Science Foundation Chapter 2
Projected Evolution of Baylands Habitats

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INTRODUCTION

The projected drivers for change, in particular climate and sea level, will likely affect the evolution of baylands habitats over the next century. We understand the baylands to be evolving in three major directions; vertical accretion based on sediment supply and organic accumulation, landward migration (also called transgression) based on availability of terrestrial transition zone space, and lateral movement of the bayward marsh edge. Because tidal marshes are highly sensitive to elevation, their sustainability in San Francisco Bay (and elsewhere) will depend on the balance between sea-level rise and marsh sediment accretion (Michener et al. 1997, Morris et al. 2002). As discussed in Science Foundation Chapter 1, the existing marshes have a range of elevations covering low to high marsh; the higher parts of the marshes give substantial "elevation capital" (Cahoon and Guntenspergen 2010), i.e., they have elevation to lose before they convert to unvegetated mudflat.

This raises two key questions: firstly, how are baylands habitats (e.g., marshes, mudflats and managed ponds) likely to evolve over the next century? To answer this question we need to understand the present evolution and then make projections of future evolution. Once we understand the future evolution we can address the second key question: what management actions can we take to guide the evolution of baylands habitat in the short- and long-term? The decision about when to implement each of these measures will depend on the rate of sea-level rise, and in particular when certain threshold elevations will be crossed that trigger the need for intervention.

HOW ARE THE BAYLANDS HABITATS LIKELY TO EVOLOVE OVER THE NEXT CENTURY?

Tidal Baylands

There are three ways in which marshes can respond to sea-level rise affecting the area and distribution of habitat, and potentially leading to the transformation of the habitat type:

1) accrete vertically, with no net loss of habitat if they keep up with sea-level rise;
2) migrate upslope as sea levels rise and convert terrestrial areas to wetlands; and,
3) if wetlands cannot keep pace with rates of sea-level rise, convert or "downshift" from mid to low marsh, or from marsh to mudflat and subtidal.

Key to how a marsh will evolve with rising sea level will be how much "elevation capital" the marsh has. This determines the inundation regime and the accretion rates that maintain the "elevation capital" and so determine the evolution of the inundation regime. As discussed in Science Foundation Chapter 1, theoretical feedback models predict that changes in salt marsh plant production and elevation will be observed in response to the position in the tidal frame and hence the inundation regime (Morris et al. 2002). This model suggests an inundation regime that maximizes sediment accretion and productivity and also represents the upper limit of flooding tolerance for a given plant species. Maintaining that elevation capital with accelerating rates sea-level rise requires increased accretion rates. Low accretion rate leads to loss of elevation capital which may lead to changes in the inundation regime, anaerobic stress levels throughout the wetland, and shifts in habitat types (Rybczyk et al 2013).

Accretion Rates

Fundamental to the resiliency of marshes and maintenance of elevation capital is their accretion rate. Presently, tidal wetlands within the Bay area are accumulating enough sediment to keep pace with sea-level rise. For example, observations by Callaway et al. (2012) who measured historic accretion rates at six tidal marshes in San Francisco Bay (including South Bay, North Bay and Suisun) show in all cases, accretion rates from mid- and high-marsh station were close to 3-5 mm/yr, with little difference in accretion rates across sites. At many sites, accretion rates were slightly greater in the low marsh locations (Callaway et al. 2012), and these patterns of greater accretion at sites closer to the Bay mirror patterns found in many other tidal marshes across the world (e.g., Hatton et al. 1983, French et al. 1995). However accretion at individual sites varies according to local conditions. Other local variations have been reported by Drexler et al. (2009) at Browns Island, where lower rates were observed due to compaction. In Coyote Creek, Watson (2004) found much higher rates associated with rapid marsh expansion along the creek. Patrick and DeLaune (1990) also documented much higher accretion rates at the adjacent Alviso Slough. The unusually rapid accretion in this area was likely influenced by very high local, short-term subsidence rates associated with earlier groundwater withdrawal for agriculture in the South Bay couple with the abundant fine sediment supply in the far South Bay (Patrick and DeLaune 1990).

Rates of sediment accretion at newly restored sites are often substantially greater, especially at sites that are subsided, as mineral sediment inputs are much greater at lower elevations (Williams and Orr 2002, PWA and Faber 2004). For example, Callaway (unpublished data) has measured rates greater than 10 cm/yr at the Island Ponds (Ponds A19, A20 and A21, breached in 2006 as part of the South Bay Salt Pond Restoration project), and even more rapid rates at Pond A6 (breached in 2010), which started at lower elevations than the Island Ponds. Accretion rates from restoration sites that are at elevations similar to natural marshes (e.g., the upper zone of Muzzi Marsh) are similar to those found in natural tidal marshes in the Bay, while accretion rates for restoration sites at lower elevations are intermediate between the high rates from highly subsided sites and those from natural marshes (Callaway, unpublished data from sites along an elevation gradient at Muzzi Marsh). As restoration sites build to elevations more typical of well-developed natural marshes, accretion rates slow down over time (Williams and Orr 2002).

Projecting accretion rates into the future requires the modeling of the complete accretion processes as described in Science Foundation Chapter 1 together with projections of sea-level rise and sediment availability. A number of models have recently been used to assess the evolution of tidal marshes in the San Francisco Bay. These include MARSH98 (Stralberg et al., 2011), WARMER (Takekawa et al., 2012; Swanson et al., 2013), MEM (Schile, 2012), and an empirical model of accretion (Thorne, 2012) (see Appendix 2.1 for details). Each model has been developed to address different aspects of marsh accretion and have been applied in different locations around the Bay. All the models record the elevation of a point within the intertidal zone from the accretion of sediment and organic matter dependent on suspended sediment availability and plant productivity (Figure 2.1). In the cases of WARMER and MEM, the compaction and decay of the soil are also explicitly included.

All of the results from these models are sensitive to the rate and magnitude of sea-level rise and the supply of sediment to the marsh. Both of these variables have uncertainty in their future values. The models were found to be less sensitive to the different organic accumulation scenarios tested.

The MARSH98 modelling (Stralberg et al., 2011) has the most comprehensive geographical coverage of the Bay. The study looked at existing marshes and also areas with potential for landward migration or restoration following dike removal. Across all sea-level rise and sediment supply scenarios, the models project an increase in mid-marsh habitat between 2010 and 2030 throughout the estuary. In each of the scenarios this increase comes at the expense of high marsh and terrestrial habitat. (Figure 2.2).

Between 2030 and 2050, the model projects that the area of low marsh habitat will increase and the area of high marsh and upland will decrease across all scenarios; for the high sea-level rise/low sediment scenario the area of mid marsh habitats throughout the estuary will also decline. In general, the area of tidal marsh habitat was projected to remain relatively unchanged between 2030 and 2050, but the composition of the marsh habitat changed, with the amount of low marsh habitat projected to increase and the amount of mid marsh habitat projected to decrease.

The model projects an increase in the total estuary wide area of mid-marsh habitat from 2010 for low sea-level rise scenarios for either sediment assumption and for the high sea-level rise/ high sediment assumption. However, the model also indicates that more than 90% of mid-marsh and high-marsh habitat will be converted to low-marsh, mudflats or subtidal habitats by 2100 in the high sea-level rise/low sediment scenario. The models do indicate that there are opportunities for unimpeded landward migration of marshes, with 5,000-7,500 acres of currently terrestrial habitat potentially evolving to tidal marsh by 2100 depending on the scenario.

The potential impact on specific marshes can be seen in the model projections of China Camp undertaken by Swanson (2013) and Schille (2012). Increasing the rate of sea-level rise and decreasing the availability of sediment increases the potential of habitats downshifting (Figure 2.3).

The NRC (2012) report shows a range of 40 cm at 2050 for the amount of sea-level rise and about 1.2 m at 2110. This range has huge impacts for what happens to the marshes. The sensitivity analysis of the MARSH98 and WARMER models (Stralberg et al. 2011, Swanson et al. 2013) indicated that these two parameters largely control the final elevation of the marsh for the range of conditions considered in those simulations. The model simulations agree that with low rates of sea-level rise (e.g., 52 cm/century), the marsh elevations can keep pace with sea-level, even with low sediment availability. However, with sea-level rise rates greater than 100 cm/century and low sediment supply there will be a decline in mid and high marsh habitat.

Downshifting of Habitats

If sea-level rise continues to accelerate, at some point it may outpace the rate of accretion and the marsh will start to 'drown'. If the vertical accretion of marshes cannot keep pace with sea-level rise then the wetlands habitats will tend to migrate landward. The horizontal rate of migration will depend upon the rate of sea-level rise and the slope of the transition zone. Historic diking steepened coastal gradients around the Bay, converting gently sloping bayland edges that rise towards the land into steep linear borders backed by basins. Sea-level rise acts very differently depending on the gradient of its landward boundary. On gentle, continuous slopes it gradually shifts tidal habitat zones landward and landward, while on discontinuous, artificial diked bayland topography it forces either acceleration of maintenance and repair of dikes, or "overstepping" the barrier – abruptly flooding the diked basin and radically shifting the shoreline and shore processes landward. If the marsh is bounded by a steep slope (such as an inboard levee) then the transition zone available for migration will be much reduced and marsh habitat will be lost through 'coastal squeeze'.

