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Creating Tidal Salt Marshes in the Chesapeake Bay

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ABSTRACT

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Draining 166,000 square kilometers of the mid-Atlantic region of the United States, the Chesapeake Bay is one of the largest tidal estuaries in the world. There are approximately 5,000 square kilometers of wetlands in the watershed, of which approximately 2,000 square kilometers are tidal. Tidal wetlands within the lower Chesapeake Bay watershed have suffered significant losses from dredging, filling, and urban development. Prior to passage of the Wetlands Act in 1972, losses of tidal wetlands in Virginia averaged approximately 243 ha per year. After its passage, permitted tidal wetland losses dropped to approximately 10 ha per year. The tidal wetlands of the Chesapeake Bay perform a number of important ecological functions which are attributed high value by humans, namely nutrient recycling, fin and shellfish habitat, and sediment trapping. Over one half of all Virginians live on the coastal plain which makes up a little under a third of the state's landmass. This population pressure has resulted in many impacts to salt marshes. Therefore, restoration and creation of these marshes have received much political and academic attention. The purpose of this paper is to review the existing knowledge base of tidal salt marsh restoration in the Chesapeake Bay. We emphasize creation of oligohaline (5 - 12 ppt), mesohaline (12-22 ppt), and polyhaline (>22 ppt) marshes and include recommendations for determining appropriate siting, design, and construction methods. Three constructed salt marsh projects are reviewed and recommendations for improvements in design and construction are presented. In no case was a clear set of goals or objectives developed prior to construction, making the determination of "success" difficult to assess.

ADDITIONAL INDEX WORDS: *Chesapeake Bay wetlands, created salt marshes, created tidal wetlands, created wetlands, tidal marsh construction and/or creation, tidal wetland construction and/or creation, wetland construction and/or creation.*

CHESAPEAKE BAY TIDAL WETLANDS

The Chesapeake Bay is one of the largest tidal estuaries in the world. Draining 166,000 square kilometers of the mid-Atlantic region of the United States, the Chesapeake Bay watershed lies within the political boundaries of six states and Washington, DC (Figure 1). Four main tributaries feed into the Bay, draining such urban areas as Fredericksburg, Alexandria, and Richmond, Virginia; Baltimore, Maryland; Washington, DC; and Harrisburg, Pennsylvania. There are approximately 5,000 square kilometers of wetlands in the watershed, of which approximately 2,000 square kilometers are tidal (TINER, 1984; 1987). The Bay is microtidal with a mean tide range varying from 1 m at the mouth of the Bay to zero in the freshwater reaches. The maximum mean tide range is 1.2 m and is found in the small village of Walkerton, Virginia, on the Mattaponi River (NATIONAL OCEAN AND ATMOSPHERIC ADMINISTRATION, 1996). The salinity of the bay's water, important in determining wetland vegetation types and their distribution, is greatest at the southern end of the bay and decreases to zero as one moves upstream in the main stem and its tributaries.

Several estimates of loss of coastal wetlands in Chesapeake Bay have shown losses ranging from 52 ha to 300 ha per year prior to the establishment of wetland permit programs (Table 1). The large variation in estimates of losses may be attributed to the methods used to determine the numbers.

Tidal wetlands within the lower Chesapeake Bay watershed have suffered significant losses from dredging, filling, and urban development (NICHOLS and HOWARD-STROBEL, 1991). Prior to passage of the Wetlands Act in 1972, losses of tidal wetlands in Virginia averaged approximately 243 ha per year (SETTLE, 1969). After its passage, permitted tidal wetland losses dropped to approximately 10 ha per year (JONES and LYNCH, 1978). A recent study of wetland loss in the lower bay region reported losses of estuarine emergent and scrub-shrub marshes of over 15 ha for the period from 1982 to 1989-90 (TINER and FOULIS, 1994). In 1988, however, the permitted losses of vegetated tidal wetlands in the lower bay totaled 1.8 ha (PRIEST *et al.*, 1990). A more extensive review of tidal wetland appears in ZEDLER and CALLAWAY (this volume).

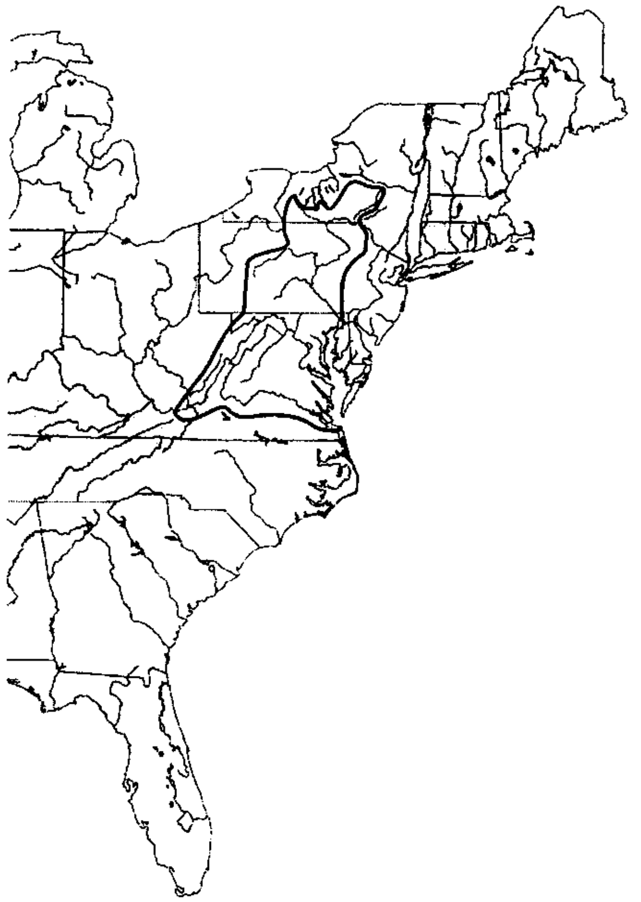


Figure 1. Chesapeake Bay watershed (enclosed in dark line). The bay's watershed drains 166,000 hectares of the mid-Atlantic coastal region of the United States and parts of five states: Maryland, New York, Pennsylvania, Virginia, and West Virginia.

Table 1. *Estimates of coastal wetland losses in the Chesapeake Bay (hectares x 100). Vegetated wetlands are estuarine (salt and brackish) emergent and scrub shrub communities. Nonvegetated include mud and sand flats and sand and cobble bars. Year that the data represents is given in parentheses.*

Study	Vegetated Wetlands (Year)	Nonvegetated Wetlands (Year)	Wetland Loss
Tiner 1987	544 (1977-78)	341 (1977-78)	Study of wetland status between 1955 and 1977 showed a loss of 15,300 acres of coastal wetlands over the time period.
Field, *et al.* 1991	1161	400	
Tiner and Foulis 1994	794 (1989)	32 (1989)	Study of wetland status between 1982 and 1989 showed a loss of 904 acres of vegetated coastal wetlands over the time period.

Tidal Wetlands of the Chesapeake Bay

The combined stress of inundation and salt water limit the types of biota that can survive in the marshes of the lower portion of the bay. However, they also provide for a diverse number of tidal wetland habitats. In upstream reaches salinity is low to non-existent. Without the stress of salinity, more species of vascular plants are able to survive (ANDERSON *et al.*, 1968; WASS and WRIGHT, 1969; PERRY and ATKINSON, 1997; PERRY and HERSHNER, 1999). In these tidal fresh water zones, over 50 species per hectare may be common (DOUMLELE, 1981; ODUM, *et al.*, 1984; ODUM, 1988; PERRY and ATKINSON, 1997; PERRY and HERSHNER, 1999). In the lower portion of the Bay only a few vascular plants are able to tolerate the tidal inundation and high salt content of the water. For a comprehensive comparison of tidal salt marshes and freshwater marshes of Chesapeake Bay see ODUM (1988).

The tidal wetlands of the Chesapeake Bay perform a number of important ecological functions which are attributed high value by humans. The most important of these functions and values are primary production and detritus availability, wildlife and waterfowl support, shoreline erosion buffering, and water quality control.

Primary productivity in tidal marshes can reach 10 tons/acre annually, with an average range of 1-6 tons/acre/year. This high level of primary productivity results in a high level of detritus production, which is the basis of a major marine food pathway that includes crabs, other shellfish, and finfish. In addition to providing food, tidal marshes provide spawning and nursery habitat. It has been estimated that 95% of Virginia's annual harvest of fish (commercial and sport) from tidal waters is dependent to some degree on wetlands (WASS and WRIGHT, 1969). Some of the important wetland-dependent fisheries in the Chesapeake Bay include blue crabs, oysters, clams, striped bass, spot, croaker, and menhaden.

The Chesapeake Bay is home to approximately 1 million waterfowl each winter. The ducks and geese benefit both directly and indirectly from the productivity and habitat provided by the Bay's marshes. Marsh-nesting birds include Virginia and clapper rails, mallard and black ducks, willet, marsh wren, seaside sparrow, red-winged blackbird, boat-tailed grackle, and northern harrier (WATTS, 1992). Chesapeake Bay marshes are also used by herons and egrets year-round, and by transient shorebirds such as yellowlegs, semipalmated sandpiper, least sandpiper, dowitcher, dunlin, and sharp-tailed sparrow (WATTS, 1992). Muskrats are the most visible marsh-dependent mammal.

Tidal marshes dissipate incoming wave energy, thereby providing a buffer against shoreline erosion. KNUTSON *et al.* (1982), studying *Spartina alterniflora* marshes in the Chesapeake Bay, found that over 50% of wave energy was dissipated within the first 2.5 meters of the marshes. ROSEN (1980) found that marsh margins form the least erodible shorelines.

Marshes in the Chesapeake Bay play a very important role in maintaining and improving water quality by trapping sediment from upland runoff and from the water column, thereby reducing siltation of shellfish beds, submerged aquatic vegetation beds, and navigation channels. Pollutants may also be filtered from runoff and the water column, and taken up by marsh plants. Nutrient uptake is also an important function of these wetlands.

Over one half of all Virginians live on the coastal plain which makes up a little under a third of the state's landmass (COLGAN, 1990; MASON, 1993). This population pressure has resulted in increased impacts to salt marshes over the past 50 years. Restoration and creation of these marshes have received much political and academic attention, and this article concentrates on the restoration and creation of oligohaline (5 - 12 ppt), mesohaline (12-22), and polyhaline (>22 ppt) marshes.

