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Salt Marsh Restoration Experience in San Francisco Bay

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ABSTRACT

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Efforts to restore ecologic functions in ten major tidal wetland restoration projects implemented in the San Francisco Bay over the last 25 years have had variable results. Although almost all restoration projects constructed do now support important wetland functions, in a number of cases they have performed or evolved in ways that were unanticipated at the time they were planned. This extensive restoration experience has provided important lessons for restoration planning and design that can be applied in other estuaries. These lessons include: 1) the need for well thought out, explicit, restoration objectives; 2) developing an understanding of restored salt marshes as evolutionary systems that have changing wetland functions as they mature; 3) the need to incorporate an understanding of the morphodynamics, or interaction of key physical processes in restoration design, and 4) the need to fully integrate monitoring into the restoration plan in order to institute a learning curve so that practitioners can build on the experience of earlier projects.

ADDITIONAL INDEX WORDS: *Salt marsh restoration, San Francisco Bay, wetlands.*

INTRODUCTION

The extensive tidal wetland restoration experience in the San Francisco Bay estuary can be viewed not just as a sequence of experiments in restoration techniques but also, more importantly, as a laboratory for testing restoration methodologies that are now being considered in other parts of the world.

At the advent of American colonization 150 years ago, approximately 220,000 ha of tidal marshes, including 80,000 ha of salt marsh, fringed the San Francisco Bay, the Pacific Coast's largest estuary (ATWATER *et al.,* 1979). The progressive diking and filling of more than 90% of these marshes (Figure 1) led to widespread public concern, and well organized environmental activists succeeded in having the first wetlands protection legislation enacted in the United States in 1966. This legislation prevented any further filling of tidal wetlands in the salt water regions of the estuary. It was inevitable that shortly following this success, plans would be proposed to reverse environmental damage through restoring tidal wetlands. The first project, restoring the 32 ha Faber Tract, (Table 1 and Figure 2) was implemented in 1972. In the 27 years since, many other projects, totaling more than 1,200 ha, have been carried out by different government agencies, using a variety of techniques and approaches, and ranging in size from a quarter of an acre to the 220 ha Pond 2A project. Combined with the effect of levee failures, a total of approximately 2,000 ha of the

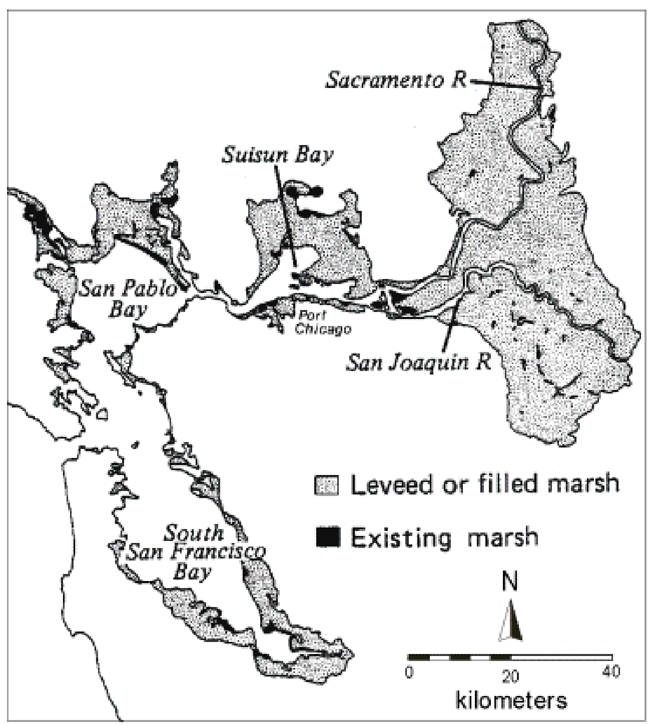

Figure 1. Historic changes in San Francisco Bay estuary.