There are a number of (qualitative) evolutionary scenarios for the baylands:

a. **Equilibration, dynamic stability**: existing tidal marshes accommodate sea-level rise with only minor long term or progressive conversion of tidal habitat types, and a gradual landward shift (horizontal displacement or landward estuarine "migration") in position. This scenario is associated with very gradual (historic) rates of sea-level rise and net positive sediment budgets (due in part to effects of diking, artificial loss of tidal prism). This scenario is not likely to occur in a regime of rapidly accelerating sea-level rise and neutral or negative sediment budgets.

b. **Gradual evolution**: gradual submergence of tidal marsh habitats with marsh type conversion ("downshifting" zones: high marsh to middle marsh, middle to low, low marsh to unvegetated tidal flat); expansion of tidal marsh pans and enlargement of tidal channels; mudflat erosion (loss of elevation); progressive but slow erosional retreat of marsh edges (wave-cut marsh "cliffs" or scarps); and either dike overtopping, erosion, and breaching, or dike raising, armoring, and increased artificial bayland drainage. The "gradual evolution" bayland scenario is compatible with coastal planning adaptation through modification of Baylands.

c. **Collapse** (abrupt conversion of ecosystem to alternative modes and habitat types): in this worst-case scenario associated with early onset of accelerated sea-level rise at the upper end of projected rates, sea-level rise would overstep marsh platforms, causing wholesale drowning of marshes: marsh plains initially respond by converting to low marsh (cordgrass), but founder as rapid marsh vegetation dieback forms extensive pans that "swallow" fragmented marshes and expand to tidal flats. This is analogous with contemporary tidal marsh loss in Elkhorn Slough, Gulf of Mexico and the Mississippi Delta. Rapid marsh edge and levee erosion, increased flooding of diked baylands or undiked adjacent lowlands, and the rapid loss of critical high marsh habitat and terrestrial buffer integrity are likely to occur in this scenario.

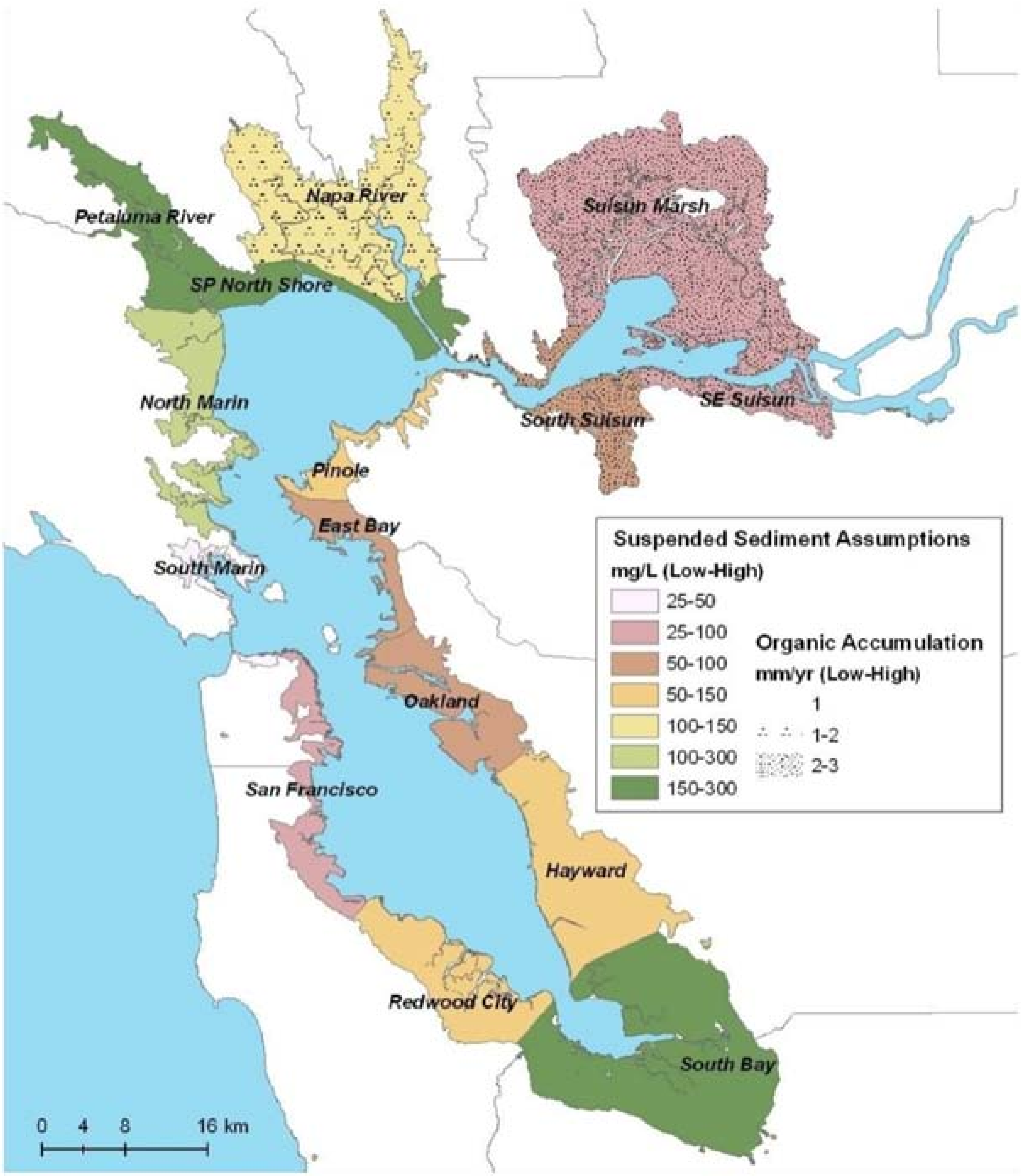

Figure 2.1. Biogeomorphic sub-regions within San Francisco Bay study area and assumptions about suspended sediment concentrations and organic matter accretion rates for climate change scenarios (Stralberg et al., 2011).

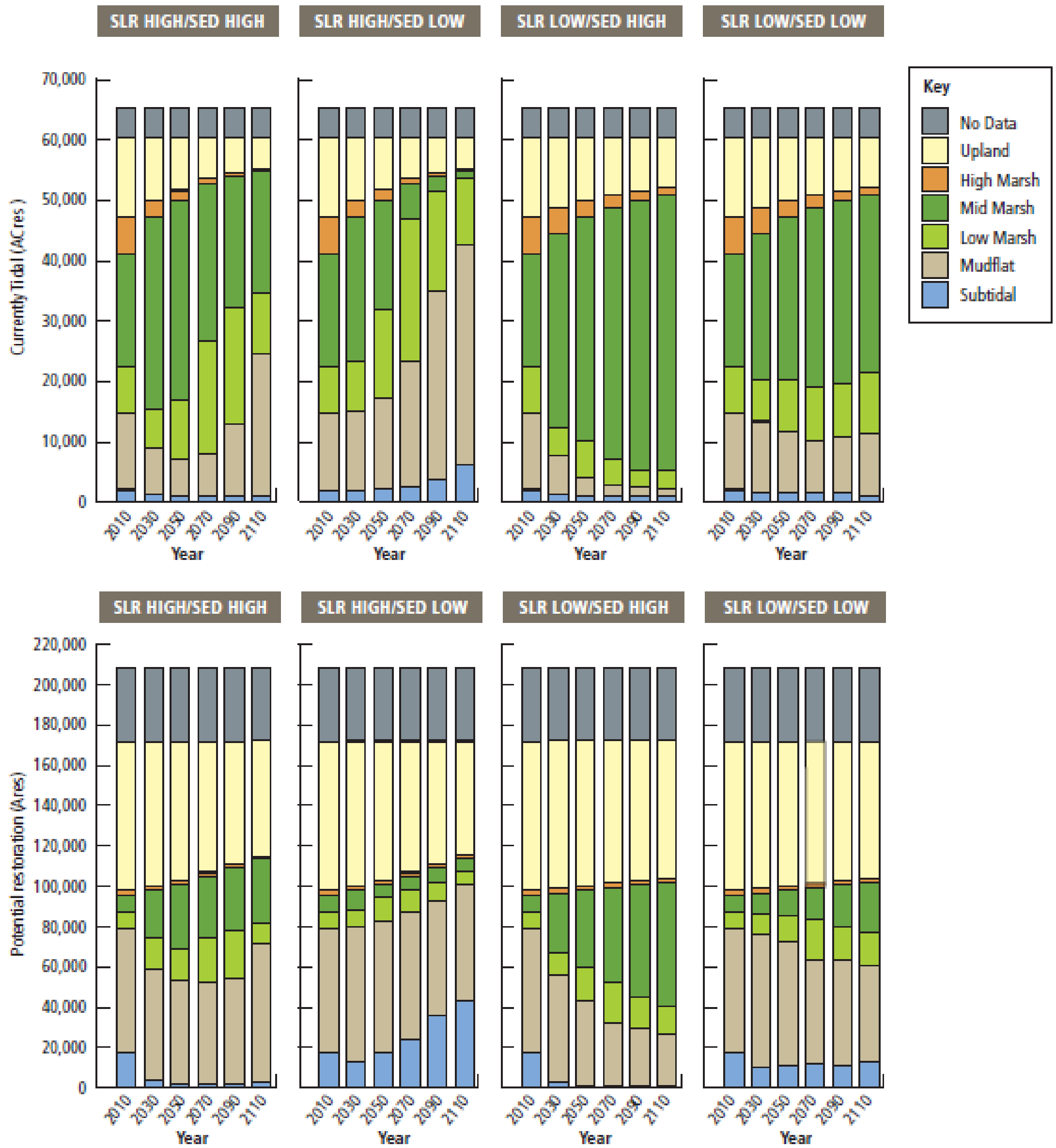

Figure 2.2. Results from the Marsh98 model showing projected marsh habitat extents under different sea-level rise (*SLR*) and sediment supply (*SED*) scenarios for both current tidal areas and potential restoration areas. Note the different *y*-axis scales. Adapted from Stralberg et al. (2011).

