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Tidal Wetland Restoration in San Francisco Bay: History and Current Issues

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ABSTRACT

Early restoration efforts in San Francisco Bay focused primarily on establishing appropriate elevations for plant recruitment, based on plant distributions in natural wetlands. Sites were graded and planted, and tidal connections were re-established with the expectation that restored wetlands would quickly resemble natural ecosystems. Over time, restoration efforts have evolved, with the realization that natural development of restoration sites is preferable, including a dense channel network and the accumulation of soils of appropriate texture. Bay restoration efforts also have grown substantially in size and scope. Whereas projects of 50 hectares were considered large in the 1980s, now many projects are 100s of hectares. Larger projects are on the scale of 1000s of hectares, with the largest approximately 6000 hectares (the South Bay Salt Pond Restoration Project). This massive increase in scale has brought enormous restoration opportunities, but it also has increased the complexity of restoration projects and highlighted the necessity of large-scale public involvement. Awareness of non-native plants at restoration sites is just one example of factors that have increased restoration complexity. Potential effects of climate change also have moved to the forefront of restoration design, because sea-level rise and potential shifts in salinity are critical factors for long-term restoration planning.

KEY WORDS

Climate change, invasive species, public outreach, regional planning, restoration, spatial heterogeneity

INTRODUCTION

Wetland losses to date have been enormous throughout San Francisco Bay (hereafter, the bay), ranging from 70% to 93% loss of historic area across regions (Table 1). Over 10,000 hectares (ha) of tidal wetlands remain in the bay (North, Central and South bays), with over 5,000 ha in Suisun Bay (Table 1). Tidal freshwater wetlands in the Delta were affected first, with substantial diking for agriculture occurring in the late 1800s (Mount 1995). While agricultural practices also affected areas in eastern Suisun Bay, most of the tidal wetlands within the western part of Suisun Bay were converted to non-tidal wetlands for duck hunting, and have been managed in this way since the late 1800s (Goals Project 1999). Wetlands in San Pablo Bay were diked for grazing and other agri-

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Table 1 Historic and current area of tidal wetlands within the San Francisco Bay, including the number and area of restoration projects. Data for historic and current area are from the Goals Project (1999), and data on restoration projects are from the Wetland Tracker (*http://www.californiawetlands.net/tracker/*). The number and area of restoration projects incorporate all completed mitigation and non-mitigation projects from the Wetland Tracker, including projects that were enhancements of existing wetlands.

Region	Historic area (circa 1800) (hectares)	Current area (circa 1988) (hectares)	Number of restoration projects	Restoration area (hectares)
Suisun Bay	26449	5488	12	850
North SF Bay	22288	6615	23	1381
Central SF Bay	5447	383	17	142
South SF Bay	22677	3778	44	1696

cultural uses, and large areas also were used for salt production. Similarly, salt pond construction, along with urban development, affected large areas of tidal wetlands in the south and central San Francisco Bay. After the Clean Water Act (CWA) was amended in the early 1970s, wetlands became protected from further filling, diking, and dredging. Loss rates for tidal wetlands have been reduced in recent decades (Goals Project 1999), and the CWA, along with a growing understanding of the value of wetland ecosystems, has led to large-scale interest in wetland restoration around the bay. In this article, we review the evolution of tidal wetland restoration in the bay, including an evaluation of current and future challenges for bay restoration.

EARLY RESTORATION EFFORTS

Restoration within the bay, and beyond, has evolved significantly over the last few decades, and will face substantial challenges in the future. While some restoration occurred prior to the CWA, the initiation of significant restoration dates to the mid to late 1970s, and restoration efforts have been growing ever since. Throughout the 1980s and 1990s, much of the restoration within the bay focused on individual projects, motivated by mitigation under the CWA, although many projects have also been completed by public agencies interested in improving conditions and increasing wetlands within the bay. Many individual projects have been completed (see the Wetland Tracker for a list of restoration projects around the bay; *http://www.californiawetlands.net/tracker/*), with 96 estuarine restoration projects in the Wetland Tracker database for the bay, covering a total of more than 4,000 ha (Table 1). This value includes a mix of habitat creation and restoration, as well as enhancement of existing wetland habitat, so it cannot be interpreted as a direct increase in wetland area. Beyond the issue of wetland area, the relative effectiveness of mitigation wetlands also has been debated, especially because of the difficulties in early attempts to establish *Spartina foliosa* in mitigation projects (Race 1985).