Table 1. *Summary of the major tidal restoration projects in the San Francisco Bay estuary*[1]

	Name	Area (ha)	Year Restored	Remarks
1.	Faber Tract	32	1972	Dredged material site
2.	Pond 3	44	1975	Dredged material site
3.	Muzzi	52	1976	Dredged material site
4.	Bair Island	60	1978	Salt pond
5.	Cogswell	80	1980	Salt pond
6.	Warm Springs	80	1986	Borrow pit
7.	Carls Marsh	22	1994	Agricultural field
8.	Pond 2A	220	1995	Salt pond
9.	Sonoma Baylands	120	1996	Dredged material site
10.	Tolay Creek	20	1999	Agricultural field

[1] Sites larger than 50 acres where full tidal restoration was planned

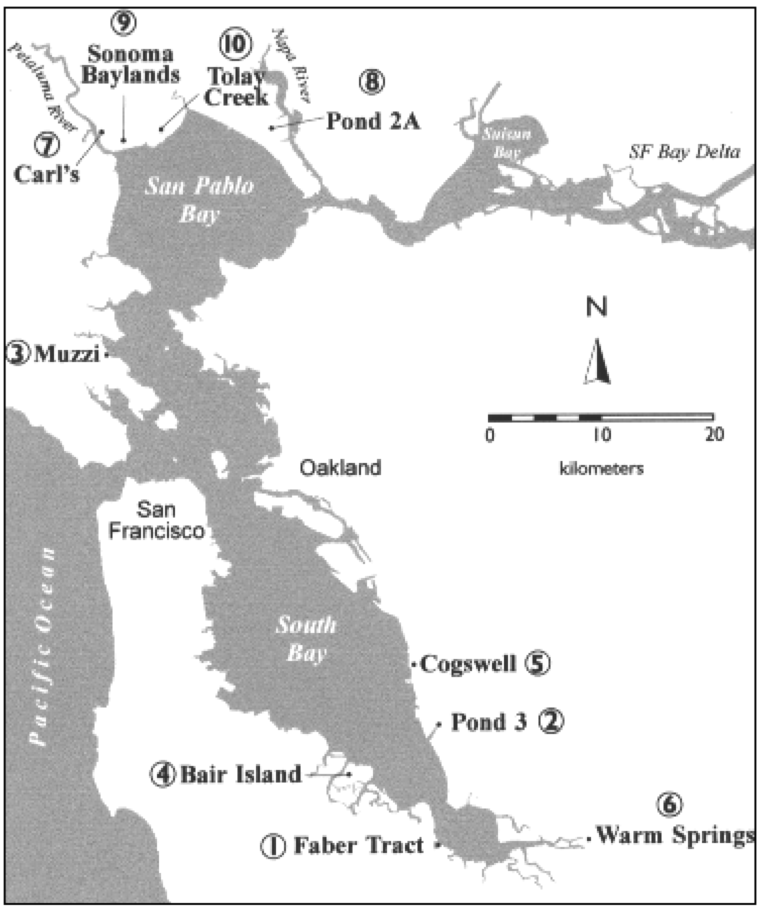

Figure 2. Major tidal salt marsh restoration sites (larger than 50 acres).

former tidal marsh has now been restored to tidal action. Active planning efforts are now underway on three large restoration projects to restore tidal action to about 4,800 ha and more than 24,000 ha are being recommended for restoration in the next few decades (SAN FRANCISCO BAY AREA WETLANDS ECOSYSTEM GOALS PROJECT, 1999).

In many respects, the San Francisco Bay estuary is a good restoration laboratory. The estuary receives runoff from the entire 257,000 square km watershed of the Central Valley of California, and is a meso-tidal, sediment-rich system formed by the sea-level transgression in the Holocene. It is subject to marked seasonal salinity variations due to large seasonal variations in freshwater inflow, is affected by strong summer sea breeze wave action, and is perturbed by only small storm surges and occasional large earthquakes. Historic landscape changes from pre-colonization to present day have been fairly well documented, and there is now a substantial governmental agency data collection and research effort underway. Its biota is fairly typical of mid-latitude systems, but species composition has been greatly influenced by successive exotic invasions (COHEN and CARLTON, 1995). Almost all restored sites around San Francisco Bay were diked former tidal marshes that had substantially subsided; some of these sites have been refilled with dredged material.