Physiographic and Vegetation Characterizations of Tidal Salt Marshes

There are nine vegetated marsh types common in the oligohaline, mesohaline, and polyhaline sections of the Bay (VIRGINIA MARINE RESOURCES COMMISSION, 1980). Most are considered to be high in biomass productivity and important wildlife, finfish, and shellfish habitat. One of these community types, the reed grass community, is controversial and considered by some managers to be invasive, low in ecological function, and therefore low in socioeconomic value. However, there is little hard evidence to support this assertion. A brief description of each community type is presented below and in Table 2. For a more detailed information on tidal marshes of the Bay see WASS and WRIGHT (1969), SILBERHORN (1999), VIRGINIA MARINE RESOURCES COMMISSION (1980), ENVIRONMENTAL PROTECTION AGENCY (1983), ODUM *et al.* (1984), PERRY and ATKINSON (1997), and PERRY and HERSHNER (1999). A profile of the topographic and positional relationships of the different tidal salt water wetlands is shown in Figure 2.

The salt marsh cordgrass community dominates the poly- and mesohaline areas and is comprised of dense, often mono-specific stands of *Spartina alterniflora* (salt marsh or smooth cordgrass). Physiographical distribution ranges from mean sea level (MSL) to approximately mean high water (MHW). A stout, erect species, *S. alterniflora* often is represented by two forms: a tall form, 1.2-2 m in height along the waters edge or along levees; and a short form 0.7 m or less in height found in poorly drained areas behind levees or at elevations slightly higher than mean high water (SILBERHORN, 1999). Other vegetative communities occur landward of the salt marsh cordgrass communities.

The saltmeadow community dominates areas located landward of the salt marsh cordgrass community in meso- to polyhaline waters. It also occurs on the higher portion of natural levees. The dominant vegetation is either *Spartina patens* (saltmeadow hay) or *Distichlis spicata (salt grass)* or both as co-dominants. Topographically, these "meadows" often remind one of grassland prairies or hay fields. Historically, these marshes have been used as a source of cattle fodder, both grazing and haying, throughout the mid-Atlantic and New England states (TEAL and TEAL, 1969). Both dominant plants form characteristically dense, low (0.3-0.7 m) wiry meadows typically with swirls or "cowlicks".

Table 2. *Common marsh communities of the Chesapeake Bay. MSL=mean sea level, MHW=mean high water.*

Marsh Type	Dominant Species	Associated Species	Physiographic Range	Distribution
I. Saltmarsh cordgrass community	*Spartina alterniflora*	*Spartina patens* *Distichlis spicata* *Limonium caroliniana* *Borrichia frutescens* *Juncus roemerianus*	MSL-MHW	CAN to FLA
II. Saltmeadow community	*Spartina patens* / *Distichlis spicata*	*Iva fruescens* *Baccharis halimifolia*	MHW to spring tide	CAN to FLA CAN to S.AM
III. Black needlerush community	*Juncus roemerianus*	pure stands	MHW to spring tide	MD to TX
IV. Saltbush community	*Iva frutescens* / *Baccharis halimifolia*	*Spartina patens* *Borrichia frutescens*	spring tide to marsh/ upland ecotone	CAN to TX MA to TX
V. Big cordgrass community	*Spartina cynosuroides*	pure stands	MHW to spring tide	MA to TX
VI. Cattail community	*Typha angustifolia*	*T. latifolia*	spring tide to marsh/ upland ecotone	CAN to FLA
VII. Reed grass community	*Phragmites australis*	invasive plant pure stands	MHW to uplands	Cosmopolitan
VIII. Saltwort community	*Salicornia viginica* / *S.europea* / *S.biglovii*	*S. alterniflora*(sf) *D. spicata*	MHW (pannes)	Altantic/Pacific Same Same
IX. Mixed brackish community	no dominant spp.		MHW to marsh/ upland ecotone	

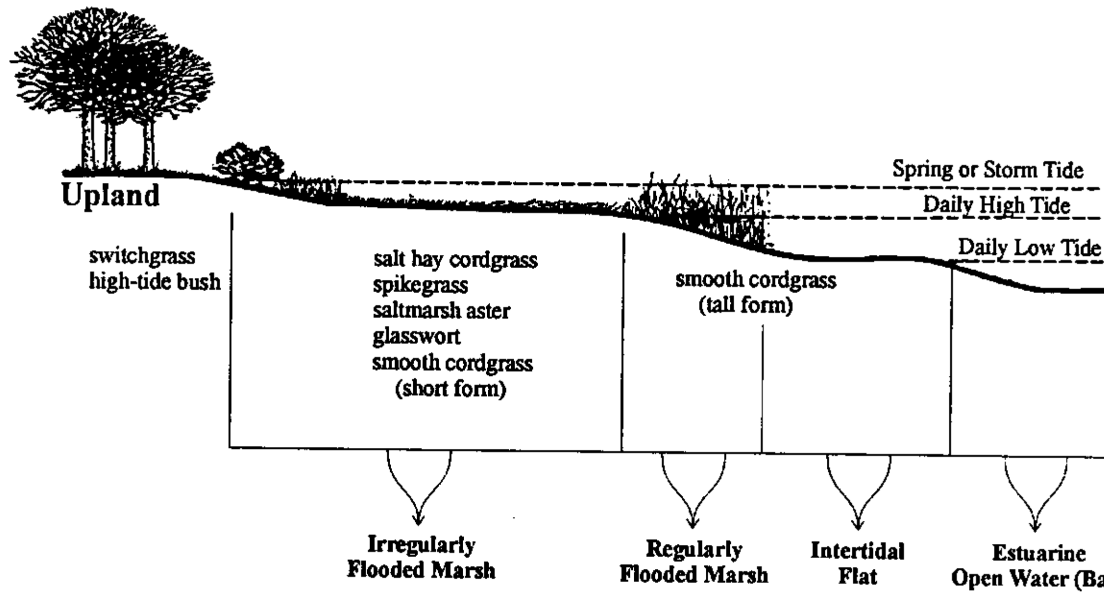


Figure 2. Profile of Chesapeake Bay salt marshes. Low marsh planting zone for smooth cordgrass (*Spartina alterniflora*) is designated as "Regularly Flooded Marsh" and high marsh planting zone for salt meadow hay (*S. patens*) and salt grass (*Distichlis spicata*) as "Irregularly Flooded Marsh" (from Wohlgemuth, 1990).

The black needlerush community is found interspersed among the saltmeadow community, and is common in the high marsh of some meso- and oligohaline areas. *Juncus roemerianus* (black needlerush) nearly always grows in mono-specific stands. The dark green (almost black), leafless stem tapers to a sharp point, giving the plant its well deserved name.

Landward of the salt meadow and needlerush marshes one encounters the only tidal salt marsh community dominated by woody vascular plants. The saltbush community is dominated by two shrubs: *Iva frutescens* (salt bush) in the lowest physiographic range, and *Baccharis halimifolia* (groundsel tree) in the higher physiographic range of the marsh. This wetland usually delineates the tidal wetland/upland ecotones. The shrubs usually reach heights of 1 to 4 m.

The big cordgrass community, dominated by *Spartina cynosuroides* (big cordgrass), is found slightly above MHW, but is variable in range (SILBERHORN, 1999). It usually forms dense, mono-specific stands in low salinity (oligohaline) marshes. This is one of the tallest grass species of our tidal wetlands, usually reaching 2-4 m in height. Its stems are stout, leafy, and have a distinct coarse branched flower (seed) head. The leaves have saw-like margins that easily lacerate human skin.

Although there are several species of cat-tails in the mid-Atlantic region, there is only one, *Typha angustifolia* (narrow-leaved cat-tail) that is common in the saline tidal reaches. The community is usually found in isolated stands in brackish marshes, often near the upland margin where there is freshwater seepage. In freshwater areas, *T. latifolia* (broad-leaved cattail) may also be present and is often an indicator of high nutrient loads.

The reed grass community is dominated by reed grass (*Phragmites australis*), a species considered invasive by many wetlands scientists, regulators, and managers. The community is usually located above MHW and is almost always associated with topographic or other disturbances such as the placement of dredged sediments or other fill material, plant die-back or surface erosion. The species usually cannot tolerate poly- or mesohaline conditions below MHW (SILBERHORN, 1999). It is a tall, stiff grass (up to 4 m) with short, wide leaves tapering abruptly to a pointed, purplish plume-like (feathery) flower head which turns brown in seed.

Pannes are shallow depressions that often form within the interiors of large salt marsh cordgrass communities. They are usually the result of wrack accumulation which kills the cordgrass or of "eatouts" caused by muskrats or snow geese. These areas normally become hyper-saline and are sparsely vegetated with several halophytic species of saltworts (*Salicornia virginica, S. europea* and *S. bigelovii*). These are succulent plants 1.5-30 cm tall. By late summer, these plants may turn a dark red, giving those portions of the marsh a striking contrast to the yellow-greens of the surrounding grasses.

The brackish water mixed community is a mix of two or more of the communities described above and may be found in meso- and oligohaline estuarine reaches. No single dominant plant species covers more than 50% of the marsh. Brackish water mixed communities have relatively high structural and species diversity which provides a variety of habitats and wildlife foods.

Salt Marsh Ontogeny

Natural succession of tidal salt marshes for temperate climates analogous to the Chesapeake Bay was first described in the 19th century (MUDGE, 1862, SHALER, 1885). These early researchers noted that trees were positioned in an upright position at the bottom of salt marsh peat. MUDGE (1862) concluded that the stumps indicated that the area was once located at an elevation above MHW. He further noted *Spartina patens* rootstock, a species normally found at an elevation above mean high water, to occur well below that elevation. He hypothesized, therefore, that salt marshes "grew" (i.e., accreted) through the gradual accumulation of cordgrass rootstock. Several studies have shown that peat accumulation over time is responsible for the horizontal soil profile found in New England salt marshes and documented the profiles relationship to relative sea level rise (REDFIELD, 1965; REDFIELD and RUBEN, 1962; REDFIELD, 1972; NIERING and WARREN, 1980). Primary succession normally occurs on a protected sand beach or overwash area. As the plant community matures, a solid subterranean rootmat develops. With sea level rises, the rootmat becomes anaerobic and creates reduced chemical conditions in the soil. Low redox conditions make it difficult, if not impossible, for aerobic soil microbes to survive. Without the presence of soil oxygen, biological degradation of the dead root material is considerably slower. The net effect is an increased amount of organic material in the soil and an increase in elevation in response to relative sea level rise (REDFIELD and RUBEN, 1962; REDFIELD, 1972). OERTEL *et al.* (1989) have shown that a similar process has occurred and is responsible for the salt marshes of the barrier islands of Virginia. See FRIEDRICHS and PERRY (this volume) for a more in-depth discussion on salt marsh formation.

