Salt Marsh Restoration

Coastal Habitat Enhancement

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written by
B.J. Copeland
Department of Zoology
N.C. State University
Raleigh, NC 27695

edited/designed by
Carla Burgess

cover photo by
Scott D. Taylor

This report is a summary of research conducted by many people during the past 30 years. The basis of the content was a workshop March 25-26, 1997, in Raleigh, N.C., attended by: Steve Broome, N.C. State University; Leon Cammen, National Sea Grant College Program; Carolyn Currin, National Marine Fisheries Service; Garry Mayer, NOAA Restoration Center, NMFS; Thomas Minello, National Marine Fisheries Center; Hans Paerl, University of North Carolina Institute of Marine Sciences; Preston Pate, N.C. Division of Coastal Management and N.C. Division of Marine Fisheries; Ronald Rozsa, Connecticut Division of Environmental Protection; and Charles Simenstad, University of Washington.

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Restored salt marsh (Photo courtesy of Steve Broome)

INTRODUCTION

Salt marshes appear on all coasts of the United States around such protected low-energy areas as estuaries, lagoons, bays and river mouths. Where there is enough runoff, they transition into brackish and freshwater marshes. Because of the tremendous volume of emergent vascular plants and subsurface plant matter, marshes are regarded among the most productive ecosystems (Teal 1962; Keefe 1972; Tiner 1984).

The fundamental character and function of tidal salt marshes are described in *Tidal Salt Marshes of the Southeast Atlantic Coast: A Community Profile* (Wiegert and Freeman 1990), published by the U.S. Fish and Wildlife Service. The short summary that follows should provide sufficient basis for understanding the elements of restoration.

Although tidal salt marshes exist on the transition zone between the land and the sea, the biogeochemical processes in a marsh more closely resemble those of aquatic systems than terrestrial ones. This ecosystem is intimately connected to the sea, its estuaries and tributaries through tidal cycles. Salt marshes are inundated by salty to brackish water and drained regularly (Figures 1, 2 and 3). Water is the active medium for circulation of organic and inorganic nutrients throughout the salt marsh; it is also the medium in which most organisms live (including the terrestrial-type plants). Sediments are characteristic of aquatic ecosystems and are chemically reduced and anaerobic. Cordgrasses (*Spartina* spp.) are the dominant plants of salt marshes. The rate of succession in a salt marsh depends on how much it is protected from the brunt of a high-energy coast. To thrive and undergo successful development, the marsh also must receive at least occasional inputs of fresh water; if salinity of the water and sediment becomes too high, plants will begin to die.

The abundance of plant material produced each year is the reason for the productivity of salt marshes and their status in coastal ecosystems. Only a small percentage of marsh grasses is directly consumed or "grazed"; most is decomposed by bacteria, producing an organic "soup" that feeds such organisms as amphipods, shrimp, crabs, snails, shellfish and some small fishes. These organisms in turn support a broad food chain that includes a variety of shellfish and finfish populations. The physical exchange of water moves both the organic soup *and* small organisms between the salt marsh and adjacent coastal waters. So the water exchange maintains the productivity of the salt marsh as well as allows the inhabitants of the coastal ecosystem to access it.

Geographic Distribution

The extent of salt marsh coverage varies from one region to another. The steep, high-energy shores of the Pacific Coast, for example, support smaller areas of marsh (Zedler 1996) than other coasts (Table 1). Marshes also differ in plant composition and development. The dominant vegetation is smooth cordgrass (*Spartina alterniflora*) along Gulf and Atlantic coasts, pickleweed (*Salicornia virginica*) and Pacific cordgrass (*Spartina foliosa*) on the Pacific coast, especially in California; and sedge (*Carex lyngbyei*) and seaside arrowgrass (*Troglochin maritima*) in the Pacific Northwest (Woodhouse 1979; Matthews and Minello 1994). Salt marshes on the Gulf Coast sometimes grow right next to the seashore, but on the Atlantic and Pacific coasts, they usually grow on sediment deposits behind protective barrier islands.

Vegetation of West Coast marshes is less uniform than on the East Coast, probably because of the large variation in salinity and irregularity of flooding (Zedler 1996). For example, in eastern marshes, grasses are the same height; West Coast marshes show more variation in plant size. To gain a successful foothold, West Coast marshes must be protected from waves and sloped so that evaporation is minimal.

Loss and Impairment of Function

Salt marshes—and the wetland habitats of which they are part—have disappeared at an alarming rate during the past century, accompanying an increase in population and coastal development (Littlehales and Niering 1991). But because of growing public awareness of the value of coastal wetlands and the establishment of more stringent regulations, losses have declined in recent years. Estimated losses are about 8,000 hectares per year during the 1920s to 1950s, 19,000 hectares per year during the 1950s to 1970s, and 3,000 hectares per year during the 1970s through the 1980s (Mitsch and Gosselink 1993). Salt marsh losses usually can be attributed to the following physical stresses.

Table 1

Salt Marsh Areas in the United States by Region (Zedler 1996)

Region	Acres
• Atlantic	1,651,900
North Atlantic	68,100
Middle Atlantic	689,600
South Atlantic	894,200
• Gulf of Mexico	2,496,600
• Pacific	121,900
Washington	18,300
Oregon	13,200
California	90,900
Total for Nation	4,270,300

Photo by Scott D. Taylor

DREDGING. The demands of water transportation gave rise to the practice of dredging navigational channels and canals through coastal marshes. Excavation of deep channels and disposal of spoil remove substrate, raising the ground above sea level or submerging vegetation. The salt marsh productivity is reduced or eliminated.

