EVALUATION OF MARSH CREATION AND RESTORATION PROJECTS AND THEIR POTENTIAL FOR LARGE-SCALE APPLICATION, GALVESTON-TRINITY BAY SYSTEM

by

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ABBREVIATED FINDINGS

This project used detailed field surveys to inventory and evaluate wetland restoration, enhancement, and creation projects in terms of their original design criteria, objectives, physical characteristics, geomorphology, hydrology, site stability, vegetation, success in meeting performance goals, and potential for large-scale application.

Field surveys provided an interesting comparison of design types, criteria, and site characteristics. Of the seven sites analyzed, two were primarily fill sites, two were fill and shape sites, two were scrape-down sites, and one was a natural substrate with shore protection.

Accomplishment of performance goals could not be evaluated in all cases because of the "youth" of some sites and the fact that some are still under development. Overall, however, design specifications were followed closely at most sites. With few exceptions, such as slight variations in transplant spacings and slope, it appeared that vegetation was planted as specified.

There were differences in development of vegetation in fill sites and scrape-down sites. At scrape-down sites the surface is cut down to achieve intertidal and subtidal elevations, whereas at fill sites, fill material is used to elevate the surface to intertidal levels. Fill sites, in general, achieved a higher density of vegetation over a shorter period of time, in part due to relatively flat intertidal surfaces. At scrape-down sites, however, more precise and intricate geomorphic and hydrologic features in aquatic and marsh habitats could be developed.

Analyses of vegetation characteristics and land surface profiles indicate that the fill, and fill and shape sites had achieved the densest foliar cover, with percentages ranging in the 60s, followed by scrape-down sites with percentages in the 40s. Heights of *Spartina alterniflora* also varied. At many sites there was a high inverse correlation between height of the land surface and height of *Spartina alterniflora.* Along some transects this relationship was exponential, and along others linear.

The average vertical range in land surface height on which *Spartina alterniflora* occurred varied from 25 cm to more than 60 cm. For successful development, it is important to define intertidal elevations at the project area or to use nearby natural marshes as reference sites to determine the vertical range in elevation of *Spartina alterniflora* for the created marsh. Although not as cost-effective, vegetation could be planted beyond its expected range and allowed to equilibrate with the mean intertidal range. A more cost-effective approach would be to plant at a narrower range with the expectation that transplants will spread and cover the normal tidal zone. At sites where organically-rich fill material is used, wider spacings, as much as 11 m between transplants, appear to work and are the most cost effective as shown at the Bayport Demonstration Marsh.

In terms of substrates, frequently inundated organically-rich muds (silt and clay) seemed to have the most potential for relatively rapid growth and development of vegetation. In contrast, low-organic, dewatered Pleistocene clays at scrape-down sites, such as at Highland Bayou, may take time to become fertile enough for a more rapid spread in vegetation.

Subsidence could be a threat in all areas if rates do not remain low, but, in terms of shoreline stability, all sites had design criteria to guard against erosion.

Among the criteria with potential for successful large-scale restoration based on sites surveyed are:

- achievement of intertidal elevations and appropriate water regimes for transplanted vegetation based on intertidal elevations of local natural marshes to account for variations in the vertical range of *Spartina alterniflora* at different sites

- protection of transplants from wave and current erosion using permanent wave barriers, or development of sites in interior protected settings

- establishment of adequate water circulation, including channels large and deep enough to provide good tidal exchange

- location of sites near existing sources of dredged material to provide a cost-effective source of material for fill

- development at sites with potential for expansion, including marginal upland and transitional areas to allow for the possibility of subsidence

- placement of transplants at cost-effective spacings, which may be as much as 11 m in intertidal fill material, but at closer spacings in irregularly flooded high marsh areas to achieve denser percent cover over the short term

- utilization of organic rich fill material for sites where rapid colonization is a goal

- creation of an on-site nursery to provide a local source of transplants and an on-site laboratory for observing plant health and survivability

Both scrape-down and fill sites, plus combinations of the two, have potential for large-scale development. Scrape-down sites are usually developed in uplands so there is the potential of adding wetlands without displacing aquatic (bay bottom) habitats, and thus expanding the overall area of wetland habitats in a bay system. In fill sites, vast quantities of dredged material from navigation channels provide a potential source of fill for large-scale development. Most of these sites displace bay bottom habitats, but in many cases in the Galveston Bay system, the sites are former marshlands that have been lost to subsidence. In currently subsiding zones, acquisition of adjacent transitional areas and uplands can provide an elevated substrate for the growth and expansion of wetlands in response to relative sea-level rise.

The criteria and techniques identified for large-scale marsh development in the Galveston-Trinity Bay system have potential for application in other bay-estuary-lagoon systems.

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INTRODUCTION

Wetland loss as a result of natural processes and human activities in the Galveston-Trinity Bay system (White and others, 1993) and in other estuarine systems along the Gulf Coast is of continuing concern and highlights the need for designing and implementing marsh restoration and creation projects at a large scale. There have been numerous efforts by many agencies, including federal, state, local, and private entities, to restore, enhance, and create wetlands in the Galveston-Trinity Bay system (Matthews and Minello, 1994). Unfortunately, these efforts have been uncoordinated, and most have been carried out at a relatively small scale. In addition, most completed projects have not been systematically monitored and evaluated on a long-term basis to determine their success in creating productive, functional wetlands. Analysis and evaluation of the most successful criteria and techniques for marsh restoration/creation in the Galveston-Trinity Bay system will help provide guidelines for large-scale application and marsh development in other bay-estuary-lagoon systems.

Objectives

This project used detailed field surveys to inventory and evaluate wetland restoration, enhancement, and creation projects in terms of their original design criteria, objectives, physical characteristics, geomorphology, hydrology, site stability, vegetation, success in meeting performance goals, and potential for large-scale application. Among the objectives were to evaluate and synthesize criteria considered important for the successful accomplishment of large-scale restoration and creation projects. In an area where thousands of hectares of marsh habitats have been lost since the mid-1950's, there is a need for planning and implementing marsh restoration and creation at a much larger scale than a few tens of acres. Plans for large-scale restoration of wetlands would greatly assist the State of Texas and the Texas Coastal Management Program in achieving the goal of no overall net loss of state-owned wetlands, and the goal of the Galveston Bay Plan (GBP) of the Galveston Bay National Estuary Program to increase the quality and quantity of wetlands in the Galveston-Trinity Bay system.

Background

Texas is currently developing a wetland conservation plan for state-owned coastal wetlands with an overall goal of no net loss of coastal wetlands. Coastal management legislation in 1991 (SB 1054) created the State-owned Wetland Conservation Plan (SOWCP) that is now incorporated into a state statute (PARKS & WILDLIFE CODE, Chapter 14). The SOWCP is a comprehensive strategy for (1) determining the status and trends of Texas coastal wetlands, the causes of declines in wetland acreage and quality, and ways to restore or mitigate for loss and damage; (2) educating the public about functions and values of coastal wetlands; and (3) establishing coordination and cooperation among all state and federal agencies that manage and protect the resource. Environmental Protection Agency (EPA) funding has assisted in developing several components of the plan, including education and the identification of existing programs and mechanisms available to protect, preserve, and restore coastal wetlands. When completed, the SOWCP must be approved by the School Land Board and the Parks and Wildlife Commission.

Texas recognizes that "it is vital to preserve state-owned coastal wetlands as areas of great natural diversity and productivity and as natural storm protection and flood buffers to protect coastal property "(PARKS & WILDLIFE CODE, Chapter 14). The State further recognizes that "state-owned coastal wetlands are seriously threatened due to increased coastal development, point and nonpoint source pollution, and subsidence." For example, wetland loss from subsidence, erosion, and other factors in the Galveston-Trinity Bay area between the mid-1950's and 1989 was approximately 19 percent (White and others, 1993).

As a consequence of the recognized importance of coastal wetlands and the losses and degradation of wetland habitats, restoration, creation, and enhancement are receiving greater attention. For example, the SOWCP requires "provisions for an inventory of sites for compensatory mitigation, enhancement, restoration, and acquisition priorities." The GBP considers wetlands loss and degradation as the number one management problem for the Galveston-Trinity Bay system and therefore is setting as a goal the expansion of the area of vegetated wetlands in the Galveston Bay area by more than 6,000 ha within 10 years. The GBP also calls for an evaluation of the effectiveness of various marsh creation and enhancement techniques.

METHODS

Records of federal and state agencies were examined and regional wetland experts involved in restoration/creation projects were contacted to locate marsh restoration and creation sites in the Galveston-Trinity Bay system. The data were entered into a geographic information system (GIS) for easy analysis of site location with respect to existing features and processes, such as bays, lakes and bayous, natural wetlands, topography, land use, sources of freshwater inflow, subsidence rates, and human activities. Examples of sites located for *Spartina alterniflora* mitigation are shown in Figure 1.

Sites greater than 0.5 ha were identified and a matrix was developed (Appendix) showing original wetland restoration and creation specifications and site characteristics, including design criteria, project objectives, size, geomorphology, bathymetry, hydrology, salinity, type of restoration, and type of vegetation. If planted, information included original density of plantings, elevations with respect to mean sea level, shoreline stability, orientation with respect to prevailing winds, fetch, rates of relative sea-level rise, lithology of substrate, and composition, volume, and properties of fill, if used. Data for the matrix were entered into a computer data management system for output display of various defining characteristics of the marsh restoration and creation projects.

The data in the matrix were instrumental in selecting seven sites for detailed field compilation, analysis, and evaluation of (1) design criteria, (2) objectives, (3) site characteristics including physical parameters, geomorphology, hydrology and salinity, shoreline and site stability, and vegetation, (4) success in accomplishing performance goals, and (5) potential for large-scale wetland creation.

The Galveston Bay Natural Resource Uses Subcommittee of the Galveston Bay Estuary Program was selected as the workgroup to review and provide advice on the seven sites selected for evaluation. The workgroup consists of representatives from Houston Lighting and Power Company, Trinity River Authority, Galveston Bay Foundation, Houston-Galveston Area Council, Texas Natural Resource Conservation Commission, National Marine Fisheries Service, Texas Water Development Board, San Jacinto River Authority, Natural Resource Conservation Service, U.S. Fish and Wildlife Service, Texas Parks and Wildlife Department, General Land Office, and Environmental Protection

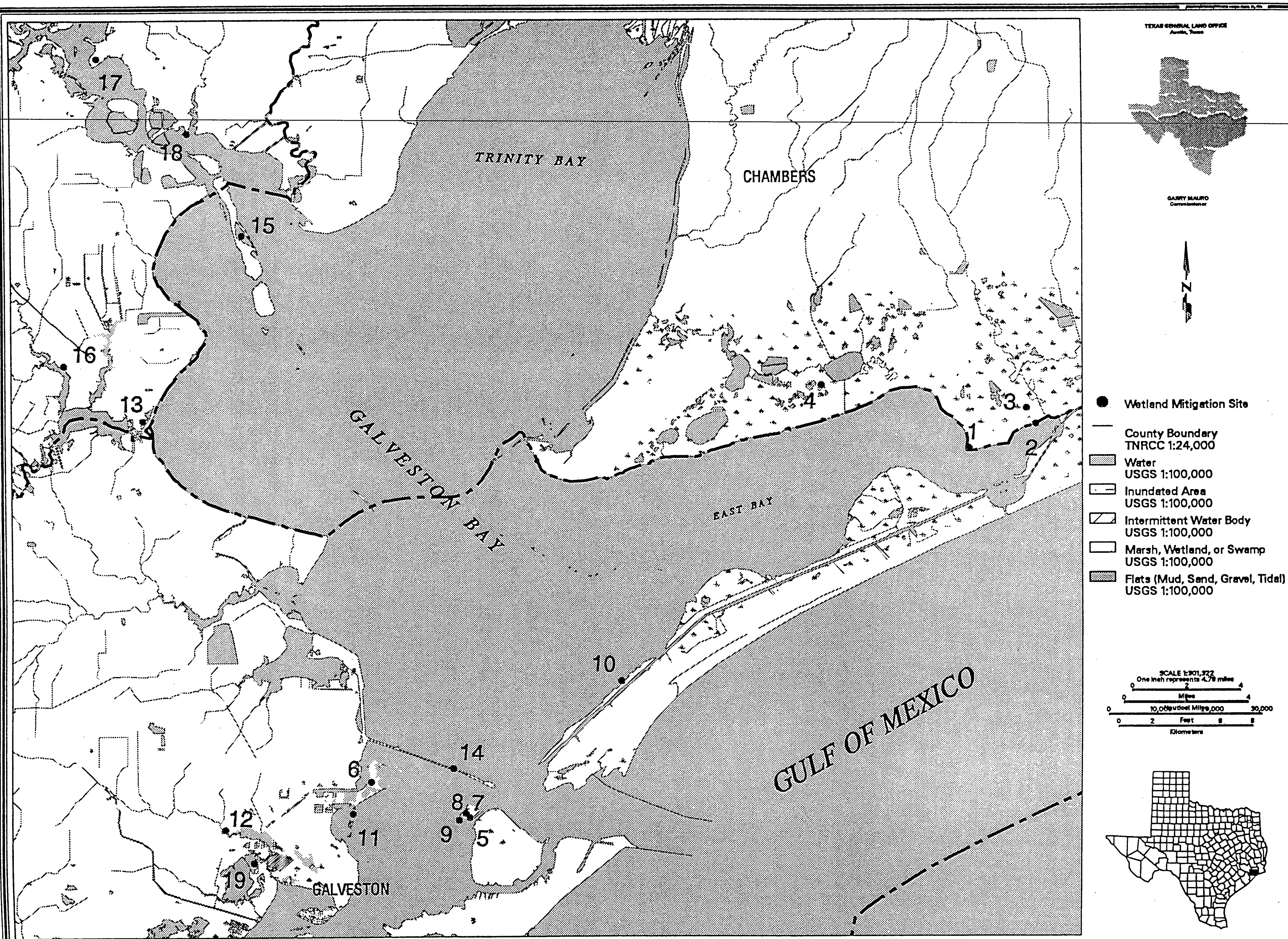


Figure 1. Marsh restoration/mitigation sites. Includes data from Matthews and Minello (1994); only sites with known latitude/longitude information are displayed.

Agency. A presentation on the project was made to the workgroup. Comments included adding a site on the north shoreline of East Bay in the Anahuac National Wildlife Refuge (Frozen Point Site, Fig. 2), because there was interest in evaluating a site that was created to help prevent shoreline erosion.

At the seven selected sites, detailed field surveys were conducted using a total station to determine land surface heights and slopes of created wetlands in relation to types of vegetation, percent cover, plant heights, vertical range in occurrence, hydrology, lithology of substrates, salinities, site stability, and exposure of shorelines to wave action. Field survey data were entered into a computer data base management system to assist in the analysis and evaluation of site characteristics in terms of the original design specifications and objectives. These analyses helped define the most successful criteria for marsh restoration and creation.

ANALYSIS AND EVALUATION OF RESTORATION/CREATION SITES

Site Selection and Field Methods

Field sites were selected on the basis of size, type restoration/creation, accessibility, and geographic distribution, among other factors. Seven sites were selected for detailed analysis and evaluation (Table 1 and Fig. 2). Each site was examined in terms of project objectives, design criteria, physical characteristics, geomorphology, hydrology and salinity, shoreline and site stability, vegetation characteristics, success in accomplishing performance goals, and criteria and potential for large-scale wetland restoration or creation.

Emphasis in field surveys was placed on transects along which measurements were made of land surface heights and slopes, vegetation composition, vegetation heights, and percent foliar cover. Methods included using a total station to survey the height of the land surface and plant community relationships. Vegetation composition, height, and density were determined within 1 m^2 quadrats along transects. Spacing of quadrats varied from 1 to 5 m depending on length of transects and variability in topography and vegetation. Along some transects, a point intercept method was used wherein changes in vegetation and water regime were recorded along with land surface heights. Correlations of vegetation height and cover with land surface height were determined at all sites. In addition, the vertical range in *Spartina alterniflora* was calculated along all transects to provide information on the probable vertical range of the intertidal zone. Heights of the land surface along transects are relative to the land surface at the surveying instrument, which was not tied to benchmarks.

Sandefer Marsh

The Sandefer marsh (Fig. 2) was created as part of a mitigation project for a well drilled by Sandefer Oil & Gas, Inc., on the edge of Jones Bay, a small extension of West Bay near Hitchcock, Texas. The company constructed a drilling pad and access road on the south edge of a railroad track that parallels highway FM 6. The site is located at Latitude 29° 19' 27.589" and Longitude 94° 57' 17.148" and is on land owned by the Texas Nature Conservancy (Webb, 1993). The well was nonproductive and the hole was plugged.

Table 1. Marsh restoration/creation projects selected for field studies or special site analysis.

Field Study Sites	Type and Year Planted	Approximate Size (ha)
Sandefer	Restoration Fill and shape (1992)	1.5
Highland Bayou	Creation Scrape down (1993)	12.6
Swan Lake	Restoration Fill (1992)	2
Armand Bayou	Restoration Fill (1995)	3
Frozen Point	Creation and protection Natural substrate (1994?)	2
Bayland Park Marina	Creation Fill and shape (1996)	4.4
Brownwood	Creation Scrape down (1995)	13.3
Site of Special Interest		
Bayport Demonstration Marsh Project	Creation Fill (1995)	73 Intertidal marsh

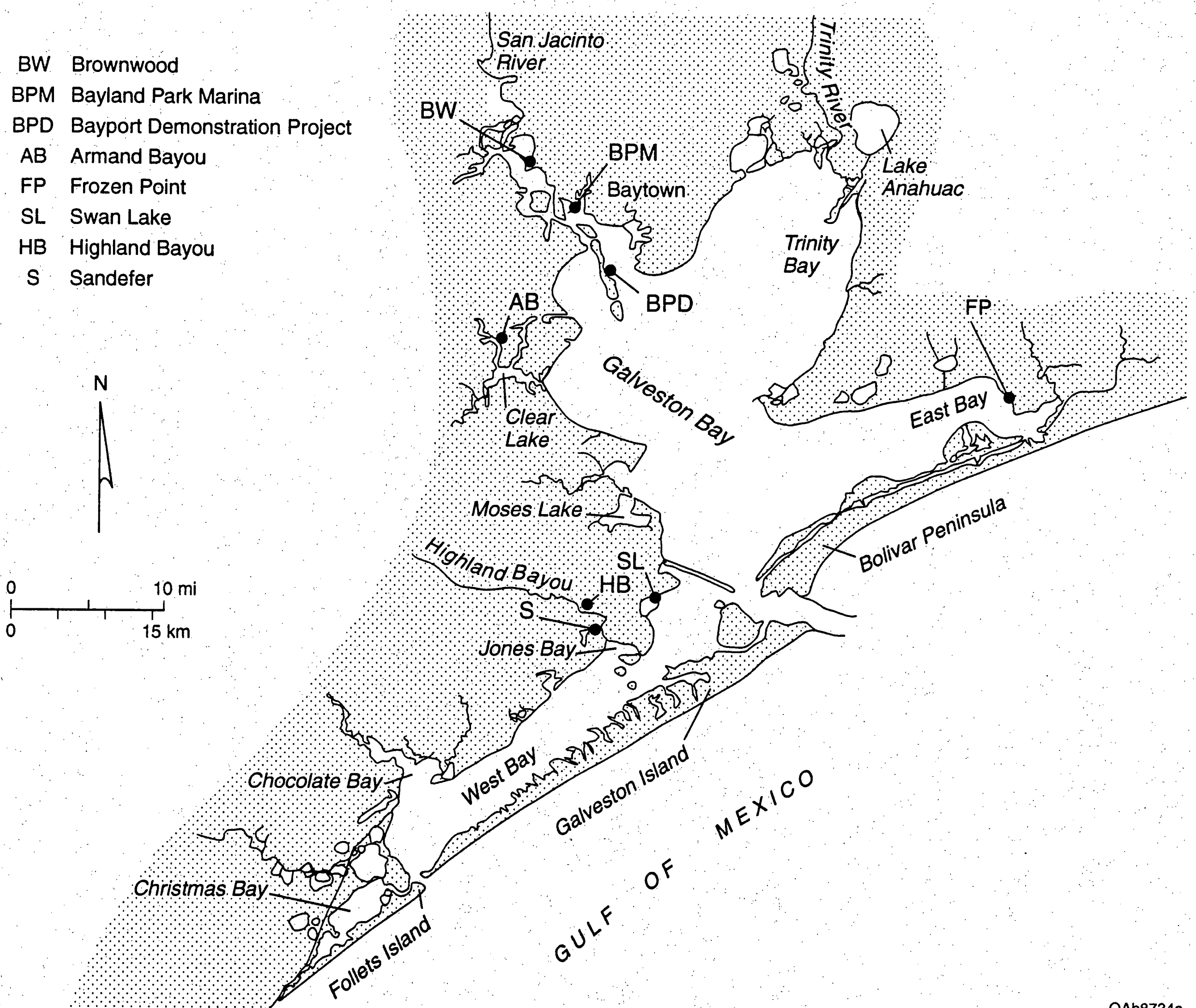


Figure 2. Index map showing location of seven restoration/creation project sites for which detailed field data were collected. The Bayport Demonstration Marsh Project is also shown.

Project Objectives

The primary objectives were site restoration and habitat creation in compliance with mitigation requirements for constructing the well pad, ring levee, and access road.