TIDAL SALT MARSH CONSTRUCTION IN CHESAPEAKE BAY

History and Overview

The oldest known salt marsh planting on the east coast is found in Cheerystone Inlet, Virginia. Planted in 1928 by the property owner with *Spartina alterniflora* for erosion control, the site was still well established in the early 1980's (KNUTSON and INSKEEP, 1982). In 1980, KNUTSON *et al.*, (1981, 1982) located 94 salt marshes that had been planted on the Atlantic coastline. Early records of salt marsh plantings in the lower Bay involved research on the use of marsh establishment (planting) for shoreline erosion control (PHILLIPS and EASTMAN, 1959; SHARP and VADEN, 1970; GARBISCH *et al.*, 1975; HARDAWAY and ANDERSON, 1980; KNUTSON *et al.*, 1981; HARDAWAY *et al.*, 1981; KNUTSON and INSKEEP, 1982). Over the following years, experiments with salt marsh establishment on the Bay were used to address questions concerning dredged material stabilization and habitat development (KNUTSON *et al.*, 1981, KNUTSON and INSKEEP, 1982; LANDIN, 1984; LANDIN and NEWLING, 1987).

Procedures for salt marsh establishment were developed during the mid to late 1970s. KADLEC and WENTZ (1974) produced a comprehensive list of wetland plant propagules and controlling parameters important for their survival throughout the United States. Specific methods for planting tidal salt marshes were developed in the mid-seventies (KADLEC and WENTZ, 1974; KNUTSON, 1977; GARBISCH *et al.*, 1975; WOODHOUSE *et al.*, 1976; WOODHOUSE, 1979; SHARP *et al.*, 1980).

The earliest records of creating salt marshes to mitigate for the loss of tidal marshes due to construction activities in the Bay date back to 1979/1980. These range from a number of small, privately owned creation efforts, to a larger tidal marsh wetland bank for highway construction and improvement in 1982 (R. Harold Jones, US Army Corp of Engineers, personal communications). Because the process was new the project planting designs usually included only three communities: big cordgrass, salt marsh cordgrass, and saltmeadow. Planning, for the wetland bank for example, involved creation of three major elevation zones: one intertidal (low-marsh) and two high marsh zones, divided into a basin and peripheral area. The species of choice were *Spartina alterniflora* planted in the intertidal zone, *Spartina cynosuroides* in the basin high marsh zone, and *Spartina patens* and *Distichlis spicata* in the peripheral high marsh zone. Planting was done by hand using either transplants from an adjacent marsh or greenhouse plants grown from local propagule sources. Profiles were taken from local tidal marshes to determine the planting zones. Little consideration was given to soil type, geochemical properties, or potential grazing and/or invasive species problems. A minimum of a one-to-one ratio of created to destroyed marsh was frequently accepted as appropriate (BARNARD and MASON, 1990).

These early attempts at creation, on both private and government owned property, marked a turning point in managing the Bay's tidal marshes. They indicated that the inhabitants of the region had begun to accept the emerging paradigm that loss of tidal wetlands within the Bay might have a negative effect not only on organic biomass production, water quality, and wildlife habitat within the Bay, but also on their own quality of living. Marsh creation represented an attempt to alleviate some of the problems associated with the loss of salt marsh habitat.

Unfortunately, early efforts to create salt marshes failed to produce some of the most rudimentary attributes of natural systems, such as vegetation structure and/or slope and elevation (RACE and CHRISTY, 1982; RACE, 1985; C.E. MAGUIRE, 1985; BARNARD and MASON, 1990; BARNARD and PRIEST, unpublished data). Similar results were found in

North Carolina (BROOME, 1990; THOMPSON *et al.*, 1995) and on the west coast of the U.S. (ELIOT, 1985; RACE, 1985). Managers and scientists now realize that establishing salt marshes to assume the role of lost natural systems is significantly more complicated.

For example, a study commissioned by the Norfolk District Corps of Engineers stated that 6 out of 19 attempted creation efforts visited were considered partially or not successful based on vegetation composition and estimated cover (C.E. MAGUIRE, 1985). BARNARD and MASON (1990) evaluated the vegetation cover, bird use, presence of invasive plant species, and faunal association of 51 created salt marshes in the lower Bay. Vegetation cover for the created marshes was significantly different than comparative natural systems with a mean cover of 41% for created vs. 63% for the natural marshes.

Critical Errors Commonly Encountered in Tidal Salt Marsh Creation in Virginia

QUAMMEN (1986) concluded that many of the failures of early attempts at salt marsh restoration could be attributed to poor regulatory oversight of site preparation. Without on-site guidance, many contractors, new to marsh creation, used incorrect elevations, poor plant stock or, in some cases, the wrong species (C.E. MAGUIRE, 1985; QUAMMEN, 1986; Perry, personal observations). BARNARD and MASON (1990) report that there were two created salt marshes in their study where the poor vegetative cover was due to improper slope runoff causing water to pool on the sites and poor tidal exchange. PYKE and HAVENS (1999) found a similarly poor result in a created marsh in the lower Bay. In this case, positioning the created marsh too far from a tidal source may have caused increased channel and/or bank erosion along the connecting channel.

Other problems noted by researchers include the loss of plantings due to too large a fetch and/or excessive wave activity (KNUTSON, 1976; HARDAWAY *et al.*, 1981; Perry, personal observations), grazers (e.g., muskrats and geese) that crop new plantings, foot and boat traffic, and collection of floating debris on the new plantings. In a 1996 Virginia Institute of Marine Science survey of ecologists and managers on created salt marshes, sent out and compiled by the first author, improper elevation was the most common problem the respondents encountered. This was followed closely by erosion of plantings due to natural causes or boat wakes, and poor planting techniques. Several responders noted problems with invasive species (*Phragmites australis*), poor plant stock (improper handling), improper planting techniques, and poor substrate (high clay content).

Inherent in the construction of marshes is the problem associated with the destruction of plants by various animals and the invasion of the newly constructed marsh by undesirable plant species (Table 3). Three of the most destructive animals are geese, muskrats, and nutria, although nutria problems are mostly concentrated in the Bay's northeast (Maryland's eastern shore) and extreme southeast (Virginia's Back Bay). Two of the most invasive plants are reed grass (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*).

Geese will uproot vegetation and consume roots and rhizomes resulting in "eat out" patches within a marsh (KERBES *et al.*, 1990; MILLER *et al.*, 1996). Geese have been reported to remove as much as 1 m^2 of *Carex subspathacea* in one hour (KERBES *et al.*, 1990) and graze for up to 18 hours per day on salt marsh flats (BAZELY and JEFFERIES, 1986). GRIFFITH (1940) noted that a flock of 5,000 geese can strip a 300 acre *Spartina alterniflora* marsh in 6 weeks, and REIMOLD *et al.* (1975) reported a 70% reduction in primary production in a grazed *Spartina alterniflora* - *Distichlis spicata* marsh as compared to an ungrazed marsh. Goose "eat outs" can lower the marsh surface by as much as 5 cm (GRIFFITH, 1940) with soil disruption to 20 cm (LYNCH *et al.*, 1947).

The problem of geese destruction and disturbance of marshes may become increasingly problematic as geese populations grow. The rise in populations of certain species

Table 3. *List of invasive plant and animal species in Chesapeake Bay wetlands and their potential impact. Sources: Fuller et al. (1985), Daiber (1986), Hill (1992), Ankney (1996), Miller et al. (1996).*

Species	Impact
Plants	
Reed grass, *Phragmites australis*	Aggressive, out competes planted species, forms dense monotypic stands
Cattails, *Typha* spp.	Same
Loosestrife (*Lythrum salicaria*)	Same
Japanese sedge (*Carex kobomugi*)	Aggressive, monotypic stands on sand dunes
Animals	
Waterfowl (e.g., Canada Geese (*Branta canadensis*) and Mallard ducks (*Anas platyrhynchos*))	Feed on rhizomes, uproots plants can lower marsh surface through grazing activity
Rodents (e.g., muskrat (*Ondatra zibethicus*), nutria (*Myocastor coypus*), and rabbits (*Sylvilagus* spp.)) Ungulates (e.g., horses, cattle, white tail deer (Odocoileus virginianus)	Overgrazing of planted species, grazing, clipping, reduced diversity of marsh plants, marsh becomes dominated by prostrate short-leaved plants, low above-ground productivity

such as Canada geese, greater snow geese, and lesser snow geese, have increased the amount of eat outs in some areas (HILL, 1992) and have resulted in the draining of some wetlands in Canada by landowners attempting to eliminate geese from their property (ANKNEY, 1996).

Muskrats, as with geese, can cause patchy "eat out" areas in marshes. Muskrats tend to disrupt marshes by feeding on the stems, rhizomes, and tubers (FULLER *et al.*, 1985). New shoots are heavily grazed (LINSCOMBE *et al.*, 1980), and muskrats appear to have a preference for rhizomes (CAMPBELL and MACARTHUR, 1994). It has been suggested that monotypic stands of vegetation, such as *Typha* or *Scirpus*, are more susceptible to complete "eat out" then heterotypic stands (LYNCH *et al.*, 1947). An overpopulation of muskrats can quickly over-exploit a marsh (ERRINGTON, 1963).

Purple loosestrife (*Lythrum salicaria*), a native of Eurasia, occurs in wetland habitats such as marshes, ponds, and reservoirs. In North America, *L. salicaria* has invaded an estimated 300,000 + acres of wetlands (ANDERSON, 1995). In Virginia, the species is probably near the southern limit of its climatic tolerance. *L. salicaria* is considered by most researchers to be undesirable because of low wildlife value and its prolific monotypic nature (RAWINSKI and MALECKI, 1984; WILCOX, 1989; MALECKI *et al.*, 1993), though ANDERSON (1995) suggests that those conclusions may be overstated.

Common reed, *Phragmites australis*, is found throughout the world and is an aggressive colonizer of disturbed sites including newly created wetlands. In a study of constructed tidal marshes in Virginia, HAVENS *et al.* (1997) found 73% of the sites invaded by *P. australis*. *P. australis* is considered undesirable by resource managers partly because of its ability to out-compete native species and form monotypic stands which reduces species diversity (HASLAM, 1973). It is also resistant to physical and biological breakdown and can clog the small rivulets of marshes (GRANELI, 1989) that serve as access points for fish to the marsh surface (ROZAS *et al.*, 1988; HAVENS *et al.*, 1995). The rapid vegetative propagation of *P. australis*, 1-2 meters per year, and its ability to suppress competitors by shading and litter mat formation (HASLAM, 1973) gives the plant a distinct advantage over other species. Once established in a marsh it is extremely difficult and expensive to eradicate.

