Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

Winter 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.

Hydrodynamic Influences on Interannual Chlorophyll Variability

Alan Jassby, University of California at Davis

The estuarine environment for phytoplankton is highly variable, ultimately reflecting the hydrodynamic variability induced by streamflow, tide, and wind. Collectively, these forces operate on many time scales, from hours in the case of semidiurnal tides to years in the case of streamflow. The longer-term variability due to streamflow, especially at time scales of at least a year, is of particular interest, as streamflow can mediate both climatic and human impacts on estuaries. The response of the phytoplankton community to these year-to-year changes has potential ramifications for both water quality and the abundance of higher organisms. Only recently have records become long enough to characterize interannual variability in estuarine phytoplankton. Because of the strong physical stirring and bioturbation of estuarine sediments, sediment cores do not offer the access to long-term variability data afforded by many layered sediments. Our understanding of the nature and mechanisms of interannual change in phytoplankton communities, therefore, has to be built up over the years by a prolonged and consistent observational program.

San Francisco Bay and the Sacramento-San Joaquin Delta exemplify both the need and the opportunity to understand hydrodynamic control of interannual phytoplankton variability. Climatic fluctuations combined with operation of freshwater storage and withdrawal facilities have led to decadal-scale variability in the seasonal distribution and annual amount of water flowing through the delta into the bay. Observations of chlorophyll concentrations — which can be used as a surrogate for phytoplankton biomass — in Suisun Bay and the delta since 1968 enable examination of phytoplankton dynamics against this background of hydrodynamic variability. In the study summarized here, we investigated hydrodynamic influences on year-to-year chlorophyll variability in the landward estuary; that is, Suisun Bay and the delta. An underlying goal was to present a unified treatment of previous results indicating the significance to phytoplankton of flow through the delta and new evidence for the significance of water export out of the estuarine system into water projects. The dataset consisted of measurements of specific conductance and chlorophyll *a* at 24 sites throughout Suisun Bay and the delta. USBR and DWR collected and analyzed the samples; hydrodynamic data were taken from the DAYFLOW database.

The first part of the analysis examined which stations and seasons were responsible for most of the interannual variability, using a novel application of principal component analysis. The single most variable feature was the chlorophyll concentration during the summer in the 1-6‰ near-surface salinity range, the approximate range of the estuarine turbidity maximum. The ETM, therefore, stands out even on a purely statistical basis, without any biological considerations. A second significant contribution to interannual variability was the size of spring phytoplankton blooms in the southern delta (not discussed in this summary). Together, the year-to-year

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changes in these two features account for almost all of the long-term change in chlorophyll patterns. Knowing this enables us to focus on specific locations and seasons, eliminating the "noise" from other stations and times of year and greatly simplifying subsequent analyses.

The next step was to examine the relationship between chlorophyll in the summer ETM and hydrodynamic variables, using a statistical modeling algorithm known as AVAS (additivity and variance stabilization). The analysis concluded that two variables were important: Q_{out}, or mean outflow from the delta in the bay, and Q_{exp}, or mean export from the delta into county, state, and federal water projects. The relationship between chlorophyll and Q_{out} was a nonlinear unimodal one, with peak chlorophyll occurring at annual mean flows of 500 cubic meters per second. On the other hand, the dependence on Q_{exp} was linear, with a negative slope. Q_{out} is known to be important for Suisun Bay phytoplankton because of its effect on primary productivity through positioning of the ETM, on grazing rates through control of molluskan density, and on chlorophyll loading from upstream. The unimodal response to outflow that we derived from purely statistical considerations is consistent with these previously postulated mechanisms. The results do not allow us to distinguish among these mechanisms; they do, however, confirm the essentially nonlinear character of the relationship between phytoplankton biomass and flow.

Q_{exp} is a separate and important source of variability for the ETM. According to the statistical evidence, export is responsible for the same general magnitude of variability as outflow. We believe this second mechanism operates through the export of phytoplankton from upstream of the ETM into water projects. To investigate this further, we estimated the mass transport of chlorophyll for three different boundaries in the delta:

- Total *influx* from the rivers.
- *Export* into county, state, and federal water systems.
- *Outflow* across a north-south boundary in the delta at Rio Vista.

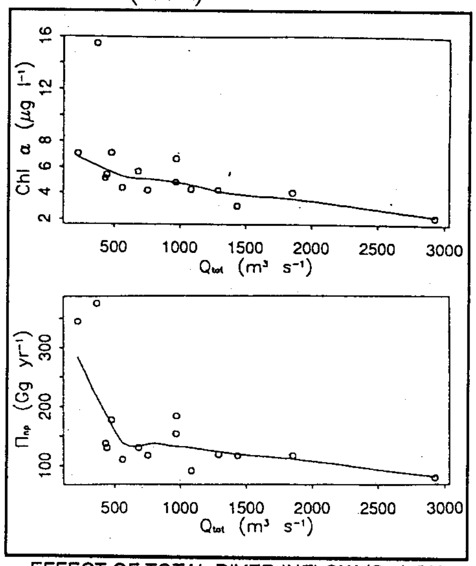
We found that median annual export of chlorophyll was 62% of total *efflux* (export plus outflow) for 1975-1989 and varied by a factor of 7, from 13% in 1983 to more than 50% in most of the years since 1983. Clearly, the diversion of phytoplankton away from downstream destinations can have significant and highly variable impacts on phytoplankton biomass in the ETM.

The question naturally arises: Does this upstream phytoplankton biomass come ultimately from the rivers, or is it produced within the delta? Our calculations showed that the delta increased incoming chlorophyll by a median of 34%. Is this augmentation of incoming phytoplankton consistent with primary production estimates? Based on theoretical and empirical considerations, we found that delta primary productivity could easily explain the additional phytoplankton biomass. In fact, the delta is a significant source of primary production. In 1980, for example, we estimate that the delta contributed 28% of net phytoplankton production in the northern estuary. Most of the phytoplankton from influx and production within the delta (79%) appears to be used locally. Some of this material is lost to aphotic phytoplankton respiration, but the rest must enter food webs within the delta, eventually to be respired by consumers or carried downstream in a form other than phytoplankton.

The analysis presented here also enabled us to speculate on how changes in delta "plumbing" might affect the delivery of phytoplankton to downstream destinations. In particular, we asked what the consequences are of diverting water for export from upstream of the delta—directly from the rivers — rather than from the delta itself. The key to this prediction is the relationship between mean chlorophyll concentrations in efflux from the delta and total inflow (Q_{tot}; see figure). In general, lower river inflow implies higher efflux concentrations. If Q_{out} is held constant but Q_{exp} is set to zero and replaced by an equal diversion from upstream of the delta, then efflux (and outflow) concentrations should increase. The net result should be a higher outflow of chlorophyll from the delta; that is, a greater supply of phytoplankton to the ETM and downstream locations. There is some indication that primary productivity within the upper delta would increase as well (see figure below). Many caveats could be added to these simple deductions, which naively treat the delta as a complete mixed reactor with a single inflow and outflow. Moreover, the desirability of enhanced chlorophyll concentrations and primary productivity in the delta cannot be assumed *a priori*.

Aquatic populations of the delta and Suisun Bay have undergone significant declines over the last several decades. The simultaneous declines in many estuarine species suggest that they are responding to common stresses, and decreased freshwater inflow due to drought and increased water diversion from the upper estuary play a role for at least some populations. The causal relationships mediating hydrodynamic influences on higher organisms are diverse, but in some cases food supply may play a role. The evidence presented here demonstrates that export of water from the estuary must be having a major impact on variability of this food supply and, therefore, possibly on the food web it supports.

For more information see: A.D. Jassby and T.M. Powell, "Hydrodynamic influences on interannual chlorophyll variability in an estuary: Upper San Francisco Bay-Delta (California, U.S.A.)". *Estuarine, Coastal and Shelf Science* 39(1994).



EFFECT OF TOTAL RIVER INFLOW (Q_{tot}) ON PHYTOPLANKTON

Upper Panel: Concentrations of chlorophyll in efflux (outflow plus export) from the Delta.

Lower Panel: Annual net photic zone production in the Delta. The solid line is less smooth with span=0.67.

A G E N D A

INTERAGENCY ECOLOGICAL PROGRAM ANNUAL WORKSHOP and BAY/DELTA MODELING FORUM

March 8-10, 1995 — Asilomar Conference Center

March 8 — Wednesday

10:00	Bay/Delta Modeling Forum Special Session — Interagency Program personnel are invited; attendance is optional.	
12:45	Arrive and Assemble in the Chapel — **DO NOT** check in!	
1:30	Welcome and Update	Pat Coulston, DFG
	BAY/DELTA MODELING FORUM	**Chair: Rich Satkowski, DWR**
1:25	Bay/Delta Modeling Forum Introduction	Greg Gartrell, Contra Costa Water District
1:45	G Model	Richard Denton, Contra Costa Water District
2:10	Daily Delta Model	Russ Brown, Jones & Stokes
2:35	Introduction to Internet	Martin Maxwell, DFG, and Kevin Wolf, Water OnLine
3:00	**CHECK IN** — Report to the Interagency Program Check-In Table	
3:30	Bay/Delta Modeling Forum Meeting	
6:00	Dinner (Served until 7:00 only!)	
7:00	Mini Social in the Chapel	
	EVENING PROGRAM	**Chair: Liz Howard, USBR**
7:30	Education/Entertainment Speaker	
8:30	Adjourn	

March 9 — Thursday

7:00	Breakfast (Served until 8:00 only!)	
8:15	Announcements	Chuck Armor, DFG
	1994 ENTRAPMENT ZONE STUDIES, PART 1	**Chair: Chuck Armor, DFG**
8:20	Hydrodynamics	Jon Burau, USGS
8:45	Sediment	Dave Schoellhamer, USGS
9:05	Phytoplankton	Peggy Lehman, DWR
9:30	Microzooplankton	Tim Hollibaugh, Romberg Center
9:55	Break	
	1994 ENTRAPMENT ZONE STUDIES, PART 2, AND OTHER CURRENT RESEARCH	**Chair: Leo Winternitz, DWR**
10:20	Zooplankton	Wim Kimmerer, Romberg Center
10:45	Larval Fish	Bill Bennett, UC-Davis Bodega Marine Lab
11:10	Asian Clam Feeding Dynamics	Jan Thompson, Stanford University
11:35	Pacific Herring Fertilization and Embryo Development	Gary Cherr, UC-Davis, Bodega Marine Lab
12:00	Lunch	
1:00	Free Time (Additional Bay/Delta Modeling Forum presentations may be scheduled for 1:00 to 5:00.)	
5:00	Social Hour — In Chapel	
6:00	Dinner	
	EVENING PROGRAM	**Chair: Perry Herrgesell, DFG**
7:00	Sound Science and Regulatory Process	Betsy Rieke, Assistant Secretary for Water and Science, U.S. Dept. of Interior
	Revision to the Endangered Species Act: How Far Should They Go?	Donald Barry, Counselor to the Assistant Secretary, Office of Fish, Wildlife and Parks, U.S. Dept. of Interior, and Paul Selzer, Senior Partner, Best, Best and Krieger
9:30	Adjourn	

March 10 — Friday

7:00	Breakfast	
8:15	Announcements	Chuck Armor, DFG
	SPECIES OF SPECIAL CONCERN, PART 1	**Chair: Pat Brandes, FWS**
8:20	The "Water Deal": IEP Monitoring Response	Pat Coulston, DFG
8:45	Status of Salmon in the Central Valley	Mark Pierce, FWS
9:10	Montezuma Slough Adult Salmon Movement Study	Terry Tillman, DFG
9:35	Splittail Gill-Net Survey	Randy Baxter, DFG
10:00	Break	
	SPECIES OF SPECIAL CONCERN, PART 2	**Chair: Pete Smith, USGS**
10:25	Delta Smelt Distribution and Special Studies	Dale Sweetnam, DFG
10:50	Delta Smelt Gear Evaluations / Zone of Influence Study	Chuck Hanson, Hanson Environmental, Inc.
11:15	Concluding Remarks	Pat Coulston, DFG
11:30	Check Out of Rooms	
12:00	Lunch	

A POSTER SESSION will be held concurrently with the Workshop. Please review the contributions during breaks or at other times.
NOTE: Unless otherwise indicated, speakers will be allotted 25 minutes: 15 minutes for presentations and 10 minutes for questions.

TIME LIMITS WILL BE STRICTLY ENFORCED

Potential Effects of Exotic Inland Silversides on Delta Smelt

William A. Bennett, University of California, Davis, Bodega Marine Laboratory

Understanding the relative importance of factors regulating the abundance of delta smelt is fundamental for managing this threatened species, yet much remains uncertain. As with many other species in the estuarine food web, the major factor thought to affect smelt abundance is low freshwater outflow, produced by drought and water diversions. Such conditions may facilitate entrainment of individuals by the pumping facilities, as well as reduce the quantity and/or quality of suitable nursery habitat (Moyle *et al* 1992). Recently, Bruce Herbold (EPA) showed that the fall abundance of delta smelt was significantly associated with the number of days during spring that the entrapment zone resided in Suisun Bay, thus providing the first statistical relationship supporting this hypothesis (Herbold 1994). He and others (Moyle *et al* 1992) suggest that when the entrapment zone is in Suisun Bay, young delta smelt are provided with a larger quantity of shallow, low-salinity habitat, which may be necessary for young smelt. In this article, I propose a more explicit mechanism to explain the decline of delta smelt and the apparent benefit of positioning 2-ppt in Suisun Bay during spring.

