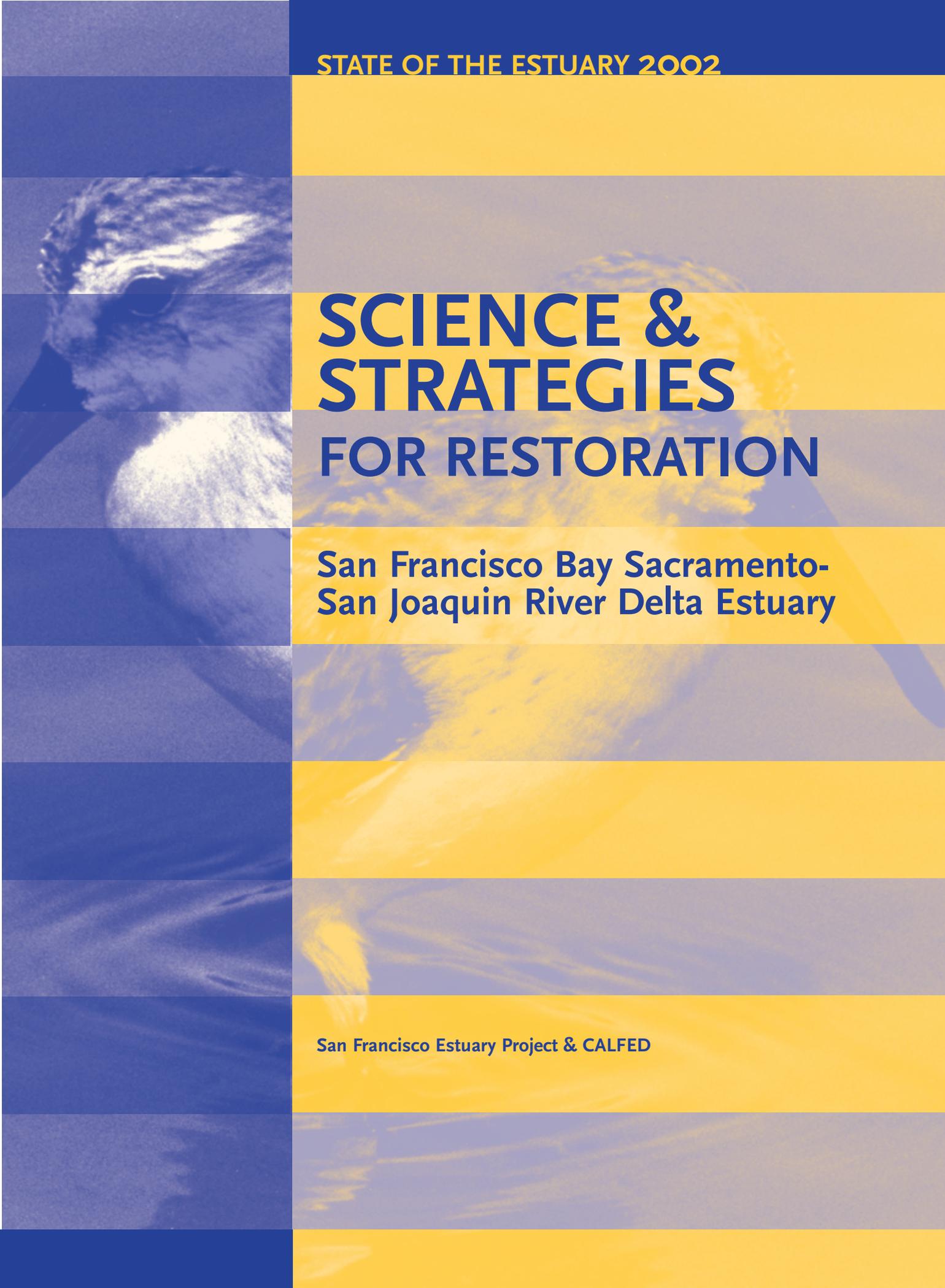


STATE OF THE ESTUARY 2002



SCIENCE & STRATEGIES FOR RESTORATION

**San Francisco Bay Sacramento-
San Joaquin River Delta Estuary**

San Francisco Estuary Project & CALFED

OPENING REMARKS

This Report describes the current state of the San Francisco Bay-Sacramento-San Joaquin Delta Estuary's environment -- waters, wetlands, wildlife, watersheds and the aquatic ecosystem. It also highlights new restoration research, explores outstanding science questions, and offers management cues for those working to protect California's water supplies and endangered species.

San Francisco Bay and the Delta combine to form the West Coast's largest estuary, where fresh water from the Sacramento and San Joaquin rivers and watersheds flows out through the Bay and into the Pacific Ocean. In early the 1800s, the Bay covered almost 700 square miles and the Delta's rivers swirled through a vast Byzantine network of 80 atoll-like islands and hundreds of miles of braided channels and marshes. Back then, almost a million fish passed through the Estuary each year and 69 million acre-feet of water crashed down from mountain headwaters toward the sea. But in 1848 the Gold Rush began and hydraulic mining plugged the rivers and bays with more than one billion cubic yards of sediments. Over time, farmers and city builders filled up more than 750 square miles of tidal marsh and engineers built dams to block and store the rush of water from the mountains into the Estuary, and massive pumps and canals to convey this water to thirsty cities and farms throughout the state.

Today's Estuary encompasses roughly 1,600 square miles, drains more than 40% of the state (60,000 square miles and 47% of the state's total runoff), provides drinking water to 20 million Californians (two-thirds of the state's population) and irrigates 4.5 million acres of farmland. The Estuary also enables the nation's fourth largest metropolitan region to pursue diverse activities, including shipping, fishing, recreation and commerce. Finally, the Estuary hosts a rich diversity of flora and fauna. Two-thirds of the state's salmon and nearly half the birds

migrating along the Pacific Flyway pass through the Bay and Delta. Many government, business, environmental and community interests now agree that beneficial use of the Estuary's resources cannot be sustained without large-scale environmental restoration.

This 2002 *State of the Estuary Report*, and its *Posterbook* appendix, summarize restoration and rehabilitation recommendations drawn from the 48 presentations and 132 posters of the October 2001 State of the Estuary Conference and on related research. The report also provides some vital statistics about changes in the Estuary's fish and wildlife populations, pollution levels and flows over the past three years, since the 1999 *State of the Estuary* report was published.

The report and conference are all part of the San Francisco Estuary Project's ongoing efforts to implement its *Comprehensive Conservation and Management Plan (CCMP)* for the Bay and Delta and to educate and involve the public in protecting and restoring the Estuary. The S.F. Estuary Project's CCMP is a consensus plan developed cooperatively by over 100 government, private and community interests over a five-year period and completed in 1993. The project is one of 28 such projects working to protect the water quality, natural resources and economic vitality of estuaries across the nation under the U.S. Environmental Protection Agency's National Estuary Program, which was established in 1987 through Section 320 of the amended Clean Water Act. Since its creation in 1987, the Project has held five State of the Estuary Conferences and provided numerous publications and forums on topics concerning the Bay-Delta environment. In 2001, CALFED joined the Estuary Project as a major sponsor of the conference. CALFED is a coopera-

tive state-federal effort, of which U.S. EPA is a part, to balance efforts to provide water supplies and restore the ecosystem in the Bay-Delta watershed.

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EXECUTIVE SUMMARY

(Reprint of an October 2001 article in ESTUARY newsletter)

Eight hundred people lounged in the red seats of the Palace of Fine Arts auditorium in San Francisco this October to hear 48 experts present the newest research, the best maps, the latest technologies, and the hottest debates over the resources, health and restoration of the S.F. Bay-Delta Estuary.

accompanied by a recognition that "the objectives of any group or interest will not be achieved simply by voicing unyielding denials of the objectives of others." Nichols closed by mentioning a number of challenges for the future, among them predicting what would be the regional effects of local construction or restoration projects; judging how non-lethal contamination levels in the Estuary's invertebrates and fish affect the fish, wildlife, and humans who eat them; and overcoming the "reticence of our institutions to take a whole system approach."

Californians practicing a minimal level of conservation managed to shave 10-14% off peak demand levels. "The regulators need to watch the generators," he cautioned.

Shaving demand might also help with the global warming problem, which the U.S. Geological Survey's Mike Dettinger described as just one part of the region's long history of climatic variability. As a result of warming, Dettinger predicted "fresher winters and saltier summers," for the Bay, and less than 25% of current snowpack levels in some areas by mid-century. "In the past 1,000 years, there have been much drier centuries with 100 year droughts and extreme flood periods. These old trends, superimposed by global warming impacts, promise that major hydroclimatic changes threaten the Estuary in the near future," he said.

Another threat will be earthquakes, said Mary Lou Zoback, also of the Geological Survey. Zoback spoke of a 60-70% chance of a major earthquake shaking the region's bridges and levees before 2030, but more ominously of the likely return to the days before 1906 when the region experienced a magnitude six quake every four years. "The stress shadow of the 1906 quake created a docile environment in the Bay Area," she said. "Future quakes will be larger, closer together and more costly." In terms of the Estuary, they might not only wipe out some levees, but also release a lot of old contaminants buried in the soft Bay mud, she added.

After lunch, the Point Reyes Bird Observatory's Nils Warnock spoke about factors affecting bird life in the Bay today, among them habitat changes (conversion of salt ponds to tidal marsh), proposed airport runways, the spread of invasive cordgrass and contaminants. Some of the contaminants come from the birds' food - invertebrates, zooplankton and fish - whose status was surveyed by Cal Fish & Game's Kathy Heib. Heib said a long-term shift from a warm to a cool ocean climate has benefited some species, like chinook salmon and English sole, but not others. A plant that is not benefiting

"When I first started thirty years ago, we'd pull in 80 tons a day of garbage. People used the Bay as a dump. Over the last 10 years, it's gotten much cleaner."

ERIC CARLSON

Retired Army Corps Debris Boat Captain

First up at the podium was Richard Katz, a member of the State Water Resources Control Board, who hammered at the theme of good science leading to good policy. His homework for the audience was to stop just talking to each other in science speak and to get out and educate "newbies" in the state assembly about how this ecosystem we are trying to save provides drinking water to 20 million Californians and affects jobs and the economy. After the dose of political realism came a little history from author Malcolm Margolin, who commented on how impressive the knowledge level of environmentalists attending such conferences had become. "Thirty-five years ago carrying a picket sign and having a flimsy poetic idea was enough, but today's activists have extraordinary scientific, political, economic, and technological expertise," he said.

A coming of age also figured in the subsequent speech by the U.S. Geological Survey's Fred Nichols, who noted that progress made in such things as reducing the impacts of raw sewage and learning about the Estuary's natural processes has been

Further talks on urban challenges followed, with Tom Schueler of Chesapeake Bay's Center for Watershed Protection reminding listeners that "the greatest threat to estuaries continues to be the conversion of natural spaces to car habitat." He said research shows a decline in sensitive species at about 30% impervious cover, a decline of food variety and abundance at about 15% and a rise in chronic coliform (fecal) contamination at less than 10%.

The water-energy connection was then made by Peter Gleick of the Pacific Institute - every acre foot of water we use costs about 2-3,000 kilowatts of power, he said. "The more water we save, the more energy we save," he said. Gleick debunked a number of popular "myths," among them that there are water and energy shortages. He attributed both these problems not to a lack of the resource, but to a shortage of "intelligent management." He added that there were no rolling black outs in the summer of 2001 not because, as the TV ads would have us believe, we've quickly built new power plants but because

anyone, however, is exotic Atlantic cordgrass and its hybrids, which Peter Baye of U.S. Fish & Wildlife said continues to colonize Bay mudflats and reshape the shoreline. "If we forge ahead and do restoration without getting rid of invasive plants, we won't achieve a lot of our objectives for ecosystem recovery," he warned. As of 2001, a total of 237 invasive species (both flora and fauna) were well documented within the Estuary, added the S.F. Estuary Institute's Andy Cohen.

Getting down to ground level, hydrologist Phil Williams then discussed how our view of sediment as a nuisance - choking shipping channels and muddying swimming beaches - has changed over the last few decades. But declining sediment delivery to the Bay (only 5 million cubic yards per year now), along with sea level rise and the creation of large new sediment sinks (restoration of subsided Delta islands, for example) will all reduce the mud supply. "Managing mud will be as important as managing toxics and exotics in the future," he said. "Large-scale restoration will be constrained by the small sediment supply."

After Williams, Stanford's Steve Monismith gave an overview of how numerical models have helped us understand hydrodynamic processes and the S.F. Estuary Institute's Rainer Hoenicke described strides in reducing toxicity in the Bay. One pollutant reduction effort has been the negotiation of TMDLs, a regulatory tool that sets a regional goal for a total allowable maximum daily load of a contaminant. The Bay's new mercury TMDL "beats on all the sources," said the S.F. Bay Regional Board's Khalil Abu-Saba. But because five old mines account for about 90% of the mercury problem, he said, "We need more bulldozers and fewer Ph.D.s to work on this." Three more speakers wrapped up the day, with talk of pesticides, biomarker research, and attributes of a healthy ecosystem. And retired Army Corps debris boat captain Eric Carlson sent everyone home with first hand tales of railroad cars full of whiskey stuck in the Bay mud, sea lions on his deck, and

a snake adrift on a clump of peat moss.

Day two of the conference opened with the theme of ecosystem restoration, which CALFED's lead scientist Sam Luoma said required three things to be successful: a sophisticated investment strategy; careful documentation of what works and what does not; and an institutional system that responds to the evaluation of effectiveness.

Three groups of speakers then addressed restoring Central Valley rivers, the Delta and the Bay. The Resource Agency's Tim Ramirez kicked off by examining how salmon have responded to river restoration strategies. Then U.C. Davis' Jeff Mount said "flood management is the single most useful tool of ecosystem restoration," but four hurdles had to be overcome to use it: a 150-year history of hard engineering approaches to river management; working within a system specifically designed to limit interchange between the channel and the floodplain; the often small and disconnected scale of restoration projects; and the need to embrace restoration as a social, not just biological and physical, science.

We also need to recognize, said Stanford's David Freyberg, that ecosystem restoration is "fundamentally a design process, and that design is a different activity than discovery," which is what most scientists perceive their work as being. The challenge then, he said, is to design for complexity, variability and long term change using tools - dams, channels, levees - designed to simplify the ecosystem. You can't rely on nature to do all the rest of the work either, said Denise Reed of the University of New Orleans, who went on to debunk other restoration "myths," including "build it and they will come." Reed said "We shouldn't expect the system to have enough sediment in it to build new land, because it's not what our rivers ever did before. We don't need to build new marshes as high as natural ones, but we do need to rebuild the substrate to the level where vegetation can take over."

Some of the substrate is so low that restoration via such processes as microbial decomposition is fast becoming the only option, according to the Department of Water Resources' Curt Schmutte, referring to his work on subsided Delta Islands. "The only other option is to let these holes get deeper and deeper," he said.

Further downstream, Bay restoration is now revolving around the Ecosystem Habitat Goals completed by scientists in 1999. Much work has been done in the North Bay, according to consultant Stuart Siegel, whose new inventory of North Bay restoration projects estimates 13,569 acres of tidal marsh has been or will be constructed in the near future - a big leg up on the Goals Project's recommendation of 28,000 acres of this sub-region for optimum ecosystem health. A healthy ecosystem comes not only from bay wetlands, but also from healthy creeks and watersheds, according to the next speaker, the S.F. Estuary Institute's Laurel Collins. Collins showed intriguing charts comparing levels of erosion, debris, sediment, vegetation and other factors along nine creeks draining into the Bay. Other speakers expanded on shoreline and watershed restoration efforts.

After lunch, the subject matter honed in on Suisun Bay - that pivotal zone of the Estuary that has one foot in the Delta and one foot in San Francisco Bay. A parade of speakers explored layer upon layer of Suisun science, from the impacts of long-term rises in spring salinity levels since the 1930s (a 5 ppt increase, according to speaker Noah Knowles) to changes in sedimentation rates from a historical depositional situation in which 3 million cubic meters (mcm) were being deposited in the Bay every year to more recent times when 1-2 mcm are eroding away annually, according to the Geological Survey's Bruce Jaffe.

Other changes include revisions to the circulation model for the Bay and Carquinez Strait, said the Survey's Jon Burau, who showed slides of where scientists now think

the water goes, and how tides, currents and topography influence turbidity, food production and sediment movement. Indeed scientists now know the area of maximum turbidity is not necessarily where the salinity hits 2 practical salinity units (or "x2"), as until recently thought, but on the seaward side of sills such as Garnet Sill adjacent to Grizzly Bay, according to presentation by the Survey's Dave Schoellhamer.

Two other scientists went on to explore the impact of the invasive Asian clam *Potamocorbula* on the Suisun Bay food web, and how contaminants affect the clams and the birds and fish that eat them. The Survey's Robin Stewart, for example, showed a chart indicating a big increase in selenium concentrations in top predators like Suisun Bay sturgeon, which feed on the clams, between 1986 and 1999 but no increase for striped bass which feed on other organisms. On the heels of all this science was a multi-agency management presentation describing the current acrimonious debate over how much of Suisun Marsh should be kept as heritage waterfowl habitat and hunting grounds and how much converted to much-needed tidal marsh.

Day three of the conference dawned with snapshots of key biological components of the ecosystem - fish, habitat and flows. U.C. Davis' Peter Moyle looked at the ever changing balance between native and alien fishes, but said both kinds of populations are in decline: "the peaks and valleys in their numbers are both getting lower" (see graph p.5). Habitat for the fish came next, with S.F. State's Wim Kimmerer discussing characteristics of the fish-friendly low salinity zone in the Estuary, and how it moves with changing flows (x2), and the U.S. Geological Survey's Larry Brown exploring the benefits of "shallow water habitat" (shoals, marshes, river flood plains) for fish. The recent push to create new shallow water habitat, and the use of this new habitat by alien species, has raised many questions about what kind of habitat is best to restore for natives. Brown says research on alien and native fish abundance in Suisun

Marsh showed natives favored the small sloughs. "This helps us choose from the universe of shallow water habitat restoration options - we want the ones that look like small sloughs," he said.

Other speakers talked about Pacific herring and the benthic community, and Water Resources' Brad Cavallo closed with the proverbial big fish in the pond: salmon. He said we had to stop trying to manage them as "freeway fliers" speeding straight up and down the rivers, and start noticing that they're more like "Sunday drivers" stopping off here and there in side channels and often moving back and forth. "Fish don't follow the robotic life history we invent for them," he said. "So we can't just continue to focus on minimizing mortality at bottle-necks."

"If we forge ahead and do restoration without getting rid of invasive plants, we won't achieve a lot of our objectives for ecosystem recovery."

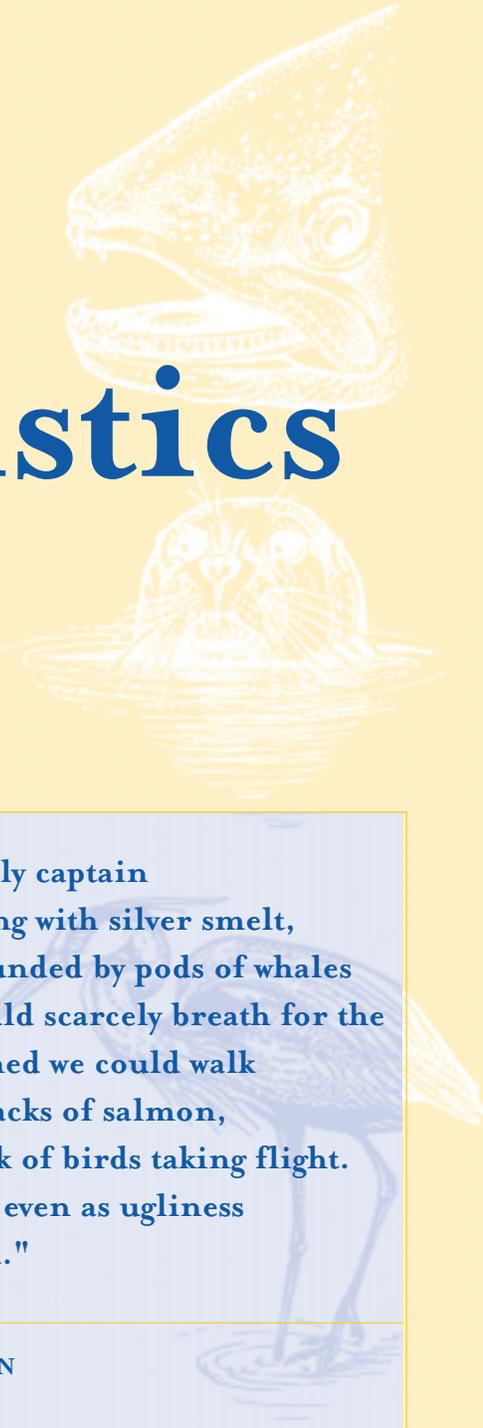
PETER BAYE
U.S. Fish & Wildlife Service

Near the end of the conference, two old hands in Estuary management provided some interesting perspectives. Steve Ritchie, formerly of the water quality board and CALFED, looked at our management track record and said that the S.F. Estuary Project's 1993 consensus-based plan for the Bay-Delta "changed the way we do our business, moving from legislative to more collaborative efforts like CALFED." But the eloquent words that rang in the ears of many leaving the conference were those of U.S. EPA retiree John Wise: "It's time to move science into the public domain, to communicate the beautiful chaos of the Bay-Delta system to those around us, and to re-engage the public in long-term programs to protect the Estuary."

STATE OF THE ESTUARY

Vital Statistics

1999-2002

The background features two faint, light-colored illustrations. The upper one is a detailed drawing of a fish's head in profile, facing left, with its mouth slightly open. The lower one is a drawing of a bird, possibly a grebe, standing in water with its reflection visible below. The entire page has a light yellow background with a thin orange border.

"I have an image of an early captain
going along the coast, the sea flashing with silver smelt,
seabirds rising off rocky islands, surrounded by pods of whales
whose spoutings were so thick the crew could scarcely breath for the
stench. It was a time when it seemed we could walk
across the river straits on the backs of salmon,
hear a hurricane in the sound of a flock of birds taking flight.
The world wants to be beautiful, even as ugliness
spreads all around."

MALCOLM MARGOLIN
Author

DETERMINING HEALTH

ANDREW GUNTHER

Center for Ecosystem
Management and Restoration

The health of the Estuary is not an objective characteristic that we can measure, but rather a subjective assessment that we make by considering measurements of the ecosystem's important attributes. We can simplify the problem a little if we inquire about the relative condition of the ecosystem over time. And so we arrive at the question, "Are things getting better or worse?"

Answering this question requires that we identify essential ecosystem attributes that are publicly meaningful and scientifically justified. We then must track the status of these attributes, or indicators of them, over time to build a record of ecological condition for the Estuary.

What I am suggesting here is not really news. In fact, work reported in the last State of the Estuary proceedings identified nine ecosystem attributes and a set of 13 ecological indicators for the Bay-Delta and its watershed. Moreover, we have much raw material to work with, from both a policy and a scientific perspective, through our adopted public goal statements and the results of scientific research and monitoring.

Yet we still need to integrate this raw material into an assessment of ecological condition. Let me suggest some strategic considerations if we are to accomplish this task. First, there are many opportunities to learn from what others are doing, as we are not alone in this effort. Across the nation those responsible for the health or integrity of aquatic ecosystems are trying to establish meaningful ecosystem goals, and find consensus metrics to evaluate progress. The National Academy

of Sciences and the Science Advisory Board of the EPA have provided or will soon be providing guidance on approaching this problem.

Second, we must recognize that developing a meaningful assessment of the ecological condition is a long-term proposition that may require specialized institutions. We need to consider all alternative institutional structures to identify those particularly well-suited to this task. If we are going to track cycles in our ecosystems for decades, this task should be assigned to institutions with a long-term mission and long-term funding mechanisms.

Third, we must recognize that developing a meaningful assessment of ecological conditions requires more than the collection, documentation, and publication of data sets.

Finally, we must recognize that we will have to learn as we go. Whatever indicators are used to assess ecological condition will be imperfect, and reaching agreement on benchmarks of evaluation will take time. There will obviously be alternative assessments that could be created from the same data, and our first attempts at an overall assessment of conditions are likely to be soundly criticized. In the long view, our assessment of condition will need to be repeated on a biannual or triennial basis, and there will certainly be an opportunity for multiple authors to take their turn.

In conclusion, consider this thought: when you need a car, you don't go to the parts department. Similarly, if we want to create a cogent assessment of the ecological condition of the Estuary, we should not examine and approve each part separately. Instead, we must build a complete assessment and take it out on a test drive, and then recommend alternate parts based upon the performance of the complete product.

It has taken us a long time to modify the Estuary to its present state, and it will take a long time for us to authoritatively document trends in its condition. Those of us who study the Bay on a regular

"Although a complete and compelling presentation of the health of the Estuary is presently outside of our experience, there is no reason to think that it is beyond our capabilities."

basis owe our fellow citizens a straightforward answer to the question, "are things getting better or worse." If we commit to the attempt, there can be no doubt that the product will inform our debate, and that we will learn over time how to improve our assessment and make it more useful. Our imperfect attempts to answer this question will not reflect as poorly on us as our unwillingness to try in the first place. Although a complete and compelling presentation of the health of the Estuary is presently outside of our experience, there is no reason to think that it is beyond our capabilities. (Gunther, SOE, 2001)



MORE INFO?

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PERSPECTIVE

CAN YOU HEAR THE CANARY SING?

RANDALL BROWN
CALFED Science Program

The San Francisco Estuary is a complex and ever-changing ecosystem which has been altered dramatically over the past 150 years, largely by water storage and withdrawal systems that change the amount and timing of freshwater inflow. Management agencies have struggled to find an index or measure that can demonstrate that efforts to balance beneficial uses of freshwater inflow are working. From the late 1950s into the 1980s, such an index, likened to a miner's canary, was an index of the summer abundance of young-of-the-year striped bass when their average size was about one inch. The index, which was positively correlated with spring outflow and negatively correlated with spring diversions, was to indicate the health of the northern estuary.

In 1978 the State Water Board issued Decision 1485, stipulating spring flow and pumping conditions intended to result in an average striped bass index of about 78. It quickly became apparent, however, that the relationship between flows, pumping and the index was changing. In the 1980s, the index fell to new lows and for the last decade it has generally been less than 10 – even in those years with apparently favorable flow and pumping. The adult striped bass population plummeted as well, with fewer than 500,000 adults in the early 1990s as compared to 1.5-1.9 million in the early 1970s.

In the late 1980s, for the first time, resource managers planted juvenile hatchery striped bass in the Estuary to help restore this economically important sports fish. Within a few years concern about declining abundance of several native fish resulted in the

California Department of Fish & Game calling a halt to the planting of this fish-eating, introduced predator.

Subsequently, state and federal agencies formally consulted on a plan to stock limited numbers of juvenile striped bass, with a goal of stabilizing the adult population at about 1.2 million. The latest estimates on adult bass indicate that the population goal has at least been temporarily achieved and, consistent with the federal biological opinion, Fish & Game curtailed planting juvenile striped bass.

“Management agencies have struggled to find an index or measure that can demonstrate that efforts to balance beneficial uses of freshwater inflow are working.”

The strength of the canary's song (the striped bass index) did follow other indicators (native fish abundance) demonstrating that conditions in the northern estuary deteriorated in the 1987-1992 drought. The apparent lack of sensitivity of the index to generally improving conditions from 1993 shows that it may have biases that make it inappropriate for use as an indicator of estuarine health. In keeping with restoring native species, perhaps we should be listening to the Suisun song sparrow instead of the canary (Brown, SOE, 2001).



MORE INFO?

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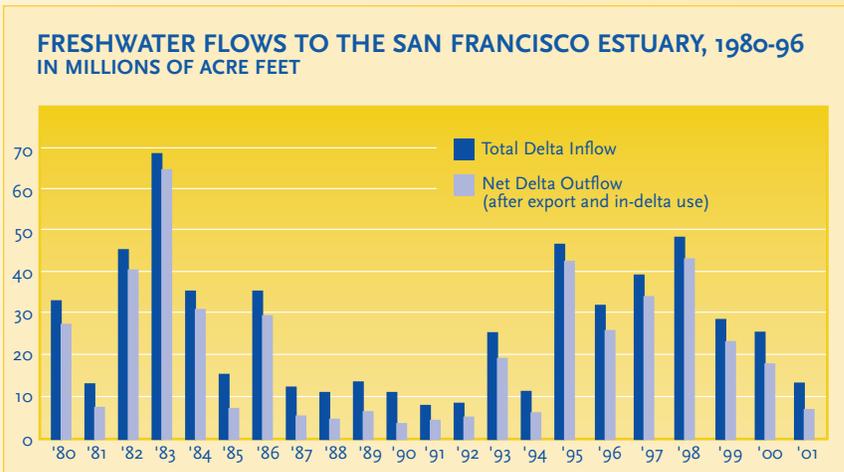
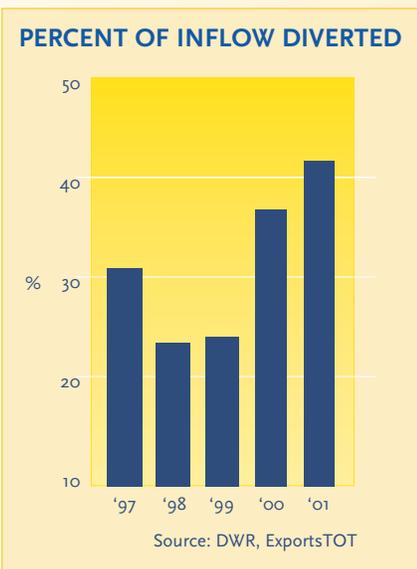
FLOWS

RECENT INFLOWS

Normal or above normal rainfall has meant improved Delta inflows in recent years. Inflows to the Delta and Estuary were 25.2 million acre-feet (MAF) in water-year 2000 (October 1, 1999 - September 30, 2000) and 13 MAF in 2001. Delta outflows were 18.2 MAF in 2000 and 7 MAF in 2001 (IEP, 2002).

DIVERSIONS FOR BENEFICIAL USE

Water is diverted both within the Delta and upstream in the Estuary's watersheds to irrigate farmland and supply cities. In-Delta exports have largely remained within the range of 4 to 6 MAF per year since 1974, but the percent of Delta inflow diverted can vary widely from year to year. In water-year 2000, 6.3 MAF were diverted, and in 2001, 5.1 MAF. The average percentages of total Delta inflows diverted were 37.6 in 2000 and 41.7 in 2001 (IEP, 2002).



WATER USE EFFICIENCY

Water use efficiency, conservation and recycling projects within the Bay-Delta region aim to provide a "drought-proof" source of water to help meet the needs of cities, industries and agriculture. CALFED is sponsoring a new water-use efficiency program that could save 1 to 1.3 MAF per year within seven years. The program involves setting ecological, water quality and water supply objectives; assessing local and regional flow patterns; evaluating how cities and farms might change their water use to achieve the objectives; and then providing appropriate financial incentives. Meanwhile, 65 water conservation projects (37 urban, 28 agricultural) received a total of \$13.3 million statewide in CALFED funding in 2001; local matching funds added another \$9.1 million. CALFED expects that these projects will collectively save 30,000 acre-feet of water per year.

At the local level, the Bay Area Water Recycling Program's (BARWRP) Master Plan, now complete, calls for recycling 125,000 acre-feet per year in the Bay Area by 2010, and about 240,000 af/year by 2025. Many Bay Area agencies are forging ahead with the design, construction and operation of water recycling projects. For example, the City of San Jose's South Bay Water Recycling Program delivers an average of 10 million gallons per day (mgd) during the summer season to over 350 customers in San Jose, Santa Clara and Milpitas. The next phase of this project, currently in design, will double the delivery amount by the year 2008. The Dublin-San Ramon

Services District recycling facility's current treatment capacity is 3 mgd, with 10 miles of distribution installed. Planned capacity for this facility is 9.6 mgd. The East Bay Municipal Utility District's East Bayshore Recycled Water Project, currently in the design phase, will ultimately run up to 24 miles of pipeline through Oakland, Berkeley, Emeryville, Alameda and Albany. EBMUD expects to start deliveries in 2003, and aims to save 2.3 mgd (more than 2,500 acre-feet/year) once enough users are hooked up to the system.



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FISH & AQUATIC ORGANISMS

ZOOPLANKTON, CRABS & FISH

The status and populations of aquatic species in the San Francisco Estuary is influenced by physical and biological factors including the magnitude and timing of freshwater flows, both in the rivers and through the Delta; ocean temperature; and ocean currents, such as coastal upwelling. Since 1999, freshwater flows have been lower than during the preceding four years, while ocean temperatures have been cooler and coastal upwelling stronger. There is strong evidence that the ocean climate along the Central coast underwent a regime shift in 1999 from a warm to cool phase.

Cooler ocean temperatures in recent years have benefited some species, but have been detrimental to others. Over the past three years abundance of juvenile Dungeness crab and English sole, both cold-temperate species, has been near or at record high levels in the Estuary for the period of record (1980-2001). Concurrently, abundance of subtropical species, such as California halibut and Pacific sardine, has slowly declined.

With the exception of copepods, abundance of all types of zooplankton in Suisun Bay and the Delta has declined in recent years. Total copepod abundance has increased since the early 1990s, but this was due to non-native species introductions.

Species that spawn in the lower rivers or upper Estuary and rear in the Estuary, such as Delta smelt, longfin smelt, striped bass, and splittail, have varied abundance trends over recent years. Delta smelt abundance was relatively high in 1999 and 2000, while longfin smelt abundance oscillated. Abundance of juvenile striped bass has been very low since the late 1980s, but the most recent population estimate for adult bass was 1.8 million, the highest

number since 1975. Abundance of juvenile splittail was low in 1999 and 2000, although adult numbers have increased recently due to very strong year classes in 1995 and 1998.

Abundance of chinook salmon, which reproduce in the rivers but rear in the ocean, is affected not only by riverine, estuarine, and oceanic conditions, but also commercial and sport harvest. The Central Valley chinook salmon index was the fourth highest in 2000 for the period of record (1970-2000).



Escapement of fall-run chinook salmon to the Sacramento River system in 2000 was approximately 400,000 fish, the highest for the period of record, while escapement of fall-run chinook salmon to the San Joaquin River system was the highest since the mid-1980s (Hieb, SOE, 2001)



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FISH ASSEMBLAGES

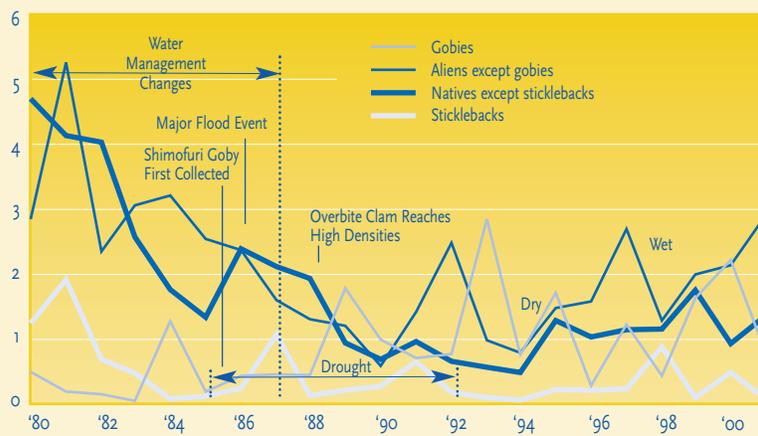
The fishes of the San Francisco Estuary are a mixture of native and alien species. The Estuary's marine portions are dominated by native fishes but the freshwater and brackish portions are dominated by alien species. A 22-year study (monthly sampling) of the fishes inhabiting

the sloughs of Suisun Marsh, in the center of the Estuary, has revealed trends in 29 fishes, 14 of them alien species. The study shows that most native and alien species are generally in decline in the upper Estuary, although the invasion of the shimofuri goby in the 1980s boosted alien numbers. The major driving force for relative abundances of species is reproductive success both inside and outside the Estuary. Success of reproduction as reflected in recruitment success is the key factor limiting native fishes of concern (e.g., delta smelt, longfin smelt, splittail, chinook salmon). Estuarine fish assemblages appear to be fairly unpredictable, due to (1) the natural fluctuating conditions of estuaries in general, especially in the brackish regions, where species come and go according to changes in temperature and salinity, (2) the general decline in fish abundance in the brackish and freshwater portions of the Estuary, suggesting a high level of anthropogenic disturbance, and (3) the frequent invasion of alien species of both fish and invertebrates. These results suggest that there will be continue to be a high degree of unpredictability in fish abundances (as reflected in assemblage structure) until estuarine processes return to some semblance of their natural range of variability and until invasions of alien species are halted (Moyle, SOE, 2001).



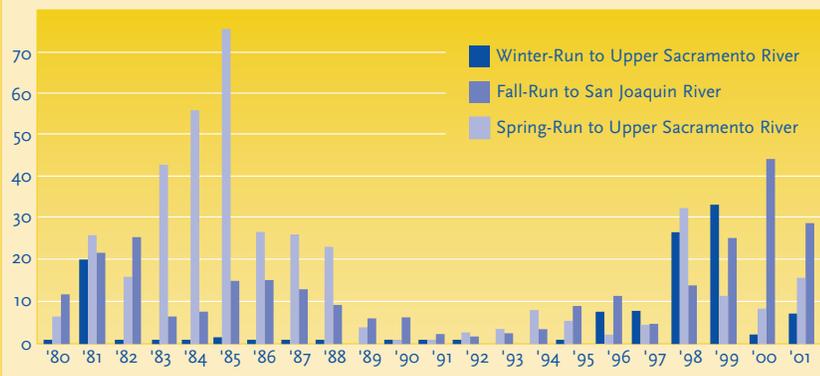
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SUISUN MARSH ANNUAL AVG. CATCH, 1980-2001



Source: Peter Moyle

SALMON RUNS OF CONCERN
IN THOUSANDS OF ADULT FISH RETURNING TO SPAWN



Source: CDFG

CENTRAL VALLEY SALMON

Most populations of Central Valley chinook salmon seem to be holding steady. These salmon occur in four discrete runs — winter-run, spring-run, fall-run and late fall-run (run refers to the season in which adults return to their native streams to spawn). The winter-run chinook, with the lowest population, has been listed as a both a state and federal endangered species since 1994. In 1999, returning salmon numbered 3,288, the highest return since 1985. The population dropped to 1,352 in 2000, then jumped to 7,572 in 2001. This fluctuation is likely due to a difference in techniques used to estimate the population; a comparison of survey results based on current and past estimation techniques is now under analysis. The next most sensitive stock, the spring-run, was state listed as a threatened species in 1998 and federally listed in 1999. The spring-run population was 10,134 in 1999, 9,404 in 2000, and 15,794 in 2001. Sacramento fall-run are the most abundant chinook stock, with 434,018 returning in 2000 and 569,976 in 2001 (includes both hatchery and in-river spawning fish; the exact proportion of each within the river is unknown). Returns of the San Joaquin fall-run in 2000, at 44,514, and in 2001, at 29,182, were both above the 1967-1991 average annual return of 22,319. The late fall-run (distinct from fall-run) population was 12,746 in 2000 and 13,148 in 2001. CALFED's new Environmental Water Account

(EWA) was used for the first time in 2000 to reduce impacts of Delta pumping operations on the winter-run, spring-run and San Joaquin fall-run chinook salmon, but it is too soon to determine whether this effort will provide population-level benefits (Kano, Pers.Comm., 2002).



