Flood Control That Leaks and Dredging That Matters:

Making Ecosystem Restoration Work in the Real World

Denise Reed
University of New Orleans

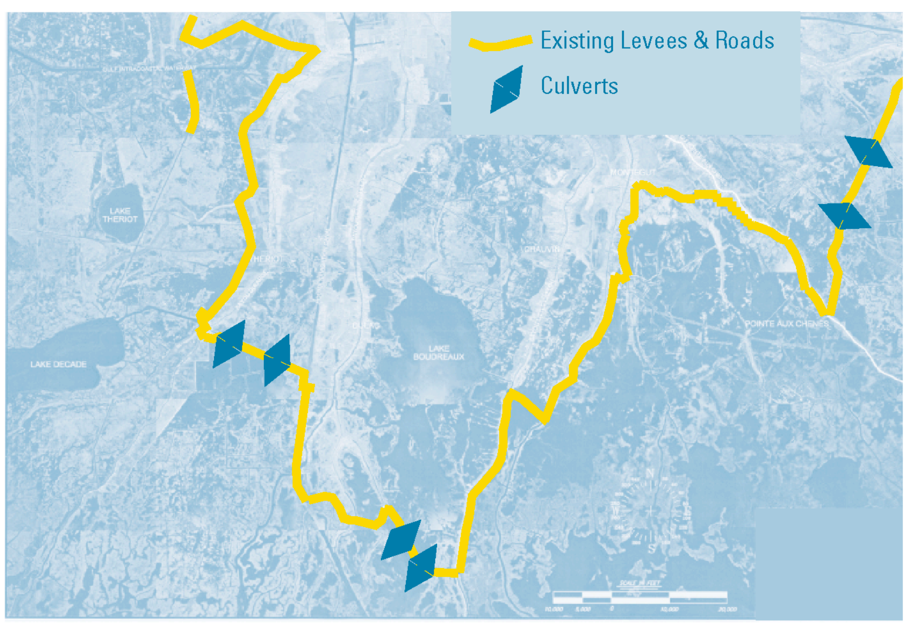
I'm going to use two examples, Jamaica Bay and coastal Louisiana, to illustrate how scientists can create opportunities to test hypotheses and learn more while at the same time working with managers to solve real-world problems.

Jamaica Bay is surrounded by metropolitan New York City. Several marsh islands in the center of the bay have changed little over time while others have lost area or even disappeared. Analysis by the New York Department of Environmental Conservation shows relatively little change in wetland area between 1924 and 1974, but dramatic change since then, with the loss of huge areas of vegetated marsh. Now "huge" is relative—the loss is measured in tens of acres—but remember that there are only a few tens of acres of marsh left in the midst of this massive metropolitan area. The changes include over-steepened banks, block collapse at the edges of the islands, areas of sparse and patchy vegetation, and in other areas massive coverage of green algae both in ponds on the marsh surface and even on the bare flats.

Most of the system is under the jurisdiction of the National Park Service, and their management approach has been no intervention in natural processes. So the question is, Is this a natural process? For many years, the changes were attributed to natural, outside-the-system effects of sea level rise and insufficient sedimentation. But eventually, as a result of stakeholder pressure from people who live around the periphery of the area and see the changes out their high-rise windows, the Park Service created a science board of which I was a member. The role of a science board in this kind of context is not so much to provide a body of information as to ask questions.

"...scientists can create opportunities to test hypotheses and learn more while at the same time working with managers to solve real-world problems."

So the science board started examining what had changed in the system, and we quickly found many more changes than just sea level rise. For example, 98 million cubic meters of material were taken out of the bay for fill between 1900 and 1970, 47 million just for JFK Airport in 1946. Every day, 900,000 gallons of leachate run into the bay from landfills and 250 million gallons of sanitary sewage are discharged into it from wastewater treatment plants. The whole shoreline has been stabilized, the inlet position has been stabilized, sediment movement has been totally altered, and the barrier islands have been fixed in space. Our challenge was to present all this information in a way that the Park Service could use. Essentially what we did was separate the problem into the vertical changes (such as internal ponding on the marsh islands) and the lateral changes (such as erosion around the edge of the marsh islands).



Proposed modification of hurricane barriers in coastal Louisiana takes advantage of tidal exchange to improve the health of wetlands restored behind the levees. Black arrows indicate culverts designed to allow tidal exchange, and thus sediment input, during moderate storms. This is an example of scientific understanding of wetland processes helping to improve the restoration function of a flood control project (figure courtesy D. Reed and Terrebonne Levee and Conservation District).

I think the most important consequence of inserting the science process into the management of Jamaica Bay was that it allowed us to identify some opportunities to test hypotheses, with the goal of learning more about the problems and finding solutions. For example, Rockaway inlet is dredged every two years by the US Army Corps of Engineers. As a science board, we've been working with people to think through how that material can be used not only to build some marsh but at the same time to test hypotheses about the processes that affect the islands laterally and vertically. One idea is to place material in particular configurations to reduce wave action, to see how that will affect the remaining marshes. Another is to build up new areas of marsh, restore the marsh platform, to see if it will survive and accumulate on its own. Going a little further, there are also some ways of experimenting with engineering tools and approaches for the placement of the material. The idea is to use the kind of articulated boom used in placing cement, and to move the material as a thick slurry, more like a cement consistency than the kind of water mix usually used for transporting dredge material. This will allow us to be much more strategic in placing the material, so that we can test our hypotheses better.

"The challenge for science has been to convert our understanding ...into an operational framework..."

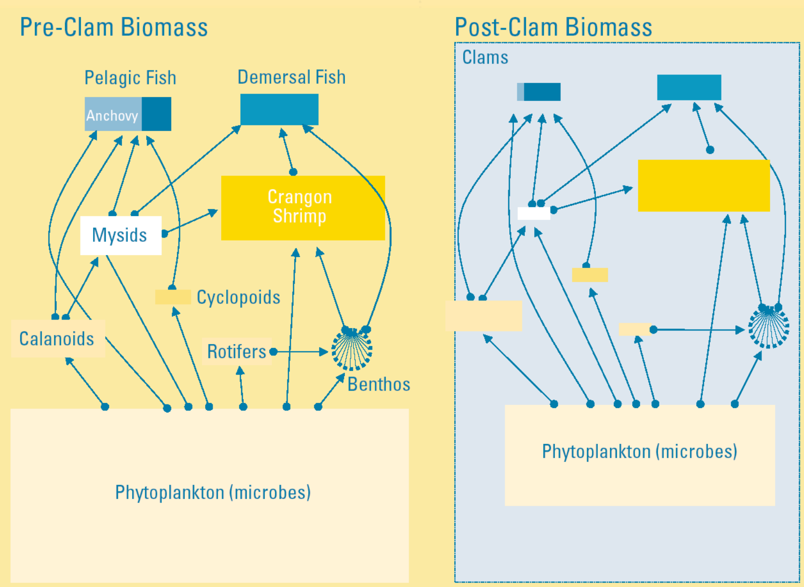
The problems in coastal Louisiana are on a very different scale. Between 1956 and 2000, the state lost 1525 square miles of land, and our projections are that over the next 50 years, unless there's a significant increase in the level of effort devoted to restoration, we will lose another 513 square miles. The Mississippi Delta plain was built over thousands of years, and until recently subsidence was essentially balanced by accumulation of sediment at the surface. What happens in the 20th century? All those natural processes, like natural compaction of the sediments, are still going on, and at the same time we've leveed the Mississippi River so all the sediment-laden waters go out into the Gulf of Mexico instead of into the wetlands. We've also dredged ship channels, allowing saltwater to penetrate further inland, and we have dredged a multitude of oil and gas canals through the marshes.

The place where I live, Montegut, is at ground zero not just for land loss but for hurricanes. For many people in this community, hurricane protection is a far more important and immediate issue than the loss of tens of square miles of land. How do we deal with both of these issues? In our case the planned solution for hurricane flooding is a protection system consisting of 72 miles of levees and floodgates that can be closed during a hurricane. Now wait a minute, we just said that levees and hydrologic alteration are part of the problem, so why are we proposing a new levee system? Well, fortunately, we can see this as an opportunity. One of the things we understand about marshes in Louisiana is that storms and cold fronts mobilize sediment and push it up into the wetlands, helping them keep their heads above water in the face of sea level rise and subsidence. The hurricane protection system will modify many existing alterations that currently impede the passage of water—for example, in many places roads that create a strong hydrologic barrier to normal tidal movement will be replaced by levees with culverts. Since the levee system will remain open except for the biggest storms, it will create more opportunities for moderate storms to move water and sediment into the 30,000 to 40,000 acres of wetlands behind these levees.