FILLING. Often coastal wetlands have been filled to raise the ground above sea level for building. Along many stretches of coastline, developers place fill in salt marshes to support roadbeds. This eliminates or impairs the salt marsh ecosystem by smothering vegetation, raising the substrate above the level for seawater inundation or inhibiting water circulation.

DIKES AND DIVERSION. In many areas, dikes are built across drainage areas or freshwater diverted to prevent flooding or provide freshwater for irrigation and domestic consumption. The interruption of water flow changes sediment deposition rates, increases salt concentration in the substrate, and decreases nutrient cycling in the marsh ecosystem. Desirable marsh species such as cordgrasses decline in favor of less productive assemblages of vegetation. In most cases, these changes reduce dramatically the productivity and use of marshes.

DITCHING. Construction of ditches to increase drainage rates has been a primary method of mosquito control in many coastal areas (Figure 4). Although ditching does not necessarily destroy salt marshes, it reduces abundance of certain plants and affects movement of animals.

FLOOD CONTROL. Where coastal flooding is a problem, managers install tidal gates in some salt marsh

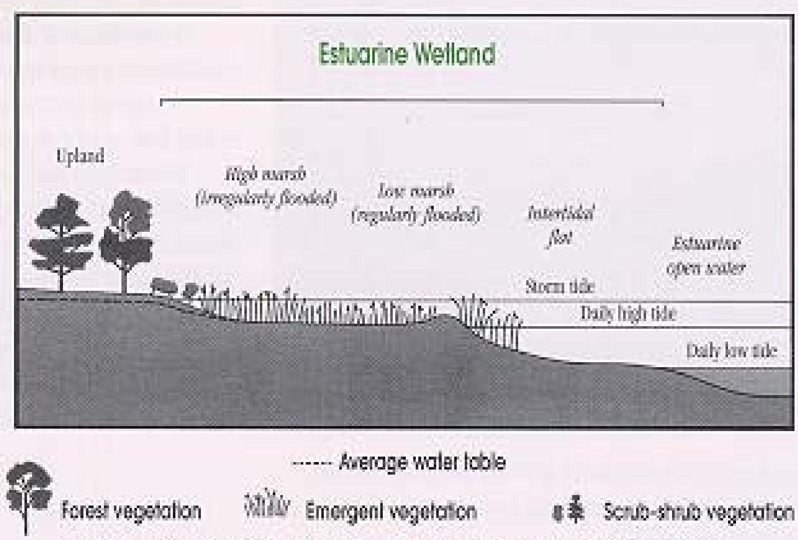


Figure 1. Cross-sectional diagram of coastal North Carolina wetland (Illustration from Bales and Newcomb 1996)

drainage systems. This is prevalent in the Northeast. Prevention of saltwater inflow reduces soil salinity and soil moisture, resulting in the replacement of native vegetation with less desirable plants. In many cases, it has decreased biodiversity and created fire hazards.

Figure 2. Much of what is understood about the feasibility of breached-dike estuarine wetland restoration has been learned by examining naturally breached sites like this one in Willapa Bay, Washington. (Photo by C. Simenstad)

Why Restoration?

Because salt marshes are of paramount ecological importance, a host of restoration technologies is emerging (Matthews and Minello 1994; Broome and Craft 1998). Depending on the goals to be met, multiple reasons exist for restoration, creation and enhancement of salt marshes:

- stabilization of dredged material
- restoration or creation of habitat
- shoreline erosion control
- mitigation to compensate for destruction or impacts on natural salt marshes
- restoration of disturbed or altered conditions to a previous condition
- removal of structures or other restrictions to tidal flow, animal movement or protection

Researchers have successfully applied new technologies to restore and create salt marshes (Kusler and Kentula 1990; Thayer 1992; Matthews and Minello 1994; Dreyer and Niering 1995; Zedler 1996; Broome and Craft 1998). Increased understanding of the role of salt marshes has driven the implementation of restoration and creation methods. A series of regulatory tools has been developed to enable local governments to protect, conserve and restore wetlands (Environmental Law Institute 1997).

The goal of this publication is to synthesize the findings and experience gained from salt marsh restoration and creation projects during the past 30 years and provide guidance for future efforts. Look for specific details in the reports and documents arising from individual site projects (Thayer 1992 and Matthews and Minello 1994 list reports and key participants).

