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Creating intertidal habitat for endangered species in southern California: achievements and challenges

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Abstract

Southern California's remaining coastal wetlands (<10% of the historical area) support several rare and endangered species, including one endangered plant (*Cordylanthus maritimus maritimus*) and two endangered birds (a rail, *Rallus longirostris levipes*, and a tern, *Sterna antillarum browni*). Populations of all 3 were jeopardized in 1984 when highway and flood control projects began at San Diego Bay. As mitigation, strict compliance criteria were established and ~12 ha were excavated from dredge spoils to create tidal marsh and channel habitats. The requirement for tern food-chain support was met in 1992 after monitoring fishes for 3 years. The plant reintroduction effort was judged successful in 1995 after 3 years of seeding and then 3 years of monitoring. However, the salt marsh habitat constructed for rails is not yet adequate. Of three standards for the clapper rail (for forage, home range, and nesting), only the first has been met. Even in the 12-year-old marsh, vegetation is still too short to support rail nesting, and high-marsh vegetation is too sparse to serve as a high-tide refuge. Four problems remain: (1) Coarse substrate impairs the marshes (nitrogen supplies are inadequate). (2) Salt accumulates on the high marsh surface and impairs plant growth. (3) Habitat configurations are unnatural and unstable. (4) Buffers are too narrow (habitat for pollinators is rare; human disturbance is common). As a result, the constructed and natural wetlands are not functionally equivalent; the endangered plant may not persist in perpetuity; and the endangered birds may not use the constructed habitats designed for them. The challenge is to create habitats with the appropriate marsh topography, hydrology, and substrate, as none of these problems is easily fixed.

Introduction

Wetland restoration efforts are widespread in California, especially as mitigation to compensate for damage to wetlands affected by dredging or filling operations. Proponents of projects that will damage one wetland often make promises (about replacing habitat) that cannot be fulfilled (Zedler, 1994). Studies of two constructed wetlands and comparisons with natural reference wetlands at San Diego Bay began in 1989 and continue to date. The details of our efforts to restore habitat for three endangered species have been published in a number of outlets. This overview summarizes the status of efforts and leads the reader to appropriate references for more information.

The Connector Marsh and Marisma de Nación were constructed in 1984 and 1990, respectively, to provide habitat for two endangered birds and one endangered plant (see Phinn, Stow and Zedler, 1995, 1996, and Zedler, 1996a for remotely sensed images of the site; see Zedler 1992 for photographs of the site). The total area excavated to provide intertidal wetland habitat is about 12 ha. The work was undertaken by the California Department of Transportation as compensation for damage to wetlands along Interstate Highway 5 during the widening of that road and the construction of a new highway interchange. A third project, the excavation of a large flood control by the US Army Corps of Engineers, led to further mitigation requirements.

The mitigation agreement (see Zedler 1991, 1996b) required that foraging habitat be provided for the endangered California least tern *(Sterna antillarum browni)*, that a population of an endangered plant (the salt marsh bird's-beak *[Cordylanthus maritimus maritimus])* be reestablished and that home ranges for up to 7 pairs of the endangered light-footed clapper rail *(Rallus longirostris levipes)* be provided.

Results and Discussion

Mitigation criteria have been satisfied for the California least tern and the salt marsh bird's-beak. However, not all of the standards for light-footed clapper rails have been met. This rail requires low marsh vegetation for nesting and high marsh vegetation for cover during high tides. These marsh types are limited both in their extent and the quality of their canopies; hence, the site falls short of achieving the criteria for mitigation compliance.

A larger question is whether the constructed marshes match the functions of natural wetlands. From an ecosystem-functioning perspective, there are many differences between the constructed and natural wetlands, even where standards have been met (e.g., fish habitat types, bird's-beak population dynamics). These differences lead to suggestions for future restoration designs and mitigation criteria that emphasize functional equivalency with natural wetlands.

Constructed channels as foraging habitat for the California least tern

The California least tern is a migratory species that nests near the construction site and feeds on small fishes in nearby subtidal areas. Criteria for mitigation compliance were that channels provide 75% of the native fish species and 75% of the density in natural marsh channels.

Fishes rapidly occupied constructed channels, and density and species lists met or exceeded the established criteria within three years of monitoring (see data summarized by G.D. Williams in Haltiner *et al.*, 1997). Most species, with the exception of striped mullet (*Mugil cephalus*) and Northern anchovy (*Engraulis mordax*), occurred in both natural and constructed channels. Differences in numbers of species or total fish density were not detectable by channel status (constructed versus natural), but there were interannual differences (although no directional trends).