The challenge for science in this situation has been to convert our understanding of how storms move sediment into wetlands into an operational framework that helps the levee district see how to design and operate the levee system. This takes a lot of work, and it takes patience and vigilance. My take-home message is that when scientists look for opportunities to apply our understanding to improve the system condition and to learn more, we can make the difference between doing just another dredge-and-fill project or just another levee project, and making a real difference in restoring the landscape.

Key Species and Communities in Bay-Delta Habitats

Bruce Herbold (EPA)
Session Chair



Biomass of organisms found in the northern Estuary before and after the invasion of the clam P. amurensis. *The area of each box is proportional to the biomass of that group. The dotted line encloses the area proportional to* P. amurensis *(clam) biomass. Note that clam biomass is now greater than all other biomass combined (figure courtesy W. Kimmerer).*

Background

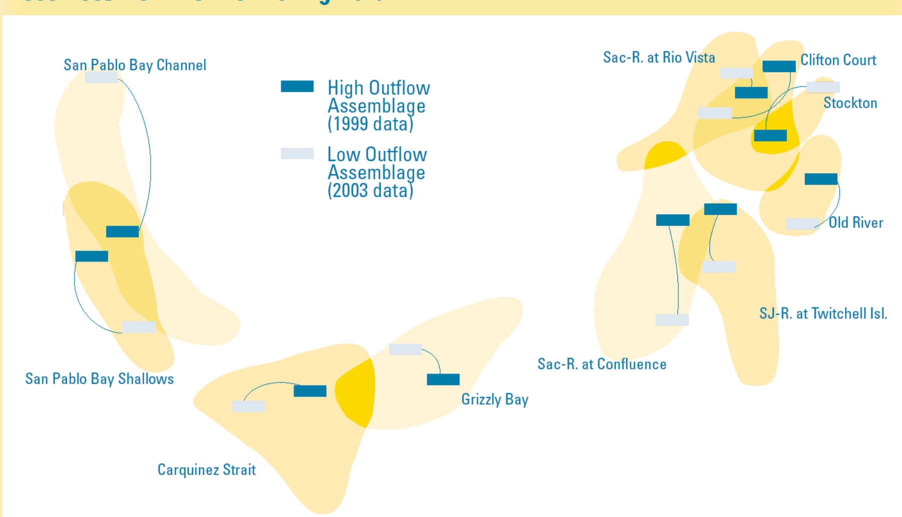
While any ecosystem is the sum of all its component parts, and each plays a role in ecosystem function, some species or groups of species may have greater ecological influence than others. In an ecological sense, 'key' species drive ecological processes or energy flows. 'Keystone' species are those that have disproportionate effects on critical functions such as food web dynamics. Implications of each can cascade to other parts of a community. For example, *Potamocorbula amurensis* and *Corbicula* sp. are both invasive clams that rapidly colonized different parts of the Estuary. In some areas, they now exist in such densities, and filter feed so voraciously, that they profoundly affect the availability of food for native species.

An alternative definition of 'key' species might be driven by human values. Many charismatic megafauna are considered aesthetically, symbolically, or recreationally important, and may also have broader influence. Lesser sandhill cranes (*Grus canadensis*), one of two crane species native to North America, depend on agriculture for foraging. However, their largest effect on the Delta ecosystem may be as an 'umbrella species' for conservation of wetlands and wildlife-compatible agriculture that in turn can benefit other species. Similarly, the Salt Marsh Harvest Mouse (SMHM, *Reithrodontomys raviventris*) is a state and federally listed endangered species. It occupies areas of high salinity, and a paradigm of its association with pickleweed (*Salicornia* spp.) has been based on studies in South San Francisco Bay. Like the lesser sand hill crane, SMHM may have indirect broad-scale effects on tidal marshes, because conservation of the high marsh areas it inhabits requires landscape-scale efforts.

Both ecological key species and human-mediated, 'umbrella' key species play critical roles for understanding and managing resources in the Estuary.

How Much Does the Assemblage Change in Response to Hydrologic Variation?

1996-2003 Benthic Monitoring Data

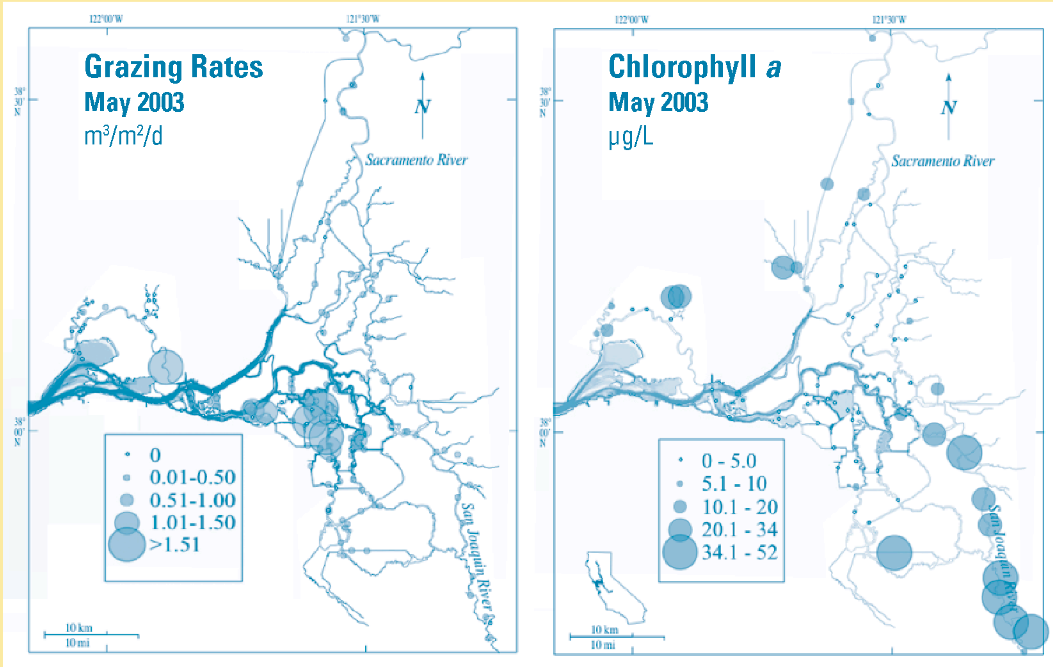


The benthic assemblage in the Bay-Delta system changes in response to hydrologic variation, both at small and large scales. In the multi-dimensional scaling analysis shown here, the position on a pair of axes is related to similarity and differences between any particular assemblages, rather than a geographic shift (figure courtesy H. Peterson).

SCIENTIFIC INFORMATION

Ecological key species

- Following the invasion of *Potamocorbula amurensis*, the biomass of this invasive clam in the northern Estuary has become greater than all other biomass combined (Kimmerer).
- Changes in foodweb dynamics can be subtle and unpredictable. Even with very large perturbations, similar species may respond quite differently (Kimmerer).