EVOLUTION OF RESTORATION APPROACHES

Tidal restoration projects in San Francisco Bay have been implemented by a variety of agencies with different objectives, expertise, financial resources and dogma. While this "balkanization" of effort has been a source of inefficiency, it has allowed for creativity and diversity in approaches. Over the last 30 years the impetus for restoration has changed. At first, most tidal restoration projects were "mitigation" projects, paid for by developers to compensate for loss of non-tidal wetlands elsewhere. As enforcement of "no net loss" provisions of wetland protection laws became more stringent, such projects became harder to win permits, and the developers' place was taken by resource management agencies undertaking "pure" tidal wetland restoration projects. Now, in the late 1990s, the emphasis is shifting again to implement large-scale tidal wetland restoration as an important component in restoring key processes for the entire ecosystem of the estuary.

"Horticultural" Wetland Restoration

In the 1960s, the prevailing argument used in defense of wetlands was that once marshlands were gone, they were gone forever. Restoration was not considered possible and the fate of whole ecosystems was considered doomed because of lost wetlands. Only acquisition of remaining wetlands would save the functions they provided. In their 1969 book, *Life and Death of the Salt Marsh* (J. TEAL and M. TEAL), the first lay book on the subject, the authors never even use the word "restoration."

By the early 1970s, attitudes had changed and restoration was considered a possibility, but only with the use of plantings. The first years of restoration were strongly influenced by new ecologic research from the U.S. east coast that emphasized Atlantic Coast cordgrass (*Spartina alterniflora*) marshes with their vast productivity (ODUM, 1961; GARBISCH, 1977). In San Francisco Bay projects like the Faber Tract (restored in 1972), and Pond 3 (restored in 1974), tidal wetland restoration objectives were defined almost entirely by the successful planting of cordgrass. The native *Spartina foliosa* was planted in the Faber tract. (HARVEY *et al.,* 1982). In Creekside Park, the exotic *Spartina densiflora*, collected from Humboldt Bay was planted. At that time, *S. densiflora* was mistakenly considered to be the native *S. foliosa.* In the Pond 3 restoration, the exotic *Spartina alterniflora* was imported from Maryland as an experiment to compare planting by broadcasting seed or by planting plugs. (Both of these exotics are now invading adjacent marshes displacing both the native *S. foliosa* and other wetland species.)

In these early efforts, physical factors were considered secondary, and restoration was accomplished by simply breaching a hole in the levee. It was rarely considered necessary to invest in developing a plan or a documented design for the project. Consequently, the evolution of some sites was impeded because either large parts of these sites were too high or they did not receive adequate tidal circulation because of constricted levee breaches.

In 1983, Margaret Race completed a critical review of these projects showing how more than 90% of *Spartina* plantings had died out and suggesting tidal restoration projects were failures because they did not meet their stated goals (RACE, 1983). Although *Spartina* did subsequently eventually colonize all these sites through natural seeding, the experience dampened enthusiasm for justification of restoration as equivalent mitigation for lost wetlands. Race's critique focused attention on the need to develop clear objectives and success criteria in wetland restoration. The subsequent debate highlighted the need to understand restored marshes as evolving systems, not as "instant wetlands" (JOSSELYN, 1988). By the early 1980s, recognizing the need to systematize restoration design, government agencies were formulating design guidelines (HARVEY and WILLIAMS, 1982) and conducting critical reviews of the success of mitigation projects (*California Coastal Conservancy*, 1985; BCDC, 1988). Furthermore, leading ecologists were emphasizing the need to properly consider physical criteria in restoration design (ZEDLER, 1984).