Over the past few months I have been exploring the role exotic inland silversides (*Menidia beryllina*) play in regulating the delta smelt population. Silversides may affect delta smelt through intraguild predation, a process by which a species both competes with and consumes a fellow species in an ecological guild (Polis *et al* 1989). Delta smelt and inland silversides qualify as members of the same guild, since both species live about a year and are similar in size and morphology. They also have similar diets, consisting primarily of copepods and cladocerans, although silversides have a wider niche breadth, also consuming benthic amphipods and terrestrial insects.

Inland silversides, native to the eastern United States, were introduced illegally into Clear Lake, California, in 1967 and made their way to the Delta in about 1975 (Moyle 1974, 1976; Meinz and Mecum 1977). Silversides colonized the near-shore (shoal) areas of the Sacramento and San Joaquin rivers and the Delta, appearing to segregate spatially from the more pelagic species of concern (striped bass, delta smelt). As a result, management agencies considered them innocuous and they were under-represented by most monitoring efforts, which focus primarily in mid-channel areas. Inland silversides are euryhaline such that their distribution extends into Suisun Marsh and the shoreline of Suisun Bay, although they appear to be more abundant in fresh water.

In 1992, we used inland silversides as predators on larval striped bass in a series of experiments in large field enclosures (1×5 meters) in Montezuma Slough. In each of two enclosures, one silverside was presented with 40 striped bass larvae (5-7 mm) and zooplankton as alternative prey items. These studies, coupled with laboratory experiments, showed that silversides can be voracious larval predators, readily consuming 60-85% of the larval striped bass in the enclosures within 4 hours (Bennett and Rogers-Bennett 1994). Recently, we have been examining silverside guts from several locations in the delta and Suisun Marsh, finding a larval goby and the potential remains of two other larvae despite the fragility and rapid digestibility of fish larvae.

While silversides prey on larval fish, they would have to co-occur with delta smelt larvae for predation to affect smelt year classes. Delta smelt have demersal and adhesive eggs, which they spawn in fresh water near the shoreline on emergent vegetation, rocks, or tree roots (Moyle *et al* 1992). These areas are precisely where inland silversides have become most abundant. Therefore, we propose that hatching larval smelt may be extremely vulnerable to schools of foraging silversides. In addition, we suggest that their effect on smelt is enhanced in low-outflow years. This is because spawning smelt and larvae remain almost exclusively in the Sacramento River between Collinsville and Sacramento, where silversides are most abundant. In high-outflow years, adults and larvae are distributed more evenly and lower in the system, thus adults and larvae may move rapidly through areas of high silverside abundance, accumulating in Suisun Bay where they have a higher probability of occurring away from shoreline areas. Therefore, is the invasion of inland silversides associated with the decline of delta smelt? And does the amount of outflow during the smelt spawning season affect this potential relationship?

Analyses

I used estimates of delta smelt abundance as measured by DFG's fall midwater trawl survey from 1967 to 1993 (except 1974 and 1979, when no samples were taken). I relied on the subset of stations recommended by the Delta Native Fishes Recovery Team (Peter Moyle and Dale Sweetnam, pers comm). The best available record of inland silverside abundance is contained in the FWS Salmon Smolt Beach Seine Survey, which began in 1976, fortunately coinciding with silverside introduction.

I compiled these data for seine hauls between January 1 and April 30 for stations from Sacramento south to Tracy, east to Stockton and west to Sherman Island to provide annual abundance estimates for silversides (catch/haul). For statistical comparisons with smelt abundance, I also used data from a subset of these stations (Figure 1) located in the spawning and larval smelt habitat. These stations are in the area from which 74% of all yolk-sac delta smelt larvae were collected by DFG in 1991, using data from Wang and Brown (1993). Outflow conditions were measured using the daily position of 2-ppt bottom salinity as estimated by X2 (Kimmerer and Monismith 1993) during April and May, the peak spawning time for delta smelt.

Estimates of silverside abundance and position of 2-ppt salinity were used to develop an "intraguild predation index". To do this, I weighted silverside abundance by the proportion of days during April and May in which X2 position was greater than 75, or upstream of Suisun Bay

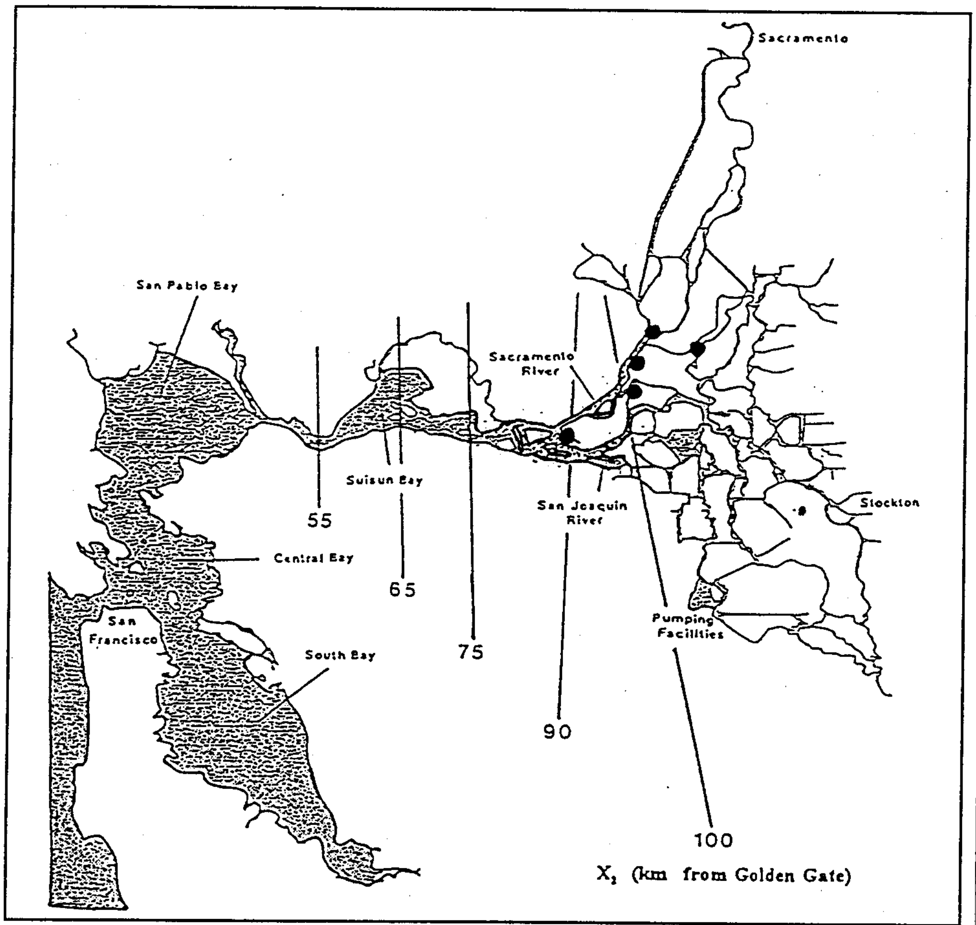


Figure 1
FWS BEACH SEINE SITES USED IN STATISTICAL ANALYSES AND
X2 POSITION IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

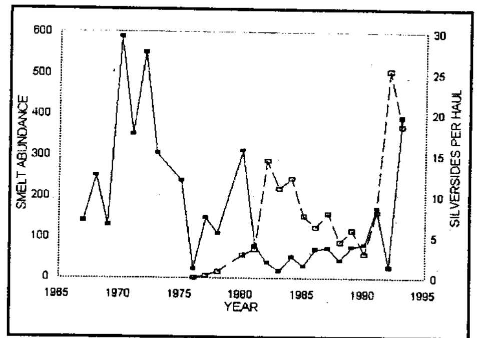


Figure 2
ABUNDANCE OF DELTA SMELT *(solid boxes)* AND
INLAND SILVERSIDE *(open boxes)*, 1965-1994

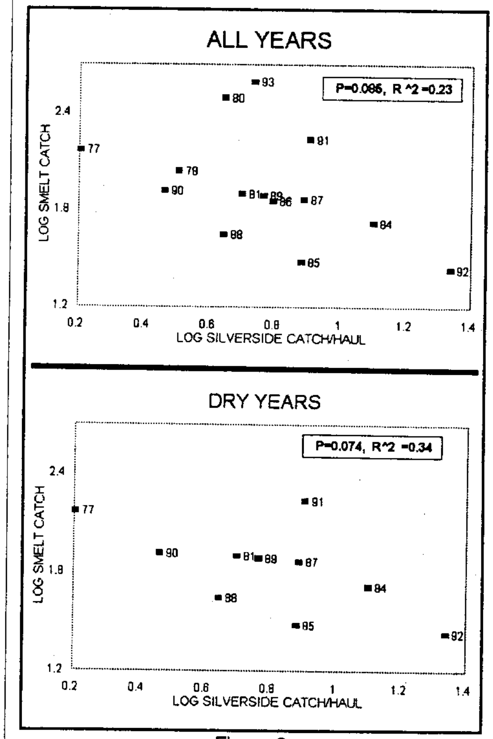


Figure 3
ABUNDANCE OF DELTA SMELT AND
INLAND SILVERSIDE IN
ALL YEARS AND IN DRY YEARS, 1977-1993

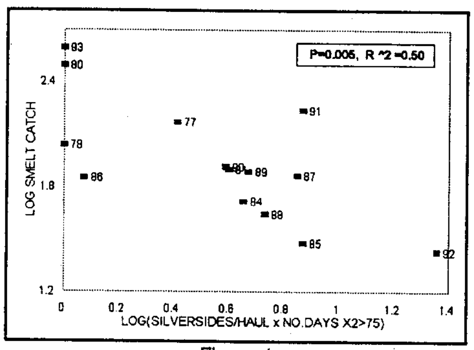


Figure 4
ABUNDANCE OF DELTA SMELT AND
INLAND SILVERSIDE WEIGHTED BY
PROPORTION OF DAYS IN APRIL AND MAY THAT
X2 WAS ABOVE SUISUN BAY, 1977-1993

(Figure 1). This index serves as a proxy for the degree of spatiotemporal overlap between the species and, thus, the potential effects of predation and competition exerted by silversides on smelt. I excluded 1982 and 1983 from the analysis, because X2 position was below Suisun Bay (X2<55) more than 50% of the time during April and May. Many believe smelt are flushed from the system in such years (Moyle *et al* 1992), thus silversides would not have an effect.

Results and Discussion

A temporal plot of abundance estimates (Figure 2) indicates inland silversides increased dramatically at about the same time the delta smelt population crashed in 1981 and 1982. Figure 3 shows a plot associating the abundance of delta smelt and inland silversides from 1977 to 1993 (all years) and a similar plot including only dry years, using DWR criteria for water year type. Both plots indicate weak associations between silverside and smelt abundance.

A plot regressing smelt abundance with the intraguild predation index (Figure 4) is significant, providing a strong association between abundance of delta smelt and inland silversides. In addition, this relationship supports the hypothesis that entrapment zone position mediates the potential effects of silversides on delta smelt. Further evidence comes from the plots in Figure 5. "Before" the silverside invasion, delta smelt catch is not affected by entrapment zone position; "after" silversides became established, X2 position is weakly associated with smelt catch (p=0.054). This graph depicts a pattern similar to the one presented by Herbold (1994), in which smelt abundance increases in years when X2 spends more time in Suisun Bay. In addition, silverside abundance is not associated with X2 position. Therefore, these analyses provide an explicit hypothesis, demonstrating how inland silversides have potentially affected the abundance of delta smelt, contributing to its status as a threatened species.

The intraguild predation hypothesis is appealing, but much remains uncertain, particularly the mechanism(s) by which X2 position influences the magnitude of these effects. Such mediation may occur at several spatiotemporal scales. For example, in wet years delta smelt may exhibit large-scale (kilometers) changes in spawning location relative to dry years or more subtle shifts of a few meters, sufficient to isolate their spawn from predation. Smelt larvae may also spend less time in vulnerable habitats. Similarly, while adults of the two species appear to be spatially segregated, silversides in Clear Lake are known to undertake diel foraging migrations away from their typical shoreline habitat (Wurtzbaugh and Li 1987). Offshore foraging by schools of silversides would increase substantially the probability of competition with adult smelt and might influence where smelt spawn. However, while much remains to be learned about the potential effects of silversides on delta smelt, as well as how such effects might be ameliorated, the data at hand clearly suggest that maintaining 2-ppt salinity in Suisun Bay during April and May will increase the probability of successful smelt year classes.