RECOMMENDED DESIGN AND CONSTRUCTION METHODS

Site Selection

While there is no truly reliable cook-book method for choosing a site, there are clear guidelines that have been researched and developed to help increase the chance of constructing fully functional created and restored tidal salt marshes. For example, KNUTSON *et al.* (1981) found a significant correlation between salt marsh planting survival and fetch, sediment grain size and shore configuration. They found no significant relationship between planting survival and slope, offshore depth, and average wind speed and direction.

Landscape Position

KNUTSON and INSKEEP (1982) found that small peninsulas or point of land reaching into a body of water are poor choices for planting salt marshes. The same would hold true for creating marshes. An area should be chosen that is protected from high wave activity. Areas that have historically high erosion rates or highly erodible soils will be difficult to stabilize. It is also important to take boat wakes into consideration.

Fetch

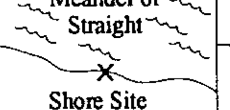
Fetch is the maximum distance winds may move unobstructed across a surface at any given location. The longer the fetch, the more wave energy is experienced by the windward shore. All salt marsh vascular plant species have a limit to the amount of wave activity they can tolerate (WOODHOUSE *et al.*, 1974; GARBISCH *et al.*, 1975; KNUTSON, 1976; WOODHOUSE *et al.*, 1976; WOODHOUSE, 1979; HARDAWAY *et al.*, 1980, 1981; KNUTSON and INSKEEP, 1982). KNUTSON *et al.* (1981, 1982) suggested that a tidal salt marsh would have only a 44% probability of surviving in a fetch over 3 km. KNUTSON *et al.* (1981) developed an evaluation form based on shoreline geometry, sediment size, and fetch conditions that can be used to determine the probability of survival of planted salt marshes (Figure 3). Several studies in the lower Chesapeake Bay have found that marshes planted in naturally non-vegetated intertidal and high marsh zones did poorly if the fetch was greater than 1.6 km (HARDAWAY *et al.*, 1980, 1981). HARDAWAY and BYRNE (1997) recommend the planting of marsh for erosion control on low energy shorelines with a fetch less than 0.8 km. In general it has been shown that salt marshes planted in beach areas where they naturally do not occur may have very low survival unless some form of protection from wave energy is used (e.g., off-shore breakwater structures such as stone filled gabbions or rip-rap) (HARDAWAY *et al.*, 1981).

Design Considerations

Elevation and Gradient

Choosing the correct substrate elevation for the establishment of planting zones is critical to the success of any created tidal marsh. Vegetated tidal wetlands in the Chesapeake Bay are topographically located between mean tide level (MTL) and just above spring high water (WASS and WRIGHT, 1969; MARCELLUS, 1972; MITSCH and GOSSELINK, 2000). This range is defined legally in the Commonwealth of Virginia as the zone from MLW up to an elevation that is 1.5 times the mean tide range upon which is growing any of a number of specified plants (VIRGINIA MARINE RESOURCES COMMISSION, 1980). This zone can be identified through one of several methods. The easiest

Vegetative Stabilization Site Evaluation Form

1. Shore Characteristics	2. Descriptive Categories (Score weighted by percent successful)				3. Weighted Score
a. Fetch-Average Average distance in kilometers (miles) of open water measured perpendicular to the shore and 45° either side of perpendicular 	Less Than 1.0 (0.6)	1.1 (0.7) to 3.0 (1.9)	3.1 (1.9) to 9.0 (5.6)	Greater Than 9.0 (5.6)	
	(87)	(66)	(44)	(37)	
b. Fetch-Longest Longest distance in kilometers (miles) of open water measured perpendicular to the shore and 45° either side of perpendicular 	Less Than 2.0 (1.2)	2.1 (1.3) to 6.0 (3.7)	6.1 (3.8) to 18.0 (11.2)	Greater Than 18.0 (11.2)	
	(89)	(67)	(41)	(17)	
c. Shoreline Geometry General shape of the shoreline at the point of interest plus 200 meters (660 feet) on either side	Cove 	Meander or Straight 	Headland 		
	(85)	(62)	(50)		
d. Sediment Grain size of sediments in swash zone (mm)	0.0 - 0.4	0.4 - 0.8	0.8 - or greater		
	(84)	(41)	(18)		
4. Cumulative Score					

5. Score Interpretation			
a. Cumulative Score	0 - 200	201 - 300	300 - or greater
b. Success Rate	15%	50%	100%

Figure 3. Vegetative stabilization site evaluation form (redrawn from Knutson *et al.*, 1981).

method is to locate an adjacent or nearby "reference" marsh that contains the desired vegetation community. If the reference marsh is in proximity, water levels can be used to transfer the upper and lower limits of the different communities to the planting site. The high and low elevations can also be transposed to the created area using simple survey techniques. Usually several elevations are taken at both the upper and lower end of the vegetation zone and an average used for the target elevations. Care must be taken to not allow the stadia rod to sink into the soil when taking the measurements from the reference marsh and, therefore, erroneously providing elevations that are lower than those actually found in the reference marsh. An alternative method, "simultaneous comparisons", requires procuring tide gauge data from a site for a minimum of 29 days and transferring the principal tidal datums (mean high water, mean low water, mean tide level) from a tidally-contiguous reference station having these datum available (BOON and LYNCH, 1972; BOON and KILEY, 1978). Simultaneous comparison can be a time consuming and expensive exercise, but the method produces excellent results that are comparable to those found through careful use of a reference marsh. An alternative to simultaneous comparisons is to collect a minimum data set (29 days), use the average level as an approximation of mean tide level (MTL), and the highest level as an approximation of mean high water line. MTL is defined as the tidal elevation midway between MHW and MLW (John Boon, Virginia Institute of Marine Science, personal communications). This allows the approximate delineation of a planting zone from just below the MTL up to the high water line. When using this alternative method it is important to consider the number of extreme tides (storm tides) and the time of year the data are collected (winter readings will be approximately 2-4 cm less due to thermal contraction). To compensate for the potential errors the planting zone could be extended below the MTL and above the high water line. The slope of the intertidal planting area should be at least 10:1 (H:V) to provide a stable effective platform for planting (GARBISCH and GARBISCH, 1994).

Substrate

The substrate used for planting salt marshes for compensation is often a subsoil that has been exposed by excavating the top soil layers to achieve a specified elevation. As such, special caution needs to be taken in the Chesapeake Bay area prior to excavation to make sure certain soils are not present. Cation rich soils (cat-soils) occur both naturally and through anthropogenic processes (previously drained marsh soils). Upon rehydration, hydrogen sulfides form in the soil, pH decreases, and re-vegetation becomes nearly impossible. Liming of these soils has shown some positive effects (BROOME, 1990). The initial amount of lime needed to neutralize the soil (12 tons ac^{-1}) (BROOME, 1990) makes marsh establishment in these areas financially and/or ecologically unacceptable. Identification of cat-soils is problematic. Indications of cat-soils include subsoils that test high in sulfur and/or appear to have been a previously drained tidal marsh (e.g., presence of old peat mat in the soil, presence of wetland vegetation or conditions on old aerial photographs or maps).

Blue-marl, a natural clay soil, is of marine origin and not uncommon as a subsoil in the transition zone between the Chesapeake Bay uplands and tidal wetlands. The thick texture of the marl clay provides a poor rooting medium, making plant survival unlikely. Unlike cat-soils, blue-marl soil is described as part of the subsoil profiles given in the local soil survey. HARDAWAY *et al.* (1980, 1981) found decreased below-ground root biomass in *Spartina alterniflora* planted in clay soil on the Chesapeake Bay. In all cases, soil samples from the planting zone should be tested and confirmed by specialists from the local Natural Resource Conservation Service or Soil and Water Conservation Service. The best planting medium is a medium to fine sand (KNUTSON *et al.*, 1982; HARDAWAY *et al.*, 1981; HARDAWAY and BYRNE, 1997).

Vegetation

The dominant tidal marsh plants in the Chesapeake Bay recommended for planting in restored and constructed marshes are listed in Table 4. All species shown use the C_4 photosynthesis pathway and require full sunlight to achieve their maximum vigor. It is important that all plants used are salt hardened to, or slightly above, the water salinity of the site where they will be planted. Over-hardened plants will show a higher survival rate during the higher salinity drought months. Under-hardened plants usually will not survive through a growing season. Long term storage (two weeks or more) on site, even with subsequent watering, should be avoided. Cat-soils are likely to form around the root ball of the plants if they are allowed to dry and then are rehydrated. If long term storage is necessary, plants should be toed-in (placed in a shallow, wet trench and roots covered with wet soil) or stored at the edge of a tidal creek where their roots will be flooded twice a day. The proper planting zone for each species can be seen in Figure 2. Although plants may survive in a higher elevation planting zone, other species will quickly invade the zone and establish dominance. Each plant should be placed in a hole (or furrow) a minimum of 20 cm deep. If planted too shallow, plants may be washed away by wave activity. Fertilizer (see below) should be placed in the hole with the plant, and the hole closed tightly to expel air or water pockets. Failure to seal the holes tightly could result in root rot and subsequent death of the plant.