Design/Restoration Criteria

The selected site consisted predominantly of shallow bay bottom habitat (U.S. Army Corps of Engineers permit 19336-01 review, 1991). Fill material was transported in to construct the road and well pad. Conditions for restoration included removal of all disturbed areas including the entire pad, ring levee and new access road and restoration to pre-project elevations, contours, substrate, and vegetation. Final conditions allowed for fill material to be spread and transplanted (Jakubik & Associates, Inc., 1991).

Transplanting and monitoring activities were under the direction of Dr. James W. Webb. By design, some fill material was left in the bay for transplanting. The southern half of the well pad was transplanted in August 1992, and the remainder of the pad and road fill was planted in late fall 1992 and early January 1993. Seventeen sites were established in January 1993, for monitoring transplant survival at six-month intervals (Webb, 1993).

Species transplanted included *Spartina alterniflora*, *Spartina patens*, *Spartina spartinae*, and *Distichlis spicata*. The spacing of transplants varied from 2 m to more widely spaced (Webb, 1993 and 1994).

Field Survey

The field survey was completed in September 1997 as part of this project. Marsh development was investigated using five transects, three across marshes on the reclaimed access road and two on the well pad (Figs. 3-8). The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based in large part on these transects and on monitoring reports by Webb (1993 and 1994).

Physical Characteristics

The size of the site is approximately 1.5 ha, including 0.5 ha of access road. Widths of the restored sites along the reclaimed access road are between 15 and 20 m. Marsh distribution at the reclaimed pad is about 135 m by 155 m (measured from 1995 imagery). Fill material is predominantly red mud, with a high clay content.

Geomorphology

Geomorphology of the site is characterized by very gentle slopes that steepen toward the edge of the fill. Macro topographic features on the restored pad include ridge- and swale-like topography created by alternating, scraped-down channels and interchannel ridges. Vertical range in height between channel bottoms and ridge crests is about 30 cm or less, as exemplified by one transect (Fig. 6).

Hydrology and Salinity

Hydrology of the marsh along the access road (Fig. 3) is similar to a fringe marsh. It consists of narrow, topographically low, frequently flooded areas near shore that grade into higher, less frequently flooded areas toward the railroad tracks. Marsh hydrology

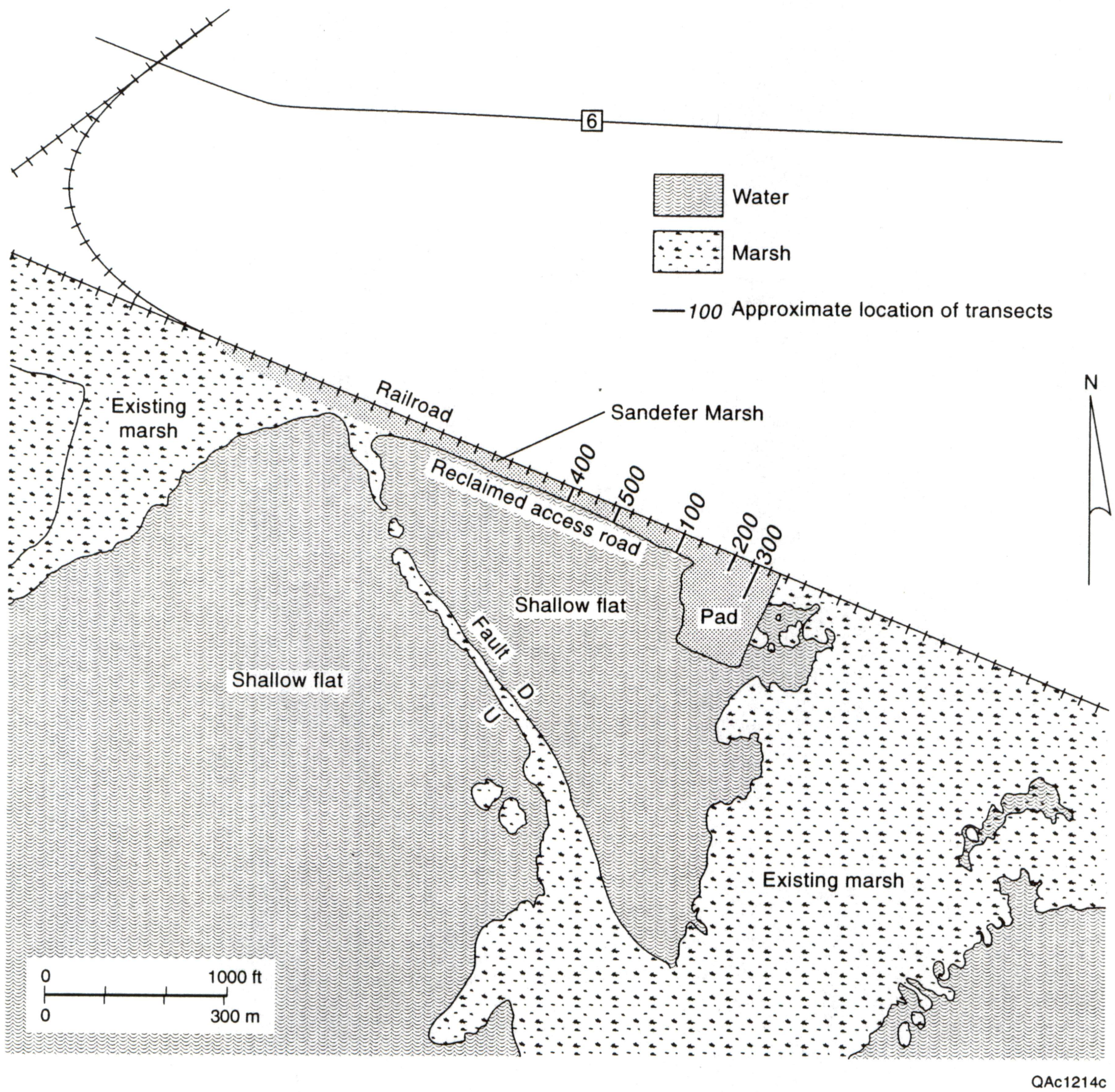


Figure 3. Map of Sandefer marsh showing general location of site and approximate location of marsh transects. Fault is also shown; D=downthrown side, U=upthrown side.

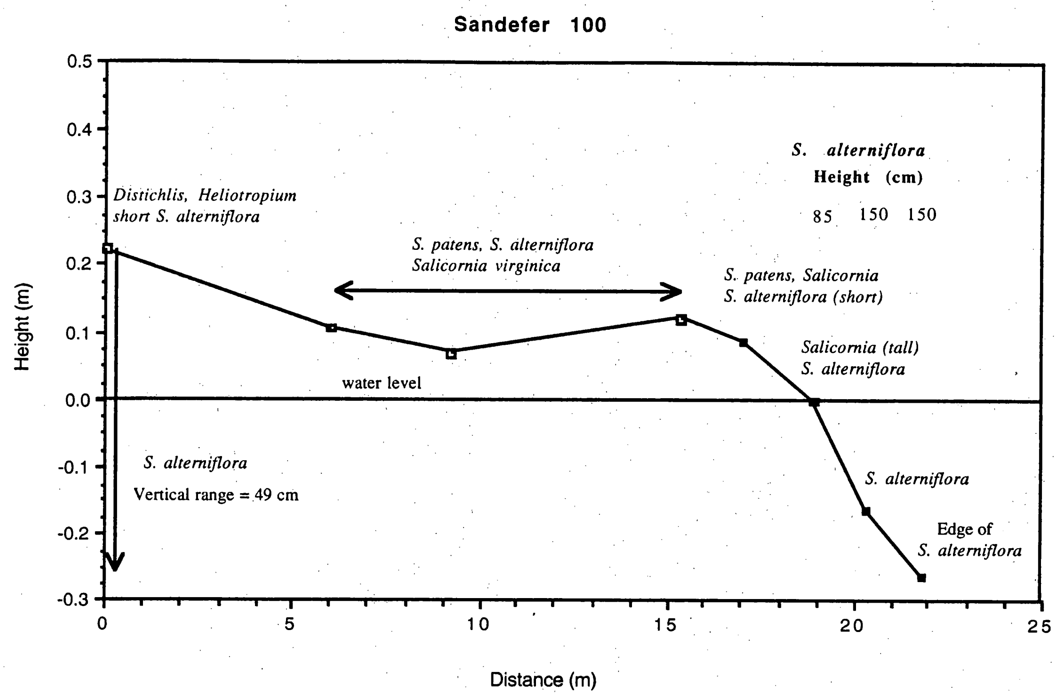


Figure 4. Transect 100, Sandefer.

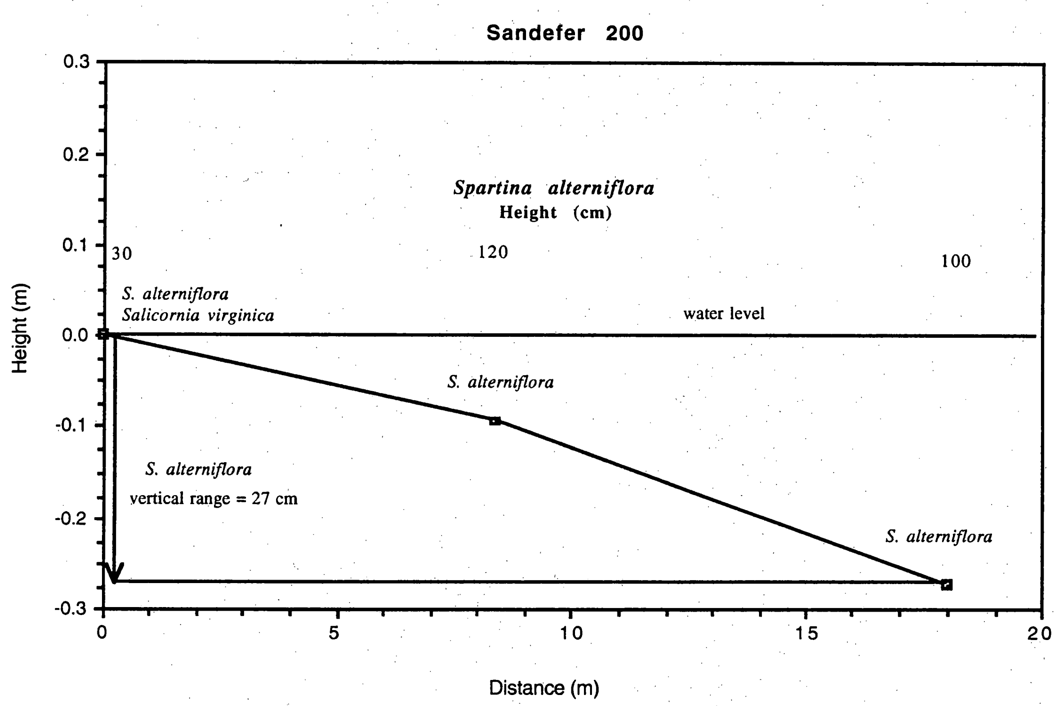


Figure 5. Transect 200, Sandefer.

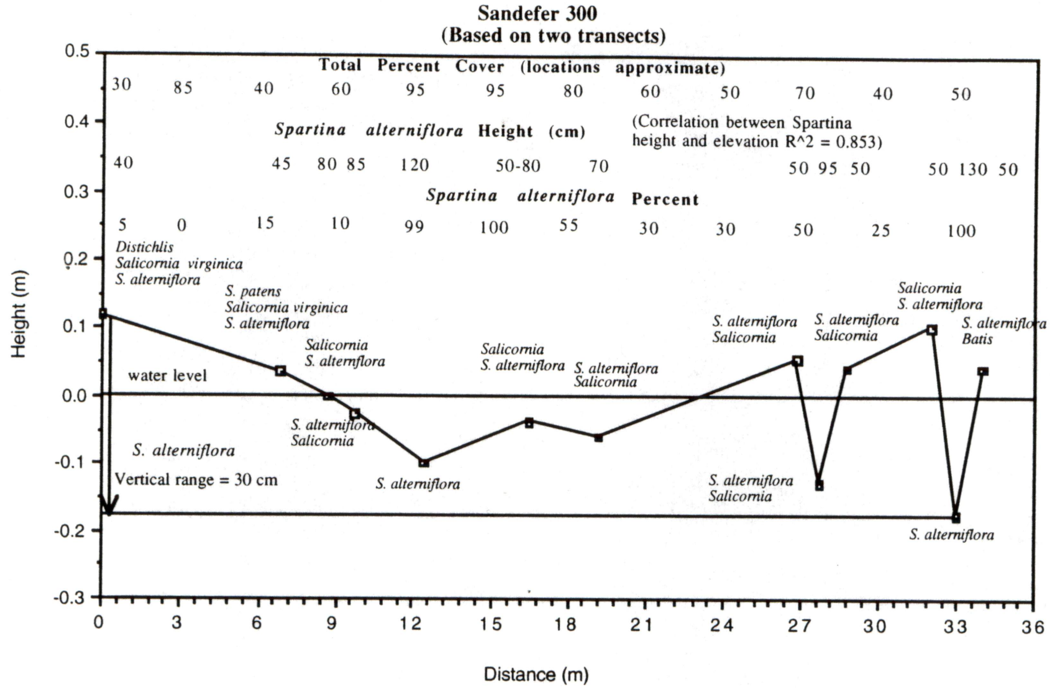


Figure 6. Transect 300, Sandefer marsh.

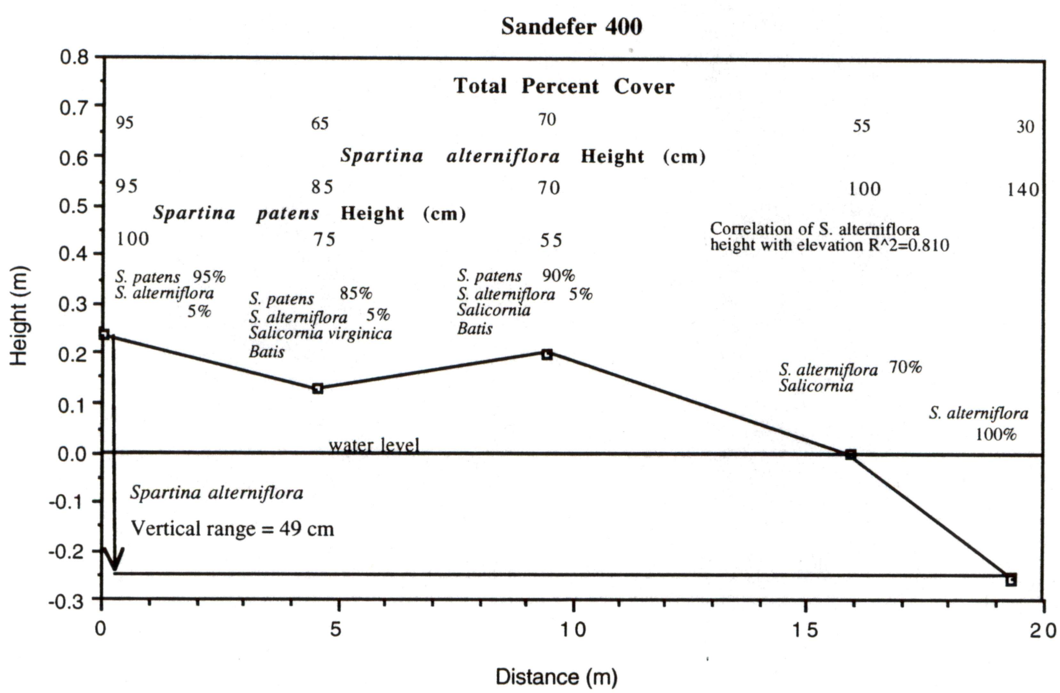


Figure 7. Transect 400, Sandefer marsh.

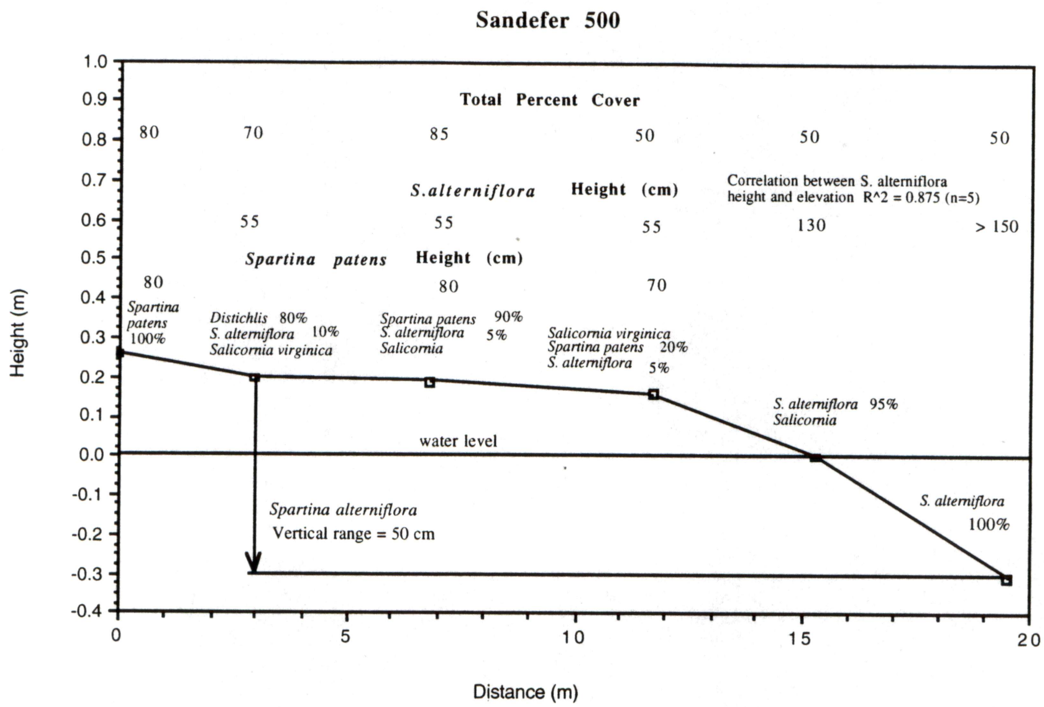


Figure 8. Transect 500, Sandefer marsh.

on the drilling pad is more complex. Alternating ridges separated by narrow tidally influenced channels characterize the eastern half of the pad (Fig. 6). On the northwestern quarter of the pad is an area of tidally connected open water approximately 50 m by 80 m (based on 1995 imagery). Narrow constructed channels are oriented east-west and connect the area of open water in the marsh with bay waters. The channels are less than 3 m wide and 0.3 m deep (Fig. 6).

Bay water salinity, which was 35 ppt at the time of the field survey, reflects the influence of the marine system through Bolivar Roads and the Galveston Ship Channel.

Shoreline and Site Stability

The very shallow, protected bay setting suggests that erosion of the marsh should be minimal. However, this site is within an area that has been affected by high rates of subsidence and loss of marshes due to submergence (Fig. 9). Part of the subsidence has occurred along an active fault (White and Morton, 1997) that intersects the reclaimed access road and railroad track (Fig. 3). Although the land surface has subsided on both sides of the fault, marshes were lost more rapidly on the northeastern downthrown side. This is the side on which most of the created marsh is located.

More recent data indicate that subsidence rates from the late 1970s to 1987 are much lower than previous rates that exceeded 1.4 cm/yr in the area near Jones Bay (Gabrysch and Coplin, 1990). Lower rates of subsidence are indicated by the cessation of marsh submergence in this area after 1979 (White and Tremblay, 1995).

Vegetation

The eastern edge of the pad was planted with *Spartina alterniflora* in summer and fall 1992 (Webb, 1994). Plant communities vary on the ridge and channel topography that characterizes the eastern part of the pad. In general, *Salicornia virginica* is dominant on the ridges and *Spartina alterniflora* in the channels (Figs. 6 and 10). At higher elevations near the railroad track, *Distichlis spicata* and *Spartina patens* occur along with *Salicornia* and *Spartina alterniflora*. Where elevations remain higher along transects, *Spartina patens* is dominant (Fig. 7).

Percent foliar cover ranged from 30 to 95 percent and averaged 63 ± 20 percent at 23 stations, 22 of which had *Spartina alterniflora*. Measurements of maximum heights of *Spartina alterniflora* at various stations ranged from 30 and 150 cm and averaged 87 ± 38 cm at 29 stations. The range in vertical height of the land surface where *Spartina alterniflora* occurred on the pad was as much as 30 cm (Fig. 6) and may have been higher at sites that were not measured. There is a strong inverse correlation ($R^2 = 0.875$ between the height of *S. alterniflora* and the height of the land surface (Fig. 11).