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DELTA SMELT

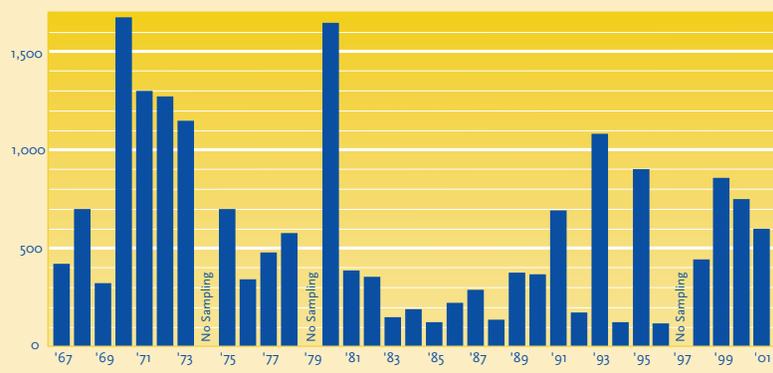
The silvery-blue delta smelt, a 55-70 mm-long translucent fish once common in the Estuary, was listed as a state and federal threatened species in 1993. Delta smelt are considered environmentally sensitive because of their one-year life cycle, limited diet, low egg production and larval survival rate, and restricted distribution within the Estuary. Possible reasons for the

delta smelt's decline include reductions in Delta outflow, high outflows (which push them too far down the Estuary), entrainment losses at water diversions and pumps, food changes, toxic substances, disease, competition and predation. The abundance of delta smelt, after a dramatic decline in the 1980s, generally increased throughout most of the 1990s. Although recent monitoring results indicate this upward trend may have downshifted again, the species appears to be faring better than in did in the 1980s. Scientists believe the 1990s population increase can be attributed to multiple synergetic factors, including the above-normal outflow conditions, which aided in the transport of larval/juvenile fish from the Delta to their rearing grounds in Suisun Bay. Cal Fish & Game monitors the relative abundance of delta smelt through two long-term monitoring programs: the Towntnet Survey (TNS) and the Fall Midwater Trawl Survey (MWT). The 2001 TNS index for delta smelt was 3.5, a decrease from 2000 (8.0) and 1999 (11.9). Meanwhile, the 2001 MWT index was 603, a decrease from 2000 (756) and 1999 (864). CALFED's new Environmental Water Account was used for the first time in 2000 to reduce impacts of Delta pumping operations on this species, but it is too soon to determine whether this effort will provide population-level benefits (Dege, Pers. Comm, 2002).



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DELTA SMELT ABUNDANCE INDEX, 1967-2001
FALL MIDWATER TRAWL



Source: CDFG

LONGFIN SMELT

Longfin smelt in the Estuary represent the southernmost spawning population in North America. Their local abundance continues to be positively correlated with Delta outflow during their larval period, December through May (Baxter 1999). Between the extremely wet winters of 1998 and 2001, Delta outflow during the December through May period declined annually and so has the abundance of longfin smelt, as measured by Cal Fish & Game's Fall Midwater Trawl Survey. In 2001, the abundance index dropped severely to 247, a level not seen since the drought broke in 1993. On a positive note, a recent increase in the incidence of 120-140 mm FL (fork-length or length measurement from the tip of the snout to the fork in the tail) spawners (about 3 years old) captured in trawl sampling suggests that survival has increased from juvenile to adult (age 2) and beyond. This bodes well because age-3 females can produce over twice as many eggs as age-2 females, and such spawners can help buffer against poor year-classes (Baxter, Pers. Comm., 2002).



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SPLITTAIL

Splittail exhibited moderate overall abundance and fair recruitment (number of age-0 surviving to the fall) in the past three years. This silvery-gold minnow, found only in Central Valley rivers and the Delta, is listed as threatened under the federal Endangered Species Act. Splittail are known to spawn on inundated terrestrial vegetation, and its recruitment appears most strongly associated with the magnitude and duration of floodplain inundation during its late February-May spawning period (Sommer et al. 1997, Moyle et al. 2001). Floodplain inundation occurred only during the first third of the spawning period in 1999 and 2000, and only for a couple of weeks in 2001. Age-0 indices for 1999 and 2000 were about what was expected

given water conditions, but the index for 2001 was unexpectedly high. Presumably, the combination of high spawner numbers (first spawning of females from the extremely large 1998 year-class) and two narrowly separated week-long periods of floodplain inundation in late February and early March, with probable ponding in between, was sufficient to produce the better-than-expected age-0 abundance index (Baxter, Pers. Comm., 2002).



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STRIPED BASS

Cal Fish & Game mark and recapture estimates for legal size (18 inches or longer) striped bass, the most important sport fish in the Estuary, increased 70% from 1998 (1,340,693 fish) to 2000 (2,276,227 fish), but the reasons for this increase are unknown. Unexpectedly, abundance indices of striped bass in their first year of life (young-of-the-year fish) from the Midsummer Towntnet Survey and Fall Midwater Trawl Survey did not increase during the 1990s. Also, supplemental fish from Cal Fish & Game's Striped Bass Hatchery Program made up only 1.95% of legal-sized striped bass in 1998 and 6.21% in 2000; not enough to account for the observed increase. This disjunction between juvenile

and adult abundance makes it difficult to predict the future course of the population (Gartz, Pers. Comm., 2002)



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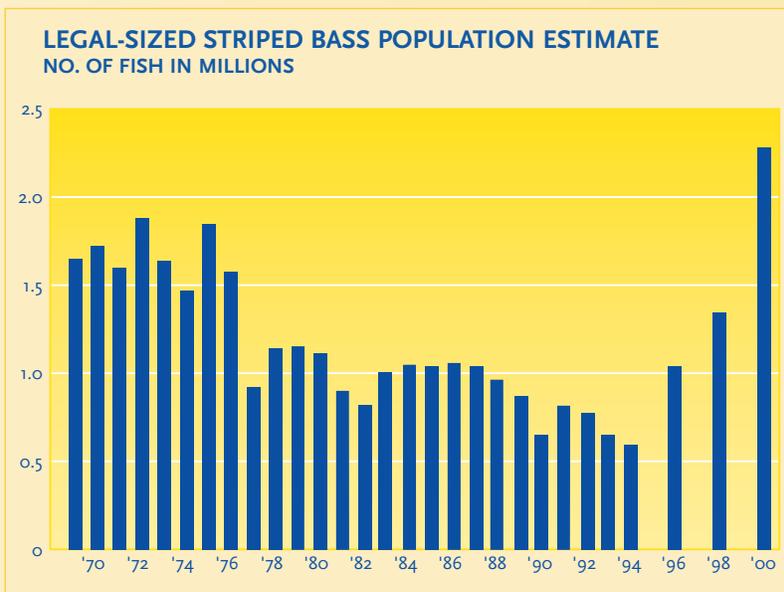
COMMERCIAL FISHERIES

Since the 1997 El Niño, the spawning biomass of Pacific herring, which supports the Bay's largest commercial fishery, has remained below the long-term (since 1978) average of 52,966 short tons. In response to this decline, Cal Fish & Game, which manages the fishery, has lowered catch quotas. Although ocean productivity has been favorable for herring over the past two years, a large recruitment of young fish to the spawning population has yet to occur. Following record high biomass levels of 99,050 tons in 1995-1996 and 89,570 tons in 1996-1997, spawning biomass plunged to 20,000 tons following the 1997 El Niño. Since then, spawning biomass estimates have been 39,500 tons for 1998-1999, 27,400 tons for 1999-2000 and 37,300 tons for 2000-2001 (Watters, Pers. Comm., 2002).



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Source: DWR

INVASIVE SPECIES

BAY-DELTA INVASIONS

The San Francisco Estuary continues to be one of the most highly invaded aquatic ecosystems in the world. Between 1995 and 2001, the number of well-documented invasive species in the S.F. Bay-Delta Estuary grew from 212 to 237. In the S.F. Estuary, there are 165 invasive species in salt/brackish waters and 87 in freshwater systems. Exotics are expanding their dominance among zooplankton and in salt marshes (Cohen, SOE, 2001).



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GREEN CRABS

The European green crab (*Carcinus maenas*) is now established in every significant bay and estuary between Monterey, California, and Gray's Harbor, Washington. It appeared in South San Francisco Bay in the early 1990s and has spread north at least as far as the Carquinez Strait. Salinity limits the crab's distribution: crabs have been collected from water ranging from 5-31 parts per thousand (ppt) salt to water, but few from water with less than 10 ppt. A nine-year study in Bodega Bay found that in contrast to their slow growth rates in Europe, green crabs here grew rapidly and reached sexual maturity in their first year. Over the course of the study, the green crab severely reduced the abundance of three common invertebrate species but did not impact the shorebird food web (Grosholz et al., 2000). While eradication is not possible at this point, a National Green Crab Management Plan now being completed recommends strategies for local population control. These include early warning methods for new range expansions, prevention measures against new introductions and coordinated monitoring of population trends, new outbreaks and losses to commercial fisheries.



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CHINESE MITTEN CRABS

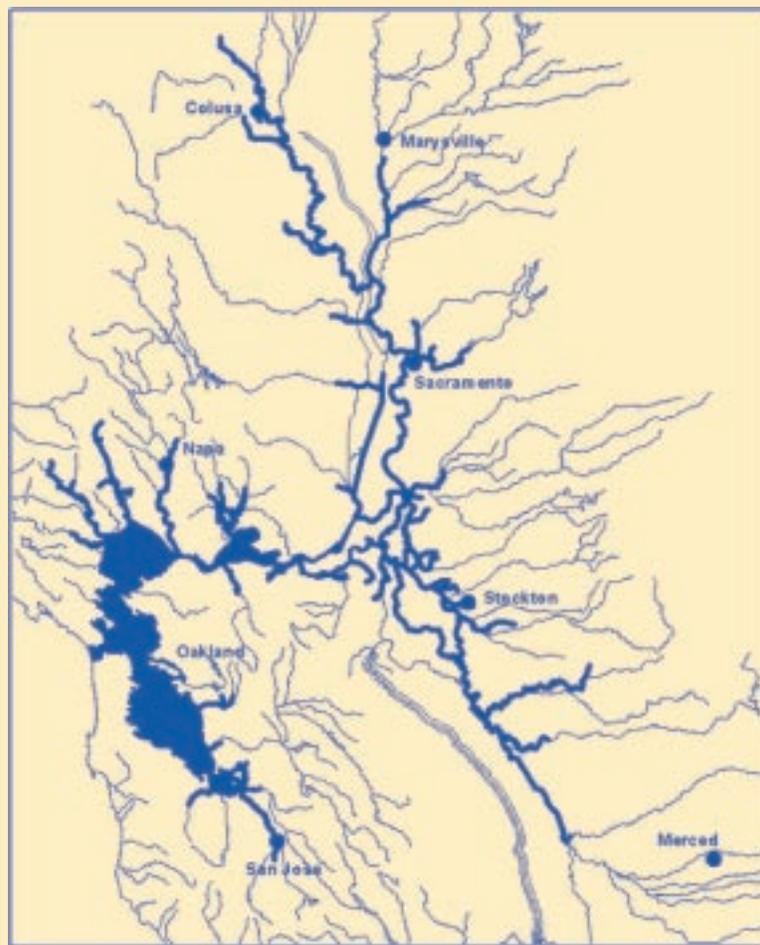
The Chinese mitten crab (*Eriocheir sinensis*) is one of the most successful of the species recently introduced to the Estuary. In summer 2001, the mitten crab ranged from north of Colusa on the Sacramento River to the confluence of the San Joaquin and Merced rivers (most reports of age-1 crabs came from the Delta and the Sacramento River basin). Although the 2001 distribution appeared to be very similar to that of 1998, crabs were not reported from as far north or as far south in 2001. In 1999 and 2000, the crab's population declined from the record high level of 1998, but it increased again in 2001. The number of adult crabs collected between San Pablo Bay and the western Delta by Cal Fish & Game trawls was higher in winter 2001-

2002 than in winter 1998-1999. The number collected at the BurRec fish salvage facility in the south Delta, however, was much lower in fall 2001 than in fall 1998. The apparent discrepancy between the 2001 state and federal numbers may be because a larger proportion of crabs reared in the Sacramento River watershed (and away from potential migration routes past south Delta fish facilities) that year than in previous years. The mitten crab's major impacts continue to be interfering with South Delta fish salvage activities, stealing bait from sport anglers and clogging West Delta power plant cooling water systems.



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BAY-DELTA MITTEN CRAB SPREAD



Distribution of the Chinese mitten crab in the San Francisco Estuary and its watershed, 1992, 1994, 1996, and 1998. Solid blue area or lines indicate presence of the crab. Source: CDFG

PIKE

The voracious Northern pike, native to Canada and the Midwest, was illegally planted in the 85,000-acre-foot Lake Davis reservoir in the early 1990s. In 1997, Cal Fish & Game treated the lake with Rotenone to prevent pike from eating lake trout and escaping into and corrupting the Delta ecosystem. The treatment temporarily shut the lake to all recreational uses and compromised local water supplies. In May 1999, about a year after more than a million trout were planted and the lake had reopened, the pike reappeared. Biologists have pulled almost 8,000 pike from the lake since 1999, mainly from shallow areas such as Mosquito Slough, a weedy channel into the lake. In February 2000, a Lake Davis steering committee, comprised of Plumas County and Cal Fish & Game officials and local citizens, released a management plan recommending 13 "control and contain" measures, including several types of barrier nets, increased electro-fishing, underwater explosions and fishing derbies. In spring 2002, biologists conducted a detonation cord "test" of one acre, to assess the range of the kill zone, and water quality and noise impacts. Based on the test results, a dozen detonations of up to 10 acres each are planned for 2003 and 2004. Despite the increased numbers of pike in the lake, they have not been found outside of Lake Davis.



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CORDGRASS

Species of *Spartina* (cordgrasses) introduced into the Estuary in the 1970s, have spread rapidly and pose a serious threat to the success of future tidal marsh restoration throughout the Estuary (see also p.62). The impacts associated with the spread of Atlantic cordgrass (*Spartina alterniflora*) include hybridization with and likely local extinction of native *Spartina foliosa*, regional loss of unvegetated tidal flat habitat, elimination of small tidal channels and loss of pickleweed habitat essential to the endangered salt marsh harvest mouse. The majority of creeks and flood control channels in the Central and South bays are infested with invasive *S. alterniflora*. Local flooding and navigation issues are expected to increase if the population continues to expand. In early 2000, the California Coastal Conservancy began coordinating an eradication project to prevent the spread of *S. alterniflora* into the North Bay and reverse the spread of the species throughout the Estuary. The project's mapping effort, completed in 2001, showed that *S. alterniflora* and hybrids cover 469 net acres within the Bay (acres counted as if there were no gaps in coverage).

Meanwhile, *S. densiflora* (transplanted from Humboldt Bay) covers approximately 13 net acres; *S. patens* (from the East Coast) covers half an acre; and *S. anglica* (originally from England but introduced to the Bay Area from Washington State) covers .09 acres. In the East Bay, non-native spartina species have spread as far north as Point Pinole, and in the West Bay, to northern San Rafael. *S. densiflora* has been found in the Napa Sonoma Marsh. Work is progressing on the eradication project's EIS/EIR, permits and planning documents. Maps, species identification guides and project documents are available.

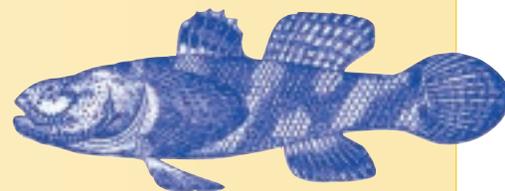


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GOBIES

Four types of non-native gobies (all of which probably arrived in ballast water) continue to inhabit Estuary waters. The yellowfin goby (*Acanthogobius flavimanus*) is the most abundant and widespread of the introduced gobies. Cal Fish & Game S.F. Bay Study catches of the chameleon goby (*Tridentiger trigonocephalus*) and the shimofuri goby (*T. bifasciatus*) have remained relatively stable over the past five years. In contrast, the catch of the shokihaze goby (*T. barbatus*) has increased dramatically, jumping from 11 in 1999 to 559 in 2001.



The impacts of this increase have not yet been determined. Within the Estuary, adult shokihaze gobies are found primarily in Suisun Bay, where they have the potential to harm native gobies, sculpin, Delta smelt, longfin smelt and shrimp and other invertebrates by competing for resources and through predation. Adult shokihaze gobies have been found in water with salinity ranging from 0.44-28.81 parts per thousand. Yet until recently, the shokihaze goby had not extended its known range seaward in the Estuary, since it was found in San Pablo Bay in December 1997. But in February 2002, the Bay Study caught two shokihaze gobies south of the Dumbarton Bridge (Greiner, Pers. Comm., 2002).



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For information on the Asian Clam, see p.66.

WETLANDS & WILDLIFE

WETLANDS

Acquisitions of fields, creekbanks, islands, floodplains and other former, current and future wetlands have tripled since the last three-year reporting period, with at least 33,042 acres secured and protected in the 12 Bay-Delta counties between April 1999 and September 2001. Restoration and enhancement work continued at a steady pace, meanwhile, with 11,453 acres and 1,320 linear feet of completed projects in the same time period. Plans for 24 wetland and riparian habitat projects will improve approximately 27,500 acres and 36,020 linear feet. The amount of wetlands lost during the same period remained small, though the extent of Delta losses is not known. In the Bay region, 122 acres of wetlands were filled and 204 acres gained as a result of 401 certification waivers and development mitigation projects. Regional interests have also continued with plans, partnerships and fundraising to implement the *Baylands Ecosystem Habitat Goals*. Though no resulting regulatory-based regional wetlands management plan has been developed, in 2001, 26 agencies, organizations and private companies signed on to the S.F. Bay Joint Venture's implementation strategy (*Restoring the Estuary*), which is based on the Goals. CALFED poured hundreds of millions of dollars into restoration projects and ecosystem planning and processes. Other points of progress in regional wetlands planning included the updating of the wetlands and wildlife section of the S.F. Bay Commission's *Bay Plan*, the launching of a regional wetlands monitoring program and the creation of a Joint Aquatic Resource Permit Application Center by the S.F. Estuary Project, ABAG and local agencies. Funding and technical assistance to individual landowners has also increased since 1999 (SFEP, 2001).



MORE INFO?

See Appendix A at www.abag.ca.gov/bayarea/sfep/reports/sfep_sep01.pdf

CALIFORNIA CLAPPER RAIL

Current Bay-wide population estimates for the endangered California clapper rail (*Rallus longirostris obsoletus*) are not available, but surveys in the mid 1990s placed their numbers at about 1,200 (up from a low of 300-500 birds in 1991). While Central and South Bay populations continue to hold steady, there is some indication that North Bay populations are in precipitous decline. Recent field studies reveal that the rails in the more pristine North Bay marshes are faring less well than those in urbanized areas. The estimated 13 pairs present in Sonoma Creek in 1993 dropped to 1-3 pairs in 1998, and in 2001, no rails were found. Along the Napa River, an estimated 16 pairs surveyed in the 1990s dropped to 4-7 pairs in 2001. Heavy rains in the winter of 1997-1998 may have caused some declines in the North Bay, as residual high water, particularly along the North San Pablo Bayshore, impacted nesting success (Albertson and Evens, 1998), and there is concern that predation by non-native mammalian predators (primarily red fox) may be further impacting North Bay populations. Predators in more urbanized South and Central Bay marshes may be finding less refuge than in the wilder wetlands to the north (Evens, Pers. Comm., 2002).



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SALT MARSH HARVEST MOUSE

It is not known whether the population of the Bay's endangered salt marsh harvest mouse (*Reithrodontomys raviventris*) has changed significantly over the past three years. Population studies are conducted only when development projects or changes in land use threaten the mice, and few such studies have been required during this time. When such studies are conducted, their piecemeal nature makes it difficult for scientists to get a take on overall population trends. Several marsh restoration projects that could impact mice populations are planned in the North Bay, but until those are underway, there are

no major projects planned or in progress that would affect the mice (Shellhammer, Pers. Comm., 2002)



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SALT MARSH SONG SPARROWS

Reproductive success of salt marsh song sparrows increased slightly in 1999 compared to 1998, which was the poorest year recorded to date; in 2000 and 2001 reproductive success continued to rise. Despite the relative increase in reproductive success, the overall success observed at most marshes (only about 19% of nesting attempts result in any fledged young) is below the level necessary to ensure a stable population. The greatest cause of mortality is predation. Current efforts are being directed toward identifying predators (potentially mammals, snakes, and crows and jays). In addition, about 10% of nests fail each year due to flooding during the highest tides. Estimated numbers of breeding Alameda song sparrows (*Melospiza melodia pusillula*), restricted to Central and South San Francisco Bay, range from 12,000-18,000 individuals; of Suisun song sparrows (*Melospiza melodia maxillaris*), found in Suisun Bay, from 36,000-53,000; and of San Pablo or Samuel's song sparrows (*Melospiza melodia samuelis*), found in San Pablo Bay, from 65,000-85,000. The presence of salt marsh song sparrows is not strongly linked to any one species of plant, but the population density of song sparrows is nonetheless correlated with landscape features. Density is greatest where the land adjacent to the marsh contains less urbanized areas, while density is lowest in small, isolated marshes. All three song sparrow subspecies are state Species of Special Concern. (Nur, et al., SOE poster, 2001)



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SALT MARSH YELLOWTHROAT

Surveys of tidal marshes in 2000 detected few salt marsh yellowthroats (*Geothlypis trichas sinuosa*), a state Species of Special Concern, in San Francisco Bay itself; likely only a few hundred are present. In San Pablo Bay, the estimated density was also low, with an estimated total population of 3,000 or fewer breeding individuals. In many marshes in San Pablo Bay, yellowthroats were completely absent. In Suisun Bay, however, densities observed were quite high (10-fold higher than in San Pablo Bay); Point Reyes Bird Observatory scientists estimate 10,000 to 15,000 breeding individuals in Suisun Bay. An additional unknown number are present in brackish and freshwater marshes. Salt marsh yellowthroats appear to respond to specific vegetation composition and are more abundant where there is a greater amount of *Scirpus* (the genus that includes tule and bulrush), rush and peppergrass (a non-native herb). In addition, they are more abundant where the vegetation structure is more complex, for example, where there is more diversity in the height of herbs. See *Posterbook*. (Nur, et al., SOE poster, 2001)



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WESTERN SNOWY PLOVER

In the Bay Area, the Western snowy plover (*Charadrius alexandrinus nivosus*) is primarily associated with commercial salt evaporation ponds and levees, which means scientists have not to date been able to actively manage resources for the species. However, the Eden Landing Ecological Reserve, a former salt evaporation pond now owned by Cal Fish & Game, will be managed for plovers by 2003, primarily through habitat enhancement, along with nest protection and predator control. The purchase and management of additional ponds could also aid the plover. A U.S. Fish & Wildlife draft recovery plan calls for increasing the South Bay breeding population from its current level of 150-200 individuals to 500 to help spur recovery of the plover, which is federally listed as

threatened. While the South Bay did not historically support 500 birds, coastal areas are heavily impacted by human activities, making it difficult to protect plover populations there. Managing salt evaporation ponds, which are typically less disturbed by humans, for snowy plovers is an opportunity for S.F. Bay to play a significant role in the recovery of this species, especially since the birds migrate not only up and down the coast, but from the coast to the Bay and vice versa. (Albertson, Pers. Comm., 2002)

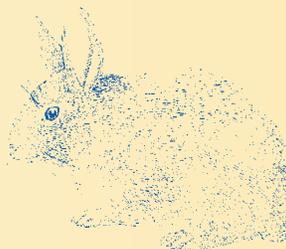


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RIPARIAN BRUSH RABBIT

Populations of the federally listed riparian brush rabbit (*Sylvilagus bachmani riparius*) are largely restricted to riparian habitat along the Stanislaus River in Caswell Memorial State Park and to some private land along the San Joaquin River near Stockton. While the 2002 trap census for the Caswell population was higher than that for 2001, it was still such a low number that population estimate tools will not work. It is likely there are fewer than two dozen rabbits left in the park. Rabbits at the San Joaquin River site fared better last year. Broad estimates based on visual observation and limited trapping suggest the rabbits were at a high point — 200 or fewer — in their population curve (the rabbit population fluctuates naturally, like those of many other small mammals). Plans for residential development at the San Joaquin site could help the rabbit; a comprehensive management plan from developers calls for more and better rabbit habitat. Meanwhile, biologists have begun a captive-breeding program. Six rabbits (three males and three females) were released into the first of three breeding enclosures during winter 2002; by the end of March, seven young rabbits had been caught in the pen, and scientists believe there are probably more. The captive-bred young will be released in



fall 2002 into the first recipient site, located at the San Joaquin River National Wildlife Refuge. Two more breeding enclosures were being built in 2002, and scientists expect the full state-federal, multi-agency program to be underway by summer 2003. (Chaltry, Pers. Comm., 2002)



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HARBOR SEALS

Bay harbor seal (*Phoca vitulina*) numbers have remained fairly stable over the past decade. Depending on the season — pupping, molting, fall or winter — they can be found in large numbers at one of three main haul-out sites. During pupping season (mid-March-May), harbor seals are most plentiful at Mowry Slough, where approximately 270 seals (not including pups) were counted during 2000 and 2001, representing an increase from 1999's count of 201. Between 80 and 100 pups were counted here each year during the 1999-2001 pupping seasons. In the winter months, when Pacific herring are spawning in the Bay, seals are most plentiful at Yerba Buena Island. In the winters of 1999-2001, researchers counted between 200-240 seals each year at this site. Castro Rocks, a chain of rock clusters just south of the Richmond Bridge, is used year round, although more seals use the rocks during pupping and molting season (June-mid-August). Since 1996's low of 96 seals, numbers have increased slightly each year during the molting season — 141 in 1999, 155 in 2000 and 172 in 2001. Seismic retrofit work began on the Richmond Bridge in early 2001, and researchers from San Francisco State University are monitoring what effect, if any, the construction is having on seal numbers and behavior. See also p.16. (Green, Pers. Comm., 2002).



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WATER & SEDIMENTS

BAY CONTAMINANTS

In the Bay, most contaminant guidelines are being met, but the level of contamination today is probably high enough to impair the health of the ecosystem (indications of impairment include the toxicity of water and sediment samples to lab organisms and the frequent presence of contaminant concentrations exceeding water, sediment and fish guidelines). A relatively small number of problem contaminants makes it rare to find clean water or sediment in the Bay. Of all the contaminants measured by the Estuary's Regional Monitoring Program (RMP), results suggest that those of greatest concern are mercury and polychlorinated biphenyls (PCBs). Also of concern are diazinon, chlorpyrifos, copper, nickel, zinc, DDT, chlordanes, dieldrin, dioxins and polycyclic aromatic hydrocarbons (PAHs). Work outside the RMP suggests that selenium is also a concern. Looking back over seven years of RMP data, scientists do not see any clear trend toward either improvement or deterioration. And a rough comparison with Washington's Puget Sound and Maryland's Chesapeake Bay indicated no significant difference from the Bay, and a similar scale of mercury and PCB contamination. In the Bay itself, sites in the lower South Bay, the Petaluma and Napa river mouths, San Pablo Bay and Grizzly Bay are more contaminated than other sites (SFEI, 2002).



MORE INFO?
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DELTA & UPSTREAM CONTAMINANTS

The freshwater side of the Estuary does not have a systematic monitoring program to evaluate contaminant levels in water, sediment, or biota. However, contaminants documented to exceed either water quality objectives or concentrations toxic to aquatic organisms in the Delta have been given the highest priority by the Central Valley Regional Water Quality Control Board for development of regional load reduction and control programs (TMDLs) under the Clean Water Act. In 2003-2004, the Board is expected to consider amendments to its *Basin Plan* to address water quality problems associated with elevated levels of diazinon and chlorpyrifos, mercury and low dissolved oxygen in the Stockton Deepwater Ship Channel. The *Basin Plan* amendments for each will include an implementation plan with a schedule and monitoring for compliance. Each plan will likely contain a reopener clause, probably after 5-10 years, to ensure that monitoring results and new scientific findings are incorporated into revised implementation plans. Money is available through Proposition 13 to fund some implementation work (Foe, Pers. Comm, 2002). Upstream of the legal Delta in the San Joaquin River watershed, selenium remains an issue but load reduction targets are being met. In the Central Valley, as of December 2002, the state was considering renewal of a long-standing waiver

exempting discharges from irrigated lands from waste discharge requirements, but may add some new conditions to the waiver aimed at curbing agricultural pollution.



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HARMFUL CHEMICALS IN HARBOR SEALS

Bay harbor seal tissues contain PBDEs (polybrominated diphenyl ethers) at levels as high as 8,325 nanograms per gram of fat (equivalent to parts per billion), with a mean of 1,730 nanograms per gram of fat, according to a recent study (She et al., 2002). The PBDE levels found in seals here are the highest reported to date anywhere in the world. The study also found that concentrations of PBDEs in seal tissues doubled every 1.3 years (on average) in the decade between 1989 and 1998, which represents a nearly 15-fold increase over the sampling period, the greatest rate of increase reported worldwide to date. PBDEs — unregulated chemicals used in relatively high concentrations as flame retardants in electronic equipment, computers, TVs, textiles and many home furnishings, particularly those containing polyurethane foam — have become ubiquitous over the last decade. California, in particular, mandates the use of flame retardants in all furnishings. While there are some point sources (foam manufacturers and electronic equipment dismantlers, for example) of PBDEs, scientists do not yet understand all their pathways into the Bay. PBDEs are suspected of altering the regulation of both thyroid and steroid hormones, but their effect on harbor seals is unknown at this point, and long-term effects may not become apparent until a population is exposed to additional stress. The effect of adding a new contaminant to the existing mix of harmful chemicals and metals in the Bay is also unknown.



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See also pp. 30, 32, 43, 68

% BAY SAMPLES MEETING WATER QUALITY OBJECTIVES*

	1994	1995	1996	1997	1998	1999	2000
Chromium	100%	100%	100%	100%	100%	n/a	n/a
Copper	83	85	88	90	97	95	n/a
Mercury	56	68	80	50	61	62	n/a
Nickel	99	97	97	99	100	99	n/a
Lead	100	100	100	100	100	100	n/a
Selenium	100	100	100	97	99	99	98
Zinc	100	100	100	100	100	100	n/a
PAHs	61	68	50	60	43	44	50
Diazinon	93	100	93	100	100	100	100
Dieldrin	80	95	93	54	87	85	88
Chlordanes	100	93	84	89	75	87	89
DDT	67	66	44	52	20	57	72
PCBs	2	9	6	19	20	19	6

*Bay data from Regional Monitoring Program, SFEI 2000. Data from 1998 are preliminary.

RESTORATION

Watershed

“The Estuary continues to change as we try to understand and manage it: exotic species continue to arrive; climate change is altering the timing and amounts of river flow, with consequences for the Estuary’s salinity; and sea level rise and earthquakes threaten the Bay’s shoreline.”

FRED H. NICHOLS,
U.S. Geological Survey, (Retired)

TODAY'S CHALLENGES

FREDERIC H. NICHOLS
U. S. Geological Survey, (Retired)

Over the past three decades we have greatly expanded our knowledge of the San Francisco Bay-Delta ecosystem and our understanding of human impacts. We better understand key food web interactions and the sources of organic matter that support the food web. We more clearly recognize the stressors that affect threatened and endangered species, including the impacts of lost habitat, flow alterations, contaminants and exotic species.

Managers, policy makers and the public better appreciate the trade-offs that are involved in managing the watershed and Estuary for both human use and for protection of species and habitats. We are making particularly great progress on two important fronts: we are achieving an unprecedented level of cooperation and collaboration among scientists from agencies and academic institutions, and the increased emphasis on and funding for restoration (largely through CALFED) is energizing scientists and local groups to undertake a broad array of new restoration projects and research studies. In addition, the Habitat Goals Project has given us the first comprehensive blueprint for restoration around the Bay.

Yet we still face important challenges. First, we lack understanding of critical problem areas, such as the most sensitive times in the life cycles of threatened and endangered species, the regional effects of local projects, such as the proposed expansion of San Francisco International Airport, and the effect of nonlethal contamination of individual fish or invertebrates on the well-being of their populations.

Second, the Estuary continues to change as we try to understand and manage it: exotic species continue to arrive; climate change is altering the timing and amounts of river flow, with consequences for the Estuary's salinity; and sea level rise threatens the Bay's shoreline.

Third, institutions that are conducting research and monitoring with different objectives still have a tendency to carry out their work independently, with the result that monitoring and research data in many cases are not integrated and synthesized; individual investigators are often reticent to place their studies into a whole-system context.

Fourth, we will continue to be challenged about how to allocate our restoration resources most effectively to achieve the highest level of overall success. We must ensure, for example, that our actions have a basis in solid scientific understanding, and that we are prepared to make political and resource management decisions to change long-held perceptions, practices and policies.

“There is a natural tendency to worry about the small parts of the ecosystem without considering the larger parts.... We must avoid the temptation to undertake restoration action simply because it seems an appropriate response to a perceived need.”

Finally, we need to assure the public that their investment is being well spent, by demonstrating that all of our research and restoration activities are fully transparent and openly and objectively reviewed, and that the results of these activities are readily accessible in understandable, useful formats (Nichols, SOE, 2001).



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FLOODS & DROUGHTS: A SIERRA NEVADA PERSPECTIVE

MIKE DETTINGER
U.S. Geological Survey

The San Francisco Bay Estuary is at the receiving end of a cascade of climatic influences. Winter storms, droughts, El Niños and La Niñas, Pacific decadal regimes — all affect the Bay through changes in runoff from the Sierra Nevada. Therefore, climate variability is an important science topic with broad policy implications for long-term planning and adaptive management for the Bay.

Floods and droughts play particularly important roles in the Estuary and its watershed, not only because they inflict social and environmental damage, but because they can override water quality management strategies. Large-scale Pacific atmospheric systems always play a role, but there is no unique pattern that causes either flood or drought. For example, despite the varied large-scale climate conditions that prevailed during the 1987-1992 drought, which included both El Niños and La Niñas, that period yielded persistently low streamflow rates from the Sierra Nevada, and as a result, Bay salinities were persistently elevated.

Paleoclimatic records (from tree rings, lakes and coastal sediments) indicate that floods and droughts in California during the historical period (the last 100 years or so) are small and brief compared to climatic extremes experienced at other times during the last 1,000 years, during

which time there have been much drier centuries, with 100-year droughts and extreme flood periods.

Climate change due to increasing greenhouse-gas concentration may soon augment such historical and prehistorical climate variations. With global warming would come less snowfall (less than 25% of current snowpack levels in certain areas by mid-century), more rainfall, earlier snowmelt and less spring and summer runoff. The dry summer regimes that typically result in the highest estuarine salinities would become more intense if Sierra Nevada streamflow declines earlier each year; winter floods could also become more severe. Indeed, Sierra Nevada streamflow has already begun to come earlier in the year, by about two weeks, leaving less runoff during the warm seasons (see graph).

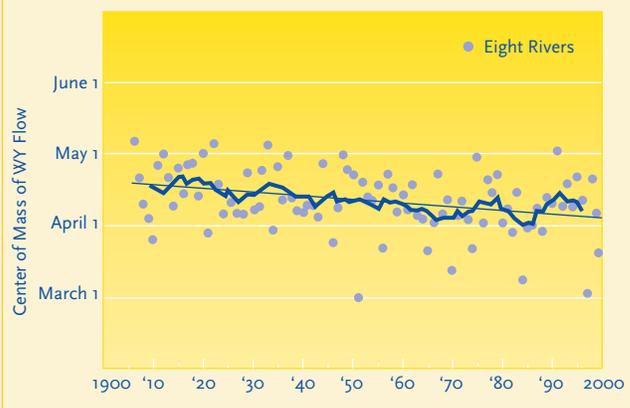
Planning for the Estuary would benefit from improved understanding of the climatic and hydrodynamic variability of the Sierra Nevada (Dettinger, SOE 2001).



MORE INFO?

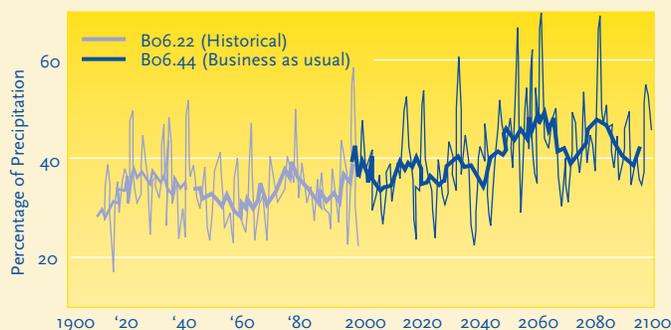
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OBSERVED EARLIER STREAMFLOWS



Halfway dates for streamflow. During the past 50 years, streamflow from the Sierra Nevada has come progressively earlier in the year, as a result of warmer winter and spring temperatures over California which have fueled earlier snowmelts.