Fertilizers

The addition of nitrogen upon planting has significantly enhanced the above- and below-ground biomass of *Spartina alterniflora* plantings (WOODHOUSE *et al.* 1974; GARBISCH *et al.*, 1975; WOODHOUSE, 1979; BROOME, 1990; see also RHEINHARDT and PERRY, 1993 for a review of the literature). However, the addition of nitrogen on a continuing basis, or

Table 4. *Planting zones for dominant salt marsh plant species. Salinity ranges given in parts per thousands (‰)*

Species	Inundation Zone	Salinity Range (‰)
Distichlis spicata	high	5 - 40
Iva frutescens	high	5 - 30
Scirpus americanus	intertidal	5 - 15
Spartina alterniflora	intertidal	5 - 40
Spartina cynosuroides	high	1 - 20
Spartina patens	high	5 - 30

on mature marshes to enhance growth, is still controversial. GIBSON *et al.* (1994) have suggested that one application of fertilizer is insufficient. The addition of nitrogen to both planted and tidal marshes of the Chesapeake Bay has been shown to significantly increase above ground biomass and height on stands of short-form *S. alterniflora* in the inner marsh (RHEINHARDT and PERRY, 1993). However, the effects of nitrogen enrichment on existing tall-form stands was not clear. The effects of fertilizers varied among soils in studies performed on coarse-grained soils versus fine grained. The former showed a significant increase in above- and below-ground biomass with nitrogen addition (BROOME *et al.*, 1975; BROOME, 1990,) while the latter showed a decrease in stem density and below-ground biomass (VALIELA *et al.*, 1973). BROOME *et al.* (1981) determined that nitrogen (at 224 kg/ha) had to be applied below-ground in a slow release form in order to significantly increase *Spartina* spp. biomass in a transplanted marsh, since surface application was ineffective in increasing production over that shown by controls. Therefore, we presently recommend that marsh fertilization should be by below ground placement of slow release fertilizer. Studies have shown that 200 kg/ha (approximately 225 lbs/acre or one ounce per plant) of a high nitrogen (we suggest a 18-6-12) slow release mix is sufficient (BROOME, 1990).

Planting Time

Planting is not necessarily limited to any particular time of year. However, we recommend early spring for planting tidal marshes on the Chesapeake Bay. Appropriate planting times for all grass species are given in Table 5. Species planted late in the growing season or during the fall or winter often do not develop enough root stock to overwinter (Perry, personal observations). Survival rates for late plantings may be low if planted in exposed locations necessitating replanting. Early planting of sprigs, however, is susceptible to spring storm erosion (HARDAWAY *et al.*, 1981; HARDAWAY and BYRNE, 1997). General planting guidelines for salt marshes have been prepared by WOODHOUSE *et al.* (1974), GARBISCH *et al.* (1975), KNUTSON (1977), WOODHOUSE (1979), and BROOME *et al.* (1981). High marsh species planted above MHW during July and August are susceptible to drought conditions, and can be lost if there is insufficient rainfall and the sprigs are not irrigated (Priest, personal communications).

Shade

The dominant east coast marsh grasses (*Spartina* spp., *Distichlis spicata*) utilize the C4 photosynthetic pathway. As such, they do not flourish in a shaded environment (CALDWELL, 1974; MOORE, 1978; LONGSTRETH and STRAIN, 1977; LEVITT, 1980). MCGUIRE (1990), working in the York River, a tributary of Chesapeake Bay, found a negative correlation between the density of *Spartina alterniflora* and shading effects of nearby piers. Other salt marsh species in the mid-Atlantic region have shown similar patterns (GARBISCH *et al.*, 1975; HARDAWAY *et al.*, 1980, 1981; Perry, personal observations). Current practices to control the negative effects of shading include: 1) removing overhanging tree limbs from the adjacent shorelines, and 2) adjusting the height of piers that may cross the marsh area. A minimum height of 1.2 m above wetland substrate and a maximum width of 1.2 m are required to qualify for the Norfolk District Corps of Engineers Regional Permit 93-RP-17.

Grazing

ANKNEY (1996) advocates a change in management regulations to allow more harvesting as a method for reducing geese populations. Wire enclosures are successful in protecting marsh vegetation but may be cost prohibitive for expansive areas (BAZELY and JEFFERIES, 1986; ANKNEY, 1996). There have been anecdotal reports that stretching wire or rope across marshes may prohibit geese from landing, and the application of some commercially available substances to plants may make them unpalatable to geese; however, empirical data are lacking. Trapping is recommended as the most effective means to control overpopulation of muskrats with harvesting starting when muskrat density reaches one house per acre (DOZIER, 1953).

Table 5. *Recommended planting times for dominant salt marsh plant species in the Chesapeake Bay. The table represents the survival probability of herbaceous and grass-like plantings (**) and trees and shrubs (++). (H)=herbaceous, (W)=woody (tress and shrubs).*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Optimum	(H)				**	**	**						
	(W)	++	++									++	++
Good	(H)			**				**					
	(W)			++	++					++	++		
Fair	(H)		**						**				
	(W)					++			++				
Poor	(H)	**											
	(W)						++	++		**	**	**	**

Invasive Plant Species

Newly constructed marshes will be susceptible to catastrophic disruption from undesirable plant invaders and foraging animals. A good design, properly implemented, with a regular monitoring program can help minimize and quickly correct adverse situations before they become unmanageable. Once a marsh reaches a self-sustaining maturity, instances of disruption from invaders or foraging animals should not be catastrophic.

Small populations of *Lythrum salicaria* can be removed by pulling up plants, but this should be done before flowering to avoid dispersing seeds during removal. Application of herbicides (such as the glyphosate Rodeo™ or a triclopyramine such as Garlon ™) can be used to effectively control *L. salicaria*, but care must be taken in their application. Broad-spectrum herbicides can destroy adjacent desirable species (GABOR *et al.*, 1995; GARDNER and GRUE, 1996; NELSON *et al.*, 1996). Research is presently being conducted on the efficacy of using biological controls such as the root-boring weevil, *Hylobius transversovittatus*, though the potential effects on native relatives of *L. salicaria* need to be determined (BLOSSEY, 1993; MALECKI *et al.*, 1993).

Salinity and flooding have been shown to have an adverse effect on *P. australis* (HELLINGS and GALLAGHER, 1992). Die-back has been reported at sites where soil salinity was higher than 15 ‰ (LISSNER and SCHIERUP, 1997). Work by PRIEST (1989) suggests that the potential for *P. australis* invasion in polyhaline areas can be inhibited by concentrating restoration efforts to elevations at or below mean high water. In a recent study, *P. australis* density was found to be significantly smaller in constructed tidal marshes that were surrounded by subtidal perimeter ditches when compared to unditched marshes (HAVENS *et al.*, 1997). Attempts to control *P. australis* with herbicides and multiple burnings have met with some success (JONES and LEHMAN, 1987; CROSS and FLEMING, 1989). Systemic herbicides, such as the glyphosate Rodeo™, that are absorbed by the foliage and translocated to the rhizomes are effective if applied in the late summer or early fall. Care must be taken to avoid too high a dosage concentration which can result in the destruction of the foliage before the translocation of the herbicide. Disruption of the translocation of the herbicide to the rhizomes can also occur if the stems are broken during the application process.

Mulching

MOY and LEVINE (1991) recommend mulching with *Spartina* wrack to increase substrate relief, provide a food source for meiofauna, and make burrowing easier for oligochaetes. No estimate of the amount needed was presented; however, studies have shown that most of the benthic fauna are located within the first 5 cm of soil (MCCANN and LEVINE, 1989). On the west coast of the United States, GIBSON *et al.* (1994) found that organics added to sandy soil did not accelerate development of the soil nutrient pool; however, plant biomass and density responded positively to nitrogen addition. Although mulching is currently used in the Chesapeake Bay area, there has been little research on the effects of mulching on created tidal wetlands (Lee Daniels, Virginia Polytechnic University, Blacksburg, Virginia, personal communications). More work in this area is needed before it is recommended in general.

Monitoring

A monitoring protocol needs to be established as early as possible in the design stage of the project. The effort needed to monitor a site will vary from project to project and depend on the complexity of the project. In all cases, it is important to clearly present the goals and objectives of the monitoring plan. Most goals will be tied to measure "compliance" to permit requirements (see ZEDLER, 1996). A minimum of 5 years of monitoring data is needed; longer time spans may be required for complicated and/or large sites.

Objectives define the methods and data collection that are necessary to assess whether each goal has been met. Objectives are descriptive and include such parameters as plant survival, plant morphometrics, vegetation ecology, site hydrology, substrate maturation (e.g., organic accumulation in the soil), and habitat use. Plant survival can be measured by counting living plants in randomly located plots. We recommend using a square plot 1 m × 1 m in size for easy comparison with existing studies; however, other shapes and sizes may be used. Plant morphometrics includes measuring the number, length, width of leaves and/or stems, number of flowers, number of mature fruits, and many other numerical measurements taken from many individual plants. It can be a time consuming process unless clear limits are spelled out in the objectives. For example, one may include counting the number of leaves on each plant in every other plot, or the height of each plant (see ZEDLER, 1996). By minimizing, where possible, the number of plots, or the size of the plots, vegetation data would be available for comparison to natural systems, yet the budget or capability of the monitoring party would not be overtaxed. Other vegetation information that is useful includes vegetation cover, easily obtained from the random plots, and/or biomass. We do not recommend the latter as it is time consuming (requires the cutting, drying, and weighing of the clipped vegetation) and is highly variable in nature. Therefore, it is difficult to use for comparative purposes.

Vegetation zones in tidal salt marshes are very distinct. Therefore, if planting zones are chosen properly, there should be little movement in species. Movement of *Spartina alterniflora* slightly above and/or slightly below its designated zone can be expected and is not a cause for alarm. An increase in high marsh species into the low marsh zone over time, however, indicates elevation or zone designation problems. Monitoring of vegetation growth can be done by direct sampling (cover and/or density of individual species) or by interpretation of aerial photographs, or a combination. In both cases, care should be taken to establish permanent markers for future reference.

The water levels of tidal salt marshes can be measured using tide gauges or other comparable methods. Apart from the formation of mud waves or occurrence of severe erosion, little change in tide zone or range should occur. Establishing a permanent elevation reference point on a stable area near the project will allow quick reference to a known tidal datum.

Measuring soil maturity is a difficult process. Soil nutrient analysis is often well beyond the capabilities and/or budget of the monitoring agencies. Other soil parameters that may be used are percentage of particulate soil organic matter, bulk density, and soil particle size composition. Since natural marsh formation usually begins on a sand substrate and maintains its relative elevation in respect to sea level through an organic substrate accumulation over the sand, one would expect an increase in soil organics and decrease in bulk density over time. Soil particle size and composition should not change significantly over time since a well designed tidal salt marsh would have a stable substrate environment (with the exception of organic matter accumulation). A small increase in clay and/or silt on the surface horizon can be expected and considered normal. An increase in sand particle size, however, indicates the loss of fine particles and may be a sign of surface erosion.