By the early 1980s, it was recognized that plantings were unnecessary because of the large seed source in San Francisco Bay that established naturally over time.

Replicated Wetlands

In response to this new focus on providing the right physical conditions for marsh vegetation, in the early 1980s some new restoration projects attempted to replicate the form of the natural marsh, but without properly addressing the underlying processes that sustained that form. Typically, in these projects, which are usually mitigation for a development project, restored marsh plains are graded or filled to the same elevation as a mature marsh and artificial tidal channels dug to replicate tidal sloughs. An example of this approach is shown in portions of the 1976 Muzzi restoration site modified in 1980 (FABER, 1980) (Figure 3) and the 1982 Cogswell Marsh. The problem with this type of design was that it created an expectation that could not be fulfilled: that wetlands with fully developed ecologic functions would be created within a few years. We now know that they take time.

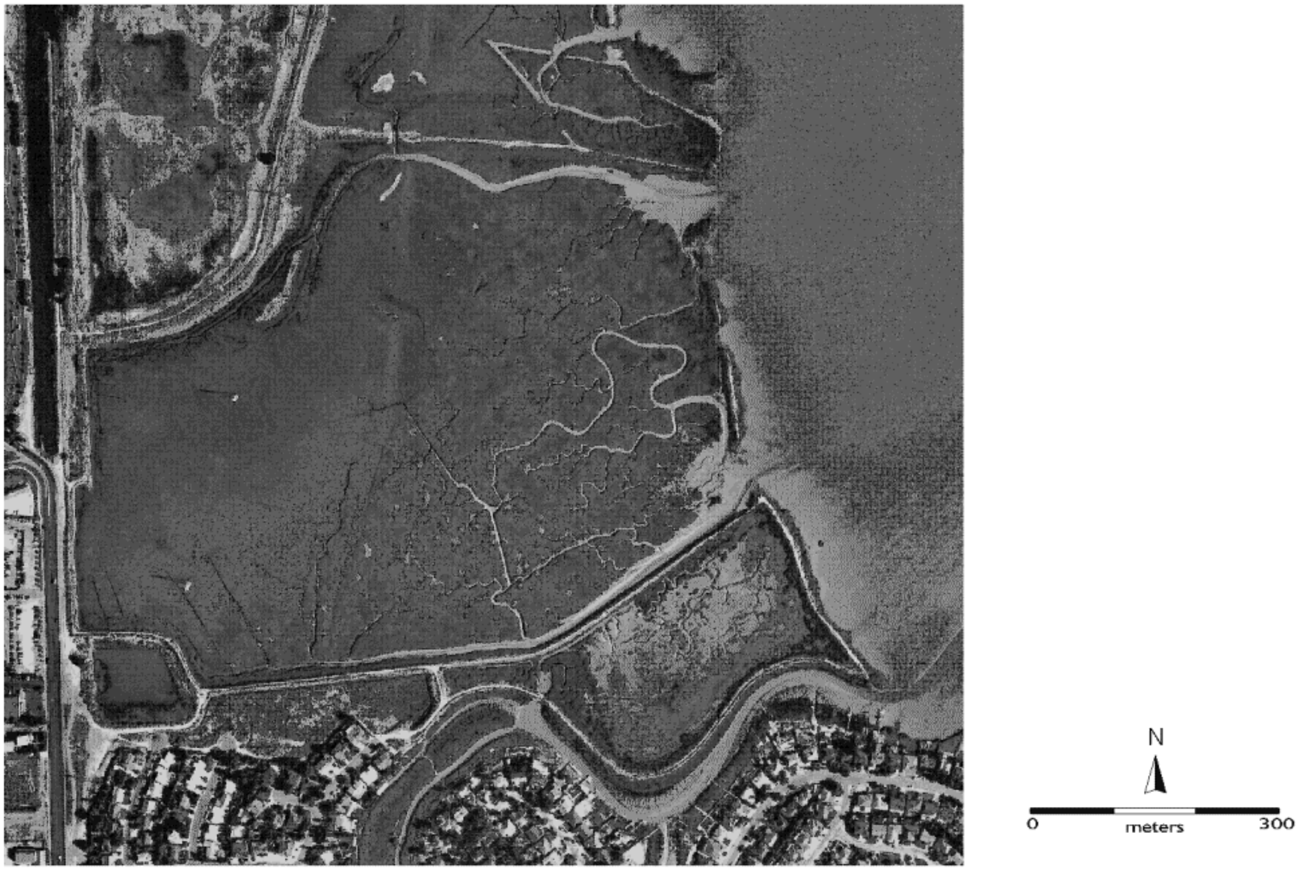

Figure 3. Muzzi marsh.

Observers noted that some accidentally restored sites, such as the abandoned subsided agricultural fields, were being colonized by marsh vegetation as rapidly as these highly engineered projects. By the late 1980s, regulatory agencies realized there needed to be greater accountability for the time-frame and success of restoration projects and started to require monitoring plans and clear definition of success criteria.

Manipulated Wetlands

In many locations, rapid wetland vegetation colonization by the replication approach was difficult to accomplish where land had subsided, or where marsh restoration projects doubled as flood control projects. On a number of these sites, a different approach was selected to create desired wetland conditions as quickly as possible. No attempt was made to restore natural tidal wetland processes, but instead, the project was designed to manage one or two physical variables, such as tidal range or salinity, to favor specific groups of such as shorebirds, or waterfowl, or even listed species such as the clapper rail or salt marsh harvest mouse. These projects typically incorporated artificial manipulation of tide levels through control gates and weirs, maintenance of a perimeter levee and grading to create sub-tidal and refuge habitat. Some sites attempted to "freeze" remnants of endangered species habitat by surrounding them with a ring levee. An example of this approach is the