Transplants on the reclaimed access road include *Spartina alterniflora*, *Spartina patens*, *Spartina spartinae*, and *Distichlis spicata* (Webb 1993 and 1994). *Salicornia virginica* and *Batis maritima* are other species that have naturally colonized some sites. Based on three transects across the access road (Figs. 4 and 7-8), average cover is about 65 percent. Cover is densest (up to 95 percent) in high marshes that are dominated by *Spartina patens* and *Distichlis spicata*. Cover decreases toward the water (30-55 percent) where *Spartina alterniflora* is dominant. Maximum heights of *Spartina patens* average 77 cm and range from 55 to 100 cm, decreasing with decreasing elevations toward the water. Maximum heights of *Spartina alterniflora* average 102 cm and range from 55 to > 150 cm. There is an inverse correlation ($R^2 > 0.810$) between the height of *Spartina alterniflora* and

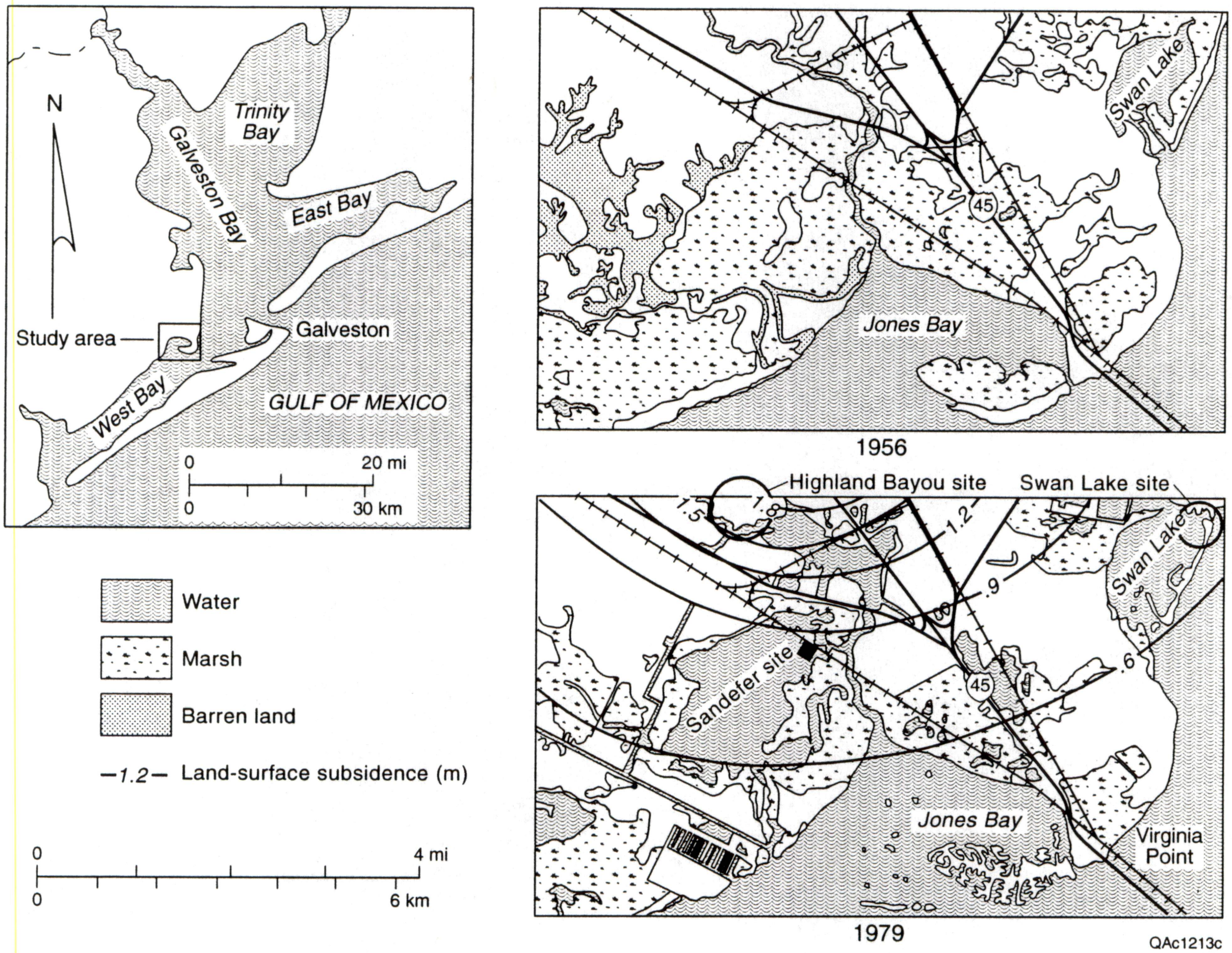


Figure 9. Changes in the distribution of wetlands between 1956 and 1979 in relation to subsidence near Jones Bay and Swan Lake south of Texas City. Note the increase in open water in 1979. Contours show the amount of subsidence (in meters) that occurred between 1906 and 1987 based on maps from Gabrysch and Coplin (1990). From White and Tremblay, 1995.

Figure 10. Photograph of ridge-and-swale like topography on the restored well pad at transect 300, Sandefer marsh. Vegetation in swales is dominated by *S. alterniflora* and on the ridges by *Salicornia virginica*.

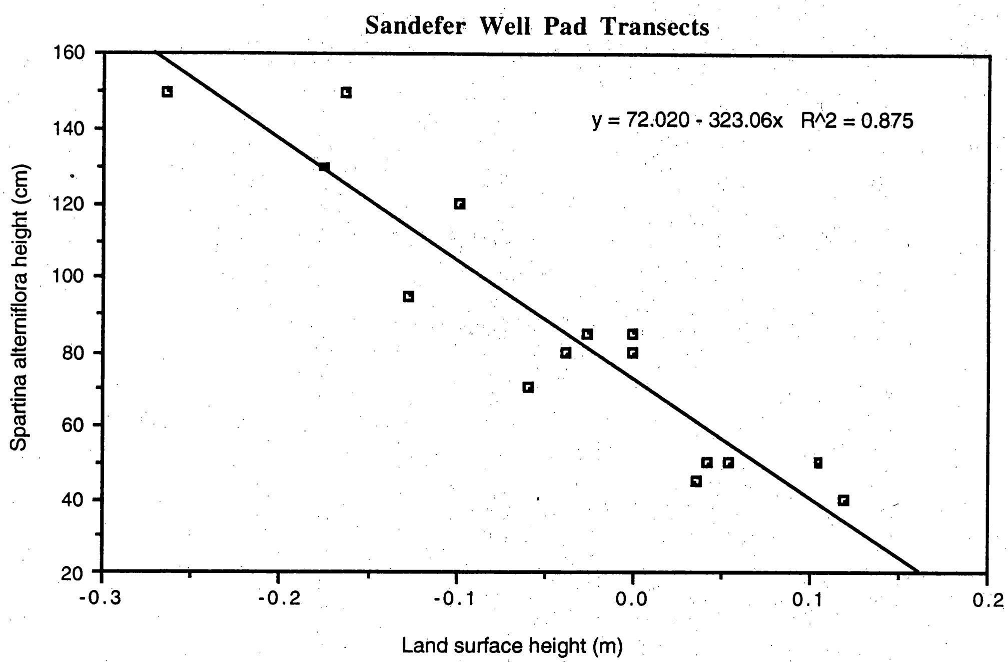


Figure 11. Correlation between height of *Spartina alterniflora* and height of the land surface based on two well pad marsh transects (200 and 300) at the Sandefer site. Land surface heights are relative to land surface height at surveying instrument.

elevation (Figs. 7 and 8). The vertical range in land surface height of *Spartina alterniflora* on the reclaimed access road was 49 to 50 cm (Figs. 4 and 7-8).

Success in accomplishing performance goals

The Sandefer marsh is a successful restoration/creation site. Webb (1993 and 1994) reported good survival of transplants overall. Transplanted on relatively barren fill in 1992 and 1993, the average percent cover as determined from 23 stations was approximately 65 percent in 1997. Transplanted vegetation appears healthy, as indicated by heights of individual plants (see discussion of vegetation above).

The vertical range in elevation of *Spartina alterniflora* on the reclaimed access road is approximately 50 cm, which is a relatively broad zone of occurrence for *Spartina alterniflora* and apparently reflects the wind-tidal range on this southerly facing shore. The range in which *Spartina alterniflora* is dominant in this area is closer to 30 cm and is more reflective of the astronomical tidal range.

Criteria and potential for large-scale marsh restoration and creation

Among the criteria with potential for large-scale marsh development are the use of consolidated fill material that is shaped to provide varying elevations, mixtures of open water and marsh, and good circulation, and a setting that enhances marsh expansion.

One difference between this and other fill sites is that the fill material was trucked in. The red color of the predominantly clay fill indicates that it is from an older oxidized substrate, and compaction should be less of a problem than in loosely consolidated material dredged from the bay bottom. Additional consolidation and compaction of the material undoubtedly occurred during construction of the access road and pad.

In preparation for transplanting, the fill material was removed and spread to achieve intertidal elevations (Webb, 1994). Final elevations provided for high and low marsh development. Some ridges on the pad were apparently too high for establishment of *Spartina alterniflora*, but *Saliconia virginica* colonized these areas. Should subsidence continue, these higher ridges provide sites for eventual colonization by *Spartina alterniflora*.

There appears to be adequate water circulation for marsh survival. The reclaimed access road is narrow and functions as a fringe marsh with regularly flooded and irregularly flooded marsh components. Scrape-down channels and an area of open water on the pad provide for circulation and edge marsh environments.

The setting of this site has some potential for large-scale marsh development, provided that subsidence rates remain low. This created marsh, including the entire reclaimed access road, has a length of approximately 1 km that fronts a large area of shallow subaqueous flat that was the site of an extensive marsh in 1956. This marsh was lost between 1956 and 1979, primarily due to subsidence (White and Tremblay, 1995). Now that subsidence may be negligible (Gabrysch and Coplin, 1990), there is the potential for emergent vegetation to expand and reclaim the area. Webb (1994) noted that within a one- to two-year period, marsh vegetation planted on the edge of the pad had coalesced with an existing adjacent marsh. However, rates of relative sea-level rise on the downthrown side of the fault near the Sandefer marsh may exceed rates of marsh vertical accretion and prevent large-scale colonization of the flats. Trucking in additional fill material is probably not cost-effective, and thus, large-scale development at this site depends on marsh growth and expansion from a smaller transplanted "seed" marsh.

Highland Bayou Marsh

The Highland Bayou marsh is part of a wetlands mitigation project by Motco Trust Group in conjunction with recreational park development by the City of La Marque, Galveston County, and the Texas Parks and Wildlife Department. The site is located in Highland Bayou Park north of the Bayou at approximate Latitude 29° 20' 30" and Longitude 94° 58' 20" (Fig. 2).

Project Objectives

A primary project objective was the establishment of salt marsh habitats in three constructed wetland areas.

Design/Restoration Criteria

Wetlands were created by scraping down Pleistocene Beaumont Clay to conform to a complex design of interconnected channels, ponds, islands, and intertidal slopes for marsh and associated aquatic habitat development (D Engineers, Inc., 1990). Design plans estimated a "cut" of 87,270 m^3 of material. Marsh transplantings included primarily *Spartina alterniflora*, and secondarily, *Spartina patens* and *Spartina spartinae*. Vegetation was to be established by transplanting or seeding areas. Sources of transplants included a nursery constructed on-site. The U.S. Soil Conservation Service was expected to provide fungi-resistant plants for the nursery. An alternative was to obtain transplants from local native stands.

Design requirements specified that *Spartina alterniflora* was to be transplanted at 1 m intervals at elevations from the 0 to 42.7 cm zone. Transplantings were to cover approximately 60 percent of a 12.5 ha area, requiring approximately 75,000 plants. *Spartina patens* and *Spartina spartinae* were to be planted at 1-m intervals at elevations from approximately 42.7 cm to 60-80 cm. Planting was apparently begun in 1993.

Field Surveys

Field surveys as part of this project were conducted in September and November 1997. Marsh development was investigated using eight transects that were located perpendicular and parallel to water features, primarily in the eastern half of the project area that includes wetland areas A and B (Figs. 12-20). The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based primarily on these transects and design plans (D Engineers, Inc., 1990).

Physical Characteristics

Engineering plans (D Engineers, Inc., 1990) show that the wetlands and aquatic habitats were designed to cover approximately 14.5 ha, of which about 10.4 ha was to be new wetlands (salt marsh) (Fig. 12). Because the site is on a Pleistocene clay formation, the substrate consists primarily of relatively stiff gray and yellow clay with local caliche nodules and sand.

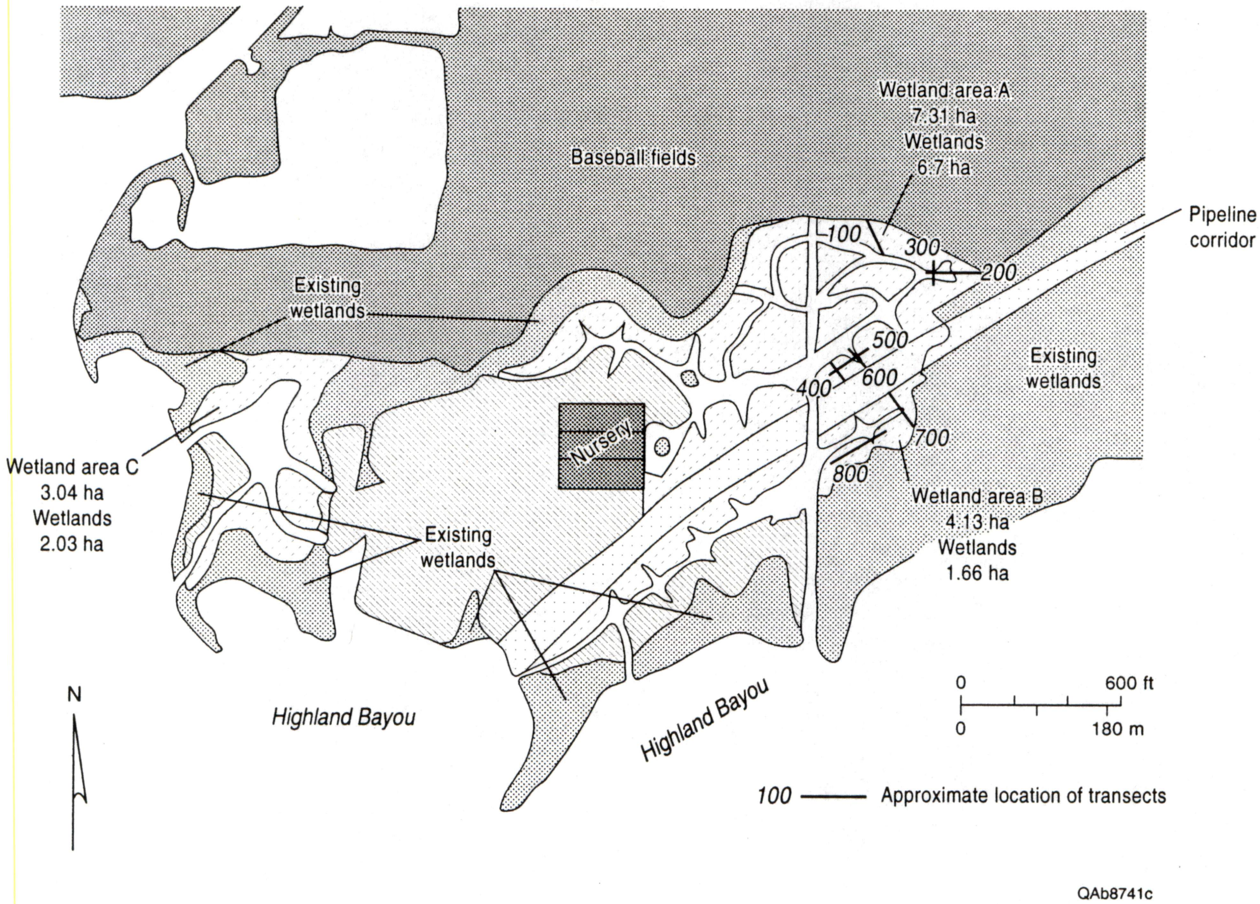


Figure 12. Map of Highland Bayou site showing general design plan and approximate location of marsh transects. Design plan from D Engineers, Inc. (1990).

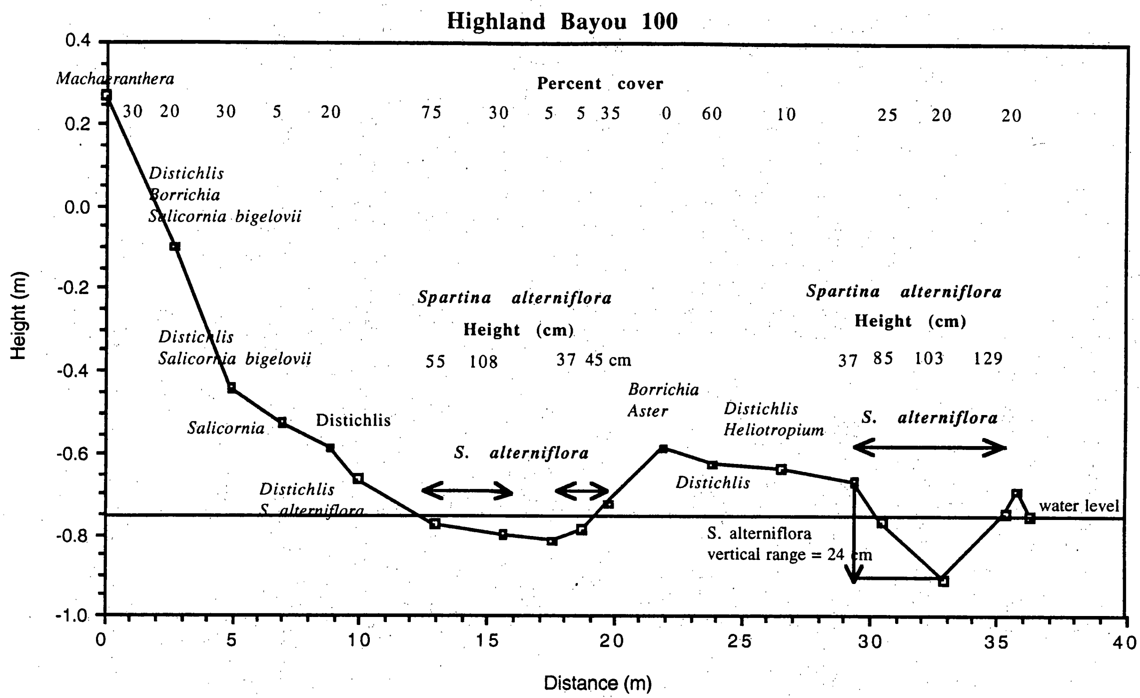


Figure 13. Transect 100, Highland Bayou marsh.

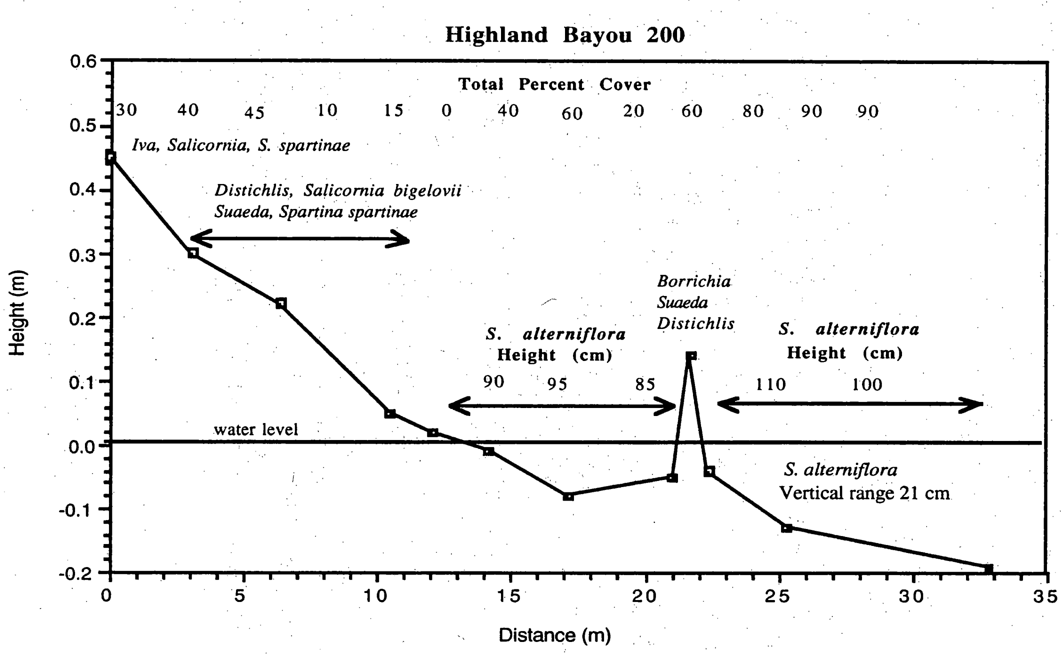


Figure 14. Transect 200, Highland Bayou marsh.

