Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

Summer 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.

Sierra Nevada Runoff into San Francisco Bay — Why Has It Come Earlier Recently?

Mike Dettinger, Dan Cayan, and Dave Peterson
USGS, San Diego

By the time most of the Sierra Nevada snowpack has melted each summer, freshwater outflows from the Sacramento-San Joaquin Delta to San Francisco Bay are typically small, even after the wettest winters. These small delta outflows during the warm months (in comparison with the large flows of winter and spring) are overwhelmed by salty coastal waters, and the bay becomes more and more salty as summer progresses. Because longer low-flow seasons allow the bay to become saltier, timing of the Sierra Nevada snowmelt and runoff, which are the source of the delta flows, has a profound influence on the salinity of the bay and, thus, can affect its ecosystems (Peterson *et al* 1995).

Consequently, a recent tendency toward earlier snowmelt and runoff — described in this article — is a matter of concern. Is it a symptom of global warming? Is it a response to local or regional urban heat-island effects? Or is it just a normal part of the variability of California's hydrology? These possibilities raise concerns also about how much earlier the low-flow seasons in San Francisco Bay might begin in the future if the observed trends continue and how well the bay ecosystems will be able to cope with the flow-timing changes.

The "earlier runoff" trend was first noted by Maurice Roos, DWR, in 1987 (Roos 1987). Although it has much year-to-year variability, the runoff-timing trend can be detected by eye (Figure 1a) and is significantly different from random-chance occurrences according to a range of statistical tests (Dettinger and Cayan 1995). Since early in the century, the average April-June fraction of annual runoff has diminished from almost 50% to less than 40%. The trend toward smaller late-spring and early-summer fractions of each year's streamflow from the Sierra Nevada is shown in Figure 1a. This trend has been compensated for by a subtler set of opposite trends toward more winter and early-spring streamflow during the same period. The influence of these monthly trends on the overall timing of streamflow in the American River near Sacramento is shown in Figure 1b, in which the average recent flow regime is compared with the average flow regime from 30 years ago, when flows usually peaked almost a month later. Inspection of a large collection of streamflow records indicates that similar changes occurred throughout much of the western United States. A clue to their origin is that in the Sierra Nevada these changes are most accentuated in middle altitudes and are muted in streamflow records representing very high (more than 2,500 m) or very low (less than 1,000 m) altitudes.

The mechanism involved in these trends is mostly a hastening of the peak snowmelt period in recent decades in response to an observed trend toward warmer Januaries, Februaries, and Marches in the Sierra Nevada (Figure 2). Actually, this temperature influence is somewhat surprising, because historically the dominant control on seasonal runoff-timing fluctuations has been precipitation timing rather than temperature (Cayan *et al* 1993). Since the late 1940s, however, temperatures throughout the year in the Sierra Nevada have increased, with the January-March season experiencing the greatest warming, a total of about 2°F) in 50 years (Dettinger and Cayan 1995). During the same period, precipitation timing has shown little if any overall

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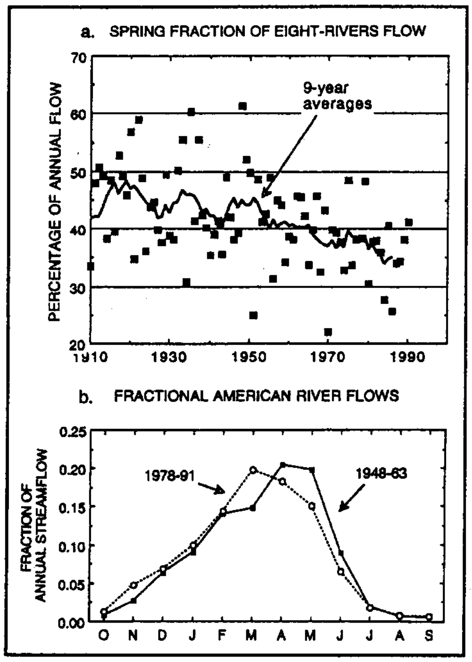

Figure 1
CHANGES IN RUNOFF TIMING
a. April-June Fractions of Annual Streamflow in Eight Major Rivers
b. Mean Monthly American River Flow Fractions

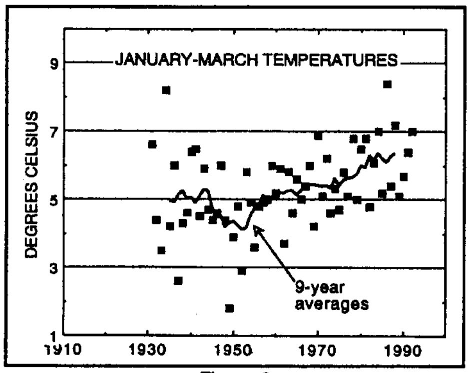

Figure 2
WINTER MEAN TEMPERATURE IN AN AVERAGE OF FOUR SIERRA NEVADA WEATHER STATIONS

trend. The runoff-timing response is most pronounced at middle altitudes because at these altitudes the snowpack and winter runoff are most sensitive to small changes in winter temperature. At low altitudes, temperature is less important because precipitation falls mostly as rain; at high altitudes, winter are so cold that fluctuations of a degree or two do not matter. About 67% of Sierra Nevada watersheds are in the sensitive middle-altitude range. Notably, the warming since the late 1940s has led to earlier snowmelt and runoff of winter and spring precipitation but no detectable change in the quantity of total runoff — in keeping with recent watershed-simulation studies by Dettinger and Jeton (1994).

To answer questions about the nature of these trends, we turned to broader-scale climate measures. Analysis of the historical fluctuations of wintertime atmospheric circulation over the North Pacific Ocean and western North America identifies broad, slow changes that have been the immediate causes of the warming and runoff-timing trends (Dettinger and Cayan 1995). The circulation changes are illustrated in Figure 3 in terms of a statistical measure of long-term changes in the atmospheric-pressure fields about one-third of the way up into the atmosphere — at 3 km above sea level. The Kendall's-tau statistic plotted in that figure is a measure of the correlation between time and the pressure series at each point on the map. These statistics range from +1 when applied to an uninterrupted rising trend, to 0 for a non-trending series, to -1 for steady negative trends. The long-term pressure changes found signify an increasing tendency for the winter wind pattern over the North Pacific and West Coast to bend away from the usual paths along latitude circles to something like the arrow in Figure 3. This wind pattern has brought air to California from farther south more often than usual in recent winters. The progression of the winter winds toward this configuration can be illustrated by a time series of "pattern correlations" between each winter's average wind pattern and the contours in Figure 3. (Like the Kendall's-tau statistic, these pattern correlations range from +1 when calculated for two maps that are the same at each point, to 0 for two maps that bear no overall resemblance to each other, to -1 for a map and its photographic negative.) This measure of the resemblance between winter circulation patterns and the contours of Figure 3 is shown in Figure 4, in which it is evident — amidst considerable year-to-year variability — that the resemblance has grown in recent decades. Thus, the change in circulation has unleashed a chain of

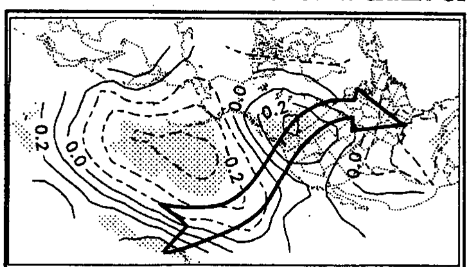

Figure 3
KENDALL'S-TAU TREND-TEST STATISTICS FOR JANUARY-MARCH 700-MBAR HEIGHT ANOMALIES, 1948-1992
Shaded where significantly trending and dashed where negative.

effects: a more southerly source for winter winds, leading to warmer winter temperatures in the Sierra Nevada, leading to earlier snowmelt and runoff, and contributing to early peaks of delta outflow to the bay (Peterson *et al* 1995).

A further aspect of these atmospheric-circulation changes concerns the persistence of weather patterns during the course of each winter and, thus, the predictability of winter weather. One measure of the month-to-month similarities between winter/spring climate patterns over the North Pacific Ocean is the season-average lagged-pattern correlations of sea-surface temperature, also shown in Figure 4. Lagged-pattern correlations are high (approaching +1) when the monthly average circulation patterns do not change much from month to month during a given season, and they are small when each month's pattern is different from the preceding month's pattern. The lagged-pattern correlations (plotted with open symbols and dashed curve in Figure 4) show year-to-year and decade-to-decade variations in the persistence of sea-surface temperatures of the North Pacific Ocean, variations which are closely related to the specific atmospheric-circulation patterns implied by Figure 3. As is clearly shown in Figure 4, month-to-month persistence of sea-surface temperature patterns has been increasing in recent decades and, even more dramatically, pattern persistence and similarity to the contours of Figure 3 go hand in hand on decadal scales (with an annual cross-correlation coefficient of +0.6). The most persistent sea-surface temperature patterns have been shown (by Dettinger *et al* 1994) to be most often

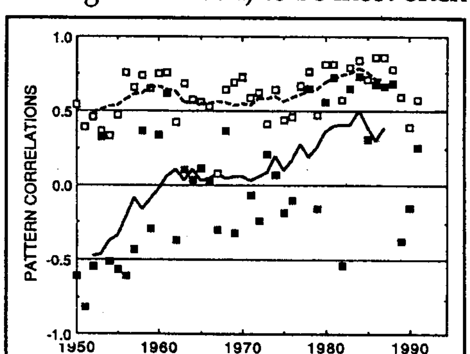

Figure 4
SPATIAL AND TEMPORAL CORRELATIONS AMONG ATMOSPHERIC AND SEA-SURFACE PATTERNS
Solid symbols and curve are correlations between contours of Figure 3 and winter mean 700-mbar anomalies. Open symbols and dashed curve show average January-May lag-one-month pattern correlations of North Pacific sea-surface temperatures.

associated with the pattern in Figure 3, which itself is the most persistent winter atmospheric-circulation pattern. Together these sea-surface and atmospheric-circulation patterns must mutually reinforce each other to sustain such persistent conditions with such regularity.

The recent trend toward more persistent ocean-air relationships and the frequent correspondence of persistence with the wind pattern of Figure 3 supports optimism that snowpack and runoff-timing prediction with several months lead time is possible. Knowledge early in the season that a winter's air-sea patterns are closely replicating the persistent patterns can suggest that circulations are most likely to persist in that mode, ultimately to fulfill the runoff-hastening potential that this atmospheric pattern holds for the Sierra Nevada. In contrast, recognition that circulation patterns are not in the persistent mode has been an indication historically that winter North Pacific climate will be highly variable and that runoff from the Sierra Nevada would be contingent on the particular (unpredictable) course of the winter to follow. This strategy was exploited in a preliminary prediction scheme for April snowpack water content in the Pacific Northwest — based on the January sea-surface temperature patterns associated with persistence — which captured 70% of the year-to-year snowpack variability between 1948 and 1987 (Dettinger *et al* 1994).

Thus, a major component of the atmospheric changes discussed here is a trend toward more frequent occurrence of the wind pattern of Figure 3. In effect, the pattern in Figure 3 has become more and more the normal weather pattern over the North Pacific and North America in recent decades. It probably is not coincidental that this pattern is associated with particularly persistent conditions in both the atmosphere and ocean. Reassuringly, further analyses (not shown here) of longer-term data series indicate that ocean-air patterns also lapsed into such persistent patterns during prior episodes in the 1920s and early 1960s. This suggests that these changes are probably part of the natural decadal variations of Pacific climatology on decadal time scales and need not be interpreted as part of some new phenomenon such as the greenhouse effect. If, however, they are part of some human-induced change in the global system, then the changes must be assuming the shapes of natural-looking mechanisms of climate variation.

The atmospheric changes discussed here are much slower than, and not directly associated with, year-to-year global fluctuations such as El Niño/Southern Oscillation (ENSO). ENSO fluctuations are usually considered to be rapid variations around some "normal" tropical state. In recent decades, however, there have been indications that the "normal" tropical state may be changing. Indeed, recently, 5 years of El Niño and near-El Niño conditions have been sustained without the usual interruptions by "anti"-El Niño conditions. This sustained El Niño/near-El Niño state has led some climatologists to suggest that near-El Niño conditions may have become the new normal tropical condition (Monastersky 1995). At least some of the long-term changes associated with this "tropical drift" actually began in the late 1940s — with the commencement of a gradual sustained warming of the western tropical Pacific. Perhaps not coincidentally, this also is when the North Pacific changes, the Sierra Nevada warming, and the runoff-timing changes began.

