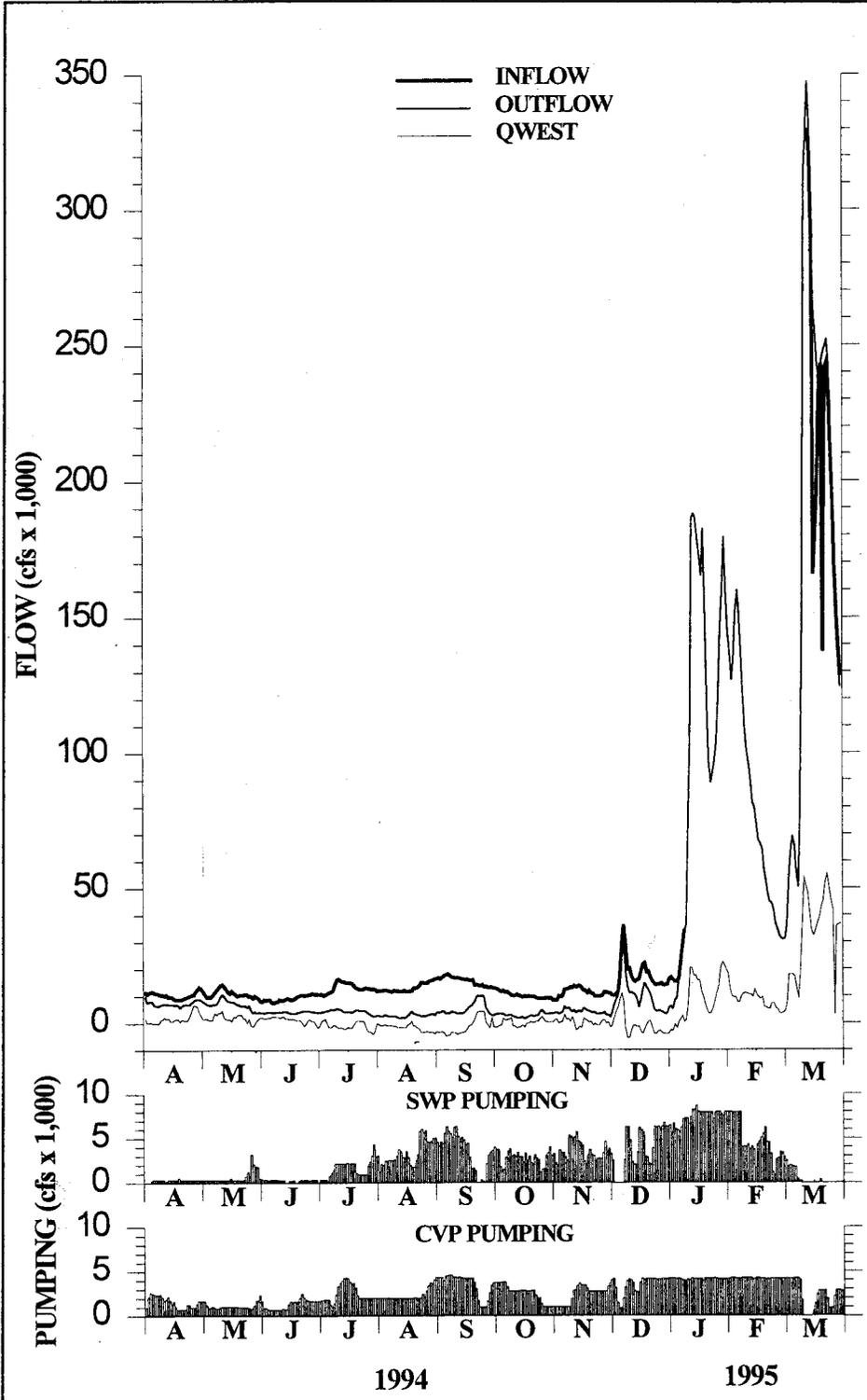
We have used results of ADCP sampling to provide data on the vertical distribution of sound-scattering particles in the water. During the cruises it became apparent from their vertical movements that scattering layers were composed of organisms. For example, layers were seen to move up and down in the water column in apparent response to tide and sunlight. However, we have not yet been able to show a convincing relationship between sound scattering and abundance of organisms. There are several possible reasons for this:

- Interference by sediment particles (backscatter data are correlated with OBS data, which represent only sediment particles).
- Inability to resolve the identification of the main scattering organisms.
- Lack of data so far on the biomass or scattering target strengths of the organisms collected in our nets.

## Delta Flows

Sheila Greene, DWR

The Delta Outflow Index averaged about 120,000 cfs from January through March 1995. February storms caused the index to increase to 180,000 cfs, and March storms caused a peak of 350,000 cfs. Combined SWP and CVP pumping was near 12,000 cfs during January but reduced during February as San Luis Reservoir filled. On March 11, SWP pumping was reduced to meet only South Bay Aqueduct demands, and CVP pumping has been about 2,500 cfs.



## Delta Environment Science Center

A consortium of Bay Area institutions, including Contra Costa County, CSU-Hayward, East Bay Regional Parks District, Ironhouse Sanitation District, Contra Costa Community College District, and The Audobon Society have initiated the planning and development of a Delta Environment Science Center.

