SOUTH BAY SALT POND RESTORATION PROJECT
CONCEPTUAL MODEL
How restoration actions affect the salt marsh harvest mouse

Salt marsh harvest mice (*Reithrodontomys raviventris*) are small mice found only in the pickleweed dominated salt marshes of greater San Francisco Bay. They are listed as an Endangered Species at both the Federal and State levels. Salt marsh harvest mice have become endangered because much of their habitat has been destroyed, and what remains has been highly modified and degraded. The southern subspecies of the salt marsh harvest mouse (*Reithrodontomys raviventris raviventris*) is only found in the South San Francisco Bay. It is the only endemic endangered species for which recovery is dependent upon tidal restoration actions that are part of this project. It was one of the pivotal species upon which the decision to initially establish a National Wildlife Refuge in the South San Francisco Bay was based. Therefore, one of the evaluation criteria for the Project Alternatives is the ability of an alternative to contribute to the recovery of this subspecies.

These mice are dependent on dense vegetation cover, usually in the form of pickleweed (the dominant salt marsh vegetation in the Bay) and other salt dependent or salt tolerant vegetation in both tidal and diked salt marshes. Historically, the marshes in San Francisco Bay were a complex mosaic of vegetation zones, generally consisting of low marsh adjacent to mudflats dominated by cordgrass, high marsh plains dominated by pickleweed, and broad transitions of peripheral halophytes (salt-tolerant plants that cannot tolerate as much inundation by the tides) to the upland habitats, with narrower transitional zones on natural levees along larger channels within the marshes. Most of the tidal marshes around the Bay and especially in the South Bay were eliminated, and those remaining have lost the upper portion of their pickleweed zones as well as the higher transitional zone of peripheral halophytes. The existing high marsh consists primarily of narrow bands along backshores against levees or other hardened structures that promote predation, inhibit further high marsh development, and are threatened by sea level rise.

The mice move into transitional zones for escape cover during the high tides. Marshes without this zone are usually the marshes that do not have salt marsh harvest mice, as mice without such cover are easily detected by predators (particularly birds). Moreover, the remaining pickleweed dominated tidal salt marshes that support the species are separated by long stretches of bare ground, salt ponds, or brackish marsh. The isolation of populations has contributed to the decline of the species, and could lead to local extinctions.

The ability of restoration actions or a restoration alternative to help with the recovery of the subspecies is dependent upon the ability to: 1) create complete salt marshes, with broad upper marsh plains dominated by pickleweed that grade into peripheral halophyte and upland habitats; 2) create these marshes to connect existing and restored salt marshes within and adjacent to the project area, and 3) create these restored marshes in close proximity to existing marshes that provide suitable salt marsh harvest mouse habitat.

The conceptual model reflects our understanding of how to design the restoration template and implement restoration actions that will lead to the creation of such a complex of marshes. The attached diagram is a graphical depiction of the conceptual model, illustrating how restoration actions can result in contribution to the recovery of the salt marsh harvest mouse. This model could also be viewed from right to left, thus answering the question, "How can the restoration project contribute to the recovery of the South Bay subspecies of the salt marsh harvest mouse?"

The model depicts how Restoration Actions are translated through various Physical Processes into creating a Habitat Structure. The Habitat Structure supports various Ecological Processes that result in a Functional Response by the mouse leading to an Outcome, hopefully achievement of the desired Objective.

Restoration Actions. We can help the species recover by using the concept of connecting existing salt marshes with restored salt marshes to help guide the restoration template. Wherever possible, restoration should be adjacent to existing marshes containing salt marsh harvest mice. Wherever possible the new marshes should be connected to each other and/or to existing marshes either as continuations of those marshes or by broad corridors of appropriate vegetation. This will allow salt marsh harvest mice to colonize newly created marshes, and move between marshes that are now isolated. Additionally, there are a few locations where tidal marsh can be restored in areas that adjoin existing grasslands. Such locations warrant extra consideration, as they are prime areas for restoring the transitional or peripheral halophyte zones so important to the mouse during high tides.

Transitional zones are rare in the South Bay, usually comprising a few feet on the side of a levee. Broader transitional zones can be created as part of the restoration process by using the limited amount of fill or dredged material that may be available. Broad, gently sloping levee side slopes will help create such habitat.

Transitional habitat used as high tide refugia can also be created in the form of natural berms and levees along the larger channels within the marsh. Creating large marshes with complex channel systems provides sufficient drainage area to allow sedimentation to create natural levees along the larger channels. This process can be facilitated by creating starter channels or starter levees in the lower marsh, where natural sedimentation can then create areas suitable for colonization by peripheral halophytes (if the sediment supply is adequate).

Breaching and/or removing artificial outboard levees can restore salt marshes. Since pickleweed occurs only in the higher elevations of tidal marshes, only comparatively small portions of the ponds are at elevations where pickleweed will colonize rapidly. Breaching levees will introduce tides and deposit sediments so that over time, elevations will increase to the point where vegetation can colonize the newly created intertidal mudflats. Eventually, as elevations continue to increase, portions of these marshes will reach the high marsh plain elevations that support pickleweed.

That sedimentation process can be accelerated in certain areas by preserving sections of levees, or creating wind breaks that help trap sediment. However, if sediments are too limited, or if other factors (wind, waves, etc.) keep the sediments from being deposited in certain areas, then tidal marsh will not be created. Broad sections of the areas where tidal action has been restored may remain mudflat, or may reach elevations appropriate for cordgrass, but not pickleweed. Current sedimentation studies should help contribute to our ability to predict these outcomes, and to predict the amount of time it will take to reach elevations that will support pickleweed. Pickleweed-dominated habitat suitable for the harvest mouse can also be created in marshes with muted tidal action, or non-tidal salt marsh where water levels are actively managed to support pickleweed.