CASE STUDIES

Goose Creek, Chesapeake, Virginia

The Goose Creek Tidal Wetlands Bank is an approximately 4.2 ha anthropogenic wetland created by the Virginia Department of Transportation for the purpose of compensating for future unavoidable wetland losses due to highway construction. The site was an active borrow pit adjacent to Goose Creek, in the tidal headwaters of the Western Branch of the Elizabeth River (0 to 18 ‰) (Figure 4). As material was removed for highway projects in the vicinity, the elevation of the bottom of the pit was matched to that of the marshes in Goose Creek. Once the desired

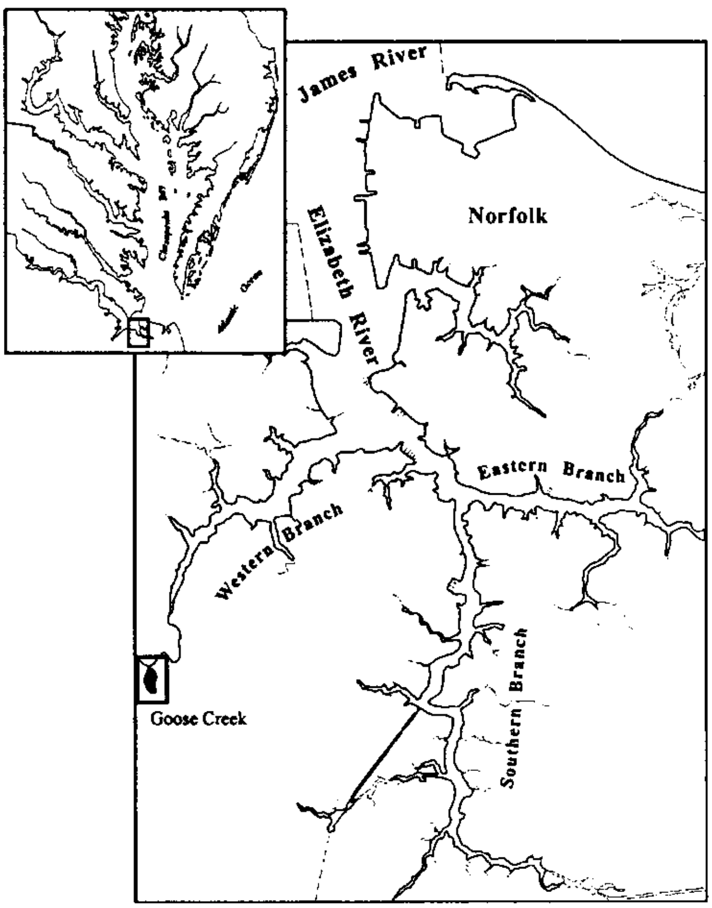


Figure 4. Location of Goose Creek Mitigation Bank. The Goose Creek mitigation site, created in 1980, is the oldest mitigation bank in the Chesapeake Bay watershed (from Barnard *et al.*, 1997).

material had been removed, state and federal permits granted, and the elevations finalized, the pit was planted with five species of salt marsh plants in July-August of 1982 (Figure 5). The majority of the area (approximately 70 %) was planted in *Spartina alterniflora* (smooth cordgrass) and *S. cynosuroides* (big cordgrass). Also planted were *S. patens* (salt meadow hay), *Distichlis spicata* (saltgrass), *Iva frutescens* (marsh elder) and *Baccharis halimifolia* (groundsel tree). More than 90,000 transplants taken from adjacent marshes were placed on approximate 0.62 m centers (Steve Russell, Virginia Dept. Transportation, personal communications). No tidal connection was made to Goose Creek until the vegetation had been sprigged. During planting, sprigs already planted were watered daily using 5 cm diameter portable gas pumps and fresh water that had accumulated in the ditches of the pit. When planting was completed, a 32 m wide section of the embankment that separated the pit from Goose Creek was removed allowing a 19 m wide tidal opening. The mean tide range at the site was 1.2 m and the marsh was planted at an elevation of 0.77 m to 0.93 m above mean low water.

Although no monitoring was required under the permits issued for the bank, both plant dynamics and nekton use have been studied. After an initial increase to 25, the number of plant species present stabilized at approximately 16. The percent cover increased steadily to 68 % over the first four years. Peak standing crop reached a high of 1,076 g/m^2, six years after planting and appeared to level off at approximately 900 g/m^2 in year seven (BARNARD *et al.*, 1997). Data from thrice-yearly blocknetting and seining indicate significant use of the 4 hectare tidal marsh by finfish and free swimming invertebrates. Twenty-one species of juvenile and adult finfish were documented along with three species of invertebrates. All biota collected and recorded was common to the Chesapeake Bay region. One invasive plant species, *Phragmites australis* (common reed), was present.

Positive Aspect

Although vegetative cover developed slowly at first due to an initial substrate elevation problem, the parameters monitored appeared to be progressing normally after 4 years (PRIEST and BARNARD, 1993; BARNARD *et al.*, 1997). Habitat use was high (BARNARD and PRIEST, 1993; BARNARD *et al.*, 1997).

Concerns

No goals, objectives, or long term monitoring plans were identified for the project. At present, the only potential problem with the wetland is the presence of the invasive native plant, *Phragmites australis* (common reed), which has now become one of the dominant species in the bank. As of this date an evaluation of the effect of this species on the overall ecological or compensatory value of the system has not taken place. The uneven elevations found throughout the marsh (i.e., variable slope) did not allow complete drainage of the marsh surface (BARNARD and PRIEST 1993; Perry personal observations).

Two recommendations could have made this a better design. First, the proposed marsh surface should have been graded to a positive slope to assure drainage. Uneven areas and low areas should have been smoothed and/or brought up to grade. Second, a simple design that avoided attempting to establish a high marsh zone and concentrated on low marsh elevations (i.e., *S. alterniflora* zone) may have avoided the invasion by *P. australis* (see case study of Monkey Bottom next).

Monkey Bottom, Willoughby Bay, Norfolk, Virginia

The Monkey Bottom Salt Marsh (MBSM) was created by the U.S. Department of Defense in an old spoil disposal area adjacent to Willoughby Bay in Norfolk, Virginia (Figure 6). As a condition of the permit to reuse the disposal area, the DOD was required to replace approximately 3.1 ha of tidal wetlands which had developed in the center of the disposal area (PRIEST, 1989; PRIEST *et al.*, 1990).

The new tidal wetland was designed for a parcel of the disposal area adjacent to a 1.3 m diameter culvert. The culvert passed under Interstate 64 causeway and connected the area to the waters of Willowby Bay. Because of the extensive stands of common reed (*Phragmites australis*) present in the disposal area, the new marsh was designed to support salt marsh cordgrass (*Spartina alterniflora*) at and below the elevation of mean high water. It was planned that this low design elevation would prevent the colonization of the compensation area by the invasive common reed (PRIEST, 1989). The correct elevation and grade were taken from an adjacent smooth cordgrass marsh (Perry, personal observations).

Construction of the marsh began in the summer of 1984 concurrent with the construction of the berm for the new disposal area. The compensation area was graded to elevations at and below mean high water. Drainage was accomplished by sloping the area to four lateral ditches which emptied into the main ditch that connected to the culvert under I-64 (Figure 7). During the grading and planting the area was isolated from tidal inundation by placing a plug in the culvert.

The marsh was planted with salt marsh cordgrass during September and October 1984 with a tree planter. The two sections closest to the City of Norfolk's Visitor Center were planted on 65 cm centers with transplants from the site. The two sections furthest from the Center were planted with six month old seedlings also on 65 cm centers. The entire area was broadcast with an especially prepared 19-5-12 slow release fertilizer at the rate of one ounce per plant. The fertilizer was mechanically raked into the soil prior to planting. The entire area was planted, even areas above and below the expected successful growth zone so that complete coverage would rapidly occur (Priest 1989). In the winter of 1984 a large mudwave formed in the southwest cell. It was removed and replanted by hand in the spring of 1985.

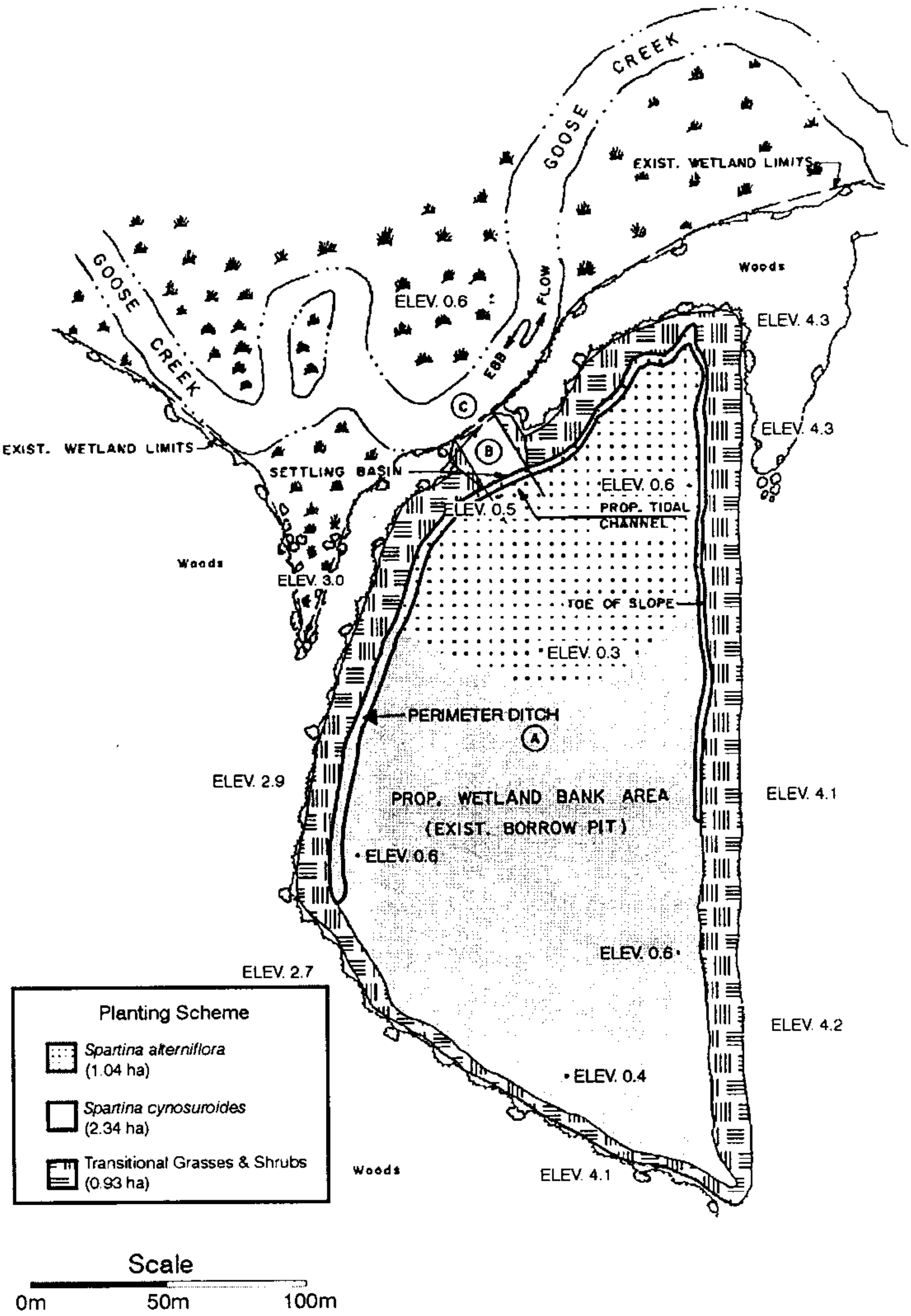


Figure 5. Goose Creek Mitigation Bank site design plan. Two major wetland planting zones were designated: low marsh (to be planted with smooth cordgrass - *Spartina alterniflora*), and high marsh (to be planted with salt meadow hay - *Spartina patens* - and salt grass - *Distichlis spicata*). Salt bush (*Iva frutescens*) and grounsel tree (*Baccharis halimifolia*) were planted on 3.5 m centers along the bank slope. Salinity at the site averages varies from 0 to 18 parts per thousand.