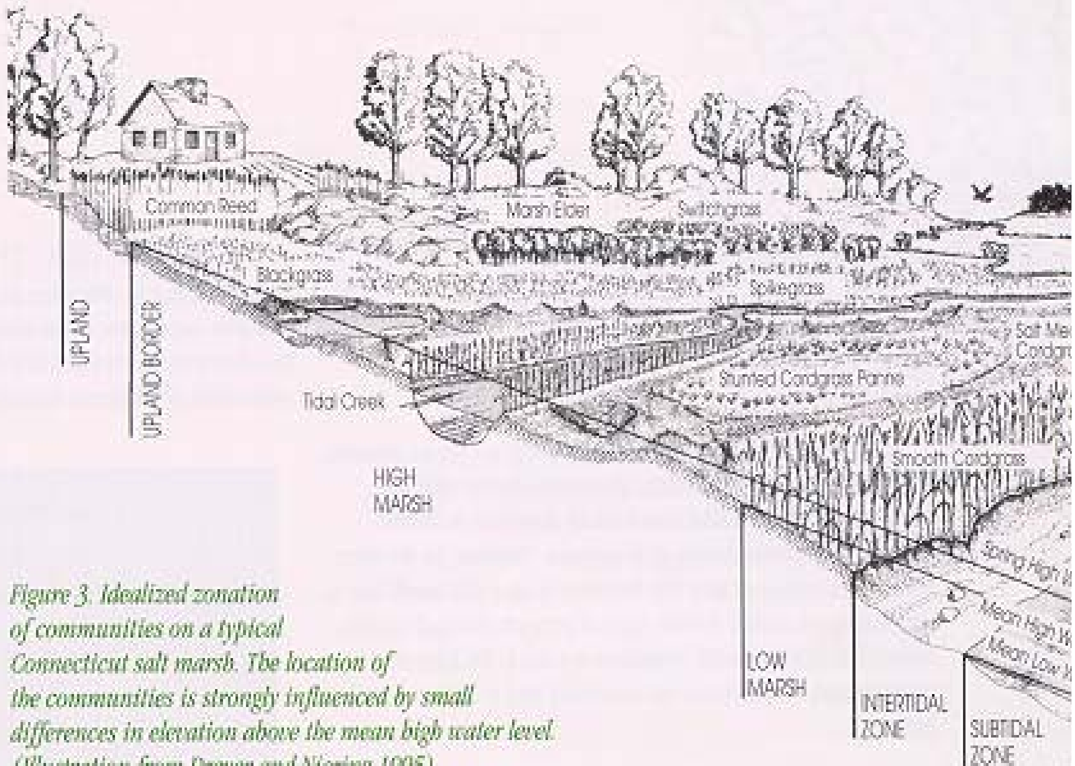


Figure 3. Idealized zonation of communities on a typical Connecticut salt marsh. The location of the communities is strongly influenced by small differences in elevation above the mean high water level. (Illustration from Dreyer and Niering 1995)

Figure 4. The extent of mosquito ditching is best seen in aerial photographs. (Photo from Dreyer and Niering 1995)

RESTORATION AND CREATION OF SALT MARSHES

The principals should establish specific goals before initiating a restoration or creation project. Restoration means applying technology to return a tidal area from its disturbed or altered condition to a previous ecological purpose. Creation, on the other hand, is converting an area that has never been a salt marsh into a functioning salt marsh. In both types of projects, the goal is often to establish or re-establish vegetation at a site in the hope that natural stages of succession will eventually lead to full ecological function.

Methods

Salt marsh restoration techniques range from simple removal of an obstruction so that nature can take its course (Peck et al. 1994; Dreyer and Niering 1995) to complex placement of vegetation and establishment of transport systems so that ecological function will develop (Broome 1990; Zedler 1996; Broome and Craft 1998). Many different types of restoration are used.

RESTORATION OF TIDAL FLOW. Alteration of marshes due to restriction of tidal flow or impoundment is a common occurrence in the northeastern United States. Removal of the obstruction so normal tidal flux can resume allows natural restoration of salt marsh ecological systems.

Tidal salt marsh, North Carolina coast (Photo by Scott D. Taylor)

REMOVAL OF FILL. Sometimes natural salt marshes are altered or destroyed because they have been covered with fill from construction and/or dredging. If the fill is removed and the substrate restored to its previous elevation, marsh plants will return. Unless supplemented with transplants, re-establishment will probably require several years.

REMOVAL OF CREEK OBSTRUCTIONS. Where saltwater intrusion interferes with upland uses such as agriculture, the creeks through a marsh may have been plugged. Removal of the plugs can restore tidal flux, which may lead to natural recovery of the salt marsh's ecological functioning.

DIVERSION OF STORMWATER FLOWS. In some places, stormwater runoff has been diverted to marshes. Large volumes of such drainage can dilute the salt water so much that *Phragmites* and other salt-intolerant plants replace the salt marsh vegetation. Sometimes, diverting or dispersing the stormwater runoff will lead to recolonization by salt-loving species such as cordgrass.

RESTORATION OF SEDIMENT SUPPLY. Because of rising sea level, a steady supply of sediment to the marsh is needed for long-term maintenance. When natural drainage is interrupted, the marsh may become sediment-starved. Eventually, the marsh system may become inundated. Renewal of sediment supplies can, over the long haul, result in some marsh restoration by providing substrate for natural invasion of salt marsh plants.

Students monitor vegetation changes at a tidal wetland restoration site in Washington. (Photo by C. Simenstad)

TRANSPLANTATION OF MARSH PLANTS. The rate of marsh restoration can be increased significantly by new plantings of salt marsh vegetation. This process requires careful site selection, preparation and transplanting. While one can "create" marsh vegetation that grows well, questions remain over when and how a transplanted salt marsh begins to *function* as a coastal habitat.

Site Selection

Site selection may be the most important step in restoring a tidal marsh. If the site is chosen properly and prepared adequately, the marsh will likely be restored successfully and contain critical habitat. Sites that once supported a functional tidal marsh system are the most likely candidates for successful restoration. Often tidal marshes are compromised by the presence or absence of a critical ingredient (e.g., tidal flows, sediment supply, fill, blockage). In those cases, adding or removing the proper component can lead to natural recolonization and tidal marsh restoration (Matthews and Minello 1994; Dreyer and Niering 1995; Simenstad and Thom 1996; Environmental Law Institute 1997). It is important to recognize, however, that some sites have been physically altered beyond recovery. Salt marsh creation, especially when attempted for mitigation or erosion-control purposes, often involves the use of sites that have never supported tidal marshes.