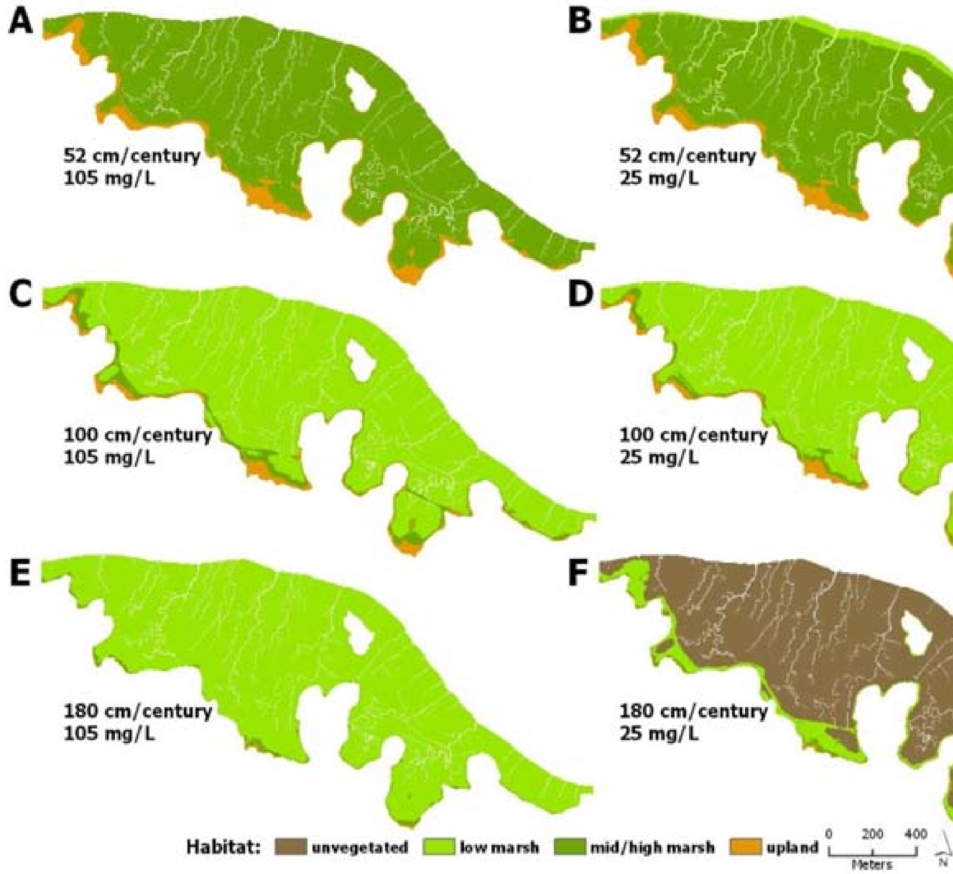

Figure 2.3. MEM scenarios results at China Camp Marsh for various rates of sea-level rise and available suspended sediment concentrations (Schille 2012).

There will probably be a variable mix of scenarios a) and b) for the first 50 years, unless there is an abrupt, rapid acceleration in sea-level rise (i.e. abrupt changes in ocean temperature or ice sheet collapse). Maintaining existing marsh zones with no conversion would be an optimistic projection because as marsh plain drainage decreases with submergence, so does marsh plant growth and vegetation height. Reduced marsh vegetation growth will mean less stem height and density for trapping and stabilizing suspended sediment and less production of organic matter in the soil profile.

The major controlling variables are rate of sea-level rise, sediment supply and space for migration, only two of which we can influence. Increasing the sediment supply by supplementing sediment onto, or close to, the wetlands may increase the local accretion rate. Increasing the terrestrial buffer area and reducing the inboard levee slope will increase the space for migration.

Brinson et al (1995) provides a summary framework for addressing the transformation from one habitat class to another as sea-level rises; from uplands through wetlands to mudflat and subtidal. This is illustrated in Figure 2.4 where estuarine-terrestrial interaction can be described as one of four possible interactions based on two conditions at the transition zone edge (migration versus squeeze) and two at the marsh edge (prograding versus eroding) for both low and high sediment availability (which generally equates to high and low accretion rates in the Bay) .

This framework simplifies terrestrial-estuarine interactions into four combinations based on sediment supply and vertical accretion rate. There two possible conditions at the terrestrial-marsh margin (i.e., overland migrating versus stalling) and two at the marsh-estuarine margin (i.e., prograding versus eroding). These four patterns shown in Figure 2.4 are:

1) **migrating** overland and **prograding** toward the estuary - sediment surpluses convert subtidal estuary into low marsh. As sea-level rises, mineral low marsh and organic high marsh encroach on adjacent terrestrial areas by migration; tidal creeks and deltas are prograding toward the estuary because sediment is abundant.

2) **migrating** overland and **eroding** away from the estuary. Rapid submergence due to a combination of sediment starvation and accelerated rates of relative sea-level rise. Loss of marsh to subtidal estuary is both a marsh edge phenomenon and the drowning of the marsh surface.

3) **squeezing** at the terrestrial margin and eroding toward the estuary, and

4) **squeezing** at the terrestrial margin and **prograding** toward the estuary. (c) and (d) are extremes of a continuum where overland migration has been virtually halted by local contact of the marsh with a steep slope.

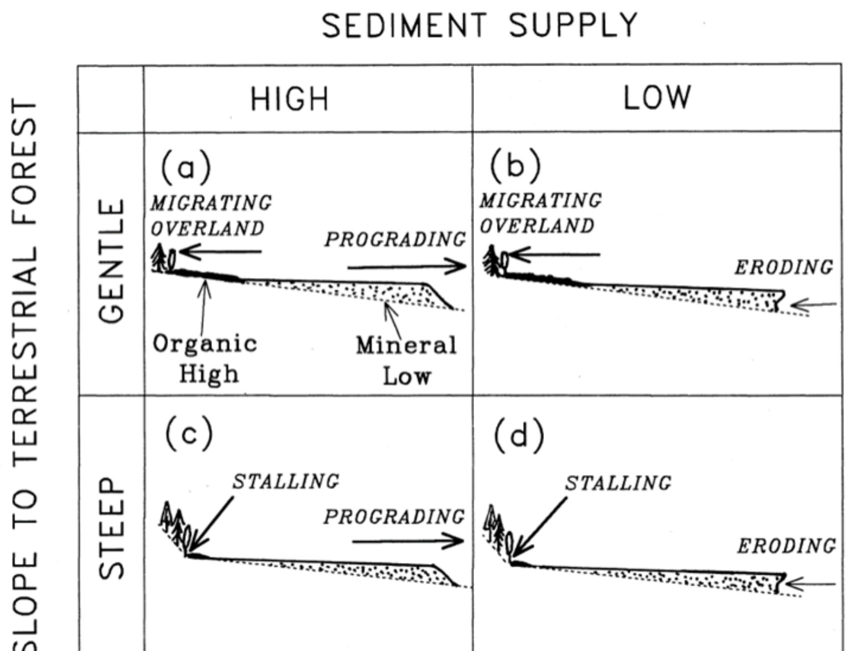

Figure 2.4. Classes of the response of marshes to sea-level rise as a function of extremes in sediment supply and landward slope, after Brinson et al (1995).

Whether the terrestrial margin of marshes is migrating or being squeezed is largely a function of the vertical accretion rate and the steepness of the slope in the transitional area at this margin. Net change in surface area in a squeezed marsh is the balance between vertical accretion, erosional losses and seaward gains.

Combining the possible combination of conditions gives a description of how the marsh may evolve. For example, a low sediment supply and shallow slope lead to marsh edge erosion and headward incision of tidal creeks into marshes, and are accompanied by migration of the marsh-terrestrial interface.

The pace of coastal habitat changes due to sea-level rise, even in "gradual" scenarios, may not be uniformly gradual. Average sea level represented in models deviates significantly from annual fluctuations in sea level, which may reach up to approximately 8 inches above average levels during strong El Niño events due to thermal expansion of warm Pacific waters. In addition, intense storms also associated with El Niño events also may be expected to achieve many years or even decades' worth of "average" erosion in extreme storms or series of storms. Thus, the coastal habitat changes expected with sea-level rise, regardless of the long-term sea level curve, may not be expected to occur in a linear or incremental pattern. The biological responses to habitat change caused by sea-level rise may similarly be expected to occur in pulses, or reflect dominant influences of extreme storm events. Local extirpation of species with limited dispersal ability, high tide refugia fidelity, or close dependence on narrowly distributed critical habitats, is a particular concern for threshold changes in habitat driven by storm events during long-term sea-level rise.

Diked Baylands

Many parts of the Bay are constrained in some way and their ability to evolve as described above is limited. Diked baylands exist in parts of the Bay that once were tidal but are now isolated from the tides and sediments. "Reclamation" typically involved the construction of earthen berms along the margins of the marsh plains where they bordered mudflats or large tidal channels. In the original Baylands Goals report, key diked bayland habitats described included diked wetland, agricultural bayland, salt pond, and storage/treatment pond. These types of diked baylands vary in their distribution around the Bay, with salt ponds largely located in the North and South Bay, waterfowl ponds in Suisun Bay, agricultural baylands in the North Bay, and water treatment ponds in the Central and South Bay.

Although diked baylands are not natural features of the Bay, some of them do provide significant habitat values (e.g., diked wetlands, salt ponds). In this update, we will refer to managed ponds as those diked baylands that are physically separated from the tides by a berm or levee, and have artificially controlled water levels and/or salinities through a water control structure (e.g., weir, culvert, flapgate, etc.) for the purposes of enhancing wildlife values. Despite the original (non-ecological) intent of some of these diked baylands such as salt ponds, ancillary wildlife benefits have been observed. More recently, attempts are being made to enhance or maximize the wildlife value of these managed ponds. The management of water levels and salinities will vary depending on the target species as well as the pond's location within the Bay. For example, management of a pond for diving ducks may include deeper water at lower salinities, while small shorebirds would require shallower water for roosting and foraging. Certain ponds may also require seasonal shifts in management to maximize benefits to target species. In addition, certain parts of the Bay are more deeply subsided, and therefore the infrastructure required to manage a specific pond will vary depending on its average bed elevation relative to the tides.

In addition to managed ponds, the Bay also supports numerous diked baylands that are managed as emergent vegetated marshes. These include diked and muted tidal marshes, treatment wetlands, and mitigation wetlands. The target habitat and wildlife species vary greatly, from large duck clubs, to small mitigation projects to support endangered species such as the salt marsh harvest mouse. These managed marshes are found throughout the entire Bay, and were designed to optimize the habitat within their footprint, with sometimes little consideration to their place in the landscape. The resulting habitats range from large, connected systems like in Suisun Bay, to small disparate marshes that are isolated from similar natural habitats. Many of these marshes also carry with them specific regulatory constraints, such as discharge standards, or minimum acreage requirements.