SIMULATED RAINFALL AS A FRACTION OF PRECIPITATION, MERCED RIVER BASIN



SCIENCE Questions

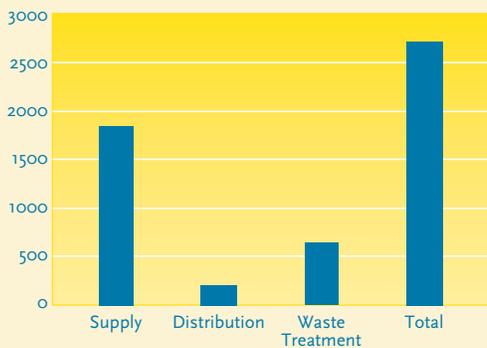
- To what extent did major, long-term droughts of the past 1,000 years in various parts of the Sierra Nevada affect the Bay and Delta?
- How likely are such droughts (and their wetter than normal complements) to recur within various planning horizons?
- What is the likely, plausible range of climate variations over the Bay, Delta, and their watersheds during the 21st century, given both past climate variations and projections of greenhouse warming?
- What are the most likely responses to such climate changes in terms of Delta inflows, Bay and Delta sediment budgets, and Bay and Delta ecosystems?

WATER & ENERGY CONNECTIONS

DR. PETER H. GLEICK
Pacific Institute for Studies
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In the wake of the “California Energy Crisis” of 2000-2001, many are asking if water is to be the next crisis. Indeed, there are important connections between water and energy, and worrisome parallels between the mismanagement of the state’s energy situation and mismanagement of our water problems. We use water to produce energy, and energy to produce water. Twenty percent of California’s electricity comes from the hydroelectric dams that line the Sierra Nevada from north to south. More water goes to cool the fossil fuel and nuclear power plants that meet the lion’s share of our current demands.

WATER SYSTEM ELECTRICITY USE SOUTHERN CALIFORNIA
KW HR / ACRE-FOOT



We also use energy to produce water — to treat, pump and use water resources. Energy is required to run groundwater pumps for farmers, to move water over the Tehachapi Mountains to the Los Angeles basin, and to operate the wastewater treatment plants that clean our wastes and protect our rivers, lakes, and beaches. Every acre-foot of water we use requires 2,000 to 3,000 kilowatt hours of electricity to collect, clean and deliver. The more water we save, the more energy we save.

There are similar myths surrounding both water and energy:

MYTH 1: *There is an energy shortage.*

There is no energy shortage, but rather a shortage of companies willing to sell it because of the structure of deregulation.

MYTH 2: *There is a shortage of water.*

Again, there is no shortage. There is a shortage of intelligent management of the discrepancy between where demand is and where supply is. There is an inadequate effort to redirect water from one user to another.

MYTH 3: *There were no rolling blackouts in the summer of 2001 because of quick efforts to build new power plants.*

There were no rolling blackouts that summer because of the success of rapid conservation, which led to a demand reduction of 3,100 megawatts. And because regulators were monitoring generators more closely to prevent market manipulation.

MYTH 4: *Water shortages are inevitable because water deregulation is on the way and new supplies have not been built.*

The problem is a demand one, not a supply one. And there is no deregulation on the horizon.

Water and energy are both vital resources. The supply and distribution of both are also natural monopolies, subject to the abuses of monopoly power. Private corporations are playing increasingly powerful roles in the provision of

both resources. Meanwhile, we have ignored or underestimated the vast potential for efficiency improvements that can delay or prevent a crisis.

SCIENCE Questions

- What demand management tools can help us avoid future energy and water crises?

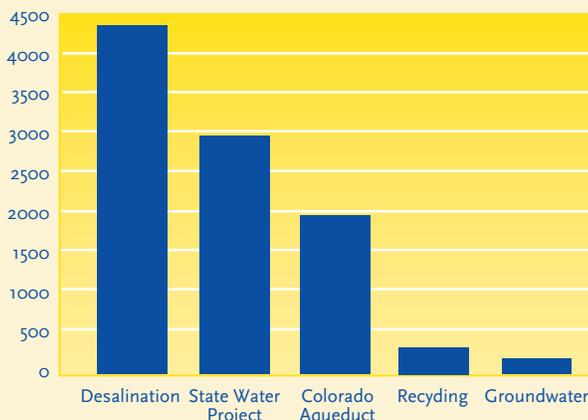
The parallels between water and energy offer some important lessons to improve water management in the future:

- There should be formal and effective programs to manage demand.
- We should not build supply systems that are more expensive than demand management.
- Private companies should not have monopoly power over public goods, without strong government oversight.
- We must protect water as a public good (Gleick, SOE, 2001).



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ENERGY FOR WATER
KW HR / ACRE-FOOT



IS THERE ENOUGH SEDIMENT?

PHILIP B. WILLIAMS

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Those concerned with the long-term management of the Estuary are changing their attitudes about the sediment that moves around the Bay. Only a few years ago, many of us assumed that the Bay had too much sediment. We viewed sediment as an expensive nuisance that choked shipping channels and muddied swimming beaches, and the region struggled with the problem of where to put all the mud that we dredged.

Today, scientists, engineers and planners are starting to recognize that sediment is a valuable resource that recreates and sustains habitats we value, such as salt marshes and mudflats. We are also recognizing that we may have been somewhat overconfident about relying on natural sedimentation to restore wetland processes in subsided areas. In other words, instead of too much sediment, there may not be enough.

To better manage estuarine sediments in the future, we need to understand how sedimentary processes created the historic habitats of the Bay, and how we have and will be changing those processes.

San Francisco Bay, like all estuaries, is a dynamic evolving system, whose shape is an expression of a changing equilibrium between competing physical processes: sedimentation, sea level rise, river flows, tidal flows and wind wave action.

The Bay is a geomorphically young estuary formed only about 10,000 years ago when rapidly rising sea level from melting ice caps inundated the mouth of the Sacramento River through the Golden Gate. About 7,000 years ago the rate of rise of sea level slowed. Marsh plants kept pace with the 1-2 millimeters per year sea level rise by capturing sediment and building peat, creating extensive marsh plains that gradually rose and engulfed the surrounding topography. As the Estuary grew larger, the tidal channels feeding the marshes

grew bigger; and wind wave fetches grew longer. Wave action eroded the bayfront edge of the marsh creating extensive intertidal mudflats.

The Estuary's marshes, mudflats and tidal channel habitats have evolved and persisted for thousands of years, sustained by the inflow of sediment. Most of the sediment entering the Estuary eroded from Central Valley watersheds and was conveyed downstream during large winter floods on the Sacramento and San Joaquin rivers. Floods and rivers deposited coarser sediments upstream on the vast floodplains, leaving the clays and silts to settle out in the shallows of Suisun and San Pablo bays and occasionally, during large flood pulses, in the South Bay. Typically later in the year, wind waves would resuspend these muds, and tidal currents would redistribute them to all parts of the Estuary.

Sediments are thus in motion through the Bay in all seasons and the mudflats and shallows act as huge sediment reservoirs. The amount of this sediment recirculation is very large — probably more than 100 times as much sediment moves around within the Estuary, as comes into it via rivers and floods, within any given year. This is why San Francisco Bay's waters are so muddy.

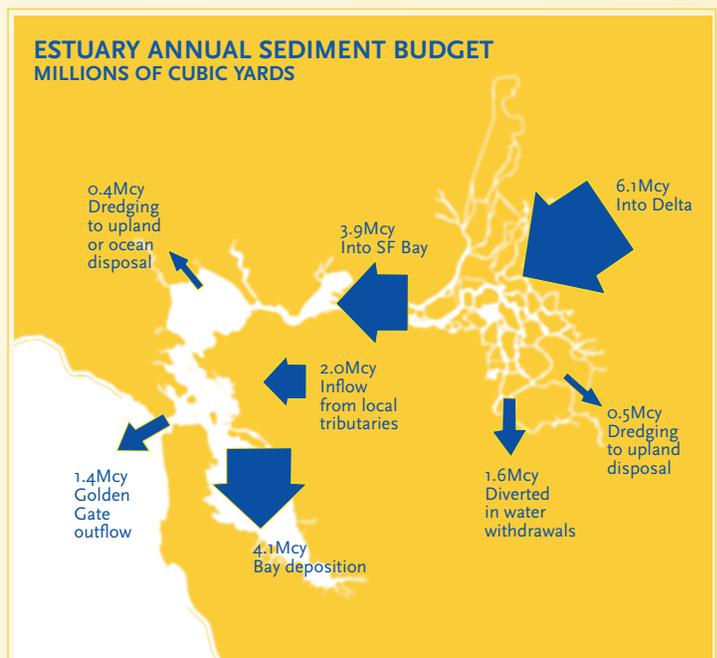
The form and extent of estuarine habitats is ultimately shaped by the sediment budget of the Estuary, the balance between sediment delivered by the rivers, sediment stored on marsh plains or in deep water, and sediment discharged to the ocean.

Sediment delivery has changed dramatically in the last two centuries (see graph p.23),

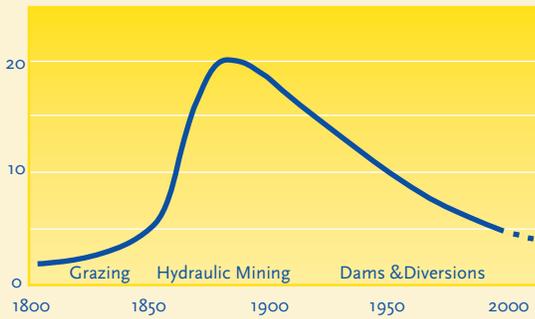
as European colonization resulted in drastic changes in the processes that sustained the landscape. A combination of overgrazing, deforestation, floodplain reclamation, and most importantly, hydraulic mining caused huge increases in the amounts of sediment delivered to the Estuary. This "Sierra mud wave" caused mudflats in San Pablo Bay to rise 3-4 feet in elevation, allowing fringing marshes to advance.

In the 20th century, sediment delivery declined with the closure of gold mines and the construction of dams that captured sediment and reduced flood flows. Researchers (Jaffe et al., see also p.42) recently documented the lowering of intertidal mudflats of San Pablo Bay, and resulting losses of about 90 acres per year of mudflats between 1951 and 1983. If this trend has continued in the last two decades, probably no more than 5,000 acres of mudflats remain — about the same acreage present in the Bay in 1850. If it continues into the future, our mudflats will be practically gone in the next 50 years.

As we continue to alter the physical processes that sustain the morphology of the Estuary, the rate of change in estuarine habitats over the next century could be as dramatic as those of the past. Three trends are likely:



CENTRAL VALLEY SEDIMENT DELIVERY TO ESTUARY MILLIONS OF CUBIC YARDS



will occur, particularly in the Delta where some areas have subsided more than 20 feet below sea level. In the last 20 years, about 3,500 acres of diked subsided land have been returned to tidal action through levee failure in the Delta.

ment (either via natural deliveries or dredged material placement) to eventually recreate a mature vegetated marshplain on this acreage.

With the creation of new sediment sinks both in the Delta and the Bay, and with the reduction of sediment inflows, we will create a sediment budget deficit, resulting in the depletion of the sediment reservoir in the shallows of the Estuary (see caption p.24). As a result, San Francisco Bay waters will likely become less muddy. Stated more scientifically, average suspended sediment concentrations (ssc) in the water column will decrease, and this decrease will directly affect how quickly restoration projects that rely on natural sedimentation, will evolve. Most restoration projects completed so far have been in favorable locations where ssc is high and wind wave action low. This allows rapid natural sedimentation, as can be seen at Carl's Marsh near Petaluma after only six years since breach. Larger projects with lower local suspended sediment concentrations, however, may take much longer to become vegetated or may stabilize as intertidal mudflats. Alternatively, to compensate for slower natural sedimentation rates, projects like the Muzzi Marsh have used dredged materials to fill subsided sites and allow for rapid revegetation (for project locations, see map p.60).

1. There will be further declines in sediment delivery to the Delta. Average suspended sediment concentrations are declining as the full effect of dams and diversions come to bear. Average annual Delta sediment inflow is now probably only about 4.5 million cubic yards (mcy), about half its 1960s level, and barely double that of the undisturbed landscape of 200 years ago.

2. Sea level rise will accelerate due to the greenhouse effect. According to the latest predictions, rates will double over the next 50 years and double again in the succeeding 50 years. Thus while the Bay's water volume increases by about 2.5 mcy every year today, these annual increases will swell to 10 mcy/yr in the next century. As the Bay increases in volume, deeper waters will capture more of the recirculating sediment.

3. Increasing amounts of estuarine sediment will be captured in new sediment "sinks" within the Estuary. The direct effect of sea level rise in capturing sediment is relatively small in comparison to its potential indirect effect of causing failure of levees surrounding diked subsided land. Over the last 150 years, we have diked, drained and pumped 90% of the Estuary's former tidal marshes. As a result, these lands have subsided below tide level, creating a huge artificial hole around the Estuary. If all the Bay's levees failed, the Estuary would more than double in size and triple in volume (see graph). At present sediment delivery rates, the resulting sediment sink would take more than 1,500 years to fill.

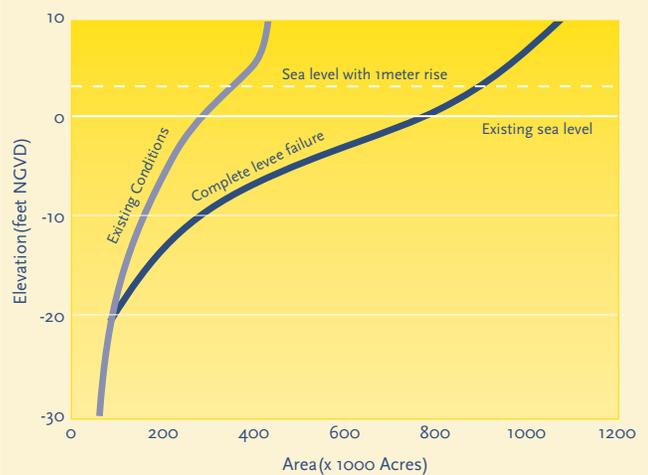
While no-one is contemplating any management scenario that considers complete levee failure or removal, accidental levee failures

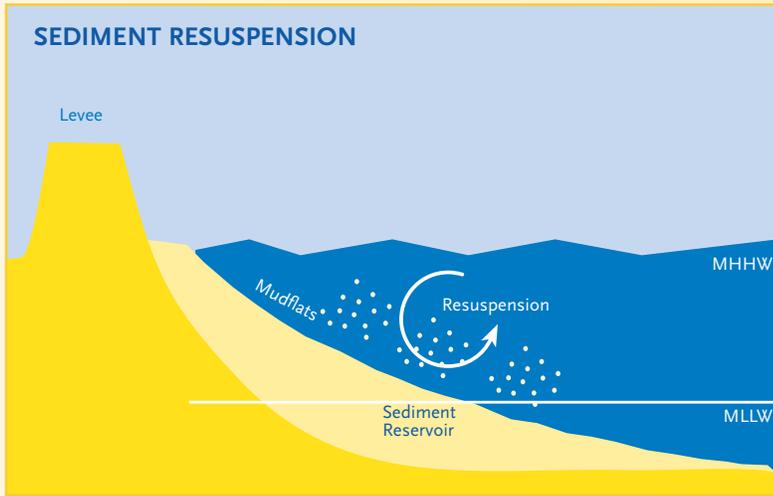
When we abandon a breached subsided site, such as Mildred Island, we create a large sediment trap. In 1983, when the 1,000 acre Mildred's levee failed, the island was about 15 feet below sea level, creating a sediment sink of about 24 mcy. For the island to silt in, and return to the freshwater tidal marsh it once was, would require the equivalent of about five years of average sediment delivery for the entire Estuary. Since much less than this finds its way into Mildred, researchers estimate it could be more like a century or more before it is shallow enough for a marsh to form.

The Mildred experience illustrates a major restoration dilemma. Freshwater tidal marsh habitat is now nearly extinct in the Delta. Current proposals to restore up to 20,000 acres of islands as tidal marsh would require very roughly 320 mcy of sedimentation (the equivalent of 70 years of sediment inflow), assuming an average of 10 feet of subsidence. The dilemma is, if such a large portion of the Estuary's sediment discharge is captured in the Delta to recreate valuable wetland habitat, will there be enough sediment left to restore and sustain extensive tidal wetlands around the Bay?

The largest regional wetland restoration initiative, coordinated by the San Francisco Bay Joint Venture, proposes to restore about 37,000 acres of tidal marsh around the Bay over the next 20 years. Assuming typical subsidence of about four feet, we would need about 250 mcy of sedi-

FUTURE AREA OF SAN FRANCISCO BAY





How big is the Estuary's sediment reservoir? To get this number, it's important to understand that mudflats and shallows are formed by the balance between deposition and wind wave erosion. With reduction of sediment deposition the mudflats will erode to compensate. The amount of this erosion is limited by the size of the largest waves scouring the shallows at low tide. Assuming that the Estuary's active sediment reservoir is roughly the erodible wedge between mean sea level and 6 ft. below sea level, it is not infinite. The reservoir greatly depends on whether we let the natural shoreline retreat landward, releasing more sediment to the Estuary through erosion of the marsh edge. If we assume we do not do this, and instead reinforce our levees, there are now (as of 1986 mapping) approximately 80,000 acres of shallows between msl and -6ft ngvd. If this entire area were to erode down to -6ft, it could provide about 400 mcv of sediment to the Estuary.

In conclusion, Estuary-wide changes in sediment dynamics have many implications for habitat restoration planning:

First, we need to understand the Estuary as a dynamic evolving physical system whose habitats will be changing with or without human intervention. This also means we need to focus research on sediment dynamics.

Second, we need to be planning for the future physical evolution of the Estuary on an Estuary wide scale. This means recognizing that actions that impact sediment dynamics like dredging, hardening levees, tidal restoration, or airport fills can have significant long-term impacts on estuarine habitats.

Third, we need to value our sediment. Specifically this means maximizing the reuse of dredged materials within the tidal zone of the Estuary system, particularly for wetland restoration.

Fourth, we need to be realistic in addressing the long-term physical constraints on tidal wetland restoration — specifically understanding

how quickly or whether sites will evolve to vegetated marsh for large deeply subsided sites with limited sediment supply.

Fifth, we need to revisit our restoration goals and priorities to match the habitats we want to restore with those that physical processes

SCIENCE Questions

- How does sediment move around within the Estuary in response to tides, wind waves and flood events over long time periods?
- Can we better predict how reductions in sediment inflow to the Estuary, large-scale restoration projects, and sea level rise, will change the shape and habitats of the Estuary, 10, 50 and 100 years into the future?

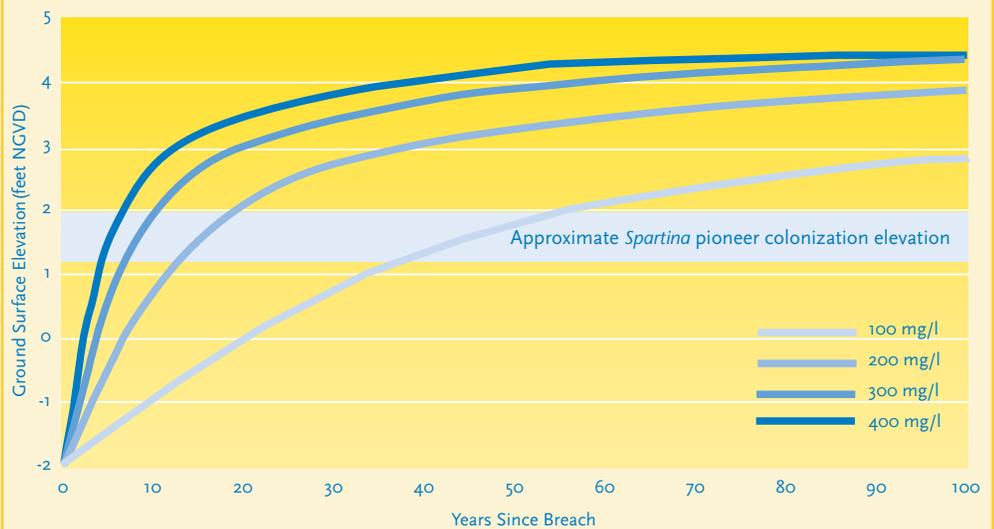
will actually sustain in the Estuary of the future. This may mean we refocus on restoring our diminishing intertidal mudflats, or give higher priority to allowing marshes to expand inland.

Last but not least we need to recognize that managing mud may be as important to S.F. Bay as the long-standing effort to manage its supply of freshwater (Williams, SOE, 2001).



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CORDGRASS COLONIZATION LEVELS



How mudflats build up in a typical subsided site at different average suspended sediment concentrations. If SSC is reduced from 200 to 100mg/L, it can make the difference for a mudflat in a breached subsided site reaching the colonization elevation for spartina in 40 yrs instead of 10 yrs.

RESTORATION

Rivers & Delta

“The variability of streamflow and sediment flux is one of the stunning complexities of the natural environment. Water resources development and land use changes alter and suppress this variability. Restoring the Delta and Central Valley ecosystem is about restoring variability and complexity.”

DAVID FREYBERG
Stanford University

THE DELTA-CENTRAL VALLEY SETTING: HYDROLOGIC COMPLEXITY AND RESTORATION

DAVID L. FREYBERG
Stanford University

Ecosystem restoration is fundamentally a problem of design. The design process translates conceptual understanding of ecosystem structure and function into concrete changes at a particular site. This process is quite different from the discovery process of science, in which observations of

specific systems or behaviors are generalized into conceptual understanding. The tools of design are similarly different from the tools of analysis. Of particular interest is the role of complexity in the design process.

The variability of streamflow and sediment flux is one of the stunning complexities of the natural environment, and the role of this complexity in the ecosystem restoration design process is fascinating. Water resources development and land use changes alter hydrologic variability and, in general, suppress variability and complexity. This is always true for in-channel or flood plain structures and diversions, and often true for land use changes. Reducing complexity is their purpose.

The Delta and its tributary rivers are a complex hydrologic system characterized by tremendous variability. Streamflow varies over a broad spectrum of time scales from seconds to tens of thousands of years. Hydrologic science provides partial predictability over some time scales, but streamflow, and with it heat, sediment, and chemical transport, remain largely unpredictable and apparently random over many other time scales. Central Valley and Delta ecosystems have evolved in the presence of this hydrologic variability, and riparian and wetland ecosystem structure and function are clearly coupled to this variability. Our use of water as a resource necessarily entails altering the natural variability of streamflow, both to synchronize availability with use and to buffer unpredictability. Different uses have different effects on different time scales, but essentially all uses involve hydrologic time-shifting (see graphs).

Restoring the ecosystem of the Delta and Central Valley is at some point, therefore, about restoring variability and complexity. This provides a peculiar challenge to the design process. Most of our familiar hydrologic design tools and design criteria are focused on problems of coping with or reducing variability. We try to find ways to simplify complexity to make design decisions. For example, we use statistical tools such as design floods and design hydro-

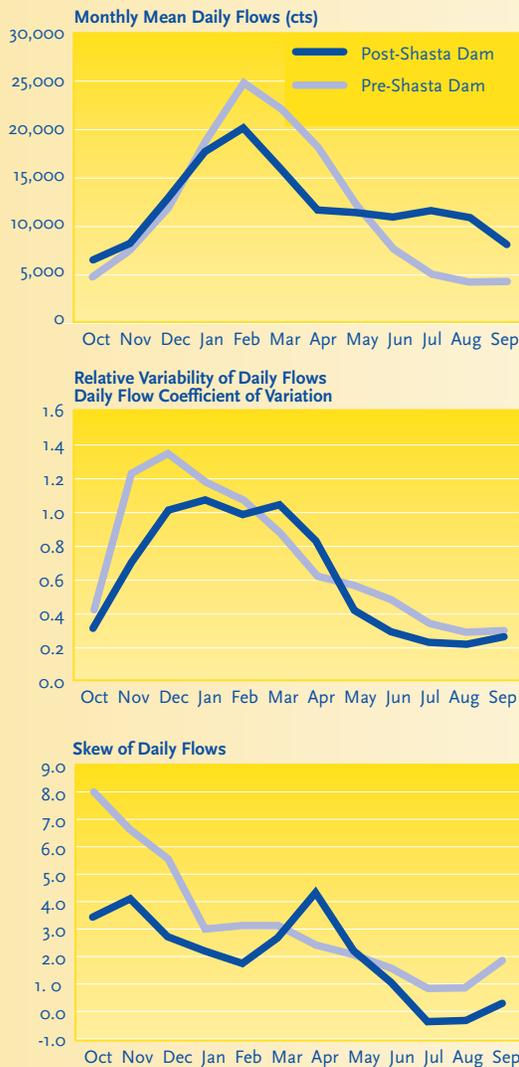
graphs to make decisions about what size to make reservoirs, channels, screens or other water control facilities. And that is exactly what's appropriate if the facility or system being designed is supposed to reduce complexity. However, these same tools may not be appropriate if our goal is designing for variability and complexity. Much riverine restoration design is struggling to adapt design concepts and tools based on reducing complexity to problems of restoring complexity.

No matter how well we understand the underlying scientific principles, or how carefully we analyze a problem, all design proceeds through failure. It does not matter whether we are talking about software, bridges, dams, water supply systems, or ecosystem restoration. Because total failure can be catastrophic when we are designing for species and ecosystem health, an adaptive process, grounded in observation and analysis of performance, is essential for successful restoration design (Freyberg, SOE, 2001).



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SHASTA DAM IMPACTS ON FLOW



Changes in flow variability due to the construction of Shasta Dam, as measured at the USGS gaging station on the Sacramento River above Bend Bridge near Red Bluff, CA (Station No. 11377100).

SCIENCE Questions

- To what extent does ecosystem restoration depend on restoring the entire streamflow variability spectrum?
- To what extent are ecosystem structure and health robust with respect to hydrologic variability?
- How should we characterize the complexity of hydrologic variability?
- Are there portions of the streamflow spectrum that are less important?
- What characteristics of streamflow should we be measuring over what temporal and spatial scales?
- How important is predictability in restoration design?

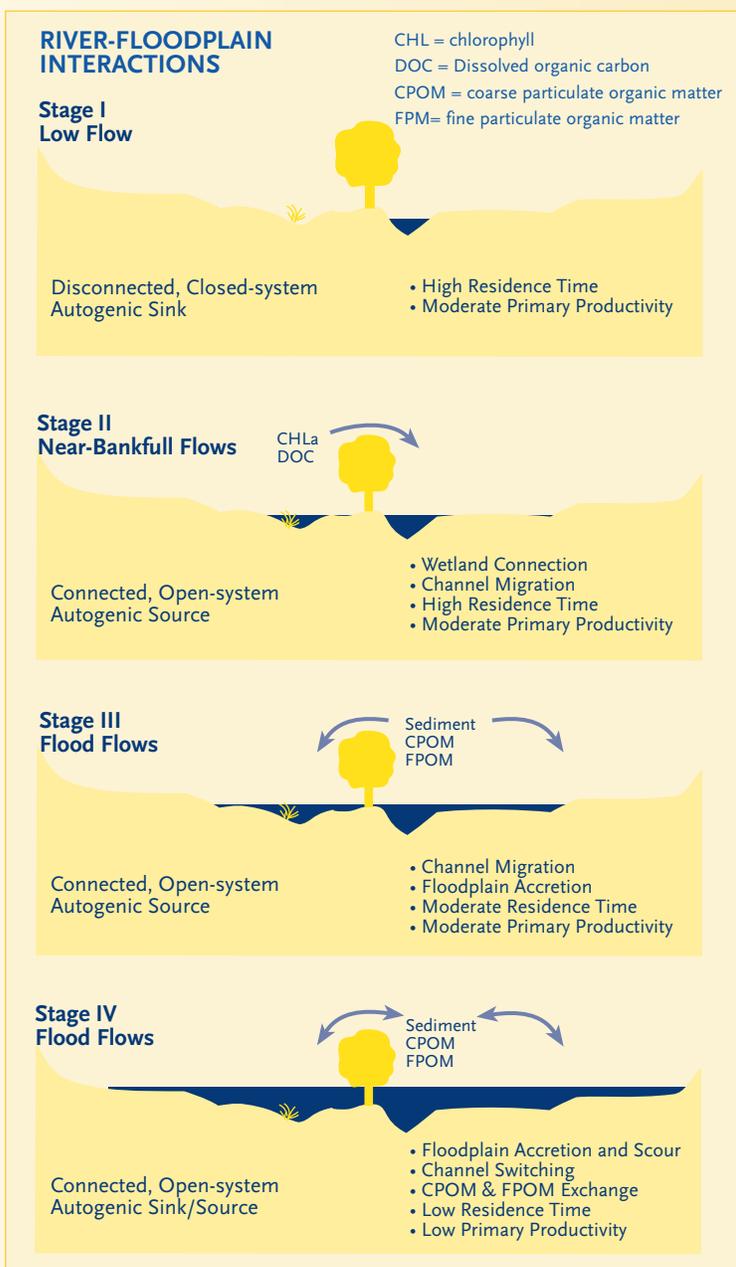
RECIPROCAL RELATIONS BETWEEN CENTRAL VALLEY RIVERS AND FLOODPLAINS

JEFFREY F. MOUNT
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The historic lowland rivers and floodplains of the Central Valley were one of the key biogeochemical engines that fed ecosystems in the Bay-Delta. Changes associated with river regulation and channelization have significantly degraded this vital ecosystem function. The learning laboratories of the Central Valley, such as the Yolo Bypass and the Cosumnes/Mokelumne River floodplains, demonstrate the direct bene-

fit that lowland river restoration provides for the Bay-Delta.

Restoration of Central Valley lowland rivers involves reestablishing the drivers that support food webs and energy flow, heterogeneity of landscapes and processes, and community structure of top-level consumers (fish, birds). The driver of ecosystem integrity in this system was the reciprocal hydrologic, sedimentologic and biogeochemical relations between the river channels and floodplains. Where reconciliation of this regionally dysfunctional relationship has occurred, there has been a significant beneficial response.



SCIENCE Questions

- What is the role of interchange between river channel and floodplain in maintaining or restoring ecosystem integrity in the Sacramento / San Joaquin system?
- How can we create “learning laboratories” within the CALFED region of interest in order to test and evaluate floodplain and channel restoration efforts?
- Are we getting our money’s worth for restoration? Can we quantify the hydrologic and ecological benefits associated with restoration projects, and the importance of scale in these systems?

In order to restore lowland rivers in the Central Valley, the winter flood pulses and the smaller, but equally important, spring snowmelt pulselets must be able to reach a significant portion of the historic floodplain. The magnitude and duration of these flood events, coupled with their hydraulic interaction with the floodplain, dictate landscape heterogeneity, as well as productivity and succession in linked aquatic and terrestrial ecosystems. The length and duration of transport pathways on floodplains and in flood basins plays a critical role in regulating interchange with the river (see opposite).

Several hurdles stand in the way of attempts to restore ecosystem functions and attributes in lowland rivers and floodplains in the Central Valley, among them institutional preferences for a hard-engineering approach, a water supply and control system designed to limit floods, inappropriate restoration project scales, and a reluctance to embrace restoration as a social science and not simply a physical/biological science (Mount, SOE, 2001).



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CENTRAL VALLEY RIVER RESTORATION AND SALMONIDS

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California Resources Agency

The success of efforts to restore Central Valley rivers and their ecosystems is often measured — for better or for worse — by chinook salmon and steelhead populations.

pying every niche of Central Valley river ecosystems, all four runs of chinook salmon (winter, spring, late-fall, and fall) and steelhead are now listed (or candidates for listing) under state and federal endangered species acts.

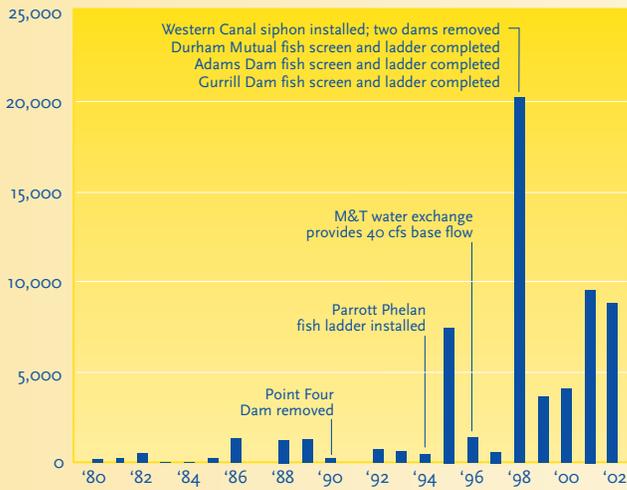
Two strategies are proposed for both looking back to measure the impact of previously funded projects and charting a course for future investments.

First, we need to restore access to areas where historically these species thrived. Winter-run and spring-run chinook salmon and steelhead all developed life cycles that depend on high elevation habitats (e.g., cold water and cool canyons above the valley floor). Dams on almost all Central Valley rivers now prohibit this movement upstream. However, in some watersheds with small dams, efforts are underway to remove migration barriers and/or improve upstream passage for

adults and downstream migration for juveniles. Investments have been made to restore access on Butte Creek, Battle Creek, and Clear Creek, and these are critical water-

The recovery of these charismatic species is called for in both state and federal law, and salmonids have a rich cultural and economic heritage in California's history. Once occu-

BUTTE CREEK SPRING-RUN CHINOOK RESTORATION EFFORTS (NO. OF FISH)



SCIENCE

Questions

- What are the impacts of improved fish passage and large-scale channel restoration on populations of endangered and threatened salmon and steelhead?
- Can rivers below large dams (e.g., Tuolumne River) be managed to restore physical processes that mimic historic hydrology (magnitude, timing, frequency, and duration) at a level that will support native salmon and steelhead populations?

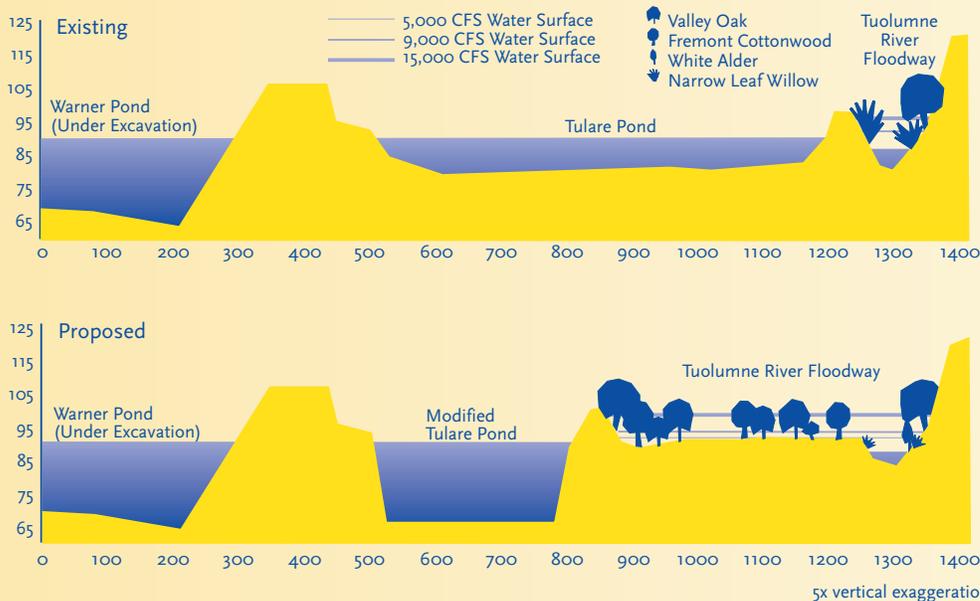
sheds for the recovery of winter-run and spring-run chinook salmon and steelhead. The dramatic increase of spring-run chinook salmon on Butte Creek, where dams have been removed and ladders and screens have been constructed, is particularly encouraging.

Second, we need to restore floodway corridors to allow for the historic connectivity between rivers and their floodplains. Physical processes are the underpinnings of a healthy river ecosystem, and floods are the heartbeat of a river. Large dam construction has eliminated winter and spring floods in reaches downstream, and channel manipulation and levee construction have isolated floodplains from their rivers.

Efforts on Clear Creek and the Tuolumne River are underway to address both the physical structure of floodway corridors and to mimic seasonal hydrology (e.g., winter rain and spring snowmelt floods) that sustains salmon and steelhead. Large-scale channel restoration on the Tuolumne River is being designed in the context of current flood management strategies, and is perhaps the best opportunity in the San Joaquin Valley to mimic seasonal hydrology to support fall-run chinook salmon.

The restoration of Central Valley rivers and their salmonids is an unprecedented challenge in river and species management, but will not require an unprecedented investment. Gold mining and water development have transformed the

TUOLUMNE RIVER FLOODWAY EXPANSION (IN FEET)



Central Valley landscape over the last 150 years. If we are to meet this new challenge, then our restoration efforts must be at the same (or greater) scale as our actions that degraded (and in some cases, continue to degrade) these river ecosystems and threaten the extinction of our Central Valley salmon and steelhead.

Since 1995, the CALFED Ecosystem Restoration Program for the Bay-Delta watershed has funded over 320 projects at a cost of more than \$330 million. The CALFED Record of Decision, signed in August 2000, calls for at least \$150 million to be available annually for the Ecosystem Restoration Program for each of the following four years. In order to account for the performance of the projects funded to date and to guide our future efforts, the Ecosystem Restoration Program needs to develop a sound strategy for measuring the impact of these investments at the landscape level scale. This evaluation must also include a feedback mechanism to ensure that project monitoring results are analyzed and used to direct future activity (Ramirez, SOE, 2001).



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SALMONID LIFE HISTORIES: FREEWAY FLIERS OR SUNDAY DRIVERS?

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Strategies for conservation and management of species are strongly influenced by our underlying assumptions about life histories, behaviors and critical habitats. Often these conceptual models are not identified explicitly, yet they shape restoration actions and perceptions of factors thought to limit species abundance.

Until recently, management of salmon and steelhead in the Sacramento-San Joaquin system has been based upon a simplified life history, consisting of freshwater and ocean phases linked by a simple riverine corridor. This view has been termed the monitoring or "production" approach to salmonid study and management. Guided by this paradigm, managers often sought to identify bottlenecks for salmonid production within a particular component of the environment (e.g., estuarine predation). However, recent studies suggest the need for an alternative framework driven by ecological understanding.