The proportion of two species differed for natural and constructed sites: Longjaw mudsuckers *(Gillichthys mirabilis)* were relatively more abundant in natural reference channels (43% of total) than in samples from constructed channels (16%), and the California killifish (*Fundulus parvipinnis)* comprised more of the catch in constructed marsh channels (36% of total) than in natural channels (14%). The long-term sampling data show that the composition of fish assemblages is related to particular physical parameters of channel habitats, rather than their natural vs constructed status (G.D. Williams, pers. comm. 1996). Mudsuckers predominate in the more narrow, steep-banked channels with high clay sediments, elevated salinities, and low dissolved oxygen levels. Killifish dominate samples from broad and shallow channels with low slopes, fringed by emergent vegetation. Samples in which topsmelt predominate are generally from broad, deep channels (mean depth 1.2 m).

The distribution of habitat types differs for constructed and natural wetlands. Small tidal creeks were not constructed in either mitigation site, and the constructed channels tended to be wider and deeper than the channels selected as reference systems. Channel morphometry, proximity and type of channel vegetation, channel location (dead-end or flow-through connector), flow rate, and sediment type are all known to influence the species and abundance of fishes (e.g., Baltz, Rakocinski and Fleeger, 1993; McIvor and Odum, 1988). The absence of small creeks is likely to reduce potential for fish nursery functions (Julie Desmond, 1996).

Although the criteria established for mitigation have been met, the mitigation site may not be functionally equivalent to natural wetlands (Zedler, 1996c). Mitigation criteria required only that fishes be present in constructed wetland channels; it is not clear that the endangered tern makes use of fishes in these channels, that fishes benefit from constructed channels, or that these fishes move to the deeper waters where terns have been seen feeding. To assess overall effectiveness of fish-habitat mitigation efforts, a larger view and more extensive monitoring program would be needed. However, these are beyond the scope of the mitigation agreement.

High marsh to support an endangered plant and to provide a high-tide refuge for light-footed clapper rails

The high intertidal marsh of natural wetlands has some ten species of native perennial plants, and a few native annuals. The endangered salt marsh bird's-beak is a hemiparasitic annual plant that grows best with a perennial host. Grass species are favored hosts (see Fink and Zedler, 1989; Parsons and Zedler, 1997; and Zedler, 1996b). The light-footed clapper rail has somewhat different high-marsh requirements. The rails move up from the low marsh during the year's highest spring tides, seeking cover and protection from predators. Tall dense shrubs provide the best protection, and of the high marsh species, a bushy succulent, *Salicornia subterminalis = Arthrocnemum subterminale,* offers the best hiding places. This plant can host bird's-beak, but it is less effective than the native grasses (Fink and Zedler, 1989).

The mitigation criteria were that a population of bird's-beak be reestablished to Sweetwater Marsh, with at least 5 colonies, each with at least 100 plants persisting for three years. Seeds were collected from nearby Tijuana Estuary and sown to a natural marsh remnant, after an attempt to establish the species in one of the constructed marsh islands indicated low rates of establishment and low seed production (as an annual plant, seed production is critical). Reestablishment within the natural marsh was judged successful in 1995, when the population had remained high for 3 successive years. Total counts of plants numbered about 5,700 in 1993, and about 14,000 in both 1994 and 1995. The counts greatly exceeded standards set forth in the mitigation agreement.

In 1996, however, there was below-average rainfall, and the population dropped below 2,000 plants. It stayed low in 1997, and the prognosis for 1998 is uncertain. Seeds do remain viable and a seed bank can lead to population recovery. However, Parsons and Zedler (1997) found evidence that both pollinators and nitrogen inputs were potentially limiting to the bird's-beak population, and we called attention to the lack of understanding of how canopy gaps form and control seed germination and seedling establishment. Clearly, the verdict is still out on whether a self-sustaining population has been established at San Diego Bay. Short-term population expansion may not guarantee long-term persistence.

The mitigation criteria further state that at least 15% of each clapper rail home range must support high marsh vegetation. Attempts to establish high marsh vegetation in the constructed wetlands have not been wholly successful. Several critical areas have insufficient high marsh to meet home range criteria (PERL 1995). Several problems have been noted: Along Connector Marsh, higher marsh is eroding next to deep, steep-edged channel (bank undercutting; Haltiner *et al.*, 1997). Also, the soils, which are dredge spoils from San Diego Bay, are very coarse in texture. In addition, the ground water is hypersaline, and salt crusts have formed in the constructed wetlands, especially the tops of islands within the Connector Marsh.