In addition to managed ponds and managed marshes, there are significant areas of other types of diked former baylands. Most significant among these are urbanized areas. Large areas of the Bay's edge was historically diked and converted to urban and suburban uses, including airports and entire cities. In addition, significant areas were similarly diked off and converted to agricultural uses. Agricultural uses vary greatly by subregion, and range in value from low (hay fields) to high (vineyards). Other, smaller diked bayland types are also present and include areas such as water treatment ponds, playa areas, and even vernal pool complexes.

When evaluated in the context of climate change, managed bayland habitats face a somewhat unique set of considerations for their long-term viability. Similar to the maintenance required of engineered levees for flood control features, the impact of sea-level rise on infrastructure associated with managed habitats will be similarly impacted.

It is likely that restored and resilient tidal marshes may not provide all of the habitat functions currently provided by managed ponds. It would however be prudent to minimize the reliance on managed systems to the maximum extent possible given the ecological goals of the Bay, as these ponds become spatially fixed features in a Bay that is dynamic and moving landward. They will become increasingly more difficult to maintain and operate as the bayland habitats around them migrate and change, and therefore should be located in areas that facilitate long-term viability as well as ease of operations and maintenance. Target wildlife species (usually birds, as fully tidal systems are generally better for fish and mammals) typically use these managed ponds for roosting, foraging and nesting. Trying to maximize these ecosystem services in the landscape requires not only considering the best location for managed ponds, but also their proximity to other resources (such as tidal mudflats for foraging) needed by these species. However, innovative ideas to make managed ponds more resilient (e.g., flexible water management, sediment capture inside the ponds, etc.) should be included in any new managed pond investments.

To adequately control water levels and salinities inside the ponds for a target suite of species, engineering considerations for the water control structures and surrounding levee systems usually require specific elevations for water intake and outlet points. Source waters for managed baylands may be the bay itself, or adjacent freshwater sources, depending on the location and habitat goals of that pond. Climate change related stressors such as higher water surface elevations, increased frequency and intensity of storm events, and regional salinity shifts will all impact the ability of managers to maintain target habitat conditions inside the ponds. For example, higher salinities in parts of the bay may mean that target salinities inside the managed pond may become harder (or easier, depending on the target suite of species) to maintain.

As water levels and salinities change, several possible management actions may be needed to sustain target habitat conditions inside the ponds. In the long term, the integrity of levees will come under pressure either due to increased overtopping of the crest, or direct erosion of the levee itself. The most immediate action would be to raise or reinforce existing levees to keep unregulated tidal waters out and retain the ability to control internal water levels (Figure 2.5). Therefore, similar to the relationship between levees and marshes, managed baylands should be located in positions on the landscape that take advantage of the protections afforded by outboard tidal marshes, or other site specific considerations.

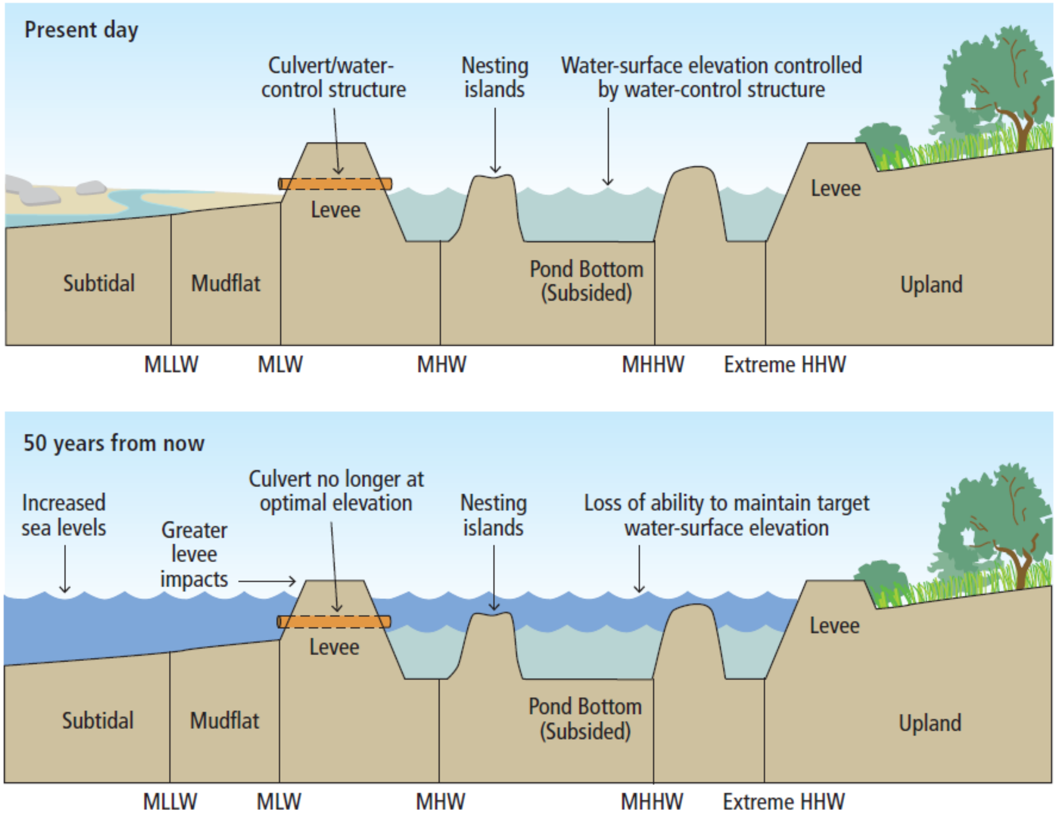

Figure 2.5. The impact of sea-level rise on managed ponds over time.

Furthermore, to sustain water management capabilities, it may require changing the management regime of the water control structures. However, it is more likely that water control structures would have to be modified, added, or replaced, and managed ponds may become more reliant on pumping of water as opposed to more passive gravity-driven configurations. In more extreme cases, a managed retreat scenario may be appropriate for some of these ponds, requiring relocation or abandonment of ponds in areas of higher threat from sea-level rise. Abandoned ponds could then be converted to other (likely tidal) habitat types dependent upon their elevation and location in the Bay. In addition, there should be large scale and long term planning between the regions of the Bay and Delta to ensure that the habitat needs of a variety of species are being met regionally as habitat types shift from restoration actions, salinity changes, etc.

WHAT MANAGEMENT ACTIONS CAN WE TAKE?

Given the projections of marsh loss in the latter parts of the century under the likely scenario that sea-level rises rapidly and sediment availability is low, we need to understand the range of management actions we can take to guide the evolution of baylands habitats in the short term and in the long term. The major drivers of change of tidal marsh evolution are the rate of sea-level rise (i.e., water depth), inorganic sediment supply, organic productivity, incident wave energy, and space for migration. These in turn control the following key factors of marsh evolution:

- rate of vertical accretion,
- rate of horizontal erosion; and
- rate of landward migration.

Vertical Accretion Measures

The purpose of the set of measures described below is to increase the vertical accretion rate of the marsh by increasing the supply of fine sediment to the marsh, by improving the pathways by which the sediment crosses the marsh or by increasing the trapping of sediment on the marsh. The intent is to accelerate inorganic accretion rates to keep pace with rising sea level, allowing the marsh to maintain its vertical position in the tidal frame.

A geomorphic process model for vertical accretion in tidal marshes is shown in Figure 2.6. The rate at which marshes accrete vertically is in part a function of the inorganic sediment supply, which in turn is a function of the average suspended sediment concentration in the water column, depth of water and period of high water and in part a function of organic productivity. For inorganic sedimentation, the higher the concentration and deeper the water over the marsh, the greater the amount of sediment available in the water column to be deposited. Marsh accretion rates can be directly affected by increasing the supply of fine sediment in the water column, either by introducing fine sediment directly into the water column (water column recharge) or by placing sediment on the mudflat that may be later resuspended by wave action (mudflat and marsh recharge) to be carried on to the marsh and deposited by natural processes. Sediment supply can also be enhanced by ensuring that there are sufficient size and density of tidal channels to convey fine suspended sediment from the Bay to the landward portions of the marshes. Significant accretion can occur during extreme events when water levels are high and there is significant wave activity to resuspend the bay sediments. Trapping efficiency of fine sediment can be improved by increasing the density of vegetation by planting or by emulating vegetation with the construction of sedimentation fences or similar features. These measures are summarized in Table 2.1.