The invasive plant species smooth cordgrass (*Spartina alterniflora*), and its hybrids, and shining peppergrass (*Lepidium latifolia*) may exclude pickleweed and other native halophytes, in some areas forming monocultures within the marsh. Because monocultures of these invasives do not provide suitable salt marsh harvest mouse habitat, management of these species may be necessary in some areas to ensure that marshes are colonized by, and dominance maintained by, pickleweed and native peripheral halophytes.

Physical Processes. Breaching of the levees will restore the twice-a-day ebb and flow of the tides through the ponds. The Bay waters bring with them sediments from the Bay, as well as from the existing mudflats, as the increase in tidal action will have a scouring action and re-suspend some of those sediments. These sediments will be re-deposited in the ponds. Vegetation will colonize the marsh plain when enough of the sediment that is carried in suspension has settled out and raised the elevation of the former salt ponds to a level that plants can tolerate. Pickleweed is adapted to certain levels of salt in the water as well as to a certain level of inundation by the tides. It rapidly colonizes such areas by seed. Not until these conditions are met will pickleweed begin to colonize the newly formed marsh plain. If enough sediment is available, sedimentation will also create levees along higher-order (i.e., 4^{th} and 5^{th} order) channels in large marshes, and where starter ditches and levees have been created. In salt marshes, these natural levees will be colonized by pickleweed and peripheral halophytes.

Within the Alviso Complex, there are currently areas that supported salt marsh within the past 30 years, but today support brackish marshes. The combination of treated effluent discharge, sedimentation that has reduced the tidal prism, and freshwater flows from rivers and streams has created conditions too fresh for pickleweed to compete and survive. The extent to which salt marsh harvest mice use brackish marshes in the South Bay, and the importance of brackish marshes to the evolutionary future of the South Bay subspecies, is uncertain. Trapping studies in the North Bay have found the northern subspecies to be more widely dispersed in a greater variety of habitats, including brackish marshes. In contrast, intensive trapping studies conducted in brackish marshes in the South Bay suggest that South Bay mice seldom use brackish marshes, and have documented a decline in harvest mice as salt marshes have been converted to brackish marsh. Whether the southern subspecies may in time adapt to the use of brackish marshes is unknown. However, breaching levees and restoring tidal action to existing ponds will increase the tidal prism, pulling more saline bay waters farther back in the existing sloughs and channels. This will not only create conditions conducive to restoring salt marshes within the boundaries of existing ponds, but will convert some existing brackish marsh to salt marsh.

Habitat Structure. The salt marsh harvest mouse's primary habitat is pickleweed. The mouse requires dense, tall cover, reaching its highest densities where pickleweed is deep and dense at the upper sections of tidal marshes. Broad salt marshes with low edge:interior ratios support higher populations, and suffer lower predation at marsh edges, than narrower bands of marsh. The harvest mouse flourishes where escape cover is available during the highest tides. Such cover is provided in transitional zones vegetated by peripheral halophytes, either on the inboard side of the marsh or on natural levees along the larger channels within the interior of larger marshes. Suitable pickleweed-dominated habitat may also be provided in managed salt marshes, where management of water levels is accomplished actively, and flooding can thus be prevented.

The mouse seldom moves across large bare areas. Thus, a relatively continuous marsh corridor with contiguous marshes is important to allow dispersal and genetic exchange among different regions of the South Bay's tidal salt marshes.

Restoring a continuum of marsh habitat along freshwater inflows (i.e., salt, brackish, and freshwater marsh) may be important to the long-term survival of the South Bay subspecies. The upper edges of brackish and freshwater marshes in the South Bay often contain peripheral halophytes that may be used as dispersal habitat by the salt marsh harvest mouse. The North Bay subspecies is known to use brackish marsh habitat. Though not documented in the South Bay subspecies, this plasticity may be present, or may develop, in South Bay harvest mice as well. Providing a continuum of habitat along the salinity gradient will also reduce the risk of extinction of the South Bay subspecies by allowing for the landward retreat of salt marsh in the face of rising sea levels.

Ecologic Processes. The mouse is largely herbivorous, eating the pickleweed plant as its primary diet. It uses broad transitional zones of peripheral halophytes primarily as high tide refuge and escape cover. During normal high tides, the animal climbs the pickleweed to avoid the high water, but during the highest tides it moves to higher ground, if it is available. Otherwise it is forced to exposed areas or to swim. In those instances, it is easy prey for predators -- as is evidenced by the multitude of egrets, herons, and gulls that often concentrate on levee side slopes during such events.

Functional Responses. Large complete marshes (i.e., those with all three zones) with appropriate high tide refuge and escape cover and connections to other marshes will allow all populations of mice to grow and reproduce and survive seasonal and longer-term fluctuations in climate, vegetation and sea level.

Outcome. As noted above, the ability of the restoration process to help with the recovery of the subspecies is dependent upon the ability of actions and alternatives to: 1) create complete salt marshes, with broad upper marsh plains dominated by pickleweed that grade into peripheral halophyte and upland habitats; 2) create these marshes to connect existing and restored salt marshes within and adjacent to the project area, and 3) create these restored marshes in close proximity to existing marshes that provide suitable salt marsh harvest mouse habitat.