We do not understand the dynamics of surface soil salinities in high-marsh areas. The bare areas of the constructed islands have soil salinities up to three times the salt content of sea water (PERL, 1995). These salt levels prevent seed germination and inhibit establishment of seedlings (Kuhn and Zedler, 1997). Thus, an area that develops a salt crust is likely to remain bare. Irrigation during periods of low tidal amplitude might help to reduce salinities, but the amount of water needed may be prohibitive. Even with the high rainfall of winter 94-95, soil salinities declined only briefly. At the end of the 1995 growing season (September), high-marsh soils were two to three times more saline than in March 1995 (PERL, 1995).

The key to controlling salt crusts may be via prevention. If vegetation can reduce salt concentration through shading, it is important to establish dense canopies soon after habitat construction. Irrigation may help establish seedlings. Once established, native halophytes can withstand considerable hypersalinity. For example, the highest soil salinities found during our annual monitoring in September 1995 were along a high marsh transect with very high vegetative cover (1% open space; PERL, 1995).

The interaction between salt crusts, hypersaline groundwater, and high-marsh plant growth needs to be understood. Plants may either concentrate salts in the soil profile, by preventing salt uptake at the root surface, or dilute salts by taking them up and depositing them on the soil surface. Rooting depths need to be determined, along with the role of roots in concentrating salts. In addition, the physical processes need to be determined, so that we know whether the shape of the habitats affects salt concentration. Domed islands may be more susceptible to salt crust formation than flat or gently sloping marsh plains.

Low marsh to support tall cordgrass for clapper rail nesting

Clapper rails require forage as well as cover and nesting sites within their home ranges. Early on it was determined that their preferred prey (crabs) were more abundant within the constructed marsh, despite the fact that invertebrates overall were less abundant than in the natural marsh reference site (Scatolini and Zedler, 1996). Forage does not appear to be the problem that keeps clapper rails from nesting in the constructed marshes. The vegetation is a more likely limiting factor.

Cordgrass (*Spartina foliosa*) is shorter in the constructed marshes than in natural coastal wetlands. Where clapper rails nest in natural marsh canopies, there are ≥90 stems per square meter that are taller than 60 cm, of which ≥30 stems are taller than 90 cm. The cordgrass canopy in Connector Marsh has consistently been shorter (Zedler 1993). It is not surprising that the constructed marshes have not yet supported nesting by the endangered light-footed clapper rail. Short cordgrass has also been linked to scale insect outbreaks in the constructed marshes of San Diego Bay (Boyer and Zedler, 1996). Part of the cause may be the paucity of the scale insect's major predator (a coccinellid beetle), which appears to need tall cordgrass to escape high tides. The tall cordgrass canopy of the adjacent natural marsh (PC), has many beetles and very few scale insects; where scale insects are abundant, canopies grow less and senesce early (Boyer and Zedler, 1996).

The poor cordgrass growth in San Diego Bay constructed marshes is explained by low levels of nitrogen in the soil (Langis, Zalejko and Zedler ,1991). Nitrogen concentrations are low in part because decomposition and leaching rates are both high in the site's sandy soil. Cordgrass is nitrogen limited, with both foliar nitrogen concentrations and biomass increasing following urea additions (Covin and Zedler, 1988; Zedler, Nordby and Kus, 1992; Boyer and Zedler, in review). However, fertilization with nitrogen has not solved the problem. Cordgrass at Connector Marsh met Zedler's (1993) canopy height criteria after several different experimental fertilization regimes in 1993, but effects were not sustained unless amendments continued year after year (Boyer and Zedler, in review). Further, when three large areas (300–400 m^2) were fertilized in 1995, only one met the canopy height criteria by August 1995 (PERL, 1995). Cordgrass in the other two areas appeared to be in competition with other species (salt wort, *Batis maritima* and annual pickleweed (*Salicornia bigelovii*), which may have limited the success of the cordgrass.

Long-term sampling of sediments in the Connector Marsh indicate slow accumulation of organic matter pools. Sediment organic matter levels increase ~0.5% per year on average. Sediment organic matter in Connector Marsh averages less than 75% of that in the adjacent natural marsh. Despite improvement in the sediment organic matter pool, the constructed marsh soil has not accumulated nitrogen, and total Kjeldahl nitrogen (TKN) levels have remained very close to 1 mg N/g since 1988. Sediment TKN concentrations in the Connector

Marsh have been about 50% of the levels in the adjacent natural marsh over the entire study period.