In summary, we find that the timing of delta outflows to the bay are linked through air temperatures over the western United States and in the Sierra Nevada to climatic fluctuations over the North Pacific and beyond. Since the late 1940s, these linkages have resulted in a statistically significant trend toward earlier annual Sierra Nevada snowmelt and delta outflow. Many other western streams show a similar trend. The trend seems to be associated with interdecadal variations of the North Pacific climate system and, possibly, with long-term changes in the tropical Pacific. As we come to understand them more, these distant linkages may form the basis for long-term Sierra-climate and delta-outflow predictions. At present, the recent trends seem to reflect natural variability of California's climate and, thus, are part of the natural variability of the San Francisco Bay ecosystem. If so, these long-term fluctuations would be part of the hydroclimatic range within which the bay ecosystems developed and, thus, probably are not threats to the viability of the ecosystems; they are extremes, however, that cannot be safely ignored in the evaluation of human influences on those ecosystems (such as the long-term decrease in spring delta outflows resulting from long-term increases in water exports).

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Real-Time Monitoring Program

Leo Winternitz (DWR), Pat Brandes (FWS), Randy Baxter (DFG), Chuck Armor (DFG)

Real-time monitoring, an idea proposed about 15 years ago, has arrived in this estuary. A combination of new technology, old equipment, and lots of hard work has made this program a reality. Reliable boats, dedicated people, and the ability to condense a logistics nightmare into a simple spreadsheet are necessary to collect the data. Fax machines, cellular phones, personal computers, and a worldwide web communications system are necessary to disseminate the data. Put both together, and you have fisheries data collected daily at a dozen sites by 15 boats and 45 people turned into information and available worldwide within 24 to 48 hours of collection. This is what the Interagency Program did in the delta during May and June this year, with financial and technical assistance from various water users — contractors from the SWP, CVP, California Urban Water Agencies, and delta and San Joaquin River tributary agencies. Field crews consisted of personnel from DFG (Bay-Delta and Region 4), DWR, USFWS, USBR, Hansen Environmental, and Beak Consultants. Cost of operating this program is estimated at $250,000 per month.

The purpose of this year's real-time monitoring (also known as near-real-time monitoring), was twofold:

- To determine if the monitoring could be conducted consistently over a long period given the uncertainties associated with operation of mechanical equipment, use of nets, and scheduling of people, and to determine whether data collected on a daily basis could be provided as reliable information within 24 to 48 hours.
- To assess the feasibility for protecting Chinook salmon, delta smelt, splittail, longfin smelt, and other fish species from SWP and CVP operations in the southern delta.

The 1995 program specifically targeted Chinook salmon, delta smelt, and splittail. The overall objective is to protect targeted fish from entrainment at the SWP/CVP facilities while providing for water supply reliability.

Data collected during May and June will be used to determine if a predictive relationship exists between catches of targeted species at designated locations and the corresponding pattern and magnitude of fish losses in SWP and CVP salvage operations. Through this effort, it may be possible to reduce overall losses of entrained fish at no net additional water supply cost to the CVP and SWP. For example, if the susceptibility of a target species to loss is greater at one facility, then pumping could be shifted to the facility where there is less susceptibility. Under another set of circumstances, export pumping could be reduced if the monitoring stations detect high densities of targeted species in the channels headed toward SWP/CVP facilities. Reduced pumping levels would result in less take. Higher pumping levels could resume once monitoring indicates the targeted species are no longer in an established zone of influence.

The real-time monitoring program was implemented in two phases. Phase 1 began May 1 and ran through May 21. It was originally targeted at juvenile salmon and 20+ mm delta smelt. However, monitoring indicated that while splittail were abundant through the delta (particularly the San Joaquin River), most delta smelt were west of Chipps Island. Therefore, emphasis shifted to splittail and salmon. Phase 2 ran from May 22 to June 30 and targeted primarily splittail. Monitoring sites, gear types, and sampling schedules are shown in Table 1.

Salmon Evaluation

About 10 million salmon smolts were released from Coleman National Fish Hatchery (below Shasta Dam) on April 24 and 25. Peak movement of the smolt into the delta was observed on May 1 in the Sacramento monitoring sites (Sherwood Harbor near Sacramento, Walnut Grove and Georgiana Slough). Many of the smolts appear to have entered the central delta via Georgiana Slough (Figure 1), with some moving farther into the southern delta (Old River at Webb Tract and Old River and Middle River stations; Figure 2). Most of the Sacramento smolts that moved into the central delta appear to have successfully migrated to the western delta via Jersey Point (Figure 3). These data suggest that although many smolts move into the central delta via Georgiana Slough and successfully migrate to the western delta (at least in a wet year), a significant fraction moves farther into the southern delta, even at high flows.

An additional 275,000 smolts were released on May 10 from the Merced River Fish Facility, with the peak numbers entering the delta at Mossdale on May 18, 26, and 31 (Figure 2). Between May 22 and 27, daily average CVP/SWP pumping was reduced by

Table 1
REAL-TIME MONITORING STATIONS, GEAR, AND FREQUENCY

At the Old River and Middle River sites and upper Old River and San Joaquin River at Dos Reis sites ten 10-minute tows were conducted daily for a total of 100 minutes at each site. At all other sites, ten 20-minute tows were conducted for a total of 200 minutes at each site. At the San Joaquin River at Dos Reis and Old River near the confluence with the San Joaquin River, sampling was conducted May 8-17.

Sampling Site	May 1-May 21	May 22-June 30
Sacramento River at Sacramento*	7 days/week Midwater Trawl	3 days/week Midwater Trawl
Sacramento River at Georgiana Slough	4-5 days/week Kodiak Trawl	4-5 days/week Kodiak Trawl
San Joaquin River at Jersey Point	7 days/week Midwater Trawl	No Sampling
Chipps Island	7 days/week Midwater Trawl	7 days/week Midwater Trawl
Old River southwest of Bacon Island	7 days/week Kodiak Trawl	7 days/week Kodiak Trawl
Middle River southeast of Bacon Island	7 days/week Kodiak Trawl	7 days/week Kodiak Trawl
Old River adjacent to Webb Tract	7 days/week Kodiak Trawl	7 days/week Kodiak Trawl
San Joaquin River at Mossdale	7 days/week Kodiak Trawl	7 days/week Kodiak Trawl
San Joaquin River at Dos Reis	7 days/week Kodiak Trawl	No Sampling
Upper Old River near the confluence with San Joaquin River	7 days/week Kodiak Trawl	No Sampling

*Sampling began April 27.

about 1,500 cfs (to 3,900-4,500 cfs) to facilitate movement of these smolts past the pumping plants. Even though the peak of smolts migrating into the delta from the Merced release should have been relatively straight forward to track, the fluctuation between the peaks made it difficult to recommend the length of curtailment necessary to provide protection. Peaks of naturally spawned salmon also will likely be difficult to detect because of the within-season fluctuations.

Between May 12 and May 20, kodiak trawling was conducted at the head of Old River and in the San Joaquin River near Dos Reis to evaluate the relative densities in the two channels and assess whether high numbers of salmon migrate down Old River (Figure 4). These sites were added in response to the release of fish from the Merced River hatchery. With the exception of one sampling day, catch per acre-foot was always greater in Old River than in the San Joaquin River downstream of Old River. This indicates that even in high flow years, many smolts migrate toward the CVP/SWP pumping plants via Old River. Information gathered in dry years indicates that survival is about two times greater if smolts migrate to Chipps Island via the San Joaquin River.

Splittail Evaluation

This year's real-time monitoring program documented the movement of young-of-the-year splittail leaving the Sacramento and San Joaquin rivers and moving through the delta (Figure 5). In 1995, nature provided one of the best water years since 1983 and splittail took advantage, producing what may be the largest year class since the mid-1960s. Although a good year class was expected, the magnitude of the spawning success, particularly from the San Joaquin River, was not expected. In conjunction with FWS beach seining and other Interagency Program sampling, real-time monitoring data will provide the best picture yet of how a large year class of splittail disperse.

One objective of real-time monitoring — to use fish density and distribution information to modify pumping levels and reduce fish impacts of water exports — was addressed in 1995. Unprecedented numbers of young-of-the-year splittail collected at Mossdale on June 4 and 5 led to a request to reduce export pumping to limit splittail entrainment. After some discussion on water costs and biological benefits, a 3-day export reduction was implemented on June 11. Although the short-term biological benefits of the action are debatable, the long-term benefits of the process are evident. Real-time monitoring provided data that identified a potential problem, the problem and alternative solutions were discussed, and a course of action was identified and implemented in a timely manner.

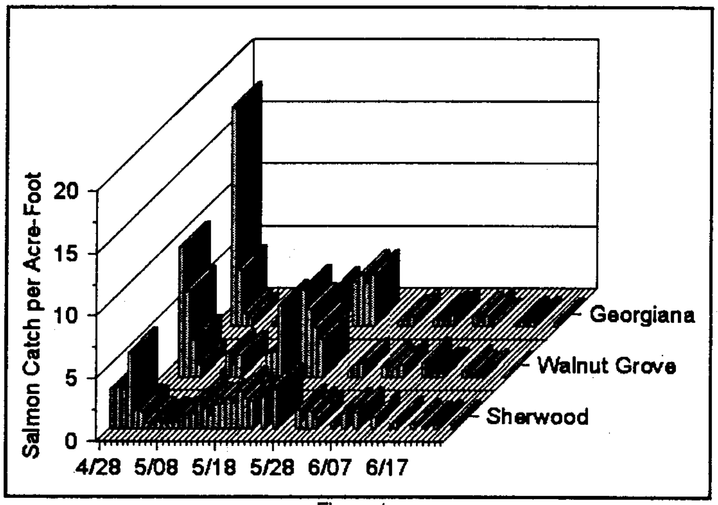

Figure 1
SALMON CATCH, NORTHERN DELTA SITES
Real-Time Monitoring Program

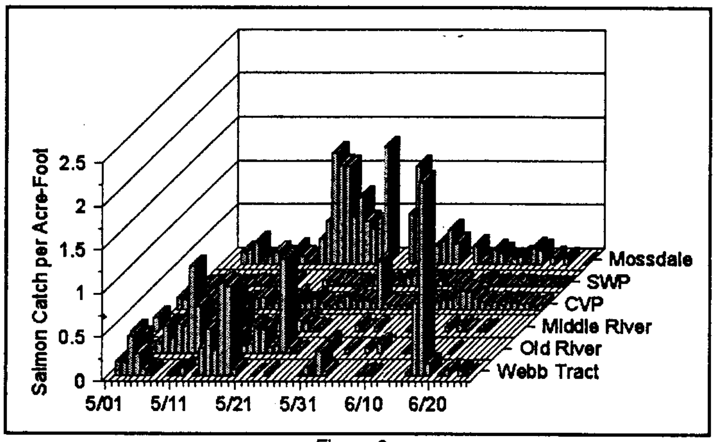

Figure 2
SALMON CATCH, CENTRAL DELTA SITES
Real-Time Monitoring Program

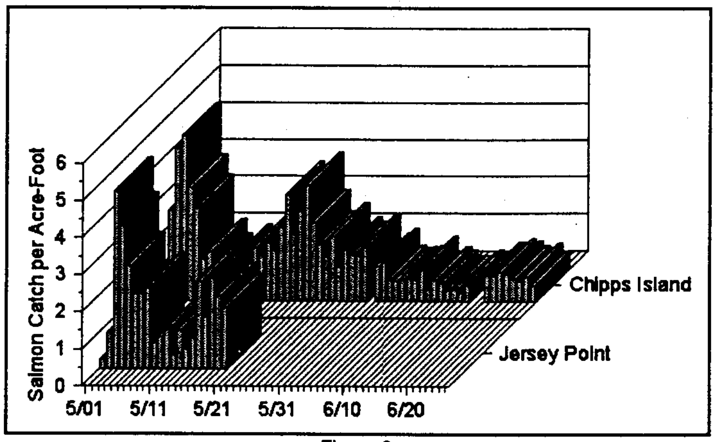

Figure 3
SALMON CATCH, WESTERN DELTA SITES
Real-Time Monitoring Program

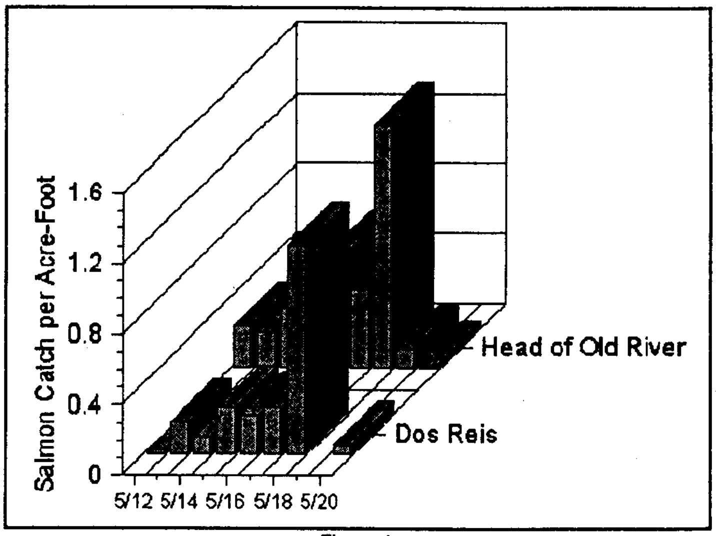

Figure 4
SALMON CATCH, OLD RIVER AND SAN JOAQUIN RIVER SITES
Real-Time Monitoring Program