Early restoration projects within the bay focused primarily on salt marsh ecosystems, with few restoration efforts in brackish or freshwater tidal wetlands. (See Williams and Faber 2001 for a more detailed review of early restoration efforts.) Planting was not widespread because early practitioners assumed that by creating appropriate conditions, plants would establish on their own, and that suitable habitat for native animals would develop. The models for these early restoration projects were well-established, natural wetlands. Plant distributions were surveyed across these natural wetlands, and target elevations were established for individual restoration projects.

The primary consideration for establishing appropriate conditions for plants was site elevation, because of its key role in determining tidal inundation rates, which in turn affects the degree of soil anaerobiosis and salinity (Mendelssohn and Morris 2000; Mitsch and Gosselink 2007). To establish the target elevations for plant establishment, restoration sites that were too low were filled with dredged material, and sites that were too high were excavated from uplands to intertidal wetland elevations. In some cases, native cordgrass, *S. foliosa*, and pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica*) were planted from cuttings or seed (Josselyn and Buchholz 1984), although few other species were planted. Some projects were simply opened to the tides, regardless of elevation, with the expectation that they would accumulate sediment and build to appropriate elevations. Though vegetation developed at these sites, many early restoration projects lacked complexity in physical features or biological diversity; e.g., they had few, relatively straight tidal channels with little branching and/or few plant species established in the early post-restoration years (see Williams and Faber 2001; Zedler 2001).

EVOLUTION IN RESTORATION DESIGN AND PLANNING

Over the last decade, restoration practitioners have acknowledged the lack of complexity in restored tidal wetlands and have begun to incorporate additional approaches into the design and implementation of tidal wetland restoration (Philip Williams & Associates Ltd. and Faber 2004). In particular, practitioners have focused on tidal channel development, using the approach of "over-excavating" sites or leaving them at slightly lower elevations than target elevations at natural sites (usually approximately 20 to 40 cm). At lower initial elevations, tidal energy is great enough to suspend and move sediment, and this energy leads to the development of a high-density network of tidal channels in restored wetlands. In addition, many early restoration projects were built on excavated uplands or dredged material with coarser sediments than natural wetlands; coarse sediments at these sites led to problems with sediment nutrient concentrations and organic matter, which eventually limited plant productivity (Lindau and Hossner 1981; Langis and others 1991; Zedler 2001). Initializing sites at slightly lower elevations allows restored wetlands to accumulate local sediment on the surface of the wetland, and these create conditions in the rooting zone that are more similar to natural wetland sediments, thereby avoiding problems associated with improper soil texture and nutrient status. One of the early projects in the bay to use this approach was Sonoma Baylands restoration project (Figure 1). This site was a former wetland that had been farmed and subjected to high rates of subsidence (1.5 to 2 m); dredged material from the Port of Oakland was used to fill the site, but it was left at elevations approximately 40 cm below target marsh plain elevations in order to maximize tidal channel development and ensure appropriate wetland sediment characteristics (Marcus 2000). Although tidal flows and sedimentation rates were initially limited because of constrictions in the tidal connection at Sonoma Baylands, the site has developed into a vegetated wetland with a mix of habitats. This approach of over-excavation has been adopted for many current or planned restoration projects within the bay (Williams and Faber 2001; Philip Williams & Associates Ltd. and Faber 2004). In addition to promoting tidal channel development, topographic complexity has been incorporated into restoration sites through the creation of islands within restored sites (e.g., Sonoma Baylands and Crissy Field; Figure 1), primarily for nesting birds; however, areas with higher elevations also can reduce wind fetch and wind waves. Small areas of higher-elevation habitats within a large, low-elevation restoration site also can serve as a nexus for plant establishment because of the plants' lower rates of tidal inundation during the early phase of wetland development (Marcus 2000; Philip Williams & Associates Ltd. and Faber 2004).