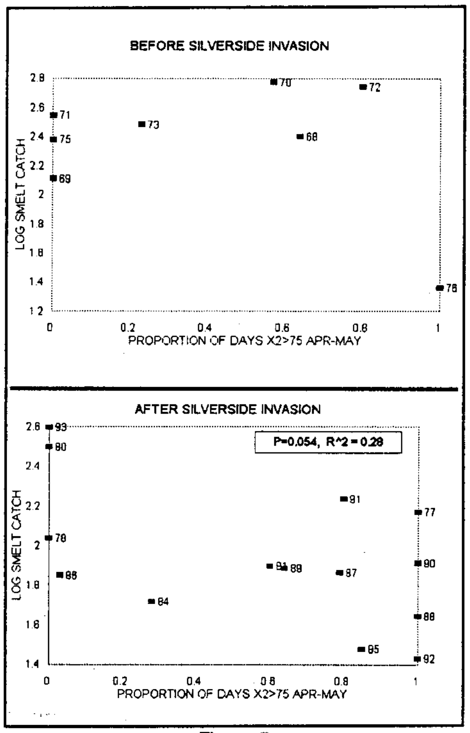


Figure 5
CATCH OF DELTA SMELT WITH PROPORTION OF DAYS IN APRIL AND MAY THAT X2 WAS ABOVE SUISUN BAY BEFORE 1967-1976 AND AFTER 1977-1993 (INVASION OF INLAND SILVERSIDE)

Literature Cited

Bennett, W.A., and L. Rogers-Bennett. 1994. Interaction of starvation and size-selective predation on larval striped bass *(Morone saxatilis)*. Submitted to *Canadian Journal of Fisheries and Aquatic Sciences*.

Wang, J.C.S., and R.L. Brown. 1993. Observations of early life stages of delta smelt, *Hypomesus transpacificus*, in the Sacramento-San Joaquin Estaury in 1991, with a review of its ecological status in 1988 to 1990. Technical Report 35. Interagency Ecological Program. FS/BIO-IATR/93-35.

Herbold, B. 1994. Habitat requirements of delta smelt. *Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter*. Winter 1994:1-3.

Kimmerer, W., and S. Monismith. 1993. An estimate of the historical position of 2-ppt salinity in the San Francisco Bay Estuary. In, Schubel *et al*, editors. *Managing Freshwater Discharge to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: The Scientific Basis for an Estuarine Standard*. San Francisco Estuary Project.

Meinz, M., and W.L. Mecum 1977. A range extension for Mississippi silversides in California. *California Fish and Game* 63:277-278.

Moyle, P.B. 1974. Mississippi silversides and logperch in the Sacramento-San Joaquin river system. *California Fish and Game* 60:144-149.

Moyle, P.B. 1976. *Inland fishes of California*. Univ. California Press, Berkeley.

Moyle, P.B., B. Herbold, D.E. Stevens, and L.W. Miller. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin estuary, California. *Transactions of the American Fisheries Society* 121:67-77.

Polis, G.A., C.A. Myers, and R.D. Holt. 1989. The ecology and evolution of intraguild predation: potential competitors that eat each other. *Annual Review of Ecology and Systematics* 20:297-330.

Wurtzbaugh, W., and H.W. Li. 1985. Diel migrations of a zooplanktivorous fish (*Menidia beryllina*) in relation to the distribution of its prey in a large eutrophic lake. *Limnology and Oceanography* 30:565-576.

Interagency Program and "The Deal"

The December 1995 announcement of the Bay/Delta deal involving water quality standards, endangered species protection, and other measures to improve Bay/Delta environmental resources and written material describing the deal include numerous references to monitoring. The draft water quality control plan released by SWRCB also emphasizes the need for monitoring to determine compliance and to provide information that will help us collectively understand if measures in the deal are having desired results.

To help expedite development of a revised monitoring program, on January 11, Interagency Program coordinators and staff met with the Urban/Ag policy folks, the Estuary Institute, environmental groups, and others to outline a process leading to the new program. The Urban/Ag group has established a monitoring technical subcommittee headed by Greg Gartrell (Contra Costa Water District) to work with the Interagency Program on specific details of monitoring and studies. This technical group met with the staff management committee on January 12 and 13. We expect much of the actual work in program development to be done by individual project work teams.

The renewed interest in monitoring the estuary and its watershed provides an unprecedented opportunity to evaluate existing programs and work cooperatively among a host of agencies and individuals to establish a coordinated program yielding the information needed to manage environmental and water resources. Interagency Program staff and management need to make the most of this opportunity. Programs and priorities may shift, but we must remain receptive to new ideas.

The Island Slough Wetland Development Project

Frank Wernette, DFG

The first chapter is nearly complete in a story of cooperation and close coordination to implement a wetland mitigation project in the Suisun Marsh. When it is finished, a new unit of the Grizzly Island Wildlife Area will not only complement the wildlife area but will be a welcome addition to the Suisun Marsh as a whole.

History and Description

Construction of the physical facilities for the initial phases of the Plan of Protection for the Suisun Marsh resulted in losses of wetland habitat including habitat capable of supporting the State and Federal listed salt marsh harvest mouse and impacts to waterfowl food supplies on Roe, Ryer, Freeman, and Snag islands. In a 1987 mitigation agreement, DFG, DWR, and USBR agreed to offset those impacts and any impacts of future phases; DWR and USBR committed to fund the mitigation, and DFG committed to acquire, develope, and manage the new wetland.

Phase A of the agreement required development of 354 acres of wetland. DFG and FWS estimated that 100 acres would need to be managed specifically as preferred habitat for salt marsh harvest mouse.

In 1988, on behalf of DFG, the Wildlife Conservation Board began to acquire property, but had difficulty finding sellers. In September 1989, the board finally acquired a 525-acre parcel known as the old Red Barn property or Dik-Dik Ranch. Now it is the Island Slough Unit of Grizzly Island Wildlife Area.

General Services' Office of Real Estate and Design Services took necessary steps to relocate tenants, and the Office of the State Architect began to design facilities to properly manage the new wetland. The project is composed of three principal components:

- Physical facilities to obtain water from Montezuma Slough and manage it to support a productive, diverse wetland.
- Fish screens at the main intake.
- Management practices to effectively maintain the new wetland.

A minor component is construction of a dirt ramp to allow access to a fishing platform on Montezuma Slough, which is accessible to the physically handicapped.

Status and Current Activities

In 1991, DFG completed a Draft Initial Study, Negative Declaration, and Biological Assessment. Following public review, DFG certified the Negative Declaration on June 30, 1992. Most permits have now been obtained. In December 1994, the San Francisco Bay Conservation and Development Commission voted to grant a permit. The COE permit is expected early in 1995.

Issues raised during the permitting process included the design of the fish screen for the main intake and mitigation for impacts to 11 acres of jurisdictional wetlands during construction of field levees, intakes, drains, etc.

The goal has been to design a cost-efficient fish screen that met criteria established by DFG, FWS, and the National Marine Fisheries Service. Meeting these criteria will ensure that species such as the threatened delta smelt and endangered winter-run Chinook salmon are protected from diversion onto the new wetland. DFG agreed to a detailed evaluation after screen installation to ensure it meets the criteria.

To satisfy concerns raised by the Regional Water Quality Control Board about wetland impacts, DFG agreed to convert an additional 20 acres of upland to wetland.

Optimism is running high that construction can begin this spring. If all goes well, by winter 1996 this addition to Grizzly Island Wildlife Area will be on line, and we can begin to enjoy the sight of swirling flocks of waterfowl and shorebirds using Island Slough.

The Estuary Institute's Policy Advisory Committee

On December 15, Perry Herrgesell and Randy Brown attended the first meeting of the Estuary Institute's PAC. (Brown represented Bob Potter, who is DWR's official representative.) This committee serves about the same function as the Interagency Program's Management Advisory Committee in that it provides general program direction to the Institute.

The presence of Interagency Program coordinators on this committee will help integrate what are now the two largest monitoring programs in the estuary. This will be particularly important as we work with the Estuary Institute and others to develop a comprehensive Bay/Delta monitoring program. If emphasis on the impacts of toxicants is increased, the Institute could be the logical organization to work on these activities.

The Institute has released its 1993 annual report, "San Francisco Estuary Regional Monitoring Program for Trace Substances", and a list of research priorities in the estuary. For copies, contact the Estuary Institute at 510/231-9539.

Brown Bagger

The Interagency Program Section of DWR's Environmental Services Office is starting a brown bag seminar series. The seminars will be held at about 2-month intervals. The first will be January 27 from 11:00 to 1:00 in the conference room at 3251 S Street, Sacramento. Jon Burau (USGS) will present his recent findings on circulation, mixing, and entrapping processes in the northern reach of the estuary. For details, contact Leo Winternitz at 916/227-7548.

Dissolved Oxygen Conditions in the Stockton Ship Channel

Steve Hayes and Staff of the Compliance Monitoring and Analysis Section, DWR

Dissolved oxygen concentrations in the Stockton Ship Channel are closely monitored during late summer and early fall each year because levels can drop below 5.0 mg/L due to low streamflow, warm water temperature, and high biochemical oxygen demand. Low dissolved oxygen levels can cause physiological stress to fish and block upstream migration of salmon. To correct the situation, DWR (in coordination with DFG and USBR) installs a rock barrier across the head of Old River in late summer or early fall to increase net downstream flows past Stockton into the ship channel.

In 1994, the barrier was completed on September 7. Because of dry summer and early fall conditions, average daily flows in the San Joaquin River past Vernalis in August and September were slightly less than 900 cfs, and net flows past Stockton ranged from -717 to +168 cfs. Reverse flows dominated the hydrodynamic pattern during this period, concealing improvements attributable to the barrier.

Compliance monitoring of dissolved oxygen levels in the Stockton Ship Channel was conducted from August through November. During each monitoring run, 14 sites were sampled from Prisoners Point in the central Delta to the Stockton Turning Basin (Figure 1). Discrete samples were taken at each site for dissolved oxygen and water temperature at the top and bottom of the water column at ebb slack tide. Results are summarized in Figure 2.

Monitoring of the channel by vessel is supplemented by continuous year-round automated dissolved oxygen monitoring at the Rough and Ready (Stockton) multiparameter water quality recording station. Because of the full monitoring effort, planning for special studies, scheduling of the Old River Closure, and other activities can be conducted in response to deteriorating dissolved oxygen conditions.

Results of monitoring by vessel show a significant dissolved oxygen sag in the eastern end of the channel from August through early October. The pre-closure runs on August 5, August 22, and September 6 confirmed the sag; lowest values were in the Rough and Ready Island area from Light 40 (site P8) through Light 48. On the bottom, levels ranged from 3.8 to 5.5 mg/L; surface levels ranged from 4.0 to 5.9 mg/L. These low levels were apparently due to warm water (24-26°C), reduced tidal circulation, and reverse flows at Stockton.

Post-closure dissolved oxygen monitoring on September 19 and October 3 showed a continued sag and a westward shift of the maximum sag area. On September 19, the sag had localized in the Light 40-43 area near Rough and Ready Island, with all surface and bottom dissolved oxygen levels less than 5.0 mg/L. By October 3, the maximum sag area had intensified and moved farther west to the area of Lights 28 to 43. In that area, bottom levels ranged from 4.1 to 4.9 mg/L, and surface levels ranged from 4.2 to 5.1 mg/L. Shifting of the maximum sag zone westward and the improved (>5.0 mg/L) levels in the post-closure studies at Light 48 (at the eastern end of Rough and Ready Island and at the juncture of the San Joaquin River with the Stockton Ship Channel) on September 18 and October 3 were probably the result of locally improved flow conditions due to the closure, but intermittent reverse flows continued.

Dissolved oxygen monitoring on October 18 showed continued improvement. By mid-October, minimum dissolved oxygen levels in the area of maximum sag (Lights 28-43) had improved to 5.6-7.0 mg/L on the bottom and 5.7-6.9 mg/L on the surface. Improved flows and cooler water (16-19°C) had apparently brought about the higher levels. In October, average daily San Joaquin River flows past Vernalis were less than 1,400 cfs, and net daily flows past Stockton ranged from -309 to +391 cfs.