This new framework acknowledges the opportunistic tendencies increasingly evident among salmonid populations. With complex and dynamic life cycles, salmonids capitalize on a variety of available habitats that extend beyond those acknowledged by the traditional "production" driven approach. In this context, distribution and abundance of healthy salmonid populations will depend upon the complex array of habitats which permit life cycle diversity, and on ecological processes such as changes in food webs and environmental conditions.

Evidence supporting this approach comes from studies of habitats often ignored by traditional approaches as insignificant or even detrimental. Off-channel habitats (floodplains, ponds, river side-

SCIENCE

Questions

- What is the population impact of salmonid mortality sources? Are these sources of mortality sufficient to drive overall patterns of salmonid abundance? If not, why are we devoting such a large portion of our efforts to minimizing these sources of mortality? Relative to predation, diversion and stranding losses, what are the population benefits (or losses) provided by complex and functional riverine and estuarine habitats?

channels) and small, low-elevation tributaries increasingly appear to serve as critical habitats for many salmonid life stages. Dive surveys of the Feather River, for example, indicated that a majority of juvenile steelhead were to be found in small, side channels, despite the fact that side channels represent a very small proportion of the total habitat available in the river (see chart). Similarly, salmon have been found to heavily utilize and benefit (in terms of growth and survival) from seasonal habitats such as floodplains and intermittent tributaries. The value of life history plasticity (opportunism) and diversity are also evident in the rapid adaptations salmonids show to altered environmental conditions in regulated rivers. With regard to factors regulating salmonid abundance, studies increasingly show that oceanic conditions play an important role. In the northern Pacific Ocean, measures of oceanic currents are now known to strongly regulate productivity of zooplankton and, in turn, productivity of salmonids.

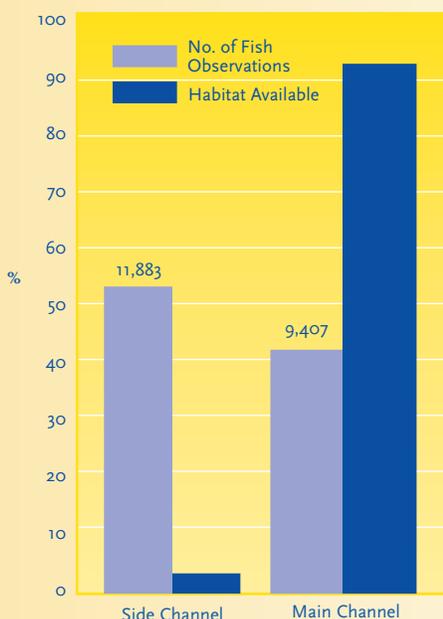
Application of ecological minded studies rather than relying on "production" driven monitoring studies has already yielded many new and significant insights to salmonid life history and behavior. Integrating these findings into our conceptual understanding will enhance our ability to manage salmonid populations and implement effective restoration and conservation actions (Cavallo, SOE, 2002).



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JUVENILE STEELHEAD FEATHER RIVER 1999-2001



TRACKING PESTICIDE EFFECTS ON NATIVE FISH WITH BIOMARKERS

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Researchers using genetic biomarker techniques have some new clues as to contaminant effects on a native fish species in the Central Valley of California. These biomarker techniques track genetic damage to organisms, such as breaks in DNA strands, that may lead to mutations and reproductive changes. The principle utility of biomarker techniques is to evaluate sublethal effects of toxicant exposure in resident aquatic species. Although chemical analyses and toxicity tests characterize toxicant exposure and effects, they cannot define latent and sublethal responses.

Researchers recently conducted genetic biomarker research on a Central Valley native fish, the Sacramento sucker (*Catostomus occidentalis*), to explore pesticide effects. Agricultural pesticides contaminate waters of the Sacramento and San Joaquin watersheds at concentrations toxic to test invertebrates (see de Vlaming, p.32). However, effects on resident native fish are only now being examined.

Researchers performed experiments using both field caging and laboratory exposure (to field-collected water) to test whether pesticide exposures are correlated with biomarker responses in the Sacramento sucker. Experiments were timed to coincide with the first rainstorm event after dormant-season application of organophosphate (OP) pesticides to orchards. Researchers measured various biomarker

responses, including DNA strand breaks (Comet Assay), and also evaluated pesticide concentrations.

In terms of the DNA damage, strand break data indicate significantly elevated damage from the San Joaquin River (38.8%, 28.4%, and 53.6% DNA strand breakage in 2000 field, 2000 lab, and 2001 field exposures, respectively) compared to a nearby reference site (15.4%, 8.7%, and 12.6% in 2000 field, 2000 lab, and 2001 field exposures, respectively).

Though the data confirmed genetic damage correlated with rainstorm events, researchers found no correlation between the damage and OP pesticide concentrations, leaving the cause of the toxicity unknown.

In 2001, the Ames mutagenicity assay, a rapid bacterial test that examines genetic mutations caused by contaminants, was applied to field-collected water. The assay indicated that San Joaquin River water was significantly more mutagenic than the reference site.

SCIENCE Questions

- What chemical is causing the genotoxic responses observed in the San Joaquin River? Are effects related to pyrethroids? Will these effects harm fish populations?
- What techniques provide the best indicators of agricultural chemical contamination?

Ongoing studies seek to further investigate the cause of the genetic toxicity observed and to further evaluate the effects of low-level contamination on individuals and populations. In this case, the biomarkers and mutagenicity studies may have uncovered the presence of toxicants that are detrimental to the health of fish, but that are not yet well characterized. Biomarker research is also underway to evaluate the health of juvenile chinook salmon and endangered delta smelt.

Any application of such biomarker techniques should occur with some basic principles in mind. For example: 1) multiple biomarkers should be used to characterize both exposure and effect, 2) time- and tissue-dependent responses should be considered, 3) laboratory and field studies should be integrated to maximize the scope of inference in any study and, 4) exposures should be well characterized with chemical analysis. The relationship between a biomarker response and a change in the fitness of an organism may vary depending on the type of technique selected.

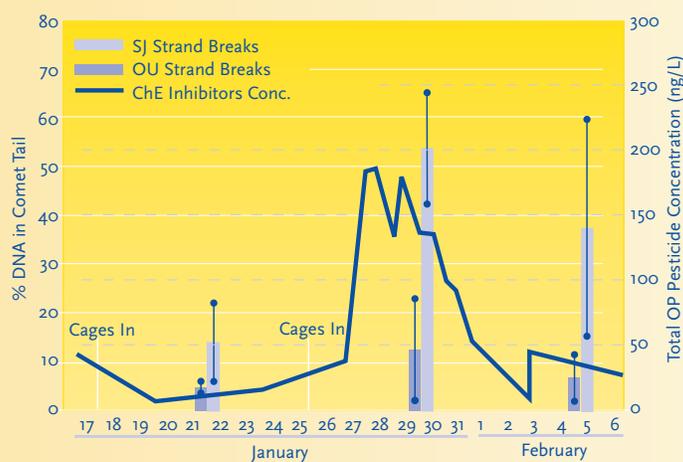
Although techniques are sometimes complicated, they can be applied to relatively simple problems. For example, they may be utilized in studies to simply determine whether contaminants are involved in poor health of a species. More complex programs can later be devised to determine the severity of effects, the nature of the contaminants, and the possibility of population-level effects (Anderson, SOE, 2001).



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DNA STRAND BREAKS IN SAN JOAQUIN RIVER SUCKERS



DNA strand breaks (comet assay) in red blood cells of fish caged at SJ during dormant season pesticide runoff events in 2001. One pair of cages was deployed on Jan. 17 and retrieved pre-runoff, and two pairs of cages deployed at the onset of rain (Jan. 25) and retrieved at different times during the runoff event. Light blue bars represent mean DNA strand breaks (% DNA in comet tail) (\pm standard deviation) in fish caged at San Joaquin River near Vernalis (SJ), and medium blue bars represent DNA strand breaks in fish caged at the field reference site (Orestimba Creek at Orestimba Road; OU). Line graph indicates total concentration (ng/L) of cholinesterase-inhibiting pesticides detected in water samples from SJ. Same letter indicates no significant ($p < 0.05$) differences among mean DNA strand breaks. Source: Whitehead & Anderson, SOE, 2001

SHALLOW-WATER HABITAT: GOOD FOR FISH?

LARRY BROWN
U.S. Geological Survey

In the last decade, many people assumed that recovery of native fish species in the San Francisco Estuary, particularly threatened fish species, depended at least partially on the restoration of shallow-water habitat — a logical assumption given the tremendous losses of habitats such as tidal wetlands over the last 150 years. The general acceptance of this assumption, however, occurred in the absence of a precise definition of shallow-water habitat and strong evidence that native species are being limited by the lack of such habitat.

The phrase “shallow-water habitat” is really not very useful unless a more detailed description of the habitat in question is available. Types of shallow-water habitat often discussed in the Estuary include shoals around deeper bays, tidal marshes and wetlands, permanent and seasonal marshes and wetlands, and river floodplains.

To humans, perceptions of shallow and deep are dependent on a person’s height. For fish, shallow and deep are best interpreted in terms of a species’ life history. For example, scientists hypothesize that delta smelt (*Hypomesus transpacificus*) spawn on hard structures along channel margins that are considerably shallower than the open channels and bays where they spend most of their adult life. They also hypothesize that the newly hatched smelt survive better and grow faster when their rearing habitat is near extensive areas of shoals in Suisun Bay, rather than confined to deeper channels upstream of Suisun Bay.

More recently, restoration of shallow-water habitat has evolved to mean restoration of floodplain in the upstream part of the watershed and restoration of tidal wetlands and the marshes in the Estuary. Recent studies in Yolo Bypass, the Central Delta, and Suisun Marsh illustrate the benefits and challenges associated with habitat restoration.

In the Yolo Bypass, recent studies (Sommer et al. 2001, 2002a,b) demonstrate the value of floodplain to native splittail (*Pogonichthys macrolepidotus*) and chinook salmon (*Oncorhynchus tshawytscha*). When the Yolo Bypass remains flooded for more than three weeks during the spawning period of splittail, spawning is very successful. Similarly, a flooded Yolo Bypass appears to provide better rearing habitat for juvenile chinook salmon than the Sacramento River. These data indicate that a flooded Yolo Bypass is a good thing for native species of concern.

In the central Delta, recent studies (Simenstad et al. 2000) of tidal wetland and marsh habitats show that the fish communities are composed of mixtures of native and introduced species. The introduced fishes strongly dominate the community. The presence of the introduced water plant, *Egeria densa*, appears to be an important factor in determining the fish community. In areas where this plant is abundant, native fishes are extremely rare, and the fish community is dominated by introduced fishes such as large-mouth bass, redear sunfish, and bluegill. The presence of the plant and associated predatory fish may disrupt natural patterns of habitat use by native fishes and may also result in increased mortality due to predation.

In Suisun Marsh, studies (Matern et al. 2002) show that smaller sloughs appear to provide better habitat for native fishes than do larger sloughs. Thus smaller sloughs may provide a template for designing habitat restoration projects in Suisun Marsh. Presumably, by designing

SCIENCE Questions

- Do we need a more precise definition of shallow-water habitat?
- Is there strong evidence that native species are being limited by the absence of such habitat?
- How well do fish communities respond to habitat restoration projects?

restoration projects to mimic habitat conditions in the small sloughs, the likelihood of promoting native fish species is increased.

Studies of existing shallow-water habitats should continue so that the responses of the fish communities to habitat restoration projects can be better predicted. Similarly, habitat restoration actions should continue but within the framework of adaptive management and with a willingness to change or discontinue practices that do not fulfill objectives (Brown, SOE, 2001).

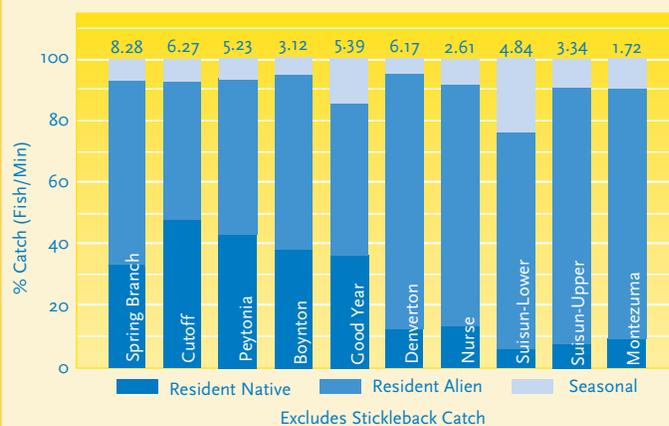


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[www.estuarynewsletter.com/
2001_12/feature_2001_12_01.pdf](http://www.estuarynewsletter.com/2001_12/feature_2001_12_01.pdf)

NATIVE/ALIEN FISH MIX IN SLOUGHS



Percentages of resident native, resident alien, and seasonal fishes captured in Suisun Marsh sloughs. The number on the top of the bar indicates the average number of fish caught per minute of trawling. Suisun Slough, Montezuma Slough and Nurse Slough are considered large Sloughs. Number at top of each is average fish/minute.

Source: Croeter & Moyle, U.C. Davis.

THE CENTRAL VALLEY INSECTICIDE SAGA

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Water quality regulators discovered organophosphorus (OP) insecticide contamination of Central Valley aquatic ecosystems in the mid 1980s, when water samples collected from the Sacramento River and San Joaquin River watersheds for toxicity tests were lethal to the zooplankton test species. Follow-up investigations by the Central Valley Regional Water Quality Control Board identified diazinon and chlorpyrifos as the primary causes of the toxicity, and land use practices as the source, and provided estimates of the magnitude, duration, and geographic extent of toxicity. Results demonstrated that in agriculture-dominated areas, almond and stonefruit orchards were the primary source of the OPs. These insecticides are applied to orchards in late December and January. OPs are relatively water soluble, and the insecticide-caused toxicity was recorded in waterways during January through mid-March during and following rainstorms.

In urban-dominated waterways OP-caused toxicity was seen following storm water runoff, but also at other times of the year. Extensive home, landscape, greenhouse, and industrial use of OPs was considered to be responsible for contamination of urban streams.

OP insecticide use in the Central Valley peaked in 1995, and is now diminishing (as substitutes come into play). In 1995, about 8,336,100 pounds of OP active ingredients were applied, or about 184 pounds per square mile of agricultural lands in California.

In 1998, more than ten years since the initial observation of the OP insecticide problem, the Regional Board placed various waterways on the Clean Water Act (CWA) §303(d) list of impaired water bodies, and initiated the allocation of allowable loads among sources of the contaminants (TMDLs) in the Sacramento and San Joaquin watersheds. Two groups, one of stakeholders and one a grower-pesticide industry group, are now assisting the board and the region with insecticide reduction efforts (de Vlaming, SOE, 2001).



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DELTA RESTORATION PRINCIPLES

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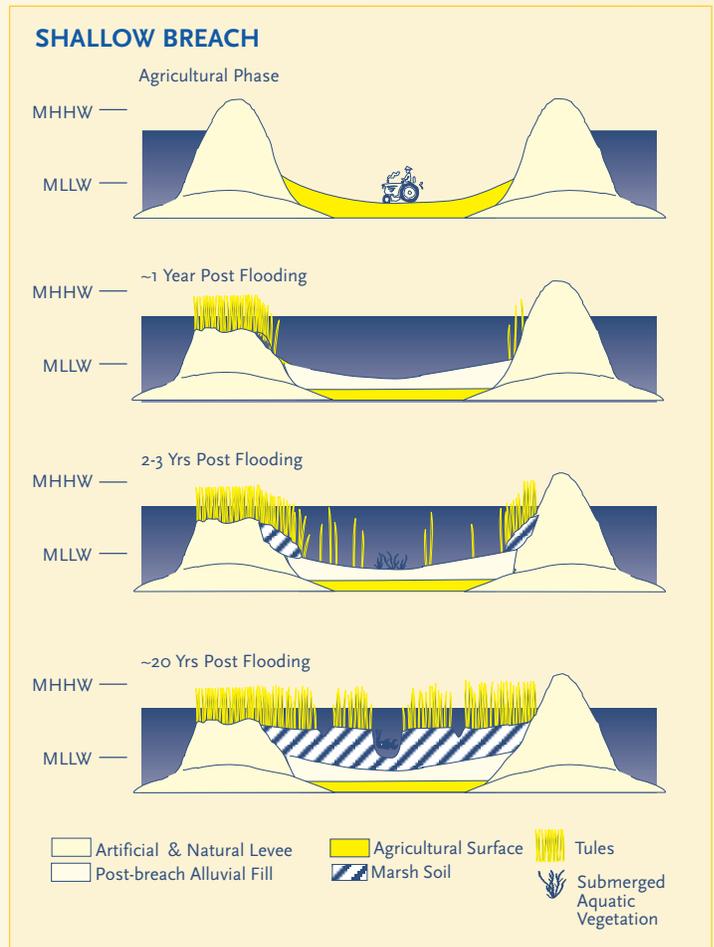
The call for wetland restoration in the Sacramento-San Joaquin Delta arises from the recognition that not only has a vast acreage of wetlands been lost but also that tule marshes have value both for at-risk species and society as a whole. Experience from other large-scale ecosystem restoration programs and from continued studies of the Delta tells us that to be successful in the long-term we must have clear objectives, use what we know, and continue to develop new information as we proceed.

The principles offered here for tidal marsh restoration in the Delta are intended to guide our efforts from a system-level perspective, and provide context for the conceptual models behind individual restoration projects. Four common restoration myths inspired my suggestion of these principles:

- 1) *Let nature do the work.*
- 2) *Build it and they will come.*
- 3) *The secret is finding enough sediment.*
- 4) *Enough of the studies, we need a plan of action for Delta restoration.*

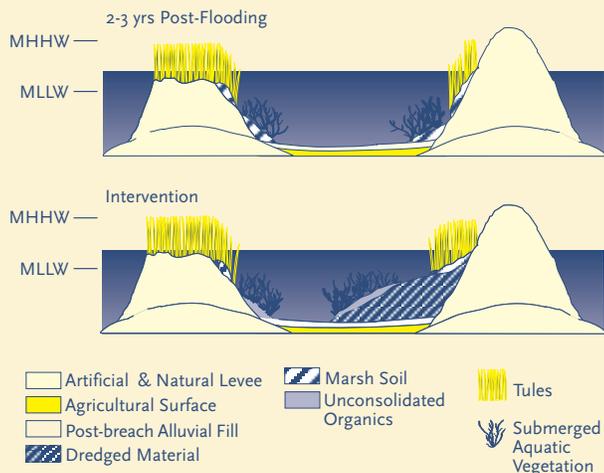
Let nature do the work: It is imperative to understand the natural processes that formed the Delta's marshes in

order to effectively restore them. These marshes did not form as the Sacramento and San Joaquin rivers brought down sediment and built new land out into open water (as the Mississippi delta formed); they formed as the sea level rose and flooded the land, spreading tidal influence landward. Restoration planners should not, therefore, expect riverine or tidal processes to build marsh substrate into open water areas (e.g., flooded islands).



In addition, the rivers themselves have been fundamentally altered and restoration must proceed, at least in the near term, under the current discharge and sediment regime. For the time being, restoration planners can't, for example, propose taking down Shasta Dam or taking out the Sacramento River navigation channel. Delta wetland restoration thus largely involves rebuilding substrate that has been lost to subsidence, and where necessary adding new material. Contemporary processes can then maintain wetland elevations in

INTERVENTION WITH DREDGED MATERIAL

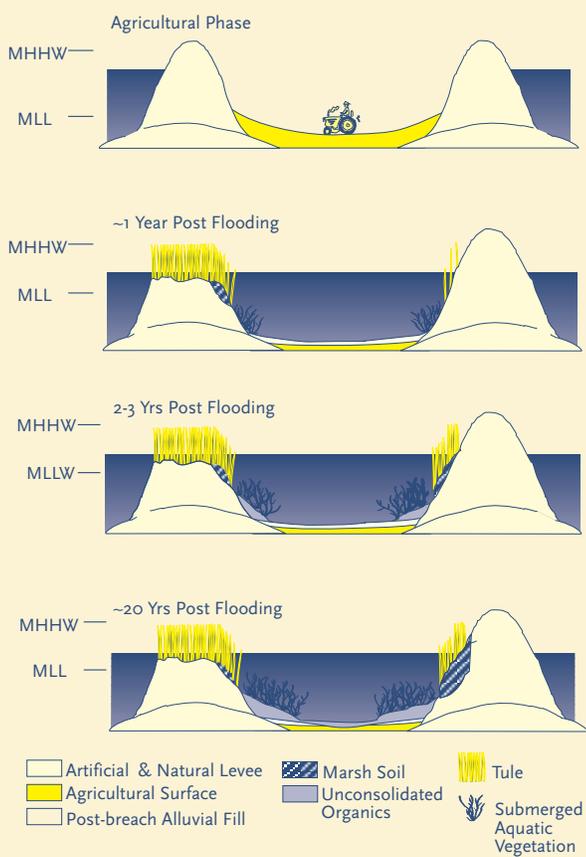


the face of sea-level rise and even build within the intertidal zone. Delta restoration principle #1 should be: Understand the natural processes that formed marshes but acknowledge that restoration must work within the constraints of current processes.

Build it and they will come: The value we associate with natural marshes comes not from the vast acreage of tules but from the dynamic interac-

tion between hydrology (river and tides) with landscape structure (marsh plain, channels, ponds). Superimposed on this is the complexity of food web dynamics and small-scale habitat structures provided by submerged aquatic vegetation, edge and periodically inundated surfaces. Creating multiple characteristics in a marsh – shallows, edges, channels – will lead to multiple uses by different plants and at-risk species, and multiple benefits in terms of levee protection and water quality and supply. Restoration planners should ensure a mix of both structural and dynamic habitat attributes and not simply seek to increase the acreage of tules. Therefore, Delta restoration principle #2 should be: Restore marshes as one component of a flowing and flooding landscape.

DEEP BREACH



The secret is finding enough sediment: One of the major challenges in restoration of tidal wetlands in the San Francisco Estuary is the availability of sediments to build back substrate in highly subsided areas (see also Williams p.22), but the role of vegetation must also be considered. Several freshwater marsh species produce substantial below-ground biomass and tules grow below the level of Delta marsh plains. Restoration efforts must ensure a minimum substrate elevation but it is not always necessary to rebuild substrate all the way up to the natural marsh levels because vegetative contributions can develop and maintain

SCIENCE Questions

- What value do the various bio-geophysical attributes (e.g., marsh edge, marsh channels, ponds) of Delta marshes provide to at-risk species?
- What values do these various attributes provide to society (e.g., bird watching, fishing/hunting)?
- Do the present-day lower elevation, tule-dominated restored marshes provide the same ecological and societal values as the historic Delta plain did?
- Does restoration of Delta marshes for ecological reasons alleviate other problem areas, such as water quality/quantity and levee protection? Are there regions of the Delta where restoration should be a higher priority because of synergistic benefits in multiple problem areas?

marsh elevations in the face of sea-level rise. Therefore, Delta restoration principle #3 should be: Marsh restoration is an exercise in biogeomorphology and must appreciate physical, biotic and sediment-related processes.

We've done enough studies, let's get on with the real work and make a plan of action for Delta restoration: Having established our goals we need a plan of how to get there but this must encompass our uncertainties both about how the system works and about future conditions. We must also ensure our plans and approaches are sufficiently flexible to take advantage of opportunities that may arise— from beneficial use of dredged material to mitigation or even floods. Therefore, Delta restoration principle #4 should be: Be prepared for surprises and make the most of opportunities (Reed, SOE, 2001).



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INTEGRATING RESTORATION SOLUTIONS

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Department of Water Resources

Tidal brackish and freshwater wetland ecological resources in the Bay-Delta Estuary have experienced significant quantitative and qualitative declines over the last century, primarily as the result of land reclamation and subsequent development. Restoration of tidal wetland habitats and enhancement of associated upland transition areas within the Estuary require large-scale, integrated and innovative solutions. Good examples of recent innovation include: 1) application of hydrodynamic modeling approaches to identify critical site-specific Bay-Delta tidal prism-related plan-form geometries that may enhance water quality system-wide; and 2) applied research focused on identifying ways to increase elevations on subsided islands using bioaccretion and sediment trapping.

Restoration solutions need to be integrated by identifying multiple project goals and solving multiple

needs simultaneously – single issue solutions are unlikely to be successful. Integrating ecosystem restoration and enhancement with water quality and flood control benefits is possible, even as we control and reverse the effects of subsidence in the Delta and Suisun Marsh. Phased construction of habitat projects within existing ecological gradients, for example, can reverse the effects of subsidence through bioaccretion and eventually return large floodplains to tidal action, as well as improve Delta flood conveyance. Large sediment loads could once again be deposited onto Delta islands, reducing the effects of 140 years of subsidence. Large, wide habitat levees will create new riparian and upland transition areas, mimic the natural topography, and provide much-needed habitat diversity while protecting tidal marsh corridors and reducing salinity intrusion.

Implementing a large-scale estuarine restoration program will require problem-solving interdisciplinary teams empowered with the authority and funding to identify and clarify restoration actions bene-

SCIENCE

Questions

- How are large scale restoration efforts in the Delta and Suisun Marsh affected by sediment transport, non-native species growth, mercury methylation, subsidence reversal, and salinity responses to plan form changes?

ficial to the ecological functioning of the complex Bay-Delta Estuary system. Implementation will also require optimism beyond reason.

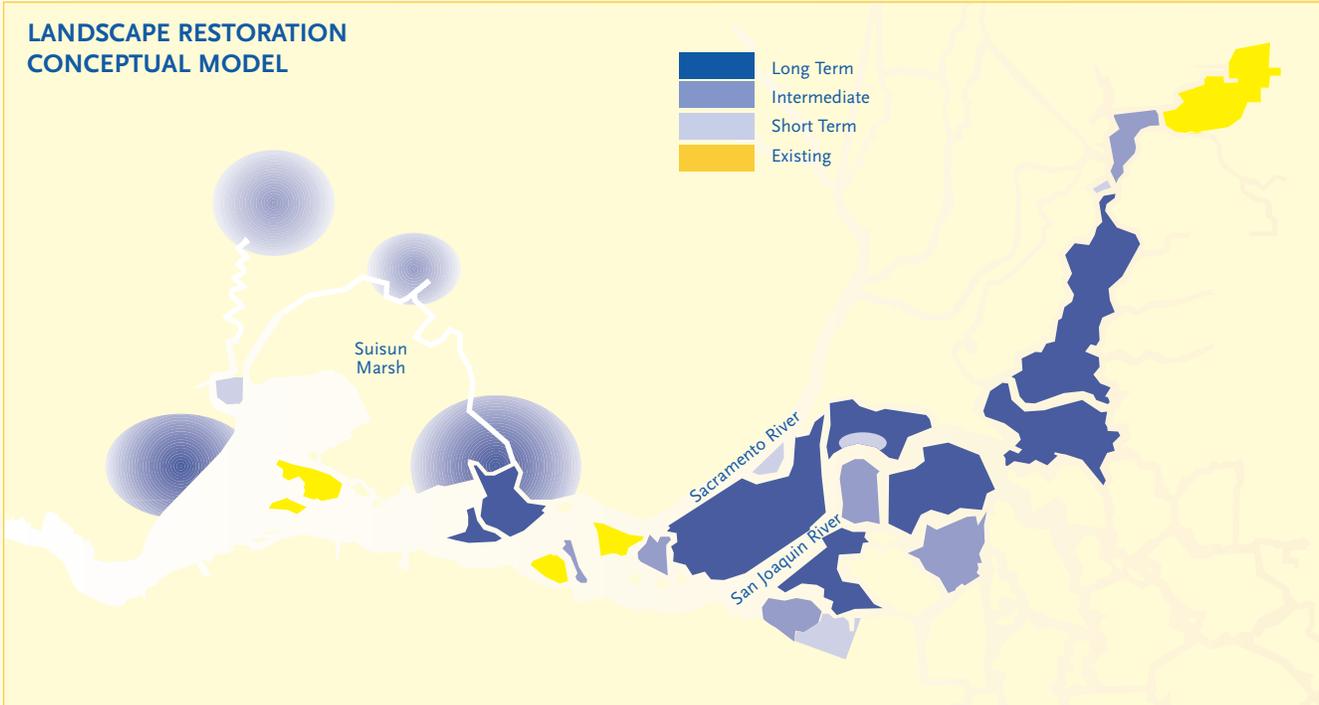
Toward this end, small demonstration projects can help improve regionally appropriate restoration science and try our hand at locally meaningful adaptive management. However, large-scale solutions are critical if we are to restore native habitats and endangered species. Research alone will not restore these ecological resources; nor will policymaking or agency action without science.



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LANDSCAPE RESTORATION CONCEPTUAL MODEL



Migration corridors comprised of emergent aquatic vegetation and shallow tidal sloughs provide transient habitat value to migrating aquatic and near-aquatic species not currently provided by riprap and steep-sided levee banks. Regional linkages reduce isolation effects of piecemeal project implementation. Regional biogeochemical cycling is linked to sediment movement and establishment and maintenance of first-order tidal channel networks.

RESTORATION

Suisun Bay

“The last decade’s research has produced a revolution in our core ideas about the movements of water, salt and sediments in Suisun Bay, the sources and biological effects of contaminants, and the productivity of the estuarine foodweb.”

JIM CLOERN
U.S. Geological Survey

APPLYING INTEGRATED SCIENCE TO SUISUN BAY

JIM CLOERN
U.S. Geological Survey

Suisun Bay is the critical transition habitat between the river-dominated freshwater habitats of the Delta and the downstream marine-influenced embayments of San Francisco Bay, and as such has been the focus of scientific study for over three decades, and of numerous high-priority environmental management debates and actions.

Of direct relevance to these management questions are the results of an integrated research effort by the U.S. Geological Survey in Suisun Bay. These results, with examples presented in the following pages (pp. 36-45), have led to a revolution in our core ideas about the movements of water, salt and sediments, the sources and biological effects of contaminants, and the productivity in the estuarine foodweb. Only 10 years ago, these core ideas included the concepts of: (1) a residual circulation pattern dominated by a single gravitational circulation cell with a null zone;

reserve fleet channel), and that the presence/absence of gravitational circulation and null zones are strongly influenced by the shape of the seafloor (see Burau p.39).

Second, we used to think particles accumulated in the null zone. Now we understand there is not necessarily one place of maximum turbidity associated with the null zone, but rather there can be multiple turbidity maxima caused by multiple mechanisms (see Schoellhamer p.41).

Third, we used to think of Suisun Bay as a geographic region with a high biomass of clams, worms, fish and other aquatic animals because it had inherent high primary productivity derived from phytoplankton photosynthesis. In the past decade, we have learned that the rate of primary production in Suisun Bay is actually very low (in the bottom 10% of all estuaries world-wide), partly because of strong grazing pressure by the introduced clam *Potamocorbula*. We have also, as a result, learned that much of the animal biomass within Suisun Bay derives from the delivery of food from outside sources. We now understand Suisun Bay as an open system that relies on inputs from beyond its boundaries rather than as a closed, self-sustaining, biological system.

Beyond these refinements of old conceptual models, the application of integrated science in Suisun Bay is creating new conceptual models of ecosystem attributes previously not considered. For example, we now know very precisely how the shape of the Suisun Bay's floor has changed since the gold-mining era, and how a slow erosional process is now exposing mercury-enriched sediments deposited a century ago or longer (see Jaffe p.42). We know that different contaminants have their own unique sources, fates and ecosystem effects that must be considered as we develop strategies to enhance living resources. Nickel, for example, is delivered to Suisun Bay by riverine input and its accumulation in biota varies with river flow. However the biological availability of cadmium is controlled by chemical changes that occur along the salinity gradient (see Brown p.43). Other new findings,

“For scientists, Suisun Bay is a beautiful model system for studying fundamental properties of estuarine ecosystems.”

For scientists, Suisun Bay is a beautiful model system for studying fundamental properties of estuarine ecosystems because it features both horizontal and vertical gradients in salinity; responds dynamically to fluctuations in river flow; encompasses complex bathymetry, including coupled systems of deep channels and shallow embayments; and exchanges water and materials between three systems, an upstream river system, a downstream marine system, and a lateral marsh system.

Water and resource managers, meanwhile, are seeking new science to help them better understand the ecological significance of salinity distribution as a broad habitat indicator (“X₂” – see Primer opposite); the potential threats of the gold-mining era legacy of mercury-contaminated sediments; the importance of Suisun Bay habitats to fish and bird species of special concern; processes that influence the bioaccumulation and trophic transfer of toxic contaminants within the estuarine food web; system-level disturbance by non-native species; the impacts of manipulating salinity as a mode of marsh management; and scenarios of response to change in the climate system.

(2) accumulations of particles in that null zone; and (3) inherent high biological productivity because of these high-particle accumulations (see Primer for an explanation of terms). We now know that these core ideas are overly simplistic, flawed, and some are even wrong.

First, our concept of water movements in Suisun Bay has changed, or more specifically of how gravitational circulation works (see diagram p.39). This is a fundamental issue because water movements carry things like salt, sediments, contaminants, and small organisms (from bacteria to plankton to larval fish).

Water movements are caused by many interacting forces. Understanding which forces are most important is essential to understanding how salt, plankton, contaminants and biota are transported within the system. These transport processes are much more complex than we understood only a decade ago. We now know that residual transports in Suisun Bay (that is, transports operating over time scales of days or longer) are NOT usually driven by a gravitational circulation, that there can be multiple cells of gravitational circulation (including cells up the

based on the integration of environmental toxicology with ecosystem science, illustrate that the ultimate effects of contaminants such as selenium are strongly regulated by the feeding pathways between predators and prey. Two distinct pathways exist in Suisun Bay, and the benthic-based pathway (linking clams to sturgeon and diving ducks) is particularly efficient at moving selenium into living resources at the top of the food chain (see Stewart p.45).

Our findings illustrate the rapid progress that we can make when we attempt to organize our expertise and scientific talents in an integrated fashion. This research mode integrates: the study of many different connected processes (such as precipitation, snowmelt, river runoff, sediment delivery, sediment movements, contaminant inputs, trophic transfers of carbon, energy and trace metals); institutional resources (results presented here are most meaningful in the context of the broader science conducted by the Interagency Ecological Program and the academic community); the use of diverse tools and approaches to unravel the complex puzzles of estuarine ecosystems (including stable isotopes, moored instruments, monitoring, mapping, laboratory experimentation, historic reconstructions and numerical models); and the examination of different scales of variability (from the hourly scale of tidal currents to the decade- and century- scales of sediment inputs and reshaping of the geomorphology of Suisun Bay).

Our science must continue to adapt to the Suisun Bay system, which is changing before our very eyes in several ways, among them, the construction and operation of salinity control gates in Montezuma Slough, the population collapse of the native mysid shrimp, decade-scale trends of increasing water exports and reduced outflows to Suisun Bay, and large fluctuations in abundance of key-stone species like the non-native clam *Potamocorbula*. In the meantime, our recent revolution in understanding the critical transition zone between the Delta and the Bay shows how scientists from multiple disciplines can work together to attack the challenges

of understanding how the ecosystem functions and to provide the foundation of scientific understanding necessary to guide management of living resources (Cloern, SOE, 2001).



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ESTUARINE PHYSICS PRIMER

Key Terms

Estuarine scientists use many terms to describe the complicated physical processes in estuaries, where freshwater from the rivers mixes with saltwater from the sea. The salinity of freshwater is 0 practical salinity units (psu) and the salinity of seawater is 35 psu.

The gravitational pull of the sun and moon generates tides with flood (landward) and ebb (seaward) currents. Tidal currents are strongest during full and new moons, called spring tides, and weakest during half moons, called neap tides. This sloshing back and forth is usually much greater than the tidally averaged (residual) movement of water caused by river inflow or wind. Tidal and residual currents carry and mix (transport) salt, sediment, plankton, and other constituents. Saltwater is heavier than freshwater; therefore, saltier water tends to be near the bottom of estuaries. The difference in the amount of salinity between the top and bottom of the water column (stratification) can be great enough to prevent the top and bottom waters from mixing.

Salinity is greatest near the ocean and smallest near the rivers. This difference in longitudinal salinity (gradient) from the river to the ocean can cause the tidally averaged currents to flow landward along the bottom and seaward along the surface (gravitational circulation). The null zone is the region in an estuary where the residual, near-bottom, landward current reverses and flows in the seaward direction as a result of river inflow. In many estuaries, the null zone contains an estuarine turbidity maximum (ETM) where suspended sediment concentrations (SSC) and turbidity are greatest (Schoellhamer, USGS).

X₂

X₂ is the distance, in kilometers, from the Golden Gate Bridge to the tidally averaged near-bed, 2-psu isohaline (a kind of “contour line” in the Estuary’s waters where the salinity is 2 psu). A salinity standard established under the 1994 Bay-Delta Accord requires that freshwater flows be released from upstream in a way that maintains X₂ within a range of positions in Suisun Bay associated with the abundance of aquatic organisms and some threatened and endangered fish.

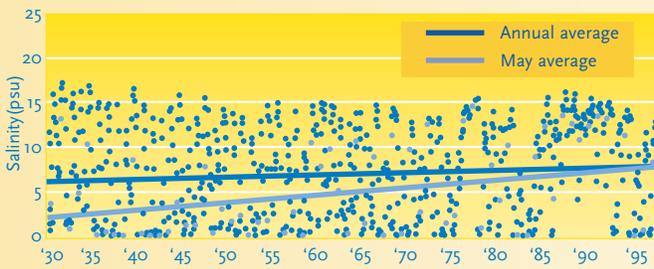
LONG-TERM INFLOW AND SALINITY CHANGES

NOAH KNOWLES
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Changes in estuarine salinity and freshwater inflows over decades and centuries form the climatic context for Bay-Delta research and restoration efforts. Examining past variations and their causes, among them long-term salinity variability in Suisun Bay, can help us understand this context and assess potential future changes.

A reconstruction of seven decades of estuarine behavior – using a model that successfully replicates observed historical salinity observations throughout the Bay (U-P model: Uncles and Peterson, 1995) – reveals a long-term trend toward higher May average salinities in Suisun Bay. This trend represents an increase of about 5 psu from 1930–present (see above). No statistically significant trend in annually averaged salinity was present. A shorter record of observed salinities at Fort Point under the Golden Gate Bridge supports these

LONG TERM MAY SALINITY RISE 1930-2000



results and demonstrates their Bay-wide character.