A net trap samples juvenile Pacific salmon emigrating from a restored wetland in Oregon. (Photo by C. Simenstad)

When projects are planned, the following considerations are important:

HYDROLOGY. Hydrology is the dominant factor that determines zonation of plant species and other wetland characteristics. To be successful, a site must have enough tidal flux to alternately flood and drain the marsh. Elevation, slope and tidal regime are the primary influences on hydrology. All of these factors determine the areal extent of the intertidal zone, which must be large enough to support a tidal marsh ecosystem.

ELEVATION. Plants in a restoration project need the proper elevation. One can learn the correct requirements by observing the upper and lower elevations of the dominant plants in a functioning marsh nearby.

SLOPE. If the area is too flat or irregular, the salinity of soil water can interfere with plant production. A gentle slope of 1 to 3 percent maximizes the intertidal area, dissipates wave energy over a large area and provides conditions that support tidal marsh plants.

TIDAL REGIME. Tidal amplitude and frequency of tidal inundation determine the area of the intertidal zone that supports the proper emergent plants and proper zonation. Adequate tidal flux is necessary for the import and export of sediments, nutrients and organic matter.

DRAINAGE CHANNELS. Large restoration sites must include creeks and channels to allow good drainage and adequate tidal exchange. These waterways also provide means for fish and other animals to travel through the marsh, as well as ensure that sediments, nutrients and organic matter are mixed between the marsh and the open estuary.

WAVE CLIMATE. Exposure to waves can be a limiting

Salt marsh restored to control shoreline erosion, North Carolina coast (Photo courtesy of Steve Broome) factor in establishing tidal marsh vegetation. The orientation of the shoreline to the waves and amount of fetch—the distance the wind blows over water—can influence the success of establishment. Before plants have produced a significant root system, they are vulnerable to being dislodged by wave activity. Offshore breakwaters can ameliorate wave action where alternative site choices are not available.

SOIL PHYSICS AND CHEMISTRY. Physical and chemical properties of soils influence establishment of plants and their development. Sandy soils are more easily manipulated for planting, but have less capacity to hold nutrients. It may be necessary to apply fertilizer and organic matter or to facilitate the transport of organic matter by increasing tidal exchange.

SALINITY. The salt content of the soil and water determines what plant species can thrive at a site. If the salinity is too high (i.e., tidewater trapped in depressions evaporates, leaving a high concentration of salt in soil water) or too low (i.e., saltwater is diluted by too much freshwater), monoculture of tidal marsh plants likely will fail.

Sampling for insects at breached-dike marsh, Oregon (Photo by C. Simenstad)

SEDIMENT SOURCE. Sediment accumulation is fundamental to development and maintenance of tidal marshes. But too much sediment can be detrimental. The successful site will have a balanced supply of sediments.

PROTECTION. During the early stages of planting, the site must be protected from pedestrian or vehicle traffic, foraging by birds and rodents, excessive shade and contaminants.

Given the appropriate site and adequate time, natural colonization will produce a tidal marsh consisting of native vegetation and animals. However, if faster restoration is necessary, one can transplant vegetation to speed up the process. In this case, choosing the right plants is as important as proper site selection. Plants must be compatible with the site's characteristics, primarily tidal exchange and salinity. The species most commonly planted in the intertidal zone of tidal marshes are *Spartina alterniflora* along the Atlantic and Gulf coasts (Broome and Craft 1998), *Spartina foliosa* in California (Zedler 1996) and *Carex lyngbyei* in the Pacific Northwest (Simenstad and Thom 1996). *Spartina patens*, *Spartina cynosuroides* or *Juncus roemerianus* may also be used, depending on tidal exchange and salinity.

Mechanical planting of salt marsh plants (Photo courtesy of Steve Broome)

Site Preparation

The success of salt marsh restoration also depends largely on proper preparation of the site. In the Northeast and Northwest, for example, where restoration involves returning a certain function (e.g., tidal flux, proper drainage, removal of barriers), site preparation requires little more than restoring that function. Rozsa (1995) developed a "Restoration Rules-of-Thumb" for Connecticut with application for the Northeast:

- Salt marsh plants will replace *Phragmites* in five to 10 years if regular tidal flushing with saltwater (over 18 parts per thousand) is established.

Tidal salt marsh, North Carolina (Photo by Scott D. Taylor)

- Salt marsh plants regenerate on their own if a nearby salt marsh supplies seed, making expensive planting or transplanting unnecessary.
- It is not always desirable to restore original tidal volumes at sites, especially in the case of subsided wetlands.
- Marsh restoration will reduce or eliminate mosquito breeding in subsided marshes.
- Marsh restoration renews scenic vistas.

When it is necessary to establish new vegetation, one must painstakingly prepare the site to increase the chances of success. Extensive preparation and protection is doubly necessary where erosion-control is the goal.

Because tidal flux, frequency of flooding and slope generally determine the area of the intertidal zone, these factors must be effectively accommodated. One can discover the requirements by comparing the new site with a natural marsh nearby, paying attention to the upper and lower elevation limits of dominant plant species. A surveyor's level is helpful in achieving the desired elevations, as is marking the planting site with stakes when the tide level reaches critical limits. A gentle slope of 1 to 3 percent seems to maximize the intertidal area and dissipate the wave energy over a greater area to minimize erosion (Broome and Craft 1998).

Depending on the degree of tidal inundation and erosion control needed, one can achieve the desired slope by grading the site. Slopes that are too flat or irregular may drain poorly; the result may be ponding, which can spike salinity as water evaporates, or waterlogging. Most desirable marsh plants are not adapted to either of these conditions, so poor drainage will impair tidal flux and kill plants. In areas of significant marsh subsidence, mainly the Northeast, restoration teams may need to install a series of structures that allow more water to leave the marsh on low tide than enters the marsh on high tide. This will foster the drainage required to grow desirable salt marsh plants.