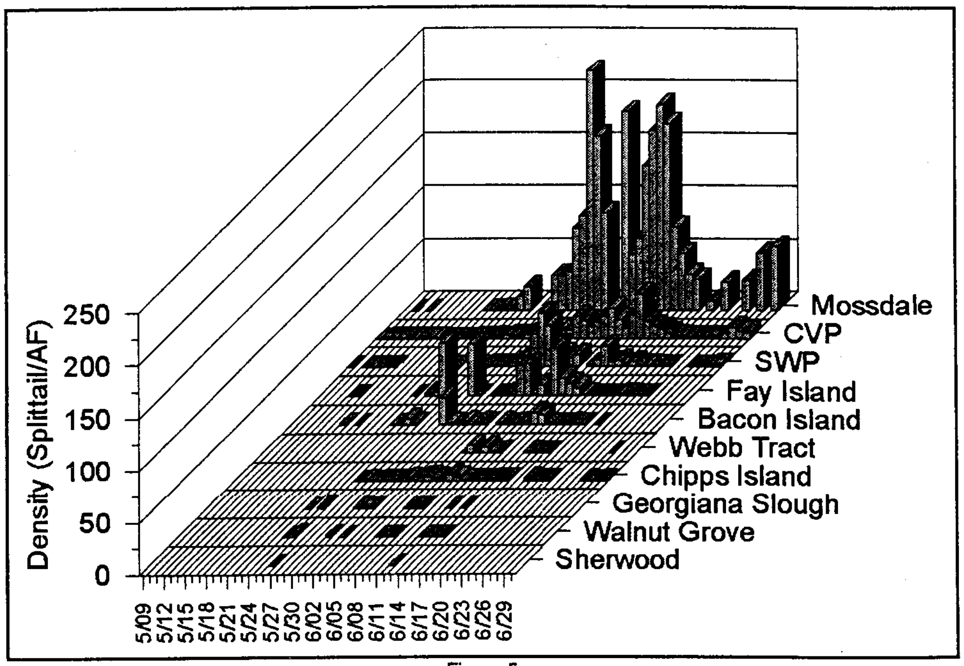

Figure 5
SPLITTAIL CATCH PER ACRE-FOOT, BY LOCATION
Real-Time Monitoring Program

Future Work

Real-time monitoring was conducted during May and June this year. For hatchery salmon, it provided valuable information on migration through delta channels. For splittail, it provided early warning on peaks of young of the year coming through the delta, which resulted in reduced export pumping for 3 days. This year's sustained high flows moved most of the striped bass, delta smelt, and longfin smelt out of the delta. Therefore, we cannot draw any conclusions from real-time monitoring about these species or whether the monitoring will prove effective for either hatchery or natural runs of salmon.

The real-time monitoring program is being evaluated for inclusion into a revised Interagency Program. Evaluation of the program will include input from agency and water user biologists, CVP and SWP operators, and members of the CALFED Operations Group. To assist in that evaluation, a report is being prepared and will be completed in August. The report will identify what went right, what went wrong, program costs, other work foregone, data analysis, and recommendations for future work.

If you would like a copy of the report, or have any questions on this program, please contact:

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Research Enhancement Program

This year the Interagency Program awarded about $100,000 to university researchers for studies that will help us develop a better understanding of important processes affecting the estuary. Three of the twelve proposals submitted were selected after a thorough review for technical merit and relevance to the Interagency Program's goals and objectives. Selected proposals are:

Principal Investigator — Deborah Penry
Institution — University of California, Berkeley
Amount — $24,705

Subject — Modeling and measuring digestive performance in the bivalves *Potamocorbula amurensis* and *Macoma balthica*.

Relevance — This study will assist in understanding the roles of the two filter-feeding clams in recycling organic and toxic materials in the estuary.

Principal Investigator — E. John List
Institution — California Institute of Technology
Amount — $49,880

Subject — Fingerprinting natural waters of the bay/delta by Inductively Coupled-Mass Spectrometry (ICP-MS) as a basis for resolving estuarine mixing problems.

Relevance — This technique may lead to estimates of net delta outflow as well as flow patterns and levels of mixing in delta channels.

Principal Investigator — Elizabeth Canuel
Institution — Virginia Institute of Marine Science, College of William and Mary
Amount — $27,394

Subject — Sources and reactivity of organic matter in San Francisco Bay including the role of hydrologic regimes and autochthonous production.

Relevance — The study will help elucidate the roles and food web importance of organic material produced in the estuary as compared to this material coming in from the watershed and waste discharges.

Cordgrass Invasions Likely in Northern San Francisco Estuary

Donald R. Strong, University of California, Davis, Bodega Marine Laboratory

Open intertidal mud without vegetation is a hallmark of Pacific estuaries, in contrast to Atlantic and Gulf Coast estuaries where vast stands of monocots prevail. Smooth cordgrass, *Spartina alterniflora*, is the most aggressive of these intertidal plants; it is dense and tall, with thick, solid turfs of roots. Estuaries comprise a far smaller fraction of the Pacific than Atlantic and Gulf coasts of North America, and open mud without intertidal grasses is key to the ecology of the geologically young communities in low-energy intertidal environments of California, Oregon, and Washington. The openness of intertidal mud is crucial to shore birds, some marine mammals, fish, and invertebrates, as well as flood control, recreation, navigation, and the esthetics of our Pacific estuaries.

Smooth cordgrass has been inadvertently and purposefully introduced to several Pacific estuaries where it has spread, covered a large fraction of previously open mud, and caused great immediate economic harm to navigation and fish. The longer-term threats of these invasions include loss of precious foraging areas of shore birds and larval fish, as well as wholesale sediment accumulation and severe channelization. In San Francisco Bay, smooth cordgrass has spread since the early 1970s from its introduction point to many sites in the south bay. Clogging the Alameda Flood Control Channel, it is now the object of an expensive and ecologically hazardous aerial herbicide spraying campaign. The longer-term threats to birds, fish, and water management are enormous. A special threat in the bay is to the noninvasive California cordgrass, *Spartina foliosa*, which remains high on the intertidal gradient and is the habitat of the California clapper rail and salt marsh harvest mouse, both endangered species. Smooth cordgrass overgrows California cordgrass and probably hybridizes with it.

North San Francisco Bay, San Pablo Bay, and Suisun Marsh are likely sites of invasion by smooth cordgrass. Salinity and tides in these areas are perfect for this alien. Fortunately, most seed produced by smooth cordgrass in the bay area is sterile, and spread here is mostly by clonal growth and fragmentation. Many clonal fragments break off in chunks of mud as large as an ice chest or larger. However, waves wash the mud away and leave the light-colored fibrous root masses to float or be carried to a new site. Most root masses are at least the size of one's fist and are attached to a green stem with bilateral leaves. The stems and leaves can be up to a meter long in late summer, but even a small, stemless root mass can be a vigorous propagule. The most likely means of dispersal of root masses from the southern to the northern parts of the San Francisco estuary is inadvertent transport on dredges and other vessels, on boat trailers, or in bait or live seafood containers (smooth cordgrass was introduced to Willapa Bay, Washington, as oyster packing material).

The hopeful aspect of the likely smooth cordgrass colonization of the northern San Francisco estuary is that young, small colonies can be eradicated with the legal herbicide *Rodeo*, or even removed by hand. Young colonies are lime green, round patches of grass in the intertidal mud, usually close to mean high water. So far, all cordgrass that we know of in the northern parts of the San Francisco estuary is the native and valuable California cordgrass. Young colonies of the two species are difficult to distinguish, but any reddish coloration of upper roots or lower stems indicates the noxious alien, smooth cordgrass.

Interagency Program Technical Reports Since 1993

No.	Year	Title
34	1993	Proceedings of the Ninth Annual Pacific Climate (PACLIM) Workshop K. Redmond, V. Tharp, editors
35	1993	Observations of the Early Life Stages of Delta Smelt, *Hypomesus transpacificus*, in the Sacramento-San Joaquin Estuary in 1991, with a Review of Its Ecological Status in 1988 to 1990 J. Wang, R. Brown
36	1994	Proceedings of the Tenth Annual Pacific Climate (PACLIM) Workshop K. Redmond, V. Tharp, editors
37	1994	Delta Agricultural Diversion Evaluation 1992 Pilot Study S. Spaar
38	1994	Long-Term Trends in Benthos Abundance and Persistence in the Upper Sacramento-San Joaquin Estuary — Summary Report: 1980-1990 Z. Hymanson, D. Mayer, J. Steinbeck
39	1994	Seasonality and Quality of Eggs Produced by Female Striped Bass (*Morone Saxatilis*) in the Sacramento and San Joaquin Rivers J. Arnold, T. Heyne
40	1995	Proceedings of the Eleventh Annual Pacific Climate (PACLIM) Workshop C. Isaacs, V. Tharp, editors
41	1995	Food Habits of Several Abundant Zooplankton Species in the Sacramento-San Joaquin Estuary J. Orsi
42	In Review	Working Conceptual Model for the Food Web of the San Francisco Bay/Delta Estuary Estuarine Ecology Team
43	In Review	Observations of Early Life Stages of Splittail (Pogonichthys macrolepidotus) in the Sacramento-San Joaquin Estuary, 1988 to 1994 J. Wang

Critical Thermal Minima and Maxima in Sacramento Splittail

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

Critical thermal minima (CTMi) and maxima (CTMa) were measured in young-of-the-year (0.1-4.0 g), juvenile (10-42 g), and subadult (79-201 g) splittail, *Pogonichthys macrolepidotus*, using the method by Cox (1974), and Becker and Genoway (1979) defined by a loss of equilibrium. Differences in thermal acclimation or size did not have any significant effect on CTMi values (Figure 1; below symbol legend). Whereas fish size and acclimation history had no effect on CTMi, they had important influences on CTMa (Figure 1; above symbol legend). Increases in acclimation temperature resulted in an increase in CTMa value except in the small size young of the year (0.1-0.5 g). In the large size young of the year (1.0-4.0 g), an increase of 3°C in acclimation temperature resulted in a 3°C increase in CTMa. A 5°C increase in acclimation temperature resulted in an 8°C increase for juveniles and a 7°C increase for subadults. Bridges (1971) reported that juvenile spot were not killed by increased temperature resulting from power plant discharges during the winter because the ambient water has a lower temperature so that the maximum temperature reached is still less than CTMa. However, our results indicated that for 17°C- and 20°C-acclimated splittail (simulating fall/spring and summer acclimation temperatures) a 12°C increase would be lethal; while for 12°C-acclimated fish (simulating winter acclimation temperature) a smaller increase of 9°C would be lethal.