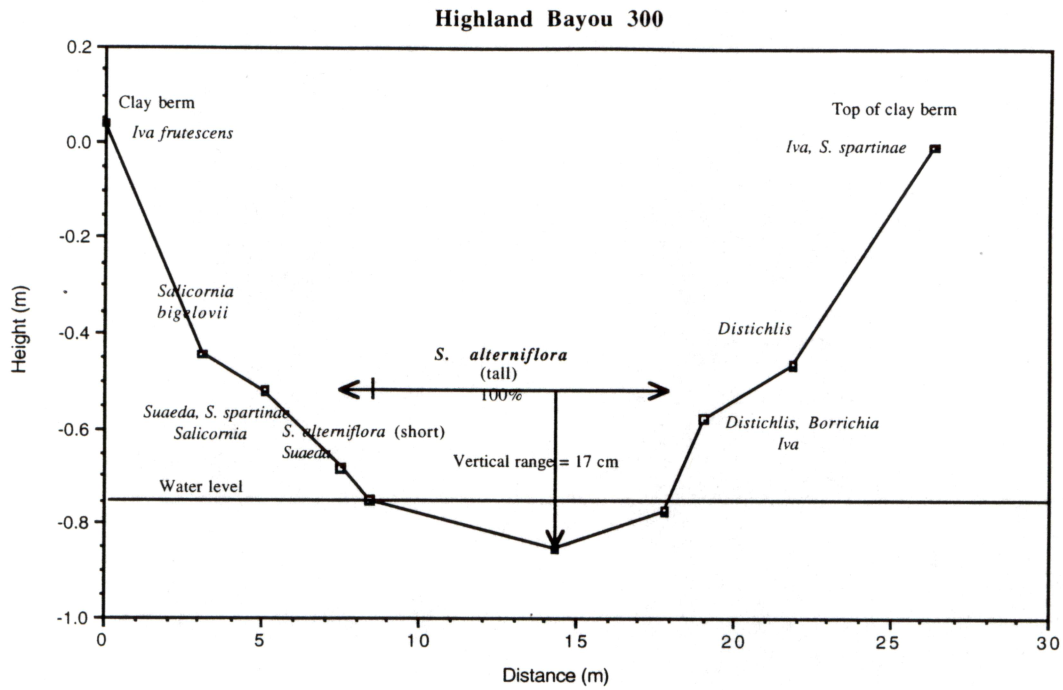


Figure 15. Transect 300, Highland Bayou marsh.

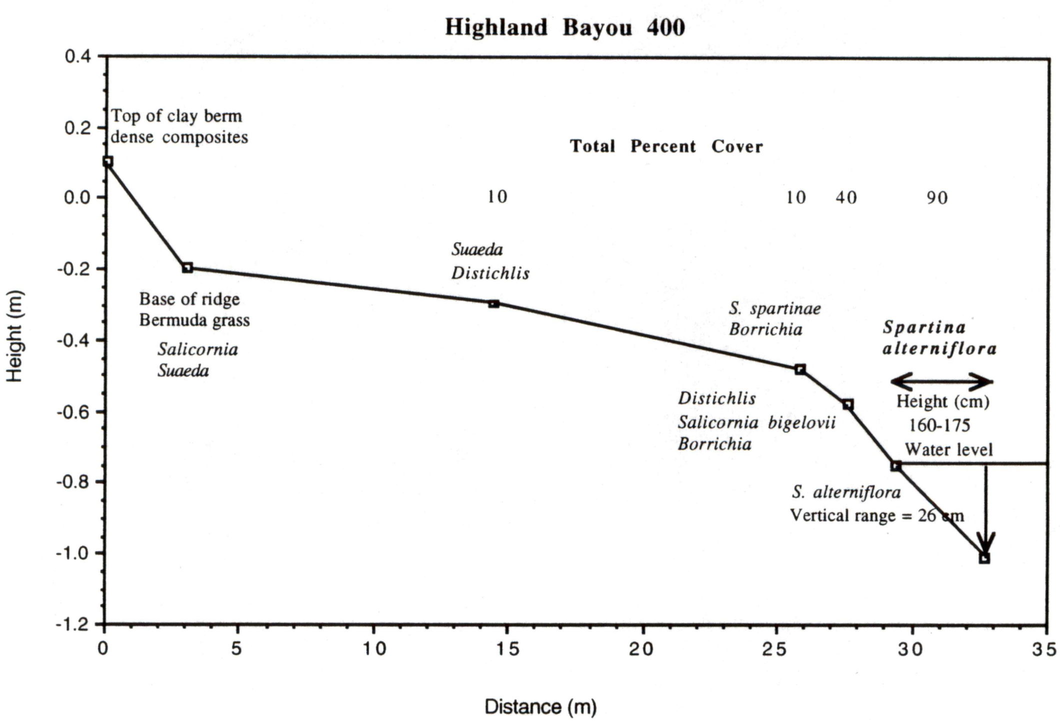


Figure 16. Transect 400, Highland Bayou marsh.

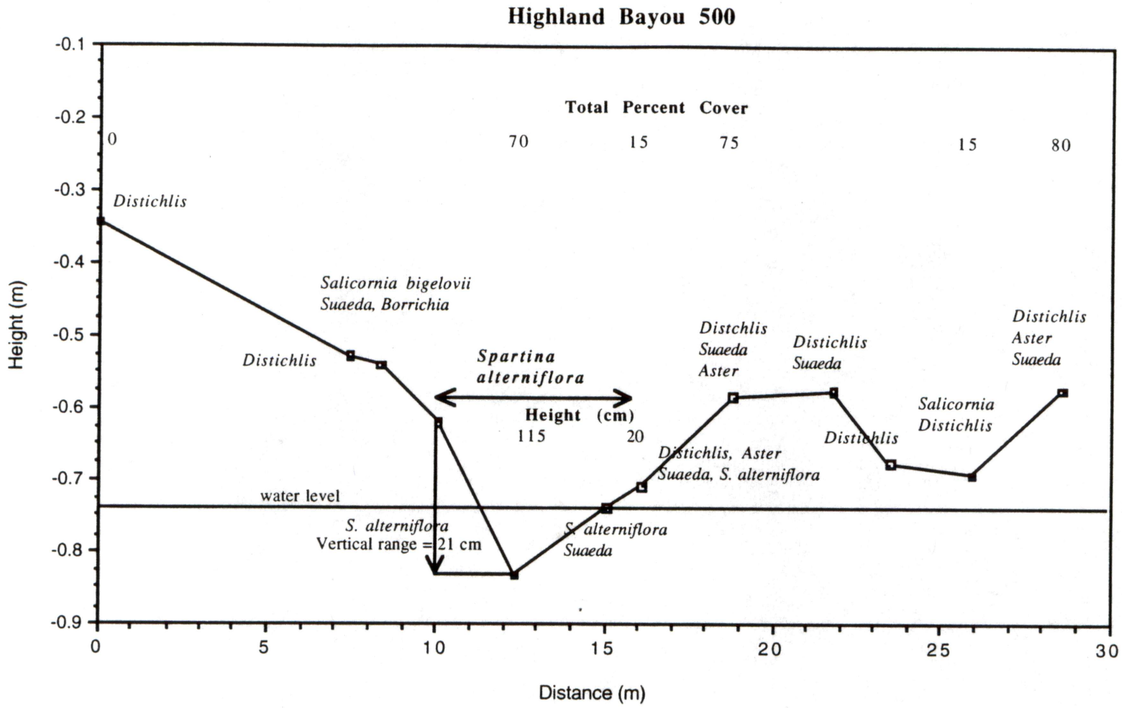


Figure 17. Transect 500, Highland Bayou marsh.

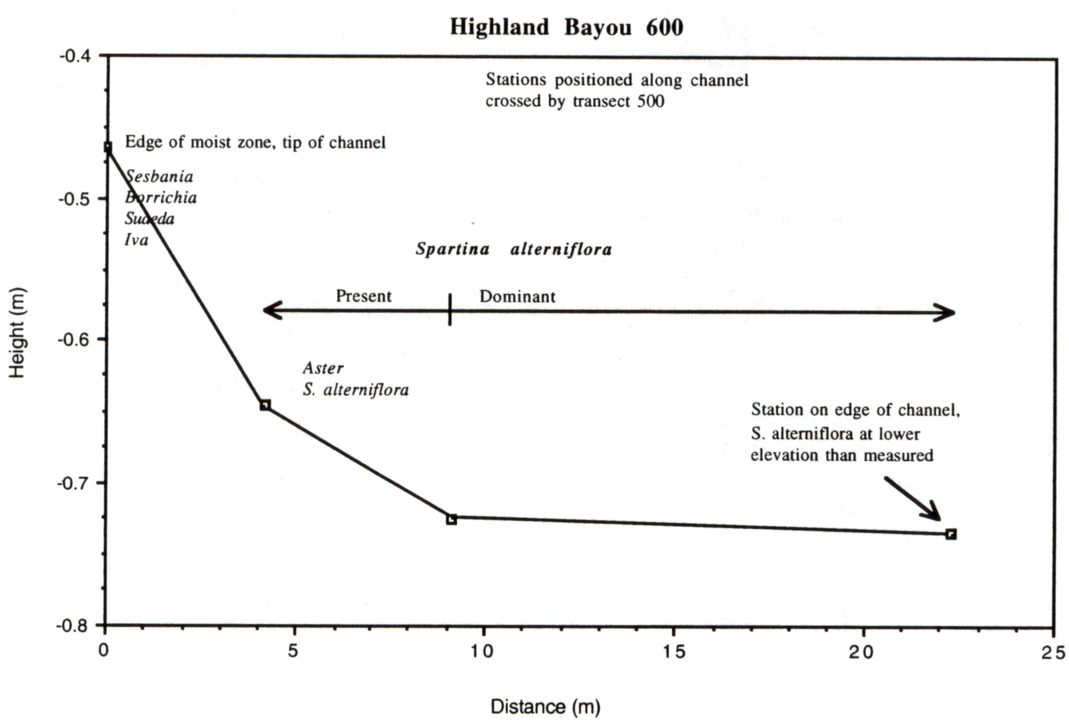


Figure 18. Transect 600, Highland Bayou marsh.

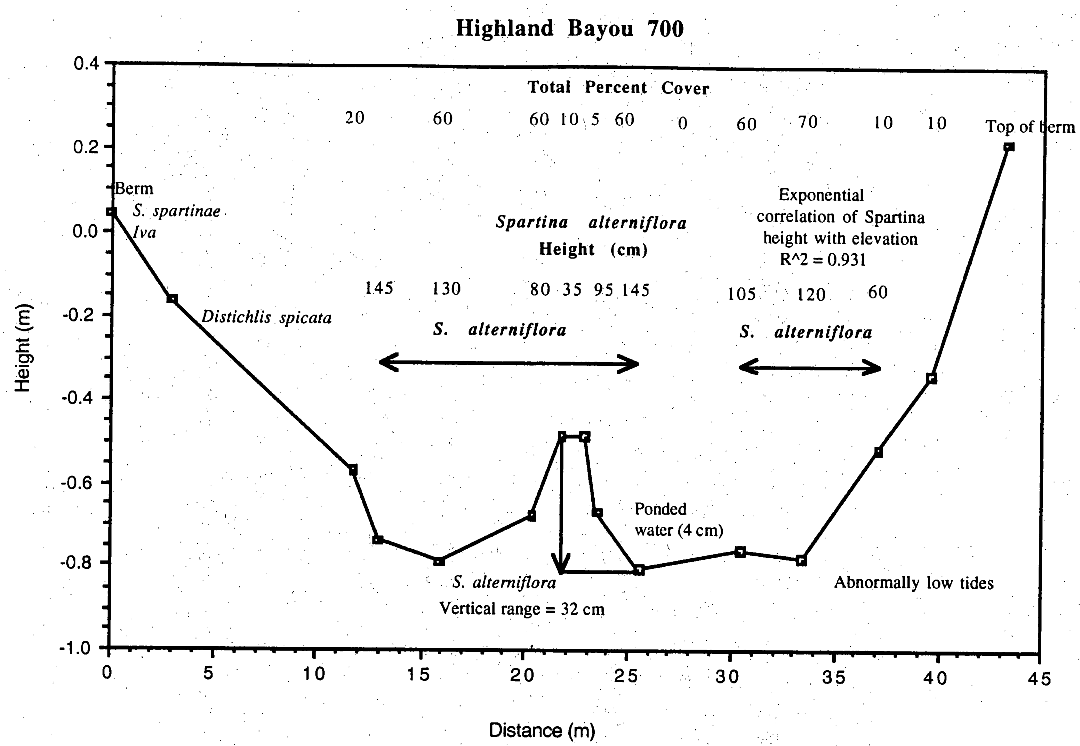


Figure 19. Transect 700, Highland Bayou marsh.

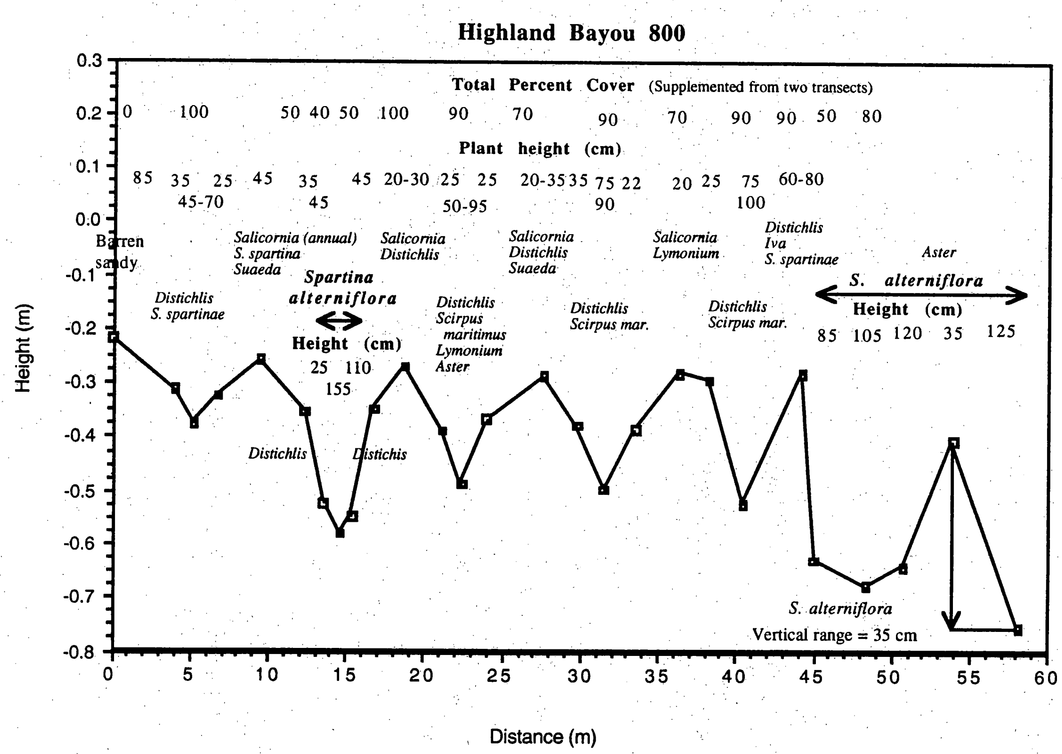


Figure 20. Transect 800, Highland Bayou marsh.

Geomorphology

The geomorphology of the site is complex. Wetland area A consists of circular and linear channels with numerous islands, and smaller truncated channels. Wetland area B is dominated by a large linear central channel that feeds numerous smaller, perpendicular truncated channels. Some stretches of marsh are characterized by ridge and swale topography (Figs. 20-21). The periphery of the wetland complex is characterized by steep slopes and clay ridges (Fig. 15).

Hydrology and Salinity

It is apparent from the design plan that a rather intricate tidally driven circulation system consisting of numerous circular, linear, and short truncated channels was an important criterion at this site. A major linear canal that connects to Highland Bayou cuts across both wetland areas A and B (Fig. 12). This was an existing channel as shown by aerial photographs taken in 1979. Additional constructed channels at the southwestern end of wetland area B connect to Highland Bayou. Ridge and swale topography in some areas consists of truncated channels and inter-channel ridges apparently designed to create sites for regularly and irregularly flooded marshes. Runoff of precipitation from adjacent uplands and transitional areas provides additional water and nutrients to some marsh areas, but peripheral clay ridges block runoff in other areas.

Salinities taken during field surveys in September 1997 ranged from 24 to 28 ppt.

Shoreline and Site Stability

Marsh shorelines are well protected from erosion because of the interior location of this site, which is far removed from large areas of open water. A more serious threat is subsidence. The area is encompassed by the Texas City subsidence bowl that in past years has submerged wetlands and uplands (Fig. 9). Immediately west of the site, marshes visible on 1950s aerial photographs were replaced by open water by the 1970s (Fig. 9). Rates of subsidence have declined over more recent years (Gabrysch and Coplin, 1990) providing a more stable post-1970s setting.

Vegetation

Although three species of cordgrass were transplanted in this created wetland complex, field survey transects were located in areas that primarily intercepted *Spartina alterniflora* (Figs. 13-20). *Spartina spartinae* was occasionally recorded, but its presence in some areas, for example on ridges, may be from natural colonization from adjacent existing marshes. Among other species recorded along transects (apparently present from natural colonization) are *Distichlis spicata*, *Salicornia bigelovii*, *Scirpus maritimus*, *Aster tenuifolius*, *Suaeda linearis*, *Borrichia frutescens*, *Iva frutescens*, *Heliotropium curassavicum*, and *Lymonium nashii.*

Average percent cover along transects was 42 percent (n = 66), with a maximum of 100, a minimum of 0, and a standard deviation of ± 30. Densities of cover in *Spartina alterniflora* communities averaged 48 ± 28 percent with a range of 5 to 95 percent (n=27). Maximum heights of *Spartina alterniflora* measured at 33 stations ranged from 20 to 175 cm and averaged 95 cm.

Ridge and swale topography at transect 800 provided an interesting setting for investigating colonization by various plant species (Fig. 20). The dominant plant on most

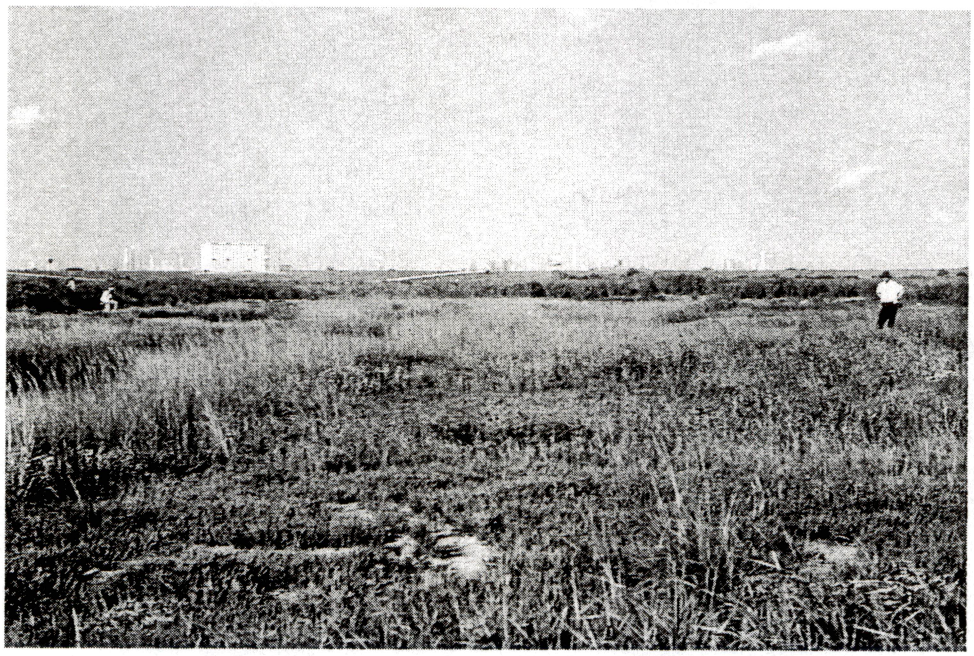


Figure 21. Photograph showing ridge-and-swale-like topography at transect 800, Highland Bayou marsh. Vegetation varies, but includes *Distichlis spicata*, *Scirpus maritimus*, and *Spartina alterniflora* in swales, and *Salicornia bigelovii*, *Distichlis spicata*, *Spartina spartinae*, and *Suaeda linearis* on ridges .

ridges was annual *Salicornia*. In shallow excavated channels, *Distichlis spicata* and *Scirpus maritimus* were dominant, and in the deeper channels, *Spartina alterniflora* was most abundant (Fig. 21). It is assumed that the occurrence of *Spartina alterniflora* is from transplants.

Based on seven transects (Figs. 13-17 and 19-20), the vertical range in land surface height at which *Spartina alterniflora* is distributed ranged from a low of 17 cm to a high of 35 cm with an average of 25 cm. This suggests that the average tidal range at this interior marsh complex is under 30 cm.

There is a high inverse exponential correlation ($R^2 = 0.913$) between the land surface height and the height of *Spartina alterniflora* along transect 700 (Fig. 22). The correlation between all plant heights and land surface height at transect 800 is linear (Fig. 23).

Success in Accomplishing Performance Goals

A limitation on evaluating the success of this marsh creation project is time. Initially planted in 1993, it is apparently still under development. In terms of following design requirements, the intricate network of channels and associated macro-topographic features captured on 1995 imagery are a close match with those detailed in site plans (D Engineers, Inc., 1990).

The site was designed to establish a mixture of aquatic and marsh habitats. Although circulation appears to be adequate in most areas, stagnation was apparent in some truncated channels where communication with major tidal channels was limited or cut off. These areas were the sites of algal mats or dead emergent vegetation. A problem for rapid and complete colonization of many relatively flat, barren areas may be the Pleistocene clay, which appears to be deficient in organics and probably other nutrients. Areas that are more frequently flooded have a better chance to receive organically rich muds and essential nutrients from Highland Bayou, but their accumulation will take time. Some flats appear too high to be regularly inundated, although they may eventually be colonized by species such as *Distichlis spicata*. Where peripheral ridges have been formed from scraped-up material, broad hydrologic communication and nutrient exchange between the natural high marshes and low, created marshes is inhibited.