The center is envisioned as a facility that provides a focus for education, field studies and research, and restoration demonstration for the Sacramento-San Joaquin estuary, as well as a physical and institutional setting for dialog and consensus-building around issues affecting the delta's future. The educational mission encompasses K-12, university level, and general public and topics ranging from the history of the delta, to environmental issues, to the interface with urban and agricultural needs.

The consortium has contracted with Mogavero Notestine Associates, a Sacramento planning, architectural, and project management firm, to undertake an initial study for the project to assess demand for the various activities, explore funding options, define the program, analyze financial feasibility, do a site analysis, and provide a conceptual design. The consultant is in the initial phases of the study and looking for ideas on:

- Needs for research and study of the delta.
- Facility needs for education or research.
- Needs for general public educational program.
- Institutional needs for dialog and consensus-building.
- Funding alternatives.
- Other ideas on possible roles for DESC.

To discuss your ideas or obtain information, please call David Mogavero at 916/443-1033.

## Guidelines for Submitting Articles to the Interagency *Newsletter*

- Keep it simple.
- Keep it short.
- Keep figures, tables, and captions simple and use them sparingly.
- Keep literature citations to a minimum.

• Keep these things in mind —

Our editor will be reformatting your article, so please:

- Submit both a hard copy and an IBM-compatible electronic copy. Any standard word processing software is fine, as long as it's IBM. Graphics files are a bit of a problem, but Lotus Freelance Graphics \*.PRE files work nicely. Vector files are better than raster files. Metafiles are also acceptable.
- Do not include **boldface** or underlined text in your headings. Use *italics* for scientific names only.
- Use a highlighter to mark scientific symbols on the hard copy so the editor can be sure they don't get lost in the conversion process.
- Include figures, tables, and their captions as separate files.
- Write concise captions.

→ Size your figures so that they fit width-wise into the narrowest possible box on this page. If they fit, you maintain control. If they don't fit, they will be reduced — and the type reduces along with the image! (You may be surprised at how much more professional your graphics look when you scale them down.) The height may not exceed 9.5 inches, including the caption, which must be brief.

→ Be aware that what looks great on your computer will not necessarily print well. A shaded background is lovely in color, but it looks like mud when printed in black and white.

→ Graphics will be printed in portrait orientation. Those submitted in landscape will be reduced and placed straight up. No exceptions!

Send a hard copy of your article to Randy Brown, 3251 S Street, Sacramento, CA 95816. Send a second hard copy, original graphics, and a diskette containing text and graphics files to Vera Tharp, 9317 Spring Valley Road, Marysville, CA 95901. If you have questions, call Vera at 916/743-4150.

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Make certain your words and numbers are large enough to read after they have been reduced.

### Real-Time Monitoring

The December "Delta Agreement" commits the CALFED Ops Group to using real-time monitoring to the extent possible to make decisions regarding water project operational flexibility. The group meets monthly to discuss project operations and, in particular, how these operations may affect listed fish species. An outgrowth of these meetings has been the creation of an intense monitoring effort this May and June to help determine if field programs can collect and disseminate fisheries information in near real time for use in project opera-

tions. This year's efforts will be aimed mainly at the logistical components of getting the boats and people in the field and turning the data around in a timely manner.

The program development has been a collaborative effort between Interagency staff and consultants representing the CUWA/Ag coalition and the State Water Contractors. Field efforts will take advantage of some existing programs such as salmon monitoring at Sacramento, Chipps Island, Mossdale (on the

San Joaquin River), and the acoustical barrier testing at Georgiana Slough. Additional sites will be added as needed to increase geographic coverage in areas that may be fish routes toward the pumps.

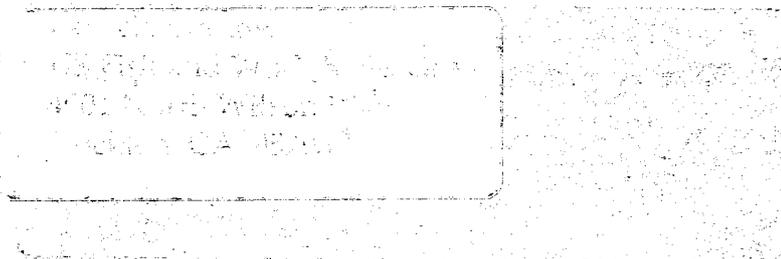
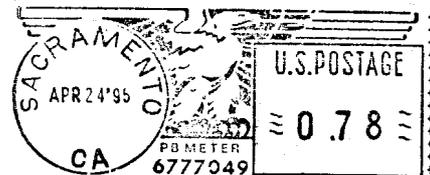
This year's field work is to be conducted mainly by Interagency Program staff, with some backup support by the State Water Contractors. About 15 boats and crews will be involved, and some programs will be deferred, modified, or eliminated to accommodate the monitoring.

Interagency Ecological Program

*Newsletter*

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Sacramento, CA 95816-7017



Interagency Ecological Program for the Sacramento-San Joaquin Estuary

# *Newsletter*

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The Interagency Ecological Program is a  
Cooperative Effort of the:

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State Water Resources Control Board  
U.S. Bureau of Reclamation  
U.S. Army Corps of Engineers

California Department of Fish and Game  
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