Cooler water (10-12°C) and cumulative effects of the Old River barrier finally brought about a significant improvement in dissolved oxygen levels. Monitoring on November 18 showed no sag in the ship channel, and dissolved oxygen levels throughout the channel were greater than 8.7 mg/L. Levels in the eastern portion were 8.7-9.3 mg/L and those in the western portion were 9.5-10.1 mg/L. Because of the dry fall, average daily flows in the San Joaquin River past Vernalis barely exceeded 1,300 cfs in November, and net flows past Stockton ranged from -308 to +224 cfs. Removal

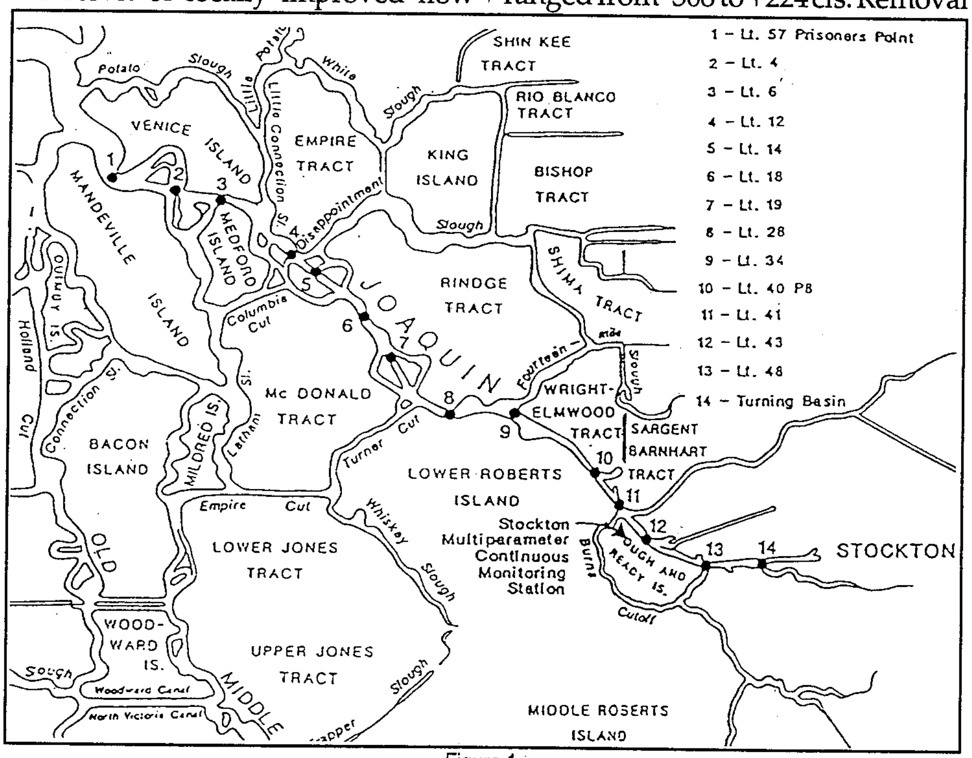


Figure 1
DISSOLVED OXYGEN SAMPLING SITES IN THE SAN JOAQUIN RIVER

of the barrier was completed November 30.

The highly variable and apparently anomalous dissolved oxygen values measured in the turning basin on September 19, and to a lesser extent on October 3, were the result of unique biological and water quality conditions in this area, independent of the main downstream channel. The turning basin, at the dead-end eastern terminus of the ship channel, is subject to reduced tidal activity, reduced water circulation, and extended water residence time. Historically, a series of intense algal blooms composed primarily of Cryptomonads and green flagellated algae produce stratified dissolved oxygen in the water column of the turning basin in late summer and early fall. In 1994, the dominant bloom organism was the blue-green alga *Anacytis* sp., which is notorious for the taste and odor it causes. On September 19, dissolved oxygen levels were exceptionally high at the surface (14.4 mg/L) and exceptionally low at the bottom (1.5 mg/L), and bloom conditions were further confirmed by the "fluorescent" green of the water.

Low dissolved oxygen conditions at or near the bottom of the turning basin are further degraded by high BOD loadings. These loadings are caused by dead or dying algae settling out of the water column during and following a bloom and from extensive boating in the harbor.

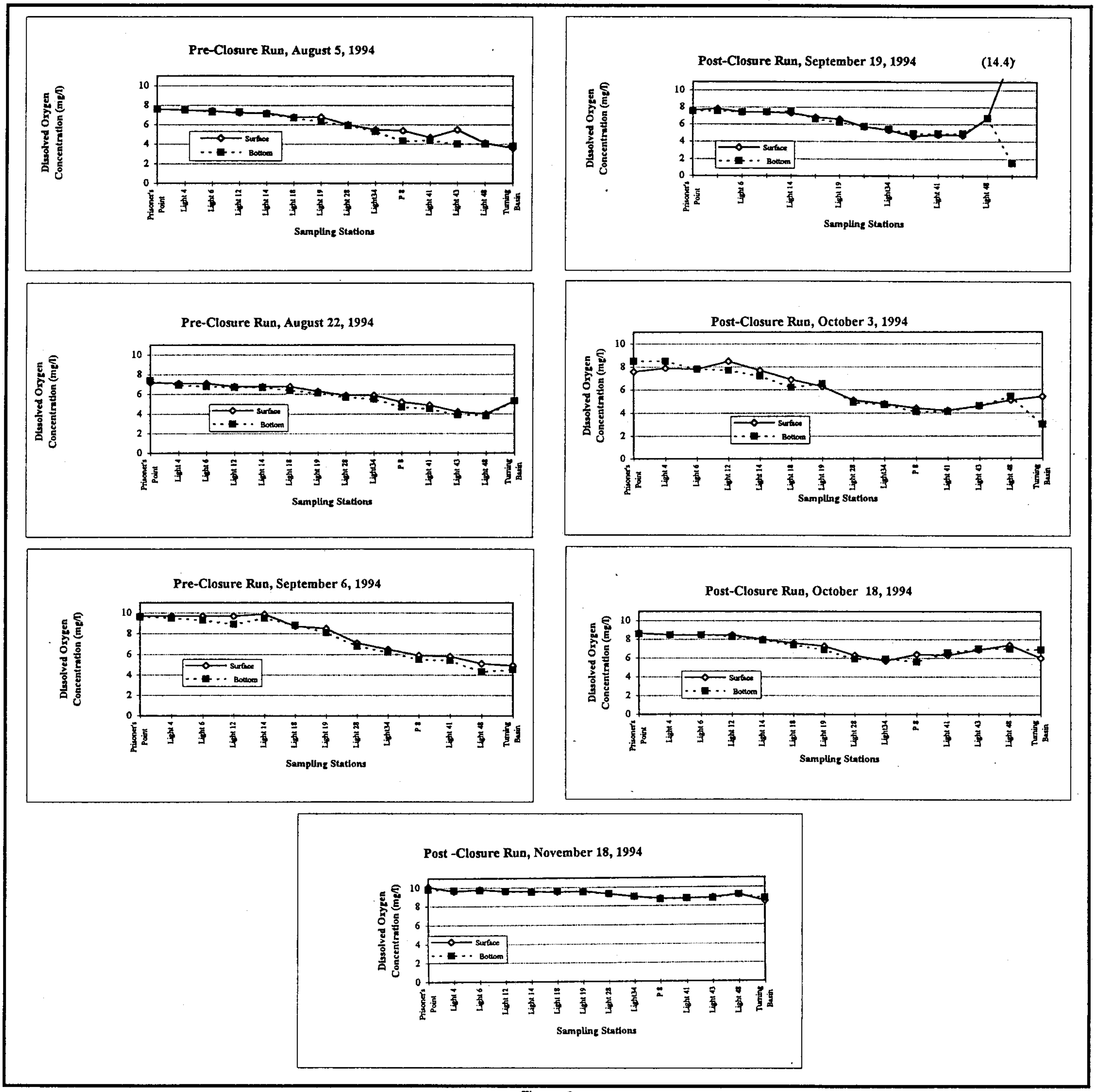


Figure 2
DISSOLVED OXYGEN CONCENTRATION IN THE STOCKTON SHIP CHANNEL, 1994

Interagency Program Data Management

Olof Hansen, USBR

Did you know that the Interagency Ecological Program visits about 800 monitoring sites, collects ecological data, and manages the data in more than 5,800 files of totaling over 2 gigabytes? These numbers are part of the *IESP 1993 Data Summary Report.*

The Interagency Program had been using EPA's national water quality database, STORET. That system, designed for chemical observations, was modified to encompass biological data as well. In 1991, the Interagency Program Data Management Team evaluated the continued use of STORET and compared it with other options, including the USGS National Water Information System (NWIS-II), personal computers, and the commercial statistical package, SAS. A report, *STORET and Alternatives*, contains the evaluation results. In February 1993, the Coordinators approved the following policies:

- The programwide required STORET storage and retrieval is suspended.
- Program managers are allowed to disseminate data on request — from their database of choice.
- As an interim measure, a file server is to be established for standardized and approved Interagency Program data files in ASCII format.
- The position of Technical Information Specialist is established to support data management.
- Program managers will provide ASCII data files and pertinent updates to the Technical Information Specialist.
- The Technical Information Specialist will create a comprehensive index of all Interagency Program data.

This article provides a synopsis of the Interagency Program data index and an overview of the future for data handling.

The Interagency Program has been adding elements over time (Figure 1). Some elements were in place before the program was formally founded. For example, sturgeon tagging started in 1954. Several elements were added just this year and have not generated much data. The North Delta Demonstration Fish Protective Facilities Program is an example. Although the Interagency Program formally began in 1970, some elements that began before that were incorporated later. Data handling now incorporates more than 30 elements.

One important factor in any ecological program is where samples are taken. Figure 2 shows major water bodies in the estuary and sites sampled by Interagency Program staff. As shown, the whole estuary is sampled, including the Sacramento and San Joaquin rivers downstream to South Bay. In fact, the Striped Bass Egg and Larval Survey monitors the Sacramento River farther upstream than the map shows.

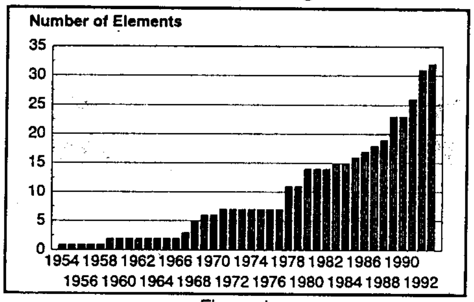


Figure 1
INCREASE IN
INTERAGENCY PROGRAM ELEMENTS

Elements of the Interagency Program are diverse, as are the number of sites per element. One element samples at only two sites; the largest visits over 160 sites. If all elements are counted separately, the program collects biological, chemical, and physical data at more than 800 sites. Figure 3 shows the number of sites per study element.

The geographic range varies from sites in a specific area, such as Montezuma Slough, to sites covering the whole estuary. In general, elements that collect biological data sample more stations than those sampling for physical

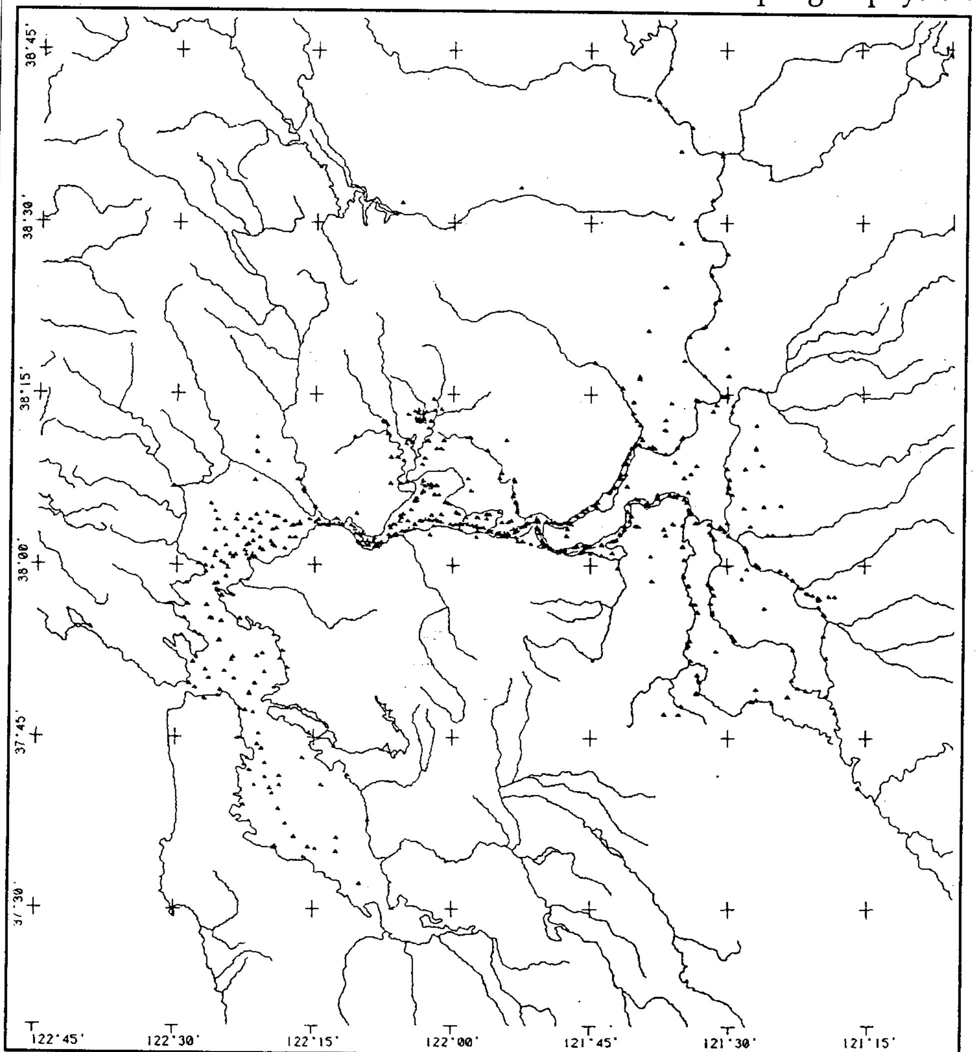


Figure 2
INTERAGENCY PROGRAM MONITORING SITES

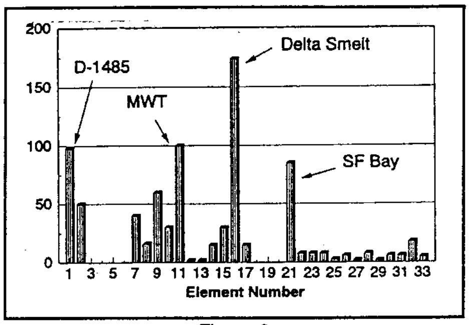


Figure 3
INTERAGENCY PROGRAM MONITORING SITES

parameters. Program elements denoted by number are identified as follows:

1. Decision 1485 Compliance
2. Neomysis/Zooplankton
3. Food Chain Group
4. Salmon Smolt
5. Salmon, Sacramento
6. Salmon, San Joaquin
7. Juvenile Salmon
8. Adult Striped Bass
9. Striped Bass Egg and Larval Survey
10. Striped Bass Tow-Net Survey
11. Striped Bass Midwater Trawl
12. Striped Bass Management
13. Sturgeon Tagging
14. Sturgeon Spawning
15. Sturgeon Year Class
16. Delta Smelt
17. Larval Striped Bass Nutrition
18. Estuary Abundance
19. Shallow Water Sampling
20. Vertical Sampling
21. Shrimp Abundance
22. Delta Hydrodynamics
23. San Francisco Bay Hydrodynamics
24. Montezuma Slough
25. North Delta Facilities
26. Clifton Court Predator
27. Skinner Facility
28. Delta Agricultural Diversion
29. North Bay Aqueduct
30. Tracy Fish Facility
31. Delta Eggs & Larvae
32. South Delta Facilities
33. Clifton Court Temperature

Data collected at the 800 sites are managed differently from element to element. The great diversity in data handling is reflected in several factors. Data are stored on personal computers, mini computers, scientific work stations, and mainframe computers. Software packages used to create data files, perform edit checks, and analyze data include spreadsheet software such as Lotus 1-2-3, database management software such as dBASE, statistical software such as SAS, in-house FORTRAN and BASIC routines, and STORET or NOMAD on a mainframe. The number of files per element ranges from just a couple to 2,400. Size of databases ranges from 500 kilobytes to more than 1 gigabyte. Some of the data structure is simple, containing only a few physical parameters; some is complex, with multiple gear types and many parameters on biotic organisms.

Data quality in one element is controlled by manuals with 60-page descriptions of protocols; other elements have no documentation on QA/QC procedures. Some elements keep little documentation; others have a full library for each data item. Figures 4 and 5 show existing conditions of in-house data management along with some inconsistencies in information management within elements. In particular, large programs use few individual files, whereas some smaller programs use many small files.

To start standardizing data handling, the Data Management Team decided on the following format to help users understand the data.

- Brief Overview (AA1READ)
- Metadata w/QA Information (DOC): All program elements have metadata descriptions — data about data.
- Format Files (FMT): Format files function as a legend to the actual monitoring data files.
- Reference Tables (REF): Some elements have reference tables such as lists of station latitudes/longitudes or taxonomic codes.
- Data Files (ASCII format)

The metadata files are probably the most important. They contain information about element name; contact person; purpose of the study; agencies carrying out the field work and data handling; and funding sources. Information about data quality assurance/quality control for field and lab protocols is also included. Elements are further described regarding the start of monitoring, frequency (months/year and trips/cruises/tows per week/month), and time span between field observation and final computer file. Geographic variables describe the number of sites visited, geographic range of sites (latitude/longitude), and number of samples per site. Monitoring parameters are defined as to physical, chemical, or biological nature. If biological data are collected, community (fish, benthos, zooplankton), taxonomic identification scheme, gear type, and instrumentation used are also described. Metadata files close with miscellaneous variables such as use of geographic information systems (GIS) and/or image interpretation/remote sensing (analog/video). Metadata are required for many other database management systems, including NWIS-II and STORET-X. Metadata provide crucial information on QA/QC of the data and help users decide whether data will serve their needs.

All of the file types, in ASCII format, are located on the Interagency Program fileserver, an IBM 3090 at EPA's National Computer Center in Research Triangle Park, North Carolina. The ASCII format allows every user to get the data from one application software to another.

Figure 6 shows some of the software packages currently being used in Interagency Program. As illustrated, ASCII serves as the bridge between different users, software packages, and computer platforms.

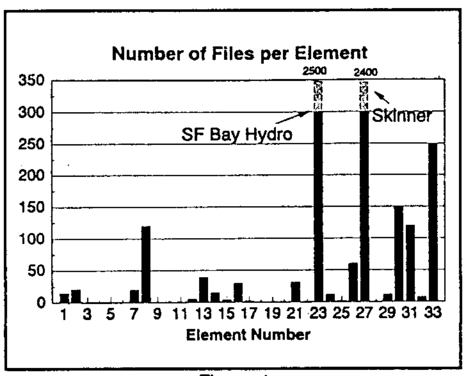


Figure 4
NUMBER OF FILES PER PROGRAM ELEMENT

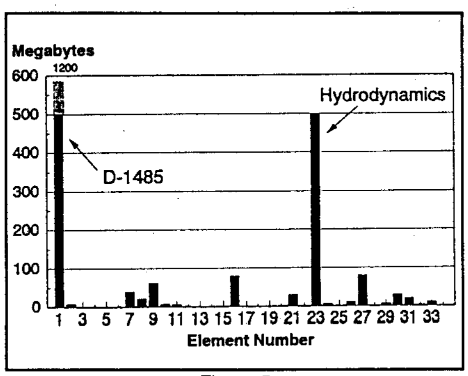


Figure 5
SIZES OF DATABASES

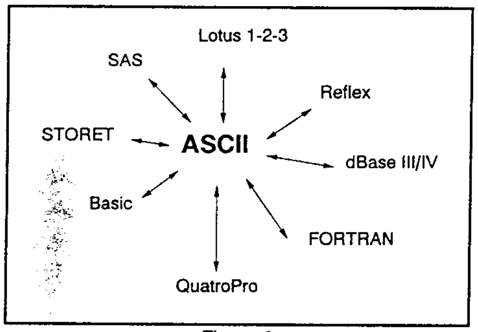


Figure 6
ASCII AS FORMAT

All monitoring data files start with five fields defining where and when data were collected. The five fields are:

- River Kilometer Index-RKI
- Station Identifier (ID)
- Sample Date(YYYYMMDD)
- Sample Time (if available)
- Sample Depth (if available)

The River Kilometer Index is the geographic identifier for all sample sites and is a mandatory field. Specific station identifiers follow. Since the turn of the century is near, the year in the date field has four digits. Time and depth are optional.

The rest of the file is element specific and is not modified from the data structure used in-house by the project. Since these monitoring data change from element to element, the files need to be explained. The name or naming convention of all files, dates the files were generated, and file sizes are listed in the FMT files, along with the structure of the files. The FMT files characterize the monitoring data with at least the minimal descriptors shown below.

- File Name(s)
- File Creation Date
- File Size
- File Length and Width
- File Structure (Variables, Records, Number, Code, Character)
- Reference Tables

This structure should explain the data (*eg*, whether a field is numeric or character). The FMT file should also define whether a number is a code or a numeric value that can be manipulated with mathematical functions, such as a taxonomic code versus abundance number.

The Interagency Program fileserver already contains metadata for most elements. Format file descriptions for some elements and some reference tables for sample stations and taxonomic codes are also complete. All of the tow-net survey data (catch and length data for 1959-1994) are now available on the fileserver. Several procedures are available to access the fileserver, including internet or modem. A cookbook-style user manual describing how to access the fileserver, browse, and download files is already in draft form. User IDs have been established for Interagency Program member agencies to allow access to files. Additional IDs are available.

The Management Team recently reaffirmed the interim data handling strategy. January 15, 1995, is the deadline for program managers to deliver their data to the Technical Information Specialist.

The Data Management Team is developing specifications for a user interface to allow users to access, browse, and download Interagency Program files. For a long-term DBMS solution, the team also monitors the development of NWIS-II and STORET, as well as efforts of the Interagency Taskforce on Water Quality Monitoring.

Having all Interagency Program data on one fileserver accessible to all who are interested will provide better and more timely access to the data until an appropriate DBMS is developed.

For information or copies of reports, contact Olof Hansen at 415/744-1965.

Science Advisory Committee Meeting

The Interagency Program's Science Advisory Committee met with Pat Coulston, Chuck Armor, Larry Smith, Marty Kjelson, and Randy Brown on December 13 and 14, 1994. The meeting was devoted mostly to briefing committee members on the Interagency Program and how the Bay/Delta system fits into the California water picture.

The Science Advisory Committee is chaired by Sam Luoma (USGS) and includes Jim Cloern (USGS), Ed Houde (Chesapeake Biological Laboratory), Alan Jassby (UC-Davis), Carole McIvor (National Biological Survey), Stephen Monismith (Stanford), and Jim Quinn (UC-Davis). The committee was generally impressed with the scope of the present program and the complexity of the issues being addressed.

Although their exact roles were not entirely clear to members, they did agree that the committee could play a useful function. The next step is for Pat Coulston to write up some ideas for the committee's review on how the Interagency Program might best use these advisors. Most of the members will be attending the annual workshop and will have a separate meeting with coordinators and staff.

We may need to add another member to the committee with specific background in salmonids. If you would like to suggest a candidate, please call Pat Coulston at 209/942-6068.

ERRATUM

The article, "Quantifying Salinity Habitat of Estuarine Species", which appeared in the fall 1994 issue of the *Newsletter*, had typographical errors in the equations on pages 7 and 8. The correct equations are:

$$X_2(t) = 122.2 + 0.3278X_2(t-1) - 17.65LOG[Q_{out}(t)]$$

$$X = -X_2((ln((31-S)/(515.67*S))/-7) - 1.5)$$

Determining Prehistoric Salinity in San Francisco Bay with Stable Isotopes

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James C. Ingle, Department of Geological and Environmental Sciences, Stanford University
Mark E. Conrad, Division of Earth Sciences, Lawrence Berkeley Laboratory

Instrumental records of delta flow and salinity in San Francisco Bay extend back only 80 years, during a period of heavy water development such as upstream storage and diversions. Thus, there is no record of *natural* (prediversion) salinity and flow into the estuary. However, sediments accumulating beneath San Francisco Bay contain a record of the pre-industrial environmental history of this estuarine system, including salinity and associated freshwater runoff.

Here we summarize results of an isotopic method developed for reconstructing variations in salinity and freshwater flow into San Francisco Bay. These data provide a heretofore unavailable baseline against which to view modern variations in salinity and inflow to the system and are important in separating human impacts on San Francisco Bay salinity from those induced by natural climatic variation.

Salinity of water in San Francisco Bay is primarily a function of the volume of freshwater inflow and of sea level, which has increased over the past hundreds to thousands of years. Ocean water (33-35‰) mixes with river water (nearly zero), producing vertical and horizontal salinity gradients in the bay (Conomos *et al* 1979; Cloern and Nichols 1985). The contours of equal salinity move toward the ocean as river discharge increases and move back upstream as river discharge decreases. Although salinity varies annually due to seasonal variations in precipitation, this study focuses on the annual average salinity (and freshwater inflow) at a given location in the bay.

The oxygen and carbon isotopic composition of the sea water and river water entering the bay are also very different, producing a gradient in $^{18}O/^{16}O$ and $^{13}C/^{12}C$ with salinity. The oxygen isotopic composition in rivers depends on the $\delta^{18}O$ in precipitation (rain and snow) and the $\delta^{18}O$ in ground water contributions. $^{18}O/^{16}O$ measurements of surface water, ground water, and precipitation from the Pacific Coast to western Nevada show a decrease in $\delta^{18}O$ from the west coast (-5.3‰) to about -16.0‰ in the eastern Sierra Nevada (Ingraham and Taylor 1991). River water entering San Francisco Bay is a mixture of surface runoff (from precipitation and snowmelt) and ground water, integrated over the entire drainage basin, and would be expected to have a $\delta^{18}O$ value representing an average of all these sources. The carbon isotopic composition of river water entering San Francisco Bay is about -10‰ due to contributions from respiration and breakdown of organic matter in soils in the drainage basin (Spiker 1980).