Spartina alterniflora is doing well along deeper channels that have a good tidal flux, but appears stunted in shallow areas where circulation is limited. The range in elevation design requirements for transplanting *Spartina alterniflora* from 0 to 47 cm appear too great. Based on measurements in this study, the vertical range of *Spartina alterniflora*, at least in the eastern half of the complex, is closer to 25 cm.

Maximum plant heights of *Spartina alterniflora* at the various stations average 95 cm and reach a maximum of 175 cm. These values exceed those at the Sandefer site where the average was 83 cm and the maximum 150 cm.

Average cover at the time of the field surveys was 42 percent, which is lower than the Sandefer site at 63 percent. Cover densities in *Spartina alterniflora* communities, however, were similar at the two sites with averages between 40 and 50 percent. A difference between the two sites is that extensive barren areas exist in Highland Bayou (Transect 400, for example), whereas the entire Sandefer site is relatively well vegetated. Part of this difference is due to differences in age; the Sandefer site is older. In the design

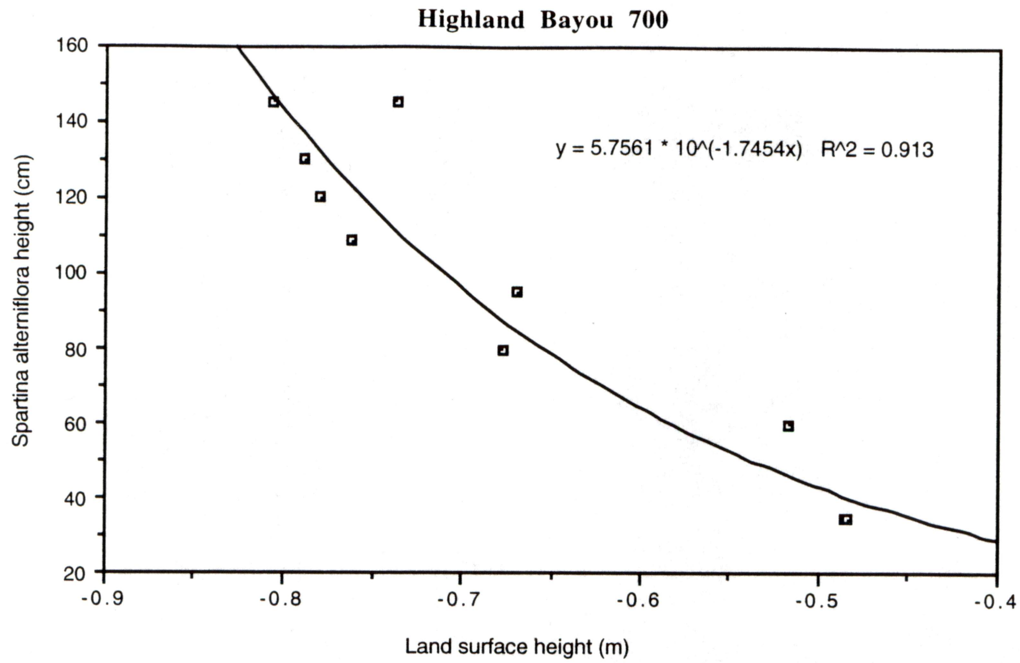


Figure 22. Correlation between height of *Spartina alterniflora* and height of the land surface at transect 700 at the Highland Bayou site. Land surface heights are relative to land surface height at surveying instrument.

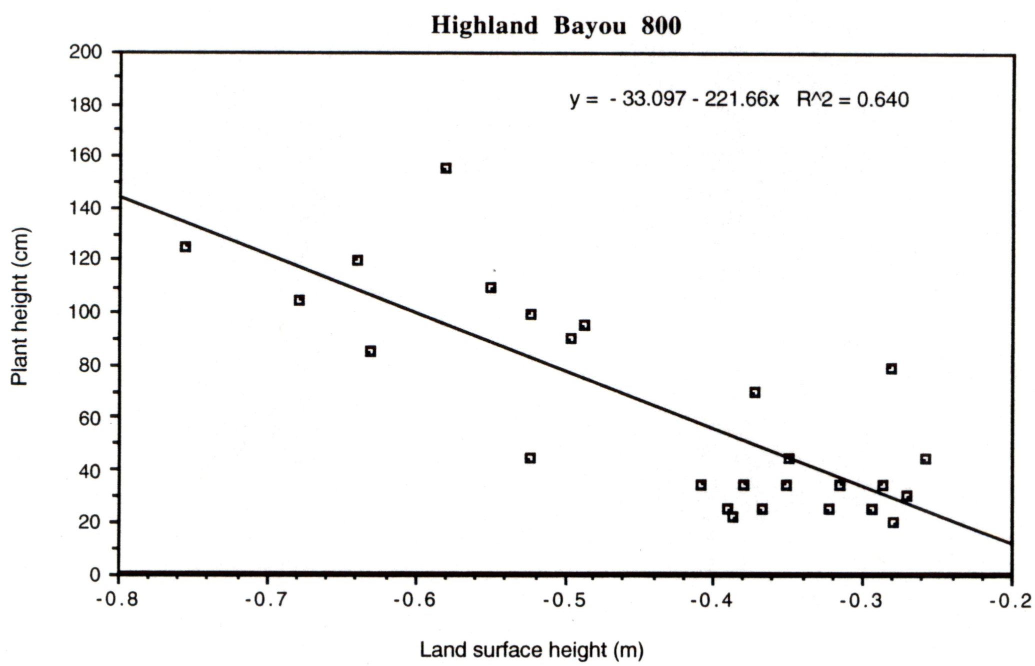


Figure 23. Correlation between height of vegetation and land surface at transect 800 at the Highland Bayou marsh.

plans, there were no requirements for percent survival or achievement of a designated percent cover for transplants

Criteria and Potential for Large-Scale Marsh Restoration and Creation

Some of the criteria used at the Highland Bayou site have potential for large-scale marsh development. The difference between this site and fill sites is that the land surface was scraped down to achieve intertidal and subtidal elevations rather than elevated to intertidal levels with fill material. Although Pleistocene clays have fewer nutrients, working with older, relatively stable sedimentary substrate has advantages. The sediments are less susceptible to compaction and dewatering compared to loosely consolidated fill. The topography of the landscape can be varied, increasing the diversity of habitats.

Because this site may undergo additional land-surface subsidence, the adjacent high marshes, transitional areas, and uplands are potential future sites of intertidal marshes as relative sea level rise continues. Retaining the initial elevations and natural attributes of the adjacent topographically high lands strengthed the prospects for long-term wetland creation and expansion.

Among other positive criteria for large-scale marsh development is the on-site plant nursery. Its design includes an intertidal connection with a constructed tidal channel. Cultivation of plants at the nursery provides ready access to transplants and allows the plants to be observed and evaluated in terms of their health and suitability for the site. If different varieties are used, judgments about probable survival and colonization can be made.

Swan Lake Marsh

The Swan Lake marsh was created as part of a mitigation project by Amoco Oil Company to compensate for the loss of about 1 ha of marsh as a result of dredging activities associated with the company's marine facilities upgrade at Texas City (Lanier and Associates, 1991). The marsh creation site is located in the northeast corner of Swan Lake at approximate Latitude 29° 21' 00" and Longitude 94° 53' 40" (Fig. 2).

Project Objectives

Project objectives included creation of salt marsh habitat and construction of a wave barrier to protect the newly created marsh and existing marshes.

Design/Restoration Criteria

The created marsh (1.41 ha) and wave barrier (0.64 ha), together, were designed to cover an area of at least 2 ha to provide a 2:1 wetland compensation ratio for the wetlands lost due to dredging (Lanier and Associates, 1991 and 1992). Dredged material was to be used to create a curvilinear ridge approximately 30.5 m by 488 m , at intertidal elevations for establishing transplants (Fig. 24). The design called for transplanting approximately 15,000 individual plants of *Spartina alterniflora* obtained from local marshes and planted on 1 m centers. Dead and washed-out plants were to be replaced within 60 to 90 days and at 1- and 2-year intervals to insure success. The transplant site received short-term protection from waves by two rows of parachute netting placed along its south and west margin.

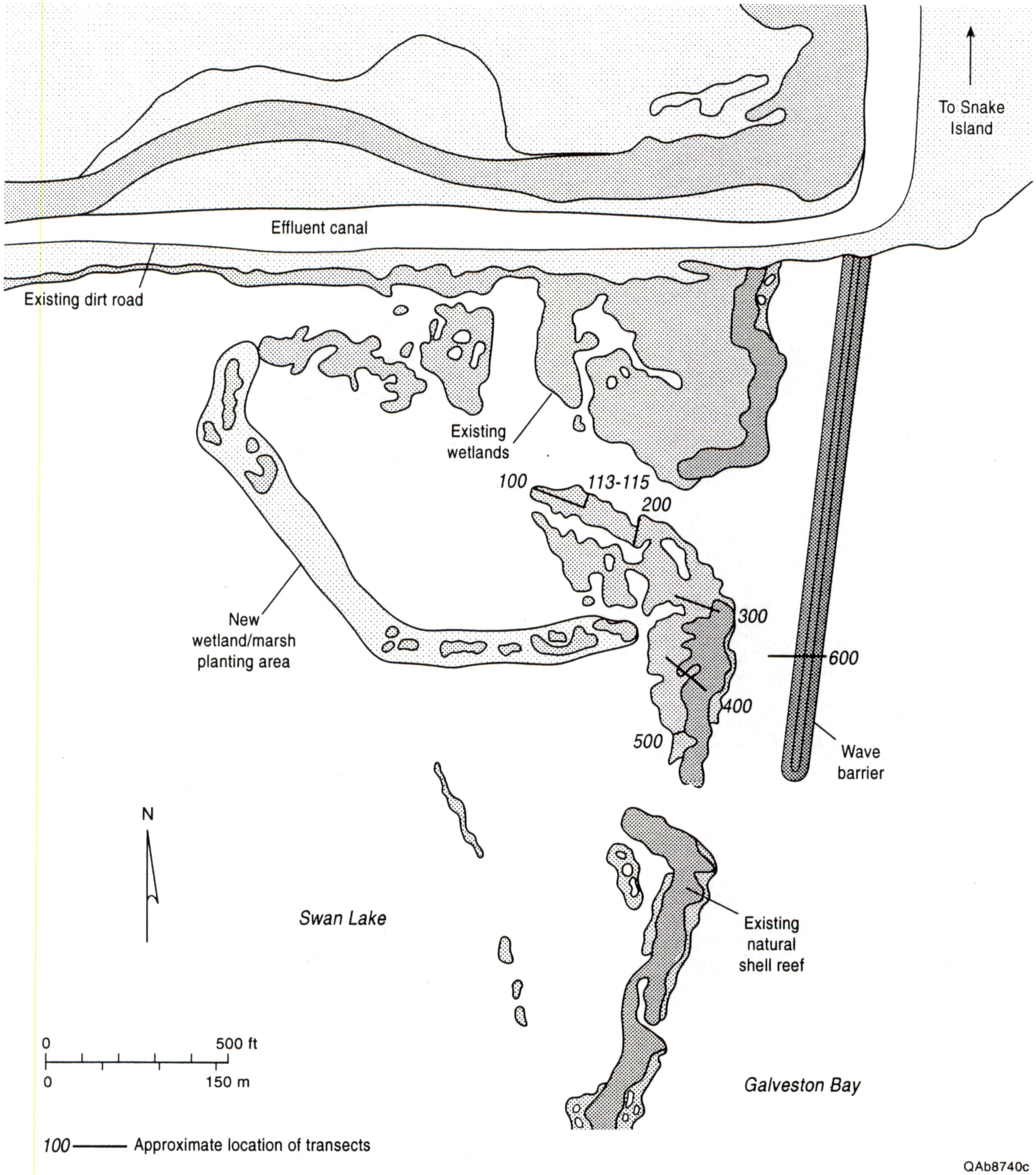


Figure 24. Map of Swan Lake site showing approximate location of marsh transects in relation to wave barrier, natural marshes, shell reefs, and planted marsh. Modified from Lanier and Associates (1991).

The permanent wave barrier designed to protect the site from erosion over the long term was to be approximately 457 m long, located along the eastern side of the marsh creation site, and connected at its north end to Snake Island (Fig. 24). The wave barrier was to consist of a core of hydraulically placed stiff clay covered by geotextile filter fabric and topped by uniformly graded stone riprap. Design specifications on the wave barrier include a 1.2 m wide crown, 1:3 sloped sides, and an elevation of +1.8 m at the top of the riprap (Lanier and Associates, 1991). The wave barrier was designed to control the majority of waves but would allow some waves to break over it to provide sediment nourishment to the natural and created marshes.

Field Surveys

Field surveys for this project were completed in November 1997. Because of extremely low tides and soft sediments, access to the transplant site was not permitted. The adjacent natural marsh and wave barrier were examined and surveyed instead. Seven transects, including one across the wave barrier, were completed (Figs. 25-31). Assessment of the overall configuration of the transplant site, including size, plant distribution, and cover, were determined from low-altitude aerial videotape surveys taken in 1992 and from imagery taken in 1998. The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based primarily on these transects and design plans (Lanier and Associates, 1991).

Physical Characteristics

The created marsh measures approximately 495 m in length and has an average width of 38.7 m (based on 1998 imagery). It is approximately 1.9 ha in size. The wave barrier is approximately 492 m in length and exceeds 1.7 m in height (Fig. 31). A perched shelf from deposited sediments has developed in the riprap on the wave protected western side (Fig. 32).

The created marsh has coalesced at each end with the natural marsh. The natural marsh substrate consists of dark organic-rich mud and is flanked on the eastern and northern sides by a wave-constructed shell berm (Fig. 24). The southern part of the berm is active and is overtopped by storm waves that deposit shell material along a migrating, steep slip face on the edge of the marsh. The northern part of the berm is protected by the wave barrier and has become stable and inactive. In this area vegetation has begun to colonize the crest of the berm. Where the shell berm is active, it remains mostly barren.

Geomorphology

The natural marsh, planted marsh, and wave breaker form a triangular, protected embayment consisting of shallow flats, estuarine intertidal emergents, and oyster reefs. The shell berm, which forms a crescent ridge along the western margin of the natural marsh, is the topographically highest natural feature with a crest that is more than 0.5 m higher than the marsh surface (Fig. 28). There is an abrupt, almost vertical drop in land surface height from the crest of the berm to the marsh surface (Figs. 28-29). The surface of the marsh slopes gradually toward the shallow flats and steepens at the edge of the marsh (Fig. 25). The created marsh and underlying dredged-material substrate form an intertidal ridge that bounds the western edge of this protected marsh-flat complex.

Hydrology and Salinity

The majority of the natural and created marshes are regularly flooded. Irregularly flooded, higher marshes fringe and occur on the inactive shell berm. At the time of the

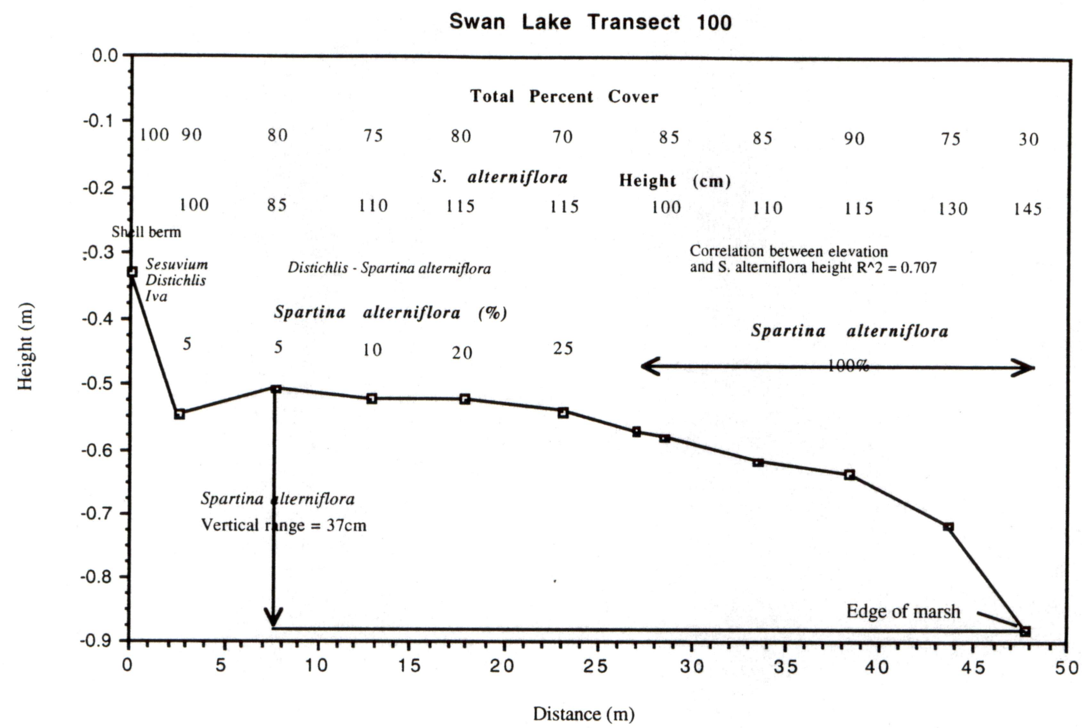


Figure 25. Transect 100, Swan Lake marsh.

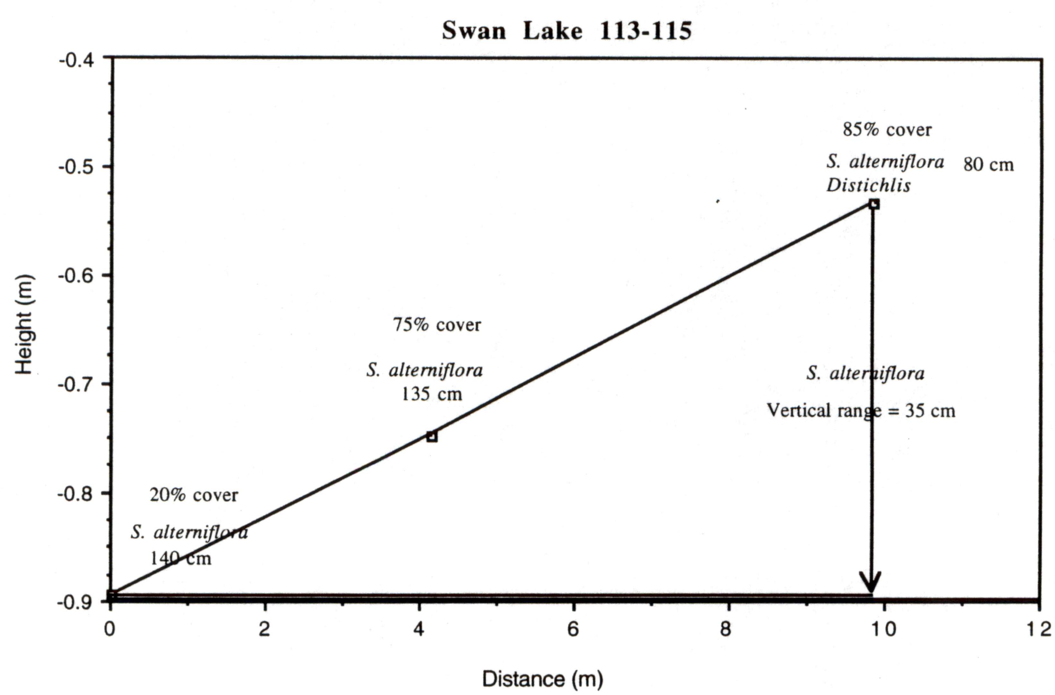


Figure 26. Transect 113-115, Swan Lake marsh.

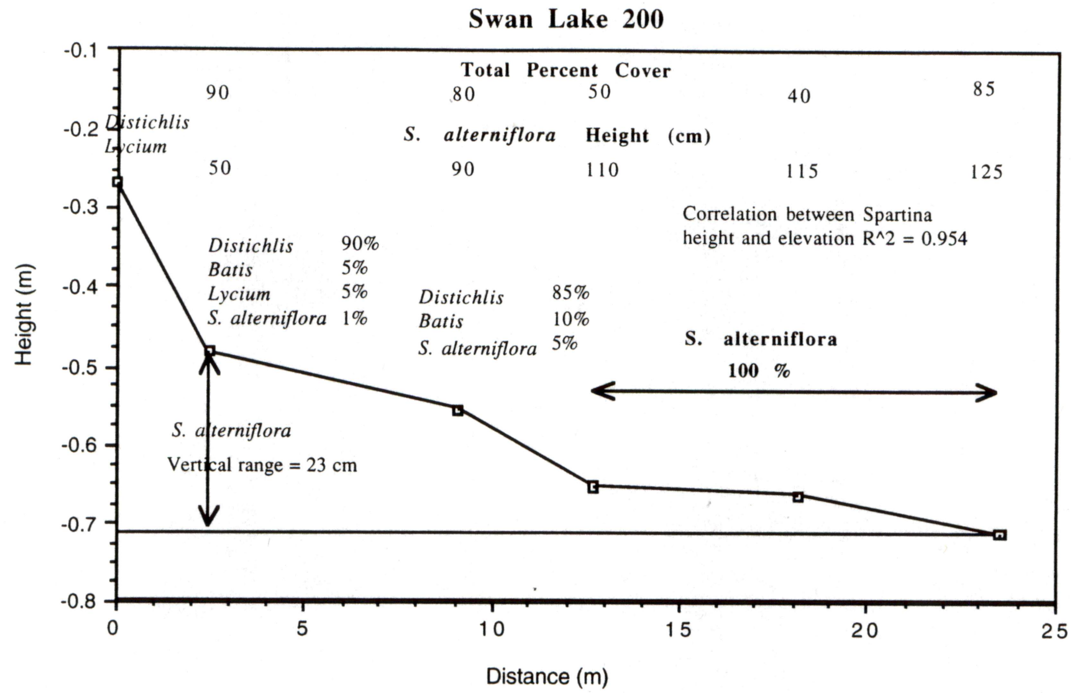


Figure 27. Transect 200, Swan Lake marsh.