For fish acclimated at 17°C, mean CTMa (28.9-30.8°C) was negatively correlated with size (Figure 2). This might be because young of the year habitats are shallower, the water temperatures are warmer, and these young fish are more adapted to the higher temperatures. Another reason might be because the subadult fish were more sensitive to heat stress in terms of loss of equilibrium. Cox (1974) reported that larger bluegill were more sensitive than small ones to heat stress in terms of loss of equilibrium but had greater stamina in resisting physiological death.

Based on the safety factor of 5°C below CTMa (Bridges 1971), upper limits of safe temperature were estimated for young-of-the-year, juvenile, and subadult splittail acclimated at different temperatures (Table 1). Upper limit of safe temperature at different times of the year may be inferred from the estimated upper safe temperature limit of different size groups of fish acclimated at different temperatures; *ie*, summer upper limit of safe temperature would be based on 20°C acclimation; spring/fall upper limit on 17°C acclimation; and winter upper limit on 12°C acclimation. Until a more detailed study is done on temperature effects on survival, growth, reproduction, *etc*, these upper limits of safe temperature would serve as the bases for estimating upper temperature requirements of young-of-the-year, juvenile and subadult splittail at different times of the year. Table 1 also provides the estimated preferred temperature (final preference) and temperature for optimal growth. Readers should be cautioned in using these data derived from equations (Jobling 1981) based on 49 different fish species. Under certain conditions, physiological processes may have different thermal optima, and this effect may result in changes in the preferred temperature (Crawshaw 1977). Other non-thermal influences (*eg*, season, photoperiod, age, light intensity, salinity, disease, pollutants, biotic interactions) can also affect temperature preference (Reynolds and Casterlin 1979).

This study was funded by the Interagency Ecological Program for the San Francisco Bay/Delta. We thank S. Matern, L. Hess, S. Siegfried, G. Weis, J. Morinaka, L. Grimaldo, R. Baxter, T. Hampson, H. Bailey, and the alosa and longfin groups headed by K. Heib and J. Arnold of DFG for assistance in splittail collection. We extend our thanks to P. Lutes and B. Bentley for assistance in fish maintenance system; L. Grimaldo for identifying the small-size young of the year, and J. Wang for confirming identification of the small-size young of the year. We also thank D. Shigematsu, D. Irwin, M. Thibodeau, S. Cummings, C. Porter, J. Lorenzo, J. Hubline, J. Khoo, G. Cech, L. Brink, and P. Moberg for technical assistance.

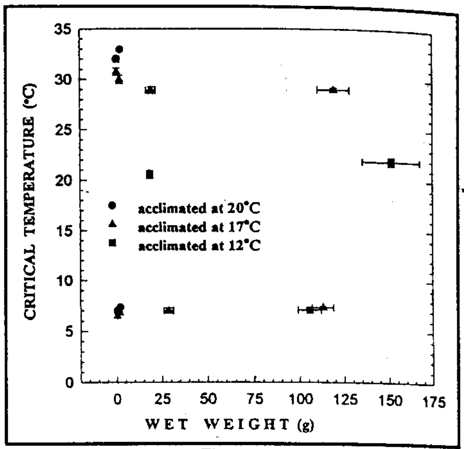

Figure 1

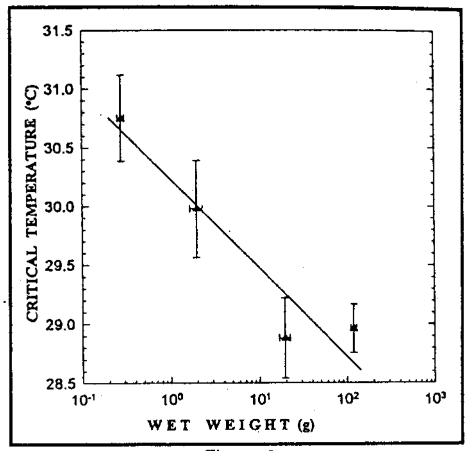

Figure 2

Table 1
ESTIMATED UPPER LIMIT OF
SAFE TEMPERATURE, FINAL PREFERENCE, AND GROWTH OPTIMUM FOR
YOUNG-OF-THE-YEAR, JUVENILE, AND SUBADULT SPLITTAIL AT
DIFFERENT ACCLIMATED TEMPERATURES

Temperature values are in degrees Celsius.

Fish Size	Acclimated Temperature	Upper Limit for Safe Temperature	Final Preference	Growth Optimum
Small YOY	20	27	24	24
	17	26	22	22
Large YOY	20	28	25	25
	17	25	21	21
Juvenile	17	24	19	20
	12	16	—	—
Subadult	17	24	19	20
	12	17	—	—

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Update on Delta Smelt Culture

This year the Interagency Program continued in its attempts to culture delta smelt, with the primary goal of rearing enough animals to conduct various tests. We divided the efforts between a UC-Davis laboratory culture study and San Francisco State University study of culturing the fish in large tanks using delta water. This is a brief summary of the tank studies using delta water.

Early this year Dr. Joan Lindberg of the Romberg Tiburon Centers collected 281 prespawning delta smelt from the CVP and SWP fish screens for use in this study. Some of the fish had been used in a handling study by DFG at Skinner Fish Facility. Use of the salvaged fish was necessary after attempts to collect them in the delta were unsuccessful.

Joan held the fish in an outdoor 20-foot-diameter tank filled with unfiltered water from the California Aqueduct. The tank is at Skinner Fish Facility near the intake to the aqueduct and is part of the facilities used to hold salvaged striped bass for use in a mitigation program.

About 87% of the prespawning adults survived the first 2 months of holding in the large outdoor tank. This survival is considered good, since the fish had all been through the salvage process and some had been used in other studies.

While examining the fish, it appeared that a large percentage of the smelt might be wakasagi. Subsequently, the stippling characteristics developed by DFG and presented in the spring issue of this newsletter were used to separate 39 fish that appeared to be wakasagi. These fish are frozen and are available for blood chemistry work to provide more definitive separation between the species.

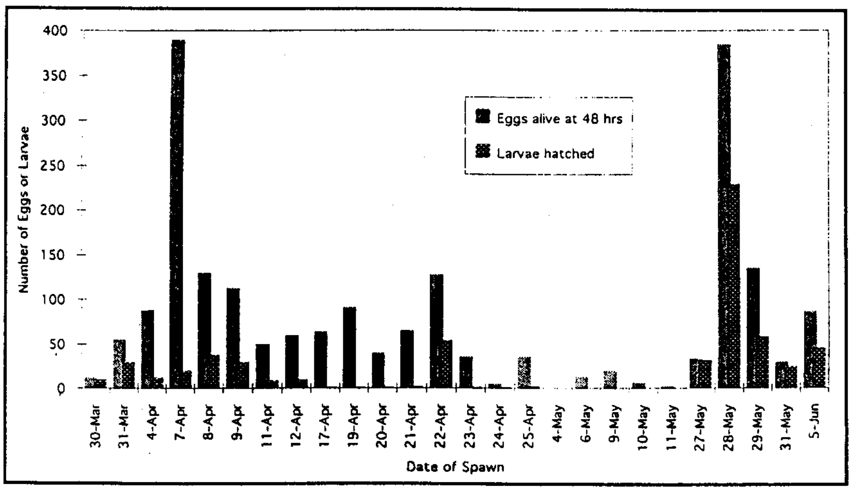
On March 22, the researchers placed 168 adult delta smelt into three 5-foot-diameter spawning tanks. Mortality during the next 2 months was low, with 93% of the fish surviving. The adults were allowed to spawn naturally, and the eggs and larvae were collected periodically to determine spawning and hatching success. Hatched larvae fed on zooplankton occurring naturally in the delta water flowing through the tanks.

A few observations from this year's studies:

- The crew observed frequent spawns, but few provided the expected numbers of eggs. It wasn't clear if this was due to lower-than-expected fecundity or if the females did not spawn all their eggs at one time.
- Egg survival varied during the season, with the best survival toward the end of the spawning period (see figure).
- Early on, the researchers encountered problems with fungal infections in the newly-hatched eggs. A new incubator design seemed to eliminate this problem, although during the middle of the spawning period most of the eggs appeared overripe and all eggs were dead at 48 hours post spawn.
- Insufficient prey density probably reduced larval survival. The naturally-occurring prey will have to be supplemented with rotifers or other zooplankton grown in culture.

The main successes this first year of these culture experiments were the construction and operation of the hatchery, the high survival of the adult broodstock, and the improved hatching as the season progressed. Aside from the low natural prey abundance, the principal problem encountered was the high silt load in the influent. The biggest surprise was the apparent high proportion of wakasagi in smelt salvaged at the fish facilities.

Over the summer, Dr. Lindberg and her staff will keep the adult post-spawning delta smelt alive in the tanks and will work on a system for producing the necessary zooplankters for the larval smelt.



QUALITY OF DELTA SMELT EGGS AND HATCH, 1995

USGS Supports "Ecosystem Management" in San Francisco Bay and the Delta

Frederic H. Nichols, USGS, Menlo Park

In the past several years, the Department of the Interior has placed particular emphasis on "ecosystem management" — the integration of scientific knowledge of ecological relationships with resource management practices to sustain ecological, cultural, and economic systems in broad habitat areas; *eg*, forest, desert, and aquatic habitats. The goal of ecosystem management is to understand the habitat requirements of many species and thereby assess the impact of a variety of human activities on regional biodiversity rather than to manage for individual species.

In support of the management of the natural resources of San Francisco Bay and the delta, the USGS is augmenting its ongoing research program to provide additional research, monitoring, and assessment information and to improve the availability of that information. Following a workshop with resource and regulatory agency representatives, hosted by the USGS in early 1994, USGS researchers identified specific areas where existing and new scientific information could contribute to resolving some of the critical bay and delta land and aquatic management issues. The "ecosystems initiative" effort now underway addresses questions in three areas:

- Freshwater flow, including sediment and contaminant transport.
- Wetlands.
- Information and data access.

Following is a brief description of activities being supported by this initiative.

Freshwater Flows and Related Issues

One of the long standing needs of water management in California is increased understanding of factors that determine water availability in the Sacramento/San Joaquin River watershed. To contribute to this understanding, past and ongoing USGS field measurements and numerical simulations will be used to examine the links between atmospheric conditions, river basin water availability, and estuarine chemistry. The purpose of this study is to quantify long-term patterns of freshwater inflow to the estuary and salinity responses within the estuary. While the initial work linking atmospheric circulation, precipitation, snowpack, and stream discharge is largely statistical, analyses of the 1987-1994 drought will be used to describe atmospheric circulation patterns that contributed to the sustained dry spell. Construction of physically-based numerical models of rainfall, snowpack, and river discharge processes on the Merced River, in collaboration with the National Park Service and the National Biological Service, is intended to close another link along the path from atmospheric circulation to delta-outflow variability.

To calibrate and validate a new numerical model of flow throughout the delta (DWRDSM2) and to gain a better understanding of the hydrodynamics of the delta, the USGS is expanding its present *in-situ* flow monitoring network by installing a new flow monitoring station on Dutch Slough. Flows at this site will be monitored using an ultrasonic velocity meter. This instrument will provide index velocity data that, when related to mean cross-sectional velocities determined from periodic flow measurements using an ADCP (acoustic Doppler current profiler), can be used to produce a 15-minute-interval flow record. Inclusion of the Dutch Slough flow monitoring site will expand the UVM network to eight delta sites. The flow data provided by the new Dutch Slough site will be combined with that from three of the existing UVM flow monitoring sites to provide a measure of delta outflow.