Salinity/Isotope Relationship in Estuarine Water

Estuarine water was collected along a salinity transect in San Francisco to establish the relationship between salinity and $\delta^{18}O$. In addition, water was collected bimonthly from 1991 to 1993 at three locations (South-Central Bay [station 25], San Pablo Bay [11], and the Sacramento River at Rio Vista [657]; Figure 1) to demonstrate that

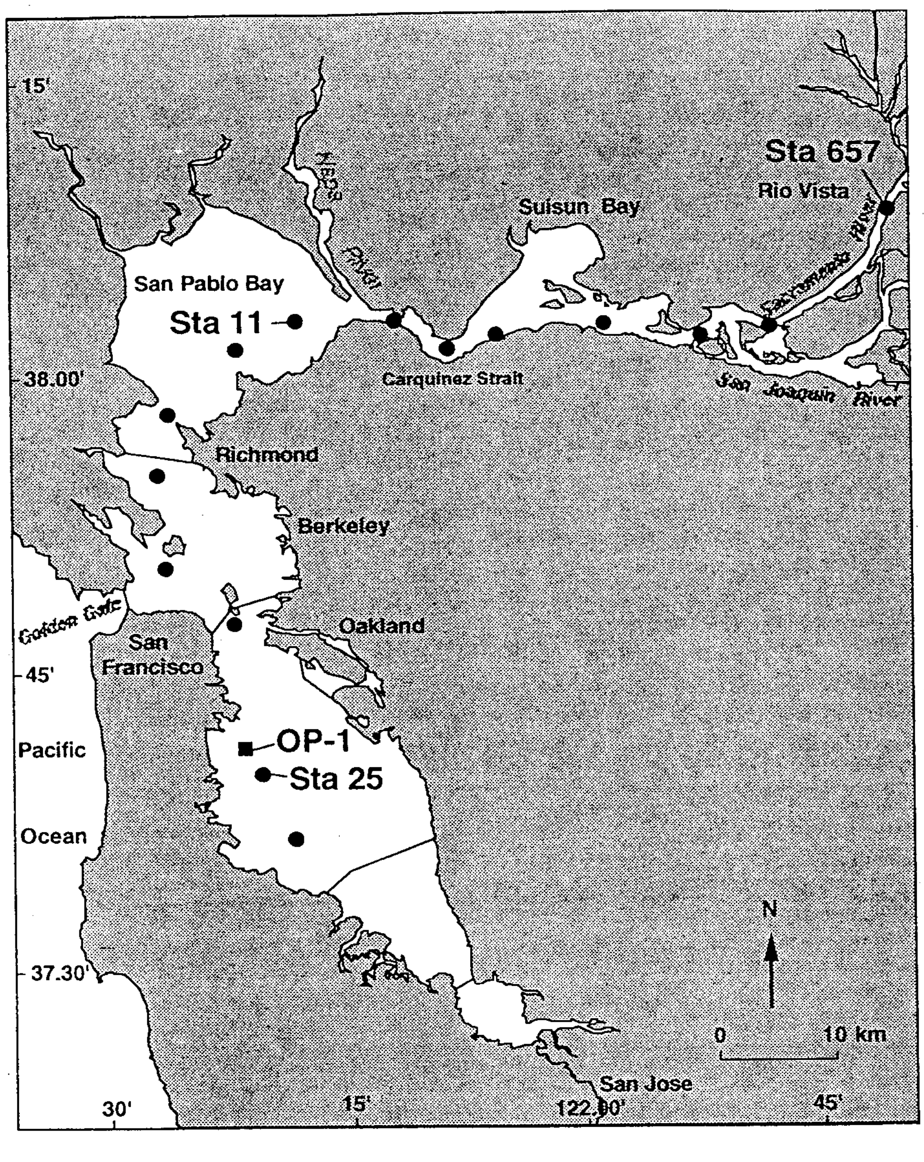

Figure 1
LOCATION OF WATER AND CORING SITES IN SAN FRANCISCO BAY

seasonal salinity variations and $\delta^{18}O$ are related and to test whether the river end-member remains constant between wet (1993) and dry (1991-1992) years. Previous work has shown a near-linear relationship between salinity and $\delta^{13}C$ in San Francisco Bay water (Spiker 1980).

The oxygen isotopic compositions ($^{18}O/^{16}O$) plotted against salinity in bay/delta water shows a linear relationship (Figure 2). The river water end-member entering the bay has a $\delta^{18}O$ value of -11‰, and sea water has a value of 0‰. The water collected from the bays in 1991-1993 shows a record of covarying salinity and $\delta^{18}O$ (Figure 3). Sacramento River samples from Rio Vista varied by only 1‰ between dry years (1991-1992) and a relatively wet year (1993) and showed no seasonal variability.

The relationship between $\delta^{18}O$ in the ambient water and $\delta^{18}O$ in the biogenic carbonate was verified with $\delta^{18}O$ measurements of mussel (*Mytilus edulis*) shells collected live from eight locations in San Francisco Bay.

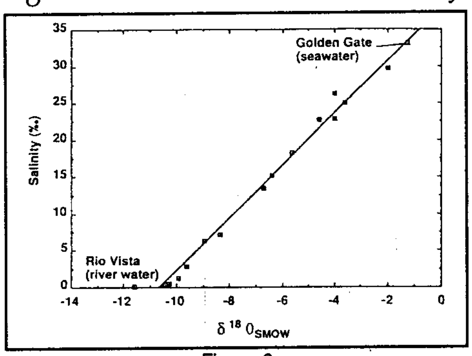

Figure 2
SALINITY AND OXYGEN ISOTOPIC VALUES FOR BAY/DELTA WATER

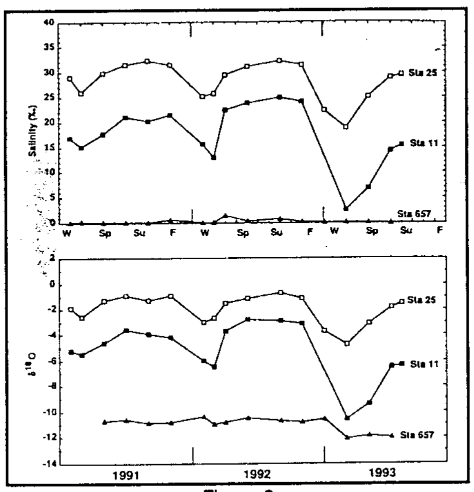

Figure 3
SALINITY AND OXYGEN ISOTOPE VALUES FOR BAY/DELTA WATER PLOTTED AGAINST TIME

Average $\delta^{18}O$ values for the whole shell, representing 2-4 years of growth, were compared with monthly salinity and temperature records obtained by USGS at nearby monitoring locations (Figure 4).

Previous studies have used the isotopic composition of strontium recorded in carbonates as a proxy for salinity in San Francisco Bay (Ingram and Sloan 1991; Ingram and DePaolo 1993). In this study, we use a similar approach to derive a paleosalinity record with oxygen and carbon isotopic measurements in fossil mussel and clam shells separated from sediment cores taken from San Francisco Bay. The large difference in values of $\delta^{13}C$ (-10‰) and $\delta^{18}O$ (-11‰) of river water entering the bay and sea water ($\delta^{13}C$, 0‰; $\delta^{18}O$ 1‰) produces a correlation between $\delta^{13}C$, $\delta^{18}O$, and salinity in San Francisco Bay, which is recorded in the carbonate shells of foraminifers and mollusks.

Sediment Cores

The sediment samples used for this study were taken from cores drilled beneath south-central San Francisco Bay near Oyster Point and in the southeastern side of San Pablo Bay near Rodeo (Figure 1). Drilling was done using a modified Osterberg vacuum piston coring sampler with a piston core barrel length of 1.15 meter and an inside diameter of 10 centimeters. Two cores were drilled near Oyster Point; the core used in this study penetrated 5.72 meters of sediment, revealing a stratigraphy of dominantly mud with intermittent shell layers in the lower 3 meters overlain by shell-rich layers of alternating oyster (*Ostrea*), clams (*Macoma*), and mussels (*Mytilus*). The one core taken from San Pablo Bay was 6.7 meters long. Results of the Oyster Point core are presented here.

Methods

The cores were X-rayed for non-destructive examination of sedimentary structures before sampling. The cores were then split lengthwise and described, noting sedimentary structure, grain size, color, and degree of bioturbation.

Sub-samples were then taken sequentially every 2 centimeters, consuming half of the core by slicing 2-cm-wide sections, yielding about 50 grams of wet sediment. The sediments were wet-sieved using a 250-mesh screen (63 µm openings) and coarser screen (>841 µm sieve) to separate macrofossil shell material from the microfossils (foraminifers). Microfossils were picked and sorted under binocular microscope. Mollusk shells (whole and fragments) from the coarse fraction of each sample were separated and sorted for isotopic analyses.

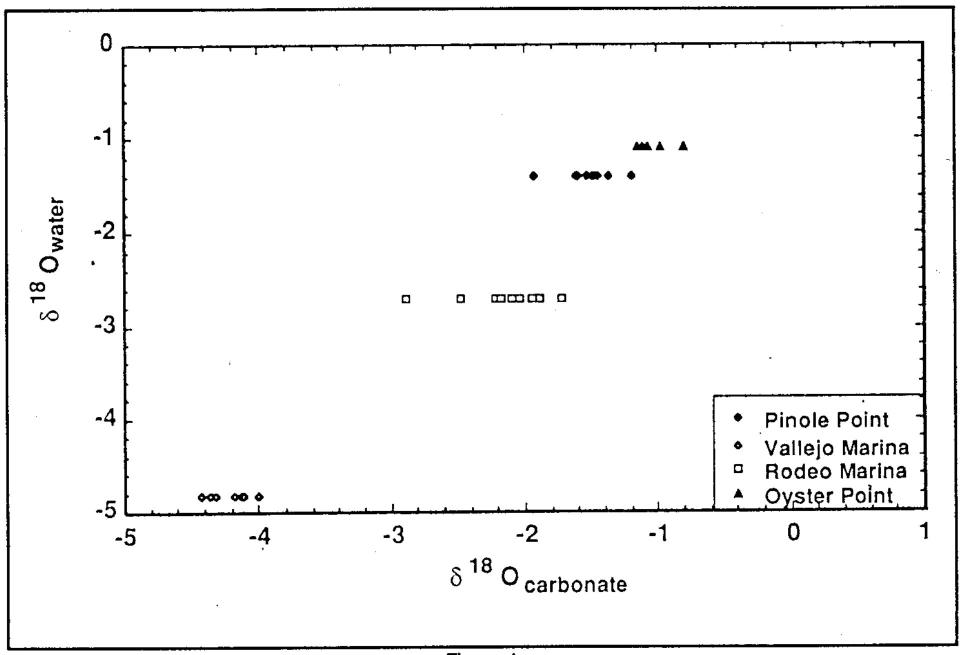

Figure 4
OXYGEN ISOTOPIC COMPOSITION OF MODERN MUSSEL SHELLS PLOTTED AGAINST THAT OF MODERN WATER COLLECTED FROM THE SAME LOCATION

The mollusk shell samples (whole and fragments) were separated from the >841-µm fraction of each sample and radiocarbon dated at the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory.

All stable isotope (oxygen and carbon) analytical work for this study was done at the Center for Isotope Geochemistry at the University of California, Berkeley. Oxygen and carbon isotopic measurements were made using a Fisons Instruments Prism Series II isotope ratio mass spectrometer. For inter-run comparison, the $\delta^{18}O$ values for each set of 24 samples were normalized relative to the average value for three analyses of the CIG water standard, TW-1 (-11.7‰ relative to VSMOW). The $\delta^{18}O$ values of all water samples are reported relative to SMOW. Duplicate analyses were within ±0.1‰.

For carbonate shell samples, CO_2 for isotopic analysis was produced by reacting 1-2 mg samples with phosphoric acid using an Isocarb automated carbonate device attached to the Prism. Sample values were corrected using 6-9 analyses of a carbonate standard, CM-1 ($\delta^{13}C$ = 2.05‰, $\delta^{18}O$ = -1.94‰), per sample run of 24 to 36 unknowns. Oxygen and carbon isotopic data are reported in the δ notation relative to the PD Belemnite standard (PDB) for carbonate samples (both carbon and oxygen), where $\delta = [({}^{18}O/{}^{16}O_{sample}/{}^{18}O/{}^{16}O_{std})-1] \times 1000$. The precision for these analyses is ±0.05‰ for carbon and ±0.1‰ for oxygen. Detailed methods for water and carbonate isotopic analyses will be published elsewhere (Ingram *et al* in prep).

Results and Discussion

The Oyster Point core from south-central San Francisco Bay has a basal age of 5,800 years before present. Thus, the 578-cm-long core has an average sedimentation rate of 1.11 mm/year. The time interval represented by the sampling interval of 2 centimeters is about 22 years. The core also seems to be missing sediment from the upper part, representing the last 90 years.

The $\delta^{18}O$ and $\delta^{13}C$ values of *Mytilus* fossil shells are plotted versus depth-in-core (in centimeters) in Figure 5. The $\delta^{18}O$ values in the upper 350 centimeters of the core ranged from -1.20 to -3.94‰, with an average of -2.4‰. Below 350 centimeters, in the interval containing *Mytilus* shells of 446 to 578 centimeters, $\delta^{18}O$ values ranged from -2.69 to -5.58‰, with an average of -3.9‰. The $\delta^{13}C$ values in the 0- to 350-centimeter interval varied from 0.03 to -2.15‰, with an average of -0.9‰. Between 446 and 578 centimeters, $\delta^{13}C$ values ranged from -0.62 to -3.26‰, with an average of -1.9‰. Both oxygen and carbon isotopic composition decreased between the upper and lower part of the core, 1.5 and 1‰, respectively. There is a good correlation between $\delta^{18}O$ and $\delta^{13}C$, indicating that salinity is the primary controlling factor, because $\delta^{13}C$, unlike $\delta^{18}O$, does not vary with ambient water temperature.