Nitrogen additions can increase cordgrass canopy heights in the constructed marshes, but one addition is insufficient (Gibson, Zedler and Langis, 1994), and even with multiple additions, the vegetation fails to retain nitrogen from year to year (Boyer and Zedler, in review). Fertilization experiments in 1993 and 1994, did not increase soil nitrogen. Belowground tissue N was evaluated in a 1995 experiment using the same fertilization regime, and the belowground crop of N was equivalent for constructed and reference marshes (PERL, unpublished data). The results of the two experiments suggest that amendments improve N storage in belowground tissues in the constructed marsh, but that these stores are not adequate to match plant growth in natural marshes or to sustain growth.

The accumulation of both soil organic matter and soil nitrogen are likely limited by the coarse sediment. Only with accretion of finer surface sediments will the constructed marsh show substantial improvement in nutrient supply. However, accretion of sediments can have a negative impact on cordgrass by shifting dominance to pickleweed, a species that is less tolerant of tidal inundation. Accretion of just 10-20 cm of sediment can shift the low marsh to a mid-marsh plain.

The Connector Marsh is accreting sediment in several locations near the eastern channel and some islands are merging as sediments fill in the channels between them (Haltiner *et al.*, 1997). One nearly pure cordgrass area is becoming dominated by salt wort (*Batis maritima*) and annual pickleweed (*Salicornia bigelovii*), following sediment accretion. While sediment deposition is desirable for improving nutrient functions, it is detrimental to cordgrass persistence. No simple solution is obvious.

Conclusions

Fish for endangered terns

It appears to be relatively easy to construct habitat for fishes, which colonize inundated areas rapidly; it is less easy to document how fish use those habitats and whether there is a benefit to endangered terns. The functioning of aquatic habitats will more nearly match that of natural wetlands if complex tidal creek networks are provided. Adding small tidal creeks may well enhance the site's ability to support reproduction and nurseries for shallow-water fishes, such as the California killifish.

To assess the value of the constructed fish habitat for endangered terns would require two additional studies. First, it should be determined that fishes feed and grow in constructed channels, not simply occur there, and second, that such fishes are consumed by the California least tern.

High marsh for an endangered plant and cover for an endangered bird

A population of the endangered hemiparasitic annual plant was introduced to San Diego Bay, and it prospered for the required 3-year period. Mitigation criteria were met. However, the population crashed during the fourth year, which had about half the average rainfall. Annual plants are subject to several constraints, including soil moisture, hypersalinity, availability of canopy openings, visitation by pollinators and influxes of nitrogen. Short-term success of reestablished species does not ensure long-term persistence. A broader view is needed, because the high marsh ecosystem is dependent on linkages with the watershed (nitrogen delivery) and adjacent uplands (pollinators, small mammals to create bare patches in the high salt marsh). Management for biodiversity within coastal wetlands requires maintenance of linkages with watersheds and adjacent uplands.

It has proven difficult to establish sufficient high marsh vegetation to meet the needs of the endangered clapper rail. Plant cover is limited by hypersaline soils, and the sparse vegetation does not provide a suitable high-tide refuge for birds. It is not clear whether soil hypersalinity is reversible or whether it needs to be prevented from developing. Early establishment of high marsh vegetation in constructed marshes appears to be very important, because seeds and seedlings have low tolerance for high salinity. Salt crusts may develop more readily on substrates lacking plant cover. Dome-shaped islands may favor salt crust formation, and other configurations, more like those of natural marshes, are recommended. Research is underway to explore the conditions that affect salt crust formation.

Low marsh for nesting by an endangered bird

Vegetation can be established, but the canopy architecture may not be suitable for nesting by the light-footed clapper rail (Zedler and Powell, 1993). Coarse soils and low soil nitrogen are limiting to plant height growth, as are outbreaks of scale insects (Boyer and Zedler, 1996). It is unrealistic to expect that a site with sandy soils will achieve functional equivalency with natural marshes having clayey soils. Fine-textured substrate and organic top soil should be salvaged from any sites that will be damaged by construction activities; it should be stockpiled and reused in the restoration or mitigation site.

Large areas of homogeneous low-marsh habitat can be constructed but should not be expected to persist, because marsh plains tend to reach an equilibrium at a mid-marsh elevation, which is too high for dominance by cordgrass *(Spartina foliosa)*. As constructed marshes accrete and shift community types, it may be better to shift expectations than to try to fight the site's dynamic hydrology. An adaptive management program is thus appropriate.

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