Application of the newly established "X2" salinity standard for the upper estuary and delta requires an increased understanding of the physical aspects of water flow and, thereby, the patterns of movement of salinity, sediment, toxicants, and biota in Suisun Bay. In response to that need, the USGS is augmenting its two Suisun Bay suspended solids monitoring sites at Martinez and Mallard Island with additional sites during summer 1995. CTD (conductivity/ temperature/depth), OBS (optical back scatter), and velocity instruments are being installed at nine stations in the shallows of Suisun Bay to provide measurements of horizontal flow, salinity, sediment, and wind-wave properties. Data from this study will be useful for explaining how variations in net streamflow (*eg*, the effect of the neap/spring tidal cycle) influence the salinity regime and sediment transport. Such information will be important in determining how to manage fresh water flow to meet the new standard. The information obtained will also be used to investigate the contribution of horizontal processes to the fluxes of salt and sediment and to help resolve patterns of spatial variability in plankton and larval fish data.

Similarly, to increase the capability for predicting the fate of dredged materials deposited in San Francisco Bay, various sites in the bay will be instrumented to provide direct information on the relationships between bottom currents, weather, suspended sediment and other climatic variables. Initially, a cluster of instruments will be deployed in South Bay to collect data relevant to the response of sediment materials to near-bottom hydrodynamic properties. This study will involve three field efforts, two of which have already been undertaken: October 1994 (calmer period between summer winds and winter rains) and March/April 1995 (period of peak runoff) using ADCPs, CTDs, and the GEOPROBE (an instrumented tripod that sits on the bottom and collects a variety of flow and water parameter measurements). The third field effort will take place in summer (period of maximum winds). In future years, the same instrument arrays will be deployed at other bay locations, including shallow areas. The goal is to develop a better understanding of interrelationships among factors contributing to flow variability and sediment movement and linkages between these processes and biological processes such as the timing and intensity of phytoplankton blooms.

An important objective of the San Francisco Estuary Institute in designing the San Francisco Bay Regional Monitoring Program is to develop an efficient sampling strategy for characterizing spatial patterns of habitat features, biological populations, and contaminant levels. To help meet this objective, a new data acquisition system (the Multiple Interface Data Acquisition System, MIDAS) has been developed to examine recently collected USGS baywide data on salinity, temperature, turbidity, and suspended sediment concentration. Analysis and interpretation of these data will permit the development of an optimal design for a network of sampling sites. The newly collected data will be incorporated into a database structure that is also consistent with the databases developed for the Interagency Ecological Program.

There is increasing evidence that pesticide concentrations in delta water periodically reach levels known to be toxic to aquatic organisms. Further, there is concern that concentrations of some potentially toxic components have not been quantified because of the lack of appropriate analytical equipment and methods. Because new pesticide regulation management plans are being considered, fuller understanding of pesticide concentrations is needed. To provide this understanding a new high performance liquid chromatography method has been developed to analyze for a suite of additional pesticides in the estuary and delta. The new procedures will be used to address key toxicity issues, particularly focusing on those compounds in delta waters that would affect the results of ongoing bioassay experiments conducted in collaboration with the Central Valley Regional Water Quality Control Board.

In an effort to better couple information about contaminant concentrations in sediments and biota with information on effects of those contaminants on biota, two measures of the health of the bivalve mollusk *Potamocorbula amurensis* (histological examination of reproductive organ development and tissue condition) are being examined at a suite of five sites in northern San Francisco Bay in relation to already collected data on contaminant concentrations (Cu, Zn, Cr, Cd, Ag, V, Ni). In the study of clam "condition" (body weight as a function of shell length), there is already evidence that condition of clams decreases with increasing contaminant concentrations.

Wetland Processes

Because of the importance of knowing the extent and condition of the remaining wetlands in the San Francisco Bay area, digital Landsat Thematic Mapper and MultiSpectral Scanner images are being generated to document changes in wetland morphology and water flow/sediment patterns since 1972. Thus far, three Landsat MSS images (April 4, 1973; April 6, 1983; April 11, 1988) have been used to compile an atlas of multitemporal Landsat MSS and change detection images.

A long-term perspective of erosion and sedimentation in the bay is important to understanding and managing wetland changes and other sediment-related phenomena such as particle and particle- associated contaminant transport and deposition. To provide that perspective, historical and recent changes in sedimentation and shoreline location in San Pablo Bay are being quantified using computer modeling of depth soundings and shoreline positions taken from hydrographic survey charts made from the mid-1800s to the 1980s. This study will document and interpret historical changes in wetland margins, water depth, areas of sediment accumulation and erosion, and sediment transport pathways in San Pablo Bay. In subsequent years the study will focus on other areas in the bay.

Choosing among management options for the protection and restoration of the bay's wetlands would be facilitated with better information on sediment movement within and adjacent to wetlands and the relationships between weather conditions and sediment loss. To provide such information, meteorological stations are being established in three wetlands sites (Sonoma Baylands marsh restoration demonstration site; Bear Island; Coyote Creek) to measure sediment flux over tidal and fortnightly cycles to derive relationships between sediment flux into and out of wetland areas. The instrument packages will provide hourly data on wind conditions, water depth, flow rate, salinity, opacity (suspended sediment concentrations), and water temperature.

As part of the effort to monitor the effectiveness of restoring wetlands using dredge spoils at the Sonoma Baylands Demonstration site, sediment core samples collected from both uncontaminated and contaminated locations, as well as from an adjacent pristine marsh, are being analyzed for organic contaminants (*eg*, PAHs, hydrocarbon biomarkers, PCBs, Chlordane, DDT, DDE, and DDD). Results from these analyses will aid in estimating the potential for exposure to contaminants by the biota that will inhabit the new wetland. In addition, naturally occurring organics (*eg*, sterols and fatty acids) will be studied to follow geochemical changes in the sediments as the wetland develops.

Data Accessibility

To provide resource management agencies and the public with ready access to USGS data and reports, the USGS is using World Wide Web protocols to develop and join various USGS databases. Called "Access USGS", the new Home Page on World Wide Web will serve as an information provider regarding all USGS work under its San Francisco Bay "ecosystem initiative", and other related USGS bay studies. Most of the present content comes from past USGS work, including the complete USGS bibliography on San Francisco Bay. The San Francisco Bay access exists in beta form at http://bard.wr.usgs.gov/access/access_sfb.html.

For further information about the overall USGS program, contact Fred Nichols (415/329-4412 or through Internet at fnichols@usgs.gov.

Category III Early Implementation Projects

In the spring issue of the *Newsletter*, Walt Wadlow described the Category III program, a component of the December 1994 Bay/Delta Agreement. Basically, Category III is to fund non-flow-related projects to improve fish resources in Central Valley streams and the delta. Over the past several weeks, several members of an *ad hoc* committee have met to evaluate proposals that can be in place, or substantial progress made, between now and the end of 1996 — the so-called "early implementation" projects. Eight projects were rated fundable based on biological and feasibility criteria.

- Restoring flows in Battle Creek.
- Fish screen and fish ladder at Durham Dam on Butte Creek.
- Restoring spawning gravel in the Sacramento River below Keswick Dam.
- Relocating a diversion pump and fish screen on Big Chico Creek, a tributary to the Sacramento River.
- Integrated pest management program to reduce diazinon and other pesticide discharges to Central Valley streams and the delta.
- Restoring riparian habitat to a small stretch of the Sacramento River.
- Screening up to five diversions in Suisun Marsh.
- Winter Chinook captive breeding program at Bodega Marine Laboratory.

The *ad hoc* work group will meet on August 19 to go through the list, and they may recommend a process to allocate the funds. They may also change the list at that time. Cost to Category III of these eight projects is about $4.5 million, leaving $5.5 million available for this year. If you have a specific project proposal, submit it soon to Walt Wadlow at Santa Clara Valley Water District.

Comparison of New Standards and Historical Flows

Bruce Herbold, USEPA

On May 22, 1995, the SWRCB adopted an estuarine water quality control plan based largely on the December 15, 1994, Principles for Agreement that was signed by diverse water interests and various state and federal agencies. The Water Quality Control Plan contains a number of measures similar to water quality standards that EPA finalized on December 15, 1994. At the March 1995 Interagency Program conference and in numerous conversations since, it appears that these standards are not well understood. I expand on the new standards and their relationship to streamflows and to the former fish and wildlife standards. I am not assessing biological impacts.

The new SWRCB standards replace only the fish and wildlife standards contained in the its 1978 water rights Decision 1485. All the agricultural and municipal standards remain in effect. In the large majority of months since adoption of Decision 1485, delta outflow has been maintained because of municipal and industrial and agricultural water requirements at the Contra Costa Canal intake. Since the Contra Costa Canal standard is unchanged in the new plan, the replacement of D-1485's fish and wildlife protection measures is unlikely to reduce the baseline patterns of delta outflow.

The new SWRCB standards address flows in the Sacramento and San Joaquin rivers, closure of the Delta Cross Channel, limits on export rates by the CVP and SWP, and the maintenance of low salinity conditions in Suisun Bay. The new water quality plan includes a number of other standards that address dissolved oxygen, salinity, salmon protection, and marsh protection. Because their impacts cannot be easily predicted, however, they are beyond the scope of this article. The new plan also allows deviations in export criteria with the goal of improving biological protection at no net change in water costs. This effort to change exports in response to biological data has the potential to greatly change the mechanisms of resource protection.

Streamflow

The new SWRCB streamflow standards for the fall months at Vernalis and Rio Vista are unlikely to result in any change in operations, because they are generally less than historical flows to meet agricultural and municipal requirements. Since 1978, San Joaquin River flows have been greater than would have been required by these standards in all but the last 2 years of the drought and in 1993. The required Rio Vista flows have been exceeded in all but three of the 60 fall months since 1978. These requirements for fish and wildlife, then, are largely redundant to the flows required to meet other unchanged standards.

Such redundancy protects wildlife and fishery flow needs if municipal or agricultural standards change, or if the SWP and CVP develop alternative methods of meeting agricultural and municipal standards. For example, it may be that the Contra Costa Canal standard could be met either by increasing flows down the Sacramento River or by increasing export rates in the southern delta so that more fresh water is drawn toward the Contra Costa Canal intake.

Since filling New Melones Reservoir in 1983, USBR has tried to meet water quality in the lower San Joaquin River by releasing fresh water from New Melones. If salt loading into the San Joaquin is controlled by other means, springtime flows at Vernalis could be reduced. The new SWRCB flow standards are largely a safeguard against such future changes. Springtime flow requirements on the San Joaquin include a baseline flow from February through June and a 31-day pulse requirement from April 15 to May 15. The baseline flow requirements are less than the historical flows in all years prior to 1991, whereas the pulse flow requirement is greater than historical flows in all but the wettest years (Table 1). Clearly, the baseline flow requirements will seldom affect project operations, whereas the dry-year pulse flow requirements often represent a doubling or tripling of dry-year flows. Required flows in spring of wet years fell far short of some wet-year flows. Interestingly, 1993, a wet year that followed several critical years, led to flows very similar to previous drought flows, but 1995, another wet year, yielded flows comparable to 1982 and 1983.

Table 1
BASELINE AND PULSE FLOWS THAT WOULD HAVE BEEN REQUIRED IN THE SAN JOAQUIN RIVER AT VERNALIS, 1979-1992

Year types under new standards: C = Critical, D = Dry, BN = Below Normal, AN = Above Normal, W = Wet.
The larger numbers would be required when X2 was required to be west of Chipps Island.
Historical averages and exports are for the relevant periods as recorded in DAYFLOW.
Baseline = February 1 to April 14 & May 16 to June 30
Pulse = April 15 to May 15

Year	Year Type	Baseline Requirement	Historical Average	Pulse Requirement	Historical Average	Historical Exports
1979	AN	2,130 or 3,420	5,492	5,730 or 7,020	2,105	6,835
1980	W	2,130 or 3,420	14,727	7,330 or 8,620	9,821	4,934
1981	D	1,420 or 2,280	2,559	4,020 or 4,880	2,497	6,824
1982	W	2,130 or 3,420	8,818	7,330 or 8,620	25,019	7,672
1983	W	2,130 or 3,420	29,997	7,330 or 8,620	34,834	3,273
1984	AN	2,130 or 3,420	10,267	5,730 or 7,020	3,709	7,474
1985	D	1,420 or 2,280	2,796	4,020 or 4,880	2,462	6,927
1986	W	2,130 or 3,420	11,529	7,330 or 8,620	13,156	4,882
1987	C	710 or 1,140	2,514	3,110 or 3,540	2,393	6,590
1988	C	710 or 1,140	1,725	3,110 or 3,540	2,130	8,525
1989	C	710 or 1,140	1,577	3,110 or 3,540	2,082	7,491
1990	C	710 or 1,140	1,357	3,110 or 3,540	1,311	5,977
1991	C	710 or 1,140	1,033*	3,110 or 3,540	1,025	4,080
1992	C	710 or 1,140	1,220**	3,110 or 3,540	1,218	1,567
1993	W	2,130 or 3,420	2,936***	7,330 or 8,620	3,913	2,958

* One monthly average below requirement.
** Two monthly averages below requirement.
*** All four months below requirement.