In most regions of the Delta, Corbicula *grazing rates may influence or control phytoplankton abundance. The clams can limit phytoplankton biomass and hence food availability (figure courtesy F. Parchaso).*

- Fish and zooplankton have been in decline in the Delta (Hall). The biomass of phytoplankton, mysids, *Crangon* shrimp species, rotifers, calanoid copepods decreased since *Potamocorbula* invasion. Diatoms are virtually gone from the northern Estuary. Anchovy appear to have moved down estuary, presumably in response to stress caused by lower food concentrations in the northern Estuary (Kimmerer).
- Declines of northern anchovy in response to Potamocorbula may have reduced the predation pressure on copepods enough to explain the muted response of other fish to Potamocorbula (Kimmerer).
- *Limnoithona tetraspina* was first detected in the Estuary in 1993, and is now by far the most abundant copepod in the Estuary. 80% of its population occurs in salinity between 0.5 and 10-psu. It likely feeds on ciliates and small flagellates (Bouley).
- The structure of Suisun Bay's foodweb has changed, becoming more complex and less efficient. Dominant species are smaller. The invasive copepod *L. tetraspina* may be an energetic dead-end in the planktonic foodweb, perhaps in part because it is so small that fish do not eat it (Bouley).
- Although two calanoid copepods, *Pseudodiaptomus forbesi* and *Eurytemora affinis*, each feed somewhat selectively, food quality does not seem to be a strong determinant of egg production rates (Hall).
- In most regions of the Delta, large numbers of *Corbicula* correlate with low levels of chlorophyll, suggesting *Corbicula* grazing rates may influence or control phytoplankton abundance. When *Corbicula* biomass reaches a grazing threshold, the clams can limit phytoplankton biomass and hence food availability. *Corbicula* feed on benthic algal mats, but do not appear to deplete them (Parchaso).
- There is a clear correlation in *Potamocorbula* between location in the Estuary and levels of C-13 isotope and selenium. Those signatures are carried into their predators. Invertebrate stable isotope signatures can identify foraging location of predators in the Estuary (Stewart).
- Long-term monitoring data reveal a gradient in benthic assemblages along the axis of the Estuary that is sensitive to inter-annual variations in flow. Variations in physical habitat influence the local benthic assemblage on both large scales (estuary-wide) and small scales (such as across a channel) (Peterson).
- Flooded island assemblages appear to be similar to the benthos in adjacent channels. Exotic species dominate upper Estuary benthic assemblages (Peterson).
- Benthic macroinvertebrates (BMIs) can be excellent indicators of ecosystem health, but their use can be constrained if variation between

sampling in time and space is too high. Variance is typically higher in sites located near urbanized areas (Breaux).

- When benthic invertebrates are common in marshes, fishes also tend to be common. The fish do not always directly reduce benthic invertebrate populations. Rather, they tend to benefit directly from numerous invertebrate food items without depleting them, or they benefit from the same conditions that benefit the invertebrates (Kitting).
- In a survey of marsh habitats, tidal pools associated with channels lead to the highest aquatic animal abundances. Marshes without these pools tended to have low aquatic animal abundances (Kitting). (see Grossinger, page 44)
- Some BMIs can be used to determine the presence of high quality prey for fish, and for assessing water quality even in highly impacted creeks. The most impacted sites had the least number of useful BMI's (Breaux).

Umbrella species

- In Suisun Marsh, density of Salt Marsh Harvest Mouse (SMHM) was generally higher in diked wetlands and in mixed halophytes than in pickleweed and grasses, which may relate mostly to the height of the plants. Reproductive potential and survivorship are similar in diked and tidal wetland systems. Uplands are seldom used by the mouse (Sustaita).
- Staten Island is important sandhill crane habitat. Staten hosted 36% of North Delta cranes for entire winter, and 53% for the core wintering period. At least 15% of Central Valley greater sandhill cranes used Staten Island (Ivey).
- Greater sandhill cranes, including a threatened subspecies, used Staten Island habitat for a significant portion of their annual habitat needs. Use at Staten exceeded Brack Tract, which was historically the most important site in the Delta. Although the cranes have foraging preferences, they feed opportunistically on many crops (Ivey).

MANAGEMENT IMPLICATIONS

Ecological key species

- Species matter when doing biomass analyses and behavior studies. For example, the response of anchovies to Potamocorbula invasion has been very different than that of other fish. Because changes in food, water quality, and other aspects of the aquatic ecosystem vary spatially and temporally, comparing responses across species is likely to yield greater understanding of how the system works than lumping species together (Kimmerer).
- Although in other systems food quality may have an influence, in the Estuary, carbon seems to be the best predictor of copepod productivity (Hall).
- The impact of invasive clam *Corbicula* is profound in many areas of the Delta. It affects phytoplankton levels at the base of the food web that can impact the entire ecosystem, and impact the success of restoration efforts (Parchaso).
- Data gathered by programs that monitor contaminants in predators may be affected by shifts in foraging behavior which can change exposure conditions to contaminants. For example, efforts to monitor selenium in sturgeon may need to consider salinities where sturgeon have been foraging (Stewart).
- Marsh restoration projects with tidal pools may provide better habitat for invertebrates and fish. Managers will need to pay attention to geomorphology, as soil accretion or animal activity can fill in constructed pools. Ultimately, suitable wetland and watershed restoration and maintenance is more expensive than simply conserving existing habitats (Kitting).
- New results suggest monitoring benthic macroinvertebrates (BMIs) in creeks could lead to effective, scientifically valid creek and watershed monitoring and assessment. Combining efforts under a single program (like SWAMP) could help make methodologies more consistent (Breaux).

Umbrella species

- SMHM use more than just pickleweed. This may present more management options for marsh restoration and conservation. Restoration efforts in Suisun Marsh will be of greater benefit to SMHM if they contain a diversity of mixed-halophyte and pickleweed vegetation (Sustaita).
- Proposals to develop Staten Island for flood storage could have serious consequences to cranes. Mitigation for loss of sandhill crane habitat would be most effective close to Staten Island. These areas would ideally have secure, undisturbed roost sites from early September through mid-March, near foraging crops and seasonal wetlands (Ivey).

Indicators of Wetland Condition

Susan L. Anderson (UC Davis)
Session Chair

Background

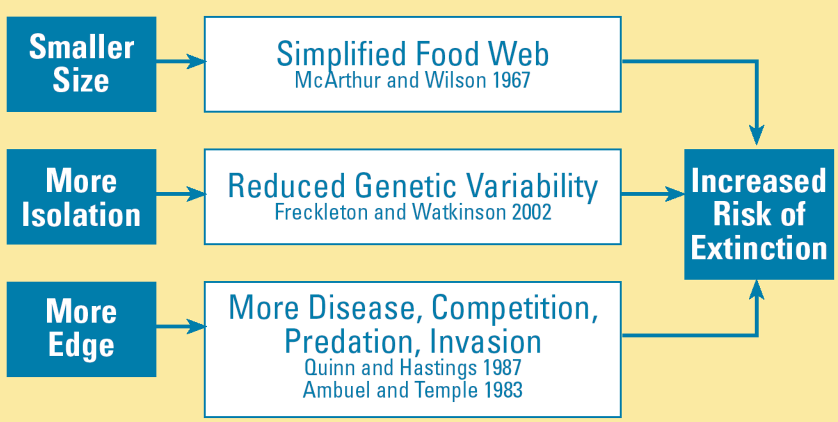
Throughout the San Francisco Estuary, tidal marshes provide rare remnant habitat for species of concern. Very little of the estuary's original habitat remains today, and CALFED goals include improving ecological conditions through restoration of thousands of acres of these tidal marshes and other wetland areas. To achieve these goals, scientists and wetland restoration planners must be able to assess the current condition of the wetlands that they are attempting to restore.

The challenge of managing our natural resources is inextricably linked to the challenge of determining what, if any, difference our management actions are making. The research presented in this session represents steps towards answering basic, but critical, questions such as "How are tidal marsh restoration efforts throughout the region affecting ecosystem processes at different scales?" and "How do you monitor to answer this question in a cost-effective way?"

SCIENTIFIC INFORMATION

- The dominant regional forcing functions of California wetland systems is the estuarine salinity gradient from the Golden Gate to the Delta and the secondary gradients along tributaries such as the Napa River. Other forcing functions include the tidal range gradient, sediment supply, local watershed and Delta outflows, and aspects of climate change (sea level rise and wet/dry years) (Siegel).
- Herbicides designed for agricultural use can reduce productivity in marsh plants. High levels of insecticides and herbicides were found in Carpinteria and Stege marshes. Herbicides and pesticides in sediments were typically found on a gradient with peak concentrations near urban or industrial areas (Kuivila).
- Salt exudate from marsh plants (*Spartina, Distichlis spicata* and *Salicornia virginica*) can be used to determine the presence of bioavailable metals in marshes (Green).
- Reproductive effects in crabs at Tom's Point, Stege, and Walker Creek marshes corresponded to a variety of stressors and stressor indicators, including metal concentration, mercury biomagnification, P450 enzyme induction, and DNA damage to blood cells. Reproductive effects were evaluated by measuring reproductive output, embryo size and weight, abnormal embryo development, hatching success, and larval survival. Reproductive effects in crabs were strongest at Stege marsh, intermediate at Tom's Point, and least at Walker Creek, which corresponds to the degree of contamination at each site. However, the opposite was true with size and abundance data (Morgan).
- Use of aggregated fish indicators (ecotoxicology, ecology, and chemistry) enables early warning detection, stressor diagnostics, and linkage to individual and population fitness. New indicators of endocrine disruption appear especially promising (Cherr).
- Fragmentation analysis of California clapper rail habitat suggests the historic array contained three areas of very large adjacent patches (Suisun Bay, North San Francisco Bay, and South San Francisco Bay) connected by many small patches. Patch shape included wide patches of marsh between uplands and open water. Today there are long narrow

Conceptual Model



Conceptual model of potential effects of marsh fragmentation on population size (figure courtesy J. Collins).