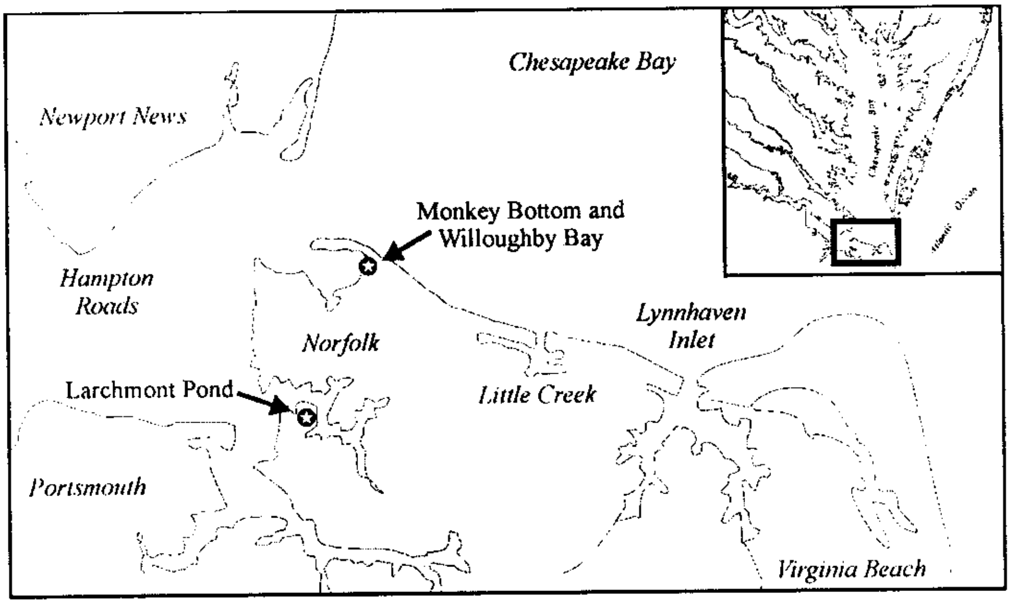


Figure 6. Location of Monkey Bottom created salt marsh. The 3.1 ha marsh was created in 1984 to compensate for loss of tidal wetlands, due to placement of spoil materials, immediately west of the created marsh site. Salinity at the site varies from 15 to 28 parts per thousand.

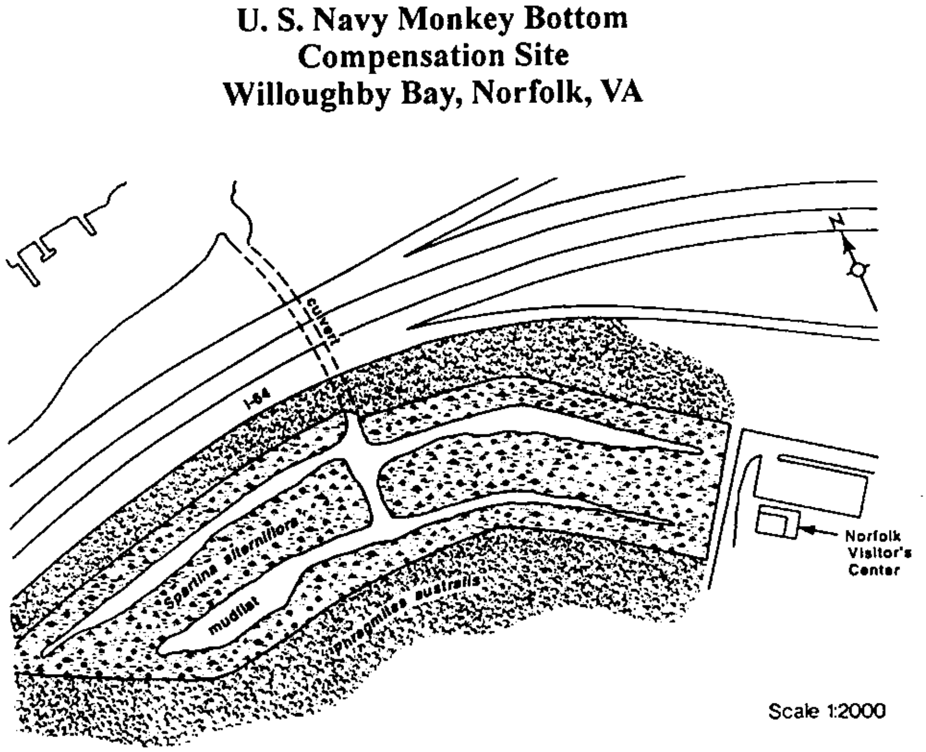


Figure 7. Monkey Bottom plan view with planting area and creek placement. Creeks were placed to provide complete drainage of the created marsh. Planting area was all low marsh and only smooth cordgrass (*Spartina alterniflora*) was planted.

Table 6. *Summary of vegetation data for the Monkey Bottom created salt marsh and two nearby natural salt marshes. Data were collected during the fourth growing season of the Monkey Bottom marsh. Cover = % m^{-2}, density = stems m^{-2}, standing crop = g m^{-2}, elevation = MLW. From Priest (1989).*

MONKEY BOTTOM	Mean	Std. Dev.	Min.	Max.	N
Cover	46	28.55	0	85	26
Density	340	220.42	0	744	26
Standing Crop	591	392.45	0	1120	26
Elevation (m)	1.54	0.40	0.96	2.43	24
WILLOUGHBY BAY	Mean	Std. Dev.	Min.	Max.	N
Cover	64	13.57	40	80	6
Density	308	112.74	180	456	6
Standing Crop	559	213.32	176	770	6
Elevation (m)	2.01	0.18	1.75	2.23	5
LARCHMONT POND	Mean	Std. Dev.	Min.	Max.	N
Cover	58	13.18	40	80	7
Density	465	87.95	392	648	7
Standing Crop	448	144.38	263	713	7
Elevation (m)	2.60	0.12	2.37	2.74	7

PRIEST (1989) compared the vegetation of MBSM, then in its fourth growing season, to that of two nearby *Spartina alterniflora* salt marshes. He found no significant difference between vegetation standing crop, cover and density (Table 6). A Pearsons correlation, however, showed a significant positive correlation between elevation and all three vegetation parameters (Table 6). Priest also noted that there were frequent non-vegetated marsh areas in MBSM but none in the natural marshes. Many of these non-vegetated areas are presently covered by *Spartina alterniflora* (PRIEST, 1989) possibly indicating that the vegetation of MBSM was still in an immature stage of succession after four growing seasons. Priest also attributes the lack of correlation between the natural marsh elevation and environmental parameters to the low elevation ranges found in the natural systems.

FEIGENBAUM and SWIFT (1989) compared substrate organics, benthic community, and fish populations of MBSM and a nearby natural marsh. Their results showed that MBSM had accumulated 2-11 cm of sediment deposits. The deposits represented sand eroding from the nearby highway and dredged spoils berm. The original excavated surface was, however, significantly lower in organic matter content and water holding capacity. They concluded that since a thin veneer of modern marsh sediment is forming over a consolidated sediment, the nutrient cycling capacity of the MBSM may be less efficient than a natural system. They further note that the compacted soil would be less conducive to burrowing invertebrates and plant roots.

Positive Aspects

The vegetation community is maturing and would soon be expected to reach cover values comparable to natural systems. Thus, the structure of the marsh, and therefore the avian habitat value, may approach or equal that of natural systems. The use of elevation in the design to eliminate *Phragmites australis* was successful.

Concerns

No goals, objectives, or long term (5 yr) monitoring plan were established for this project. The late planting dates allowed little time for establishment of the plants before the onset of winter weather. Therefore, winter die-back was severe (Perry, personal observations). After three seasons of growth the vegetation of MBSM, as judged by the low vegetation cover and large density counts, was still in an immature state (PRIEST, 1989). The compacted subsoil will diminish the nutrient function ability and possibly the benthic invertebrate community and below-ground vegetation biomass of the system.

Several things could have been initiated early on in the design that could have alleviated many of the problems seen in this project. First, goals and a long term (5 yr) monitoring plan should have been required. Second, the problem of lost functions and values could have been addressed by having completed the planting earlier in the growing season. Earlier planting would also have provided an extra growing season for the vegetation to reach maturity. Reestablishing the nutrient cycling processes, benthic communities, and below-ground vegetation biomass to ones similar to a natural system may have been accelerated through a more rigorous review of, and recommended changes to, the original construction design. The differences in hydraulic conductivity and soil plasticity of clay verses sandy substrate have been well documented (see GREENBLATT and SOBEY, this volume). Therefore, modifications should have been made to the planting substrate. Several options existed, such as adding soil amendments such as sand and organics; however, the most appropriate may have involved removing the dredged spoils from the site. Many million cubic tons of sand were dredged as part of the project and used to replenish a nearby beach (PRIEST, 1989, Perry, personal observations). If excavation of the creation site were increased to approximately 0.5 m below the desired elevation, and sand were instead used to bring the marsh up to the required planting elevation, the results would have been a more natural substrate and, therefore, promoted a more natural evolution/succession process in MBSM.