Tidal amplitude and frequency of flooding will determine the width of the intertidal zone that will support emergent vegetation and a healthy zone of plant species. These characteristics are also basic to the required import and export of sediment, nutrients and organic matter typical of the salt marsh ecosystem. It is harder to establish salt marsh vegetation where the tidal amplitude is narrow. In this case, more precise determination of the elevation to be planted is required. Besides, exposed shorelines are less resistant to erosion damage than areas where wide fringes of vegetation exist.

In many places along Northeast shores, salt marshes have been altered due to disrupted tidal flow and the subsequent decomposition of the exposed peat bottom (Rozsa 1995). To remedy the problem, one must carefully balance the renewal of

Tidal salt marsh, North Carolina (Photo by Scott D. Taylor) tidal flux with elevation of the marsh surface, which usually means supplying less tidal flow than was originally present. Applying backfill may also be necessary to compensate for the subsidence. Restoration of tidal flow most always removes or suppresses *Phragmites*, which cannot tolerate salinity levels above 18 parts per thousand. However, accumulation of freshwater runoff will negate the tidal influence unless drainage is accommodated.

To prepare large sites for restoration, one needs to construct or rehabilitate drainage canals or creeks. These pathways promote good drainage, better tidal exchange, optimum utilization of the marsh by fish and other organisms, and increased exchange of sediments, nutrients and organic matter between the marsh and estuary. One can cut channels to the proper grade or reopen existing creeks. Because fish feed primarily at the edges of channels, it is important to create meandering channels to increase the amount of edge and access to the marsh (Minello et al. 1994).

Salinity of the water above and in marsh soils determines what plant species are suitable. Adjustment of tidal flux, elevation and freshwater drainage during site preparation will create the proper salinity.

The condition and chemical properties of the soil dramatically influence the success of transplants. Sandy soils, for example, are easier to manipulate and prepare than clay or silt soil, and have more favorable bearing capacity. Proper levels of organic matter and nutrients are also essential. Since most sandy soils contain few nutrients, restoration teams should rely on enhanced tidal flooding to deposit significant amounts of nutrient-rich sediments or apply the correct formulation of fertilizers. On nutrient-poor sites, one may apply fertilizer as a follow-up treatment. If the site is graded, the topsoil, which is more fertile, can be stockpiled and reapplied over the planting surface.

Moderate sediment accumulation, either natural or supplemental, stimulates plant growth and increases the elevation and width of the marsh. Accumulation of sediments also allows the marsh surface to keep pace with rising sea level (or subsidence); but too much can smother plants or elevate the marsh surface above normal tidal flux.

Physical Protection: A Little Extra Insurance

Waves can hinder salt marsh development when they are strong enough to erode shorelines and planted surfaces. To protect the newly planted marsh, one may need to erect physical barriers to reduce wave damage and prevent erosion. A low-height "breakwater" has been proved an inexpensive, efficient mechanism to lessen wave damage (Rogers 1994). However, it is not appropriate for high-energy beaches. If fetch is less than a mile, breakwaters are very effective; but where fetch exceeds 4 miles, such breakwaters are not useful.

Breakwaters typically are installed (Figure 5) about 20 feet from the shore (no more than 50 feet) at mean low water (Broome et al. 1992). The top of the breakwater should be about 6 inches above the water surface and only slightly higher than the desired level of the marsh's permanent root mat. Breakwaters are usually wood, but people in the Chesapeake Bay area have built them with stone (Hardaway et al. 1985). Unlike bulkheads, which are designed to trap sediments and buttress the shoreline behind them, breakwaters should be porous. Small gaps left between boards and open space at each ends will permit water circulation. Breakwaters longer than 200 feet may require larger openings along their length.

Establishing Vegetation

When a site is restored to an elevation that allows tidal flushing and proper salinity, salt marsh vegetation will regenerate in several years (Sinicrope et al. 1990; Dreyer and Niering 1995; Simenstad and Thom 1996). In the