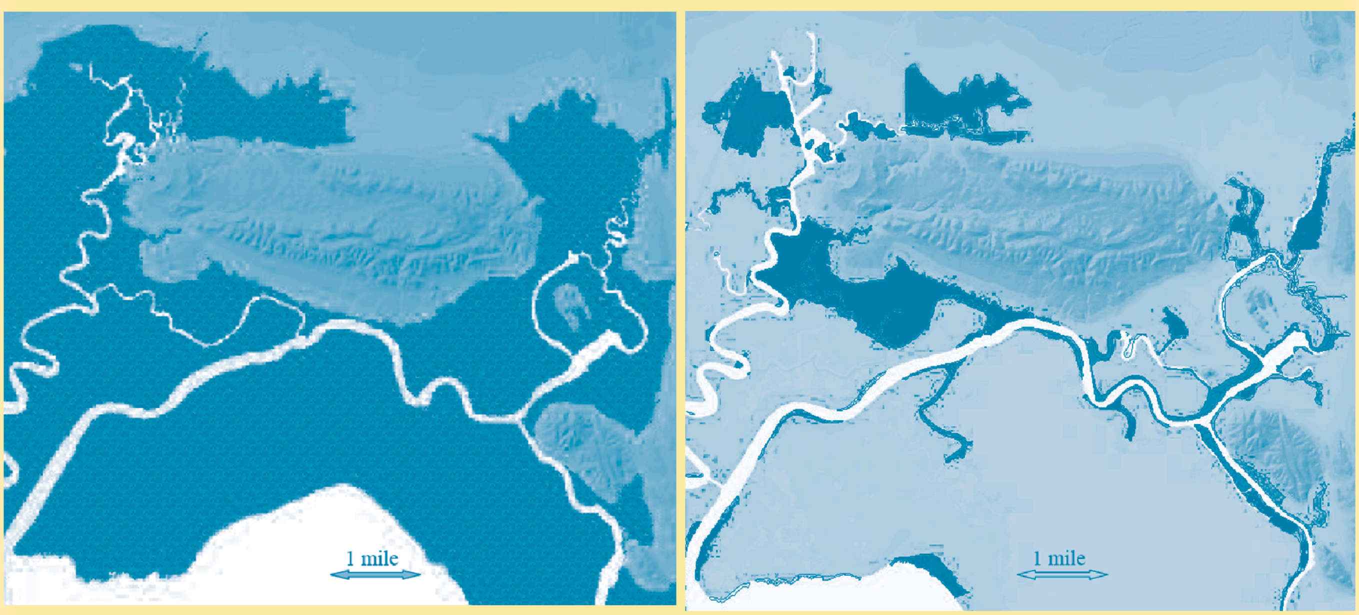
MANAGEMENT IMPLICATIONS

- Tiered conceptual models (landscape physical and ecological processes; vegetative and geomorphological structure; habitats and species; food webs, nutrient cycling, and primary productivity) can be used to frame evaluations of wetland ecosystem processes (Siegel).
- Mercury muscle tissue analysis in crabs could be extended geographically to understand the scale at which the mercury-to-size relationship applies. This indicator could be used as a screening tool to prioritize sites with high mercury bioaccumulation potential (Nelson).
- Reproductive effects and larval abnormalities in crabs can provide early warnings about stress and contamination in both intact and restored wetlands (Morgan).
- By assessing the response of wetland organisms to pesticide exposure at the cellular, physiological, and population levels, detection can be integrated with remote sensing to assess the state of wetlands and assist managers in making decisions regarding restoration efforts (Ustin, Kuivila).
- By using a portfolio of integrated indicators in resident species, managers could move beyond the information available from currently available toxicity tests and chemical analysis to help determine whether contaminants are involved in the declines of species of concern (Anderson).
- Fragmentation analysis suggests 1) an array of habitat should contain a range of patch sizes, 2) gaps between patches should be filled, and 3) projects should be "round" with at least 100 meters of naturalistic buffer (Collins).
- Findings on endocrine disruptions in wetland fish in a central San Francisco Bay marsh indicate a need for studies to determine how widespread the phenomenon may be elsewhere in San Francisco Bay (Cherr).

patches between levees and open water. The three large areas are smaller and further apart and there are fewer connective patches in between, potentially causing more isolation for the birds (Collins).

- Traditional toxicity tests and chemical analyses are being enhanced by an indicator organism approach. This approach links exposure
  - cell or physiologic response
  - individual response
  - population response
  - ecosystem response.

The conceptual model incorporates model animal and plant species, stressor characterization, and an ecosystem model and the approach results in a portfolio of integrated indicators for resident species (Anderson).



Historical Suisun Marsh wetlands (left) had wide, continuous patches of marsh between uplands and open water. Modern patches (right) are discontinuous, long and narrow, between uplands and levee (figure courtesy J. Collins).

Re-Emergence of Shallow Water Ecosystems Across the Bay and Delta

Charles (Si) Simenstad
(U. of Washington)
Session Chair

Background

The San Francisco Estuary was once almost completely ringed by tidal wetlands. Human impacts have reduced the amount of this habitat by 90%, with profound impacts on species of concern and the surrounding ecosystem. CALFED's commitment to restore thousands of acres of tidal marsh habitat in the Estuary will only be successful if we can understand the implications of our actions and the potential of future restoration. The South Bay salt pond acquisition marks the beginning of the largest ecosystem restoration project outside the Everglades. This is a symbol of the importance of shallow water habitat restoration in the Estuary, but it is only one of many sites.

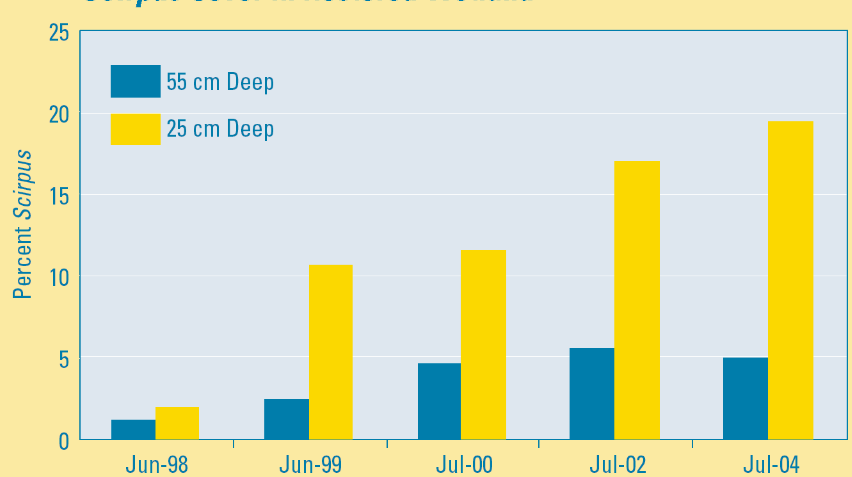
Shallow water habitat takes many forms from marshes to mudflats. Each naturally occurring habitat type serves a variety of ecological functions, such as providing nurseries for fish, and refuge for waterfowl. Tidal marshes also have farther-reaching implications for the Estuary: beyond providing ecosystem services such as trapping sediment and buffering tidal energy, they are valuable to the broader aquatic ecology landscape because they can produce and export food in the form of organic detritus and organisms that are prey for fish and wildlife. In addition, phytoplankton is of particular concern in the Estuary as a potentially limiting food source in the Delta, because zooplankton are limited by low phytoplankton biomass, and have also declined in the past decades. Shallow water habitat can be a net source of primary production, detritus and secondary production, each of which can be a limiting factor for different pathways in the Estuary's food webs.