The primary cause of this long-term rise in May salinity is the gradual development of freshwater management capabilities in the upstream watershed over the last half-century. Use of this infrastructure has significantly reduced freshwater inflows to the Estuary in May, contributing to the long-term salinity increase. Another contributor is the progressively earlier occurrence of snowmelt in the upstream watershed over the last century. Researchers associate the trend – originally identified by Roos (1991) and subsequently investigated by Dettinger and Cayan (1995) – with a century-long temperature increase. The trend is characterized by progressively lower May runoff, and by more runoff coming before May. In this way, the warming trend has contributed to the long-term increase of May salinity.

Though the historical warming trend may be associated with natural modes of climate variability, the effects are similar to what may be expected under conditions of human-caused climate change and may therefore offer a glimpse of changes to come. Simulations of changes in snowpack, streamflow and estuarine salinity projected by combining models of state-of-the-art global climate change (PCM: Washington et al., 2000), watershed hydrology (BDWM: Knowles, 2000) and estuarine water quality (U-P model) paint a picture of the following potential impact on the Bay-Delta system by 2060: a projected average increase of 1.6°C in surface air temperatures over the watershed, resulting in the loss of over one-third of the total April snowpack, with the

most severe losses occurring in the Cascade and northern Sierra ranges (Knowles and Cayan, 2001). This would increase winter storm runoff and reduce the snowmelt-driven runoff of spring (see below).

As winter runoff increases and spring runoff decreases over the coming century, the watershed might lose its ability to generate spring flows. Water agencies should prepare for the likelihood that they may not be able to mitigate for climate change impacts and changes in seasonal flows with today's freshwater management infrastructure. The historical long-term rise in May salinity might continue, and in fact accelerate, in the coming decades, causing more salinity intrusion into the Delta, and potential difficulties maintaining the X2 standard in Suisun (Knowles, SOE, 2001).

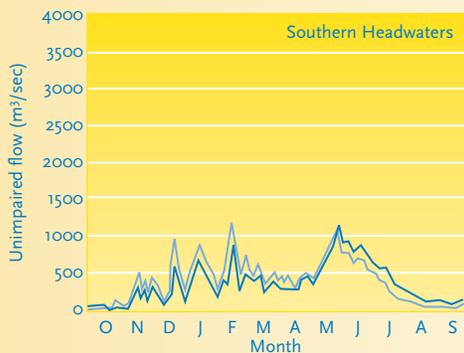
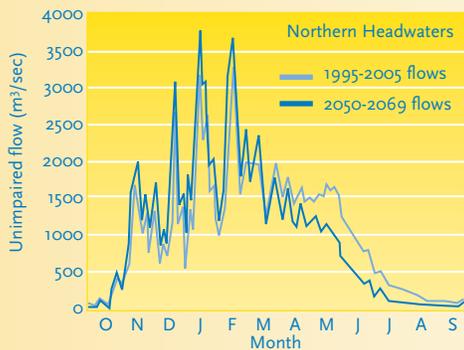


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SNOWMELT-DRIVEN OUTFLOW CHANGES



(1,000 mfs - 35,000 cfs)

SCIENCE Questions

- How much of a role have other long-term climate factors, such as the Pacific Decadal Oscillation, played in shaping riparian and estuarine variability?
- How can we build the current considerable uncertainties about the nature of future climate change into our research and management programs?

NEW CONCEPTS OF GRAVITATIONAL CIRCULATION AND THE NULL ZONE

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Circulation patterns in the biologically productive zone where fresh and salt water mix in northern San Francisco Bay — a zone encompassing Suisun, San Pablo, Grizzly and Honker bays — are quite different from other estuaries, largely as a result of the interaction between classic water transport mechanisms and the North Bay's unusual bathymetry (see also Jaffe p.42).

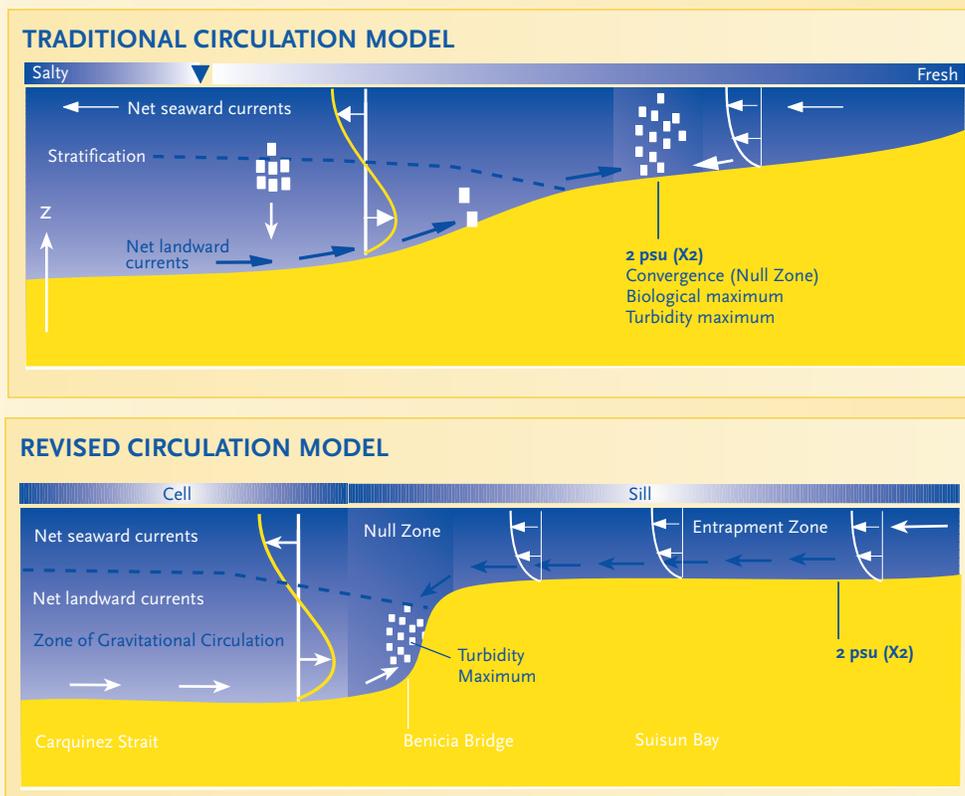
Even though tidal currents generally dominate transport in the North Bay, relatively subtle mechanisms, such as "gravitational circulation," can play a significant role in transporting physical and chemical

materials and biological organisms within the Estuary. Gravitational circulation is caused by salinity differences that occur along the axis of the Estuary, and is characterized by a two-layer, tidally averaged flow that is landward along the bottom of the Estuary and seaward along the water surface. The position of the saltwater/freshwater interface, known as X₂, depends upon freshwater inflows from rivers upstream. X₂ is the approximate upstream limit of gravitational circulation, and is statistically related to the abundance of certain aquatic organisms (see Primer p.37 and Kimmerer, p.46).

Hydrodynamic studies in Suisun Bay show how the position and structure of the salt field, in relation to key bathymetric features, can affect hydrodynamic transport by gravitational circulation. In many drowned-river estuaries the basin geometry is characterized by a grad-

ual increase in width and depth from the head to mouth of the estuary (Chesapeake Bay, the Hudson and Columbia rivers). In contrast, the geometry of the northern reach of San Francisco Bay is characterized by a sequence of large, shallow subembayments (San Pablo Bay, Grizzly Bay, Honker Bay) that are incised by deep channels.

A series of shoals or sills exist (such as Pinole Shoal) in the deep-water channels of the northern reach of Suisun Bay that can reduce or eliminate, by topographic blocking, the landward-flowing near-bed current associated with gravitational circulation. Thus, a so-called "null zone" — a region in the Estuary where the residual, near-bottom, landward current reverses and flows in the seaward direction — is created at each sill within the Estuary and at X₂. A distinct gravitational circulation cell exists between each sill (see diagram).



Gravitational circulation, a two-layer flow pattern (where the bottom current flows landward and the surface currents flow seaward) is shown in the upper panel to occur seaward of X₂. In this traditional model, the along-channel salinity differences (gradients that create gravitational circulation cease to exist landward of X₂ and thus the vertical structure of the currents is top-to-bottom towards the sea landward of X₂. Therefore, at roughly X₂, a transition in the vertical structure of the currents occurs which creates a near-bed convergence, which in turn, creates, in many estuaries, a turbidity maximum. The traditional circulation pattern and entrapment mechanism shown in the upper panel is substantially modified in the presence of bathymetric variability, as is shown in the lower panel. Rather than being located at X₂, the null zone and turbidity maximum occur in locations of significant changes in depth

In San Francisco Bay and other estuaries, a null zone is often associated with an estuarine turbidity maximum (ETM or “Entrapment Zone” as it is commonly referred to in the San Francisco Estuary) where suspended-solid concentrations and turbidity reach a local maximum (see also Schoellhamer, p.41). Thus, whereas Chesapeake Bay and the Hudson and Columbia rivers essentially have a single gravitational circulation cell, null zone, and ETM associated with the 2-psu isohaline because of their gradually sloping bottoms, San Francisco Bay has a sequence of gravitational circulation cells, null zones, and ETM associated with sills and X₂ (Burau, SOE, 2001).



MORE INFO?

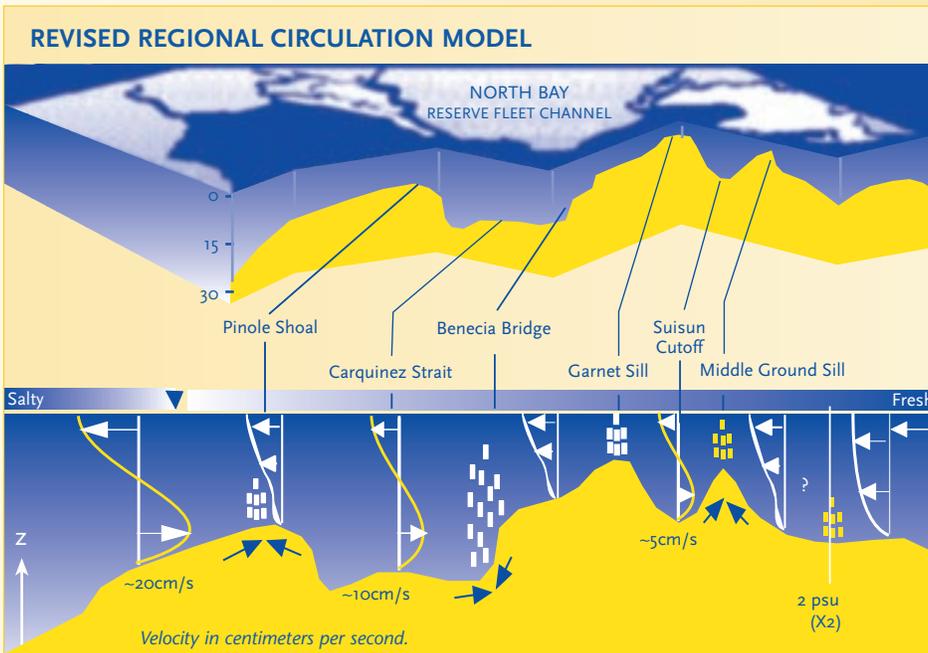
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<http://sfbay.wr.usgs.gov/access/suisunbay/dschoell/contents>

SCIENCE Questions

- How does the strength of the gravitational circulation cells change with the seasons?
- What are the ecological implications of geographically fixed ETMs (since we now know that the ETMs associated with sills are much stronger than the relatively weak ETM that exists at X₂)?
- What are the ecological implications of ETMs associated with large, presumably biologically productive, shallow regions (such as Pinole Shoal in San Pablo Bay and Garnett Sill in Grizzly Bay)?



This model recognizes the interaction between the along-channel and vertical salinity differences (gradients) with the bathymetry in the channels of North Bay. Shallow areas in the channels, such as Pinole Shoal, and the change in depth that occurs near the Benecia Bridge and Garnet Sill, significantly reduce or completely eliminate gravitational circulation. Thus, conceptually, gravitational circulation in North Bay occurs as a sequence of gravitational circulation cells, which occur in the deeper channels, bounded by sills.

SUSPENDED SEDIMENT DYNAMICS

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Suspended sediment affects the ecosystem in Suisun Bay by limiting light availability and photosynthesis, carrying food to benthic filter feeders such as the clam *Potamocorbula amurensis*, and providing a transport pathway for contaminants. One objective of freshwater flow management (i.e., the X2 standard) is to maintain the zone where suspended sediment accumulates (locally known as the entrapment zone), adjacent to the broad, shallow waters of Suisun Bay.

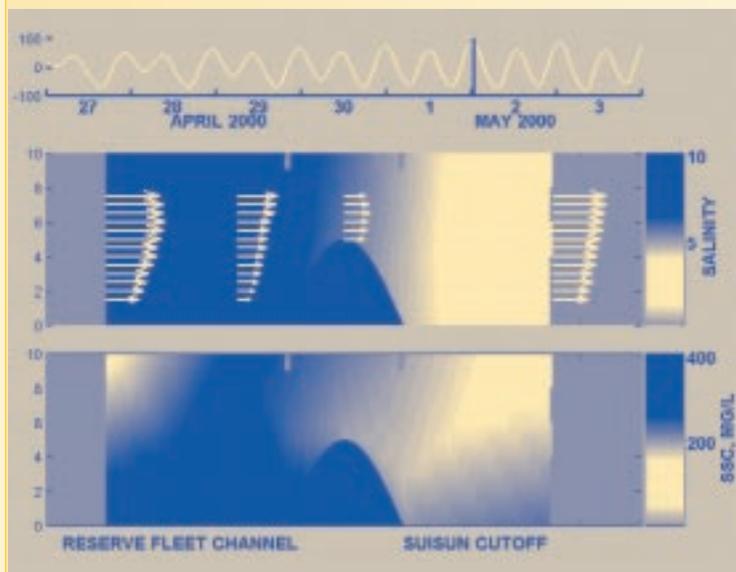
To better understand processes affecting suspended sediment concentration (SSC), researchers made continuous measurements of SSC, hydrodynamics and meteorology at 19 sites in Suisun Bay between August 1999 and June 2000. These sites were concentrated in the shallow waters of Grizzly Bay and in the adjacent deep tidal channel.

Many factors affect the variability of SSC (suspended sediment concentrations) in Suisun Bay, including bathymetry, salinity, the spring/neap tidal cycle, wind, erodible sediment supply, freshwater flow (Knowles), watershed disturbance (Jaffe), and the semidiurnal tidal cycle (see Primer p.37 for an explanation of terms).

When salinity is present, Garnet Sill in the channel adjacent to Grizzly Bay is the terminus of a gravitational circulation cell (Burau) and the location of a turbidity maximum.

In this channel, tidally averaged SSC is determined by the variation of tidal energy primarily by the spring/neap tidal cycle. Energetic spring tides resuspend bottom sediment and prevent vertical stratification of the water column, a process that promotes deposition. Thus, spring tides increase SSC, compared to weaker neap tides. In Grizzly Bay, however, SSC is determined by wind-wave resuspension and the quantity of erodible sediment on the bed.

MAY 2000 ESTUARINE TURBIDITY MAXIMUM NEAR GARNET SILL



A frame from a video showing an ETM (dark blue in bottom panel) seen in Reserve Fleet Channel seaward of Garnet Sill (idealized blue bump in middle and bottom panels), where it generally remains. The salinity is about 8 psu and the current is flooding (white arrows in middle panel). Water level is at a high tide (intersection of time line and water level line in the top panel). This video frame shows the suspended sediment in the ETM deposits at slack tide and resuspends as the current speed increases.

A tidal variation in suspended sediment concentrations in the center of Grizzly Bay often distinguishes two water masses—one that has moved into Grizzly Bay during flood tide from the turbidity maximum in the channel and one that has moved during ebb tide from shallower water in Grizzly Bay where wind-wave resuspension is greatest.

This work, and other findings (Schoellhamer 2001, Brennan and others in press) has substantially altered our conceptual model of turbidity maxima in Suisun Bay. One of the rationales for the X2 standard is to maintain a turbidity maximum at a salinity of 2 psu adjacent to the shallow waters of Suisun Bay. As long as salinity is greater than zero, however, a turbidity maximum is located adjacent to the shallow waters of Grizzly Bay. The rationale for the X2 standard and the explanation of how the turbidity maximum and shallow waters provide ecological benefit should be revised accordingly (Schoellhamer, SOE, 2001).



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SCIENCE Questions

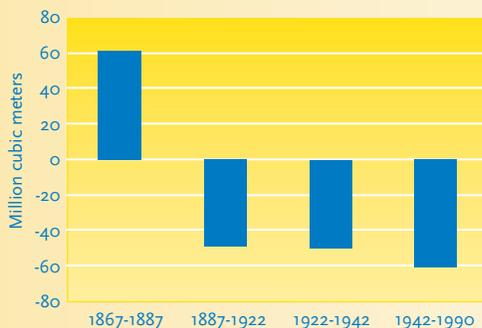
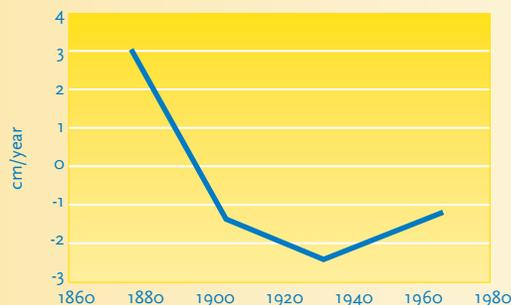
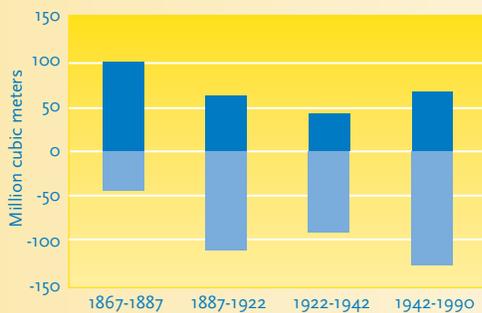
- How does the bathymetrically controlled turbidity maximum seaward of Garnet Sill affect contaminant transport and the ecology of Suisun Bay?
- To what extent do the turbidity maximum and shallow waters of Grizzly Bay interact?
- What are the physical processes that account for the turbidity maximum on the tidal time scale?
- How and why does the magnitude of the turbidity maximum vary with the spring/neap cycle and seasonally?
- How is sediment transported within Grizzly Bay?

SEDIMENTATION, EROSION, AND MERCURY CONTAMINATION

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Understanding long-term sediment movements can help us predict how much debris from upstream Gold Rush-era hydraulic mining is still in Suisun Bay, its distribution, and whether it is buried or near the surface where the associated mercury could be available to the ecosystem.

SUISUN SEDIMENT CHANGES



Hydraulic gold mining removed more than a billion cubic meters of sediment from the foothills of the Sierra Nevada during the middle to late 1800s. Rivers transported much of this sediment to San Francisco

Bay. These sediments have high mercury concentrations (typically 0.3 to 0.5 parts per million) because they contain mercury lost during the gold-extraction process (as much as 10,000 tons of mercury).

To improve our understanding of long-term sediment transport patterns and the present 3-D distribution of mercury-contaminated hydraulic mining debris in Suisun Bay, researchers undertook quantitative analysis of historical hydrographic surveys. The data set contains more than 150,000 depth soundings collected during five surveys from 1867 to 1990. Surface models of bathymetry showed patterns and quantities of morphologic change and sedimentation between surveys. A more sophisticated model was then developed that tracks the fate of hydraulic mining debris in Suisun Bay.

Results of this analysis indicate just how radically the Bay's sediment system has changed over the past 150 years in response to human activities and natural forces. Before the massive input of sediment from hydraulic mining, channels were broad and more developed in Northern Suisun Bay. During the hydraulic mining period the high delivery rate of sediment overwhelmed erosive forces, resulting in filling of channels. At that time, approximately two-thirds of Suisun Bay was depositional and one-third was erosional.

Suisun Bay has lost sediment since that era and continues to today as sediment delivery has decreased and natural forces (e.g., tidal currents, wind wave resuspension) continue to remove sediment. During the last period of change analysis, 1942 to 1990, more than two-thirds of Suisun Bay was eroding.

SCIENCE Questions

- How much of the mercury-contaminated debris is in a zone where physical and biological processes release mercury into the system?
- How will water management strategies affect the rate at which mercury is released from hydraulic mining debris in San Pablo and Suisun bays?
- Is the mercury in the hydraulic mining debris bioavailable?

As a result of changing sediment dynamics, most of the hydraulic mining debris has left Suisun Bay, but tens of millions of cubic meters of contaminated debris still remain at locations both in the Bay and in the marshes along its shores. This is in contrast to San Pablo Bay, which retains more than a hundred million cubic meters of mercury-contaminated debris. Resource managers setting restoration priorities should take into account the higher likelihood of mercury releases from marshes composed of mercury-contaminated hydraulic mining debris (Jaffe, SOE, 2001).



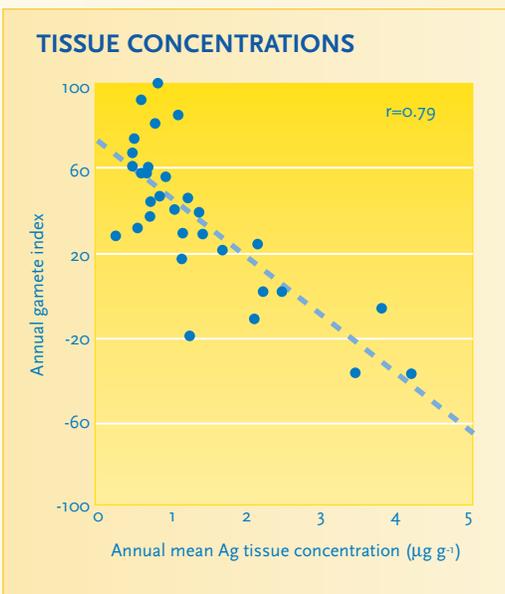
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TRACE METALS IN SUISUN BAY BIVALVES

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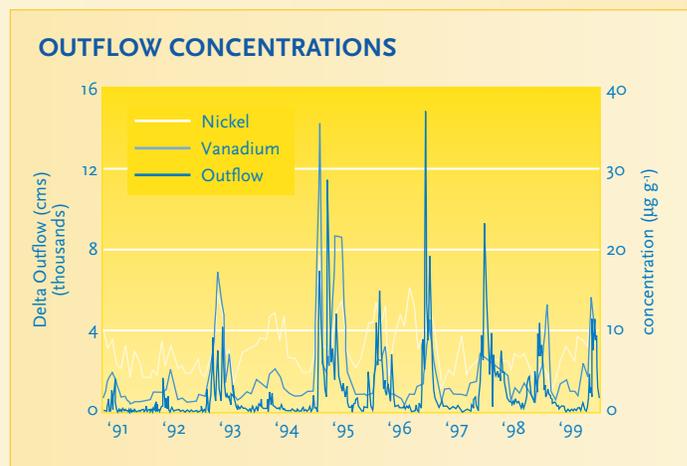
Researchers analyzed four metals in the clam *Potamocorbula amurensis* — vanadium, nickel, silver and cadmium. Each of these has a different pattern of accumulation and thus reveals something different about the processes in the Estuary. These patterns tell us where to look for the sources of contaminants, what controls contaminant availability and how contaminants may affect aquatic organisms.

The non-native clam *Potamocorbula amurensis* is a useful indicator of trace metal contaminants because it lives in



salinities ranging from 1-32 parts per thousand, and can thus be used to compare a variety of habitats. Researchers have been collecting and analyzing about 100 clams monthly at a number of stations in the North Bay for this study since 1990.

Researchers compared the patterns in variability of trace metal accumulation in the clam with the patterns of variability of other environmental and biological factors — hydrodynamics, sediment dynamics, reproduction and geochemistry. The results indicate that some metals have external sources to the Estuary, i.e., input from the rivers



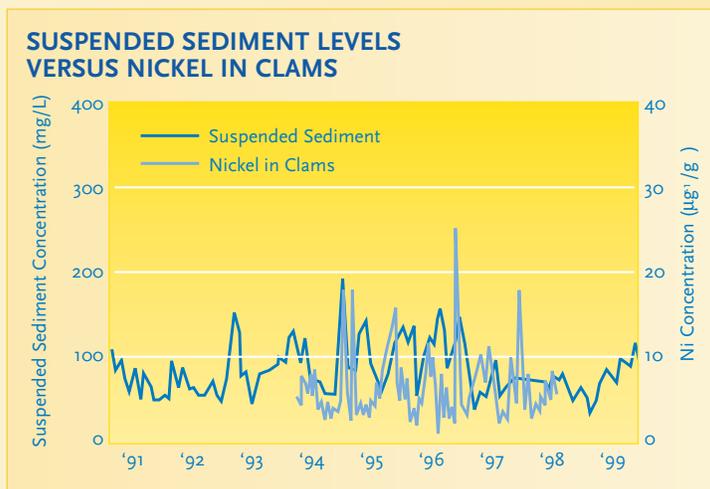
(V and Ni); some are influenced by internal processes, i.e., resuspension of sediments (Ni); some have internal sources in the Estuary and have an adverse effect on the clams (Ag); and that for others, availability for possible uptake into the food web is driven by the geochemistry of Suisun Bay (Cd).

Vanadium (V) and nickel (Ni) occur naturally in the ultramafic rocks of the watershed, an external source to Suisun Bay. Their availability to the clams is related to the bay's hydrodynamics (see above). The primary sources of V and Ni in the tissues are tied to the Delta outflow into the Bay from the Sacramento and San Joaquin rivers. The concentrations of these metals are high in the clam coincident with high flows.

However, V in the tissues drops to baseline levels between periods of high flow, whereas Ni increases again in the clams during some summer low flow periods. With Schoellhamer's suspended sediment data (see p.42), we see that Ni availability increases with increasing suspended sediment concentrations in the water column (see right). During low

summer flow periods, winds pick up, causing wind/wave resuspension of the bottom sediments. This appears to increase the availability of Ni to the clam. Thus the primary source of V and Ni appears to be from the rivers, however, unlike V, internal processes (resuspension) also make Ni available to the clams when river-flow into the Bay is low. Regardless, Ni and V do not appear to have an adverse effect on the health of the clam.

Silver (Ag) is naturally rare in the environment. The source of the Ag, according to the data, appears to be internal to the Bay. Highest Ag concentrations occur in clams in Suisun Bay and the Carquinez Strait. The data indicate that clams with more Ag in their tissues have a lower "gamete index," in other words, there are fewer reproductive clams (see left). Clams are not reproduc-

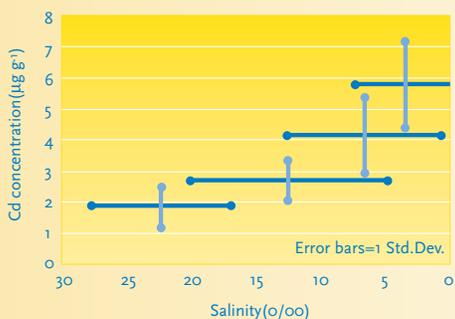


How the concentration of Ni in the tissues of the clams (right y-axis) relates to how much sediment is in the water column (left y axis), indicating that the Ni in the tissues may be influenced by possible Ni on the sediments and that resuspension of the sediments may make the Ni more available to the clams.

tively active when Ag tissue concentrations are high.

Cadmium (Cd) is rare to the natural environment, and its availability is driven by the geochemistry (salinity gradient) of Suisun Bay, unlike any other metal measured. Cadmium is more available in fresher water as free ions. When the river water mixes with ocean water, the Cd combines with the chlorine in the seawater and becomes unavailable to the clams (see below). Lab experiments show uptake of Cd by *Potamocorbula* is greater at low salinities (<10 ppt) than at higher salinities, and there is some evidence that Cd may have an adverse effect on the clams.

CADMIUM VS. SALINITY



These results suggest two important insights: the bioaccumulation and the impacts of one contaminant do not necessarily explain the patterns of bioaccumulation of other contaminants; and inputs of trace metals cause biological signals that can be detected in the Estuary, as seen with silver and the clam reproduction data. They also underline our ability to integrate trace metal data with data on hydrodynamics, sediment dynamics, reproduction and biogeochemistry in a way that enables us to better understand this complicated ecosystem (Brown, SOE, 2001).



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SCIENCE
Questions

- How will continued changes in the hydrodynamics and sediment dynamics affect the availability of metals to the biota in the Estuary?
- What do the effects we see in the biota due to metal uptake mean to the ecosystem?
- How do these metals transfer within the food webs?

SELENIUM IN THE FOOD WEB

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U.S. Geological Survey

Introduced species may not only impact the ecology of the estuarine ecosystem, but may also change contaminant dynamics. This research identified a link between the introduction of the exotic clam *Potamocorbula*, a highly efficient bioaccumulator of selenium in the North Bay, and elevated Se concentrations in clam-based predators following the invasion.

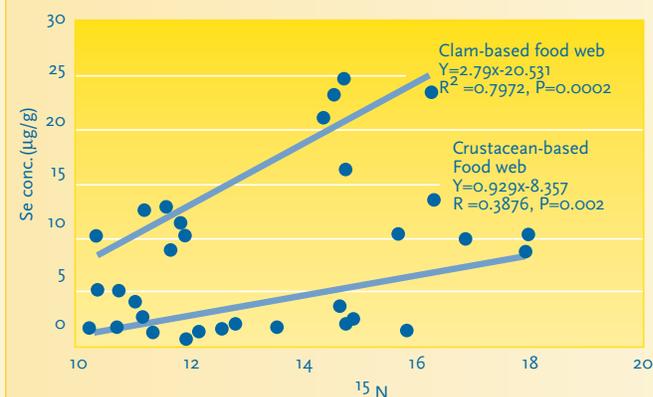
Selenium (Se) is an essential element that requires a delicate balance in nature. Insufficient quantities can cause deficiencies, while too much produces a potent reproductive toxin. Selenium's complex geochemistry and variable patterns of bioaccumulation have made it a challenge for managers to predict its fate and toxicity under variable hydrologic, geochemical and biological regimes typically found in estuaries.

Selenium studies conducted from 1986–1990 by the California Department of Fish and Game found elevated Se concentrations in S.F. Bay diving ducks and sturgeon. Over the same time period the clam *Potamocorbula* invaded the Estuary resulting in significant changes to the structure of the North Bay food

web. This led to questions regarding the relationship between the rise in predator Se levels and the clam invasion in the fall of 1986. Could a species invasion have implications for contaminant cycling in food webs?

Prior to 1986, a pelagic (in the water column) food web fueled by a seasonal phytoplankton bloom dominated Suisun Bay. There was also a benthic (on the bottom) food web with predators such as sturgeon and diving ducks, but their benthic food supply was unpredictable. The arrival of *Potamocorbula* in 1986 virtually eliminated the seasonal bloom that fed the pelagic food web and was associated with a decline in several species of mysid shrimp and zooplankton, apparently due to a lack of food. The energy tied up in the pelagic food web was redirected to the benthos and into a single species of clam. Unlike many bivalve species present before the invasion, *Potamocorbula* were spatially and seasonally abundant, surface dwelling, and palatable due to their soft shells. These factors resulted in

SELENIUM IN THE CLAM FOOD WEB



in the increasing selenium levels turning up in predators. In order to rule out contributions from other food sources, researchers conducted a study in the fall of 1999 analyzing invertebrates at the base of both the pelagic and benthic food webs for Se. The analysis revealed Se concentrations in clams (*Potamocorbula*) that were potentially toxic to predators and lower concentrations in crustacean invertebrates (amphipods, zooplankton and isopods). Laboratory biokinetic studies showed that clams and crustaceans accumulated Se at similar rates, but clams lost Se from their tissues at slower rates, resulting in higher Se tissue levels in the clams (Schlekat et al., 2000).

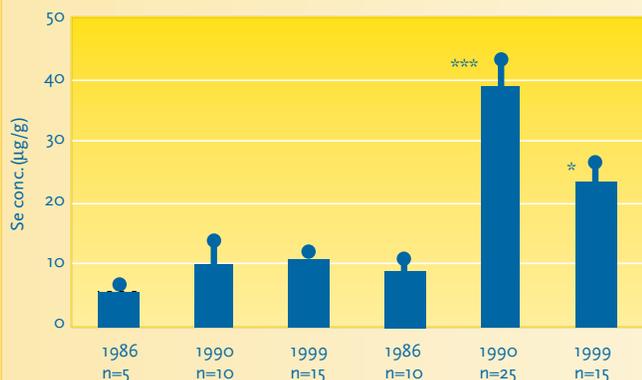
Researchers then used stable isotopes of carbon and nitrogen to distinguish between the clam-based and crustacean-based food webs in the North Bay and to quantify Se accumulation based on trophic position. Although Se was shown to accumulate through both food webs, the clam-based food web had a higher Se biomagnification potential than the crustacean-based food web (see above).

Researchers also compared absolute Se levels in striped bass and sturgeon, top predators of both food chains, before and after the invasion of the clam (see left). Significant increases in Se concentrations were observed following the introduction of *Potamocorbula* in sturgeon, a clam-based predator, between 1986 and 1990 and 1999,

Potamocorbula becoming a very important part of the Suisun Bay food web.

Researchers then found that *Potamocorbula* was a highly efficient Se accumulator compared to previously abundant bivalves, highlighting the invader's potential role

SELENIUM IN STRIPED BASS AND STURGEON



n= number of samples

but not in striped bass, a crustacean-based predator.

Continued monitoring of Se levels in *Potamocorbula* will be an important step in understanding future dynamics of Se in the Estuary. Se concentrations in clam-based predators suggest that dungeness crab, white sturgeon and splittail are potentially at risk for reproductive toxicity. Resource managers should be aware that introduced species may not only impact the ecology of a system, but may also change contaminant dynamics (Stewart, SOE, 2001).



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SCIENCE Questions

- How does the source of food particles influence the seasonal cycle of Se in *Potamocorbula amurensis*?
- Why do *Potamocorbula* have different Se concentrations than other bivalves?

X2 & THE ESTUARY'S BIOLOGICAL RESOURCES

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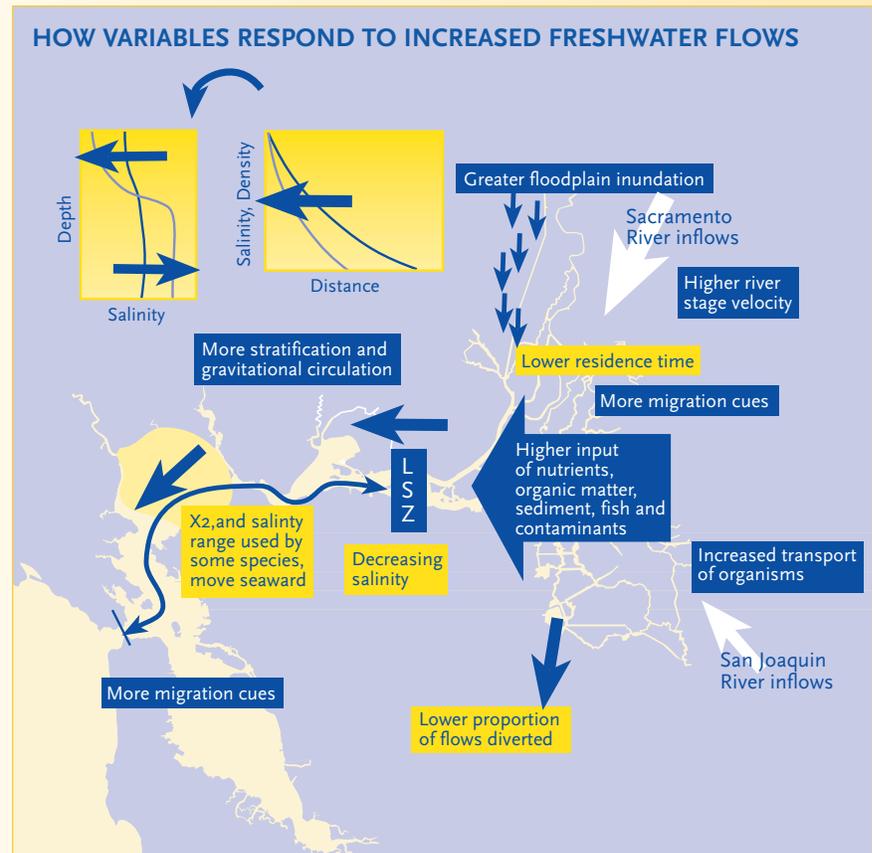
Freshwater flow is the principal cause of seasonal and longer-term variability in estuaries. Increasing freshwater flow can have many physical effects: it can inundate flood plains, increase loading and transport of materials and organisms, dilute or mobilize contaminants, compress the estuarine salinity field and density gradient, alter the spatial distribution of salinity and temperature, increase stratification, and decrease residence time.

In the San Francisco Estuary we use "X2", the distance up the axis of the Estuary to where the near-bottom salinity is 2 psu, as an index of the physical response of the Estuary to flow. The abundance or survival of several estuarine-dependent

species increases with flow or, conversely, decreases with X2. These "fish-X2" relationships were used to justify salinity standards established in the Bay/Delta Accord of 1994.

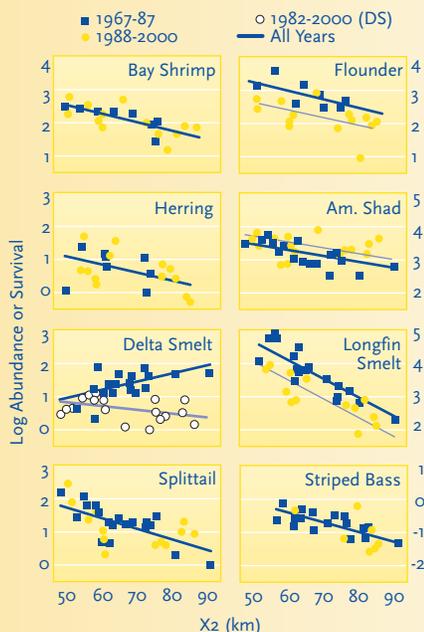
Many of the "fish-X2" relationships (see graphs) probably have little to do with the characteristics of low-salinity habitat, as we previously thought, but depend instead on other correlates of flow and X2.