Delta Cross Channel Gate Operations

The new SWRCB standards require a substantial increase above Decision 1485 in the number of days the Delta Cross Channel is closed. Under Decision 1485, the gates were to be closed to protect fish passage whenever the delta outflow index was greater than 12,000 cfs between January 1 and April 15. At the request of DFG, an additional 20 days were available in the April 16-May 31 period, but only if the delta outflow index exceeded 12,000 cfs. The new standards call for up to 45 days of gate closure in November through January, constant closure for the 109 days from February to May 20, and about 15 days of closure from May 21 through June 15. The Decision 1485 restriction to times of higher delta outflow no longer applies, so that the greatest changes affect drier years. Gate closures continue to be mandated at any time of flood danger. Table 2 presents the historical number of days when the cross channel was closed. Note that in 1992 and 1993, requirements of the winter-run Chinook salmon biological opinion required closures similar to those of the new SWRCB standards.

Table 2
NUMBER OF DAYS THE DELTA CROSS CHANNEL GATES HAVE BEEN CLOSED DUE TO WATER QUALITY OR FLOW AND NUMBER OF ADDITIONAL DAYS OF CLOSURE REQUESTED BY DFG

The last column indicates the increased number of days that the new standards would have required.

Year	February June	Annual Total	Additional Requirement*
1979	76	103	66
1980	77	156	13
1981	80	114	55
1982	138	217	0
1983	150	248	0
1984	79	168	21**
1985	51	131	58**
1986	110	147	22
1987	52	107	62
1988	0	47	122
1989	45	52	117
1990	2	13	156
1991	44	45	124
1992	105	105	64
1993	134	165	4

* Additional number of days that would have been required under the new standards.
** Increment based on springtime requirement.

Exports

In the new SWRCB standards exports are allowed at four different levels, depending on the time of year. Exports are limited to 65% of delta inflow from July to January, 35-45% in February, and 35% from March through June. Concurrent with the pulse flow on the San Joaquin, exports are restricted to 100% of the flow at Vernalis or 35% of total inflow, whichever is smaller. A variety of other factors ensure that these limits are approached only during dry conditions. For example, during the wet spring of 1995, the SWP and CVP could only take about 4-8% of the total inflows.

In the December 15, 1994, Principles for Agreement, the April 15-May 15 restriction to 100% of the San Joaquin flow was linked to installation of a barrier at the head of Old River. The barrier ensures that the SWP and CVP would draw all their water out of the central delta, thereby including a large fraction of Sacramento River water. At Vernalis flows greater than 4,000-5,000 cfs, USBR and DWR are concerned that a barrier would lead to unacceptable flood risks in the southern delta and Stockton, so it is unlikely that a temporary barrier will be used in any but dry and critical years. A permanent barrier that could be opened and closed might allow operation in other year types. The new water quality plan does not address the issue of a barrier, but DWR and USBR are actively pursuing the necessary permits and funding.

The restriction of exports to an amount equivalent to 100% of the San Joaquin flow is a large reduction in both absolute and percentage terms from recent conditions (compare the historical exports in Table 1 with the historical flows). During the 1987-1992 drought, the SWP and CVP exported as much as 500% of the flow of the San Joaquin. In some years, even if the new pulse flows had been required, exports would have had to be less than half of the historical exports (in Table 1 compare historical exports with the pulse requirements). Obviously, much of the water exported historically was Sacramento River water and, even without the Old River barrier, much of the exports under the new standards will still consist of Sacramento River water. On the other hand, the new requirements for closure of the Delta Cross Channel throughout this period may reduce the percentage of Sacramento River that goes for export. The restriction of total exports to an amount equivalent to 100% of the San Joaquin flow has been frequently mischaracterized as a removal of the entire flow of the San Joaquin River or as an increase in exports fueled by the required San Joaquin releases elements; in most years this restriction would be the most stringent of the restrictions on exports.

The restriction to 35% of total inflow from March to May is less dramatic in comparison to historical conditions but would have required reductions in exports during 19 of the 36 spring months during the 1987-1992 drought. This restriction pertains to 3-day running averages of both pumping and inflow during times when reservoir releases are feeding the export pumps and to 14-day averages of delta inflow at times when the pumps are taking unregulated flows into the delta. There is often considerable day-to-day variability in historical pumping rates such that monthly averages are often much lower than many of the 3-day averages contained within the month. Thus, the impact of the new restrictions are better reflected in comparison with historical daily conditions rather than with historical monthly averages. Table 3 includes both comparisons.

Table 3
PERCENTAGE OF INFLOW EXPORTED SINCE ADOPTION OF DECISION 1485

Bold numbers show months in excess of the 35% standard.

Year	Feb	Mar	Apr	May	Jun	Total Days >35%*
1979	10	12	31	29	41	52
1980	10	5	16	17	24	1
1981	28	20	**47**	29	33	44
1982	13	12	7	9	11	0
1983	6	2	3	3	6	0
1984	13	17	35	31	34	33
1985	35	**49**	**47**	**39**	**43**	120
1986	7	1	8	23	23	11
1987	**37**	25	**46**	**42**	**42**	100
1988	**75**	**62**	**45**	**47**	**47**	140
1989	**60**	25	**47**	**37**	35	94
1990	**69**	**71**	**58**	29	31	106
1991	**49**	**37**	**61**	31	20	81
1992	18	**49**	26	23	21	42
1993	18	**12**	12	11	14	0

* Total number of days during the 5 months when daily export percentages exceeded 35% are given in rightmost column.

The July through June restriction of exports to 65% of inflow represents little improvement over historical conditions. Monthly average exports in the July to January period have exceeded 65% in only 2 months in the historical record (note from Table 2 that the 65% level was also exceeded in February and March of 1990). However, daily exports have exceeded 65% on some days in every year and, on average, for about 9% of the time. This standard is likely to result in increases in the monthly average diversions but decreases in the number of days when exports exceed 65% of inflow.

The intent of the 65% limit is not to improve conditions that have damaged fish populations in the past but, rather, to cap the extent to which the reductions of spring exports can be made up in other months. In wet years, much of the springtime flows cannot be retained for later export, but in drier years, reservoir releases would likely be delayed as much as possible until after June. Given that historical export rates have seldom been sustained above 65% and that other delta withdrawals are greatest during the summer, the 65% limitation is likely to be redundant to other water quality standards.

Estuarine Habitat, aka Delta Outflow

One of the most significant aspects of the new water quality standards is the inclusion of a very slightly modified version of the "X2" standard developed by EPA and a number of interested parties. X2 refers to the distance upstream from the Golden Gate where mean salinity is 2 ppt; X2 is strongly correlated with delta outflow. In the new SWRCB water quality control plan, this standard is contained in Table A, which is referred to in footnote 14 on the second of 14 lines describing required delta outflows. A reader unfamiliar with the history and context of this table would be unlikely to realize its significance. However, compliance with this standard, alone, accounts for more than half, and in many dry years as much as 90%, of the total water costs associated with the new water quality control plan.

The standard requires X2 to be downstream of each of three points in the estuary—Collinsville, Chipps Island, and Roe Island — for a specified number of days. The standard can also be satisfied by minimum daily outflows of 7,100 cfs, 11,400 cfs and 29,200 cfs, respectively. In all years since 1978, the standard would have kept X2 downstream of the confluence for the entire February-June period. In each year, a different number of days would have been required for X2 to be downstream of Chipps Island (Table 4). The timing and duration of this requirement is determined by the previous month's unimpaired flows on the eight major rivers of the Central Valley. There are two differences between the EPA and SWRCB standards.

- The level of protection targeted under the EPA standard corresponds to an estimated level of development in 1968; under the SWRCB standard, the targeted level of protection is 1971.5. The greatest difference between these two targeted levels is about 1 day of Chipps Island requirement, although in most cases there is no difference.
- The SWRCB standard allows for relaxation of the 150 days required at the confluence in exceptionally dry years; the EPA standard does not. Both years of the 1976-1977 drought met the criteria for relaxation; none of the 1987-1992 drought years did.

Table 4
NUMBER OF DAYS MINIMUM X2 LOCATION OR SPECIFIED NET DELTA OUTFLOW WOULD BE REQUIRED HISTORICALLY AND UNDER THE NEW STANDARDS

Requirement at Collinsville is 150 days in all years. Requirement at Chipps Island is function of previous month's inflow to reservoirs.

Year	Chipps Island Historical	Chipps Island Requirement	Collinsville Historical
1979	121	128	143
1980	151	122	151
1981	79	92	133
1982	150	150	150
1983	150	150	150
1984	92	115	151
1985	39	64	110
1986	139	118	150
1987	51	61	96
1988	7	46	52
1989	45	72	111
1990	0	56	38
1991	35	30	59
1992	48	56	82
1993	150	150	150

Dry year X2 positions in 1979-1992 were often substantially different than these standards would require (Table 4). The requirements at Roe Island are unlikely to lead to substantial reductions in water available for other uses, because these requirements are closely timed to periods of elevated delta outflow. For example, in 1993 the Roe Island component of the standard would have been triggered, but flood control operations would have incidentally satisfied the requirements. In 1995 the Roe Island requirement was triggered and incidentally satisfied with flood control operations.

Delta outflows mandated for other months are generally much lower than those of the February-June period. Nevertheless, some of these requirements represent changes from recent historical conditions. These requirements are based on year type and have their greatest impact on July and August of critical years. Of the 14 years from 1979 to 1992, eight of the July average flows are below the new mandates; 7 of the August average flows are below the new mandates, and three of the historical averages for September are below the new mandates. Flows in the October-January period have generally been in accord with the new requirements, although three monthly averages are slightly below the target.

Summary

- Most flow changes in drier years will arise from flows needed to meet estuarine protection measures in the February-June period. Most mandated streamflows are generally less than would occur anyway.
- Mandated pulse flows at Vernalis from April 15 to May 15 and their simultaneous restriction of exports are both major changes from most historical conditions.
- Mandated changes in Delta Cross Channel gate operations are similar to those in the NMFS winter-run opinion but allow closure over a longer period.
- Restrictions of pumping relative to a percentage of delta inflow represent a significant decrease in export rates during dry conditions in the spring but not during the rest of the year.

Delta Smelt Draft Recovery Criteria

Deborah McEwan (DWR) and Dale Sweetnam (DFG)

The draft *Recovery Plan for the Sacramento San Joaquin Delta Native Fishes* was prepared by the Delta Native Fishes Recovery Team, which consists of ten members from federal and state agencies, universities, and a private consultant. The Recovery Team, chaired by Dr. Peter Moyle of UC-Davis, and the draft Recovery Plan serve an advisory function for use by the USFWS and other agencies as a guide in recovery activities for the species considered in the Recovery Plan. USFWS released the Recovery Plan for public review and comment in December 1994.

The Recovery Plan considers eight species that occur in the Sacramento-San Joaquin estuary: delta smelt (listed as threatened in 1993); Sacramento splittail (proposed as a threatened species in 1994); longfin smelt; green sturgeon; spring-run, late fall-run, and San Joaquin fall-run Chinook salmon; and Sacramento perch. For each species, the Recovery Plan contains species descriptions, abundance and distribution information, habitat requirements, life history, and taxonomy and discusses the species' status and recovery potential, reasons for decline, conservation measures and actions needed, and restoration objectives and criteria. For the threatened delta smelt and the proposed-threatened Sacramento splittail, the Recovery Plan recommends recovery objectives and criteria.