Another substantial change for restoration planning efforts within the bay has been a shift from the early focus on individual mitigation projects to a consideration of regional restoration needs and opportunities. A major step in this regard was the development of the Habitat Goals Project (Goals Project 1999), which considered the importance of restoration issues for a broad range of wetland organisms and dynamics, among them: plants, invertebrates, fish, birds, mammals, hydrology, and sedimentation. The Goals Project developed detailed maps of priorities for restoration across the bay and helped to identify the need to consider restoration planning at the landscape level (Goals Project 1999).

In addition to the broader scope for restoration planning, restoration efforts shifted from the early, relatively small projects to much larger projects over the last decade. For example, some of the large-scale early restoration projects in the bay were Muzzi Marsh (52 ha in 1976), Cogswell Marsh (80 ha in

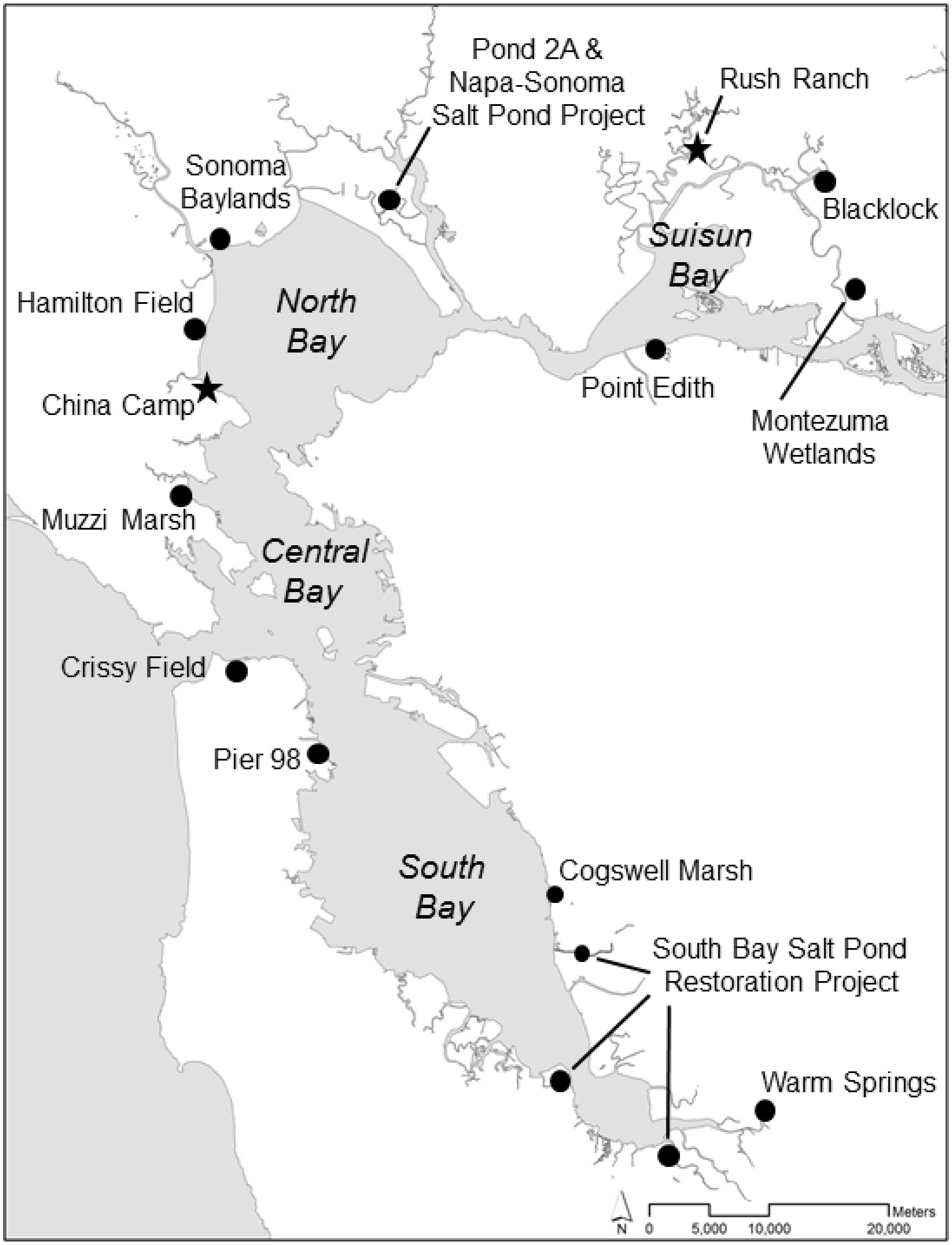

Figure 1 Location of major tidal wetland restoration projects in the San Francisco Bay and the San Francisco Bay National Estuarine Research Reserve (NERR) sites (China Camp State Park and Rush Ranch). Restored tidal wetlands are in the South Bay (Warm Springs, the South Bay Salt Pond Restoration Project, and Cogswell Marsh), the Central Bay (Pier 98 and Crissy Field Marsh), the North Bay (Muzzi Marsh, Hamilton Field, Sonoma Baylands, and Pond 2, which is a component of the Napa–Sonoma Salt Pond Project), and Suisun Bay (Point Edith, Blacklock, and Montezuma Wetlands).

1980), and Warm Springs (80 ha in 1986; Williams and Faber 2001). By the 1990s, the size of individual projects had grown, with Pond 2A (220 ha in 1995) and Sonoma Baylands (120 ha in 1996) (Figure 1). Current projects are considerably larger, with Montezuma Wetlands currently underway at 930 ha, close to 3000 ha in the Napa–Sonoma Salt Pond Project, and over 6000 ha being considered for restoration as part of the South Bay Salt Pond Project (data from the Wetland Tracker; *http://www.californiawetlands.net/tracker/*; Figure 1). These new projects are large enough that they will have landscape-level effects on the bay. In addition, restoration has moved beyond the salt marshes of the bay, with large-scale restoration and management efforts in brackish and freshwater tidal wetlands. The CALFED Bay–Delta Program (*http://calwater.ca.gov/*) and the Bay–Delta Conservation Plan (*http://baydeltaconservationplan.com/*) have been motivating factors for much of the freshwater wetland restoration within the