Shorebird Marsh in Cort Madera (GALE and WILLIAMS, 1988) (Figure 4). Subsequent experience has shown that the long-term management and maintenance costs were often underestimated and many sites were not managed as intended. In addition, the resilience of invertebrate populations and vegetation in these marshes responding to extreme events, such as large floods and their long-term sustainability, was overestimated. Recent reviews of managed marshes across the U.S. have cast doubt on their long term effectiveness and ecologic value as compared to restoring natural systems (EPA, 1998). Local resource managers now view with disfavor any system that requires active management. An unfortunate result of implementation of the managed marsh approach is that it has created com-

Figure 4. Shorebird marsh.

petition for easily restorable diked former tidal marshes between projects directed towards ecosystem restoration and those focused on shorter term single species management. Nevertheless, this conflict has had a positive result: it has forced attention on the need to define and understand exactly what is meant by the restoration of tidal wetland habitat.

Restoring Physical Processes

Observation of the rapid evolution of restoration sites where natural physical processes are unimpeded has now led practitioners to rely on encouraging natural physical processes as much as possible to restore ecologic functions (see WILLIAMS, this volume). This means grading an appropriate site template prior to breaching the levee to restore tidal action. The first large project of this type was the 80 ha Warm Springs Restoration, designed in 1981 and completed in 1986 (MORRISON and WILLIAMS, 1986). Here, encouraging rapid natural evolution of the site was a necessity because the site had not only subsided but had been used as a borrow pit for nearby development and had been excavated about 4 m below sea level. Unlike previous restoration efforts, this restoration relied completely on encouraging natural processes to evolve the site from subtidal to intertidal mudflats and vegetated tidal marsh. We were confident that this would happen rapidly because cohesive sedimentation measurements and predictions for the nearby Alviso Marina indicated siltation rates in excess of 60 cm per year. This site has been monitored since 1986 and shows that it is evolving as expected towards a fully developed marsh plain (Figure 5). Subsequent projects of this type include Carl's Marsh, a site that was restored in 1994 and has been monitored extensively since then (SIEGEL, 1998).