The recovery objective for delta smelt is to remove it from the federal endangered species list by returning its abundance and distribution patterns to levels similar to those during the pre-decline period (1967-1981). The recovery plan is based on both abundance and distribution criteria, requiring specific levels to be met over a period covering five generations. For delta smelt, five generations covers an evaluation period of 5 years. For a longer-lived species, the valuation period is longer (*eg*, the evaluation period for splittail is 35 years). These criteria are consistent with other recovery plans.

Both the abundance and distribution criteria employ DFG fall midwater trawl data from 35 stations throughout the delta. The fall midwater trawl survey covers the entire range of the smelt's distribution, and the data provide one of the best and longest measures of smelt abundance. Actual catch numbers are used instead of the abundance index. Only data from September and October are used, because these are the months sampled most consistently throughout the years of the survey and because in November and December stormy weather and the movement of delta smelt upstream to spawn can result in more variability in fish-capture numbers.

Recommended Recovery Criteria

The recommended distribution criteria require that delta smelt be captured at a certain number of sites within three specific areas throughout the delta over the 5-year evaluation period. Smelt do not need to be caught in all areas every year. However they must be caught in at least one area for two of the years, two areas for one of the years, and all three areas in two of the years. Failure to capture smelt at the required number of sites in all three areas in any year restarts the 5-year evaluation period for distribution criteria.

The recommended abundance criteria are twofold: a low number that is a 2-year running average below which abundance cannot fall, and a high number to be reached or exceeded in 2 of the 5 years. If either of the two conditions are not met, the 5-year evaluation period is restarted.

Recovery and Delisting

If both the distribution and abundance criteria are met over the 5-year evaluation period, delta smelt will be considered to have recovered. The Recovery Plan proposes that delisting be considered when the recovery criteria are met over a 5-year period during which two sequential years of extreme outflow occur, with one of the two years being dry or critical. Extreme outflow is considered to be either very high or very low outflow. Occurrence of two successive years of extreme outflow is important in evaluating species recovery, since such conditions could put delta smelt at risk of extinction.

Tracking Delta Smelt Recovery

A spreadsheet has been written to track whether or not the recommended recovery criteria approach are being or have been met. The spreadsheet is designed to have catch numbers entered, and then performs a number of formulas to check whether or not the criteria have been met. It is also designed to tell us if the 5-year evaluation period is to be restarted due to a failure to meet the recovery criteria. The first 5-year evaluation period began with 1993, the year delta smelt were listed. Delta smelt distribution requirements were met in all three areas during 1993 and only one area in 1994; thus, so far, the recovery criteria are being met. For abundance criteria, the high number was exceeded in 1993 (one of the required two years), but not in 1994. The 2-year running average of 209 also exceeds the low number criteria. Interestingly enough, the recovery criteria are being met, despite the fact that 1994 fall midwater trawl samples indicate the delta smelt population hit an all-time low. As described above, one of the two abundance criteria is a 2-year running average of abundance (not to fall below 84), which is being used to allow for the high degree of variability in delta smelt abundance. Because delta smelt had a good year in 1993, the 2-year running average for 1994 exceeded 84, and the criteria continued to be met, despite the bad year for delta smelt. This year could be a "make or break" year for delta smelt. We had back-to-back years of extreme outflow in 1994 and 1995 — 1994 was a critical year and 1995 is a wet year. It will be interesting to see what numbers of delta smelt turn up in this year's fall midwater trawl samples.

For further information about the draft *Recovery Plan for the Sacramento-San Joaquin Native Fishes*, the recommended delta smelt recovery criteria, or the spreadsheet for tracking delta smelt recovery, you may contact Debbie McEwan (916/227-7624) or Dale Sweetnam (209/948-7800).

Radical Changes in the Estuary's Zooplankton Caused by Introductions from Ballast Water

James J. Orsi, DFG, Bay-Delta and Special Water Projects Division

Copepods and mysid shrimp are crustacean plankton important as food for larval and small fish. Large changes have occurred in their abundance and species composition in Suisun Bay and the Delta since 1978 and especially since 1992. The cause is introduction of non-indigenous species from ballast water of ocean-going ships. Such introductions, first detected in 1978, became frequent in 1992-1993, when 3 copepods and 2 mysid shrimp were introduced (Table 1). The spate of introductions in 1992-1993 appears related to a sharp increase in shipping at the Port of Oakland. None of the other major ports in the bays or on the rivers showed such an increase in these years.

The native copepod fauna (excluding the small, benthic harpacticoids) of Suisun Bay and the delta consisted mainly of several species of *Diaptomus* and *Cyclops* in fresh water and 3 *Acartia* species in saline water seaward of the entrapment zone. *Eurytemora affinis*, the important entrapment zone copepod, was possibly introduced along with striped bass in 1879. *Oithona davisae*, a cyclopoid copepod native to Japan, was already present in San Pablo Bay in 1963 when zooplankton sampling was first done. For some reason it did not appear in DFG Suisun Bay samples until 1979.

In 1978, the first exotic calanoid copepod to appear, *Sinocalanus doerrii* from China, apparently slipped into an unoccupied niche between the ranges of *Eurytemora* in the entrapment zone and *Diaptomus* in the San Joaquin River between the mouth of Old River and Stockton. Although *Diaptomus* species were found throughout the delta, their abundance was highest in this section of the San Joaquin River. *Sinocalanus* eventually spread to Stockton, and *Diaptomus* abundance fell to low levels. Although the range of *Sinocalanus* overlapped the upstream extent of *Eurytemora*, it had, at most, a minor impact on *Eurytemora* abundance. Since 1987, however, *Eurytemora* has been replaced in the entrapment zone by two other Chinese calanoids and in 1994 *Sinocalanus* disappeared throughout its range. *Diaptomus* abundance, however, has not shown a resurgence.

The replacement of *Eurytemora* was in part due to the introduction of an exotic clam, *Potamocorbula amurensis*, in 1986. This clam feeds on the nauplii of copepods, and *Eurytemora* nauplii appear to be particularly vulnerable. Competition with a Chinese calanoid, *Pseudodiaptomus forbesi*, introduced in 1987, may also have played a role. The replacement of *Eurytemora* has been a seasonal one; *Eurytemora* is present during winter and spring when clam grazing rates are low and when *P. forbesi* abundance is also low. In the San Joaquin River at Stockton, upstream from the range of the clam, *Eurytemora* is present until late spring, when *P. forbesi* becomes very abundant. All native copepods are now most abundant in winter and spring, while summer and fall are dominated by the exotics, many of which are subtropical or even tropical species.

Pseudodiaptomus forbesi is now sharing the entrapment zone with still another Chinese exotic, *Acartiella sinensis*, introduced in 1993. This species is not abundant in fresh water and does not reach the eastern delta.

A major change in the habitat of all of these calanoid copepods has been the reduction in phytoplankton, their primary food resource, especially since the introduction of *Potamocorbula*. Phytoplankton had already been declining throughout the bay and delta since the mid-1970s, but *Potamocorbula* grazed phytoplankton to very low concentrations in Suisun Bay and the western delta. A reduction in food availability would not affect copepods until a limiting or threshold level is reached. At this level egg production would decline sharply. laboratory experiments have shown that such threshold levels are generally $<3\ \mu g/L^{-1}$ chlorophyll *a*. Such concentrations have been typical of the estuary in recent years.

In 1979, a Chinese cyclopoid copepod, *Limnoithona sinensis*, entered the estuary and became abundant. In 1993, still another *Limnoithona* species, *L. tetraspina*, appeared and by early 1994 had replaced *L. sinensis*. The abundance of *L. tetraspina* has exceeded 40,000 m^{-3}, making it the most abundant copepod we have ever seen in the estuary. Thanks to *Limnoithona*, cyclopoid copepods became more abundant than calanoids in 1992 and continued their dominance in 1993 and 1994 (Figure 1).

Table 1
NATIVE AND INTRODUCED COPEPODS AND MYSID SHRIMPS AND YEAR OF INTRODUCTION

NATIVE COPEPODS	INTRODUCED COPEPODS	YEAR INTRODUCED
Diaptomus spp.	*Eurytemora affinis*	1879?
Cyclops spp.	*Oithona davisae*	Before 1963
Acartia spp.	*Sinocalanus doerrii*	1978
Minor species	*Limnoithona sinensis*	1979
	Pseudodiaptomus marinus	1986
	Pseudodiaptomus forbesi	1987
	Acartiella sinensis	1992
	Tortanus sp.	1993
	Limnoithona tetraspina	1993

NATIVE MYSIDS	INTRODUCED MYSIDS
Neomysis mercedis	Acanthomysis aspera
Four minor species found mostly in San Pablo and San Francisco bays	Acanthomysis sp.

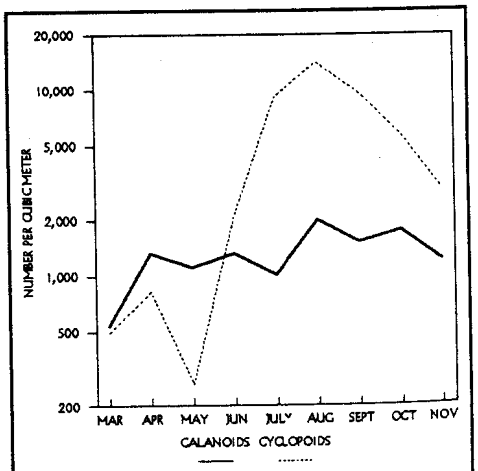


Figure 1
CALANOID AND CYCLOPOID COPEPOD ABUNDANCE IN 1994

This sudden explosion of cyclopoid copepods suggests that something has happened to the trophic status of the estuary. Cyclopoids have a different feeding mode than calanoids. They grasp particles rather than filter them from the water as calanoids do. As a consequence, they are more predacious than most calanoids. Although calanoids are also capable of predacious feeding, they are not active predators. An exception is a large calanoid, *Tortanus* sp., introduced in 1993. It is a known predator on other copepods and may have been responsible for the disappearance of *Pseudodiaptomus* in western Suisun Bay in 1994.

Food availability (phytoplankton) for calanoids has been reduced, but cyclopoid food resources may have increased. What the cyclopoids consume is unknown. The introduced cyclopoids are small — 0.6 mm long at maturity — and would not be able to feed on adult calanoids, which are generally twice their size. Even the nauplii of the calanoids should be too large. Rotifers are a possible prey item, but rotifer abundance has been declining since the late 1970s. Ciliated protozoa may be a food source, but we know nothing of the abundance of ciliates aside from protozoan counts made in 1966-1967 by the original DFG Delta Study.

Mysid shrimp have also been affected by changes in the trophic status and by introductions. The only abundant native mysid in Suisun Bay and the delta, *Neomysis mercedis*, underwent a long-term downtrend starting in the late 1970s. This decline became pronounced after 1986 and has been attributed to the reduction in the food resource for young mysids, phytoplankton. In 1992, two Asian mysids appeared in eastern San Pablo Bay and western Suisun Bay. The abundance of one, *Acanthomysis aspera* from Japan, remained low and it did not move into the entrapment zone. The other, an undescribed species of *Acanthomysis*, moved upstream during 1993, and in 1994 occupied the same range as *Neomysis* and achieved a higher abundance than *Neomysis*. The invading mysids are somewhat smaller than *Neomysis* but probably have similar feeding habits. Competition with introduced amphipods may also affect *Neomysis*.

Because of the exotic species, the abundance of native copepods and mysids is unlikely to rebound even if the estuary becomes more eutrophic. Unless ballast water dumping is controlled, more non-indigenous and possibly harmful species may arrive. These can be fish and benthos, such as the European ruffe and the infamous zebra mussel, as well as zooplankton. In January 1994, the "ballast water initiative" became law in California. This law merely asks ship masters to follow the International Maritime Organization's Guidelines for the Discharge of Ballast Water. These guidelines suggest that ballast water be exchanged in the open sea at depths >2000 meters before a ship enters a port. The assumptions are that freshwater and estuarine organisms will be pumped out of the tanks or killed by the sea water if they remain in them, and oceanic organisms pumped into the tanks will not be able to live in coastal or estuarine waters. The California law does not require ballast exchange but does require under penalty that a ballast water control form be filled out to show what the vessel master has done with his ballast. The law also provides a penalty for falsifying information on the form. However, the Coast Guard has failed to provide support for DFG, and this law has not been enforced. Ballast water dumping is still totally unregulated.