Understanding the processes involved – and the linkages between ecology, hydrology and geomorphology – is a non-trivial task for scientists and managers. Doing so on multiple scales will be a daunting, but critical necessity if the myriad restoration and management opportunities in the Estuary are to meet their goals.

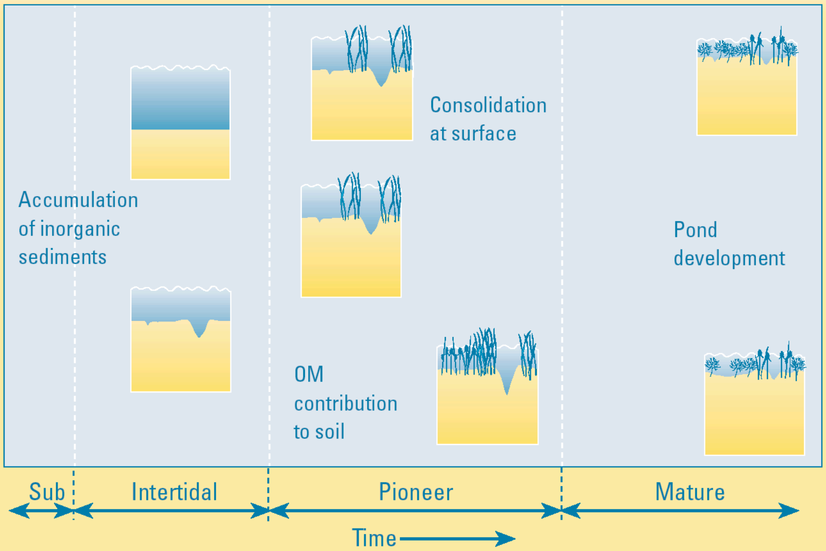
SCIENTIFIC INFORMATION

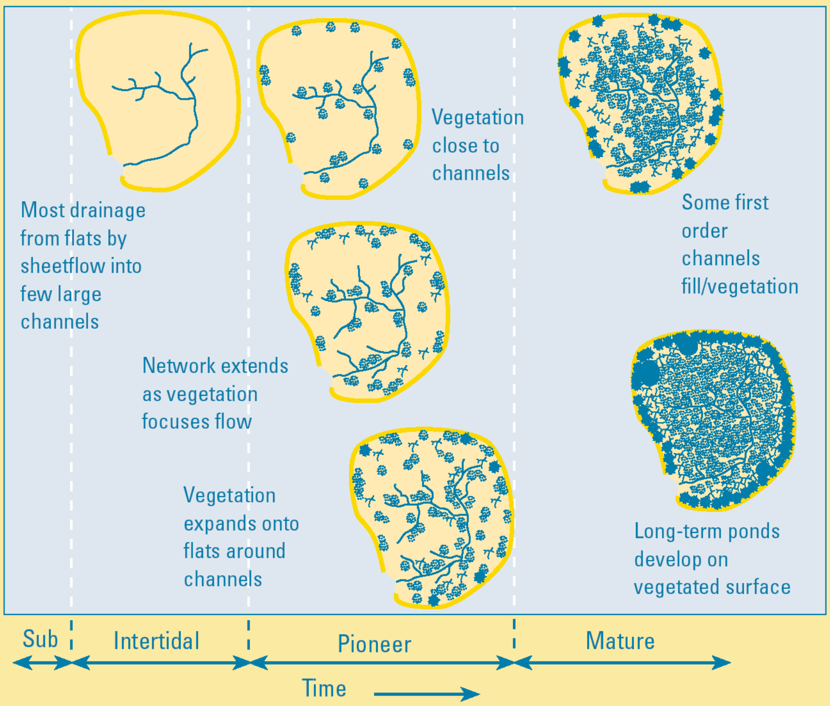
- Combining historical U.S. Coast Survey maps with GIS technology has produced modern digital maps of 19th and 20th century San Francisco Bay marshes with new detail, including specific channel networks. The original system of marshlands in the Estuary was heterogeneous. Some parts of the marsh had up to 200 small salt pannes per 1,000 acres. Other swaths of marshland had ponds as large as 10,000 square feet and significantly wider channels than today. South Bay marshes were renowned for waterfowl, and had a patchwork history of diking for various purposes (Grossinger).
- New results from the BREACH team have changed their conceptual model. The model now suggests that land-surface elevation and the type of vegetation established are the key factors determining a restoration project's evolution, rather than the age of the site per se. Emergent marsh vegetation influences prey availability, provides structure for birds and,submerged aquatic vegetation, supports exotic fish species. Colonization by different vegetation types marks critical thresholds in the transition from one habitat type to another (Reed).
- Channel development at restoration sites depends on tidal range, slope, and substrate, and on the initial vegetation colonization. The complexity of the channel network decreases as elevation increases (Reed).

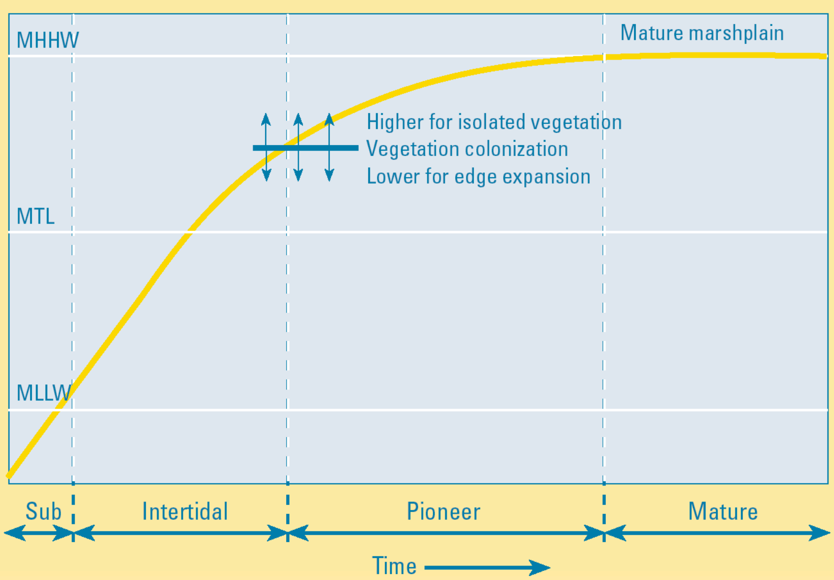
Scirpus Cover in Restored Wetland



Both vegetation cover and type depend on depth in an experimental restored wetland (figure courtesy R. Miller).







Figures courtesy BREACH Team

- Experimentally restored marshes on Twitchell Island have become more effective at storing carbon over the past six years. This increased substrate accretion suggests that restoring wetlands can combat subsidence in the Delta (Miller).
- In experimentally restored marshes, vegetation type and production depended on water depth. Emergent vegetation colonized the shallow water (25 cm) more rapidly and completely than in deeper water treatments (55 cm). Above and belowground production seemed to 'balance' one another's biomass production. Submergent vegetation and algae in deeper water produced significantly less biomass than the emergent vegetation in shallow water. The plant community in turn affects a variety of environmental factors, including, water temperature, pH and carbon dynamics (Miller).
- Trace element signatures for different sediments can provide more detailed information on what sediment deposition can be expected over time from different sources (Roam).
- Napa-Sonoma salt pond salinity ranged over an order of magnitude, and influenced bird diversity at the site. Bird species also segregated by pond depth (Athearn).
- Biotechnical methods such as installation of root wads, brush walls, and other structures were experimentally used to mitigate erosive

-continued

These figures illustrate the current conceptual model developed by the BREACH team for tidal marsh succession. In each figure, as development progresses from subtidal mudflat to mature marsh, average elevation gradually increases. Increasing elevation is accompanied by changes in geomorphology, vegetation, and soil profile (figure courtesy BREACH Team).