The low-salinity zone does not appear to work through gravitational circulation (see Burau, p.39). The change in perspective from one in which the X2 relationships derive from the low-salinity zone as habitat to one in which they derive from some correlates of flow is based on the fact that there has never been any evidence that the low-salinity zone is a hotbed of flow-related variability. In fact, phytoplankton and zooplankton abundance in the low-salinity zone change rather little with flow.



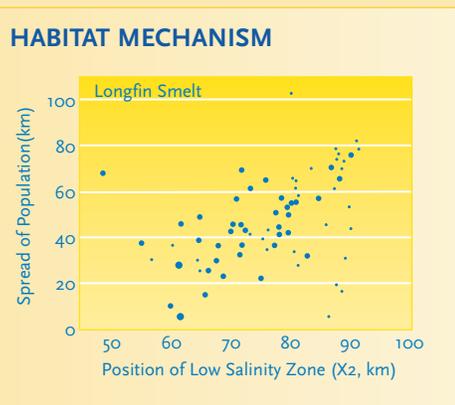
Estuarine species are related to freshwater flow through mechanisms that may involve a variety of flow-related variables occurring throughout the system. This schematic diagram shows what variables increase (blue boxes) and decrease (yellow boxes) with increased flow. LSZ refers to the low salinity zone.

FISH X₂ RELATIONSHIPS



Although some of the fish-X₂ relationships have changed over time, those for some fish and bay shrimp have retained the same slope, that is, the proportional response to X₂ (or its correlates) has not changed.

The mechanisms for the fish-X₂ relationships differ by species, and for most species at least two plausible mechanisms are consistent with the available data. Some species, such as longfin smelt, may have mechanisms more closely related to the low salinity zone than others like Pacific her-



Longitudinal spread of the population of longfin smelt as a function of X₂. Size of symbols indicates relative abundance. There is no evident tendency for longfin smelt to be more spread out in the Estuary when X₂ is seaward than when it is landward, suggesting that the area of their habitat does not increase with increasing flow.

ring and Sacramento splittail, whose abundance appears to relate to different mechanisms elsewhere in the Estuary. These mechanisms may include fish transport, by which eggs and larvae are moved more rapidly to rearing areas when flow is high than when it is low; movement of larvae into and up the Estuary, which may increase with gravitational circulation and therefore with flow; food supply, which may increase with increasing flow, although evidence for this is weak; water clarity, which decreases with increasing flow, possibly protecting young fish from predation; or habitat space, which may increase with increasing flow for some species.

Given the high cost of water needed to meet the Bay-Delta standards, continued periodic assessment of the status of the fish-X₂ relationships remains important (Kimmerer, SOE, 2001).

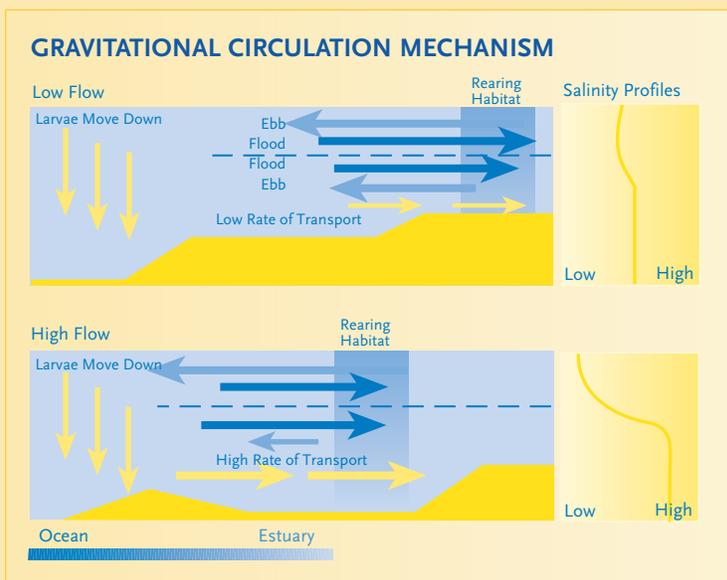
SCIENCE Questions

- What are the underlying mechanisms of the fish-X₂ relationships? The estuarine ecosystem does better when flow is high than when it is low, regardless of the mechanisms, so the main questions are: how much better does it need to be, for how much of the year, and in every year or just some?



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Conceptual diagram of changes in gravitational circulation as flow increases. At low flow (upper diagram), the low-salinity zone is in shallow water where gravitational circulation and stratification are inhibited by strong vertical mixing. Transport of sinking particles or larvae that swim downward is relatively weak. High flow (lower diagram) changes the situation through compression of the longitudinal density gradient, producing a larger density gradient, and through movement of the low-salinity zone into deeper water. Both of these effects increase the tendency for the water column to stratify and for gravitational circulation to be strong. This should result in more effective landward transport of particles and larvae.

**MODELING:
WHERE IS IT GETTING US?**

STEPHEN MONISMITH
Stanford University

Much of the focus on understanding hydrodynamic processes has come to rest on the use of numerical models. In an engineering context, they are particularly useful for examining how engineering or management actions will alter aquatic ecosystems. Such management actions might include the regulation of water supply and flows; the operation of pumps, water diversions and other facilities; or the construction of gates, shallow water habitat or runways. Large parts of the current environmental impact research for the San Francisco Airport runway expansion, for example, rely on studies done using two and three-dimensional circulation models. Similarly, evaluation of CALFED alternatives for improving Delta water flows, supply and endangered species management makes use of a sophisticated model of the linked channel network that comprises the Delta.

of biological versus physical mechanisms of retention, for example, in Northern San Francisco Bay near X2 (see p. 37 & 46), through the Golden Gate, or in the context of evaluating CALFED Environmental Water Account actions.

Three kinds of models have been used to help us understand aspects of the functioning of the Bay-Delta system and how this has been changed or will be changed by human actions. Physical models, such as the Bay Model in Sausalito, offer miniature replicas of the system for physical simulations of tidal flows. Statistical models manipulate data to explore relationships such as salinity as a function of flow, or species abundance as a function of flow or diversions. Dynamical models are generally based on fundamental principles like Newton's laws of motion or integration, or on low level empirical relationships like photosynthesis rate as a function of irradiance. They are designed to predict cause and effect, such as: salinity as a function of flow, gate operations or reconfiguration of channels; the physical movement of salt, parti-

sed by the Denton G model, now built into the DWR model, DWR-SIM, used to represent statewide water operations.

Examples of dynamical models include the several models of networks of open channels (pioneered originally by Hugo Fischer) to represent flows and transport in the Delta. CALFED has made extensive use of these to explore how different channel configurations may affect salinity and transport patterns. More recently, TRIM3D, a three dimensional circulation model developed by Vincenzo Casulli of Trento, Italy, and first applied to San Francisco Bay by Ralph Cheng of the U.S. Geological Survey, is being used to study effects on tidal hydrodynamics and sedimentation of different proposed S.F. airport runway expansions (S. Inagaki), how various materials (phytoplankton, contaminants, etc.) move around under the action of tides (Monsen), and most recently to examine sediment transport in the context of habitat restoration of upland streams (Mike MacWilliams and colleagues at Stanford).

To date, models have taught us that we can design facilities and operations in the Delta to achieve specific limited goals. The big challenges for the present are to extend these models to enable their effective use in real time in support of water project operations, to develop and test improved coupled models of physics and biology of the Bay-Delta, and to develop the capability of modeling long-term sedimentation in the Bay, Delta, and river systems. Nonetheless, the prospects for using models creatively to guide management actions in the future seem excellent (Monismith, SOE, 2001).



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"Models have taught us that we can design facilities and operations in the Delta to achieve specific limited goals."

Hydrodynamic models can also be used to help test hypotheses formulated by biologists about physical-biological interactions. These models improve our understanding of how the system works, exploring factors such as the role of tidal mixing in the dynamics of the ETM (see p. 39-41); the importance of shoals to phytoplankton blooms; the variability of residence time inside flooded islands; and the role of transport in recruitment of organisms or their habitat in the Estuary. By inserting particles with "behavior" into a circulation model, for example, transport of organisms can be predicted allowing an assessment to be made

cles or eggs; and the primary production of plants and animals at the base of the food web and nutrient uptake.

Jassby et al (1995) developed a statistical model of X2, for example, which linked flow to abundance of species at all trophic levels. This modeling work was important to the Bay-Delta Accord of 1994, in which EPA set a salinity standard requiring that freshwater flows be managed to maintain X2, the 2 psu isohaline, within a certain range of positions in Suisun Bay associated with species abundance. The X2 flow model was later super-

PERSPECTIVE

SUISUN'S BIOLOGICAL RESOURCES

CARL WILCOX
California Department
of Fish and Game

Suisun Marsh, prior to the arrival of Europeans in western North America, encompassed an extensive tidal marsh of approximately 60,000 acres. Dense riparian corridors shrouded tributary streams, such as Suisun and Green Valley creeks in the hills north and west of the marsh, and provided habitat for significant runs of steelhead. To the northeast lay expanses of grasslands and vernal pools (still visible today north of the Potrero Hills and at the Jepson Prairie).

The marsh itself historically consisted of large tidal plains bisected by large channels and containing ponds. Tidal flats were relatively rare in adjacent Suisun Bay. Freshwater inflows and runoff to the marsh varied, depending upon annual rainfall and snow melt patterns, but were not impaired by today's upstream diversions. Salinity in the marshes was fresher in the winter and spring and more saline in the summer and fall, a pattern that varied widely with periods of drought and precipitation, with the eastern marsh being fresher and the western marsh being more brackish, as it is today.

The marsh supported diverse fish, wildlife and plants. The same types of fish lived there that exist today, among them delta smelt, splittail, chinook salmon, steelhead, longfin smelt, starry flounder and tule perch. Even with introductions such as striped bass and gobies, the fishery remains dominated by native species. The abundance of fish helped sustain a large Native American population and later a large fishing industry.

The extensive bays, tidal channels, tidal ponds within the marshes, surrounding seasonal wetlands and riparian habitats also supported large numbers of waterfowl and

other birds. This abundance of waterfowl attracted market hunters to the marsh in the late 1850s. They focused on the western marsh's many-acre tidal ponds - which yielded varied bags of dabbling and diving ducks, as well as geese and other species of commercial value in nearby cities - and paved the way for the first duck clubs in the marsh 20 years later. Few examples of tidal ponds remain in today's marsh, except in the 3,000-acre Petaluma Marsh, the largest extant tidal marsh on the West Coast.

The marsh and adjacent grasslands also supported tule elk, antelope, deer and visiting grizzly bears and beavers, as well as enormous plant diversity, especially in the transitions between the tidal marshes and the adjacent uplands. These transition zones no longer really exist, due to diking and upland development.

Today the Suisun Marsh is a very different place — having changed from an open tidal marsh to a managed marsh within dikes. Efforts to reclaim the marsh for agriculture began in the late 1800s, and focused on Grizzly Island, with the reclaimed land used to grow asparagus, wheat and grapes and to graze dairy cattle. Duck hunters bemoaned the loss of marsh to farms. Reclamation in the western marsh lagged behind that in the eastern marsh, with the first reclamation district not being formed until about 1920.

By the 1950s, agriculture began to fail and farmlands were converted to managed marsh — only limited grazing now remains. Suisun Marsh today contains about 54,000 acres of managed marsh. Reclamation reduced the expanse of tidal marsh by 79%, to 13,562 acres, much of it in strips along the edge of tidal sloughs. The largest remaining tidal marshes are Hill Slough, Rush Ranch/Cutoff Slough and Peytonia Slough. Bays and channels account for 34,000 acres, shrinking by 17%, and tidal flats 1,124 acres, a loss of 53%.

Spring freshwater flows to the marsh, meanwhile, declined substantially with mid-1900s damming of the Sacramento and San Joaquin rivers and their tributaries. The reduction of inflow during the spring tends to increase salinity in the marsh along with subsidence of the managed marshes, and adversely affects the ability to manage wetlands and tidal marsh species of concern.

Managed marshlands, “managed” to optimize waterfowl habitat, dominate the Suisun Marsh landscape today. The marsh provides important habitat for ducks and shorebirds on the Pacific Flyway, particularly early in the fall and during drought when water from the Bay is available to flood the marsh early in the season. The marsh also supports a reintroduced herd of tule elk, and hosts salt-loving pickleweed, an important habitat for the endangered salt marsh harvest mouse. But railroad construction, dredging for navigation, flood control projects and further reclamation in the marsh have largely eliminated natural gradients from uplands to tidal habitats and now threaten, along with invasive plants, sensitive flora such as the Suisun thistle, soft birds-beak, Delta tule pea, and marsh aster.

The dilemma in Suisun Marsh, as in other parts of the San Francisco Estuary, is how to restore habitat for listed and sensitive species while balancing the needs of waterfowl and other species that depend on managed habitat. The Suisun Charter Process (see p.52) has been initiated to bring scientists and stakeholders together to develop a plan to restore tidal habitats for sensitive species while maintaining the hunting heritage of the marsh, which has been the driving force in the preservation of the largest wetland in western North America (Wilcox. SOE, 2001).



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SUISUN MARSH FACILITIES



MANAGING SUISUN MARSH

BARBARA MCDONNELL
California Department
of Water Resources

Since the mid-1970s, regulatory requirements and contractual obligations have required the California Department of Water Resources and the U.S. Bureau of Reclamation to maintain the unique brackish conditions of the Suisun Marsh. On the regulatory side, the two agencies were required to mitigate for state and federal water project exports. Instead of mandating that the projects release more freshwater for the marsh, the State Water Resources Control Board chose to set channel water salinity standards for Suisun. A compliance and monitoring network was established.

The Plan of Protection, developed in the mid-1980s, described a phased approach for meeting the standards through the construction of large facilities including water distribution channels, fish screens and the salinity control gates. The Plan served as a guide for marsh

District in 1987. This contract obligated the water projects to implement the facilities described in the Plan of Protection, and it provided for specific activities to assist landowners.

Monitoring later indicated that completed facilities provided greater water quality benefits than anticipated, and that management activities

dard (see p.37). Hydrodynamic modeling studies showed that salinity in the northwestern marsh would not be affected by increased outflow. Also, physical facilities were not felt to be effective compared to their environmental impacts. As a result of these conclusions, the agencies stopped work on Phases III and IV of the Plan of Protection and began negotiations on Amendment Three to the Suisun Marsh Preservation Agreement.

Amendment Three includes a negotiated series of specific actions and funding to assist landowners in managing their property as waterfowl habitat. The specific actions were already authorized under the existing Regional General Permit (RGP) issued by the U.S. Army Corps of Engineers under Section 404 of the Clean Water Act and thought to be easy to implement. To address federal fish and wildlife concerns, Amendment Three also established the Suisun Marsh Preservation Agreement Environmental Coordination Advisory Team and identified mitigation funds for multi-species benefit.

In summer 2000, during a joint Section 7 consultation for Amendment Three and renewal of the regional permit, the U.S. Fish & Wildlife Service threatened to issue a jeopardy opinion. Also at this time,

“The Charter is like a shotgun marriage, it’s now in a rocky honeymoon but we haven’t had to call the marriage counselor yet. It’s not just about waterfowl and clapper rails and Suisun thistles and killing red foxes, it’s also about the heritage of Suisun Marsh as a historic hunting area. I think we can help both waterfowl and endangered species.”

CAY GOUDE
U.S. Fish & Wildlife Service

activities until the mid 1990s. In addition, the two agencies entered into the Suisun Marsh Preservation Agreement with the California Department of Fish and Game and the Suisun Resource Conservation

(flood/drain cycles) conducted on private lands by individual landowners have a big influence on habitat. In addition, the State Water Board released Decision I64I increasing Delta outflows under the X2 stan-

the CALFED Suisun Marsh Levee Investigation Team released its draft report describing the effects of uncontrolled levee breaches in Suisun on Delta water quality. The report recommended that Suisun levees be included in the CALFED Levee Integrity program. Tensions between the agencies grew and stalled the planning and permitting process. Also at this time, the CALFED Record of Decision was signed, and agency management agreed that a jeopardy opinion was unacceptable. Instead, in November 2000, CALFED stepped in and tasked the agencies, including U.S. Fish & Wildlife, to come up with a coordinated and comprehensive solution for Suisun Marsh and develop a new Charter for resolving the conflicts that had escalated over Amendment Three, the Regional General Permit, the levee investigations, and endangered species recovery.

Since fall 2000, the Charter Group has been meeting to address the issues in a comprehensive way (see next page). The goal of the Charter, they agreed to in spring 2001, is to: "Develop a regional plan that balances implementation of the CALFED program, the Suisun Marsh Protection Agreement, and other management and restoration pro-

“The western marsh was developed for waterfowl hunting and the eastern marsh for agriculture. The Suisun Marsh has 120 years of waterfowl hunting heritage and more than 158 privately owned properties managed as water habitat. These brackish wetlands provide irreplaceable values to the resident population of wildlife and migratory birds of the Pacific flyway. These resources need to be protected and enhanced to maintain their current value.”

STEVE CHAPPELL
Suisun Marsh Resource Conservation District

grams within Suisun Marsh in a manner responsive to the concerns of stakeholders and based upon voluntary participation of private landowners.”

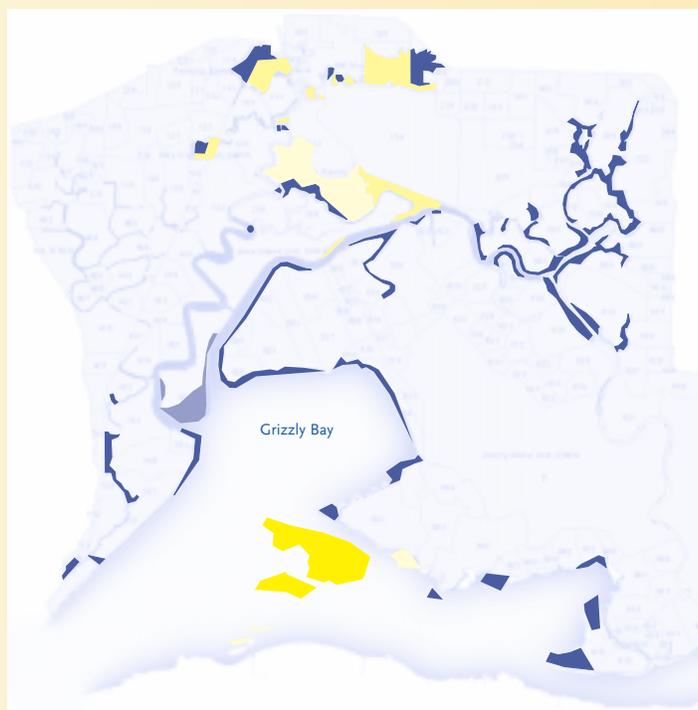
The Charter agencies acknowledge that there are difficult issues to deal with in determining an overall balance between water quality needs, landowner needs, levee needs and endangered species recovery needs and are developing a long-term

implementation plan. The plan will likely be a programmatic document with detailed specific actions addressing different needs on an equal basis, as well as integrated provisions for overall improvement to the beneficial uses of the marsh (McDonnell, SOE, 2001).



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SUISUN TIDAL MARSH OWNERSHIP AREAS



- Private
- Navy
- Dept of Fish & Game
- Solano County
- Suisun Resource Conservation District
- Ownership Boundaries

**SYNERGISTIC SOLUTIONS:
MEETING SUISUN'S
ENDANGERED SPECIES,
HERITAGE USE AND WATER
QUALITY NEEDS**

CHRIS ENRIGHT
California Department
of Water Resources

Until recently there has been a deep divide in views about resource protection needs in the Suisun Marsh. Private landowners in the marsh value the waterfowl hunting heritage and need assurance that restoration actions will not diminish traditional land use through regulation. Regulatory agencies require conservation measures that protect endangered species with a high degree of certainty. The water agencies have contractual obligations and public trust responsibility to mitigate for the impacts of state and federal projects and protect water quality.

There is growing recognition of a synergy between solutions for the marsh that would exceed all the parties' needs. Emerging wetland restoration science is uncovering solutions that protect and enhance beneficial uses for everyone. The integration of innovative habitat levee designs, microtidal diked wetland management, selected intensive management actions, emergency flood planning, and tidal marsh

Habitat Levee Design

Habitat levees are designed to re-establish facsimiles of marsh topographic gradients. They are lower, wider, and more gently sloping and vegetated than conventional levees, and they may be overtopped during storm surges with nominal erosion or destabilization. Periodic flooding of lower edges of habitat levees may promote dense, tall, low marsh vegetation, which provides cover for resident native marsh wildlife. Linear bands of upper marsh vegetation may develop higher on the habitat levee slope. Intermittent overtopping by spring tides will flood out terrestrial predator dens (rats, raccoons, skunks,

fox) where they are not compatible with local management priorities and endangered species recovery.

Lower crest elevations and vegetated slopes will also: facilitate the dispersal of tidal litter, an important natural component of tidal refugial habitat; minimize levee erosion and eliminate maintenance requirements; and slow subsidence compared to levees capped at higher elevations. Elimination of the recurrent disturbance cycle associated with dike erosion and maintenance may also reduce the competitive advantage of many non-native plants.

restoration, signals a turning point in planning the future of the Suisun Marsh.

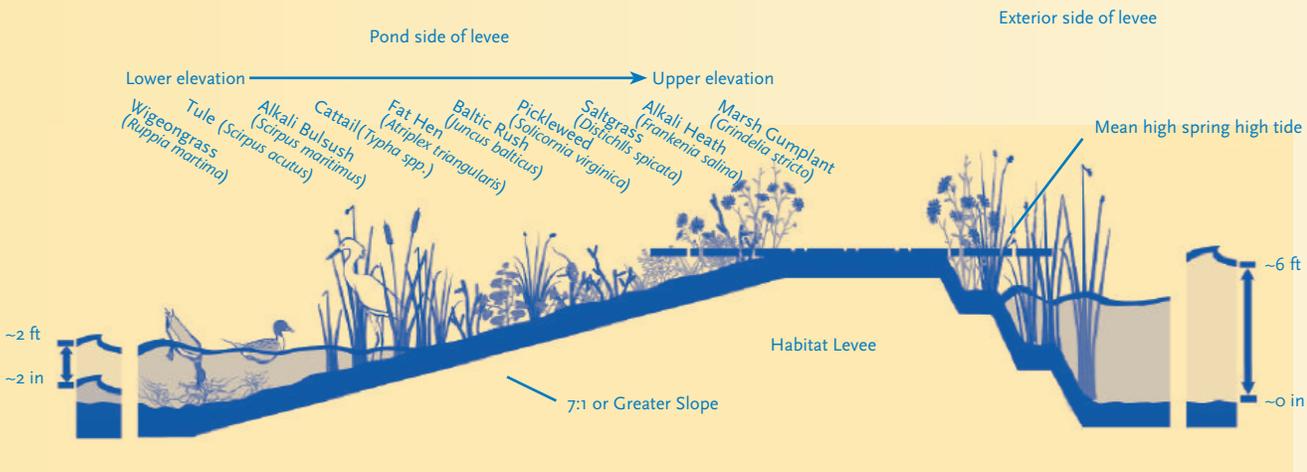
Agency and stakeholder participants in the Suisun Marsh Charter Implementation process are now working together to realize this potential. The developing plan will implement CALFED Ecosystem Restoration Program goals for Suisun Marsh. Everyone agrees that the solution package must co-equally meet the fundamental needs of all parties including endangered species recovery, enhancement of current uses, and water quality protection.

The synergy among the emerging solutions is exemplified by habitat levees constructed in concert with microtidal wetland management on subsided land. This integration could provide duck, salt marsh harvest mouse, and fish habitat, while enhancing flood control and Delta water quality protection, controlling subsidence, negating fish screen requirements, stabilizing soil chemistry, and reducing regulation (Enright, SOE, 2001).



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MICROTIDAL POND MANAGEMENT FEATURES

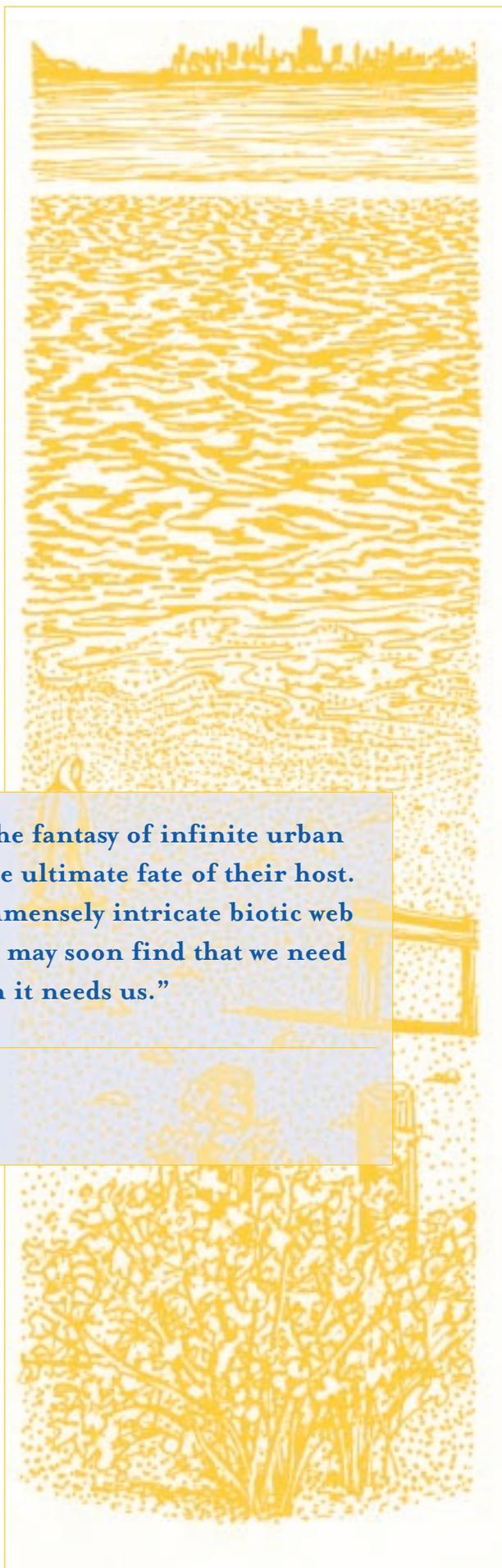


RESTORATION

Bay

“Our economy remains predicated upon the fantasy of infinite urban growth, as mindless as are cancer cells to the ultimate fate of their host. In this case, the victim appears to be the immensely intricate biotic web which shows alarming signs of collapse. We may soon find that we need phytoplankton far more than it needs us.”

GRAY BRECHIN
U.C. Berkeley



WATERSHED MANAGEMENT FOR URBANIZING ESTUARIES

TOM SCHUELER
Center for Watershed Protection

Urbanization poses a strong challenge to watershed managers seeking to maintain the quality of estuaries and the streams that feed them. The greatest threat to estuaries continues to be the conversion of natural spaces to car habitat and impervious spaces.

The amount of impervious cover (i.e., concrete and asphalt) in a watershed is a good overall indicator of the severity of urbanization's impacts. Stream quality correlates directly with the amount of impervious cover in the watershed, and a relatively small amount of development can have significant impacts on streams (see chart).

REMOVAL RATES FOR STORMWATER TREATMENT PRACTICES (STP)

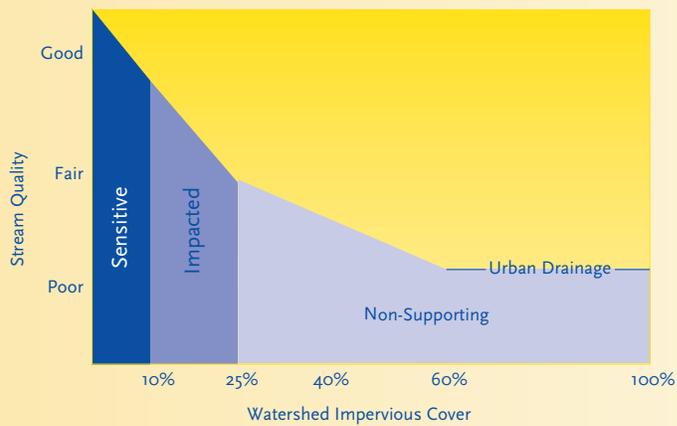
STP	Total P	Total N	TSS
Group Dry	19%	25%	47%
Ponds Wet	51%	33%	80%
Ponds Wetlands	49%	30%	76%
Filters	59%	-	81%
WQ Swales	34%	38%	86%

Median nitrogen, phosphorus and total suspended solids (TSS-TK) removal rates measured for five kinds of stormwater treatment practices. Rates are based on 134 performance monitoring studies conducted across the nation.

Source: Center for Watershed Protection

Impervious cover also contributes to coastal runoff polluted with a variety of contaminants, including nitrogen, bacteria, PAHs and heavy metals. The impacts of this runoff can include sharp increases in nitrogen loads, harmful algae blooms, bans on shellfish harvesting, swimming prohibitions, and marina hotspots. Coastal runoff can also affect tidal creeks, creating salinity fluctuations, declines in aquatic communities and fish, and dramatic increases in nitrogen and bacteria levels.

RELATIONSHIP BETWEEN IMPERVIOUS COVER AND STREAM QUALITY



How 26 different aquatic indicators respond to different levels of impervious cover. At 30% cover there is a decline in sensitive taxa; at 15-20% cover, a decline in food variety and abundance; at less than 10% cover, chronic fecal and coliform contamination.

There are eight primary tools that can be used with varying degrees of effectiveness to mitigate the impact of development. These tools include the development of local watershed plans that adjust zoning to be consistent with desired stream and estuarine quality objectives, as well as land conservation, stream buffers, better site design to reduce impervious cover, erosion and sediment control, stormwater treatment practices, non-stormwater discharges and watershed education and stewardship programs. Each of these tools must be adapted to reflect the intensity of development within the watershed.

Restoring urban watersheds is challenging. However, even communities with watersheds that are more than 25% impervious cover can restore them using the "smart watershed" model (see sidebar). Whatever the approach, it is important for restoration scientists to avoid worshipping at the altar of complexity and to keep things simple (Schueler, SOE, 2001).



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SMART WATERSHED PRINCIPLES

1. Engage in small watershed restoration planning
2. Map and analyze subwatersheds
3. Rapid assessment of stream corridors
4. Integrate water quality monitoring
5. Provide adequate funding for programs
6. Conserve natural area remnants
7. Implement watershed retrofits
8. Implement stream restoration
9. Eliminate untreated sewage discharges
10. Engage in watershed forestry
11. Reclaim public lands
12. Implement smart sites principles in municipal construction
13. Target education efforts to reduce watershed pollution
14. Intensively involve community in restoration planning
15. Launch pollution prevention campaigns
16. Train municipal employees in pollution prevention
17. Maximize opportunities for personal stewardship

WATERSHED RESTORATION STRATEGIES

LAUREL COLLINS
Watershed Sciences

Geomorphic field analyses of conditions in streams throughout Bay Area watersheds can help us identify and prioritize watershed restoration strategies. Examples from nine different stream assessments illustrate the usefulness of such analysis, and report on the status and relative importance of processes operating on Bay Area streams.

Researchers studied each of the nine watersheds to determine changes in the supply and distribution of water and sediment since the

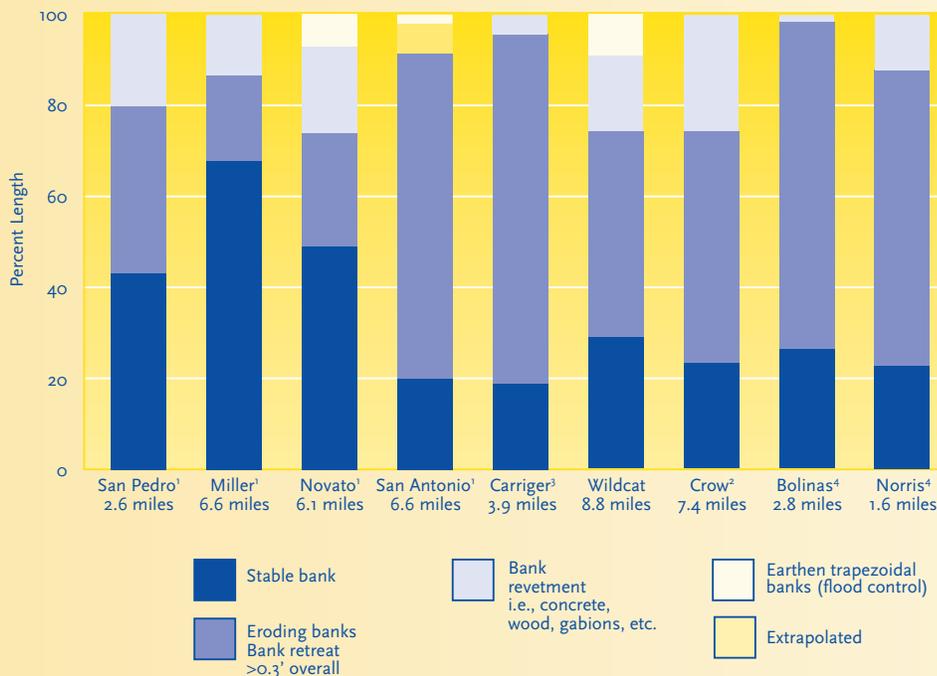
time of non-native settlement. By evaluating the relative importance of different geomorphic processes and by establishing historical channel conditions, a useful picture of local variation and the impacts of early land use practices has emerged that helps explain current physical conditions and inform restoration approaches.

Restoration can involve various elements such as increasing aquatic or riparian habitat, removing migrational barriers, or creating a stable self-maintaining system. One current challenge for land managers and regulators is how to approach restoration at the watershed scale, rather than the reach or lot scale. Restoration strategies need to go beyond piecemeal sections and short

reaches on mainstem channels and involve entire systems from the hillsides to the tides, integrating efforts to restore tidal marshes and headward tributary channels with those on mainstem streams.

A method of prioritization for Bay stream restoration projects could be developed by comparing standardized measurements on different watersheds. Among the prominent factors in Bay watersheds that continue to create instability and sustain degraded habitat are the loss of tidal marshlands, the loss of capacity in tidal sloughs, diminished base flow in streams, reductions in groundwater level, increased peak runoff, loss of riparian trees, headward erosion of tributary channels, and accelerated rates of bed incision, bank erosion, and sediment supply.

EXISTING BANK CONDITIONS FOR MAINSTREAM SITES



- 1 Study site begins upstream of maximum extent of high tides.
- 2 Study site begins at confluence with Cull Creek, both are tributaries to San Lorenzo Creek.
- 3 Study site begins at confluence of Felder Creek.
- 4 Study site begins at confluence of Crow Creek.

The physical condition of the nine different watersheds researchers studied is highly varied. For example, Miller Creek, considered to be in relatively good condition along its lower half, has 68% of its mainstem bank length measured as stable. Yet many other creeks have less than 25% of their banks measured as stable (see left). About 26% of Crow Creek's 7.4 mile length has artificial bank revetments, the highest among all the streams studied. Unfortunately, ad hoc construction of artificial bank revetments in all the streams has been the usual mitigation for bank erosion, leading, in terms of cumulative impacts, to further loss of natural stream functions and increased rates of bed incision. Future restoration strategies should give priority to alternative approaches such as biotechnical solutions, reconstruction of channel geometry, or natural stabilization following efforts to reduce runoff.

These charts show the various bank conditions of the Bay Watershed Study Sites. Both right and left banks were assessed for banks above and below bankfull elevation, thus terrace banks that are influenced by flood flows are included. Dark blue represents banks that show less than 0.25 feet of retreat over the entire bank height since the time of non-native settlement, which was established for each site. Dark blue sites are considered stable banks. The medium blue represents banks with greater than 0.25 feet of overall retreat. Many banks have had several feet or more of retreat. The light blue represents banks with revetments such as concrete, rock rip rap, or other artificial structures.

Reducing runoff into the headward tributaries is a key factor for reducing channel extension. Increased runoff from land use practices has caused side channels to extend upslope into previously unchannelized hillsides and downhill into previously unchannelized alluvial fans, leading to increases in overall drainage density and the amount of connection between side channels and the mainstem channel. The increase in drainage density (length of channel per unit area) has increased peak floods and flood frequency. Creation (or restoration) of alluvial fans on small tributary channels, to disconnect them from the main streams, could prevent the tributary supplies of sediment from reaching the mainstem. Such efforts would also reduce downstream flood hazards, raise the water table at valley bottoms, enhance mainstem baseflow, and thus improve riparian and in-stream biological resources.

Downcutting of the bed surface, as a result of historical and present land use practices, has been as dominant a process as bank erosion in many Bay watersheds. It often leads to bank erosion and increased sediment supply, creating highly unstable channels during large flood events. In San Pedro and Wildcat creeks the amount of sediment supplied from bed erosion has exceeded that supplied from bank erosion by 3 and 7 times, respectively (see chart). This factor has been grossly overlooked as an important sediment source for many highly entrenched streams (see also Williams p.22).