Program Revision

The Agency Directors are scheduled to meet on October 17 to review the recommended changes in the Interagency Program's monitoring and special studies elements. In this short 3-month period, staff and other interested parties must pull together into a program all the information being gathered for the revisions. Following are some of the steps and meetings underway to help accomplish this formidable task.

- Over the past few weeks, there has been a flurry of meetings of the project work teams with part of their charge being to develop recommendations for specific monitoring and special studies elements.
- On July 6 and 13, staff responsible for implementing the Central Valley Project Improvement Act is discussing its Comprehensive Assessment and Monitoring Program. Parts of this program may complement the Interagency Program.
- On July 6 and 7, Leo Winternitz and Pat Coulston met with Judd Monroe, Jim Buell, Chuck Hanson, and Bill Alevizon of the stakeholders to go through a formal process leading to recommended changes. Their results will be summarized in a draft report from the stakeholders to the Interagency Program.
- On July 26 and 27, the Interagency Program's Science Advisory Committee will hold a 2-day workshop with staff and others to review the program and develop recommended changes.
- On August 1, the Modeling Forum is sponsoring a 1-day workshop to discuss the data needs of physical, chemical and biological modelers.
- On August 7, Interagency Program staff will hold an all-day meeting to review information gathered to date and further define the process leading to the recommended program.
- In mid-August, Interagency Program staff is scheduled to have a draft report from this spring's real-time monitoring evaluation. The report will probably contain recommendations about how real-time monitoring should be included in the overall program.
- DFG will soon be releasing a draft document describing a comprehensive Central Valley salmonid monitoring program.
- A management advisory group composed of representatives of water interests, environmental interests, and agencies has met several times to provide management input to the Agency Coordinators.

It will be a challenge to take all of these often disparate pieces and shape them into a comprehensive data collection and interpretation effort that can provide the kind and volume of information needed by decision makers. In addition, any program developed through this process must be coordinated with existing efforts such as those underway at the San Francisco Estuary Institute to arrive at a program that provides a systemwide information network.

Observation of Possible Larval and Prejuvenile and Wakasagi/Delta Smelt Hybrids in the Delta and Tributary Streams

Johnson Wang, National Environmental Sciences, Inc.

DFG data indicate that wakasagi was collected occasionally in the upper estuary and lower rivers during the early 1980s (Sweetnam 1995). Other DFG data show that wakasagi became abundant in several Northern California reservoirs during the late 1980s and early 1990s (Dennis Lee, personal communication). Two of these reservoirs, Folsom and Oroville, contain wakasagi and can contribute large numbers of them to the delta, where they can compete or hybridize with delta smelt.

Before showing the data, it may be helpful to review the status of larval wakasagi identification.

Biologists are still having difficulty making a clear-cut distinction between wakasagi hybrid larvae and delta smelt larvae. Many "off and on" characteristics have been recorded, and it is very confusing. In general, the associated factors are:

- Heavy overlapping of morphological characteristics of two species, while adding more complications from the hybrid.
- Insufficient field experience and specimens gathered from the Sacramento River and delta.
- Wakasagi larvae collected from lakes and reservoirs not always matching with specimens collected in the Sacramento River and delta.
- Not knowing whether the electrophoretic analysis on species identification is completely accurate (Trenham *et al* 1994) to compare it with current morphological characteristics know-how.
- When specimens reach 20-30 mm total length or are in the prejuvenile to early juvenile stages, the problems on identification of wakasagi/hybrid (as a group) from the delta smelt are gradually diminished. Using organology, morphometric measurements and pigmentations are all helpful (Young and Cech 1994; Sweetnam 1995).

Table 1 is a listing of the possible wakasagi and wakasagi/delta smelt hybrids in various sample collections over the past several years.

Between 1990 and 1992, the larvae were found in the vicinity of the American River and Sacramento River above Walnut Grove, which is on the margin or above the usual spawning ground of delta smelt (Wang and Brown 1993). Larvae were observed from March to June.

In 1993 and 1994, a relatively high number of larvae were observed in the American River, the Sacramento Metropolitan Airport area of the Sacramento River downstream to the Cache Slough, Barker Slough, and Mokelumne River area of the delta. In these 2 years, the distribution range and observation period of the wakasagi/hybrid larvae heavily overlapped that of the delta smelt.

In 1994, prejuvenile, juvenile, and adult wakasagi/hybrid were observed at various locations on the American River (below Lake Natoma), Sacramento River (from Sacramento Metropolitan Airport and Bryte areas downstream), Delta Cross Channel, Mokelumne River, Cache Slough, Barker Slough, and CVP/SWP fish protective facilities (Sweetnam 1995; USBR/USFWS unpublished data; Lisa Lynch, personal communication).

In summer 1994, selected smelt (in prejuvenile and juvenile life stages) taken from CVP, SWP, Cache Slough, Mokelumne River, and Decker Island were stored in dry ice when the fish were still alive and shipped to the UC-Davis for electrophoretic analysis to distinguish them to the species. Hybrid fish (wakasagi/delta smelt) were detected as part of the result (Trenham *et al* 1994). Before this testing, some morphological characteristics of wakasagi from other known smelt were noted by CVP and SWP biologists. There, the smelt had been identified as longfin smelt, delta smelt, wakasagi, and wakasagi/delta smelt (this study; personal communication with Lloyd Hess, Scott Siegfred, Jerry Morinaka). The morphometric differences were also reported by other researchers by using the specimens collected at CVP and SWP (Young and Cech 1991; Cin Cin Young, personal communication).

Stevens *et al* (1990) reported collections of wakasagi from Folsom Lake in 1989. Since 1992, DFG has been sampling wakasagi populations at Folsom Lake, Lake Oroville, and Lake Almanor. All life stages of wakasagi have been captured (Lisa Lynch, personal communication). Recently, DFG biologists have found more morphological characteristics to separate the juvenile and adult wakasagi from delta smelt; the pigmentation patterns at mandible and isthmus are particularly useful (Sweetnam 1995).

Judging by the larvae and other life stages of wakasagi taken, a possible scenario is: the wakasagi appeared in the Sacramento River in 1990, invaded the Delta in 1993; a self-reproduced population appeared in the American River, Sacramento River, and possibly Cache Slough areas (where the delta smelt spawning concentrated in the last many years) in 1994. Hybridization might have happened as early as 1993.

Knowledge of identification of larvae wakasagi is in progress, but more research and development is needed to make it into a comprehensive field key. The native delta smelt now is in threatened status, but the introduced wakasagi is not. A complete separation of the two species is ecologically important.

Table 1
OBSERVATIONS OF WAKASAGI HYBRID LARVAE IN THE DELTA AND TRIBUTARY STREAMS

Year	Observation Period	Sampling Area	Sample Source	Number Observed
1990	4/20 to 5/16	Lower Sacramento River	DFG	4
1991	4/17 to 6/09	Lower American River	Hanson Assoc.	9
		Sacramento River near Bryte	USBR	1
		Sacramento River below mouth of American River	DFG	3
1992	3/27	Lower Sacramento River	DFG	1
1993	3/11 to 5/04	Lower Sacramento River	DFG	75+
1994	3/07 to 5/06	American River through Delta	DFG	34
		San Luis Creek of San Luis Reservoir	USBR	3
		Sacramento River, Air Force Pier (near Bryte)	USBR	4
Total				129+

Stevens, D.E., L.W. Miller, B.C. Bolster. 1990. *Report to the Fish and Game Commission: A Status Review of the Delta Smelt, Hypomesus transpacificus, in California*. DFG. Candidate Species Status Report 90-2.

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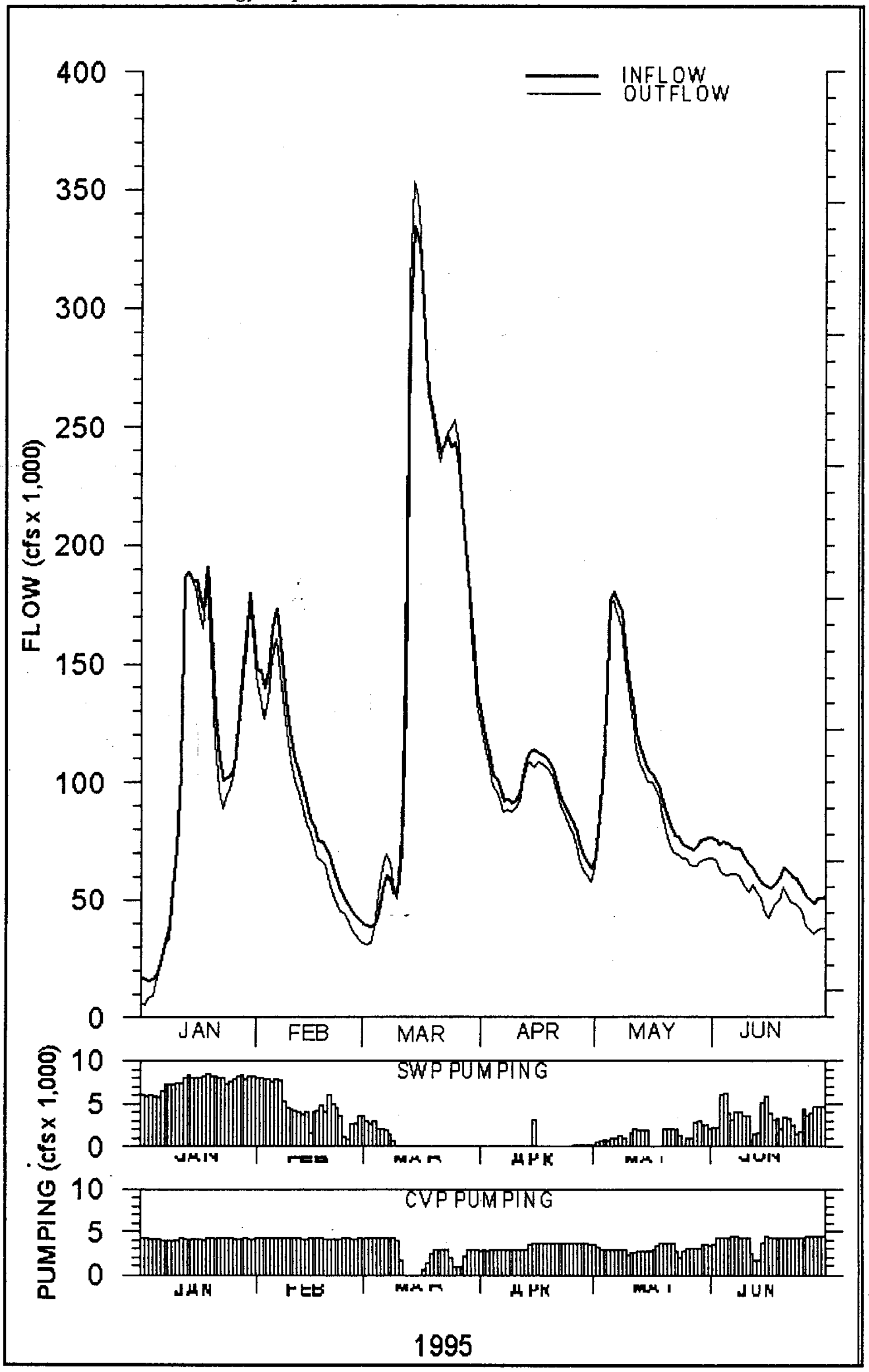
Delta Flows

Kate Le, 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/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.

From April through June, the Delta Outflow Index averaged about 80,000 cfs. During the early part of May, outflows peaked to about 180,000 cfs due to increased releases for flood control following earlier storms. Combined SWP/CVP pumping averaged about 5,000 in April through June because of low demand. During part of April, SWP pumping was very low.

The DWR O&M Division has modified calculations for determining Delta inflow to reflect the December 1994 Draft Water Quality Control Plan.



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Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

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California Department of Water Resources
State Water Resources Control Board
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Environmental Protection Agency
National Marine Fisheries Service

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