SCIENTIFIC INFORMATION CONTINUED

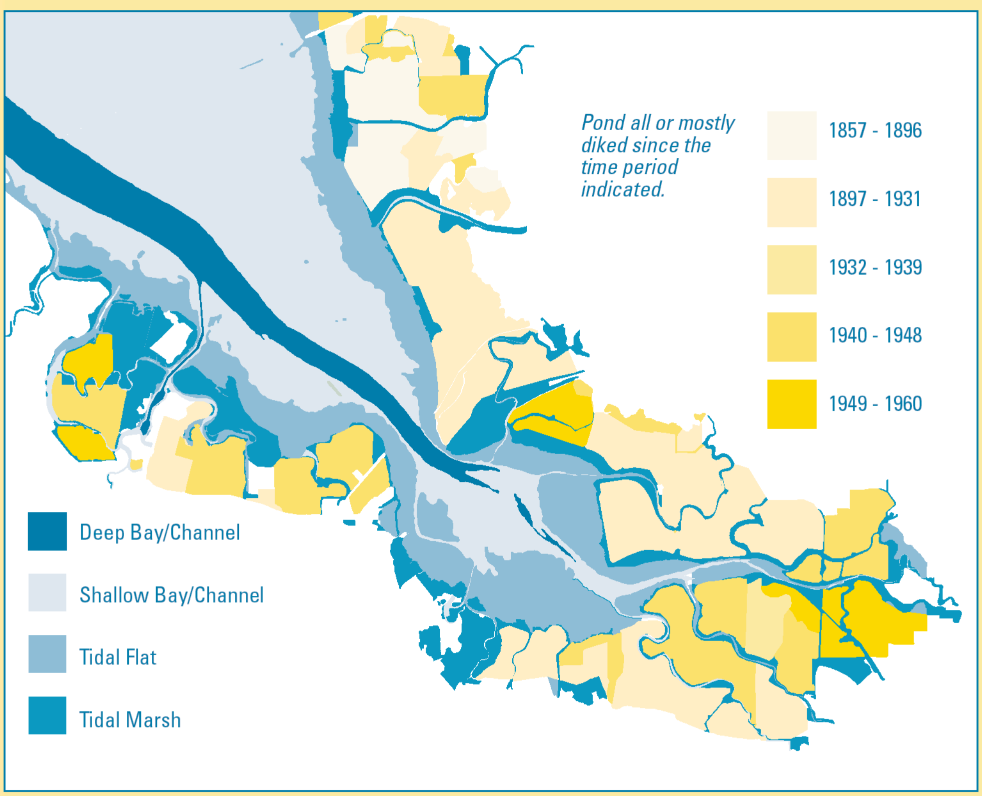
forces such as waves, boat wakes, tidal flows, and fluvial currents. The treatments seem effective: monitoring shows a decrease in erosion, and increase in native emergent wetland plant cover (Nichols).

- Liberty Island has been inundated for seven years without management for restoration and with little monitoring. Much of the wetland habitat created on the island now resembles natural wetland habitat. Agricultural furrows remain in some mudflats, but others, particularly protected areas, have distinct channelization and emerging tules. This freshwater marsh provides habitat that supports more native fishes. Mudflat habitat now provides important early-season waterfowl habitat in an area where other managed lands are dry (Mager).

- In a study of Frank's Tract and Mildred Island, phytoplankton grew more quickly in shallow water habitats and was generally higher there than in deep water habitats. However, the pattern does not mirror growth rates – there are likely other factors mediating phytoplankton biomass than production alone, such as benthic grazing and transport to deeper water. In contrast, zooplankton biomass was independent of depth. This suggests other processes besides depth affect zooplankton abundance and secondary production (Lopez).

- A study in China Camp used stable isotopes to investigate trophic transfer. The authors found little evidence of trophic transfer between the marsh plain and adjacent tidal channels. High marsh productivity was not being used by resident fish, or other vertebrate consumers. This suggests that the food web is spatially compartmentalized in this marsh habitat: it is unlikely that this marsh 'subsidizes' the Estuary (Grenier). (See also Floodplains, page 26)

Timing of Salt Pond Establishment



Historical progression of salt pond establishment in South San Francisco Bay may have implications for tidal marsh restoration (figure courtesy R. Grossinger).

MANAGEMENT IMPLICATIONS

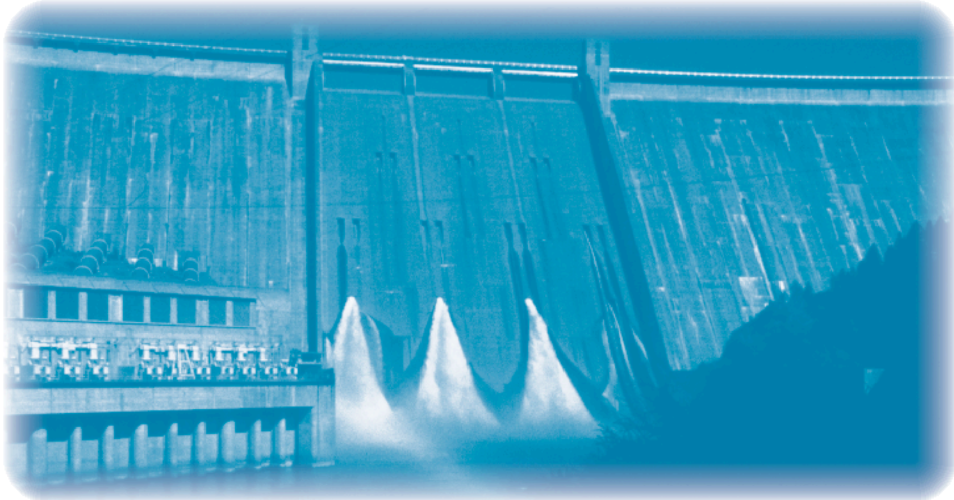
- New detailed historical maps allow quantification of tidal marsh elements and structures important for restoration and could serve as a guide for restoration efforts. Historically heterogeneous marshlands suggest that one aim of restoration should be to restore a variety of ecosystem types in the South San Francisco Bay (Grossinger).
- The management history of tidal marshes may predict the current distribution of contaminants such as mercury (Grossinger).
- Tidal marsh restoration may benefit waterfowl as much as it does other species of concern, particularly if historical conditions are taken into account in planning (Grossinger). Antecedent marsh conditions can serve as a predictor of restoration trajectories and as a target reference. That said, we may need a new paradigm in marsh restoration. Some managers fixate on the how long a project will take to reach some stable endpoint. This may not be productive. A focus on what the early and interim stages contribute to the system is warranted (Simenstad).
- Restoration must consider both landscape and temporal scales. Important variables include position along estuarine gradients, landscape setting (size, mosaic, patch and landscape connectivity, high and low tide refuge), ecosystem dynamics (disturbance regime; episodic events), and antecedent condition (Simenstad).
- Think vertically, think complexity: Land-surface elevation may be the primary driver of restoration trajectories in tidal marshes (Reed, Simenstad).
- Assessing the ecological value of habitats will require a suite of indicators (including measures of biomass, production, and ecological efficiency). Shallow-water ecosystems such as Frank's Tract or Mildred Island do not exist in isolation – they are inter-connected with the rest of the system, and need to be viewed and managed as such (Lopez).
- A given area of habitat can have value elsewhere in a connected system. For example, shallow water habitat can positively affect surrounding channels through transport of food resources (Lopez). However, not all marshes have significant trophic connections to the surrounding environment (Grenier). Increased productivity may not impact fish performance in cases where there is little trophic transfer or connectivity between spatially distinct habitats.
- Restoring Delta agricultural land to shallow water wetlands could be an effective tool for reversing subsidence (Miller, see Table).
- Changes in water levels and salinity greatly impact bird populations using the ponds, and these bird populations respond rapidly to such changes – community composition can change even if overall number do not. Large salt ponds with bathymetric variation could support more diverse bird populations (Athearn).
- Biotechnical methods can cost-effectively control island erosion (Nichols).
- If lessons from Liberty Island apply elsewhere, micro-management of wetland restoration projects may not be necessary. An island that was inundated and left in its submerged state returned to a somewhat-natural state, supporting native fauna and flora, in a relatively short time span (Mager).