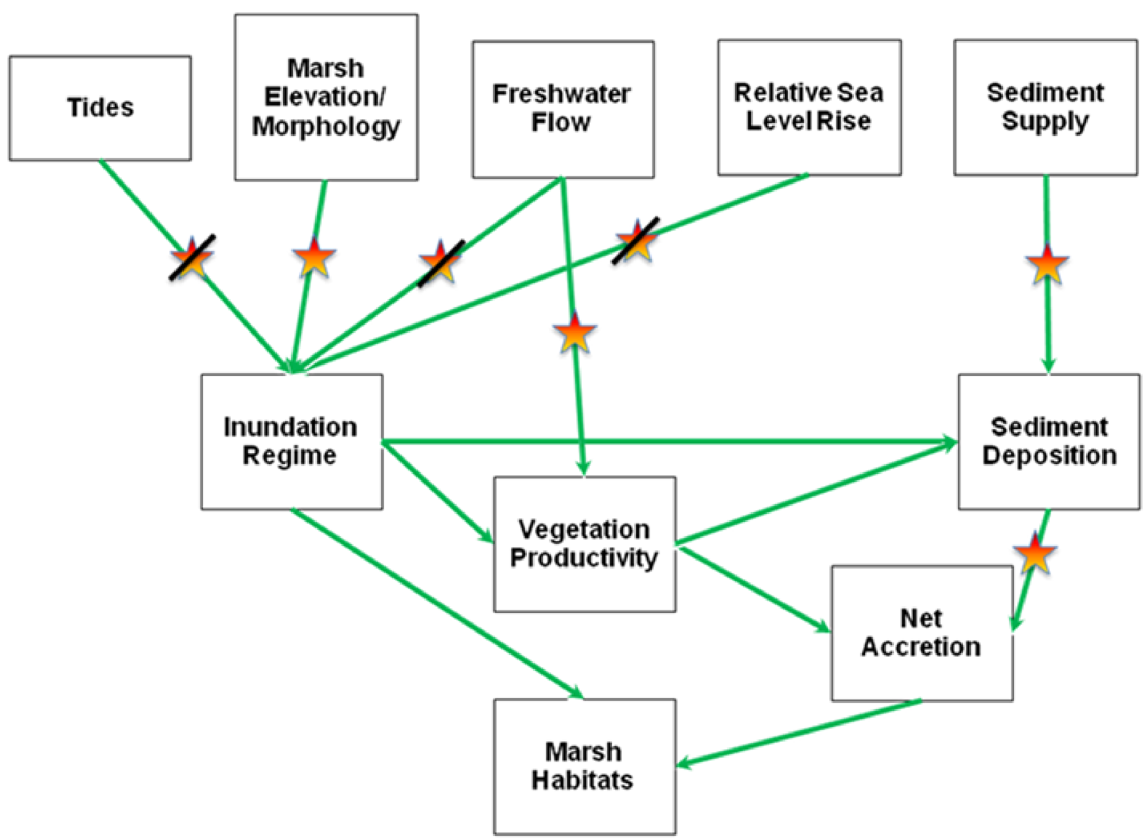

Figure 2.6. Conceptual model of vertical accretion. The stars indicate linkages that could be influenced by management measures. Stars with a bar across them are linkages where management measures are impractical.

Table 2.1. Vertical accretion management measures

Key Factor	Driver of Change	Measure	Examples
Vertical Accretion	Sediment Supply from fluvial and oceanic sources	Mudflat and marsh recharge	Mudflat and marsh charge
		Improve sediment pathways	Improve channel network
	Sediment Deposition	Enhance sediment trapping	Sedimentation fences

Mudflat and Marsh Recharge

A number of methods have been suggested to increase the local concentration of fine sediment in the water column. As an example, typical suspended sediment concentrations in the bay are of the order of 100-200 ppm and typical accretion rates of 2-5 mm per year (Callaway *et al* 2012) while observations of accretion rates in Alviso Slough in the South Bay have shown that concentrations of 450-600ppm result in inorganic accretion rates of up to 1-2 feet per year (Ruth and Going 1980 in PWA 2005) while brackish marsh vegetation that supports wildlife is maintained on the marsh surface. By focusing the introduction of fine sediment close to the target tidal marsh, it should be possible to increase the local marsh and mudflat accretion rates. The intent is to make use of natural wave action and tidal currents and watershed outflow to transport the sediment into and deposit it onto the marsh. This avoids both the difficulty of mechanically placing sediment to accurately mimic a natural marsh and the impact of construction equipment on the existing (or restoring) marsh. However there are detrimental impacts from some of these approaches (e.g., smothering benthos on the mudflats) that need to be evaluated.

To introduce sediment directly into the water column, fine sediment could be pumped from a barge adjacent to the tidal marsh. The release would occur on a flooding tide that would carry the sediment to the marsh. An alternative method can be used where the site is exposed to moderate wave action. Fine sediment is introduced indirectly into the water column by placing the material on an adjacent mudflat as a mound either by split bottom barge, hydraulic pipe or 'rainbowing'. Wave action on the mudflat mound then re-suspends the fine sediment into the water column and conveys it into the tidal marsh (Figure 2.7). In addition, sediment sources from the landward side of the Bay should also be considered for sustaining marshes, either from direct placement of clean fill material into subsided areas to be restored, or enhancing natural sediment pathways through watershed level enhancements and the reconnection of creeks and rivers to the marsh.

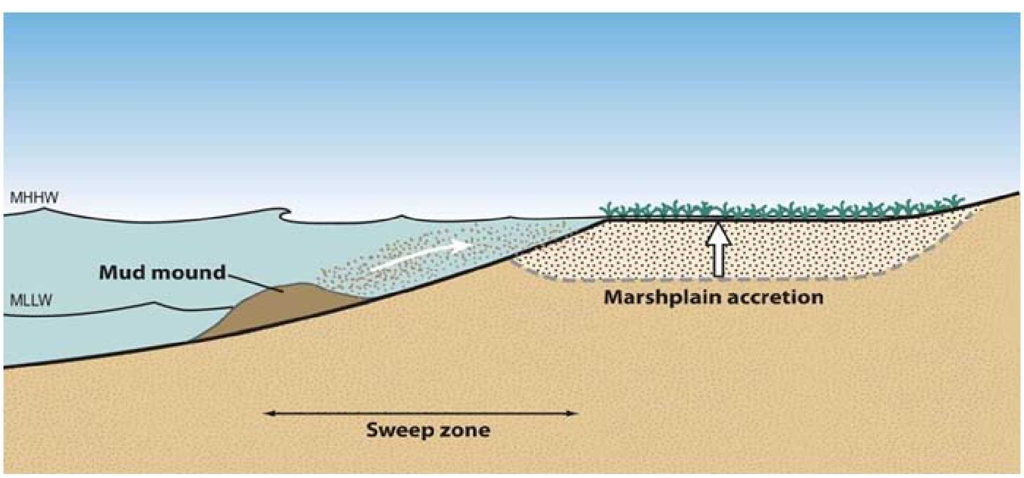

Figure 2.7. Recharge of marshes.

Opportunities and Constraints

Recharging the water column and the mudflats has considerable benefits as it allows the choice of when, where and how much sediment to introduce to the system in a targeted fashion to offset some of the overall reduction in suspended sediment forecast for the next century (Schoellhamer 2011). Many of the ecosystem services of a tidal marsh are a function of elevation and inundation regime and so are dependent upon the marsh maintaining its position in the tidal frame. Recharge will help maintain tidal marsh ecosystem services (such as wave attenuation) longer with rising sea levels by increasing vertical accretion of the mudflat and tidal marshes.

However, mudflat, water column recharge and reconnecting creeks to marshes are untried in the Bay and present significant permitting challenges as they could have detrimental impacts particularly on existing habitat. Once the recharge has occurred there is little control on where and how much sediment will be finally deposited as it is controlled by natural processes; the location and timing of recharge is therefore very important. Mudflat recharging with fine sediment will also result in the burial of existing mudflat habitat and associated impacts on species using that habitat. Finally, recharge is likely to work best with relatively small volumes released at frequent intervals – the recharge would be scaled to the marsh area and long term deposition rate. This may conflict with the availability of dredged material, which may occur more infrequently and in larger volumes. Pilot projects to determine the efficacy of this approach should be conducted and studied.

Improve Sediment Pathways

Tidal channels are important elements in tidal marshes as they act both as pathways for sediment, organisms, detritus etc and also as habitat for fish and birds. Mature natural marshes tend to have extensive and complex dendritic drainage networks with several orders of sinuous channel, often divided into watersheds with tidal slough connections to the Bay. These channels convey turbid Bay water into the marshes and on to the marsh plain at high water allowing sediment deposition to occur across the whole marsh. Distance from channel is important in determining the rate of accretion. Coarse material is deposited closer to the channels and forms natural levees which are higher than the surrounding marsh plain and support particular plant species such as gumplant (*Grindelia*). Finer sediment is deposited further away from the channel, diminishing with distance away from the channel and organic material becoming more important. If the channel density is low, parts of the marsh may be far from channels, have few natural levees, be poorly supplied with fine sediment and have low rates of accretion.

The characteristics of channels and channel network are determined in large part by the tidal prism of the marsh, which in turn is controlled by the tidal range and the area and elevation of the tidal marsh. If there is insufficient tidal prism, due to filling of the marsh or diking, then channel networks may not fully evolve resulting in poor habitat and low accretion rates at the back of the marsh away from the channels (Figure 2.8). The relationship between tidal prism and channels can be predicted using hydraulic regime theory (PWA 2002, Williams et al 2002).

Opportunities and Constraints

Creating a complex channel system that is configured for the size of the marsh will improve the connectivity of the marsh with the estuarine tidal processes, allowing tidal access to all parts of the marsh. This will increase the tidal prism which in turn will allow larger channels to be maintained as well as increasing the volume of sediment available for deposition on the marsh. Many species of plants and animals also rely on channel bank habitat. Increasing the sinuosity of channels provides more heterogeneity in the habitat. A complex drainage system with a variety of channel orders provides a variety of channel sizes, elevations and inundation regimes for different species.

When tidal action is reintroduced to a subsided site, tidal flows tend to concentrate in existing ditches or depressions that then fix the location and shape of the tidal drainage system. It is likely that once the existing drainage system captures the tidal flows this pattern will persist. Modifications are often made to the drainage, such as the creation of ditch blocks, to avoid such capture.

Figure 2.8. Muzzi Marsh showing difference in channel density with elevation of the site due to filling.

Enhance Sediment Trapping

Increasing the period of sedimentation during a tidal cycle may be achieved by decreasing transport velocities. The rate of deposition is controlled largely by the interaction between tidal current velocities and vegetation cover. One example is traditional fine-grained sediment-deposition ('warping') methods where high tide waters are impounded and sediments allowed to settle, before draining the waters off ('dewatering') via a sluice gate, or as the tide falls. Another method is the use of sedimentation fences which are brushwood structures designed to slow the passage of water thereby enhancing the deposition of sediment. Brushwood fences can be arranged on the shore either as groins or polders.

Opportunities and Constraints

This measure is largely focused on managed ponds that have yet to be restored, and takes advantage of natural tidal flow to trap fine-grained alluvial sediments across areas of mudflat and saltmarsh. Sedimentation fences either constructed as groins or polders require intensive management and maintenance and so these techniques may be only feasible for relatively small marsh areas and must take local sedimentary trends into account to be successful. This could be combined with shoreline stabilization methods (described below) that reduce waves and capturing resuspended sediment with plantings behind the wave breaks.

Shoreline Stabilization Measures

The purpose of the measure is to decrease the horizontal erosion rate of the marsh by reducing the incident wave energy or increasing the stability of the shoreline. The intent is to slow the loss of tidal marsh due to erosion, allowing the marsh to maintain its width for longer.