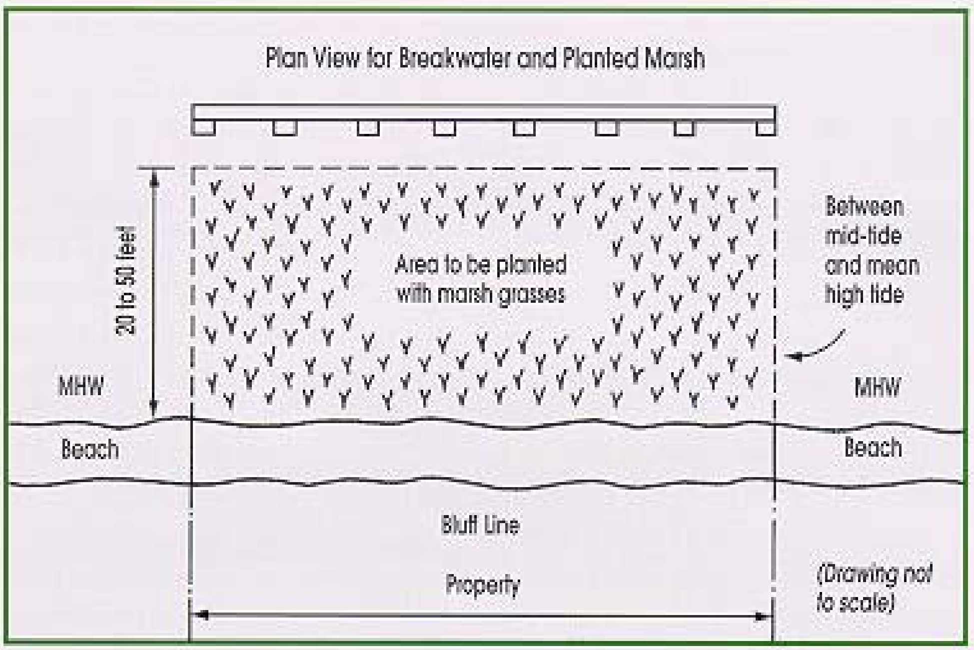


Figure 5. Layout of a breakwater with planted marsh grasses (Illustration from Broome et al. 1992)

meantime, the marsh is vulnerable to spurious invasions by other plants and recurrence of the barriers to normal salt marsh function.

The reduction or elimination of tidal flooding causes most of the salt marsh degradation in the Northeast (Rozsa 1995). Dilution of salt water creates conditions favorable for dense growth of *Phragmites*. Since *Phragmites* is sensitive to salinity above 18 parts per thousand, re-establishment of tidal flow is the best way to reduce or remove the unwanted plants. With proper tidal flushing and raised salinity, smooth cordgrass becomes established in five to 10 years. Unless there is a compelling reason for speeding up the process, costly planting or transplanting programs are unnecessary. Salt marsh plants self-sow if a natural seed source is close by. Managers in the Northwest also rely on this strategy when cessation of tidal flooding is the cause of salt marsh degradation (Simenstad and Thom 1992). *Spartina alterniflora*, once a popular transplant at some West Coast sites, is considered a nuisance species and transplanting of nonnatives is discouraged.

Preconstruction of wetland restoration project, Puget Sound, Washington (Photo by Justine Barton, USEPA)

In most of the Southeast and Southwest, managers of salt marsh restoration and creation projects prefer transplanting salt marsh plants at a prepared site (Broome and Craft 1998). Researchers have documented rapid development and recruitment of tidal marsh flora and fauna at transplanted sites. *Spartina alterniflora* is the species commonly planted in the intertidal zone of Atlantic and Gulf coasts; on the California coast, *Spartina foliosa* is the favorite choice. *Spartina patens*, *Spartina cynosuroides* and *Juncus roemerianus* are among other species that have succeeded along the Gulf and East coasts.

Although transplanting is popular, the demand for plants still exceeds the supply. But restoration teams can consider a variety of sources. They may be able to harvest plants from native stands or collect seeds from local sites to cultivate in greenhouse pots or flats (Garbisch et al. 1975). Creating plants by tissue culture (micropropagation) has been investigated (Li et al. 1995), but is not yet widely used. Plant material, whether seedlings or seed, must originate from native stands near the transplant site. This will minimize the introduction of ecotypes that will fail in local conditions or genetically "dilute" native populations.

If one digs plants from nearby native stands, he should thin selectively and keep disturbance to a

New vegetation recruitment at breached-dike marsh site, Oregon (Photo by C. Simenstad) minimum. Places designated for destruction, such as dredge disposal sites, can be a good source of plants. More commercial nurseries culture native plants now that habitat restoration is a more routine mitigation tool.

Sometimes one can grow new salt marsh plants by sowing seed directly. In this case, seeding is most productive in the upper half of the intertidal zone.

Techniques for transplanting seedlings are similar, whether the plants were dug from the field or cultured in pots. Transplanting can be done mechanically, using horticultural and agricultural machines, at sites where the soil will support the equipment. In small areas, along tidal creeks, or at places with wet soil, manual planting is preferable. Workers can use tree-planting dibbles, spades or other tools to open holes.

Planting of emergent marsh vegetation

(Photo by Curtis Tanner, USFWS)

Snug plant spacing is critical if quick coverage is the goal (Broome et al. 1992). For *Spartina alterniflora*, 60-by-60 centimeter spacing will usually promote adequate plant cover in one growing season where erosion is not serious (Broome and Craft 1998); spacing of 1 meter is acceptable on sites with the best growing conditions—fertile soil, gentle slope and minimum erosion. Cost of plants is usually the factor that determines spacing. For optimum results, one should transplant early in the growing season.

Plants usually mature

more quickly when fertilizers are applied at the time of transplanting. Ordinary soil tests can measure a site's fertility. If natural inputs from such sources as sedimentation are not sufficient, supplemental fertilizer may be needed. For surface applications, specialists recommend ammonium sulfate and concentrated superphosphate at rates of about 100 kg/ha N and 50 kg/ha P. Experts believe that slow-release N fertilizers, preferably polymer-coated, are much more effective than ordinary soluble materials and can be put in planting holes without damaging the plants.

Cultivation, Adaptation and Maintenance

Success depends on a combination of suitable horticultural choices: plant selection, seed collection and storage, seedling production, site preparation, transplanting technology, proper plant spacing, and adequate fertility.

Created salt marshes often lack organic matter in the substrate, especially if the sediment source is dredged material or upland soil. To encourage microbial growth and increase nutrient cycling, restoration teams can add organic matter to the soil at transplanting. It may also be necessary to "top dress" a newly planted marsh to encourage root formation, attract organic matter and develop "reducing" soil conditions. But before deciding what type of organic amendments to use, one should carefully assess the soil and drainage conditions at a site (Broome et al. 1999); in severely reduced, waterlogged soils, the addition of organic matter may adversely affect early plant growth.