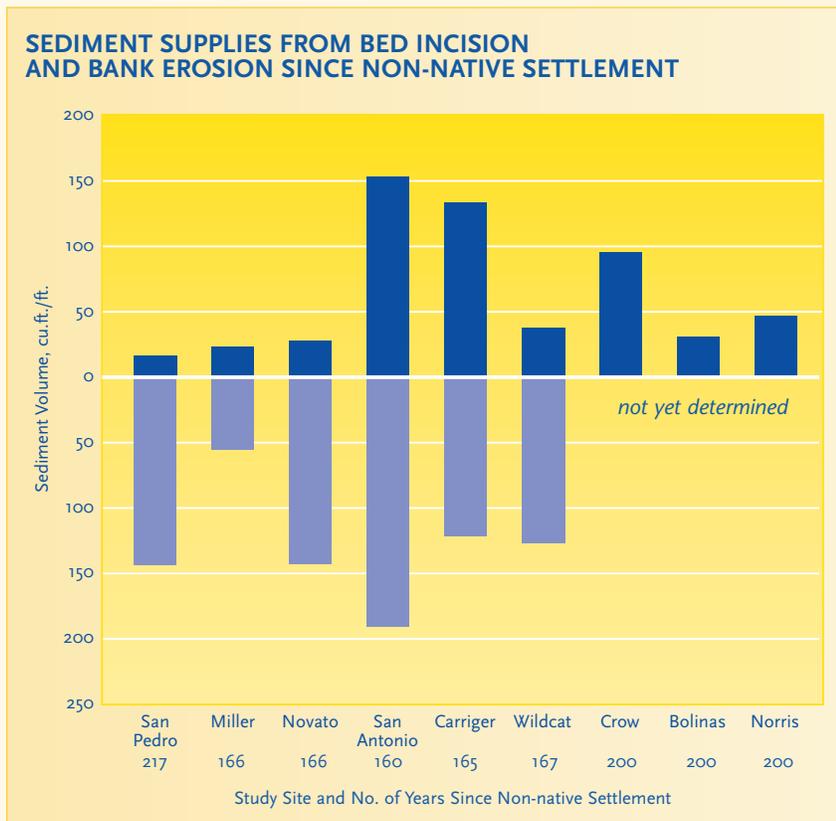
Measurements of other channel attributes can also be compared including amount and distribution of low flows; amount of remaining stable channel, aquatic and riparian habitat; pool and large woody debris spacing; numbers and types of aquatic species (existing and his-

toric), amount of dredging, etc. Consider pool conditions in Crow Creek for example. Data show that it does not have adequate pool spacing even though it is a perennial stream (see pie charts p.57). The number of pools associated with woody debris, which benefits fish habitat, is relatively small. San Antonio Creek has the worst pool spacing, even fewer pools associated with wood, and much of its channel is dry even though it used to be perennial and an excellent steelhead fishery. A restoration strategy for San Antonio Creek, which would increase summer base flow and pool spacing, could involve restoration of its historic headwater lake.

The results of these kinds of studies, when integrated with other important channel and watershed attributes, can allow us to develop a ranking system of overall stream condition and restoration priorities for the Bay region. By assessing the status of each of the important attributes that not only influence physical and biological condition, but also that are compatible and beneficial to the needs of the community living in the watershed, restoration strategies can be tailored to the individual stream and achieved by planning over the long-term. In the future, it will be important to standardize ways to compare attributes and sediment loads of different streams to provide a regional picture, and to develop a long-term goals process for watersheds as was done for Bay wetlands (Collins, SOE, 2001).

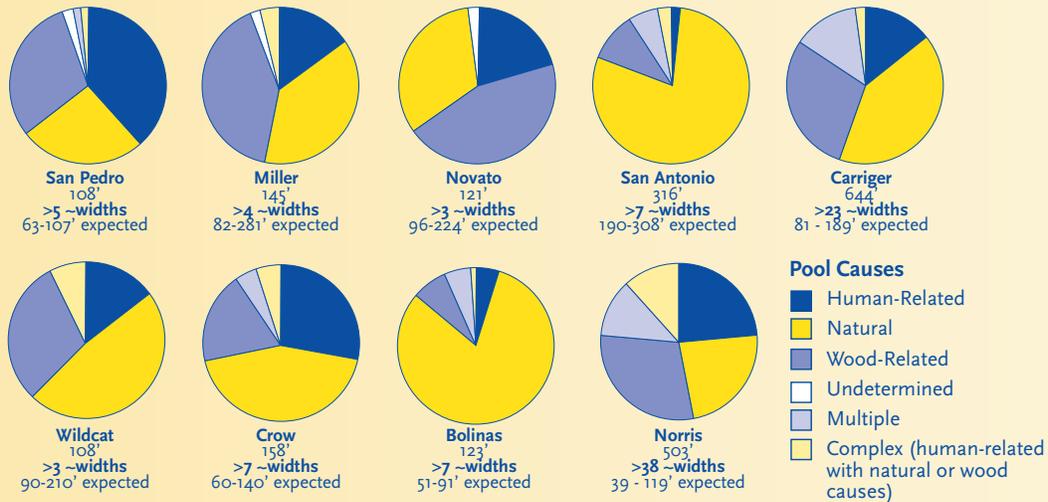


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Normalized volumes of sediment supplied per linear foot of mainstem channel from either bed incision (light blue) or bank erosion (dark blue) since the time of non-native settlement, which is shown as years for each watershed in the small boxes at the base of each graph. As can be seen, bed incision has been as important (if not more important) as bank erosion to contributing sediment to the San Francisco Estuary.

POOL FORMING MECHANISMS AND POOL SPACING FOR PERENNIAL POOLS GREATER THAN ONE FOOT DEEP FOR STUDY SITES



Note: Expected spacing is based upon 3 to 7 bankfull widths, which allows for a range of morphologic conditions that can include entrenched and confined channels.

These pie charts show the major pool forming mechanisms for the different Bay Watershed Study Sites. Pools formed by flow obstructions from bridge abutments, rock rip rap, or check dams are examples of human-related mechanisms (shown in dark blue). Natural pools are associated with bends, gravel bars, or bedrock abutments (yellow). Wood-related pools, although natural, are separated out to determine the influence of woody debris. This category includes large woody debris, live tree trunks and roots (medium blue). Combinations of these pool forming causes are shown as multiple and complex (light blue and light yellow). Average pool spacing is reported below the pie charts and the distance is compared to the average bankfull width for the study reaches.

SCIENCE Questions

- Is the contribution of sediment from the Estuary’s local watersheds much larger than thought? Have we underestimated the combined influence of disturbed local watersheds historically, in the early to mid-1800s, compared to the long-thought more important sediment contributions from the Sacramento and San Joaquin system?
- Are many of the mainstem channels currently responding to accelerated rates of erosion of tributary channels, particularly in grassland coast range streams and earth flow dominated terrains?
- What is the amount of sediment coming from grassland hillslopes from overland flow that is directly supplied to the streams at the channel head in grazed rangelands.?
- On appropriate tributary streams, is it possible to create or recreate natural functioning alluvial fans to decrease flood peaks, increase summer base flow, decrease sediment load, and increase biological diversity?

A STREAM RESTORATION PARTNERSHIP FOR THE SAN FRANCISQUITO WATERSHED

PAT SHOWALTER
San Francisquito
Watershed Council

The San Francisquito Watershed Council is a voluntary collaboration among 30 organizations interested in fostering a diverse and healthy watershed, valued as a natural and community resource, in a manner consis-

mal Joint Powers Authority to bridge the political gaps between the two counties and five cities of this small watershed, recognizing that the complex nature and expense of flood protection was beyond the expertise of a voluntary nonprofit collaboration. After the flood of record on February 3, 1998, local officials remembered the recommendation of the Watershed Council and worked to form the San Francisquito Joint Powers Authority. The Watershed Council is still actively involved in the authority as an Associate Member.

“Recognizing what kinds of projects this voluntary collaboration can accomplish, and those that are beyond its capacity, has been an important success factor.”

tent with public health and safety and respecting property rights. The Watershed Council is sponsored by the nonprofit Acterra and its predecessor, the Peninsula Conservation Center Foundation. Over the last seven years, a variety of partnerships between the signatory organizations have formed, disbanded and reformed to perform various projects around the watershed.

Recognizing what kinds of projects this voluntary collaboration can accomplish, and those that are beyond its capacity, has been an important success factor. In the latter case, the Watershed Council functions as a catalyst to inspire a better-suited organization to take action.

One example of the Watershed Council's approach addresses the high flood risk in the lower reaches of San Francisquito Creek. Due to the political complexities of the watershed, no major flood works or flood risk reduction plan has ever been implemented. The Watershed Council identified the need for a for-

In another example, the Watershed Council has been working to tackle barriers to steelhead trout migration, a serious problem for this ESA-listed threatened species. The Watershed Council secured a grant from the California Department of Fish & Game to fund an assessment of barriers to fish migration in the Bear Creek sub-basin. The resulting assessment identified 34 features impeding the fish, and suggested modifications to about half. Watershed Council volunteers modified seven logjams soon afterwards, and the Watershed Council wrote a grant to modify three other barriers. The most complex situation in the sub-basin is a water supply diversion dam, where the Watershed Council has served as a liaison between the owner and the Department of Water Resources to study possible modifications that would improve fish passage (Showalter, SOE, 2001).



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NORTH BAY WETLAND RESTORATION INVENTORY

STUART SIEGEL
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An inventory of North Bay restoration projects provides a new framework for evaluating the success of regional efforts to manage and restore wetlands to benefit fish and wildlife species.

Though wetland restoration has been going on for decades in the North Bay, early projects differed from more recent ones in size and purpose. Early projects were comparatively small, and often involved mitigation for wetlands lost to development nearby. Recent projects are comparatively large, and sponsored, in many cases, by agencies and non-profits working to promote recovery of the Estuary's wetland-dependent fish and wildlife resources.

Researchers compiled an inventory of completed and pending North Bay tidal, nontidal and mixed hydrology wetland restoration and enhancement projects within the historic margins of tidal influence. They then mapped these projects based on the EcoAtlas GIS and prepared an accompanying database providing basic information on each (name, sponsorship, size, type, and status).

For the inventory and map (see p.60), wetlands were classified into three groups based on their hydrologic regime: tidal, non-tidal, and mixed. Presence or absence of full, unrestricted daily tidal exchange classifies sites as "tidal." Sites without full exchange are "non-tidal" and have one or more hydrologic regimes: muted tidal (restricted daily tidal exchange), managed tidal (periodic tidal flooding and draining), and freshwater (rain-fall and runoff). Sites combining tidal marsh with any type of non-tidal marsh are labeled "mixed." In all cases soil and water salinity levels varied widely within and between sites, and seasonally.

Based on the inventory, a total of 30 projects comprising 1,501 acres of tidal marsh and 3,560 acres of non-tidal marsh had been constructed (see tables). Planned projects will improve an additional 17,767 acres in a total of 30 projects. The study area for S.F. Airport runway expansion mitigation sites in North Bay baylands totals 18,587 acres. The Habitat Goals project (see p.61) recommends about 28,000 acres of tidal marsh be restored in the North Bay by 2020 to rebuild ecosystem health –about 65% more than this

NORTH BAY WETLAND PROJECTS AND BAYLANDS

STATUS	TYPE	ACRES	NUMBER OF PROJECTS
Restoration and Enhancement Projects Constructed			
	Tidal Marsh	1,501	14
	Nontidal Marsh	3,560	16
Subtotal, Constructed:		5,061	30
Planned	Tidal Marsh	12,035	13
	Nontidal Marsh	2,758	11
	Mixed Tidal/Nontidal	2,974	6
Subtotal, Planned:		17,767	30
Total, Projects:		22,828	60
Other Baylands Within Historic Margins of the Estuary			
Existing	Wildlife Management Area	3,306	
	Tidal Marsh	14,843	
	Nontidal Lagoons	660	
Naturally Restored	Tidal Marsh	584	
Unprotected Lands	Diked Baylands	23,455	
Total, Other Baylands:		42,848	
North Bay Baylands – Projects and Other Baylands Combined			
TOTAL BAYLANDS:		65,676	
SFO Runway Expansion Mitigation Sites in North Bay Baylands Study Area			
	Planned Projects and Diked Baylands	18,587	

PROJECT SPONSORS & SITE OWNERS

ORGANIZATION	STATUS	TYPE	ACRES	NUMBER OF PROJECTS
USFWS	Constructed	Tidal	306	1
		Nontidal	46	1
	Planned	Tidal	4,769	4
		Nontidal	90	2
		5,211	8	
CDFG	Constructed	Tidal	873	3
		Nontidal	2,509	4
	Planned	Tidal	4,347	1
		Nontidal	1,731	4
		9,460	12	
CSCC	Constructed	Tidal	322	2
		Nontidal	1,051	2
	Planned	Tidal	4,535	3
		Mixed	2,473	3
		8,381	10	
MAS	Constructed	Tidal	28	3
		Nontidal	287	2
	Planned	Tidal	322	3
		Nontidal	186	1
		823	9	
Corps*	Constructed	Tidal	303	1
		Nontidal	938	2
	Planned	Tidal	5,203	3
		Mixed	2,434	2
		8,878	8	

USFWS = US Fish and Wildlife Service

CDFG = California Dept. of Fish and Game

CSCC = California State Coastal Conservancy

MAS = Marin Audubon Society

*U.S. Army Corps of Engineers provides federal cost sharing and technical services

NORTH BAY WETLAND RESTORATION & ENHANCEMENT PROJECTS



Source: Stuart Siegel

NORTH BAY PROJECTS BY WETLAND TYPE

TYPE	STATUS	ACRES	NUMBER OF PROJECTS
Tidal Marsh	Constructed	1,501	14
	Planned	12,035	13
	Subtotal:	13,536	27
Nontidal Marsh	Constructed	3,560	16
	Planned	2,758	11
	Subtotal:	6,318	27
Mixed Tidal-Nontidal	Planned	2,974	6
Total:		22,828	60

inventory shows as currently constructed or planned (13,536). The report also calls for 17,000 acres of non-tidal restoration, about 6,318 of which are constructed or planned. Another 2,974 acres of mixed hydrology projects are also planned.

The inventory and map provide a framework for evaluating the status and effects of regional efforts to manage and restore tidal and non-

tidal wetlands to benefit fish and wildlife species. It shows the spatial relationship between completed, planned, and existing wetland areas and it identifies diked baylands in private ownership that could be restored or subject to development. Uses of this inventory include site selection for regional monitoring efforts and scientific research, and identification of parcels for acquisition and restoration (Siegel, SOE, 2001).

SCIENCE

Questions

- How can the sediment deficit needed to restore marsh plain elevations on diked, subsided baylands be addressed in an environmentally-sound manner?
- How can we promote open water habitats for migratory shorebirds and waterfowl while restoring diked baylands to tidal marsh?
- How can vital infrastructure lying behind dikes and below sea level, such as roads and rail, be protected at reasonable cost?

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PERSPECTIVE

ECOSYSTEM GOALS
PROJECT UPDATE

MICHAEL W. MONROE
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In June 1999, the San Francisco Bay Area Wetlands Ecosystem Goals Project released its report entitled *Baylands Ecosystem Habitat Goals*. The report recommended the kinds, amounts, and distribution of wetlands and related habitats that are needed to sustain diverse and healthy communities of fish and wildlife resources in the San Francisco Bay Area. It was the culmination of more than three years of work by scientists, resource managers, and other Goals Project participants.

The *Goals Report* calls for restoring more than 60,000 acres of diked baylands to tidal salt marsh. It also stresses the need to manage large areas of shallow saline ponds for

shorebirds and waterfowl and to restore and enhance transitional habitats, riparian vegetation, and seasonal wetlands.

Last year, the Goals Project issued a companion document to the Goals Report entitled *Baylands Ecosystem Species and Community Profiles*, which presents information on the life histories and environmental requirements of many of the plants, fish, and wildlife species for which the Goals were developed.

Nearly 3,000 copies of the *Goals Report* have been distributed, and many public and private entities have embraced the Report's recommendations and begun to use them as guidance as they seek to improve habitat conditions around the Bay (Monroe, SOE, 2001).

Since the 2001 conference, progress has been made in establishing a new institutional framework for coordinating sound habitat restoration throughout the Bay Area

in the coming years. The San Francisco Bay Area Wetlands Restoration Program, a partnership of public agencies involved in implementing wetlands action items in the S.F. Estuary Project's *Comprehensive Conservation & Management Plan* for the Bay and Delta and the broad recommendations in the Goals Report, is now underway. The program aims to: improve inter-agency communication and coordination; improve projects through early review of design concepts (before they reach permitting); reduce delays and project costs; and foster greater understanding and accountability through design review and improved monitoring (Monroe, Pers. Comm., 2002).

MORE INFO?

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www.sfei.org/sfbaygoals/index.html
www.abag.ca.gov/bayarea/sfep/reports/Species.pdf
www.sfwetlands.ca.gov/home.html



PLANT SPECIES IN DECLINE IN THE S.F. BAY ESTUARY

PETER R. BAYE
U.S. Fish & Wildlife Service

Many native wetland plants are on the wane in the S.F. Estuary. Among the principal causes are declining quality of marsh habitats, lack of suitable habitat in restored marshes, and the residual effects of past destruction of both habitats and plant populations. One threat to local vascular plant communities currently stands out among all others, however, in terms of its ability to permanently change the structure and function of all tidal marshes: the rapid invasion of the San Francisco Bay Estuary by nonnative plants.

The most advanced and aggressive invasion is a hybrid swarm of cordgrass derived from a founder population of smooth cordgrass, *Spartina alterniflora*, from the Atlantic coast. The hybrid swarm interbreeds with, and assimilates, native populations of Pacific cordgrass, *Spartina foliosa*, and

results in new populations that behave ecologically like Atlantic smooth cordgrass. Recent genetic analysis from U.C. Davis indicates progressive interbreeding will assimilate and extirpate native *Spartina foliosa* regionally, replacing it with a more robust, competitively superior non-native hybrid type (see also p.13).

Hybrid smooth cordgrass populations in San Francisco Bay have demonstrated that they are potent geomorphic and ecological agents. Unlike native Pacific cordgrass, the Atlantic-type hybrid cordgrasses rapidly colonize unsheltered intertidal flats and marsh pans, and fully colonize the beds and banks of small tidal creeks and ditches, resulting in a relatively homogeneous marsh. Hybrid smooth cordgrass may also eliminate estuarine sand spits and beaches. Estuarine beaches are among the rarest remnant habitats in the region, and important for recovery of some endangered species.

In contrast with the more complex structure of sinuous, branched sloughs and mosaics of pans in

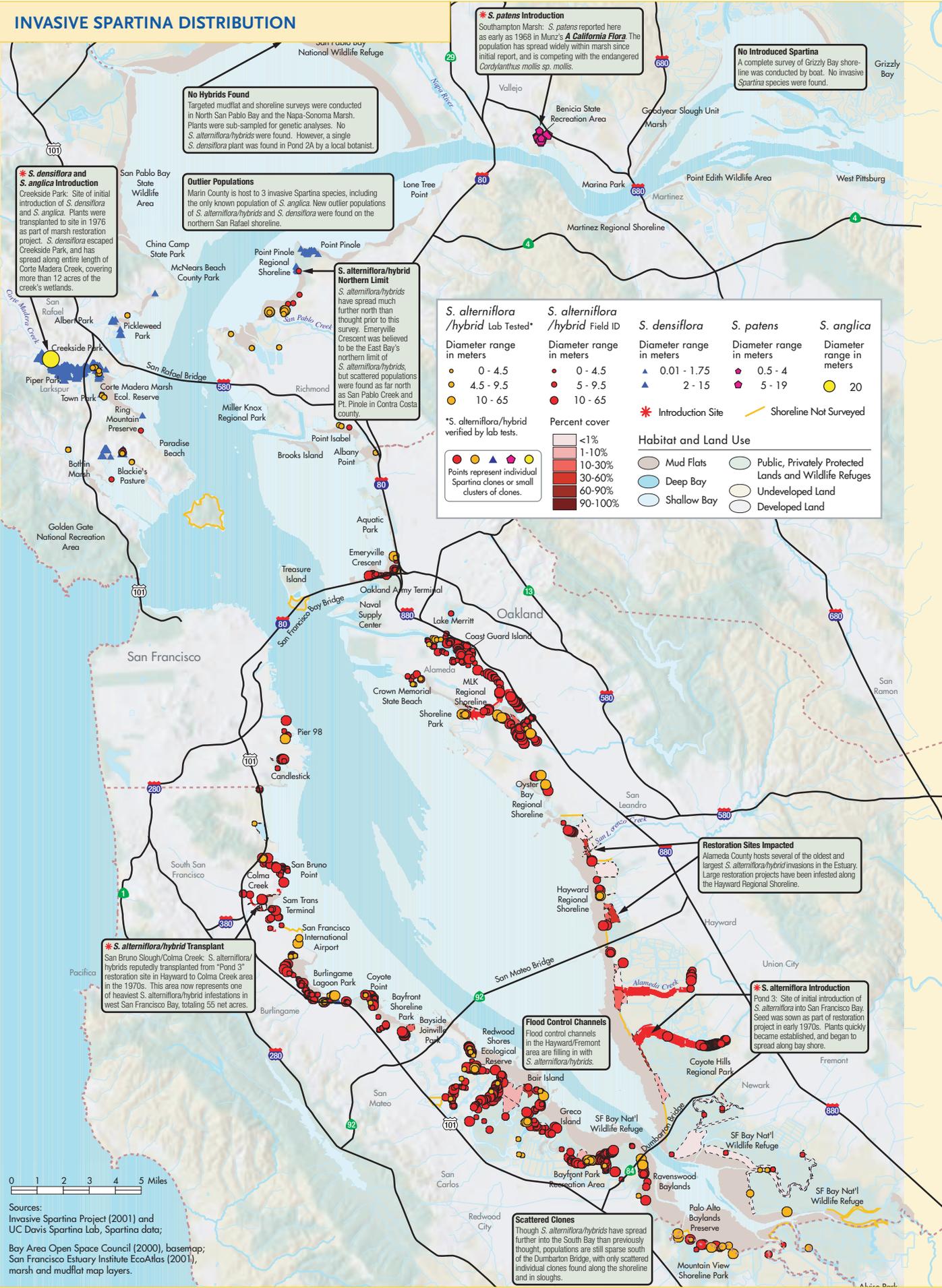
native San Francisco Bay tidal marshes, natural Atlantic salt marshes include extensive "short form" *Spartina alterniflora* vegetation on poorly-drained extensive marsh plains (smaller drainages and creeks choked with cordgrass), and restriction of "tall form" *S. alterniflora* to well-drained banks along Atlantic marsh edges (see below and p.64). If restoration trends progress towards Atlantic-type marsh structure and its vegetation patterns, it is doubtful whether tidal marsh restoration objectives can be achieved for a wide range of endangered and other native species.

Other invasive cordgrasses likely to dominate high tidal marsh zones have also invaded the Estuary, but have not spread as rapidly as the *Spartina alterniflora* hybrids. These include Chilean cordgrass, *S. densiflora*, a tough bunchgrass; and salt-meadow cordgrass, *S. patens*, the Atlantic high marsh counterpart to *S. alterniflora*, which forms extensive meadows of dense, fine shoots.

HOW SMOOTH CORDGRASS INVADES BAY TIDAL HABITATS



INVASIVE SPARTINA DISTRIBUTION



*** S. densiflora and S. anglica Introduction**
 Creekside Park: Site of initial introduction of *S. densiflora* and *S. anglica*. Plants were transplanted to site in 1976 as part of marsh restoration project. *S. densiflora* escaped Creekside Park, and has spread along entire length of Corte Madera Creek, covering more than 12 acres of the creek's wetlands.

No Hybrids Found
 Targeted mudflat and shoreline surveys were conducted in North San Pablo Bay and the Napa-Sonoma Marsh. Plants were sub-sampled for genetic analyses. No *S. alterniflora*/hybrids were found. However, a single *S. densiflora* plant was found in Pond 2A by a local botanist.

Outlier Populations
 Marin County is host to 3 invasive Spartina species, including the only known population of *S. anglica*. New outlier populations of *S. alterniflora*/hybrids and *S. densiflora* were found on the northern San Rafael shoreline.

S. alterniflora/hybrid Northern Limit
S. alterniflora/hybrids have spread much further north than thought prior to this survey. Emeryville Crescent was believed to be the East Bay's northern limit of *S. alterniflora*/hybrids, but scattered populations were found as far north as San Pablo Creek and Pt. Pinole in Contra Costa county.

*** S. patens Introduction**
 Southampton Marsh: *S. patens* reported here as early as 1968 in Munz's *A California Flora*. The population has spread widely within marsh since initial report, and is competing with the endangered *Cordyallanthus mollis* sp. mollis.

No Introduced Spartina
 A complete survey of Grizzly Bay shoreline was conducted by boat. No invasive *Spartina* species were found.

<i>S. alterniflora</i> /hybrid Lab Tested*	<i>S. alterniflora</i> /hybrid Field ID	<i>S. densiflora</i>	<i>S. patens</i>	<i>S. anglica</i>
Diameter range in meters	Diameter range in meters	Diameter range in meters	Diameter range in meters	Diameter range in meters
● 0 - 4.5 ● 4.5 - 9.5 ● 10 - 65	● 0 - 4.5 ● 5 - 9.5 ● 10 - 65	▲ 0.01 - 1.75 ▲ 2 - 15	◆ 0.5 - 4 ◆ 5 - 19	● 20

*S. alterniflora/hybrid verified by lab tests.

Percent cover

□ <1%
□ 1-10%
□ 10-30%
□ 30-60%
□ 60-90%
□ 90-100%

Points represent individual *Spartina* clones or small clusters of clones.

Habitat and Land Use

- Mud Flats
- Deep Bay
- Shallow Bay
- Public, Privately Protected Lands and Wildlife Refuges
- Undeveloped Land
- Developed Land

* Introduction Site

— Shoreline Not Surveyed

*** S. alterniflora/hybrid Transplant**
 San Bruno Slough/Colma Creek: *S. alterniflora*/hybrids reputedly transplanted from "Pond 3" restoration site in Hayward to Colma Creek area in the 1970s. This area now represents one of heaviest *S. alterniflora*/hybrid infestations in west San Francisco Bay, totaling 55 net acres.

Restoration Sites Impacted
 Alameda County hosts several of the oldest and largest *S. alterniflora*/hybrid invasions in the Estuary. Large restoration projects have been infested along the Hayward Regional Shoreline.

*** S. alterniflora Introduction**
 Pond 3: Site of initial introduction of *S. alterniflora* into San Francisco Bay. Seed was sown as part of restoration project in early 1970s. Plants quickly became established, and began to spread along bay shore.

Flood Control Channels
 Flood control channels in the Hayward/Fremont area are filling in with *S. alterniflora*/hybrids.

Scattered Clones
 Though *S. alterniflora*/hybrids have spread further into the South Bay than previously thought, populations are still sparse south of the Dumbarton Bridge, with only scattered individual clones found along the shoreline and in sloughs.

0 1 2 3 4 5 Miles

Sources:
 Invasive Spartina Project (2001) and UC Davis Spartina Lab, Spartina data;
 Bay Area Open Space Council (2000), basemap;
 San Francisco Estuary Institute EcoAtlas (2001), marsh and mudflat map layers.

Eradication of Chilean and salt-meadow cordgrass, and other infrequent non-native cordgrasses in the Estuary, is highly feasible, and has been initiated by the regional Invasive Spartina Project (see p.13). Eradication of the hybrid smooth cordgrass invasion is also underway, but remains complex, difficult, and costly in terms of natural and financial resources.

In contrast, the most serious invasive plant of brackish marsh plains, broadleaf pepperweed (*Lepidium latifolium*), has no regional control program. The rate and extent of *L. latifolium* spread increased alarmingly during the wet years of the late 1990s when tidal marsh salinities were relatively low. Like invasive hybrid smooth cordgrass, *L. latifolium* forms extensive dominant cover, often single-species stands, from creeping below-ground parts.

Many of the region's endangered plants are threatened by these invasions, as well as by habitat loss and other factors. The most critically endangered of these listed species is Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*). Its habitat is also under rapid invasion by perennial pepperweed. It survives as a few unstable local sub-populations in northern Suisun Marsh, but little research, management, or restoration has gone into its recovery.

While the population of endangered soft bird's-beak (*Cordylanthus mollis* ssp. *mollis*) continues to fluctuate, its overall distribution has neither declined nor recovered significantly in recent years. Research at U.C. Davis is now underway on reintroduction and restoration of this species. Endangered California sea-blite, long extinct in the Estuary, has been reintroduced experimentally to a restored salt marsh in the Presidio, San Francisco.

Numerous plant species of concern are subject to the same basic threats as legally protected plant species. Some, like Bolander's water hemlock (*Cicuta maculata* var. *bolanderi*) may be rarer and at greater risk of extinction than species currently listed.

One of the most basic needs for the recovery of rare or endangered plants of the Estuary is restoration of suitable tidal marsh habitat. But tidal marsh restoration without adequate control of wetland weeds may threaten, rather than promote, recovery of endangered species. Therefore, control of the most important nonnative plant invasions must have equal priority with wetland restoration itself, or restoration efforts will be self-defeating (Baye, SOE, 2001).



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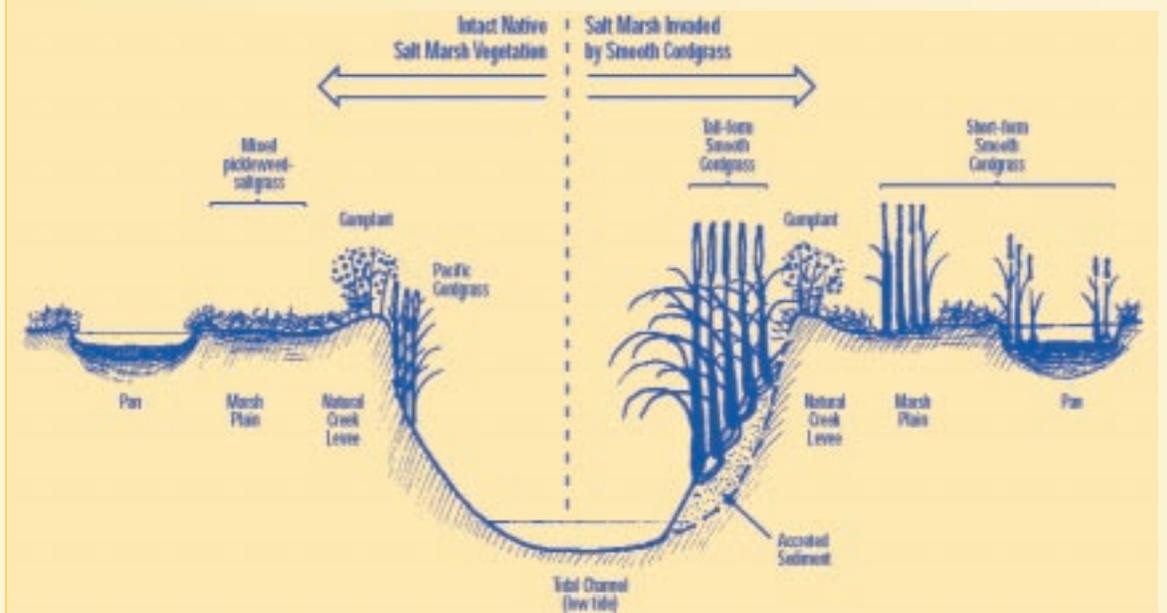
www.cdfa.ca.gov/purpleloosestrife

SCIENCE

Questions

- Will hybrid smooth cordgrass stands in S.F. Bay generally delay or inhibit establishment of other native plants (including dominants, such as pickleweed, as well as rare plants) when suitable substrate elevations have accreted? Or will new (or restored) tidal marshes dominated by hybrid smooth cordgrass be sustained in “arrested development” as persistent cordgrass as sea level rises?
- Will characteristic geomorphic features of S.F. Bay tidal marshes, such as salt pans and small, sinuous tidal creeks, develop under the influence of hybrid smooth cordgrass when new tidal marshes are restored?
- Will mature hybrid smooth cordgrass in S.F. Bay develop single-species “short form” cordgrass marsh typical of Atlantic marshes? If so, how rapidly may this occur? Will California clapper rails nest successfully in short-form hybrid smooth cordgrass, as they do in young colonies of tall-form cordgrass?

ATLANTIC VS. PACIFIC CORDGRASS MARSH STRUCTURE



Not to scale.

PERSPECTIVE

SOUTH BAY RESTORATION

CLYDE MORRIS

U.S. Fish & Wildlife Service

Though restoration in South San Francisco Bay has been proceeding at a slow pace, it may be on the verge of a new era. South Bay wetlands have succumbed to many of the same pressures found elsewhere in the Bay — the development of residential, commercial, transportation and landfill projects. However unlike other areas of the region, much of the loss in the South Bay has been to development of commercial salt ponds. The loss of these tidal wetlands has been a severe blow to the ecosystem, and has placed some tidal wetland dependent species, such as the California clapper rail and the salt marsh harvest mouse, on the endangered list. However, because these tidal wetlands were converted to salt ponds, rather than commercial or residential development, there is a much greater opportunity for restoration.

At the Don Edwards S.F. Bay National Wildlife Refuge Headquarters in Fremont, several salt pond restorations have already been accomplished. A number of former salt crystallizers were restored in the 1980s by re-establishing the tidal connection to the Newark Slough — resulting in excellent growth in endangered species numbers. As of the October 2001 conference, other projects were being planned or built including Deep Water Slough on Middle Bair Island in Redwood City, an S.F. Airport-sponsored project on Outer Bair Island, an Eden Landing Ecological Reserve restoration project near the San Mateo Bridge, and a 1,400-acre restoration of former salt ponds at Bair Island. Post-conference progress has been made on many of these projects, notably restoration at Eden Landing is well on the way and the draft restoration plan

for Bair Island will be submitted for public review the winter of 2002-2003.

All this progress may be just a warm-up for long-term restoration of 15,500 acres of San Francisco Bay salt ponds planned for acquisition by federal and state governments in 2002-2003. This project is big enough to offer the exciting possibility of bringing the rails and harvest mice back from the edge of extinction, but presents significant funding, technical, and management challenges: How do we retrofit the ponds to stop making salt and provide habitat for at least the species who are now dependent on these saline ponds? How do we select which ponds will become which types of habitat? How do we deal with the existing infrastructure, flood con-

“The South Bay's tidal wetlands were converted to salt ponds, unlike the commercial or residential development that claimed wetlands elsewhere in the region, so there is a much greater opportunity for restoration.”

trol, and treated wastewater flows? How do we accommodate urban demand for open space recreation (such as jogging, cycling, and dog walking) while protecting sensitive species and wildlife dependent recreation (such as hunting, fishing and bird watching)? Where do we get the funding for the interim retrofit and operations; and the massive planning and design (the restoration itself may cost more than the land purchase)? Addressing these issues will require an unprecedented level of regional cooperation and partnership among us all (Morris, SOE, 2001).



MORE INFO?

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THE EVOLVING BENTHIC COMMUNITY

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The composition of the Estuary's community of clams, worms and other bottom-dwelling, or benthic, organisms has been in a near-constant state of flux since the 1860s due to the introduction of non-indigenous species. The introduction of the Asian clam *Potamocorbula amurensis*, for example, not only changed the structure of the benthic community in San Francisco Bay and the Delta, but also brought about ecosystem level responses such as alterations in the food web and in the trophic transfer of contaminants.

It is in this context that it is important to explore why some invasive species affect ecosystem function and others do not.

pelagic (open water) communities. These details explain, for example, why the North Bay's phytoplankton biomass greatly declined with the introduction of *P. amurensis*, while the South Bay's phytoplankton biomass did not (phytoplankton are tiny drifting plants at the base of the food web). The different system responses to the invasion derive from the timing of the phytoplankton bloom and the magnitude of seasonal cycles of the bivalve in the two systems (see graphs).

Biomass of *P. amurensis* in the South Bay can be of similar or greater magnitude (20-45 grams dry weight per square meter) to that seen in North Bay (10-15 grams), but is more seasonally variable in the South Bay where *P. amurensis* essentially disappears in winter in the shallow water. Due to the high turbidity in both the North and South Bay, the shallow water is critical for phytoplankton growth, and thus seasonal differences

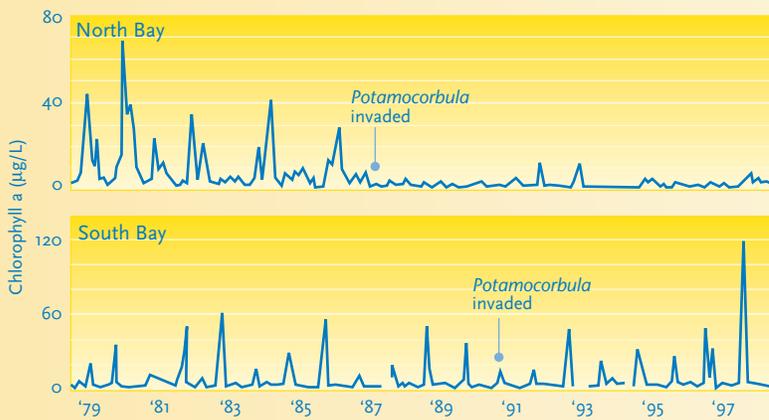
Researchers have noted a similar, but much smaller, effect of inter-annual and seasonal differences in shallow water *P. amurensis* grazing on the North Bay phytoplankton. With the return of freshwater following the 1987-1992 drought, shallow-water *P. amurensis* began to consistently drop to a seasonal low in biomass in the early spring. This has resulted in several phytoplankton blooms of short duration (less than a month), and varying magnitude. Thus, the North Bay's phytoplankton bloom, historically short in magnitude but lasting several months from summer into fall, has now been reduced to a shorter bloom occurring at a different time of year. The effect this change in bloom dynamics will have on the higher trophic levels dependent on the phytoplankton for food remains to be seen.

Learning how *P. amurensis* is affecting the Bay ecosystem can help us project system responses to future changes in the benthic community. It can also help us hypothesize if the *P. amurensis* effect is in any way unique or if other introduced species have similarly altered the ecosystem.

The work of Cohen (1996) indicates a near continuous import of benthic species into the system, 10 of which are of the same functional feeding group as *P. amurensis*, and thus might have affected phytoplankton bloom dynamics if sufficiently abundant. The lack of seasonal phytoplankton data from the mid 1800s-1960s makes a thorough investigation of such historic changes impossible. Two introduced benthic species offer some clues, however, because they were cultured or harvested in the Bay, and their biomass and spatial distribution documented.

