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Using Soil Amendments in Salt Marsh Restoration Along the Southern California Coast

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Background

The warm climate and attractive coastline of southern California has resulted in an increasingly large human population. The natural landscapes of the area have been greatly modified to provide a setting for development. Coastal marshes have flat topography and occur near waterways. These attributes have made them prime sites for this development. Seventy five percent of the southern California coastal wetlands have been destroyed by development (Lonzarich et al. 1992). This area was not large to begin with and now only 31,600 acres of it remain. Changes in the watershed and levels of pollution have altered these remaining areas as well (Lonzarich et al. 1992). These losses have a catastrophic effect on the migratory waterfowl utilizing the area. These habitat losses are especially critical because stopping places for waterfowl are rare in the arid landscape of southern California. In addition, losses and alteration of wetlands have resulted in dissected marshes with barriers to animal movements. Barriers include increased noise levels, buildings, and changes in water circulation and quality. These barriers have hampered the ability of birds to reach alternate resting and feeding sites near tidal wetlands. In addition, barriers are preventing the dispersal of plants (Zedler 1982). Human caused disturbance has occurred for so long and to such a great extent that it is difficult to distinguish natural and unnatural features in coastal marshes. There are no pristine examples of coastal wetlands left in southern California to use as a template to reconstruct marshes (Zedler 1982). Nevertheless, restoration projects have been undertaken. This paper will discuss the use of soil amendments as a restoration technique in southern California salt marshes.

Coastal salt marshes occur in the intertidal zone of moderate to low energy shorelines along estuaries, bays, and tidal rivers. The coastal marshes of southern and central California are very distinct from the marshes found on the Atlantic and Pacific northwest coasts (Lewis 1982). This distinction is due to the seasonally high levels of salinity in the southern and central California estuaries which limits the diversity of intertidal vegetation.

The coastal wetlands of southern California are small and discrete. They are found in narrow river valleys and are separated by mountains and hills. The marshes located within these wetlands have variable characteristics. These variations are due to human caused disturbance and to differences in tidal flushing. The marshes are located on intertidal slopes and the tops of creek banks. Several halophytes, low-growing succulents, and cordgrass can be found within most marshes. Tidal creeks dissect the marshes and run out to larger channels or bays. The wetlands are partially enclosed by sand dunes. Tidal circulation is very critical to these wetlands. Due to low rainfall and low runoff, sea water is the primary source for soil moisture. Longshore currents move sand bars down the coast and can cut off lagoons from ocean circulation. This closure is a natural occurrence but its frequency has been increased by human disturbance. Closure results in increased salinity of the coastal wetland, elevated temperatures, and decreased oxygen (Zedler 1982).

The principal value of southern California's wetlands is providing habitat for the several plant, animal, vertebrate, and invertebrate species that depend entirely on their estuaries. Providing habitat for these species helps to maintain biodiversity in the area. This area supports ten endangered or threatened animal species identified by the California Department of Fish and Game including the California brown pelican (*Pelecanus occidentalis californicus*), light-footed clapper rail (*Rallus longirostris levipes*), California least tern (*Sterna antillarum browni*), and the San Francisco garter snake (*Thamnophis sirtalis tertrataenia*). There are six coastal habitats identified in southern California. Within these six habitats, the California Native Plant Society has recognized 298 species of plants as endangered or threatened (Zedler 1991). Though only six percent of these endangered or threatened species are found in coastal wetlands, these wetlands have only a few species of plants that are considered indigenous. Therefore, these rare plants are important in the diversity of the wetlands (Zedler 1991).

Nitrogen is an important aspect of wetland function. Its availability and supply affects plant biomass, reproduction, productivity and quantity of plant species. Vertebrate and invertebrate animal species are in turn affected by how nitrogen inadequacy alters primary productivity, decomposition, and the food chain hierarchy. Approximately six percent of marsh nitrogen requirement is met by nutrient poor tidal import. Though floodwaters are high in nitrogen content, they are infrequent and move too quickly through the coastal wetland for significant plant uptake of nitrogen (Langis et al. 1991). The remaining nitrogen requirements must then be met by recycling or fixation.