Subsidence Management Option	Projected 10-year outcome
Current management of island draining, elevation loses 1-2 cm/yr.	Lose about half a foot of elevation, incurring increased levee maintenance and repair costs.
Permanent flooding with submergent vegetation, elevation maintained.	Little substrate elevation change and algal blooms and concomitant increases in pH.
Shallow flooding with emergent marsh vegetation, elevation gains >2 cm/yr	Gain less than one foot of elevation, (more than one foot elevation gain compared to no wetland restoration). Water temps cooled by shading, and higher relative humidity in canopy may reduce water loss from evaporation.

Projected subsidence trajectories with different management scenarios. Shallow water flooding may be a good subsidence mitigation option (table after R. Miller).

Physical Controls on Habitats

Mark Stacey (UC Berkeley)
Session Chair



Shasta Dam

Background

CALFED goals include the rehabilitation of natural processes and restoration of functional habitats. An understanding of physical factors is ecologically important because physical controls play key forcing roles in many fundamental ecological processes. These physical factors vary spatially and temporally. A consistent message from scientists across many restoration-related disciplines is that healthy habitat is usually dynamic. The recognition that physical controls on many scales can influence the success of our restoration actions, and understanding of how, is critical to making effective restoration decisions.

A key underlying factor in many types of aquatic habitat restoration is sediment supply and dynamics. Restoration of tidal wetlands requires sediment deposition to bring a project to a sufficient elevation that vegetation can colonize. Mudflats are intimately connected geomorphically to marshes. They function as buffers for wave action and as the immediate sediment supply for the intertidal wetlands that are the subject of massive restoration efforts, and thus must be included in these efforts. In rivers, fish species of concern require gravel of particular size and disturbance regime for good spawning and rearing habitat. In each of these habitats, sediment dynamics and supply are ultimately influenced or determined by physical controls. Understanding physical controls, and learning how to account for them in an adaptive management context, will be an important task in our restoration efforts.

MANAGEMENT IMPLICATIONS

- Every river diverges from textbook understandings, so every habitat restoration project must be based upon a genuine assessment of what the river is doing, not what it should theoretically be doing. Because California's rivers are highly engineered, changing flow and sediment regime alone will not be enough to restore them. Restoration will be most effective if it proceeds adaptively, with monitoring designed to answer specific questions within a hypothesis-driven framework (Pasternack).
- SHIRA is an approach to adaptive management of river restoration that involves four steps: Identify design constraints and opportunities, develop preliminary design sketches, test design hypotheses using modeling and data analyses, and refine design (Pasternack).
- Flows control migration of active reaches of the Sacramento River by limiting erosion and transport of bank material. The maintenance of migration rates for regeneration of habitat in the Sacramento requires unimpeded downstream translation of bends, a coarse sediment supply, and flows equal to or greater than bankfull discharge (Constantine).
- Restoration sites located along the Sacramento River and the North Delta will have the greatest available sediment supply. Levee breaches for restoration of wetlands or floodplains will likely be most effective during the wet season when sediment transport is highest, although higher flows might also increase erosion (Wright).
- Mudflats are linked to tidal marshes, both as a buffer for wave energy, and as the immediate supply of tidally borne sediment. Mudflat habitat area changes as a function of changing sediment supply. Changes in sediment deposition or erosion may result in departures from historical patterns witnessed historically, creating altered distributions of mudflats (Jaffe)

SCIENTIFIC INFORMATION

- Submergent Aquatic Vegetation (SAV) influences hydrodynamics in Franks Tract, significantly reducing water velocities and limiting sediment re-suspension within the canopy, while creating a mixing layer above the canopy. A model using a vertically variable drag coefficient more accurately represents the effects of SAV than do traditional Bottom Benthic Layer models with perturbations in bed roughness or bed elevation (Sereno) (see Native and Resident Fishes, page 17).
- Because of the drag induced by SAV, vegetation that develops seasonally may impact channelization of flow, residence time and sediment re-suspension. An accurate representation of these effects is required for long-term modeling of Delta shallow water habitats (Sereno).
- In the Sacramento River from Red Bluff to Colusa, actively migrating reaches alternate with stable sections. Underlying bank material is a primary determinant of whether a reach migrates or not: Pleistocene terrace is resistant to erosion and hence to migration. Migration rates are also highest where bankfull discharges are highest, which reflects increased transport of eroded bank material (Constantine).
- During water years 1999-2002, about 4.4 million metric tons of net sediment deposition occurred in the Delta, corresponding to about 2 cm of deposition averaged across the Delta. Sediment supply comes mostly in the rainy season, and mainly from the Sacramento River, at a rate almost an order of magnitude greater than the San Joaquin (Wright).
- From 1951-1983, sediment input to San Francisco Bay decreased from peak hydraulic mining-supplied deliveries. Mudflat area has responded by decreasing from its peak following hydraulic mining deliveries, and showing a changed spatial distribution (Jaffe).
- The Spawning Habitat Rehabilitation Approach (SHIRA) evaluates fish spawning habitat at three scales, from the hydraulic scale of a fish experiencing the river to reach scales necessary for self-sustaining riverine processes. SHIRA is currently is use for planning and evaluating restoration projects on the Mokelumne, Trinity and Yuba rivers. It is transparent, hypothesis-driven, and provides predictions at ecologically relevant scales (Pasternack).

Physical Factors Vary Throughout the Estuary

Physical controls vary from site to site in the Estuary. The trends in this figure are not meant to indicate literal gradients, but rather to put general tendencies into perspective. One implication of these differences is that different parts of the Estuary may respond differently to large-scale changes such as sea-level rise, drought, or inflow changes (source: Steve Culberson and Michael Kiparsky; illustration: Darren Campeau).

Effects and Management of Nonnative Invasive Species

Lia McLaughlin (USFWS)
Session Chair

Background

San Francisco Estuary may be the most invaded estuary in the world, and invasive species will continue to dramatically change the aquatic ecosystem. Non-native species arrive in the Estuary accidentally (such as in ballast water) or intentionally (often through introduction of game species). In most cases, species which establish in the Estuary are here to stay, and for managers to deal with. Education can go a long way to prevent both types of introduction, but will not be enough. Plant species require vigilance for rapid identification and response to the first invaders. Tough regulatory efforts to prevent further invasions will be critical, particularly for animals. Ultimately management of invasive species will require integration of new arrivals into our understanding of the altered ecological system.

Talks in this session focused on three invasive aquatic plants, two of which are tidal marsh plants. Other science on invasive species and their effects is presented in the Key Species and Communities (page 39) and Native and Resident Fishes (page 17) and throughout the Conference Summary. *Spartina alterniflora* is a smooth cordgrass native to the eastern U.S. It was first introduced three decades ago when planted in marshes to control erosion. Whereas many successful invasive species outcompete natives and displace them, *S. alterniflora* instead hybridizes with *S. foliosa*, the native Pacific cordgrass. Some of these hybrids have higher tolerances for salinity and other factors than either *S. alterniflora* or *S. foliosa*, allowing them to spread into novel habitats and to displace both parent species.

Pepperweed (*Lepidium latifolium*), native to Eurasia, has invaded throughout the U.S. It spreads not only in tidal marshes, but also agricultural, alkaline, riparian, and freshwater marsh areas. The salinity tolerant weed is noxious and widespread, occurring in all but three California counties. It disperses by seeds and root fragments, and has high seed productivity and viability in freshwater. In tidal wetlands, *Lepidium* is of particular concern because it actively encroaches on some endangered species of native marsh plants and animals.

Water hyacinth (*Eichhornia crassipes*) was introduced as a pond ornament, and now overruns waterways and ecosystems in the Delta. In addition to displacing native species, it causes seasonal problems when it dies and decomposes, resulting in water column anoxia. An herbicide used until recently in attempts to control the weed has recently been banned and mechanical methods are being considered as an alternative.

Water hyacinth (Eichhornia crassipes)

MANAGEMENT IMPLICATIONS

- *Spartina* hybrids not only outcompete natives, but will continue to hybridize and displace remaining native species genetically. *Spartina* hybrids may also colonize open mudflats, elevating them into meadows. If this occurs, aquatic habitat may convert to terrestrial habitat, decreasing the quantity and quality of shore bird foraging habitat (Ayres).
- Another newly identified *Spartina* hybrid is not spreading quickly. If it shows evidence of sexual reproduction, action will be needed to stop its spread. At this time, that is not a high priority since they are currently not reproducing by seed (Lee).
- Pepperweed recruitment in saline marshes may be episodic and dependent on freshwater inputs. The fresh end of the Estuary is most susceptible to invasion via seed recruitment (Spenst).
- The mechanical method of water hyacinth removal presents potential problems because it also shreds other plants, and may result in further spread of water hyacinth. Mechanical removal methods can also stir up sediment (Toy).
- Water hyacinth is a resilient invader, and can displace sensitive and native species. No known technique is completely effective for controlling it, as both chemical and mechanical methods have drawbacks (Toy).