People cultured the Eastern oyster (*Crassostrea virginica*) in San Francisco Bay from 1869 to 1910. As the oysters never successfully reproduced in the Bay, they were cultured by placing imported "spat" (juvenile oysters that are attached to adult shells) in localized areas, so the oyster never became widely distributed. Record keeping on the acreage of oyster beds and the pounds of oysters harvested suggests that in areas where

COMPARISON OF PHYTOPLANKTON BLOOM SUCCESS IN NORTHERN AND SOUTHERN SAN FRANCISCO BAY FOLLOWING THE INVASION OF *POTAMOCORBULA AMURENSIS*

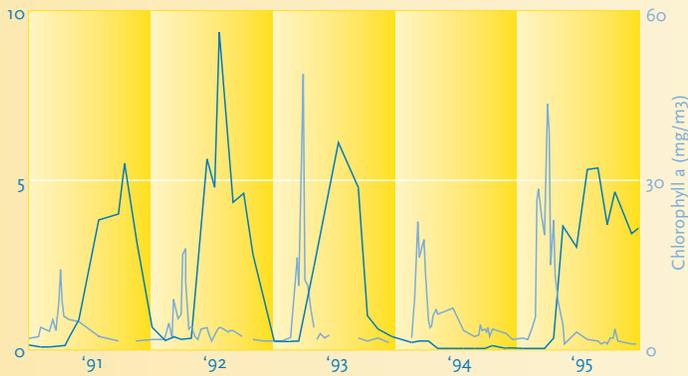


Source: DWR, USGS ACCESS

The Asian clam replaced a benthic community that had few filter feeders and a low biomass. *P. amurensis*, as a large, abundant filter feeder with a seasonally more stable population than the previous community, and a wide distribution, had a large effect on the ecosystem. Ecosystem responses to the introduction of *P. amurensis* show that the effect of the benthic community on the food web is dependent on the details of the connection between the benthic and

toplankton bloom has historically occurred, and still occurs, in early spring during a period of low tidal energy and high light availability (see chart opposite). This period coincides with the annual minimum in *P. amurensis* biomass. Therefore the South Bay phytoplankton bloom has not been changed by the invasion of *P. amurensis* due to the particular coincidence of the phytoplankton bloom with a seasonal minimum in the grazers.

THE PHYTOPLANKTON BLOOM IN SOUTH BAY OCCURS DURING PERIODS WHEN SHALLOW WATER BENTHIC GRAZING IS LOWEST



the oyster was cultured, the oysters were likely to have greatly reduced the phytoplankton biomass.

Estimates have been done of the number of times in a day that the oysters could have filtered the overlying water column (expressed as the water column turnover rate per day) and compared to the phytoplankton growth rate (about 0.5/day according to Cloern et al., 1985, if we assume bloom or near-bloom conditions). In these comparisons, any water column turnover rate in excess of the phytoplankton growth rate will result in an "overgrazed" system.

Results from these calculations suggest that the water column turnover rate during oyster culturing varied from a high in the earliest years of near 10 times per day (assuming a 2-meter-deep water column) to an average of about two times per day until 1900. Thus it is likely that phytoplankton was locally depleted around the oyster beds, but since the beds covered such a small area, it is unlikely that phytoplank-

ton reductions occurred on the same spatial scale seen with *P. amurensis*.

The second introduced species about which there is distribution and harvest data is the Eastern soft-shell clam, *Mya arenaria*. Unlike the Eastern oyster, the softshell clam was accidentally introduced into the Estuary in the 1870s and spread rapidly from San Pablo Bay down to the South Bay (Skinner, 1962).

Estimated water column turnover rates for this clam, based on harvest records in the commercial beds, exceeded 10 times per day prior to 1900 and leveled out to rates between one and five times per day until the 1930s. Due to the softshell clam's wide distribution and large biomass, it is possible that its grazing did change phytoplankton dynamics in the Bay. Indeed a paper published by Nichols (1985) shows that the North Bay's greatly reduced phytoplankton bloom during the drought of 1976-1977 was likely due to the overgrazing of the system by

SCIENCE

Questions

- What epi-benthic community is emerging around invasive aquatic vegetation?
- What potential invaders are of particular concern in this system?
- Could grazing of *Corbicula* affect the success of Bay-Delta restoration projects? What factors control the distribution of large filter feeders such as *Corbicula*?

M. arenaria. The softshell clam, unlike *P. amurensis*, is intolerant of North Bay's low salinity during non-drought years, and thus the reduction in phytoplankton was limited to the drought years.

Upstream in the Delta, we find other examples of how past introductions may have permanently altered the ecosystem. Recent studies of the filter-feeding freshwater bivalve *Corbicula fluminea*, unintentionally introduced in the 1940s, show that it can be a controlling factor in phytoplankton biomass on flooded islands. Given the declines in Delta zooplankton and fish populations in the last half century, we might ask if this shift in the benthic community may have, at the least, contributed to changes in the ecosystem.

In conclusion, we find that some invasive benthic species affect ecosystem function more than others, and that the changes to the system that have been brought about by *P. amurensis* are probably not unique, although the persistence of these changes may be unique. We have learned that it is important to know the details of the invaders' life histories, including feeding mode and the seasonal patterns of growth, reproduction, and predation, if we are to understand and eventually predict the potential effects of an invasive species on a system (Thompson, SOE, 2001).

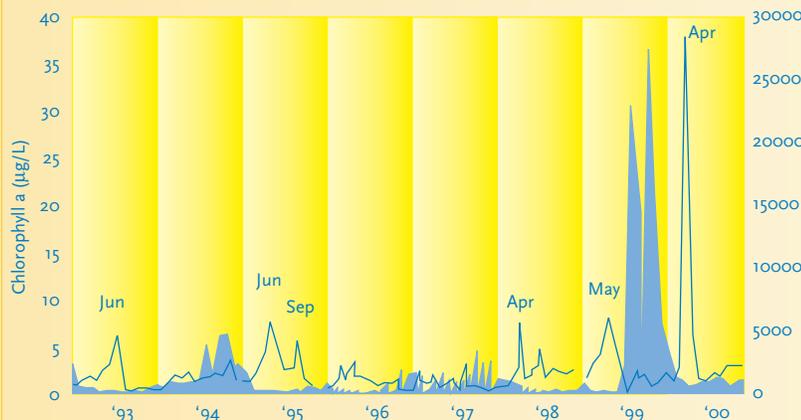


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WILL CHANGING THE TIMING AND DURATION OF THE PHYTOPLANKTON BLOOM AFFECT THE FOOD WEB?

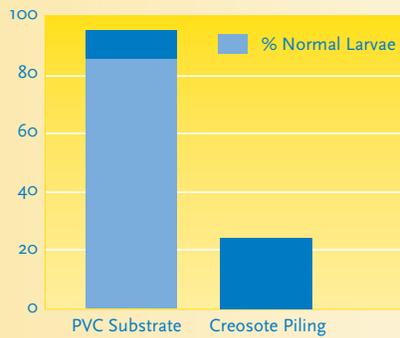


ENVIRONMENTAL FACTORS AFFECTING PACIFIC HERRING

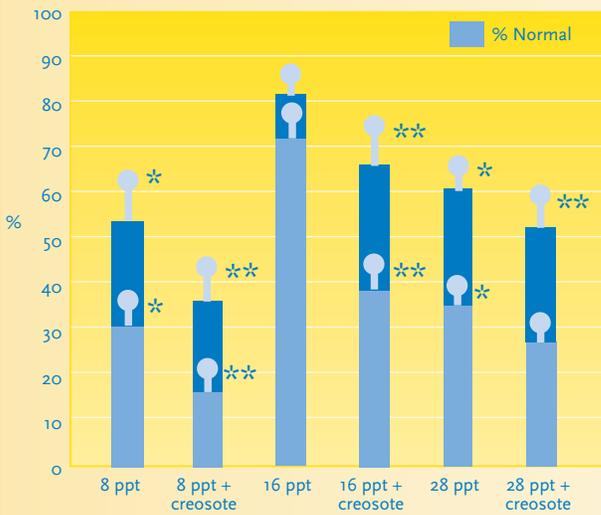
GARY CHERR
U.C. Davis

The S.F. Bay Estuary population of herring is California's largest and experiences increased variability with respect to environmental conditions, particularly salinity and spawning substrates (see also p.11).

PERCENTAGE OF NORMAL LARVAE OF NATURAL SPAWN IN FIELD



EFFECT OF SALINITY AND CREOSOTE ON LARVAL MORPHOLOGY



* Statistically significant from controls at $P < 0.01$

Pacific herring is an economically and environmentally important marine fish that utilizes San Francisco Bay for critical stages of its lifecycle and contributes to the marine and estuarine food web. Adults and juveniles consume plank-

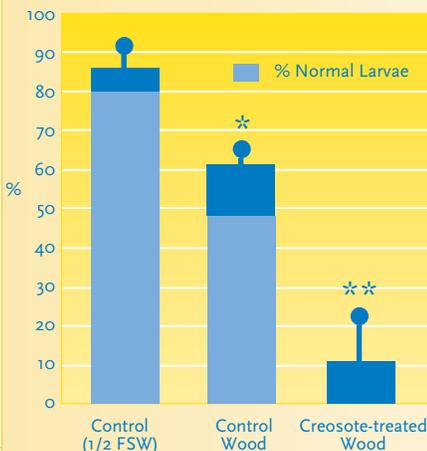
ton and are preyed upon by salmon, rockfish, lingcod, birds, and marine mammals. Spawn (developing embryos) is a food source for birds, crustaceans and sturgeon.

Pacific herring reproduction in the S.F. Estuary is dependent on low salinity water, or more specifically, on decreased salinities during the winter months. Both successful fertilization and embryo development require reduced salinities, with the optimum rates of development and hatching of embryos occurring at approximately half strength seawater. Larval herring

survival may also be reduced at elevated salinities. The impacts of extreme salinities, which may occur during drought or El Niño conditions, have been documented in both lab and field.

Although salinity fluctuations can be further modulated by human activities such as freshwater diversions, other anthropogenic impacts on reproductive success are more obvious. Herring often use tar creosote pilings as spawning substrates, for example, and researchers have found that the survival rate of such embryos is extremely low. The effects of altered salinities and creosote exposures include acute mortality of embryos attached to the pilings, or abnormalities in larvae floating in the creosote-laced water at short distances from the pilings (Cherr, SOE, 2001).

EFFECT OF CREOSOTE ON HATCHING SUCCESS AND NORMAL LARVAL MORPHOLOGY



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MERCURY IN S.F. BAY

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The history of mercury in California is recorded in the sediments of San Francisco Bay. The Bay is downstream of 40 percent of the land area of California. Three billion kilograms of sediments are annually flushed from local watersheds and the Central Valley and deposited in the Bay.

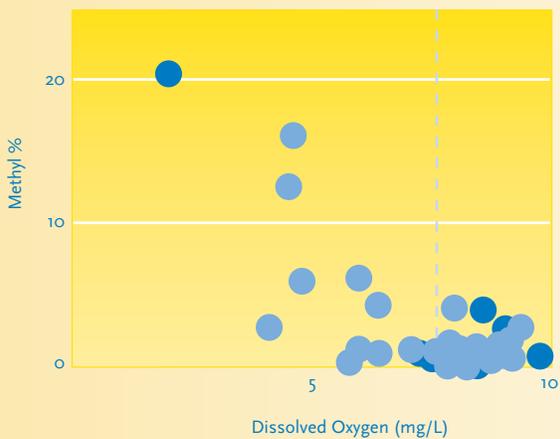
During and after the Gold Rush, over seventy thousand tons of mercury was produced in Coast Range cinnabar mines. Much of this mercury was used as quicksilver to extract gold from placer formations in the Sierra foothills, and later in the production of munitions, electronics, health care and commercial products. Today the legacy of mining sources, from both remote and local watersheds, is superimposed on air deposition, the climate and geography of California, heavily managed water supply and flood control projects, wetland restoration and rehabilitation, urbanization, wastewater discharge and water reclamation.

That legacy—combined with more current sources of mercury—is impacting beneficial uses of San Francisco Bay today. Surveys of contaminant levels in fish conducted by the San Francisco Bay Regional Monitoring Program (RMP) in 1994 and 1997 show that there is too much mercury in fish caught from the Bay, so the beneficial use of commercial and sport fishing is not attained. The Bay is an important fishery, a food source for approximately 150,000 anglers, and habitat for rare and endangered species. Monitoring data indicate that mercury concentrations in popular sport fish exceed acceptable risk levels for developmental impairment of children and expectant mothers. Based on the latest criteria guidance from U.S. EPA and local consumption surveys, mercury concentrations in popular sport fish need to be reduced by two-fold to fully protect the majority of subsistence fishers.

Strategies to reduce mercury concentrations in aquatic ecosystems must focus both on mercury loads

and mercury methylation, because methylmercury is the primary chemical form that accumulates in biota. Since the vast majority of mercury in aquatic ecosystems is bound to particulates, mercury loads are assessed by evaluating how different sources affect mercury concentrations in Bay sediments. Prior to the European settlement of California, the concentration of mercury in Bay sediments was approximately 0.06 ppm. Today, it is approximately 0.4 ppm, a six-fold

MERCURY METHYLATION



Source: Fairfield-Suisun Sewer District

under urban runoff permits and waste discharge requirements. Recent monitoring data demonstrates that mercury methylation efficiency in the Bay increases four-fold when dissolved oxygen drops below 6 mg/L (see above).

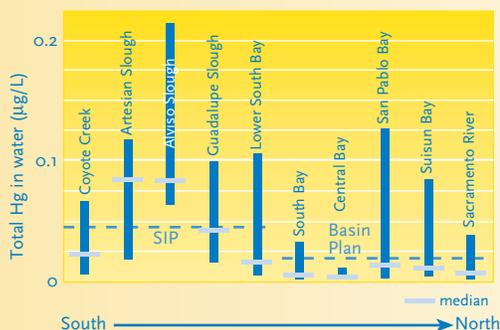
While load reductions can reduce total mercury inventories by a half over long (decadal) timescales in large areas, watershed management to reduce eutrophication and anoxia could result in rapid reductions in tissue concentrations in localized areas. Consequently, the Total Maximum Daily Load (TMDL) implementation plan being established by

the S.F. Bay Regional Water Quality Control Board will call for load reductions through restoration of inoperative mine sites in rural watersheds, pollution prevention measures in the urban environment, and adaptive management strategies to identify and control factors (e.g., nutrient loading, dissolved oxygen) that create conditions favorable to mercury methylation (Abu-Saba, SOE, 2001 & Abu-Saba & Mumley, 2002).

SCIENCE Questions.

- Are there ways to create, enhance, and manage wetlands that minimize the conversion of mercury to methylmercury? Adaptive management means systematically trying different designs, and then seeing which one works the best. Factors such as vegetation type, final elevation, channel depth, flushing rates, and source water composition are examples of the different design factors that could be considered.
- What is the role of atmospheric deposition in mercury methylation? Is atmospheric mercury more easily converted to methylmercury than mercury from mining legacies, and thus a key contributor of mercury to the food chain? How much of the atmospheric load to the Bay comes from local air emissions, and how much is coming from long range transport (source is key to controllability)?

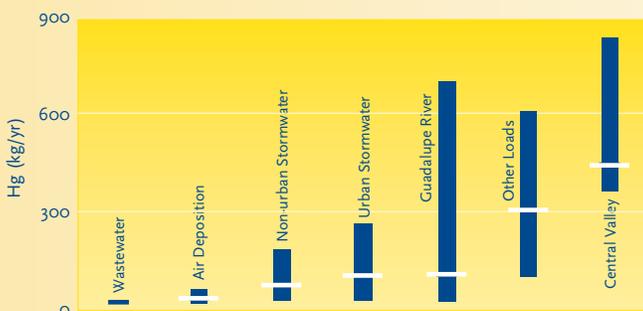
NUMERIC OBJECTIVES VIOLATED



excess compared to pre-settlement conditions. It is projected that controlling all controllable sources will, after decades of equilibration, produce a steady-state mercury concentration of approximately 0.2 ppm, or half of the current concentration in sediments.

It is unlikely that fish tissue targets can be attained over time through load reductions alone, because mercury bioaccumulation is mainly driven by the methylmercury concentrations in aquatic ecosystems, rather than total mercury concentrations. To reduce mercury concentrations in fish, controllable water quality factors that promote mercury methylation in the aquatic ecosystem must be considered in conjunction with mercury load reductions. Some of these water quality factors (i.e., dissolved oxygen) are already subject to regulation

SOURCE ASSESSMENT



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LESSONS LEARNED IN EIGHT YEARS OF CONTAMINANT MONITORING

RAINER HOENICKE
S.F. Estuary Institute

The Regional Monitoring Program for Trace Substances (RMP) was established in 1993 as a tool for the Regional Water Quality Control Board to evaluate regulatory policies related to the Clean Water Act and the California Water Code. The RMP has also been used by other agencies to evaluate the effectiveness of pollution prevention and reduction actions outlined in the 1993 *Comprehensive Conservation and Management Plan (CCMP)* for the San Francisco Estuary.

Eight years of RMP data have taught us several things:

1. Most metals that had been of key regulatory concern no longer need the attention they once received.
2. Recovery from pollutant impacts, especially from persistent, bioaccumulative contaminants, will take decades or longer.
3. Synthetic organic contaminants, including emerging pollutants, are becoming a higher priority.
4. Pesticide runoff and its effects on non-target aquatic species is a continuing cause for concern.
5. The watersheds surrounding the Estuary sometimes represent substantial reservoirs for certain pollutants that will ultimately be mobilized and transported into the Estuary.

These findings demonstrate that as long as the basic principles of sustainability, and those specifically related to pollution prevention (i.e., substances from the

Earth's crust and those produced by society must not systematically increase in nature) are violated, the regulatory system will remain mired in an endless, costly assessment-evaluation-remediation cycle.

ment before their persistence and unintended side effects are known; and it's a good idea to turn off the tap to the overflowing sink before mopping the floor (Hoenicke, SOE, 2001).

"We have yet to learn two lessons: It's a bad idea to release man-made substances into the environment before their persistence and unintended side effects are known; and it's a good idea to turn off the tap to the overflowing sink before mopping the floor."

The implications of these lessons are many. We need to place a greater emphasis on biological indicators of pollution impacts. We need to supplement monitoring with research to remain relevant. We need to communicate monitoring information more effectively to legislators and policy makers. Environmental management agencies and the scientific community are not in all cases the most important recipients of the monitoring information.

In addition, the institutional framework needs to be better prepared to generate and act on a comprehensive picture of ecosystem integrity that could be used to focus resources in areas where relief of pressures on the ecosystem could provide the greatest environmental benefit. Revisions to the legislative framework should also be considered to prevent new synthetic compounds from becoming emerging pollutants with unexpected and unintended adverse environmental effects.

In sum, it is clear that we have yet to learn two important lessons: It's a bad idea to release man-made substances into the environ-



MORE INFO?
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PERSPECTIVE

A HISTORY OF BAY FILL & PERPETUAL URBAN GROWTH

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Those who came before and during the California Gold Rush quickly realized that the real fortunes were to be made not in Sierra gravels but in land speculation as long as people continued to be drawn to the Golden State by its promise of riches. They therefore acquired — by whatever means possible — water lots, tidal lands, and the Bay itself with the intention of eventually filling their aqueous properties to create more lucrative real estate for themselves and their descendants. The Bay was thus seen chiefly as a thing to get rid of, and the solemn superstructure of Western property titles rose upon a quicksand of epic fraud and theft from the public domain.

Those who sought to profit from urban growth did so by importing energy and water into the city to transform its natural environment, and in the process, they further transformed those wider hinterlands from which they took the energy and the water. All cities do this; they are like collective organisms that have a metabolism that must be sustained by constant inputs, and they produce waste proportional to those inputs. But, unlike any other collective organism of which I am aware, a few of the city's constituent parts profited far more from its growth by monopolizing the land than did the mass.

Wood was at first used for fuel, sending out a shock wave of deforestation whose effects on the Bay no one has studied. Poor lignite was then imported from Mt. Diablo, and then better grades of coal were brought from as far away as Wales and Australia. In the 1890s, imported oil and hydroelectricity began to replace coal. The fossil fuels produced wastes which continue to contaminate Bay sediments.

Water was also imported by the private Spring Valley Water Company, first from Pescadero and then from San Mateo and Alameda Creeks, beginning the destruction of the steelhead runs in the immediate Bay Area. Freshwater inputs were replaced by sewage and industrial wastes which gave the Bay a notorious odor.

By the turn of the century, those who owned land and Bay realized that they needed public assistance to increase the value of land in order to grow more cities....what they called “Greater San Francisco.”

point, three Berkeley women organized their friends and others into a group called Save the Bay to stop the filling, resulting in the creation of the S.F. Bay Conservation & Development Commission (the BCDC), whose first major contest was its opposition to a proposed fill south of the Ferry Building for a U.S. Steel complex. Democratic Mayor Joseph Alioto vowed to weaken the BCDC in Sacramento, but did not succeed.

The BCDC could not, however, stop urban growth but only redirect it away from the water — views of

“The Bay region, and its transportation planners, are trapped in a self-fulfilling prophecy of sprawl and gridlock, of projections as destiny. The question throughout the region, and for the S.F. airport expansion project, is how can we take control of the demand side of the equation?”

STUART COHEN

Bay Area Transportation & Land Use Coalition

They did so by creating new public agencies such as the Bureau of Reclamation, the Hetch Hetchy system, EBMUD, the Muni, the state Highway Department and the Department of Water Resources. The Reber Plan proposed to use public monies to turn much of the Bay into freshwater reservoirs by building massive dikes. The plan received enthusiastic support from the *San Francisco Chronicle* and other business interests that hoped to profit from the urban growth it would kick off.

By the latter half of the twentieth century, those nineteenth century land claims to the Bay were still owned by some of the original families, but many had passed on to corporate interests such as Utah Mining & Manufacturing (the Eccles-Wattis clan), which began to fill in vast tracts of the Bay. At that

which became chief selling points for expensive developments around its perimeter. Despite abundant lessons provided by the Loma Prieta and other seismic events, growth has continued apace in such hazardous locations as Mission Bay where a massive biotech facility is being constructed on a prime liquefaction site. The economy remains predicated upon the fantasy of infinite urban growth, as mindless as are cancer cells to the ultimate fate of their host. In this case, the victim appears to be the immensely intricate biotic web which shows alarming signs of collapse. We may soon find that we need phytoplankton far more than it needs us (Brechin, SOE, 2001).

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PLANNING FOR FUTURE AIRPORT NEEDS

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The San Francisco Bay Area is currently struggling with the environmental issues posed by the need to expand the capacity of the commercial airport system serving the region. The region is facing the prospect of continuing long-term growth in the demand for air travel. While the full implications of the events of September 11 and subsequent developments are not yet clear, it seems unlikely that the social and economic forces that have been driving the worldwide growth in air travel in the past will disappear.

fill, as will some of the options likely to be considered for Oakland.

These projects bring up two important questions: First, to what extent will these projects, if implemented, meet the long-term air transportation needs of the Bay Area? Second, to what extent can future air traffic management technology, better management of existing airport resources, or the development of a fourth air carrier airport in the region minimize the need for Bay fill?

A recent update of the Regional Airport System Plan (Metropolitan Transportation Commission, 2000) attempted to address these questions. Unfortunately, limitations in the scope of the analysis undertaken for the Plan make the answers

Subsequently, SFO released additional consultant studies that have addressed the potential contribution of better management of regional airport resources and an Independent Technology Panel convened by SFO and BCDC has undertaken an assessment of the potential capacity gains that might be achieved through new air traffic management technology. While potential capacity gains from new air traffic management technology appear promising in the long term, the implications of the Panel's findings for future levels of air traffic delay remain to be determined.

Alternative strategies to meet the future air transportation needs of the region involve difficult trade-offs between Bay fill, airport capacity, and user convenience. These trade-off decisions are not primarily technical, but revolve around the value that our society places on environmental and other goals. In order to have an informed public debate about these trade-offs, it is important not only that the technical studies of the complex issues involved be performed in an open, unbiased manner, but that appropriate efforts are undertaken to explain the significance of the findings to decision makers and the public at large (Gosling, SOE, 2001). Since the 2001 conference, SFO has released the Final Report on Airfield Development Planning (March 2002), but the only new air traffic management technology considered in the capacity and delay analysis it presents is the use of Simultaneous Offset Instrument Approach procedures, which SFO has already committed to implement. With the drop in traffic and revenue at the airport since September 2001, almost all work on the Airfield Development Program has been suspended (Gosling, Pers.Comm. 2002).

“We need to better manage the ballet of planes crossing the runways. To do this, we've looked at many options, ranging from building a 400-1,200-acre new runway to expanding the airport upland and using new technology and better demand management. As a result of public input about minimizing Bay fill, we've developed some new hybrid runway alternatives which will create about 600 acres of new land in the Bay. We're still investigating related issues of where to dispose of dredged material, where to get fill material, and how to mitigate for loss of aquatic habitat.”

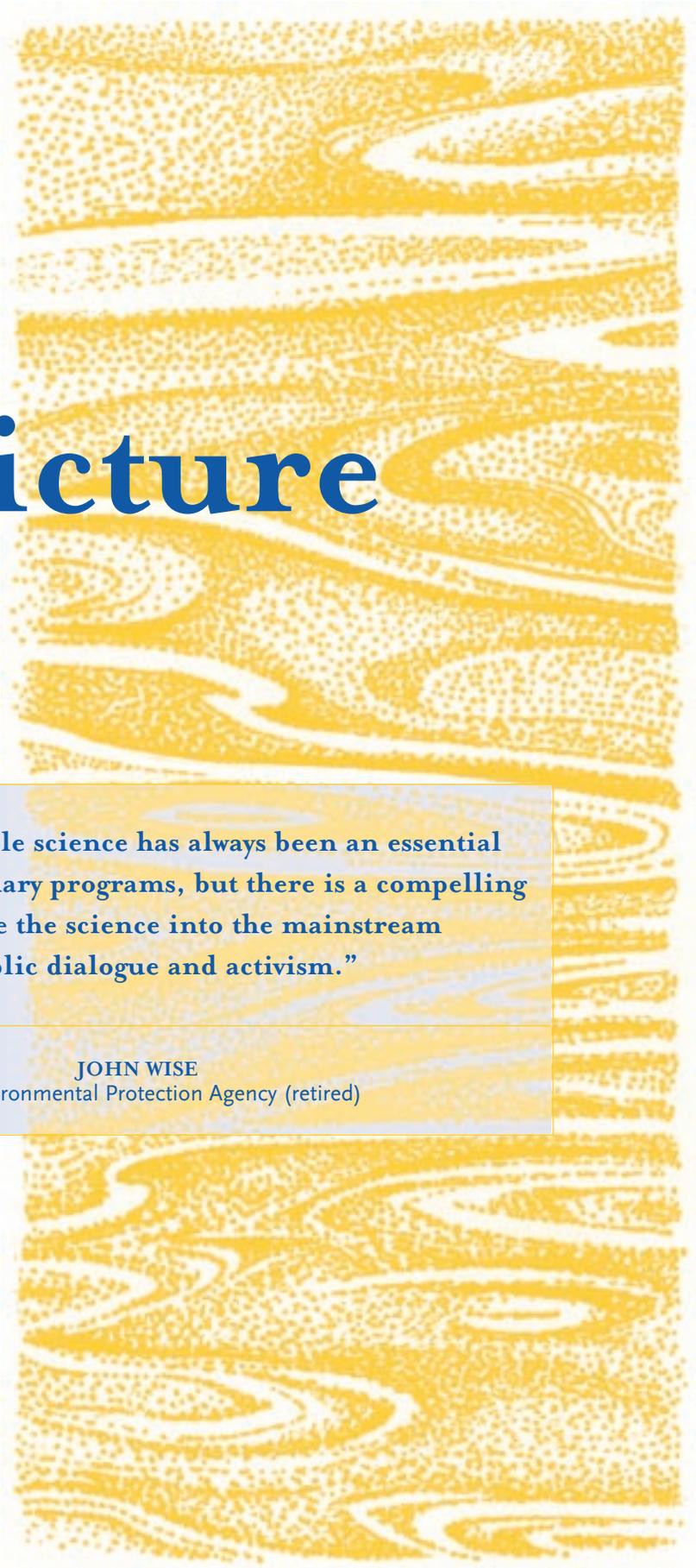
LEE HALTERMAN
SFO

San Francisco International Airport (SFO) recently opened its new International Terminal, which has significantly expanded its terminal and landside capacity, soon to be further enhanced by the opening of the Bay Area Rapid Transit extension to a station in the airport terminal complex, and is currently considering a major reconfiguration of its runway system. San Jose International Airport is in the process of implementing its master plan expansion, and Oakland International Airport is planning additional terminal facilities and considering its future needs for a new runway. The proposed new runway configurations at SFO will involve significant amounts of Bay

that it provides of limited value in addressing these questions. For example, the forecasts upon which the Plan is based looked only 20 years into the future, less than 10 years beyond the earliest date when the proposed new runways are likely to become operational. In addition, the Plan gave only the most superficial attention to the potential contribution of new air traffic management technology and did not perform any quantitative analysis of the potential role that a fourth airport could play in the future regional system or how air traffic would be distributed among the region's airports under different air service or demand management assumptions.”



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STATE OF THE ESTUARY

Big Picture

“The best available science has always been an essential feature of our Estuary programs, but there is a compelling need to move the science into the mainstream of public dialogue and activism.”

JOHN WISE
U.S. Environmental Protection Agency (retired)

SCIENCE AND POLICY: ESSENTIAL TO ESTUARY RESTORATION

RICHARD KATZ

Member, State Water Resources
Control Board

Background: 2001 marked the beginning of the CALFED implementation process. It follows and builds upon the Comprehensive Conservation and Management Plan for the Bay and Delta that was approved by the Governor and U.S. EPA Administrator in 1993. The task ahead is daunting, namely launching the largest, most comprehensive water management program in the world. It is the most complex and extensive ecosystem restoration project ever proposed.

and its advisory committee be responsive to scientific developments and base decisions on sound science as well.

The CALFED Science Program will bring world-class science to all elements of the program — ecosystem restoration, water supply reliability, water use efficiency and conservation, water quality, and flood management. Performance measures and indicators for each program element will track progress. Incorporation of peer review into the science program ensures a strong and credible scientific component in all programs.

Role of Legislature and

SWRCB: Much of the need for science review is focused on habitat restoration efforts, and experience

habitats, restoration of urbanized creeks and baylands, Delta restoration, climate change, etc. Bringing together outstanding scientists, policy makers, regulators, elected and appointed officials and the concerned public will advance and enhance future decisions to keep the Estuary protected and improve the quality of life not only in the Bay Area but also for all of California (Katz, SOE, 2001).



MORE INFO?

www.swrcb.ca.gov

“Good science leads to good policy, but the environmental and scientific community attending this conference has to do its homework. You have to explain to newly elected legislators how this ecosystem is also the drinking water supply for 20 million Californians, how this ecosystem affects the state, their constituents, and the state's ability to create jobs. Good science will not lead to good policy without political action and education.”

Science-based Program: A central feature of the program is science-based adaptive management. There is a strong commitment to assure that decisions and actions are based on well-grounded science and a \$1 billion science-driven ecosystem restoration program. Science CAN inform policy and using it is the obligation of decision-makers, from the State Water Resources Control Board (SWRCB), and its nine regional boards, to the state and federal agencies, which have statutory responsibility for implementing some aspect of the CALFED program. It is imperative that the new CALFED governance commission

in the legislature tells me that, frequently, legislation follows when new and irrefutable information demands change. Of course, the SWRCB has continuing interest and jurisdiction on both water quantity and quality issues and initially, will count on the first annual science report due by the end of this year and the Independent Science Board for information.

Role of the Conference:

This State of the Estuary Conference provides invaluable information to confront the challenges of urbanization of the Estuary by focusing on topics related to contaminant loads, biological resources and

PERSPECTIVE

ECOSYSTEM COMPLEXITY & RESTORATION

SAMUEL N. LUOMA
CALFED & U.S. Geological Survey

The degradation of ecosystem structure and function by human activities is widely documented, threatening important values that include preservation of biodiversity and prevention of species extinctions. Restoring ecosystems is an important goal of modern environmental management, including the CALFED Bay-Delta Program. However, a growing body of evidence suggests that restoration of ecosystem structure or function, and restoring populations of threatened species, can be a substantial challenge. In addition, sustaining successful restoration can require on-going investments that few programs anticipate. These observations mean that an ecosystem restoration program requires:

- A sophisticated investment strategy,
- Careful documentation of what works and what does not, and
- An institutional system that responds to the evaluations of effectiveness.

Effective investment in ecosystem restoration requires allocating resources among investments in new projects, investments in enhancing the effectiveness of existing projects, and investments in sustaining successful efforts. Documentation of what works requires more than routine monitoring. Necessary ingredients include interdisciplinary study of existing efforts, creative retrospective approaches and development of new knowledge about pressures, ecosystem state and response at multiple levels. We are fast learning that ecosystem restoration rarely succeeds without pre-established

stakeholder buy-in and collaboration between government and non-governmental stakeholders. Rational institutional response to knowledge about how to effectively accomplish restoration may depend upon a social environment of trust.

ture watersheds, areas with representative impediments and a scattered baseline of projects. Allocation of the investment between engineering, monitoring, and developing new knowledge might also vary with the category. Effective prioritization demands

“Rational institutional response to knowledge about how to effectively accomplish restoration may depend upon a social environment of trust.”

Priorities are essential in an ecosystem restoration program because finances are always finite. In the Bay-Delta Program, we are identifying “signature opportunities” for restoration. Some criteria for such opportunities might include a strong biological justification for investment and a high likelihood of the investment having a short-term, detectable biological impact at a reasonable scale. Success is more likely if resolution of institutional impediments has at least begun. A history of prior investment might also be an advantage. In an ecologically complicated setting, no program should prioritize all its funding to a few projects, however. Some localities or subject areas could have long-term potential for restoring species or functions, but impediments or potential constraints to restoration need to be better understood (deeply subsided islands in the Delta are an example). Investment in understanding impediments could reap immense benefits in the long-term. Similarly a baseline of investment in smaller or more isolated projects, and in general ecosystem understanding, across the system, is also critical. We should not expect that we know where the all the best opportunities exist. Rational prioritization might involve investing equally in the three categories: a few signa-

appreciating ecological complexity, if ecosystem restoration is to live up to its potential (Luoma, SOE, 2001).



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FUTURE OPPORTUNITIES

JOHN WISE

U.S. Environmental Protection Agency (Retired)

The major overarching challenge, or opportunity, facing the San Francisco Estuary is to re-engage the public in an active program to ensure that the long-term integrity of the Estuary ecosystem is sustained for future generations.

The public has been significantly and meaningfully engaged for well over 40 years, as Save the Bay led to the creation of the S.F. Bay Conservation & Development Commission (BCDC), which in turn led to the Porter-Cologne Basin Plans, the *Comprehensive Conservation and Management Plan*, Bay-Delta water quality standards and the Bay-Delta Accord, the creation of CALFED and the S.F. Estuary Institute, and the checking in on our progress every few years with these State of the Estuary Conferences and the *Bay-Delta Environmental Report Cards*. Continuous public involvement has been essential in driving the process forward; time and again contentious issues have been overcome by engaging the public in the process.

Yet the distractions of modern life—the prevalence of international tensions and terrorism, the ups and downs of our economy, the performance of our schools, affordable housing, traffic congestion—all command our attention. This, along with the public’s ingrained complacency, call for renewed vigor in public engagement and public action. Moreover, we may have hit the “green wall” of communications. We are comfortable talking to ourselves (to the faithful inside experts); but because of our language, our message is not getting out to a broader audience – a broader community of interest.

We need to re-energize this process of re-engaging the public by organizing around the following four themes:

Ecological science: The best available science has always been an essential feature of our Estuary programs, but there is a compelling need to move the science into the mainstream of public dialogue and activism. “Ecological science” means a multi-disciplinary approach to the science of the ecology of the Estuary: the myriad interrelationships among the physical attributes, the chemical and biochemical and geochemical processes, and the biological dynamics of life forms at every level — the beautiful chaos, the extraordinary variability and complexity of the system. All of this is of course a heroic task, pushing the limits of our knowledge. But to the extent that we can unify our science and knowledge, we can organize a public engagement process to benefit from such knowledge, and in turn support the continued development of such knowledge.

Goals and indicators: Goals and indicators—framed by the best available science—are the driving force of progress and public engagement. What gets measured gets done. The Ecosystems Habitat Goals Project (see p. 61) is an excellent example of how goals and indicators drive involvement.

As we measure and assess our indicators of progress towards our goals, we must also utilize the emerging management technique known as “adaptive management.” We often do not know the course, or the impact, of our policies. As we measure our indicators, we must be prepared to modify, adapt or change direction. Adaptive management is of course implicit in how we currently seek to manage the Estuary. Notably, CALFED has embraced this approach in its plans and investment decisions.

We need to bring adaptive management, based on the goals and indicators, explicitly into the realm of public engagement.

Restoration: Restoration must proceed simultaneously on a landscape scale and on a local watershed scale. It will be a challenge to mobilize public involvement in restoring the Sierra headwaters and the major Valley rivers. On the other hand, people often have a passion for a “place.” Restoration projects within their neighborhood, their watershed, their community can be a compelling basis for public engagement. And, in turn, such project-based involvement can be mobilized in service of the restoration of the entire Estuary.

Vision of sustainability: The Estuary is an essential element in the “interconnectedness” of the environment, the economy and social equity—the mosaic of relationships that will determine the sustainable future of the Bay Area. Therefore, progress toward sustainability and progress in protecting our Estuary are intimately connected. Both will directly depend on how well we are able to infuse our ecological science into the fabric of our schools, our institutions, our governmental systems and our daily lives. The ultimate vitality of our democratic society depends on science-based, knowledge-based and information-rich policies driving a comprehensive public engagement process. Public education and public involvement are the essential foundation to secure the integrity of our Estuary, and to guide us on our journey toward a sustainable future.

These four themes, individually and collectively, form the core of our opportunity, indeed our obligation, to ensure the integrity of the Estuary for present and future generations (Wise, SOE, 2001).



MORE INFO?
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ACRONYM KEY

- CALFED: CALFED Bay-Delta Program
 DFG: California Department of Fish and Game
 DHS: California Department of Health Services
 DWR: California Department of Water Resources
 GGNRA: Golden Gate National Recreation Area
 MWD: Metropolitan Water District of Southern California
 NMFS: National Marine Fisheries Service
 NOAA: National Oceanic and Atmospheric Administration
 NOS: National Ocean Service
 PRBO: Point Reyes Bird Observatory
 RCD: Resource Conservation District
 SFBBO: San Francisco Bay Bird Observatory
 SFBCCDC: San Francisco Bay Conservation and Development Commission
 SFBWRQCB: San Francisco Bay Regional Water Quality Control Board
 SFIE: San Francisco Estuary Institute
 SFEP: San Francisco Estuary Project
 SWRQB: State Water Resources Control Board
 USACOE: United States Army Corps of Engineers
 USBR: United States Bureau of Reclamation
 USDA: United States Department of Agriculture
 USEPA: United States Environmental Protection Agency
 USFWS: United States Fish and Wildlife Service
 USGS: United States Geological Survey