Delta, with large projects such as Dutch Slough and Liberty Island. Within Suisun Bay, some of the recent projects involving brackish tidal wetlands include Montezuma Wetlands, Point Edith, and Blacklock (Figure 1). As with other regions, the design of restoration sites within Suisun Bay drew upon natural tidal wetlands, including Rush Ranch, a component of San Francisco Bay National Estuarine Research Reserve (NERR) (e.g., Pearce and Collins 2004).

As larger projects have been initiated, there has been a push towards the incorporation of a stronger scientific basis for restoration. CALFED put substantial focus on the use of adaptive management in their restoration efforts (Brown 2003; Kimmerer and others 2005; Zedler 2005). The South Bay Salt Pond Restoration Project also has explicitly incorporated science with reviews from both local and national science panels (see *http://www.southbayrestoration.org/science/*), and with the explicit use of adaptive management in the development and implementation of the project, including in the framework of the Environmental Impact Report (EIR) (EDAW and others 2007; Trulio 2007). In particular the South Bay Salt Pond Restoration Project has emphasized the identification of critical uncertainties that may limit restoration progress, as well as the development of experimentation and monitoring plans to address these uncertainties in the early phases of the project so that large-scale implementation in the future will be better informed (Trulio 2007).

CURRENT ISSUES

Over the last decade, the importance of biodiversity has been recognized because of its role in retaining high levels of ecosystem functions (Hooper and others 2005; Tilman and others 2006; Hector and Bagchi 2007) and, in particular, promoting biodiversity and ecosystem functions in restored ecosystems (Naeem 2006). Much of the effort in evaluating the role of biodiversity for restored tidal wetlands has come from research in southern California wetlands, and this work has highlighted the importance of incorporating diversity into restoration sites in order to achieve a range of desired ecosystem functions (Zedler and others 2001; Callaway and others 2003; Sullivan and others 2007). Despite the lack of research on this topic in the San Francisco Bay, interest is growing in maintaining and restoring diversity in bay wetlands (Baye and others 2000). In the bay, much of this interest has focused on transitional wetland–upland plant communities (e.g., restoration of *Suaeda californica* at Crissy Field and Pier 98; Figure 1), where much of the plant diversity in tidal wetlands is found (Baye and others 2000).