SCIENTIFIC INFORMATION

- Some newly identified hybrids of *S. alterniflora* and *S. foliosa* were taller, had more rapid rates of lateral expansion, higher tolerance to salinity, and higher rates of self pollination than either parent species. Hybrids had more effective sexual reproduction with the native species than either parent species. Hybridized species had invasive advantages, such as tall stems that allowed them to better survive in saturated soil, rapid lateral expansion to anchor into soft and shifting mud, a tolerance to both salinity and fresh water, and high seed and pollen production (Ayres).
- Rapid evolution is taking place among *Spartina* hybrids. Natural selection may favor the traits of the hybrid plants in a positive feedback that results in an accelerating population growth rate of the fittest, most invasive hybrid genotypes. The hybrids' range is slowly expanding from the South Bay to the North Bay, particularly in areas exposed to tidal action. Hybrids are also moving into restoration sites. The rate of expansion is accelerating exponentially, fueled by genetic variation resulting from hybridization. Alterations to the intertidal ecosystem are accelerating: scientists expect the extinction of native cordgrass unless the hybrids are controlled (Ayres).
- A greenhouse experiment indicates that newly discovered hybrids between exotic *Spartina densiflora* and native *S. foliosa* have greater tolerance to salinity than the native or exotic parent species suggesting they may be able to invade native tidal marsh habitat. However, hybrids in this study were not able to reproduce sexually, slowing their invasive potential (Lee).
- In a study of 50 tidal marshes, birds do not appear to avoid pepperweed (*Lepidium latifolium*), which tends to grow in elevated areas next to channels where some species nest (Spautz).
- Elevated salinity, presence of native vegetation, and increased flooding frequency significantly reduced pepperweed seedling recruitment. These results imply that freshwater tidal marshes, and in particular disturbed ones, are more susceptible to pepperweed invasion. Pepperweed recruitment into saline marshes may be more episodic and dependent on freshwater inputs (Spenst).
- Use of the AquaTerminator shredding machine for water hyacinth removal in experimental treatments resulted in slight decrease in overall water quality. Cleared hyacinth patches regenerated over half of the cleared area from fragments in the shredder. Fragments can potentially spread the invasive plant to other areas (Toy).

Spartina foliosa

Water Hyacinth

Restoring and Managing California's Native Grasslands

Jeanne Wirka (Audubon California),
Session Chair

Background

The verdant rolling hills of winter, alternating each year with the golden brown rolling hills of the dry season, are familiar images for many Californians. However, many people don't realize that the annual grasses responsible for this cycle are primarily exotic species, mostly from the Mediterranean region. Although the botanical history of California is difficult to reconstruct, many ecologists believe that the lowlands of California were historically dominated by perennial bunchgrasses. Native grasslands still exist, but only in limited, remnant areas.

Native perennial grasses have two main growth forms. Some are sod-forming or rhizomatous (mostly in wetter areas); others are bunch grasses that grow in clumps and form prairies with space between the clumps. This varied structure is important for grassland-specialist animal species and for native forbs that tend to grow between the clumps. Introduced annual grasses are structurally more uniform, with very little open space. They die at the end of their life cycle, leaving material that is not palatable to livestock. Many native perennials, on the other hand, have tissue that can be foraged during a longer portion of the growing season.

Vernal pools have become a rare feature in California's grasslands, and their management brings up unique issues. They are often located in areas used heavily for grazing and often support mixtures of native and invasive species. Because maintaining the hydrology is critical to their continued existence vernal pools are very sensitive to how they are managed.

The differences between native and invasive grasslands go beyond the aesthetic, relating directly to core CALFED goals. Native grasses provide important forage and nesting habitat for wildlife, reduce erosion, and improve water quality.

MANAGEMENT IMPLICATIONS

- Active management for establishment and persistence is essential to the success of native grass. Restoring native grasslands will require replacing a focus on individual, short-term projects with coordination across agencies and landowners on long-term, larger scale management (Wirka).
- Native grass can be established within riparian restoration projects, but different species respond to different conditions. Intensive weed control before and during establishment is important (Efseaff).
- At the Sacramento National Wildlife Refuge, prescribed fires enhanced native plants, but burns were limited, competing with local farmers given air quality restrictions. Cattle grazing worked better than sheep because the sheep ate many of the native species in addition to the invasive species (Silveira).
- Annual and perennial grasses require very different management treatments. For annuals a goal is to maintain appropriate levels of residual plant material after the growing season. However, build up of thatch in perennial fields reduces the palatability of some native bunchgrasses for livestock. Managing perennials on a monthly or seasonal basis so as not to leave behind dead and undesirable plant parts could address this issue (Laca).
- Grass species composition used in restoration projects and grassland management can influence the avian community using restored grasslands. Grassland specialist bird species often require a more heterogenous structure for foraging and nesting (Goerrissen).
- Remote sensing results can be communicated more effectively using traditional satellite imagery that allows ranchers to actually see the difference made by management techniques on species composition. Remote sensing technology can be used to research the history of a restoration site by comparing previous years' imagery. Landowner response suggests such analyses enhanced their ability to evaluate the impact of management activities (Malmstrom).
- Removal of cattle grazing from vernal pool grasslands negatively impacts native plant and aquatic invertebrate species diversity as well as pool hydrology (Marty).

SCIENTIFIC INFORMATION

- In long-term experiments in Yolo County, prescribed fire and pulse grazing by cattle successfully controlled invasive species during the first growing season in fields restored to native grasses. There appears to be a slower rate of re-invasion by exotics in sites seeded with native grasses, but it is unclear how much is due to competitive exclusion and versus the increased management in general (Wirka).
- After two years of rangeland restoration experiments in Yolo County, the native grasses retain their cover, despite some return by non-natives. Mowing greatly reduced non-native grass cover, without affecting native grasses. *Nasella* sp. has good restoration potential, but only average performance per dollar. Convergence was towards a bunchgrass-dominated community, and forb dominance was only achieved through primary introduction (Lulow).
- Experimental plots in northern California preliminarily suggest native perennial grasslands may produce more biomass, contain higher tissue nitrogen at season's end, and allow plant roots to absorb more soil bound water, especially under drier conditions (Griffith).
- Native perennial grassland soils may allow for more surface water infiltration, which could help minimize erosion on steeper hill slopes (Griffith).
- Sheep were given pots of *Nassella pulchra* (purple needle grass, a native perennial species) and *Bromus* sp. (an exotic annual grass). *Bromus* was preferred when *Nassella* was unclipped or flowering. *Nassella* was preferred with it was clipped and not flowering (Laca).
- In the Sacramento Valley in winter, Savannah Sparrow (*Passerculus sandwichensis*) abundance tended to be greatest in grasslands that had a forb component. Western Grasshopper Sparrows (*Ammodramus savannarum perpallidus*) were more abundant in perennial bunchgrass than in grasslands dominated by exotic annual grasses, and their breeding territories occurred exclusively in native or restored grasslands (Goerrissen).
- A novel technique allowed estimation of rangeland grass cover through remote sensing on watershed scales. Results showed an increase in forage production in response to burning, when precipitation is adequate (Malmstrom).
- Species richness of native plants and aquatic invertebrates was significantly higher in grazed versus ungrazed vernal pools. Grazing removal increased exotic grass cover (Marty).
- In vernal pools where grazing was removed, there was a dramatic drop in maximum ponding periods. Hydrologic changes were no longer buffered by vegetation, causing a loss of animal taxa in the vernal pool system. Ungrazed pools were inundated for a shorter period of time, and were more likely to dry and refill multiple times throughout the season than grazed pools (Marty).
- Management must be paired with greater understanding of the habitat requirements of target species, and careful monitoring and planning, to ensure weed control methods are effective and ultimately benefit native species (Leger).