A geomorphic process model for horizontal erosion in tidal marshes is shown in Figure 2.9. Marsh erosion rates can be directly affected by decreasing wave energy on the marsh edge. This can be achieved by increasing the wave attenuation over the mudflat by increasing its elevation, by increasing the bottom friction of the mudflat by planting submerged aquatic vegetation and by constructing low-crested breakwaters or berms/sills, including living shoreline elements such as shellfish reefs. The stability of the marsh edge may be increased by armoring it with a beach constructed of relatively coarse material and stabilizing the beach with control structures such as groins and headlands constructed with large woody debris (LWD) or rock. These measures are summarized in Table 2.2.

Coarse Beach Stabilization

Coarse gravel beaches are a natural form of shoreline that can adjust to local wind-wave conditions and water levels even under conditions of extreme wave events. Unlike typical engineered revetment systems, such as rip rap, movement of cobble and gravel are an inherent characteristic of a coarse beach and not an indication of failure. Dunes fronted by composite gravel beaches experienced erosion rates that were typically 20-40% of pure sand beaches (Allan et al 2005), highlighting the level of protection offered by a gravel beach as compared with a pure sand beach. In Southern California, researchers have noted that gravel beaches tend to gain material and increase their crest elevations during severe storms, while adjacent sand beaches eroded (Lorang et al. 1999, Everts et al. 2002).

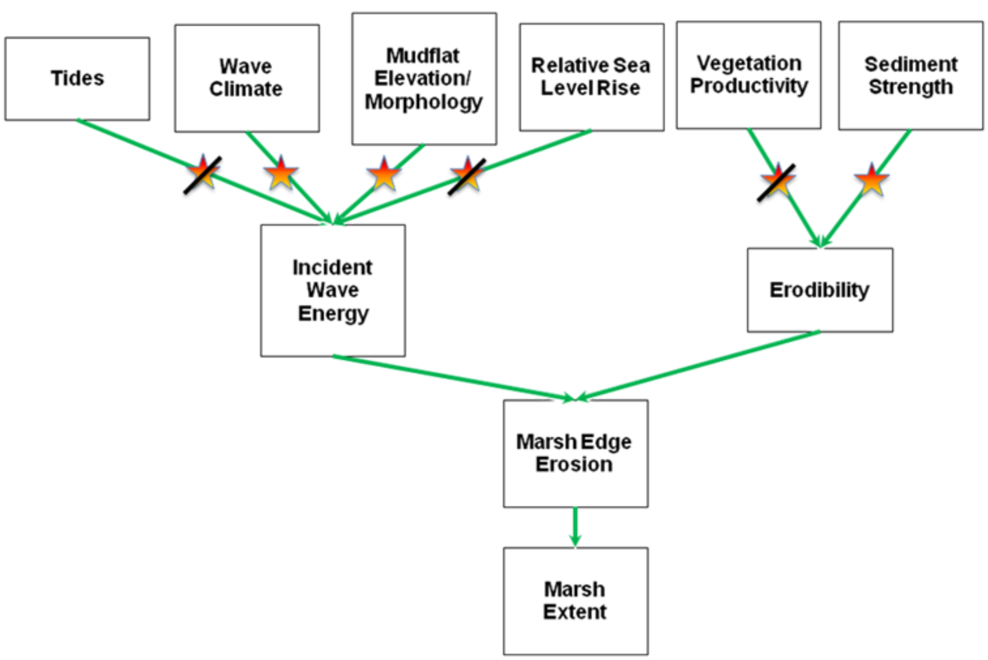

Figure 2.9. Conceptual model of horizontal erosion. The stars indicate linkages that could be influenced by management measures. Stars with a bar across them are linkages where management measures are impractical.

Table 2.2. Horizontal erosion management measures.

Key Factor	Driver of Change	Measure	Examples
Horizontal Erosion	Erodibility	Coarse beach stabilization	• Coarse sediment pocket beaches • Crenulate shoreline - rock/LWD headland • Sand/shell barrier beach
	Wave Climate	Wave attenuation	• Static rock berm • Dynamic gravel/cobble berm • Oyster reef/eel grass beds

Opportunities and Constraints

Marsh erosion due to wave action can cause narrowing of marshes and compression of wildlife habitats closer to terrestrial edge buffers. Gravel beaches are one of the most effective forms of coastal protection, exhibiting significant stability under sustained wave attack (Ahrens 1990, Ward and Ahrens, 1991). The sloping, porous coarse beach, once prevalent in the Central Bay, is able to dissipate the wave energy by adjusting its shape in response to the prevailing wave conditions. This approach would provide the geomorphic foundation for gradual migration and ecological transition of native vegetation and habitats associated with the shoreline.

A major constraint that likely limits the adoption of coarse beaches as a viable option is the identification of suitable gravel sources that could be utilized in the construction and maintenance of such structures. Few natural sources are available in the Bay. In addition, the potential impact of longshore drift should be considered in any beach design and low groins, constructed across the gravel beach, may be necessary to reduce the rate of longshore gravel transport. The placement of gravel and cobble on the shoreline would also lead to the conversion of habitat types and effects on benthos.

Wave Attenuation

Conventional offshore breakwaters are based on armoring (hardened surfaces, such as rock armor). Low-crested berms constructed from coarse gravel or oyster shell (Figure 2.10), are potential alternatives. These would be able to accommodate rising sea level by naturally rolling landward, driven by wave forces. They may also enhance rather than conflict with ecological and aesthetic objectives for tidal wetlands, and provide additional recreational benefits in suitable locations.

For typical nearshore conditions in the East Bay, the wave heights could be reduced by between 10% and 70% by these types of structures during normal tidal conditions which could significantly reduce horizontal erosion rates. The height of the berm will determine the amount of wave attenuation. The offshore distance of the berm from the marsh edge, together with the length of the berm, will determine how much of the marsh is protected.

Opportunities and Constraints

Several studies have found that breakwater reefs constructed of loose oyster shell provided substrate for oyster recruitment and harbored a more diverse community of fish and invertebrates than control areas without reefs (Subtidal Goals 2010).

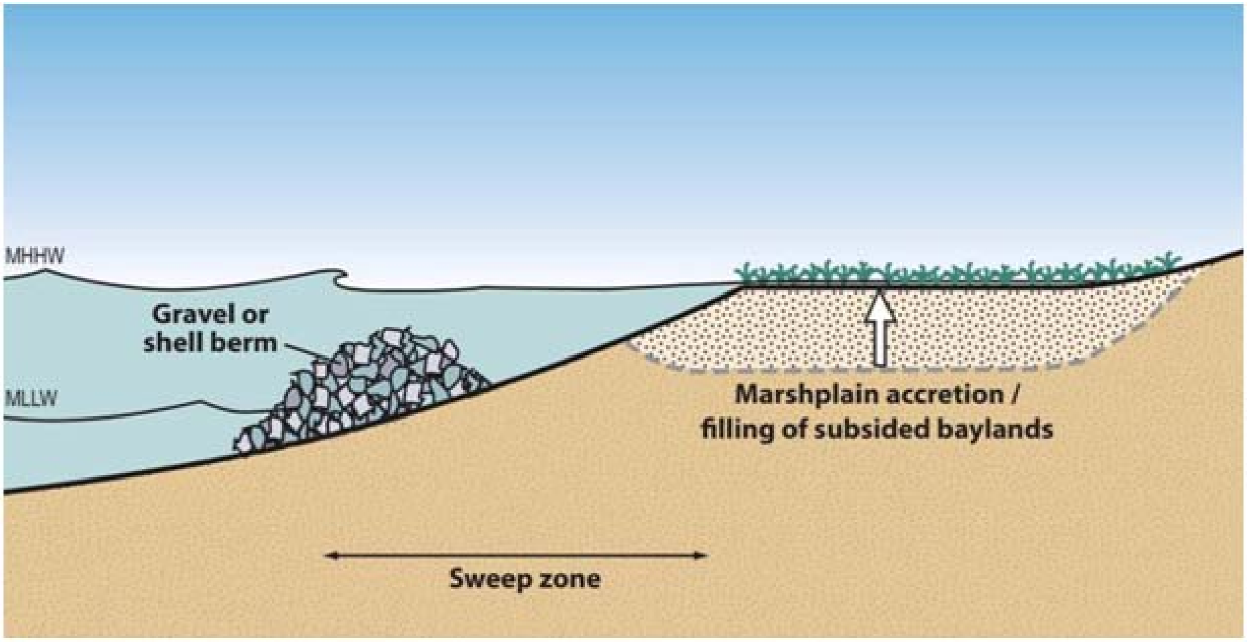

Figure 2.10 Gravel or shell wave attenuation berm – note vertical exaggeration

While oyster shell breakwaters have been successful in creating valuable habitat, they do not provide the same level of protection that could be offered by traditional engineered designs. However, this approach could serve as an immediate solution to the marsh/shoreline losses experienced along the bay shore.

The potential impacts of offshore wave breaks include smothering of invertebrate communities from both placement of shell and potential accretion in the lee of the structure, local scour around the structures, the possible need for long term maintenance/replenishment, and potential hazard to navigation and recreation.

Landward Migration

The purpose of the measure is to increase the space available for the landward migration of the tidal marsh with sea-level rise. The intent is to slow the loss of salt marsh due to "coastal squeeze" against steep levee faces, allowing the marsh to maintain its width for longer. More details of the management of the transition zone are provided in Science Foundation Chapter 4.

The rate of landward migration is a function of landward slope and the rate of sea-level rise. Wide transition zones adjacent to high marsh will allow the migration of tidal wetlands with rising sea level, as opposed to being squeezed against steep-sided levees. Healthy transition zones and terrestrial buffers also transport surface and subsurface flows of water and sediment, maintain water quality, provide nutrient input from decaying plants, stabilize shorelines, and store flood waters. All of these functions are affected by the width of the transition zone. These measures are summarized in Table 2.3.