DEVELOPING A LEARNING CURVE

One of the greatest obstacles to improving restoration design has been the absence of documented design plans, clear statements of objectives and systematic long term monitoring of the evolution of key wetland functions in restored sites. Although monitoring has been recognized as an important priority since the mid 1980s (SAN FRANCISCO ESTUARY PROJECT, 1993), until recently very little has been sponsored by government agencies, leaving the burden to underfunded private initiatives. It was therefore not until 1992, twenty years after the first restoration project, where design criteria for a new project was developed from monitoring the evolution of earlier projects. This was the 120 ha Sonoma Baylands Project implemented in 1996 (USCOE, 1994) (Figure 6). Here,

1986 (Pre-breach grading)

1997 (11 years of tidal evolution)

Figure 5. Warm Springs marsh.

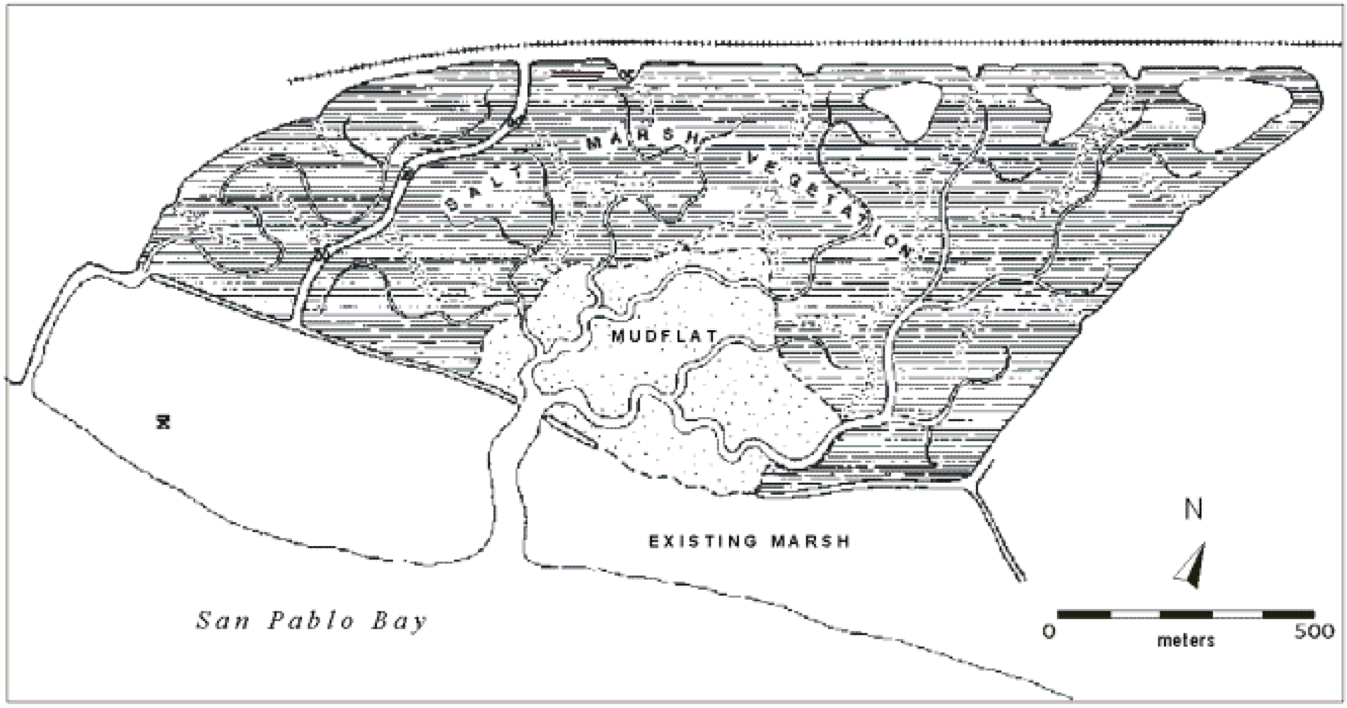

Figure 6 . Recommended design for Sonoma Bayland Marsh (approximately 10 years of evolution).