Grazing, if significant, can retard production of plants, slowing the establishment of vegetative cover and accumulation of organic matter. Temporary fencing can prevent excessive grazing.

When restoration entails reopening pathways to drainage and flooding, managers may have to maintain the openings for optimum tidal flushing until the salt marsh grows and is colonized by natural fauna. If the restored marsh floor has subsided, less flooding might be necessary than before the marsh was degraded.

If the ultimate goal for salt marsh restoration is to create high-quality habitat for marine fauna, restoration teams must provide pathways between the adjacent ecosystems to support colonization. Creeks and ditches are imperative. Managers must create and maintain a hydrologic regime that is favorable for development of salt marsh vegetation and chemically reduced soils.

ASSESSMENT AND OUTCOME

Authorities disagree on whether salt marsh creation and restoration projects can replace or duplicate the functional attributes of natural systems. To gauge success, one must first consider the goals that preceded the project. One can evaluate several criteria to assess habitat value, but data is lacking on the ultimate value of created and restored salt marshes. Researchers have evaluated only a few transplanted salt marshes to assess their efficacy as functional habitats (Matthews and Minello 1994).

Landscape Assessment

The quality of created and restored salt marshes is significantly influenced by site selection, preparation and planting. The land must be near a source of salt water, have the proper elevation for tidal flushing, be accessible to relevant fauna, cover a large enough area to provide functional linkages, and be properly planted. If the initial site work creates the right physical base, biological development will follow. Researchers estimate that it takes 10 to 15 years for a created or restored salt marsh to resemble a functioning natural marine habitat (Broome et al. 1999).

Faunal colonies build on developing plant communities. If hydrology is favorable for growth and propagation of hydrophytic vegetation, salt marsh plants quickly become established and develop complete coverage in as little as three years from transplanting (Broome 1990). Development of salt marsh fauna, which relies largely on natural recruitment, will require more time. The salt marsh will start attracting characteristic animals as it adds abundant aboveground plant biomass and underground root materials. Some animals will arrive by land and air; others will ride the tides from nearby marshes and estuaries. Fauna that lack planktonic forms or live in more remote areas can be introduced manually into the growing salt marsh system.

Development of reduced soil in created and restored salt marshes generally takes several years to equal conditions present in a natural marsh. This is particularly true on dredge spoil and oxidized upland soils. However, it takes less time to achieve reduced soil when managers rehabilitate degraded salt marshes by restoring original drainage patterns.

Monitoring

It is difficult to gauge the efficacy of created and restored salt marshes. Development of an effective salt marsh ecosystem is a long process compared to the expediency of most management decisions. Unfortunately, science lacks the necessary level of understanding temporal patterns in development of salt marsh processes to adequately predict the outcome of creation or restoration projects. To test and predict long-term success, researchers must analyze the results from long-term monitoring of salt marsh processes. Only a few such analyses have been performed to date (Matthews and Minello 1994; Simenstad and Thom 1996; Broome et al. 1999). To make quick assessments, researchers will have to be able to recognize salt marsh attributes they can use to forecast long-term trends in critical salt marsh functions and processes.

Are restored and created salt marshes equivalent to natural marshes? The answer is so elusive because we do not have functional models of natural salt marsh ecology. Regional assemblages of salt marsh (e.g., Northwest Pacific vs. South Atlantic/Gulf coasts) are very different from each other; you can't use a model from one region to judge another effectively. Indicators of functional trends and variability are not well known regionally. We need assessment parameters to characterize fundamental processes, identify surrogates and quantify ecological attributes. Long-term monitoring should focus on three main characteristics (Simenstad and Thom 1996; Broome et al. 1999):

• Time that is required to attain salt marsh structure that resembles natural marshes (i.e., aboveground and belowground biomass, primary productivity rates, diversity, hydrologic regimes, soil organic matter)

• Presence and prominence of surrogate (or indicator species) that can be used to determine the relative success of salt marsh structure and function

• Successional development and cycling rates that indicate ecological functions similar to natural salt marsh systems

Ecological Implications

Most restored or created sites will establish plant biomass within a short time, given the right hydrologic regimes and location (Table 2). But it is the linkages among plants, sediments and animals that foster establishment of quality coastal habitat.

If ample pathways for water exchange, large amounts of marsh edge, and desired animals are available, fish and macroinvertebrates usually will utilize the new salt marsh in a short time (Minello and Zimmerman 1992). Abundance of fish is similar in created and natural salt marshes (Minello et al. 1994). A close relationship exists between the time of flooding and the abundance of organisms (Table 2), especially when adequate edge is available.

Accumulation of organic matter in the soil fuels the physical, chemical and biological processes in salt marshes. Besides increasing the holding capacity of soil water, nutrient storage and nutrient cycling, organic matter influences the number and kind of sediment-dwelling invertebrates (Levin et al. 1998). Scientists think these infauna are the link for transferring plant material from the marsh to the ecosystem's food webs (Currin et al. 1993; Zedler 1996; Broome et al. 1999).

Organic matter accumulates in the soil when salt marsh plants die and decay. Other organic inputs include algae, sediments, bacteria and detritivores, which assist with decomposition processes and translocation of organic matter. The rate of accumulation is often key to achieving ecological equivalency in restored and created marshes. Adding organic matter to marsh soils at the time of planting can stimulate nitrogen fixation and accelerate nutrient cycling. However, too much organic matter on the surface can interfere with heterotrophic processes and smother new seedlings (Thompson et al. 1998; Broome et al. 1999). Though nearly all constructed salt marshes quickly produce plant biomass similar to natural salt marshes, they generally have low levels of organic matter (Table 2). But over 20 years or so, they reach concentrations that approach natural conditions (Broome and Craft 1998).