Non-native, invasive plants are a major threat to the biodiversity of bay tidal wetlands (Grewell and others 2007), and they will continue to be an on-going issue for tidal wetland restoration projects across the bay. *Spartina alterniflora* and its recombinants with *S. foliosa* are particularly problematic as they currently are widely distributed, are prolific seed producers, establish readily from seed, and most importantly have substantial effects on native species and wetland ecosystem functions (Callaway and Josselyn 1992; Ayres and others 2004; Neira and others 2006), although large-scale efforts are underway to eradicate invasive *Spartina* spp. (see the Invasive Spartina Project, *http://www.spartina.org/*). Other problematic invasive plants include *Lepidium latifolium* in salt and brackish marshes, *Ludwigia hexapetala* and *Eichornia crassipes*, floating species that have recently been observed clogging entire channels in the western Delta, and *Egeria densa*, an aquatic weed that is widespread in the Delta (Andrew and Ustin 2009; Okada and others 2009; Santos and others 2011). Further upriver, *Ludwigia peploides* ssp. *montevidensis* has become a tremendous problem in Sacramento River oxbows and is dispersed down to the Delta. A large number of other non-natives are established in the Delta, including *Iris pseudacorus*, although it has not developed dense cover in most areas where it has become established. Effects from invasive species are likely to be complicated by shifts in both wetland salinity and inundation rates associated with climate change; these interactions are discussed in more detail below.

Beyond plants, non-native animals can have substantial effects on both restored and natural tidal wetlands and adjacent estuarine ecosystems, from burrowing isopods to benthic clams (Talley and others 2001). As with plants, invasive animals are problematic when they substantially affect native species or ecosystem functions. Some native predators have also become concerns in natural and restored wetlands, in particular, gulls and corvids, as well as introduced red foxes, all of which prey on bird eggs and chicks.

Contaminants have always been an issue for urban restoration projects, whether it is from watershed inputs (e.g., mercury, selenium, and other agricultural runoff), former military land use, (e.g., Crissy Field, Hamilton Air Field, Port Chicago/Concord Naval Weapons Station), or other land use issues (e.g., storage tank leakage, metals from chrome plating, solvent runoff, etc.). Mercury has been of particular interest recently in the bay, in part because of elevated levels in the South Bay and the plans for large-scale salt pond restoration, as well as inputs from the larger watershed (Marvin–DiPasquale and Agee 2003; Miles and Ricca 2010; Gehrke and others 2011). While elevated levels of mercury have existed for a long time in the bay, managers are concerned that rates of mercury methylation may increase once areas are converted from present subtidal, unvegetated conditions to vegetated wetland ecosystems (Choe and others 2004; Conaway and others 2008). Substantial research is presently underway to evaluate mercury biogeochemistry within a variety of habitats in order to better understand controls on methylation rates and potential effects on wetland organisms; the evaluation of this issue is a major component of the adaptive management approach of the South Bay Salt Pond Restoration Project.

Loss of elevation is a major factor affecting opportunities at many bay restoration sites: subsidence of former wetlands from oxidation of soils is a major issue in the Delta (Rojstaczer and Deverel 1995; Mount and Twiss 2005); water extraction and compaction of underlying aquifers presents an enormous challenge for the restoration of some sites in the South Bay (Poland and Ireland 1988). Vegetation will only establish at sites when threshold elevations are met. This will either take many decades or could be expedited through fill with dredged material (e.g., Montezuma Wetlands) or the accumulation of organic matter through plant productivity, as has been tried experimentally at Twitchell Island in the Delta (Miller and others 2008).

GROWING COMPLEXITY: RESTORATION CONTINUES TO EVOLVE

The realization that wetland restoration is more complex than simply breaking down a levee and establishing plant cover has grown over time, with continuing focus on both physical and biological complexity within restored wetlands. In terms of physical heterogeneity, most of the focus remains on tidal channels and their role in providing connectivity between aquatic and wetland habitats, as well as their importance in affecting plant distributions in tidal wetlands (Sanderson and others 2000). More recently, there also has been interest in restoring ponds and pannes (which typically do not hold water as long as ponds but remain unvegetated), with some consideration of how these habitats form in wetlands and how they might be sustained in both natural and restored wetlands (Collins and Grossinger 2004). The natural abundance of pannes across the bay varies widely, with large numbers in Petaluma Marsh, and historic accounts of large ponds in salt marshes on the east side of the South Bay (Collins and Grossinger 2004), but few at China Camp, a component of San Francisco Bay NERR (Figure 1; Baye in press). Within the context of the South Bay Salt Pond Restoration

Project, there is special interest in restoring wetland ponds, because these may provide habitat for many bird species that currently rely on artificial salt ponds; however, the specific issues and methods for establishing and sustaining ponds within restored wetlands have yet to be identified.