design parameters were developed based on observed sedimentation, tidal channel evolution and vegetation response at projects such as Pond 3, Faber Tract and Muzzi Marsh, making it a truly "second-generation" design (WILLIAMS and FLORSHEIM, 1995). It was desired to accelerate the evolution of the subsided site to tidal marsh faster than was occurring at Warm Springs. This was done by partially filling the site with dredged material. However, unlike the replication approach, natural sedimentation was allowed to dictate the evolution of the tidal drainage system and marsh plain, but influenced by a predetermined grading template that considered the full range of physical processes acting on the site. Another important aspect of this design was the incorporation of a complete long term monitoring program as part of the project-enabling the future design of third generation projects.

THE CHALLENGE OF LARGE SCALE ECOSYSTEM RESTORATION

The first restoration projects were planned at a time when there was little consciousness or understanding that they were an important habitat within a larger estuarine ecosystem. As late as 1971, important State officials denied that San Francisco Bay formed part of an estuary (HEDGEPETH, 1979). In addition projects were small (less than 20 ha), and their objectives were limited to providing ecologic benefits on site. As we have gained a better understanding of how tidal wetlands evolve in response to estuarine sedimentation, tidal range and salinity regime, we understand the need to plan them within a larger ecosystem context. At the same time, resource managers are now recognizing the important role tidal wetlands play in sustaining key functions in the estuarine/watershed ecosystem. So much of the historic tidal wetlands had been destroyed, that it had become a forgotten landscape whose important contributions as a fishery nursery or in increasing primary productivity has been neglected by researchers.

Now the potential for large scale restoration is starting to be understood and there are plans to significantly increase the area of tidal marshes. These larger scale initiatives pose new institutional challenges to successful restoration. One of the highest priorities is to develop restoration strategies and objectives that are compatible with long term estuarine processes. This can be difficult where there are many different overlapping agencies and organizations with differing biologic goals.

In addition, these larger projects pose new physical design considerations. Over time, restoration projects in San Francisco bay have become larger and, within the next decade, it is likely that the 480 ha Montezuma wetland project, the 480 ha Cullinan Ranch and the 280 ha Hamilton Air Force Base restoration will be completed. As sites become larger, additional physical constraints such as wind wave erosion, flood hazards, and sediment supply limitations become more important—and the consequences of failure become more significant. Extrapolating from the experience of smaller sites alone may not provide an adequate guide for successful restoration.

LESSONS LEARNED

The science, or art, of salt marsh restoration has progressed in a number of important ways since the 1960s—with a number of lessons learned that can be incorporated into new projects today. These include the following:

- Vegetated tidal salt marshes can be restored quite quickly if the appropriate site template is designed prior to breaching.
- The science of restoration is still experimental—we still do not fully understand what percentage of the original ecosystem function returns nor how long it takes.
- The key to successful restoration is insuring that physical processes are restored.
- It is very important in restoration projects to have clear statements of measurable, achievable biologic objectives that have been agreed on by all parties.
- Restoration is best viewed as re-creation of an immature system that evolves towards maturity over time.
- Natural evolution of the ecological processes of a restored salt marsh takes time—far longer than initially thought in the era of replicated wetlands.
- Manipulated systems do not work well as long term sustainable wetland ecosystems: natural tidal rhythms are not maintained, plants and invertebrates cannot tolerate the extreme conditions that occur and consistent operation is rarely maintained over time.
- Monitoring of projects is mandatory if lessons are to be learned for future projects.
- Planning for physical parameters should preferably be on the conservative side to allow unimpeded evolution of natural processes.
- For common plants with large seed sources in the bay, planting is both unnecessary and wasteful of resources.
- Cumulative impacts and cumulative benefits to the entire estuarine system need to be recognized.

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