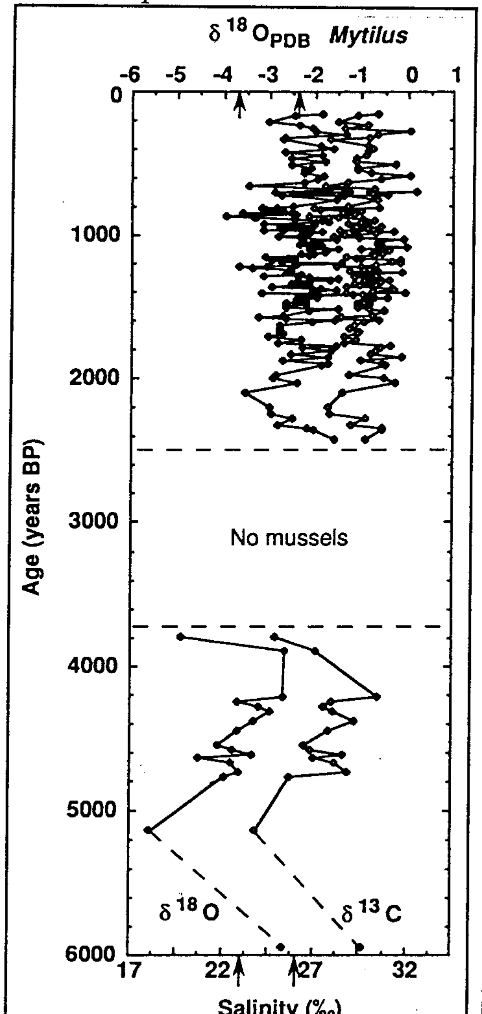

Figure 5
OXYGEN *(closed symbols)* AND CARBON *(open symbols)* PLOTTED AGAINST AGE
Salinity scale is also shown, with arrows indicating average salinity for top and bottom portions of the core.

Paleosalinity

We believe $\delta^{18}O$ and $\delta^{13}C$ variations in the mussel shell carbonate primarily reflect variations in $\delta^{18}O$ and $\delta^{13}C$ of the estuarine water in which the shell precipitated, which varies as a function of salinity. This assumption is supported by the covariation of the oxygen and carbon isotopic compositions. However, changes in the ambient water temperature also affect the $\delta^{18}O$ value of the carbonates. Under equilibrium conditions, the amount of isotopic fractionation is about 0.2‰ per 1°C (Epstein *et al* 1953). The average annual surface water temperatures measured at this location between 1969 and 1977 show a total range in variation of about 3°C (13-16°C; Conomos 1979; Conomos *et al* 1979), which should account for a maximum of 0.6‰ in the $\delta^{18}O$ signal.

The calculated salinities corresponding to the $\delta^{18}O$ carbonate values in the core range from 21.5 to 28.8‰ over the last 5,800 years. Average annual salinity in the upper 350 centimeters of the core is 25.5‰. In the lower 350-578 centimeters, the salinity range is 15.2 to 24.4‰, with an average of 22‰.

Although the carbon isotopic results are harder to interpret (Spiker 1980), the relationship between salinity and $\delta^{13}C$ shown is: $\delta^{13}C = -9.2+0.34(S)$, using an average $\delta^{13}C$ value of 0.9‰, the average salinity in the upper 350 centimeters of the core indicates an average salinity of 24.4‰, which is in agreement with that indicated by $\delta^{18}O$.

The modern average annual salinity at Oyster Point (as measured in surface water from 1969 to 1977) is 28.8‰ —2.5‰ higher than the natural, long-term salinity indicated by our record in the upper 350 centimeters of the core. Modern salinity in the bay may be higher due to diversion of river water within the drainage basin (Nichols *et al* 1986).

Summary

We have demonstrated that the use of stable isotopes (oxygen and carbon) is a valid method for determining paleosalinity and natural delta flow into San Francisco Bay. Our initial stable isotopic dataset from Oyster Point indicates average annual salinity and corresponding average annual delta flow are similar to the estimated unimpaired values for 90 to 2,400 years before present. The average salinity during 3,400 to 5,800 YBP was 23.0‰ — 2.5‰ lower than in the upper part of the core and 5‰ lower than the modern value of 28‰. The decrease in average salinity in the older part of the section may be a result of either an increase in average freshwater inflow or, more likely, to a smaller bay volume, which may have been lower during this time due to lower global sea level of 2-4 meters.

Acknowledgments

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References

Conomos, T.J., R.E. Smith, D.H. Peterson, S.W. Hager, L.E. Schemel. 1979. Processes affecting seasonal distributions of water processes in the San Francisco Bay estuarine system. Pages 115-142 in *San Francisco Bay: The Urbanized Estuary*, T.J. Conomos, editor. Pacific Division, Amer Assoc Advance Sci, San Francisco.

Conomos, T.J. 1979. Properties and circulation of San Francisco Bay waters. Pages 47-84 in *San Francisco Bay: The Urbanized Estuary*, T.J. Conomos, editor. Pacific Division, Amer Assoc Advance Sci, San Francisco.

Epstein, S., H.A. Buchsbaum, H.A. Lowenstan, and H.C. Urey. 1953. Revised carbonate-water isotopic temperature scale. *Geol Soc Am Bull* 64:1315-1326.

Ingram, B.L., and D.J. DePaolo. 1993. A 4300-yr Strontium isotope record of paleosalinity in San Francisco Bay, California. *Earth and Planet Sci Lett* 119:103-119.

Ingram, B.L., and D. Sloan. 1992. Strontium Isotopic Record of Estuarine Sediments as Paleosalinity-Paleoclimate Record Indicator. *Science* 255:68-72.

Ingraham, N.L., and B.E. Taylor. 1991. Light stable isotope systematics of large-scale hydrologic regimes in California and Nevada. *Water Resources Research* 27:77-90.

Nichols, F.H., J.E. Cloern, S.N. Luoma, D.H. Peterson. 1986. The modification of an estuary. *Science* 231:525-648.

Peterson, D.H., D.R. Cayan, J.F. Festa, F.H. Nichols, R.A. Waters, J.V. Slack, S.E. Hager, L.E. Schemel. 1989. Pages 419-442 in *Aspects of Climate Variability in the Pacific and the Western Americas*, AGU Monograph 55, D.H. Peterson, editor. Washington, DC.

Spiker, E.C. 1980. The behavior of ^{14}C and ^{13}C in estuarine water: effects of *in situ* CO_2 production and atmospheric exchange. *Radiocarbon* 22(3):647-654.

Management Advisory Committee Meeting

The Management Advisory Committee, chaired by Steve Ford (DWR), met for the first time in December. The committee was established to help Interagency Program staff and management determine if we are doing the right things from a management perspective. That is, are we addressing the most important issues? The committee represents environmental, academic, and water communities as well as divisions within Interagency Program member agencies that are not usually involved directly in the program (for example, DWR's Division of Operations and Maintenance).

Although representatives of the environmental community were unable to attend this first meeting, those who did attend had many suggestions, ideas, and concerns. (The environmental groups want to participate and will attempt to be at future meetings.) The committee will meet quarterly, at least for the first year. The next meeting is scheduled for February 1.

For a copy of the meeting summary or for more information on the Management Advisory Committee, call Steve Ford at 916/227-7534.

Georgiana Slough Acoustical Barrier

Hanson Environmental has recently completed 1994 field studies to evaluate the effectiveness of an acoustical barrier in preventing downstream-migrating salmon smolts from entering Georgiana Slough. The studies were conducted under the auspices of the Interagency Program with DWR and USBR funding and in-kind services from the San Luis and Delta-Mendota Water Authority. Interagency staff reviewed the study plans, assisted in the field work, and provided peer review for the final report.

The field studies consisted of tests to estimate the exclusion efficiency of the test barrier and impacts of the barrier on upstream migrating sonic tagged and untagged adult Chinook salmon. Chuck and his staff also tested the direct impacts of the sound waves on developing Pacific herring eggs, subadult delta smelt, and inland silversides. A report describing the results can be obtained from Darryl Hayes (DWR) at 916/227-7546.

Preliminary evidence indicates that the barrier effectively deflects juvenile Chinook salmon without affecting adult salmon or early life stages of other fish tested. The Interagency Program, under DWR management, is planning to conduct a final year of testing beginning April 1, 1995.

The Georgiana Slough barrier is part of the Delta water deal, which calls for its installation between November 1 and June 30 of all water year types. The acoustic barrier is to provide protection to all races of juvenile salmon migrating down the Sacramento River.

Preliminary Estimates of Intertidal Benthic Microalgal Production

C.A. Currin, National Oceanographic and Atmospheric Administration
E.A. Canuel, Virginia Institute of Marine Science,
S.B. Joye, San Francisco State University

The contribution of benthic microalgal production to overall estuarine production in San Francisco Bay may be significant, as has been suggested in several recent studies. Jassby *et al* (1993) estimated annual production of the benthic microalgal community by combining benthic chlorophyll (biomass) values from San Francisco Bay with production estimates from other estuaries. They concluded that BMP represents 7% of the total organic carbon supply to the North Bay and 28% to the South Bay and that annual BMP is equal to one-third to one-half of annual phytoplankton production. In addition, unpublished data (J. Thompson, USGS) indicate that secondary production by the clam *Potamocorbula amurensis* is uncoupled from primary production in the overlying water column. It has been suggested that resuspended benthic diatoms may support this secondary production.

Estimates of annual BMP in other estuaries indicate that benthic microalgae may represent 20 to 50% of estuarine primary production (Pinckney and Zingmark 1993). Moreover, multiple stable isotope studies have shown that benthic microalgae are an important food resource for estuarine fauna (Sullivan and Moncreiff 1993, Currin *et al* submitted). Despite the potential importance of benthic microalgae to estuarine primary production, nutrient cycling, and food webs, there have been no direct measures of BMP in San Francisco Bay.

We have completed a preliminary investigation of BMP at several tidal elevations from diked (Muzzi Marsh) and undiked (Corte Madera Marsh) sediments in the Central Bay region. The transects sampled include mudflats (MLW to +2 feet), the *Spartina foliosa* zone (3-4 feet above MLW), and high marsh dominated by *Salicornia* spp and *Distichlis spicata* (6+ feet above MLW). We are using the approach developed by Pinckney and Zingmark (1993), where annual BMP is estimated from measures of benthic chlorophyll biomass combined with measures of *in situ* irradiance and biomass-specific photosynthesis-irradiance curves. Photosynthetic rates are estimated using oxygen microelectrodes.

Light attenuation by the marsh macrophyte canopies was measured in June and November 1994. In June, average light attenuation by the *S. foliosa* canopy was 57% and the average for the high marsh canopy was 79%. Average midday irradiance under the *S. foliosa* canopy was 870 μEinstiens m^{-2} sec^{-1}, and under the high marsh canopy was 370 μEinstiens m^{-2} sec^{-1}. In November, average light attenuation was 67% for the *S. foliosa* canopy and 85% for the high marsh canopy. Average midday irradiance was 350 μEinstiens m^{-2} sec^{-1} under the *S. foliosa* canopy and 190 μEinstiens m^{-2} sec^{-1} under the high marsh canopy. Light reaching benthic microalgae is also attenuated by the water column during periods of submergence; this aspect of the light regime will be modeled later.

Benthic chlorophyll values are shown in Figure 1. In general, the bayfront mudflat had the lowest benthic microalgal biomass. Microalgal biomass in marsh tidal creeks (+2 feet above MLW) ranged from 51 to 190 mg Chl a m^{-2} and were higher in March and June than in November. Sediments from the *S. foliosa* and high marsh regions of the undiked Corte Madera marsh tended to have higher chlorophyll values than comparable sediments from the diked Muzzi Marsh (data not shown). Benthic chlorophyll values from the vegetated portions of both marshes ranged from a mean of 400 mg Chl a m^{-2} in summer to a mean of 80 mg Chl a m^{-2} in late fall and were always equal to or higher than values from the unvegetated mudflats.

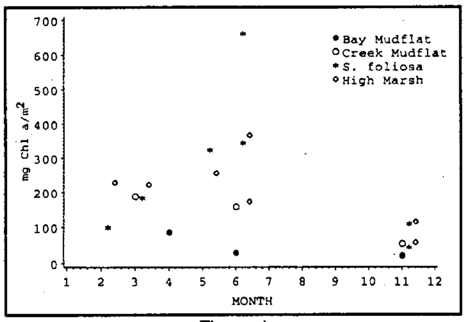


Figure 1
1994 BENTHIC CHLOROPHYLL

Biomass-specific photosynthesis-irradiance plots for benthic microalgae in July and November are shown in Figure 2. These figures represent depth-integrated, whole-community rates of photosynthesis and the response of the community to increased light levels, rather than an organism-specific physiological response. For example, at low light levels (*eg*, 100μE m^{-2} sec^{-1}) photosynthesis may be restricted to the top 150 μm of the sediment surface. At higher levels, photosynthetically active radiation penetrates deeper into the sediment, and photosynthesis may occur up to 1 millimeter deep in the sediment. Therefore, at higher light levels the biomass of microalgae actively photosynthesizing may be greater than at low light levels (Pinckney and Zingmark 1993).