Soil Nutrient Pools

Several studies compare soil nutrient levels of natural and constructed salt marshes. Research at the Tijuana Estuary demonstrated that cordgrass growth is limited by nitrogen. Foliar nitrogen was calculated to be 16% lower in constructed marshes than in natural marshes while phosphorus levels were similar (Zedler et al. 1991). Studies conducted in the San Diego Bay Sweetwater Marsh National Wildlife Refuge compared nutrient levels in a constructed marsh known as the Connector Marsh and the natural marsh at Paradise Creek. These studies demonstrated that the foliar nitrogen in the Connector Marsh was only one-third to one-half of the nitrogen in the Paradise Creek Marsh (Zedler et al. 1991). Further studies in these marshes calculated the amount of nitrogen in soil pore water and sediment. The constructed marsh sediments had one-quarter to one-third the nitrogen of the natural marsh. The pore water from the constructed marsh contained only one-tenth the nitrogen of the natural marsh. Experiments involving the addition of glucose and detritus to marsh soils in the lab determined that nitrogen fixation was limited by low concentrations of soil organic matter (Langis et al. 1991). Furthermore, studies comparing substrate nutrient levels in constructed and natural marshes on the coast of Texas also indicate lower levels of soil organic matter in constructed marshes. Similar studies were done in North Carolina with the same results (Langis et al. 1991).

Soil Amendments

Soil amendments in the form of organic matter and fertilizer have been used to attempt to increase the soil organic matter pool. Only one study performed in southern California has been well documented. The site of this experiment is Marisma de Nacion which was excavated in

1989 from a fill deposit that had been dredged from San Diego Bay in 1969 and deposited along the Sweetwater River. Three to five meters of fill were removed from this 6.9 hectare site to lower the elevation to a level suitable for *Spartina foliosa*. A sinuous channel was excavated between San Diego Bay and the site to allow tidal flows from the bay. Construction was completed in 1990 (Gibson et al. 1994). Comparisons were made to a natural marsh site adjacent to San Diego Bay.

The experimental site consisted of four blocks of land along the sinuous channel. Each block had seven test plots with 1 x 5 meter dimensions. Alfalfa was used as a nitrogen rich amendment and straw as a nitrogen poor amendment. The rate of application was not determined by the amount of nitrogen in the amendment but by the amount of the amendment itself. Ammonium sulfate (N) was used as an inorganic fertilizer. (See Table 1 for application data). Two sites were designated as controls, one rototilled, one not. Site preparation consisted of rototilling to a depth of 15 cm (except for the no till control). *Spartina foliosa* was planted in each plot in March of 1990 (Gibson et al. 1994).

Table 1. Mass of amendments and quantity of nitrogen in that mass.

Treatment	Mass Added (g/m2)	Nitrogen Added (g/m2)
Untilled control	0	0
Tilled control	0	0
N (ammonium sulfate)	105.4	11.2
Straw - N	3000.0	42.0
Straw + N	3000.0	53.2
Alfalfa - N	3000.0	96.0
Alfalfa + N	3000.0	107.2

The results of the study concluded that the aboveground biomass of *Spartina foliosa* responded to amendments in proportion to the amount of nitrogen added. Alfalfa + N had the greatest biomass and the tilled control the lowest (~175 g/m2 vs. ~28 g/m2). The tilled control had a significantly lower dry mass than the untilled, suggesting rototilling inhibits plant growth. Overall, the biomass at the end of each year was less than half the biomass of natural cordgrass marshes (Gibson et al. 1994).

There were no discernible effects of treatments on plant height and foliar nitrogen. This data conflicts with previous studies at the Tijuana Estuary. Gibson et al. (1994) suggest the plants at Marisma de Nacion took up enough nitrogen to stimulate overall growth but not enough to be evident in height or foliar nitrogen analysis (Gibson et al. 1994).