Another indicator of functional equivalence is the ratio of carbon to nitrogen. The carbon to nitrogen ratio is inversely related to the age of the marsh (Table 2). Researchers believe that created and restored marshes do not become functionally equivalent to natural marshes until the carbon to nitrogen ratio falls below about 20, especially in terms of nitrogen availability to macrophytes and marsh consumers.

Accumulation and cycling of nutrients are

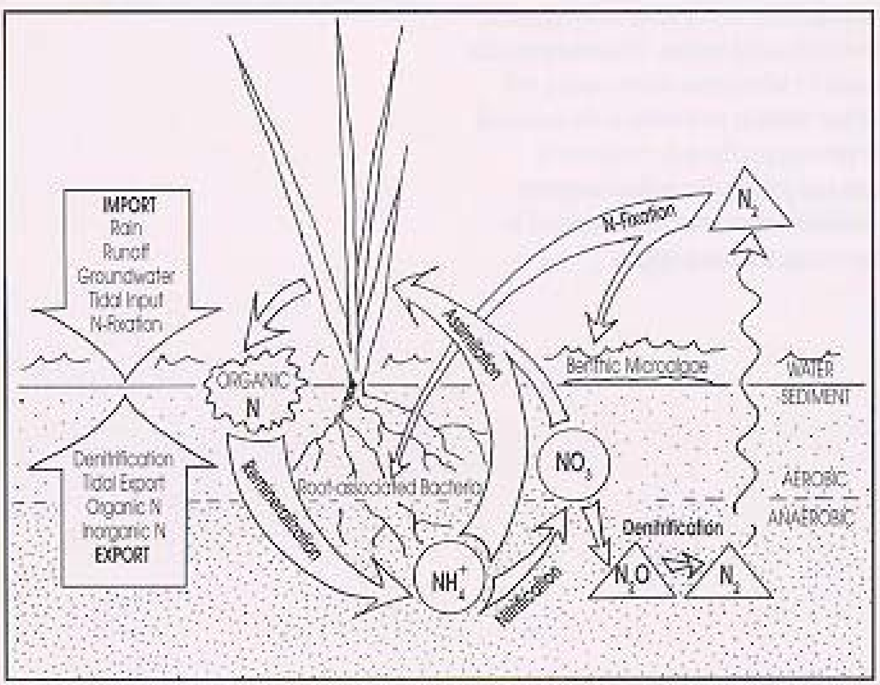
Table 2. Some Ecological Attributes of Created Salt Marshes vs. Natural Salt Marshes

Attribute	*Created Marsh*		*Natural*
	New	*5 years*	*Marsh*
Standing Crop Biomass[a] (gm/m^2)	150	1,000	800
Belowground Biomass[a] (gm/m^2)	50	2,400	2,000
Infauna Density[c] ($\#/m^2$)	17,500	20,000	50,000
Fishes[b] ($\#/m^2$)	0	2.01	2.33
Organic Matter[a] (%)	NA	0.6	45
Soil[a] C:N	25	23	18
Ammonia Nitrogen[c] (kmol/ha)	NA	1.76	3.17
N Fixation[d] ($gm/m^2/yr$)	NA	12	6
Denitrification[c] ($gm/m^2/yr$)	NA	0.1	1.0

[a]Broome and Craft 1998, [b]Zedler 1996, [c]Craft et al. 1991, [d]Currin et al. 1993
NA = Not Available

critical to ecological development of salt marshes (Currin et al. 1993; Currin et al. 1996). Nitrogen is imported to the marsh by rainfall, groundwater, tidal flooding and nitrogen fixation. Young salt marshes are sustained by external nutrients; but the maturing marsh depends more on internal cycling of nutrients. In a new marsh, nitrogen fixation at the surface and among the plant roots is generally high; but it decreases as the marsh accumulates and stores its own nitrogen (Table 2). As plant biomass, decomposition rates and infaunal activity increase, nitrogen fixation declines and the rate of nutrient cycling increases. For restored and created salt marshes to achieve ecological equivalency, internal cycling of nitrogen must occur in chemically reduced soils of adequate organic content (Figure 6). Adequate nutrient cycling occurs much sooner in degraded salt marshes in which tidal flows have been restored (Northeast and Northwest) than at sites created on non-marsh soils.

Figure 6. Nitrogen cycling in salt marsh sediments



Although there is disagreement about the definition of successful restoration, one point is certain: The projects nearly always lead to creation of some type of habitat. If a marsh is established on the proper elevation, protected from severe waves and currents, planted with plants suitable to the site, supplied with adequate nutrients, and managed to ensure optimal plant coverage and growth, ecological development will eventually occur.

Mitigation

In response to changing political, policy and management parameters, coastal managers are relying more on mitigation to maintain the current level of coastal habitats (Environmental Law Institute 1997). The need for information about creating and restoring salt marshes has grown in proportion to the increased use of mitigation. The growing number and complexity of regulations, agreements and policies dictate that mitigation projects need better technical information and assessment to correspond with better recognized social values.

CONCLUSION

Using this report, coastal interest groups, management entities and technical practitioners should be better equipped to set goals for creation and restoration of valuable salt marsh habitats. More detailed information about individual project histories and technical aspects is available in the literature referenced in the following section.

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North Carolina Sea Grant College Program, Raleigh, NC 27695
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