Using the data we have collected so far, we can estimate the annual BMP for the intertidal habitats we have sampled (Table 1). These estimates are preliminary and are based on a limited set of sampling points. Also, the light regime model used to calculate daily production rates does not account for light attenuation by the water column during submerged periods, variability in incident irradiance due to clouds or fog, or microalgal vertical migration. In the model developed by Pinckney and Zingmark (1993), inclusion of these factors reduced model estimates of annual intertidal BMP by 12 to 36%. Accordingly, we have reduced our annual estimate (summed from daily rates) by 25% to factor in these additional sources of light attenuation. (Note that tidal submergence and vertical migration effects will be greater in the mudflat habitats than in the higher marsh habitats.)

Given these caveats, it is still clear that BMP in intertidal habitats of San Francisco Bay represents a substantial amount of primary production. Our estimate for annual BMP on the bay

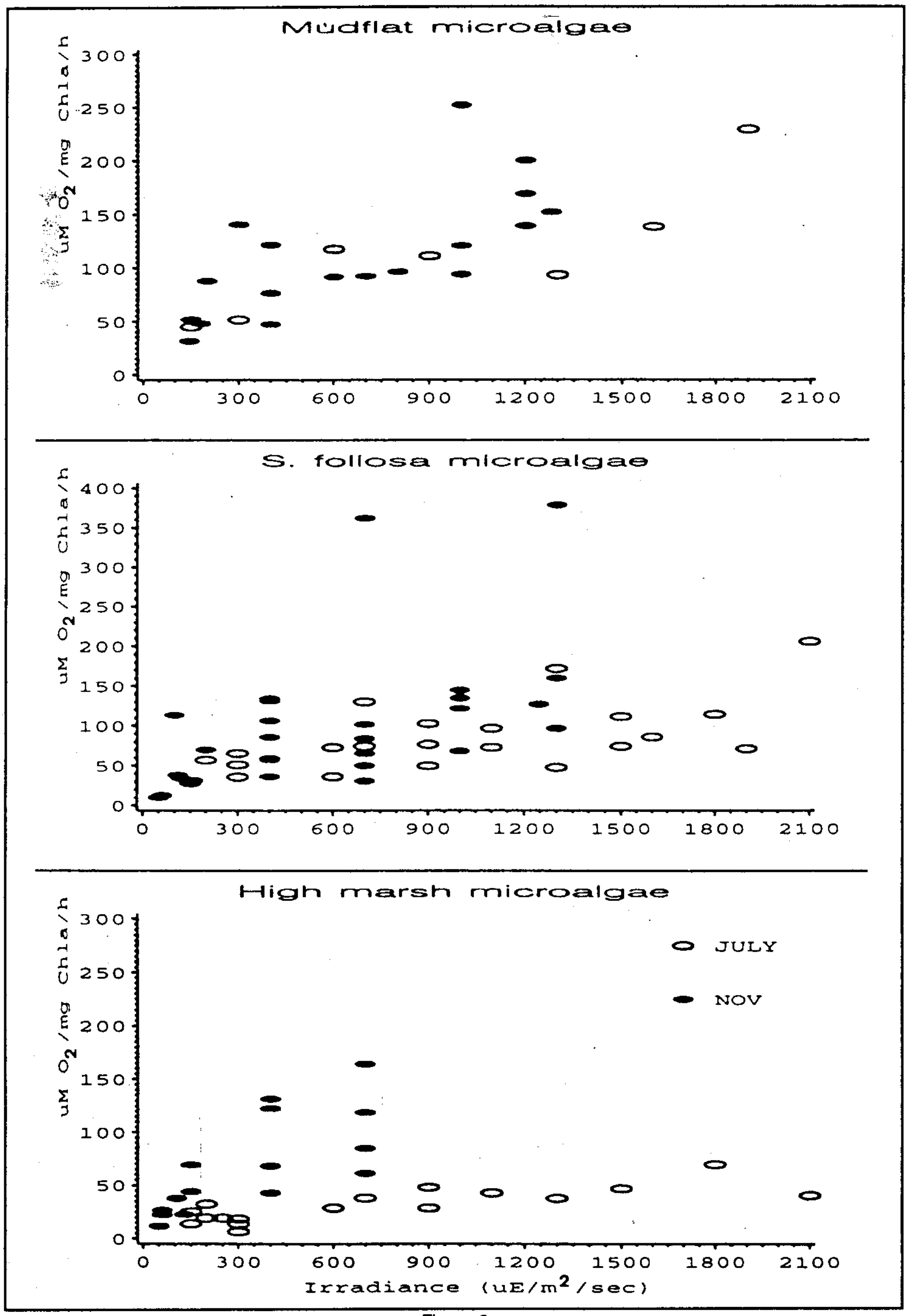


Figure 2
PHOTOSYNTHESIS-IRRADIANCE RELATIONSHIP OF BENTHIC MICROALGAL COMMUNITIES

mudflat (151 g C m^{-2} yr^{-1}) is slightly higher than the median literature value (110 g C m^{-2} yr^{-1}) used by Jassby et al (1993). The rates of annual BMP calculated for intertidal habitats within the marsh zone are even higher, ranging from 138 to 411 g C m-2 yr-1. These values are higher than those reported by Pinckney and Zingmark (1993) for an *S. alterniflora*-dominated marsh in South Carolina and are comparable to the estimates of Zedler (1980) for a southern California salt marsh. We plan to refine our estimate of annual intertidal BMP by collecting additional data on microalgal biomass and photosynthesis-irradiance curves and by constructing a more precise model of the light regime experienced by benthic microalgae at different tidal elevations. Also, we will characterize the composition of intertidal benthic microalgae using a combination of stable isotopes and lipid biomarker compounds (Canuel *et al* 1995). This information will be used to investigate the contribution of intertidal benthic microalgae to suspended particulate and sedimentary organic C in San Francisco Bay.

Funding for this study was provided by DWR and the National Oceanic and Atmospheric Administration's Coastal Ocean Program. We also thank San Francisco State University's Romberg Center for Environmental Studies and the USGS for logistical support.

Table 1
ESTIMATES OF ANNUAL BENTHIC MICROALGAL PRODUCTION IN CENTRAL SAN FRANCISCO BAY
Sum of daily production values is reduced by 25% to account for tidal submergence, clouds, and vertical migration.

Microalgal Habitat	Biomass (mg Chl a / m^2) Spring	Summer	Fall	Daily Production (mg C / m^2 / day) Spring	Summer	Fall	Annual Production (g C/m^2/y)
Bay mudflat	85.2	26.3	18.1	1070	417	166	151
Creek mudflat	188.0	157.8	51.9	2047	2152	437	348
S. foliosa	183.3	443.0	74.5	1274	3704	505	411
High marsh	222.3	270.2	84.8	574	824	443	138

Canuel, EA, JE Cloern, DB Ringelberg, JB Guckert, GK Rau. 1995. Application of molecular and isotopic tracers to understanding sources of organic matter and its incorporation into the food webs of San Francisco Bay. *Limnol Oceanogr.* In press.

Currin, CA, SY Newell, HW Paerl. Submitted. Standing dead *Spartina alterniflora* and benthic microalgae in salt marsh food webs: Considerations based on multiple stable isotope analysis. Submitted to *Mar Ecol Prog Ser.*

Jassby, AD, JE Cloern, TM Powell. 1993. Organic carbon sources and sinks in San Francisco Bay: Variability induced by river flow. *Mar Ecol Prog Ser* 95:39-54.

Pinckney, J, and RG Zingmark. 1993. Modelling intertidal benthic microalgal annual production in an estuarine ecosystem. *J Phycology* 29:396-407.

Sullivan, MJ, and CA Moncreiff. 1990. Edaphic algae are an important component of salt marsh food-webs: Evidence from multiple stable isotope analyses. *Mar Ecol Prog Ser* 62:149-159.

Zedler, J. 1980. Algal mat productivity: Comparisons in a salt marsh. *Estuaries 3:122-131.*

Delta Flows

Sheila Greene, DWR

The Delta Outflow Index averaged about 5,000 cfs from June to December 1994. The significant peak of 30,000 cfs in early December was due to a combination of reduced exports for Delta salinity control and increased inflow from a storm. Average SWP exports were 2,800 cfs and CVP exports were 2,500 cfs during the June-December period.

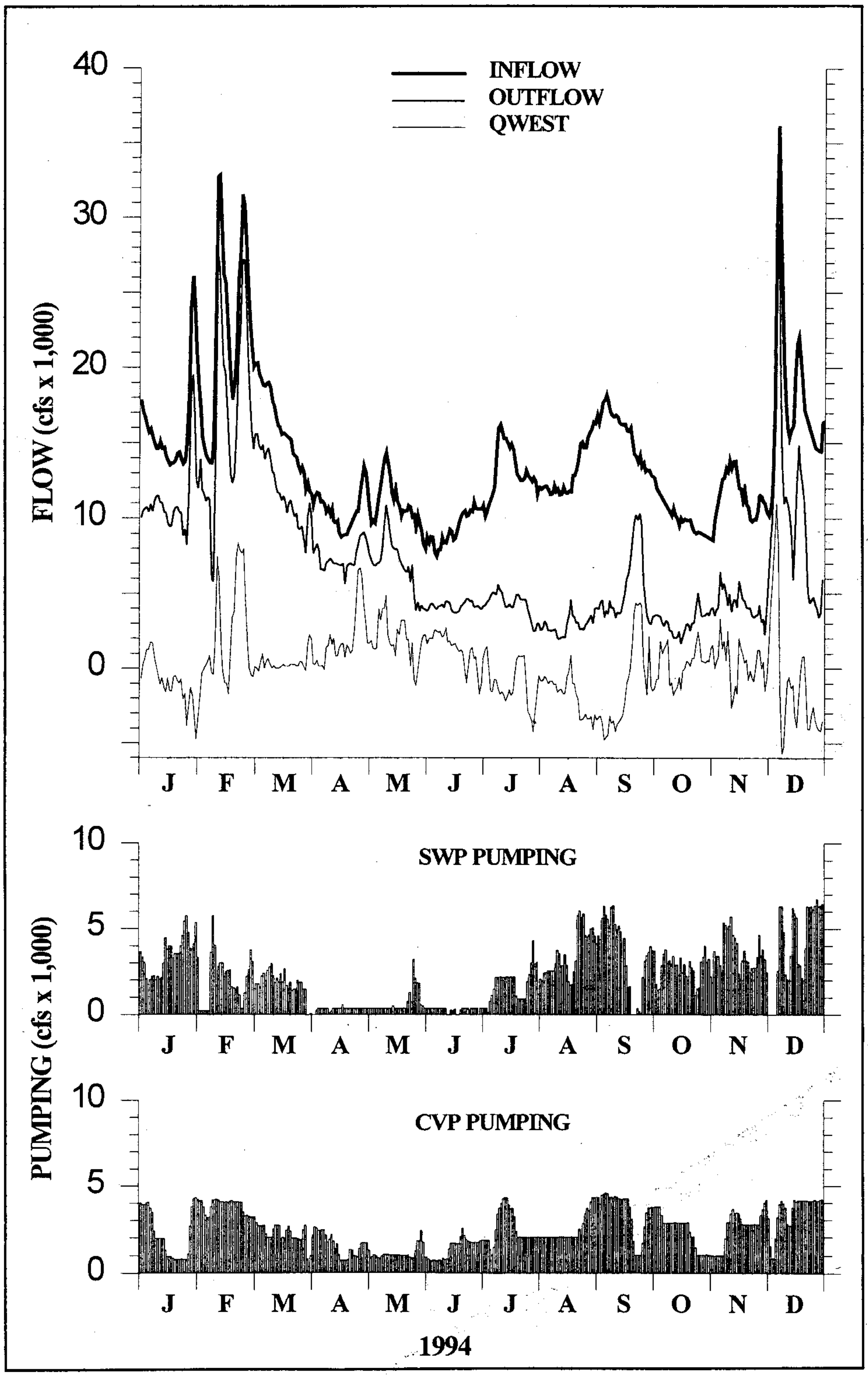
DAYFLOW

DAYFLOW for water year 1994 will be available from Sheila Greene (DWR) after January 20. You may obtained either hard copy or electronic format by writing Sheila at:

Department of Water Resources
3251 S Street
Sacramento, CA 95816

DAYFLOW has been modified somewhat. Sheila has deleted some values published in past and has added the export:inflow ratio and North Bay Aqueduct diversions. The new dataset is available (electronic format only) for the period of record, which begins with water year 1956.

When requesting an electronic copy of either the 1994 data or the period of record, please enclose a 3.5-inch IBM-compatible diskette with your request.



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