Tidal restoration within the bay also has moved beyond salt marsh restoration to consider a wide range of habitats and functions along a gradient from mudflats to upland habitats, and from salt marsh to freshwater marsh. Given this broader scope, some consideration of the trade-offs of different types of restoration is required. Simply maximizing the tidal area of every single restoration project within the bay will not re-create the wide range of functions that natural ecosystems provide. There is increasing awareness of the important link between tidal wetlands and adjacent aquatic ecosystems through food web dynamics (Howe and Simenstad 2011). In addition, transitional upland habitats provide many benefits, as do lower elevations that are transitional from wetlands to unvegetated mudflats. The upland transitional sites have very high plant diversity, with a large number of rare and threatened plant species (Baye and others 2000). These areas have been overlooked in the past, primarily because they may not be counted as jurisdictional wetland habitats or as “in-kind” mitigation for tidal wetland effects. These systems also have a large number of potential exotic plants that invade from adjacent degraded uplands, e.g., *L. latifolium* and many Mediterranean grasses, among others (Fetscher and others 2010). Substantial challenges may exist in restoring these habitats (e.g., there are very few if any undisturbed reference sites to give us insight into what a “pristine” transitional habitat may have looked like and how it might have functioned). Transitional habitats also provide important buffers to reduce human effects from adjacent urban and residential areas that commonly border wetlands around the bay, and they provide refuge for wetland animals during extreme high tides (Goals Project 1999). Over the long term, these transitional habitats also could provide substantial benefits because they could serve as critical areas for upland migration of wetlands, when considering predicted increases in rates of sea-level rise.

Managers have realized that a range of wetland habitats can be highly valuable because different types of habitats will provide benefits for different species and provide for a range of different ecosystem functions. However, making management decisions for priorities across different ecosystem types will be very challenging, as different ecosystems provide a range of functions with varying societal values. For example, how do we compare the benefits for different species or for different functions: water quality improvements from one type of wetland versus improved habitat conditions from a different type? While science can provide input on individual benefits, evaluations of ecosystem functions and benefits are not now available for most wetland and transitional ecosystems. In addition, decisions weighing the relative benefits across different wetlands ultimately will be based on economics, perceptions of benefits, and other social science issues, rather than on individual measurements of ecosystem function.

A major issue for all tidal restoration projects around the bay is the need to improve our understanding of the potential constraints on the development of restored wetlands, so that we can better predict how future restoration projects may evolve, especially as larger and larger areas are restored. Some recent projects have not evolved exactly as predicted. For example, the development of a vegetated wetland at Sonoma Baylands occurred more slowly than expected, primarily because of restrictions on tidal flows at the site (Williams and Faber 2001). By learning from projects with varying success, we can identify potential constraints for future restoration, whether they are geomorphologic restrictions, limits on plant establishment, the effects of non-native species, or other factors.

Finally, a major realization for wetland restoration over the last decade has been the need for improved public outreach and involvement. The restoration of Crissy Field in densely urban San Francisco in the mid-late 1990s had an enormous public outreach effort, with the incorporation of thousands of volunteers (Boland 2003). This effort highlighted the benefits of public involvement in restoration: citizens are much more likely to support projects if they actively engage in them. Similar efforts to improve public awareness of projects have been incorporated into the South Bay Salt Pond Restoration Project, which has worked to involve local citizens and organizations through "stakeholder forums" on a variety of issues and at many locations across the South Bay. Other large restoration projects have also made substantial efforts at public education and outreach, with the realization that publicly funded restoration efforts will only continue with strong on-going public support and involvement.

Other on-going restoration challenges include mitigating flood effects, securing restoration funding, and incorporating landscape issues, such as habitat connectivity, propagule sources, large-scale questions of sediment availability, and the potential effects of restoration on sediment dynamics in existing ecosystems (Brew and Williams 2010).