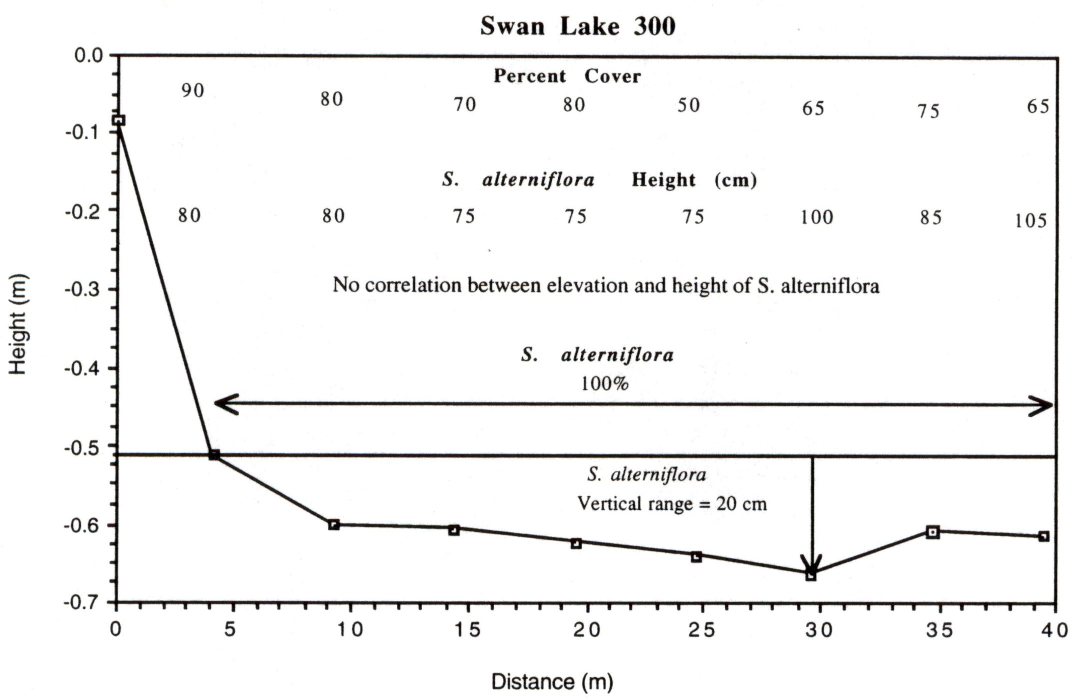


Figure 28. Transect 300. Swan Lake marsh.

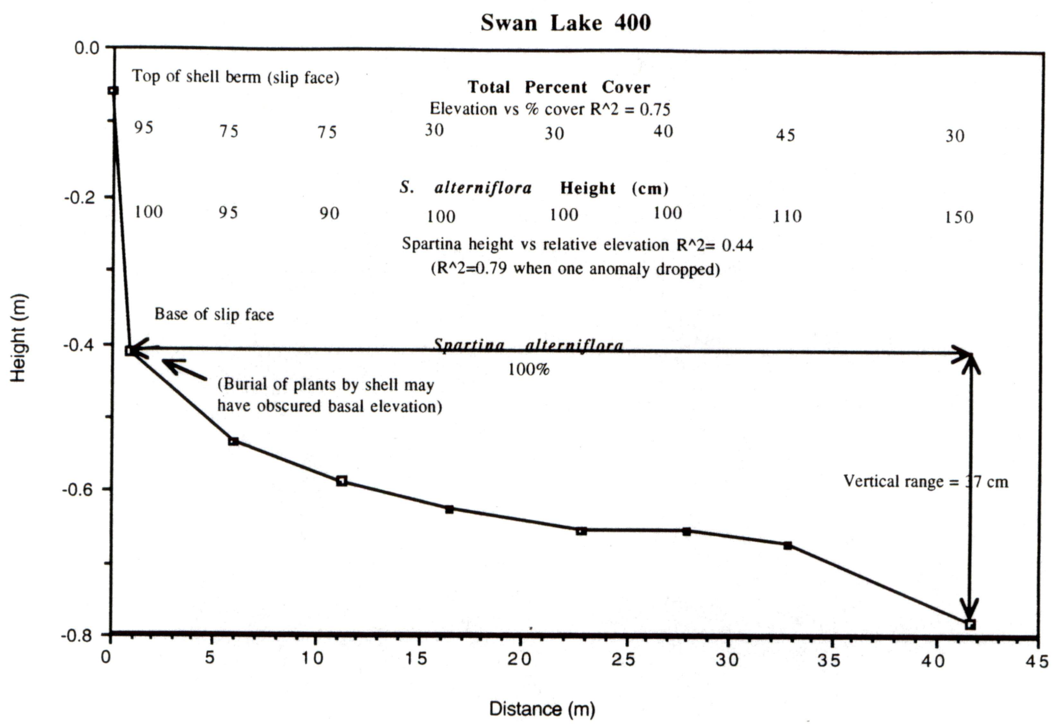


Figure 29. Transect 400, Swan Lake marsh.

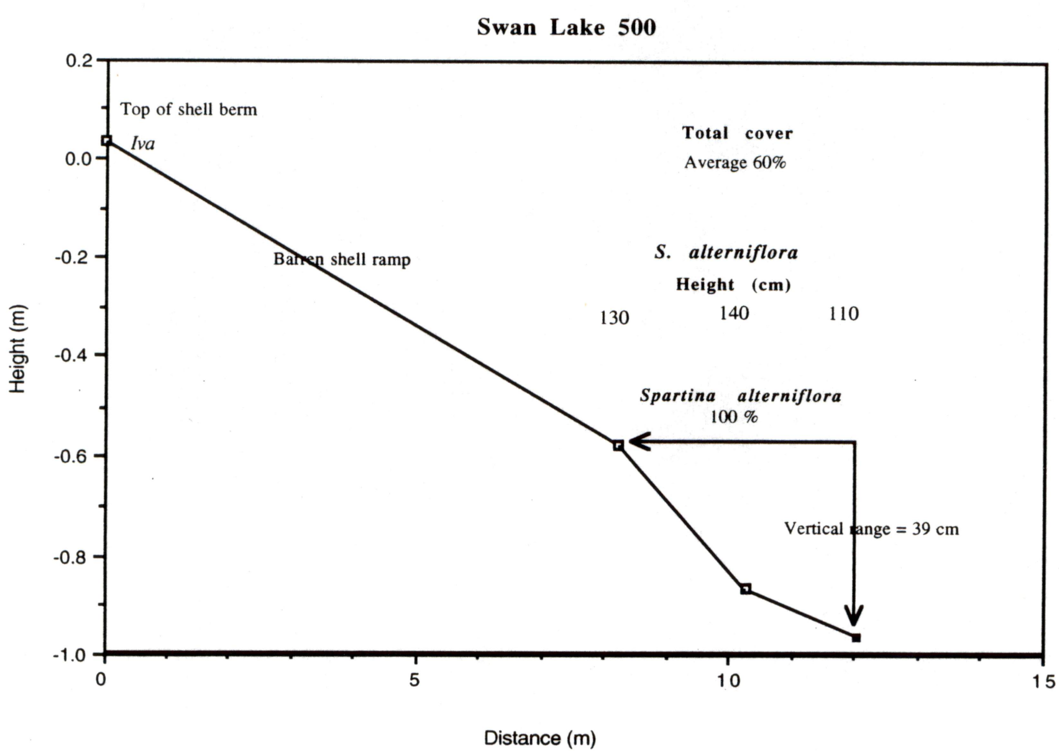


Figure 30. Transect 500, Swan Lake marsh.

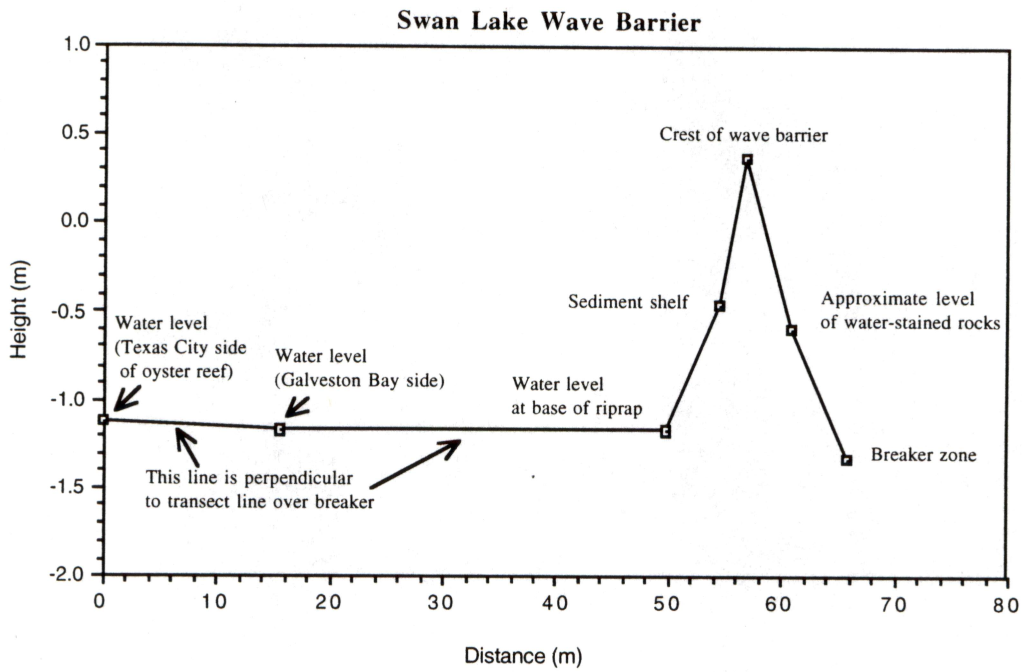


Figure 31. Transect across wave barrier, Swan Lake marsh. See Figure 24 for location and Figure 32 for photograph of barrier.

Figure 32. Photograph of wave barrier, Swan Lake marsh. View is north; Galveston Bay is on right. Note buildup of sediment in riprap on protected (left) side.

field survey in November 1997, tides were extremely low and on an ebb cycle. Currents were strong as water drained from the marsh and shallow flats across a reef that forms a low bridge between the wave barrier and shell berm. It appears that most of the tidal flow into the area, at least during normal and lower than normal tidal cycles, is through the channel between the shell berm and the wave barrier.

The salinity in the channel at the time of field survey was 28 ppt.

Shoreline and Site Stability

Before the wave barrier was constructed, erosion rates along the shell berm exceeded 1 m/yr from the 1930s to the 1980s (Paine and Morton, 1986). Human-induced subsidence is among the processes contributing to erosion and marsh loss (White and others, 1985, 1993). Swan Lake is encompassed by a subsidence bowl that is centered on Texas City (Fig. 9). Sipocz and Swafford (1995) estimated that approximately 100 ha of intertidal marsh fringing Swan Lake was lost between 1963 and 1989. More recent measurements of subsidence, however, indicate that rates have been greatly reduced since the late 1970s (Gabrysch and Coplin, 1990). The newly constructed wave barrier will help protect the created marsh from wave erosion, but rates of subsidence will have to remain low to prevent the marsh from being submerged and replaced by open water. Countering the possible effects of submergence is the process of marsh vertical accretion from accumulating sediments and organics. There is evidence that sediments are being deposited in some areas west of the wave barrier (Sipocz and Swafford, 1995), which can help marsh vegetation keep pace with a continuing rise in relative sea level.

Vegetation

Marsh vegetation was investigated along six transects (Figs. 25-30) in the natural marsh immediately west of the wave barrier. At 35 stations measured along the transects, the average percent foliar cover was 68.3 $\pm$ 21.6; the minimum was 30 and maximum 100 percent. In areas dominated by *Spartina alterniflora*, the average cover was 63.9 $\pm$ 22.3 percent, with a maximum of 95 and minimum of 30 percent (n=27).

At 37 stations, the average maximum height of *Spartina alterniflora* was 104 $\pm$ 23.3 cm, the maximum 155 cm, and the minimum 50 cm. On transects where the full vertical range in land surface height of *Spartina alterniflora* could be measured (Figs. 25-26 and 29-30), the average vertical range in height was 37 cm, with a minimum of 35 cm and a maximum of 39 cm. This suggests that the average tidal range in this area is about 37 cm.

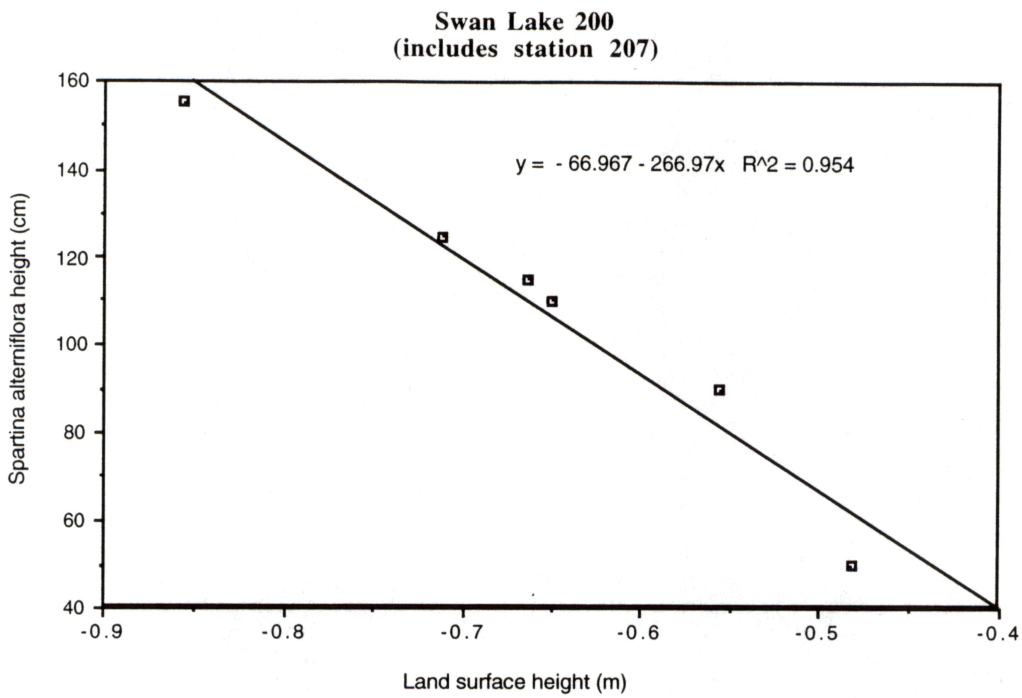
There is a strong inverse correlation between the height of *Spartina alterniflora* and land surface height along most transects. For example, at transect 200, $R^2 = 0.954$ (Fig. 33a), and at 38 transect stations (excluding two anomalies), $R^2 = 0.518$ (Fig. 33b).

Plants typical of high marshes along the margins of the shell berms include *Distichlis*, *Sesuvium*, *Batis*, *Lycium*, and *Iva*.

Success in Accomplishing Performance Goals

Sipocz and Swafford (1995) stated that the constructed portion of the Swan Lake project was regularly examined and considered highly successful because all project goals were achieved or exceeded. They further noted that the wave barrier has prevented erosion in

(a)



(b)

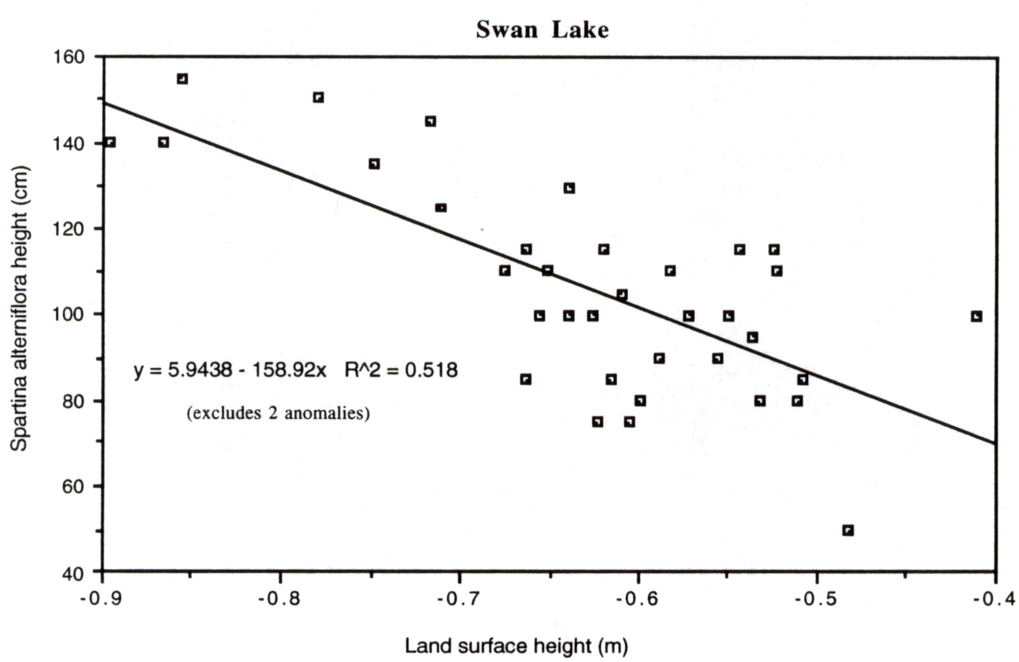


Figure 33. Correlation between height of *Spartina alterniflora* and height of land surface at Swan Lake for (a) stations at transect 200, and (b) stations at all transects.

both the created and natural marshes, and that the created marsh has expanded by colonizing sediments trapped by the breakwater. Recent (1998) imagery shows that the sizes of the created marsh and wave barrier exceed project specifications. Each has a length that exceeds 490 ha, which is more than required. The average width of the created marsh is approximately 38.7 m, exceeding the project design width of 30.5 m. The total area of the created marsh in early 1998 was approximately 1.9 ha, again, larger than the project requirements of 1.41 ha, suggesting that the created marsh has expanded.

Criteria and Potential for Large-Scale Marsh Restoration and Creation

Among the criteria showing potential for large-scale marsh creation are (1) use of dredged material from nearby dredging projects to build up the bay bottom to construct wave barriers and intertidal substrates for marsh plantings, (2) construction of wave barriers that are topped with stone riprap at heights that block most waves but allow storm waves to transport sediments into the protected embayment, and (3) use of design features that allow wave barriers and marshes to be expanded in segments that ultimately result in large-scale wetland development (Sipocz and Swafford, 1995).

Armand Bayou Marsh

The Armand Bayou marsh was created as part of a cooperative effort of the Clear Lake Marsh Restoration Task Force, composed of the Galveston Bay Foundation, U.S. Fish and Wildlife Service, Texas Parks and Wildlife Department, Texas General Land Office, Texas Department of Transportation, Houston Lighting and Power, Port of Houston Authority, Armand Bayou Nature Center, National Marine Fisheries Service, and Army Corps of Engineers (USACE, 1995). The site is located on the margin of the bayou and adjacent to land owned by the Armand Bayou Nature Center in Harris County (Figs. 34 and 35). The approximate location is Latitude is 29° 35' 10" and Longitude 95° 04' 15".

Project Objectives

The primary project objective was to create an intertidal marsh habitat in an area of open water that historically contained marshes.

Design/Restoration Criteria

Design plans detailed the construction of a 2.8 ha intertidal area using 13,000 m^3 of fill hydraulically dredged from the floor of Armand Bayou (Figs. 36-37). The fill was to raise the surface 0.3 - 1 m, and *Spartina alterniflora* was to be planted at 1 m centers (USACE, 1995) over an area of 2.32 ha (Linda Shead, Personal Communication, 1998). An earthen berm was used to retain the fill, and a brush fence and silt curtains were used to reduce turbidity in adjacent waters (Fig. 37). Maximum height of the earthen berm was to be + 0.18 m NGVD or + 0.61 m MLT (Cris Ransome & Associates, Inc., 1995) and depth of fill 0.15 m to 0.76 m (USACOE, 1995). Dimensions of the brush fence were 472 m long with a 46 m opening through which water could discharge during filling. The fence was constructed of 7.6 cm posts driven 0.6 m apart and secured with nylon lashings. Plastic fences were used as liners to secure the brush bundles placed in between the rows of posts (USACE, 1995). The marsh was planted in the summer of 1995.

Figure 34. Photograph of Armand Bayou marsh. The marsh is between Armand Bayou, in distance, and prairie grasslands in foreground.