Table 2.3. Landward migration management measures

Key Factor	Driver of Change	Measure	Examples
Landward Migration	Landward Elevation and Slope	Create transition zone through placement of fill	Placement of dredged material bayward of levee to increase elevation
		Managed realignment	• Levee realignment in a landward location • Relocation of people and infrastructure out of a flood hazard zone

Create Transition Zone

This measure creates a transition zone on fill slopes landward of the tidal marsh (OLSD 2013). These slopes of 1:20, 1:30 or more could:

- create transition zone habitat that is missing in many parts of the bay due to diking;
- create gently sloping habitat between tidal marshes and existing flood risk management levees to act as buffers to sea-level rise to allow migration using broad, gently sloped gradients;
- provide additional ecosystems services such as act as treatment to polish wastewater discharge.

The transition zone slopes would be an engineered equivalent of lowland floodplain moist grassland habitat (lowland wet grassland and sedge-rush meadows) of broad, flat alluvial fans that historically graded into the tidal marshes of most of South San Francisco Bay. When such slopes have been created in the Bay in the past they have been invaded by pepperweed (*Lepidium*), therefore creating a salinity gradient across the slope would allow native plant species to compete more effectively. For example, treated wastewater could be allowed to seep through the ecotone slope to support the moist grasslands.

The transition zone would be located landward of the existing tidal marsh and bayward of the flood risk management levee (or other logical configurations given the site specific layout). Rather than placing fill directly on existing marshes fronting levees there maybe opportunities to fill manmade ponds (such as salt or oxidation ponds) which lie between the levee and the outboard marsh. Refer to Science Foundation Chapter 4 for a more detailed discussion of transition zones.

Opportunities and Constraints

This measure would provide long gentle slopes more in keeping with natural historic marsh edge slopes than steep sided levees. The measure will help maintain tidal marsh ecosystem services, such as wave attenuation, for longer with rising sea levels by allowing landward migration. These shallower slopes would allow tidal marshes to migrate landward rather than be squeezed against steeper levee slopes. The now-rare groundwater seep-dependent transition zone would provide seasonal terrestrial habitat for the endangered salt marsh harvest mouse spring foraging habitat and increasingly important terrestrial high tide refuge, particularly as sea-level rises.

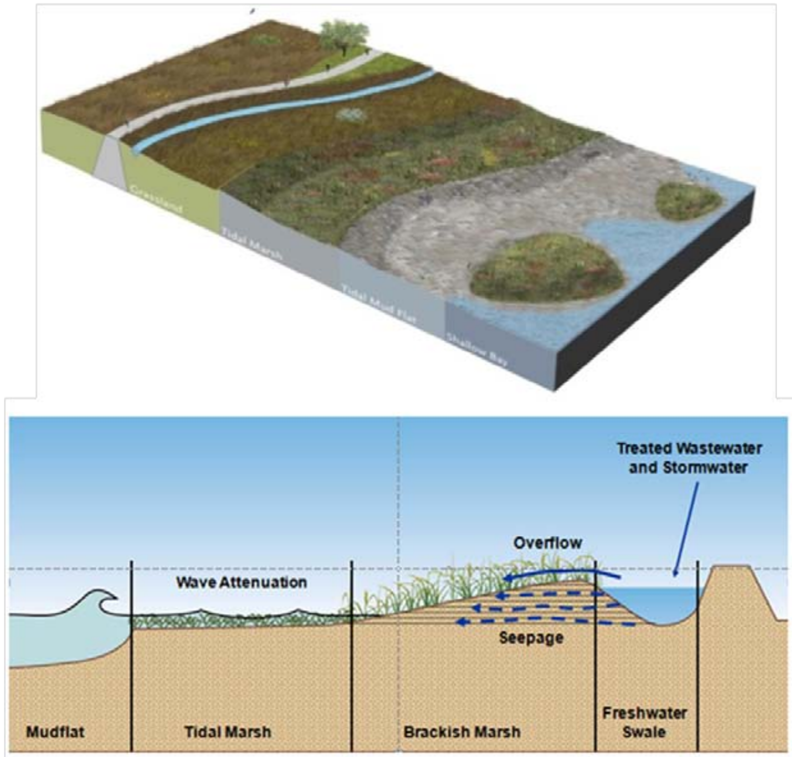

Figure 2.11. Oblique and cross section through transition zone.

However, impacts to existing wetlands could present permitting challenges associated with converting existing tidal marsh habitat to terrestrial habitats and brackish wetlands. In addition, the construction and maintenance of the transition slopes would require large volumes of fill material. Water or land access would be required to allow the placement of fill including up to 3 feet of clean, capping soils to accommodate the rooting zone of the terrestrial native plants. If brackish marshes are to be constructed then a supply of fresh water is required.

Managed realignment

A complementary strategy is to realign the flood risk management levee to a new location further inland. This allows marshes and mudflats to migrate landward naturally. Realignment takes advantage of the natural protection provided by marshes and mudflats (including extant, restored, and potential future marshes and mudflats) to reduce the risk of flooding and erosion allowing smaller levees to be built (Figure 2.12).

Bayland slopes behind the existing levees are often very flat (1:1000 in subsided areas) and tidal marsh accretion rates may not be sufficient to keep up with rising sea levels. This means that the rate of landward migration of the shoreline could be very rapid under certain scenarios. In concert with the moving shoreline, the hazard zone associated with flooding will also move inland. Realignment over relatively flat slopes uses large amounts of land, but may provide flood risk management benefits for only a relatively short period, particularly if vertical accretion rates and plant establishment rates lag behind sea-level rise. It would be necessary to include other measures to promote vertical accretion, such as enhancing channel networks, together with managed realignment.

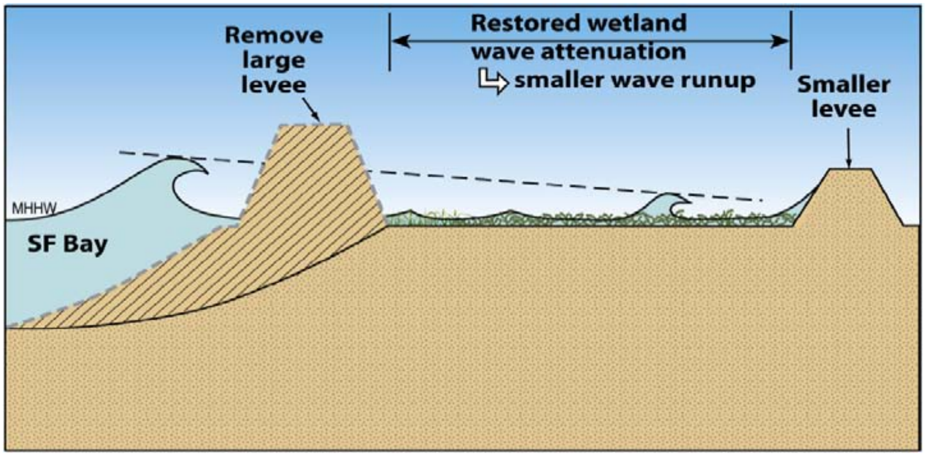

Figure 2.12. Managed realignment of levee to create opportunities to restore tidal action to diked baylands.

Opportunities and Constraints

Environmental benefits include the potential to mitigate the effects of previous diking and of future sea-level rise, including the potential for new habitats to compensate for change to other habitat of the same type elsewhere. Ultimately, the goal would be the development of a sustainable estuary shape to contribute to flood risk management.

Managed realignment also has flood risk management benefits. These include the potential to change the hydrodynamics of an estuary so as to reduce the risk of flooding at another location or to improve the functioning of the hydrodynamic and sedimentation system. In addition, it can reduce the costs, particularly where it is no longer economic justification to defend land or where realignment enables the levees to be moved to naturally higher ground.

However, managed realignment has some significant capital and political constraints, especially if it requires the relocation of people or critical infrastructure. Areas of sensitive habitat or possible contamination sources that are currently located landward of existing flood risk management structures would also need to be carefully considered.

Management Action Strategy

Decision Process

The selection of management measures for implementation will require thoughtful consideration of trade-offs between competing uses, near- and long-term benefits and impacts, and different priorities regarding ecosystem services (i.e., which are protected and to what degree). The decision about what constitutes near-term and long-term will depend on the rate of sea-level rise, and in particular when certain threshold elevations will be crossed that trigger the need for intervention (BCDC 2013). Ultimately, successful implementation of a sea-level rise management action strategy will involve adaptive management, defined as a rigorous process of learning by doing and using the results to improve management actions (Figure 2.14). Restoration practitioners have found that, because knowledge of natural and social systems is incomplete, systems can respond in unexpected ways (Trulio 2007). Given this, many data gaps can only be addressed by implementing management measures and conducting long-term monitoring to evaluate their performance.

A distinct conceptual sea-level rise management action strategy will need to be developed for each Segment or distinct marsh unit. The conceptual frameworks will likely consist of multiple management measures to be implemented in a number of phases dependent upon the amount of sea-level rise. The first phase provides immediate ecological benefits to enhance the existing marsh and to maximize its resilience to 2050 – 2070, when sea-level rise rates will still be relatively low. The second phase prepares the marsh for accelerating rates of sea-level rise expected after 2070, when rates may out-pace vertical accretion and marshes will need to migrate landward to survive.

The recommended actions for each baylands segment (main report under 'New Opportunities: How We Can Achieve Healthy, Resilient Baylands,') initiate this planning process by providing near- and long-term visions and accompanying actions to take. Actions plans for each marsh can then be built out from the more general segment plans.

Localized conditions will play an important role in the decision making process as to which areas should be selected for action. The decision about when to implement each of these measures will depend on the rate of sea-level rise, and in particular when certain threshold elevations will be crossed that trigger the need for intervention. Figure 2.13 illustrates this concept graphically. Similarly, because of the need to capture as much sediment as possible, areas of the Bay that have high suspended sediment concentrations and a recent history of rapid accretion rates should be prioritized for tidal marsh restoration. Restored marshes with a greater elevation capitol will be more resilient in the long term.