CONCLUSIONS AND FUTURE CHALLENGES

Although approximately 90% of bay tidal wetlands have been lost (Table 1), current interest in restoring tidal wetlands in the region is great, with opportunities for large-scale projects that will substantially increase the present area within the bay. For example, in south San Francisco Bay, the South Bay Salt Pond Restoration Project may more than double the area of tidal wetland habitat in the South Bay, even though some former tidal wetlands will continue to be managed as ponds. Other bay regions also could add thousands of hectares through current or future projects. Similarly, restoration has evolved from a simplistic approach that initially focused primarily on elevation, to a consideration of wetland complexity and regional ecosystem functions.

As the bay area population continues to grow and put pressure on natural ecosystems, future efforts at wetland restoration around the bay will continue to face these same issues. Changing land use, increased water demand, greater pollution, and the potential input of new non-native species (in part through continued international trade) all act to constrain wetland health and limit restoration success. Because tidal wetland restoration is inherently unpredictable, new, unexpected challenges will arise as well (Williams and Faber 2001).

The greatest future challenge for tidal wetland restoration will be climate change (see article by Parker and others in this volume). While specific effects are unpredictable, some general trends are extremely likely: (1) there will be seasonal shifts in estuarine salinities, with higher concentrations during the growing season resulting from reductions in snowmelt and shifts in the timing of watershed runoff (Knowles and Cayan 2002; Cayan and others 2008); and (2) rates of sea-level rise will increase over the next century, although the magnitude of change is not certain (IPCC 2007; Rahmstorf 2007). Changes in both salinity and inundation will have large-scale effects on tidal wetlands in the bay. Increases in salinity during the growing season are likely to cause more salt-tolerant species to migrate up the estuary over the long term (Parker and others 2011). Tidal wetlands can keep pace with some increases in sea-level rise through increased mineral and organic matter accumulation (Morris and others 2002); however, large-scale increases in sea-level rise are likely to lead to wetland loss. Kirwan and others (2010) reviewed a number of recent models of tidal wetland responses to sea-level rise and found that tidal wetlands could withstand conservative projections of increased sea-level rise with moderately high rates of suspended sediment, but higher rates of sea-level rise could lead to wetland loss.

Furthermore, recently restored wetlands are likely to be more sensitive to effects associated with climate change than well-established, mature wetlands. Germination rates and the survival of newly established vegetation at restored wetlands are both very sensitive to increases in salinity and inundation rates (Callaway and others 2007). In addition, newly restored wetlands with little or no vegetation will be more susceptible to the sediment erosion associated with higher water levels, while at the same time they need substantial amounts of sediment to build elevations from early restoration stages to conditions where plants can establish (Grewell and others 2007). Beyond direct effects, shifts in salinity and inundation associated with climate change also could cause unpredictable changes in restored bay wetlands, including creating increased opportunities for invasive species, both plants and animals. Newly restored sites are highly susceptible to invasives because of their inherently disturbed condition, and climate change could allow for a different suite of invasive species to establish under new conditions within the bay. Although these interactions are difficult to predict and evaluate, several recent articles have highlighted the potential for compounded problems between climate change and invasive species (Hellmann and others 2008; Rahel and Olden 2008; Mainka and Howard 2010).

To maximize the flexibility needed to address the uncertainties of climate change, potential restoration sites should be restored sooner rather than later, because vegetated wetlands are likely to be more resilient to climate change than unvegetated sites. Identifying restoration sites where adjacent uplands with shallow slopes could serve as locations for future wetland migration also would provide for increased flexibility, because wetlands that do not keep pace with sea-level rise could migrate to nearby higher elevations. More opportunities for wetland migration to adjacent uplands exist in the North Bay and Suisun Bay than in the South Bay, because of large-scale urbanization in the South Bay. For example, opportunities to restore muted tidal wetlands at China Camp (Back Ranch and Miwok Meadows) and Rush Ranch (Spring Branch Creek) are promising restoration opportunities that would allow for wetland migration. However, if the magnitude of climate change effects is high, long-term effects on tidal wetland ecosystems could be catastrophic, because these wetlands are unlikely to keep pace with rapid increases in rates of sea-level rise or with large-scale shifts in salinity regimes.

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