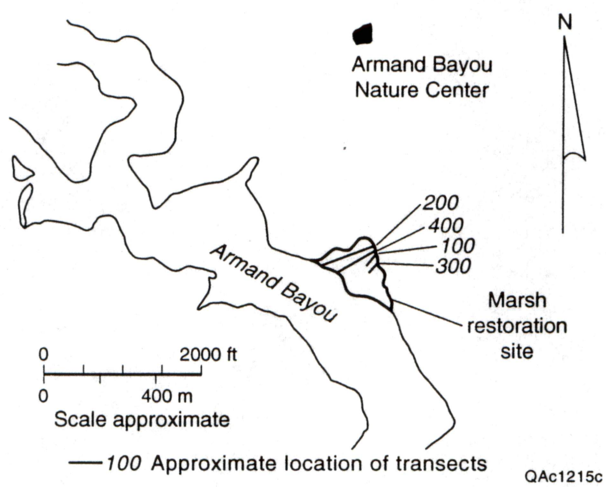


Figure 35. Location of Armand Bayou marsh site and approximate location of marsh transects.

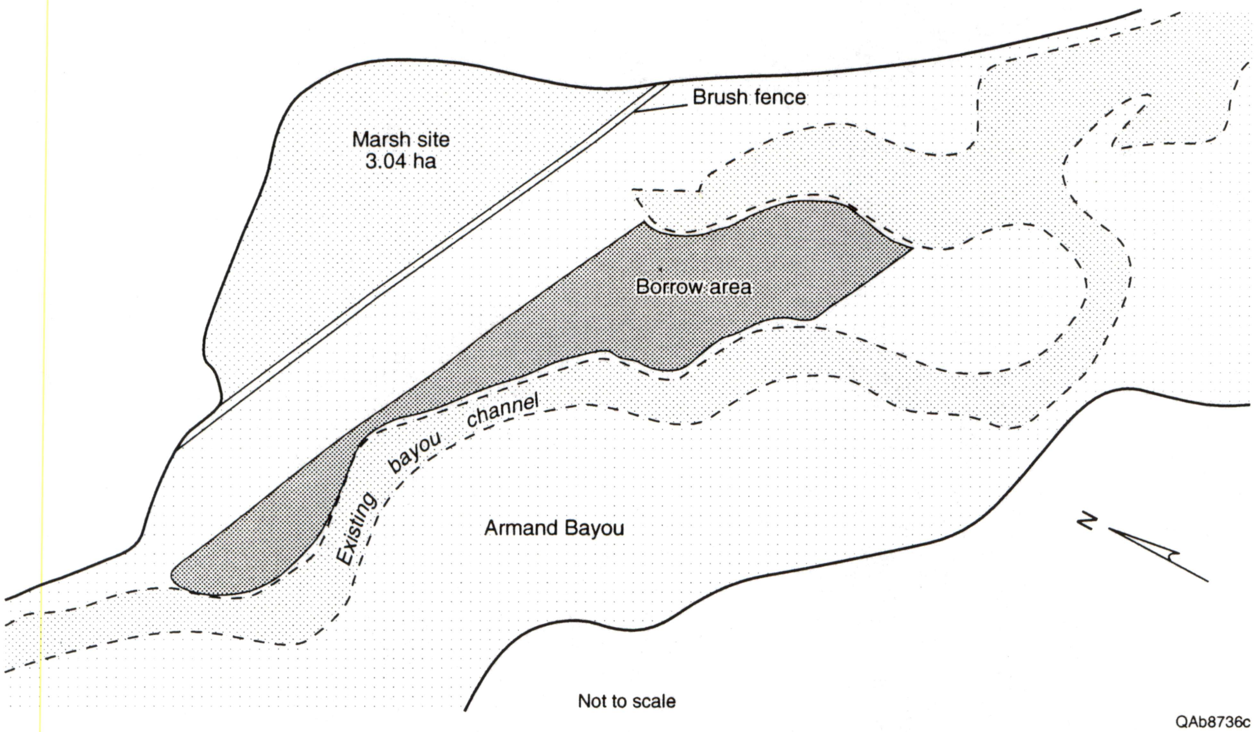


Figure 36. Armand Bayou general design plan showing location of marsh and borrow area. From Galveston Bay Foundation.

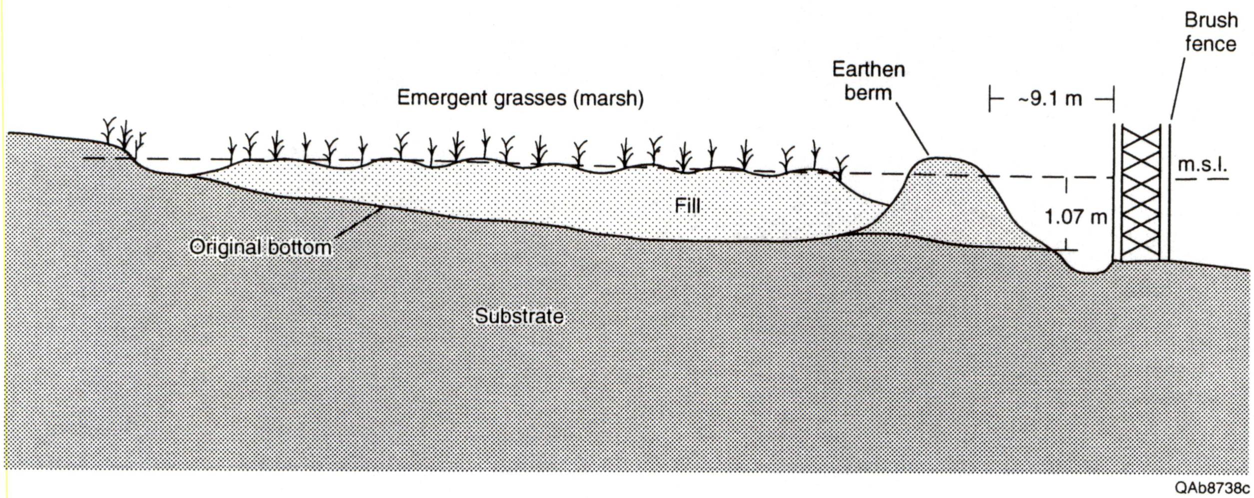


Figure 37. General cross section of the Armand Bayou marsh site showing approximate thickness of fill, earthern berm, and brush fence. From Galveston Bay Foundation.

Field Surveys

Field surveys as part of this project were conducted in November 1997 at a time when water levels were abnormally high. Marsh development was investigated using four transects, two of which crossed the marsh from the earthen berm to the upland shore and two that defined slopes and characteristics of the margin of the marsh (Figs. 35 and 38-41). The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based primarily on these transects and design plans.

Physical Characteristics

The calculated area of the marsh in April 1996 was 2.34 ha (Redd, 1996). Marsh elevations based on spot surveys of tennis balls scattered on the sediment surface averaged 0.82 m MLT and ranged from 0.58 to 1.11 m MLT (Redd, 1995).

Pre-dredging sediment samples collected from the marsh site and borrow area and analyzed to define geotechnical properties revealed that the substrate is primarily soft, firm, and stiff gray and brownish yellowish clay, silty clay, and sandy clay (HVJ Associates, Inc., 1995).

Geomorphology

The marsh was constructed in a shallow V-shaped embayment that has relatively steep upland margins. An earthen berm borders the created marsh along its contact with Armand Bayou (Fig. 37). The height of the berm varies but locally is 0.15 - 0.30 m higher than the marsh surface (Figs. 39-40). Two openings were cut in the berm for circulation and for fish ingress and egress. The marsh substrate was purposely left hummocky to provide varying elevations for marsh development, and to provide some open water habitat.

Hydrology and Salinity

The created marsh is regularly flooded. Two openings (3 - 3.6 m wide) cut in the berm allow water to flow in and out. Several smaller channels have also formed. In addition, hydrologic communication with the bayou occurs around the ends of the berm (Galveston Bay Foundation, 1995). An area of open water with intertidal connections is centrally located and is an integral part of the marsh complex. Salinities were not taken at this site.

Shoreline and Site Stability

The restored marsh is in an area that has been affected by high rates of land-surface subsidence (Fig. 42). Marshes established in the pre-1950s were permanently inundated as estuarine waters flooded the entrenched valley. Losses in emergent wetlands along Armand Bayou exceeded 91 percent of the resource between the 1950s and 1979 (McFarlane, 1991). Rates of subsidence from 1964 to 1973 exceeded 6 cm/yr (Gabrysch, 1984). More recent data on subsidence indicate that reductions in groundwater pumpage after the 1970s have dramatically reduced subsidence rates (Gabrysch and Coplin, 1990). Rates from 1983 to 1987 were less than 2 cm/yr. Over the past two years, 1995-1997, rates were much lower as indicated by reoccupation of a tide gauge and bench mark at Eagle Point on Galveston Bay south of Clear Lake; significant subsidence was not detected, indicating that rates were less than 0.5 cm/yr (Roberto Gutierruez, 1998, personal communication). If rates of subsidence remain low, then it is likely that marsh vertical accretion rates can keep pace with relative sea-level rise. If not, the emergent marshes will again be replaced by open water.

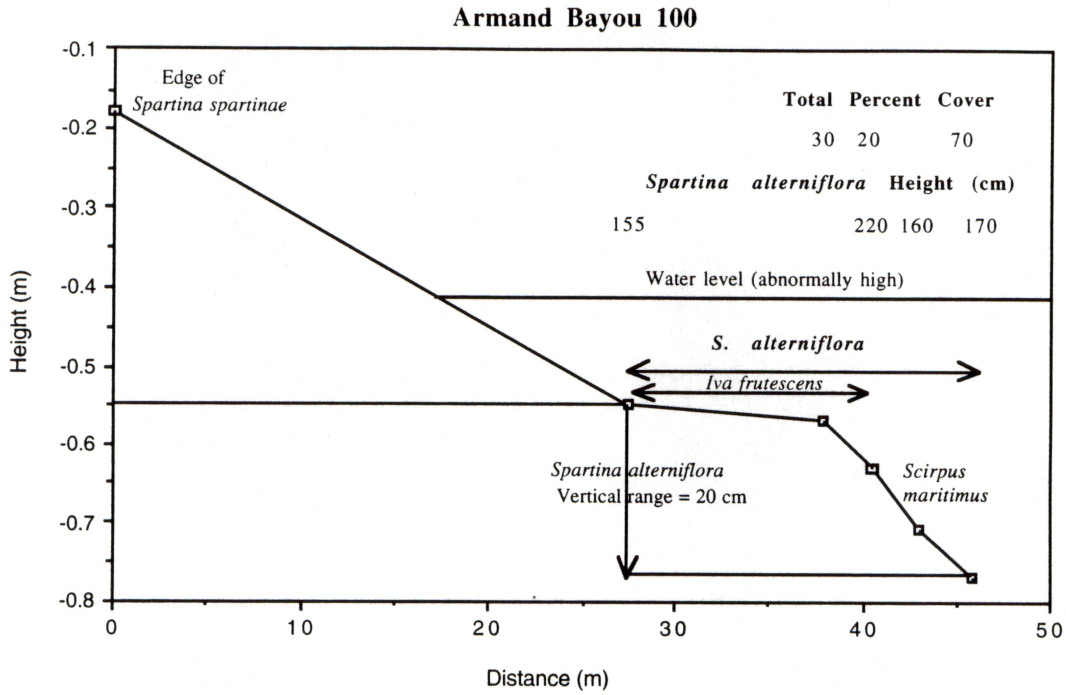


Figure 38. Transect 100, Armand Bayou marsh.

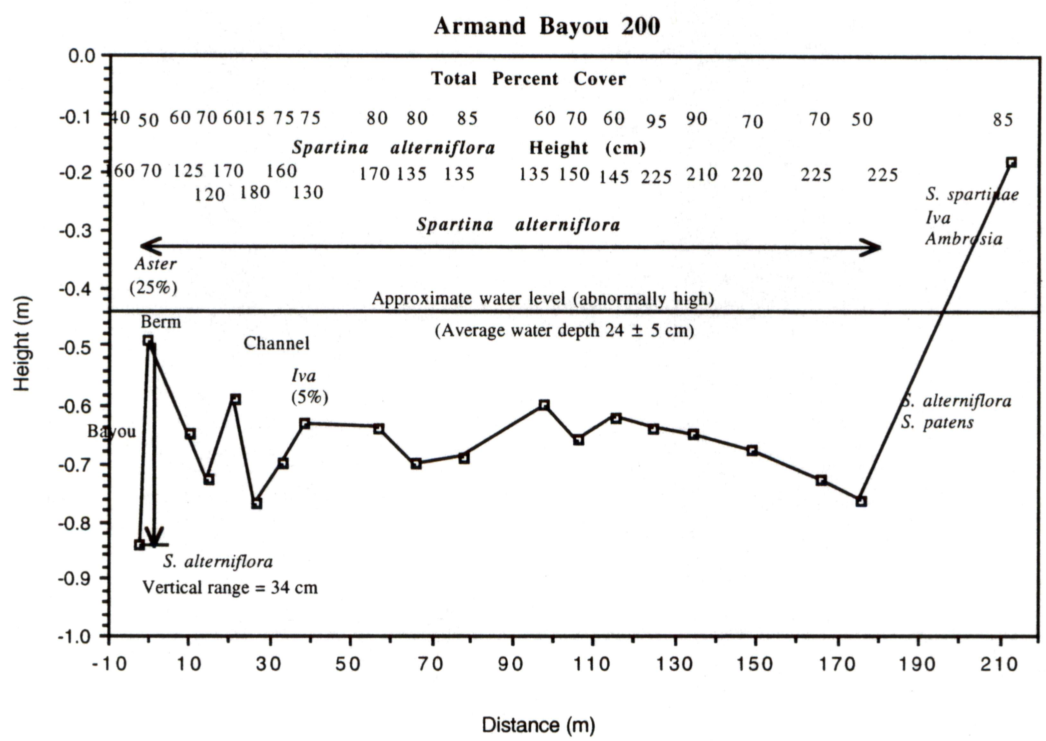


Figure 39. Transect 200, Armand Bayou marsh.

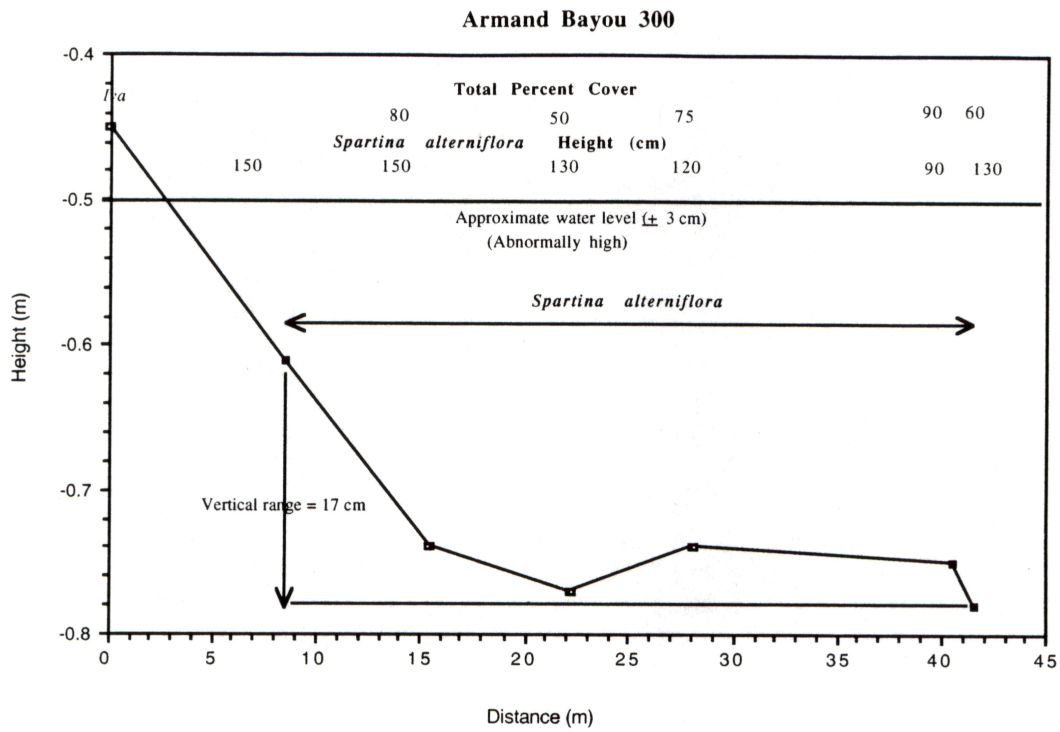


Figure 40. Transect 300, Armand Bayou marsh.

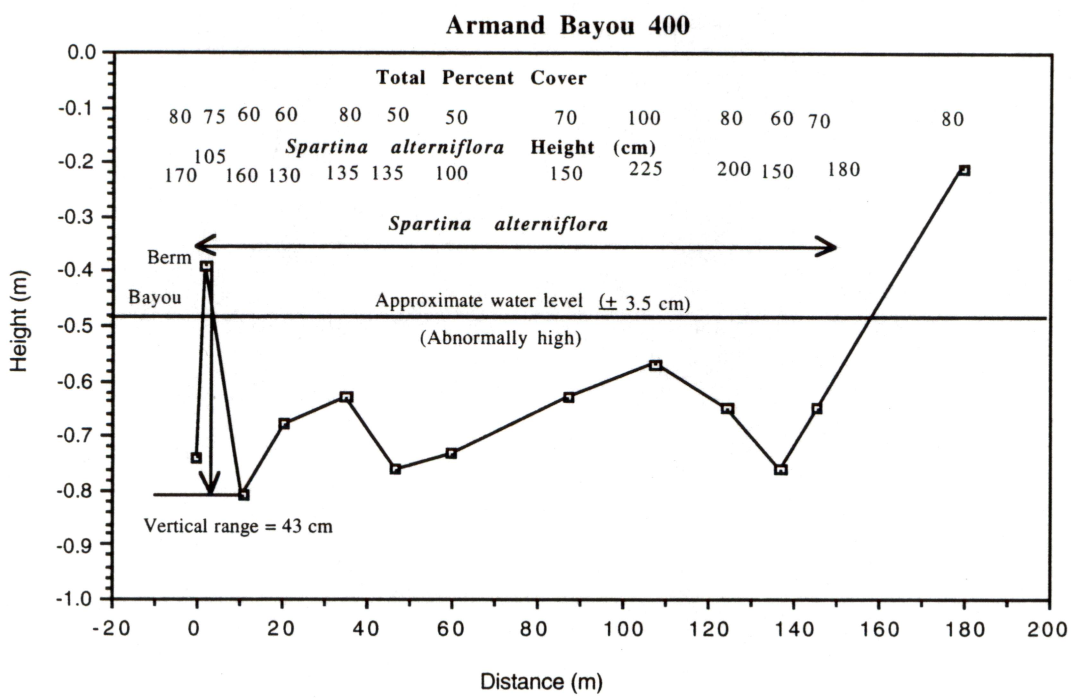


Figure 41. Transect 400, Armand Bayou marsh.

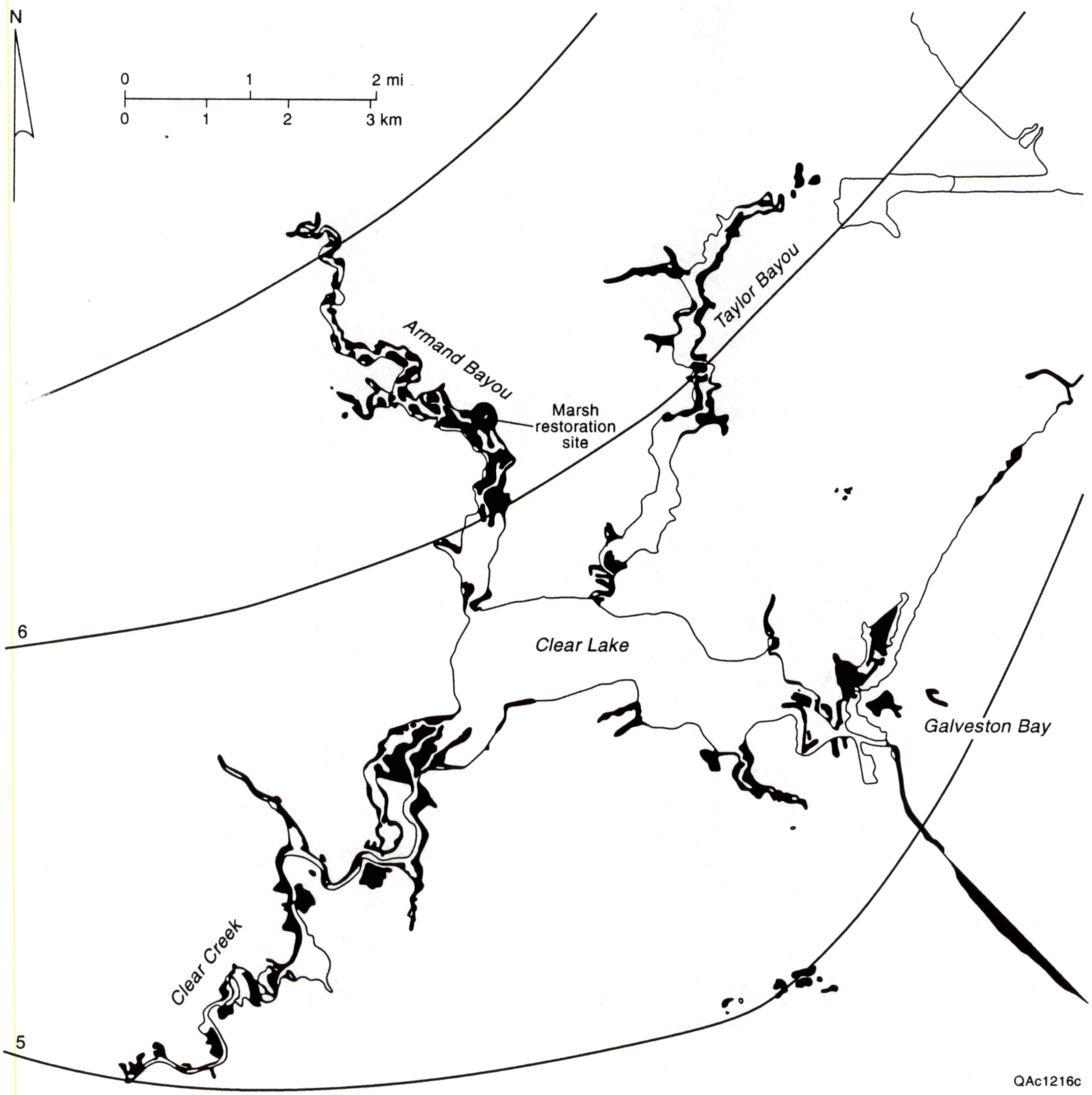


Figure 42. Relationship between subsidence and losses in emergent wetlands (shaded) by conversion to water and barren flats in the Clear Lake area. Contours (in ft based on maps from Gabrysch and Coplin, 1990) show amount of subsidence that occurred between 1906 and 1987. From White and others, 1993.