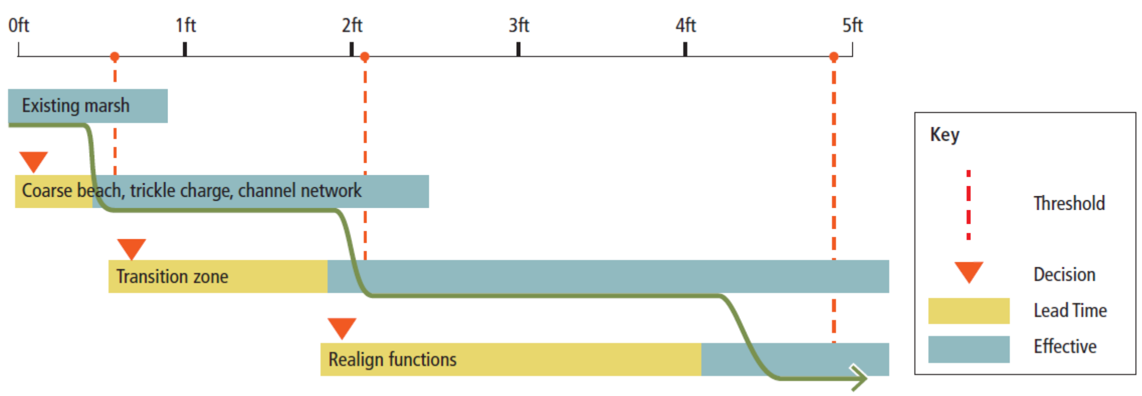

Figure 2.13. Potential phasing of adaptation measures triggered by rising sea levels. The timing of different strategies is set by Bay elevation rather than chronological time. Because many of the management measures have fairly long lead times for planning, permitting, and construction, decisions about how and when to implement them will have to be made well in advance of when they are needed.

Finally, because many of the management measures have fairly long lead times for planning, permitting, and construction, decisions about how and when to implement them will have to be made well in advance of when they are needed. For example, large-scale restoration projects can take up to a decade to plan, permit, fund and implement. More challenging projects such as large levees can take longer, and building consensus on innovative concepts, or controversial actions such as managed realignment, could need multiple decades of planning.

Trade-offs of marshes versus hard engineering solutions

In the 2013 Bay Institute report (TBI 2013), findings indicate that tidal marsh can reduce storm wave heights by over 50% depending on water depth and marsh width. This finding suggests that flood risk management is improved significantly when areas of tidal marsh exist between the developed shoreline and the open waters of the Bay. Further, by using tidal marsh in combination with a levee constructed at the landward edge of the marsh, the size of the levee could be reduced significantly while still providing the same level of flood protection benefit as would be provided by a larger levee that was not fronted by tidal marsh.

Their analysis concluded that a flood risk management system comprising a landward levee and an adjacent tidal marsh provides an equal level of flood protection to that of a much larger landward levee alone. Moreover, the results indicate that it would be more cost effective to build a flood risk management system that incorporates a tidal marsh than it would to only build a conventional earthen levee.

Significant marsh restoration efforts already are underway in San Francisco Bay. What began with a small, one-off project in the late 1970s has evolved into a regional program with the goal of restoring over 100,000 acres of bay marshes. However, that program has only lately come to incorporate sea-level rise projections into marsh restoration design. Restoration scientists now recognize that many of the restored wetlands are at risk of being drowned by rising tides. In addition, the decreasing availability of suspended sediment in bay waters also poses a threat to the success of marsh restoration efforts.

A new restoration design is needed in order to respond to these changing conditions. The TBI horizontal levee study describes a potential new marsh restoration paradigm that is appropriate in many parts of the Bay and that can provide an interim solution to the problem of tidal marsh inundation and low sediment supply. This new paradigm recommends the addition of a broad estuarine-terrestrial transition zone slope of moist grasslands and/or brackish marshes landward of the existing tidal salt marsh. The transition zone slope would provide both elevation and salinity gradients that would allow the tidal marsh to both move landward and accelerate vertical accretion in order to keep pace with sea-level rise. This new marsh restoration paradigm also proposes the use of clean fill material such as upland sources of construction material or sediment dredged from nearby flood control channels as construction and maintenance material for the transition zone slope. In addition, reclaimed wastewater effluent from existing public water treatment plants along the shore could be used to irrigate the transition zone slope and/or create areas of fresh and brackish marsh.

Many other options for addressing sea-level rise should also be explored, including areas where restored baylands may provide adequate flood protection without new levee construction. Restoring severely subsided landscapes and providing sediment to help sustain naturally accreting marshes may be more cost effective than constructing new levees.

Near Term Priorities

In the near term, the priority should be focused on 1) enhancing the resilience of existing marshes, 2) expediting the restoration of marshes, and 3) creatively retaining or enhancing the habitat functions of the other Bayland habitats. Within the context of these three priorities, we would emphasize the importance of performing pilot studies to understand the efficacy of various innovative enhancement and restoration techniques to enhance the various processes that increase the resiliency of a marsh (e.g. Figure 2.12). By initiating and monitoring pilot projects for less well-understood measures, lessons about potential opportunities and constraints can be learned, and future implementation can more readily achieve project goals. Each of these three near term priorities results in a specific set of recommended actions.

1) Enhancing the Resilience of Existing Marshes

There are varying degrees of understanding about the efficacy of various short term marsh enhancement measures in San Francisco Bay. For example, restoration practitioners have experience improving sediment pathways in Bay tidal marshes, and there is information available on how to design, build, and monitor tidal channel development. However, using eelgrass and oyster reefs (e.g., 'living shorelines') to reduce nearshore wave energy and using coarse beaches to stabilize eroding shorelines are currently in the early testing phases in the Bay. Other measures are untested in the Bay, although some have been tested elsewhere. Potential enhancement measures for existing marshes have been described in the preceding sections and can be summarized as:

A. Reduce nearshore wave energy
B. Stabilize with coarse beaches
C. Recharge mudflats and/or marshes
D. Improve sediment pathways
E. Enhance sediment trapping

2) Expediting the Restoration of Marshes

There are large areas of former bayland that are in public ownership and are scheduled for tidal restoration. These areas should be prioritized based on their location in the landscape and likelihood for long-term sustainability.

For example, areas of the bay that have greater suspended sediment concentrations or are at a higher starting elevation (more elevation capital) should be prioritized above areas where marsh establishment and persistence is more doubtful. Restoring significant amount of tidal marsh in the next decade will be of critical importance to capitalize on the existing sediment supply in the Bay as well as the relatively lower current rates of relative sea-level rise. The sooner more tidal marshes can become established in the next 30 years, the better.

In addition, all of the concepts outlined above for enhancing existing marshes should also be applied to newly restored marshes where appropriate. In particular, the creation of broad transition zones and the beneficial re-use of dredge material and upland soils.

3) Creatively Retaining or Enhancing the Habitat Functions of Other Bayland Habitats

Other types of bayland habitats besides tidal marshes, especially diked baylands, provide significant ecosystem services. To sustain their functions and values, it may require changing the management regime, and even consider re-thinking their sustainability. Apart from management adjustments, a managed retreat scenario may be appropriate for some of ponds, requiring relocation or abandonment of ponds in areas of higher threat from sea-level rise. Abandoned ponds could then be converted to other (likely tidal) habitat types dependent upon their elevation and location in the bay. However, pilot studies should be conducted on how to maximize or retain the ecosystem services provided by these other bayland habitat types.

Long Term Priorities

In the longer term it will be necessary to consider other measures, in addition to those listed in the preceding section. Successful pilot studies performed in the near term should be scaled up as appropriate, and regional coordination on multi-purpose projects and spatially appropriate habitat trade-offs should be explored.

1. **<u>Increase transition zone</u>**
   This measure creates an estuarine-terrestrial transition zone on fill slopes located landward of the existing tidal marsh and bayward of the flood risk management levee. There may be opportunities to fill man-made ponds (such as salt or oxidation ponds) located between the levee and the outboard marsh to avoid placing fill directly on wetland habitats. Broad transition zone slopes would create a habitat type that is missing in many parts of the Bay due to diking, and provide space to allow for landward migration, buffering the tidal marsh from coastal squeeze between a rising bay and steep levee slopes. Although stated as a long term priority, opportunities to couple these features with expedited tidal marsh restoration in the short term should not be missed.

2. **<u>Realign levees</u>**
   Realignment of the flood risk management levee to a location further inland is complementary to the aforementioned transition zone slope measure as it provides additional space for landward migration. Realignment would increase the distance between the bay and shoreline development, allowing for the dissipation of wave energy over distances of several hundred feet or more and allowing the construction of much lower levees inland. It can also be done in a way to provide greater connectivity between upstream watershed processes and the baylands.

   A future strategy may then include the following ideas:
   - Plan for future marsh configurations: fringing marsh with wide transition zone slopes for landward migration
   - Natural, process-based connections to the larger watershed for sustained sediment delivery.
   - Concomitant changes in habitat extent/conversion
   - Begin accumulating/stockpiling material (either dredge material or upland fill) in strategic locations

SUMMARY

Presently, tidal bayland habitats (marshes and mudflats) are accumulating enough sediment to keep pace with near-term projections of sea-level rise. The future of these habitats depends significantly on the actual rate of sea-level rise and the availability of suspended sediments in the bay to support them. In the near term, it appears that marshes and mudflats throughout the Bay will continue to persist. However, greater uncertainty on their fate occurs as we approach the turn of the next century. Similarly, the functioning of diked baylands will be most impacted as sea-level rise escalates later in the century. Continued monitoring remains key to understanding bayland response to sea-level rise, evaluating ongoing changes, and determining the accuracy of past (and future) marsh modeling efforts.

Specific recommendations are outlined in the main report under 'New Opportunities: How We Can Achieve Healthy, Resilient Baylands,' but the primary overarching recommended actions include:

1) The need to have a strong sense of the management action timeline, linking planning and subsequent implementation to elevation thresholds to ensure adequate preparation time.

2) Immediate implementation of pilot studies to explore and validate many of these recommended measures.

3) Flexibility from the regulatory community to allow for new and creative solutions when project objectives include restoring or retaining bayland habitat and function.

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