Sarah's Creek, Gloucester Point, Virginia

The construction of a 0.65 ha tidal salt marsh in Gloucester County (37°16'30"N 76°29'40"W) adjacent to Sarah's Creek, a tributary of the York River (Figure 8), was required by regulatory agencies as compensatory mitigation for wetlands impacted during the construction of a shopping center (R. Harold Jones, US Army Corp of Engineers, personal communications). The project site prior to construction consisted of an upland wooded area dominated by loblolly pine (*Pinus taeda*), sweetgum (*Liquidambar styraciflua*), and red maple (*Acer rubrum*).

The design concept of the constructed marsh called for salt marsh cordgrass (*Spartina alterniflora*) and saltmedow hay (*Spartina patens*) dominated islands, surrounded by a subtidal perimeter channel, with additional planting along the channel/upland fringe. An extensive amount of excavation (2-3 m) was required to lower the elevation to allow tidal inundation from Sarah's Creek (15 ‰). The site was excavated into the subsoil and no soil amendments were added during marsh construction. One-year-old greenhouse-grown *Spartina alterniflora*, *Spartina patens*, and *Distichlis*

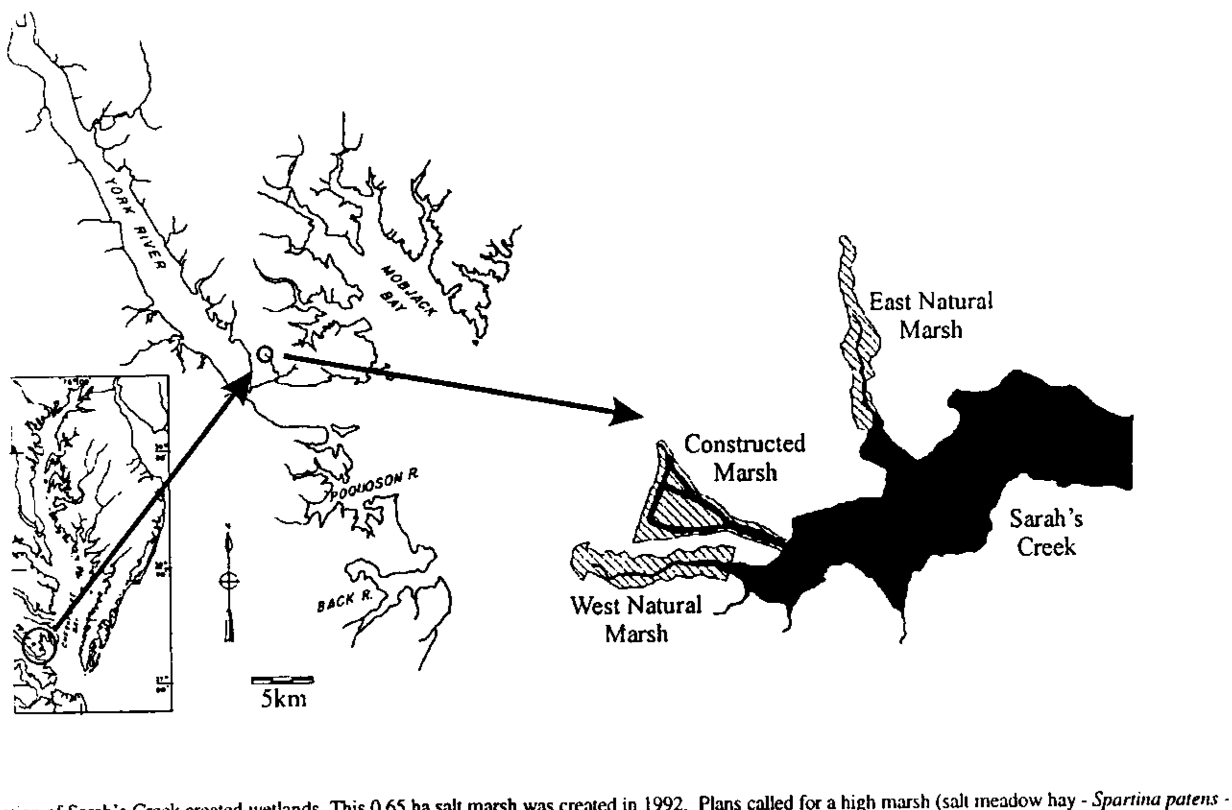


Figure 8. Location of Sarah's Creek created wetlands. This 0.65 ha salt marsh was created in 1992. Plans called for a high marsh (salt meadow hay - *Spartina patens* - and salt grass - *Distichlis spicata*) and low marsh (smooth cordgrass - *Spartina alterniflora*) zone. Salinity of the constructed site varied from 4.7 to 8.2 parts per thousand in the spring and summer of 1992 (from Havens *et al.*, 1995).

spicata were planted on 50-90 cm centers on the graded land in the spring of 1987. The channel was excavated to a depth of 1 m below mean low water.

No monitoring plan was included in the project plan; however, an intensive study was conducted in 1992 comparing the constructed marsh to two nearby natural marshes (HAVENS *et al.*, 1995). Significantly lower stem density, subsurface organic carbon content and density of bird nesting sites were observed in the constructed marsh as compared to the natural marshes. Seasonal differences in fish utilization were also noted, probably attributable to a lack of microtopography in the constructed marsh.

Positive aspects

This marsh has successful growth of the target marsh species, *S. alterniflora* and *S. patens*, with only a trace of the invasive species *Phragmites australis* which has probably been restricted by the presence of a subtidal perimeter channel (HAVENS *et al.*, 1997), salinity of the system, or the elevations selected.

Concerns

No goals, objectives or long-term (5 yr) monitoring plan were established for this project. There was significantly lower stem density, subsurface organic carbon content and density of bird nesting sites and seasonal differences in fish utilization. The design of the created marsh, particularly the constricted tidal exchange, is unique to created marshes and has not been documented in nature. Its impact on the hydrology and ecological functions of the created system and the adjacent ecosystem are unknown. Planting on 30 cm centers, adding sand and/or an organic soil layer (also see recommendations for Monkey Bottom above) and incorporating some microtopography (runlets and rivulets) into the design could have resulted in this marsh functioning more like the adjacent natural marshes on a quicker time scale. Tidal exchange should have been increased by designing for a salt marsh that is wider toward the mouth and tapers gradually upstream, thereby reproducing the natural landscape position and alignment found in the other salt marshes of the Sarah's Creek ecosystem.

SUMMARY AND CONCLUSIONS

Current trends point to an increase in the use of salt marsh construction as mitigation of (i.e., compensation for) natural systems lost to permitted activities in wetlands. To date the most common problems recognized with created tidal salt marshes in the lower Chesapeake Bay have been improper elevations and/or substrate, poor drainage, poor tidal exchange, and, to a lesser extent, poor planting stock or poor on site handling of planting stock. Many of these same problems are discussed by ZEDLER and CALLAWAY (this volume).

However, even though construction of tidal salt marshes has a checkered past, if proper design, construction, and planting methods are incorporated, the success of created systems can be vastly improved. Landscape position, substrate type and elevation, along with correct species selection are critical, but make up only pieces of the puzzle. Although there is no cookbook method that works for every site, there are some tried and true methods that will maximize the chances of establishing a self-sustaining tidal marsh system. We have the following recommendations:

1. Landscape: Avoid areas that are exposed to heavy wave activity, have historically high erosion rates or highly erodible soils, and/or may receive constant heavy boat wakes. Wind fetch for wave generation should be less than 0.8 km. Protective engineered structures (breakwaters, offshore rip-rap or bars, tombolas) need to be considered for sites >0.6 km. Cobble beaches do not make good planting habitat.

2. Elevation: Ensure the elevations are appropriate. Planting zones are defined by plant species of choice and should always be related to a tidal datum. Low marsh plants should be planted between mean tide level and mean high water. High marsh plants should be between mean high water and spring high water. It is always a good idea to plant species above and below the determined zones to compensate for errors in calculation of variations in environmental parameters. There are three methods that can be used to determine elevations and make the planting zones: 1) Survey elevations taken from an adjacent marsh, 2) determination of the tide range through the collection of 29 days of tide gauge data referenced to the nearest 19 year tide data location, or 3) determination of the tide range through the collection of 29 days of tide gauge data, averaging the data, and assuming that the average is the mean tide level.

3. Grading and tide exchange: All sites should be graded to a minimum slope of 10:1 (H:V) wherever possible and designed for adequate tidal exchange. The latter is particularly important if the created marsh is not immediately adjacent to tidal waters. Sites should be graded to effect positive drainage and minimize areas of standing water at low tide. Planting survival will be poor in areas that drain poorly.

4. Soils: It is important to avoid cat-soils and soils comprised mostly of clay (particularly marl). Soils should be tested and confirmed by a specialist. While some studies have shown that mulching promotes substrate relief and benthic community development, more research is needed before it can be recommended with confidence.

5. Vegetation: Salt hardened plants are most likely to survive. Plants hardened to tolerate salinities of 5 to 10 ‰ above the ambient water column salinity are recom-

mended for summer plantings. Plant storage on site should be kept short (less than 2 weeks). If they must be stored longer, it is preferable that they be placed in a shallow, wet trench and roots covered with wet soil in the appropriate tide zone. If the latter is not possible, they should be watered twice daily with ambient water and protected from drying.

6. Planting: Make certain species are placed at appropriate elevations and planted at the proper depth (20 cm). Holes need to be closed completely to eliminate air and water pockets. Preferred planting time is March through June; however, planting at any time is acceptable other than in areas prone to winter storms and high marsh areas in the heat of summer. Replanting will more than likely be necessary for planting done outside the preferred window.

7. Fertilizer: A nitrogen-rich slow-release fertilizer should be added to each planting hole prior to closing.

8. Shading: Any design should minimize shading by trees or structures. Piers or walkways over the marsh should be a minimum of 1.2 m in height.

9. Invasive species: Possible invasive species (plants and animals) should be identified during the early design phase of the project. A monitoring and contingency plan for control, if necessary, should be developed.

10. Monitoring: A monitoring protocol needs to be established as early as possible and should outline methods for measuring plant survival, presence/absence of invasive species, and tide range (verification). A minimum of 5 years of monitoring data is needed; longer time spans may be required for complicated and/or large sites.

Finally, as the science of restoration ecology matures, we will learn more and more about how to improve our methods for creating salt marshes. Therefore, all engineers, managers, regulators, and scientists involved in the design, construction, and monitoring of tidal salt marshes must remain up to date concerning the most recent improvement to our methods for creating compensation sites and should not hesitate to incorporate them into their most recent projects.

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