Sediment organic matter content was not affected by treatments nor was pore water. Nineteen months after amendments were added, sediment organic matter levels were only one-fifth of the natural marsh reference site (~4 mg/cm3 vs. ~21 mg/cm3). Pore water nitrogen levels were higher in the constructed marshes, but because there were no significant differences among the treatments, it is unlikely the higher levels were due to amendments (Gibson et al. 1994).

The results indicate that additions of nitrogen stimulate cordgrass growth in salt marshes. Gibson et al. (1994) suggest that repeated applications be administered. However, it is not clear whether application should be in the form of organic matter or inorganic fertilizer since it was never shown that organic amendments increased nitrogen pool levels (Gibson et al. 1994).

Technique

There is little information available on adding organic matter as a soil amendment. Gibson et al. (1994) do not suggest any specific rates of application but rather discuss its appropriateness. Organic matter must be rototilled into the soil. Therefore, additions must be done when sites are dry. This method prevents the amended material from floating away. Rototilling should be avoided when native vegetation has begun to emerge to prevent damage. As Gibson et al. (1994) point out, rototilling may also be detrimental to plant growth based on the Marisma de Nacion results. This method is also extremely expensive. However, adding organic matter benefits macroinvertebrates, improves soil cation exchange capacity, and increases nitrogen fixation. When the addition of organic matter is not feasible, multiple applications of inorganic fertilizer is recommended (Gibson et al. 1994).

Experimental evidence for the effectiveness of inorganic fertilizers is much more complete for the Atlantic Coast than the Pacific Coast. Nevertheless, the findings are considered applicable to Pacific coastal wetlands (Lewis 1982). The recommended rate of application for soluble materials is 100 kg/ha of nitrogen at the time of planting. It should be applied by broadcasting, being placed in a hole next to the planting hole, or placed in the bottom of the planting hole and covered with a layer of soil. Six to eight weeks after planting an additional top dressing of 100 kg/ha of nitrogen may be applied if sites are deficient. Slow release materials can be used in place of soluble. The suggested application rate is 100 kg/ha of nitrogen. No additional application during the growing season should be necessary. If plant cover is not adequate by the beginning of the second season, a 100 kg/ha application of soluble material can be broadcast at low tide (Lewis 1982).

There are problems associated with inorganic fertilizers. Foliage, rich in nutrients as a result of fertilizer application, are a prime target for herbivorous vertebrates and invertebrates (Langis et al. 1994). Also, it has not be proven that inorganic fertilizer will increase nitrogen pools. The sandy substrates often encountered at restoration sites are poor at retaining fertilizer and would benefit more from organic matter applications. Incorporation of organic matter before planting is more effective at supplying nitrogen gradually with decomposition allowing nitrogen fixation processes to develop (Langis et al. 1994).

Conclusion

If a salt marsh fails to achieve functional equivalency with natural salt marshes because of nutrient deficiencies, restoration can not be considered successful. Such a failure occurred with the Connector Marsh of the San Diego Bay project (Gibson et al. 1994). This project's goal was to provide alternative habitat for the light-footed clapper rail (*Rallus longirostris levipes*). However, due to nitrogen deficiency, cord grass (*Spartina foliosa*) failed to achieve a certain height needed by the clapper rails to build a canopy over their floating nests. This inability prevents the rails from hiding from predators. Eight years after the marsh had been created it still did not attract rails due to the lack of appropriate cover.

A review of literature reveals that salt marsh restoration is not feasible if the goal is to achieve function similar to a natural system. Even high mitigation ratios are not adequate to overcome functional losses. Zedler (1991) suggests that if development and the subsequent loss of a marsh is unavoidable, mitigation should be required in advance to insure that a functional replacement can be constructed before the original habitat is destroyed. The lack of success with soil amendments seems to prove that we do not currently have the means or knowledge to restore a functional salt marsh. The literature suggests that the only way to have no net loss of coastal wetlands is to avoid damaging them in the first place.

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