Vegetation

Marsh vegetation is predominantly *Spartina alterniflora*, some of which is the *vermillion* variety (John Huffman, 1997, Personal Communication). Other species occurring in the marsh include *Scirpus maritimus* and *Aster* sp. (Figs. 38-39). High marsh plants along the upland margin include *Spartina patens*, *Spartina spartinae*, and *Iva frutescens.*

Average foliar cover at 40 stations along 4 transects was 67.8 ± 17.3 percent, with a minimum cover of 15 percent and a maximum of 100 percent (Figs. 38-41). At 38 stations where *Spartina alterniflora* was dominant, the average cover was 67.0 ± 17.4 percent.

Based on measurements at 42 stations, maximum heights of *Spartina alterniflora* averaged 149 ± 43.5 cm and ranged from 60 to 225 cm (Figs. 38-41).

The maximum and minimum marsh surface heights on which *Spartina alterniflora* occurred at the time of the field survey were 0.84 and 0.39 m, yielding a maximum vertical range of *S. alterniflora* of 45 cm. This range is identical to that (44.7 cm) measured in a natural marsh along Armand Bayou (Cris Ransome & Associates, Inc., 1995). The range in vertical height along the 4 transects was 17 cm to 43 cm. There was no correlation between the height of *Spartina alterniflora* and the height of the land surface at this site. The reason may be due to the hummocky, yet overall topographically low mash substrate (Fig. 39) and the heterogeneity of the fill material characterized by varying sediment textures, nutrients, and organics.

Success in Accomplishing Performance Goals

This project has been very successful in accomplishing performance goals. The fill, earthen berm, brush fence, and transplants were completed as designed and have established a relatively dense marsh habitat over a short period. Foliar cover had an average density of more than 65 percent within two years of planting. *Spartina alterniflora* appears healthy, and maximum heights of some stands exceed 225 cm. Elevations of the fill material and the vertical range of transplants correlate well with nearby natural marshes. The overall size of the marsh complex in April 1996 was 2.34 ha (Redd, 1996), which is slightly larger than the final design area of 2.32 ha. The prospects for the marsh to expand in size are uncertain and dependent, in part, on the balance between rates of subsidence and marsh vertical accretion.

Criteria and Potential for Large-Scale Marsh Restoration and Creation

Among the criteria with potential for large-scale marsh development are use of fill material hydraulically dredged from a borrow area adjacent to the restoration site, employment of an earthen berm and brush fence to contain sediments and protect transplants from erosion, achievement of appropriate intertidal elevations for transplant survival, and development at a site that historically contained marsh habitat.

Frozen Point Marshes

The Frozen Point marshes are part of a marsh creation and shoreline stabilization project located on the northern shore of East Bay along the Anahuac National Wildlife Refuge in Galveston and Chambers Counties (Fig. 43). The permit for construction of the project was initiated by U.S. Fish and Wildlife Service, Anahuac National Wildlife Refuge (USACE, 1992). Other cooperating agencies included the USDA Natural Resources

Conservation Service and the Galveston Bay Foundation. The sites are near Latitude 29° 33' 25" and Longitude 94° 31' 50".

Project Objectives

The primary objective of the project was to protect and restore marshes along an erosional shoreline of the Anahuac National Wildlife Refuge (USACE, 1992).

Design/Restoration Criteria

Design specifications included placement of approximately 2,800 m^3 of limestone riprap to construct shore-parallel breakwaters approximately 6 m from shore (Fig. 44). The breakwaters were to be in discontinuous segments that were 1.2 m wide, 0.76 m high, and with a total length of 3.2 km. Areas behind the breakwaters were to be planted with *Spartina alterniflora*.

Field Surveys

Field surveys as part of this project were conducted in November 1997, at a time when water levels were abnormally low during a norther. Marsh development was investigated using eight transects, seven of which crossed riprap breakwaters and one that did not, located at sites north of Frozen Point (Figs. 45-52). The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based primarily on these transects and design plans.

Physical Characteristics

The total area of created marshes and the length of breakwaters were not determined. Of seven transects that crossed breakwaters (Figs. 45-47 and 49-52), the average distance from the landward edge of *Spartina alterniflora* to the bayward edge of the riprap was 7.5 m. The maximum and minimum distances were 10.5 m and 5.7 m. At transect 600, *Spartina alterniflora* was established on both the landward and bayward sides of the breakwater (Fig. 50).

The limestone riprap consists primarily of moderately sized, subrounded boulders (Fig. 53). Heights of the riprap relative to the height of the sediment surface on the bayward side averaged 0.39 m and ranged from 0.15 to 0.62 m. Average width of the riprap was 1.7 m with minimum and maximum widths of 1 m and 2.5 m.

Marsh substrates are predominantly mud with a high clay content and local thin shell veneers along the landward margins of some transects. Shell veneers are as wide as 6 m.

Geomorphology

The geomorphology of the shoreline is characterized by erosional steep slopes and near vertical scarps along the landward margins of the planted marshes. Slopes become more gentle from the base of the scarps to the water's edge (Figs. 48-52). On several transects, there is a relatively flat, perched sediment shelf between the erosional scarp and riprap breakwater (Figs. 49-52). The perched shelves are about 0.4 m higher than the sediment surface at the bayward edge of the riprap.

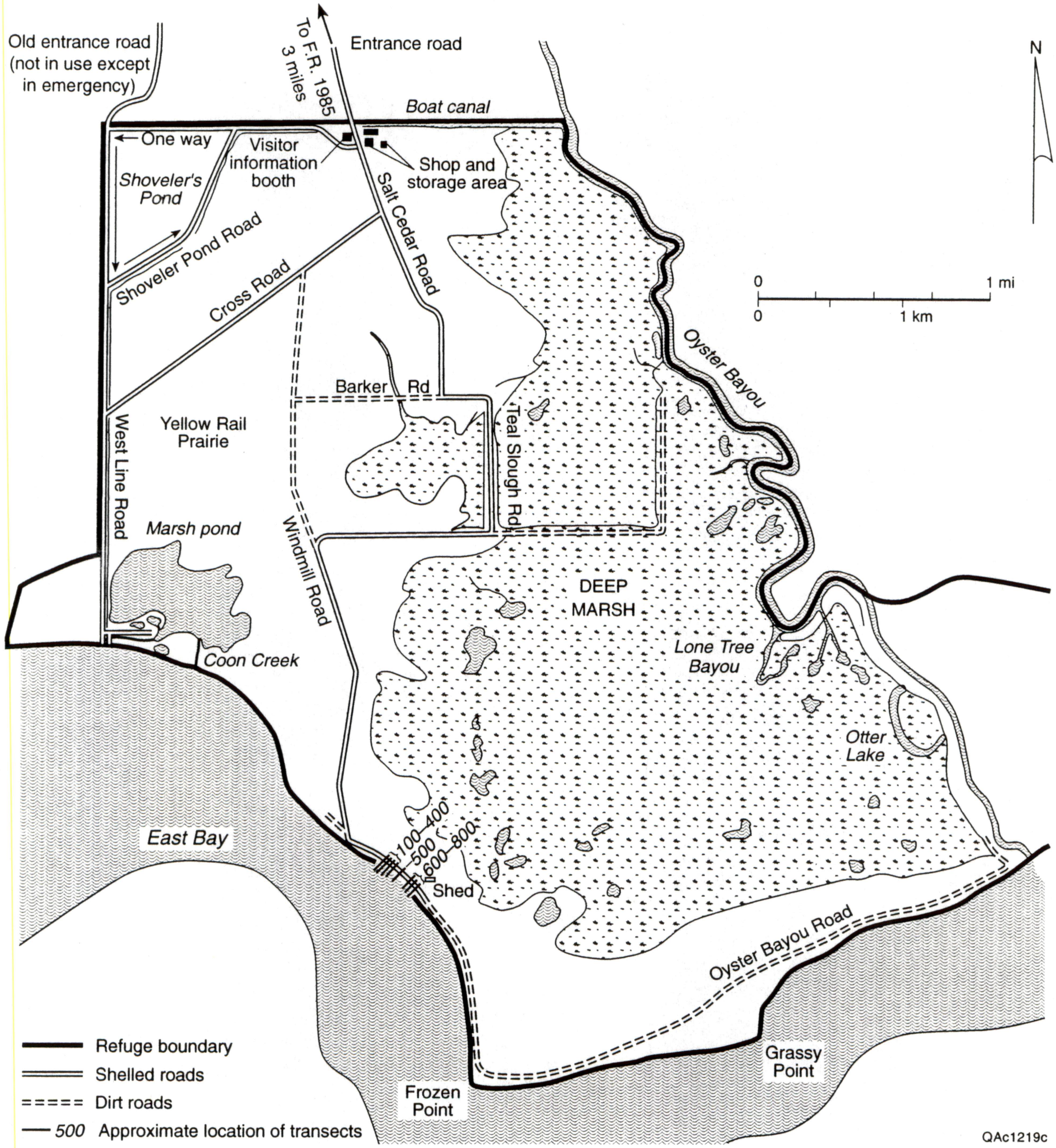


Figure 43. Map showing Frozen Point marsh creation sites and approximate location of marsh transects. Modified from USFWS map of the Anahuac National Wildlife Refuge.

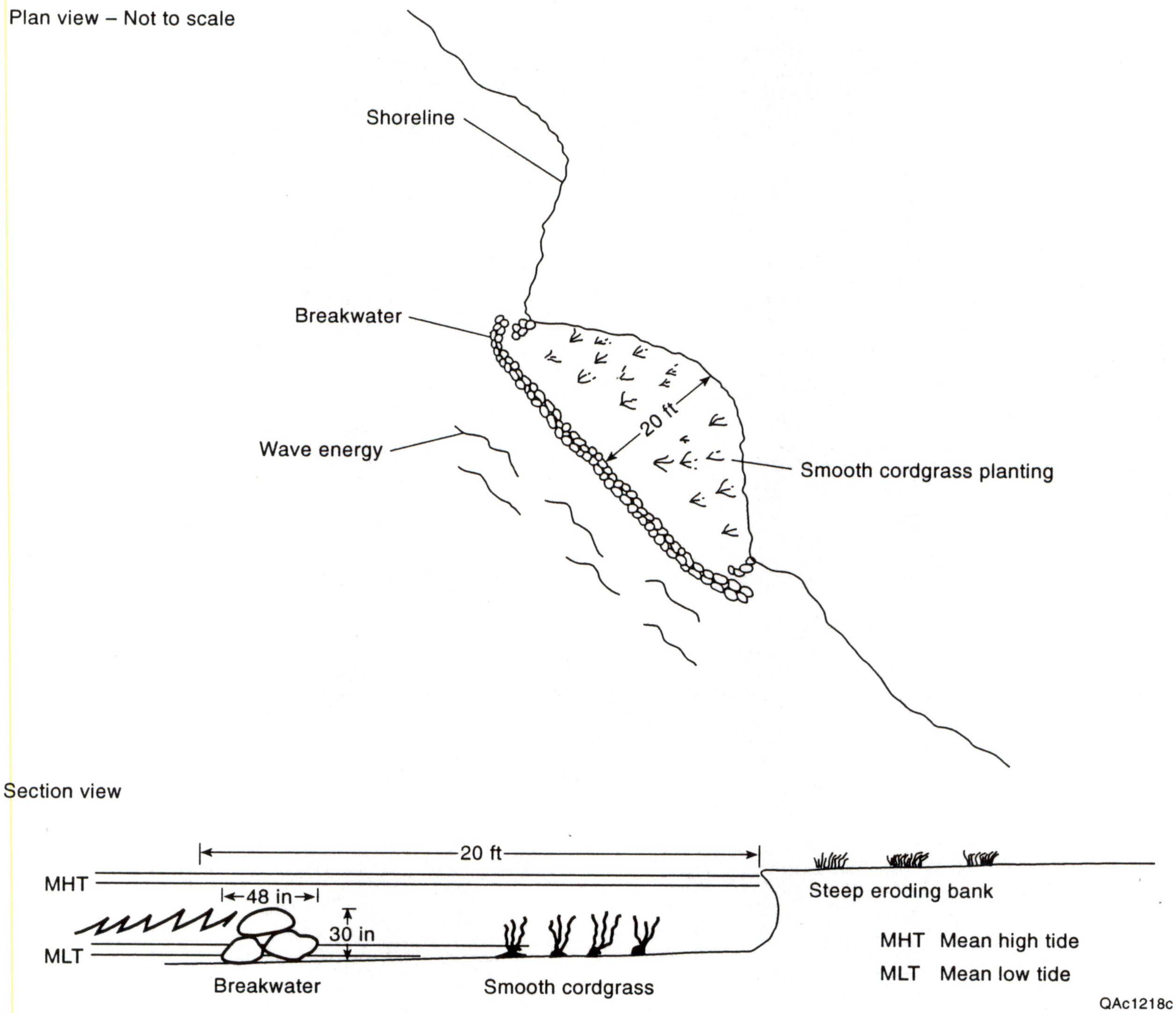


Figure 44. Illustration of marsh design features at Frozen Point. From USACE (1992) permit application.

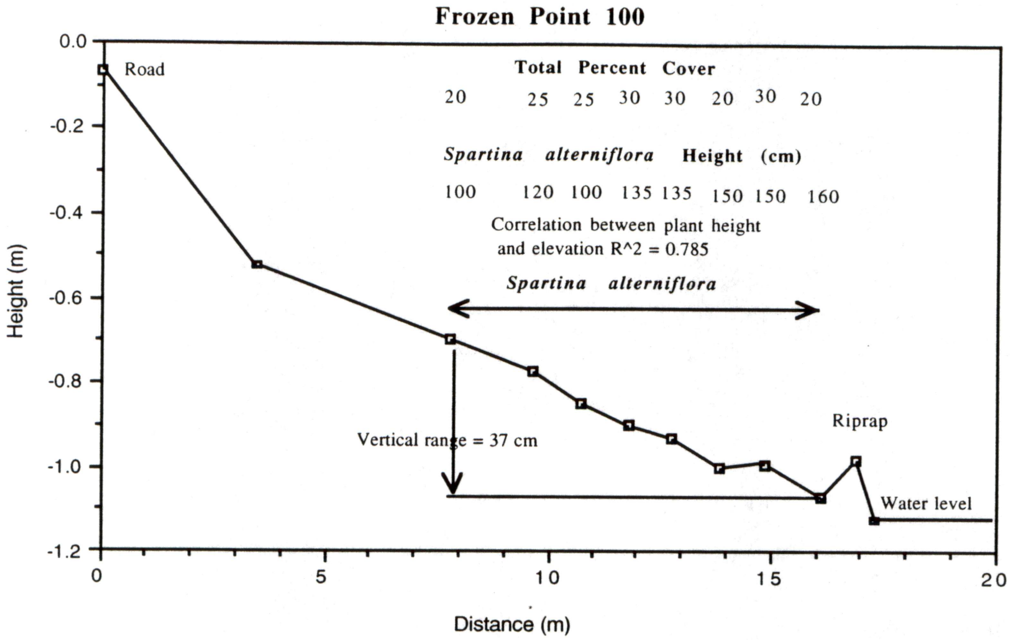


Figure 45. Transect 100, Frozen Point marsh

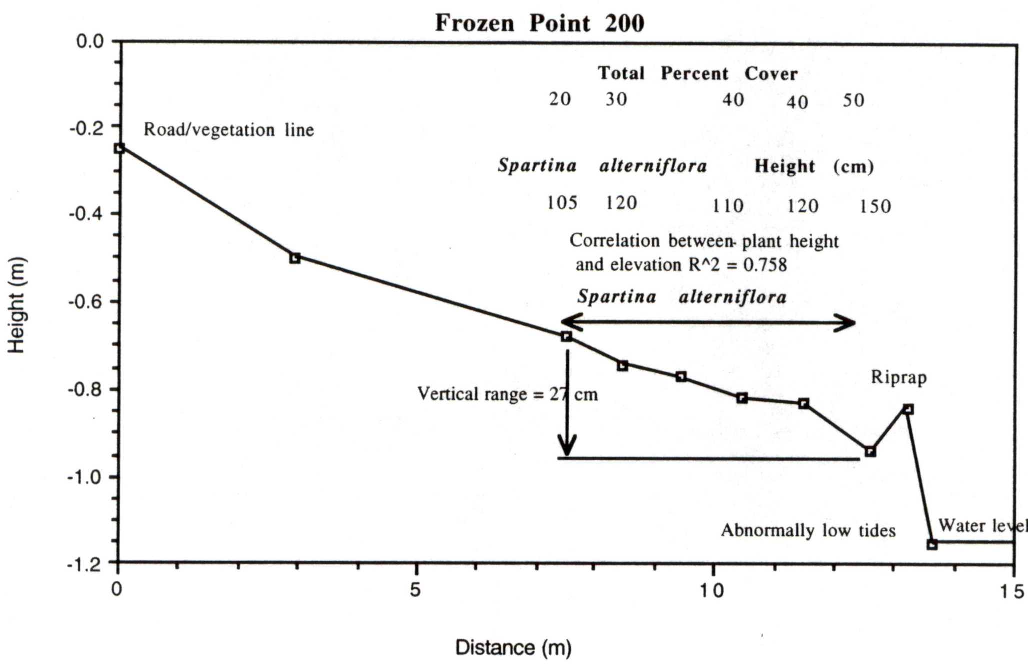


Figure 46. Transect 200, Frozen Point marsh.

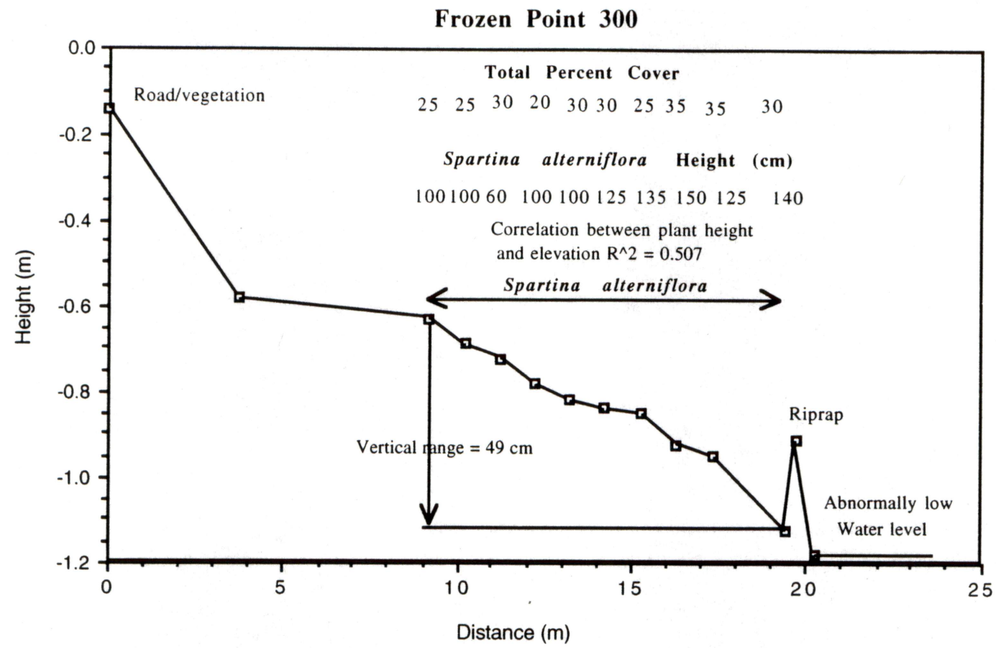


Figure 47. Transect 300, Frozen Point marsh.

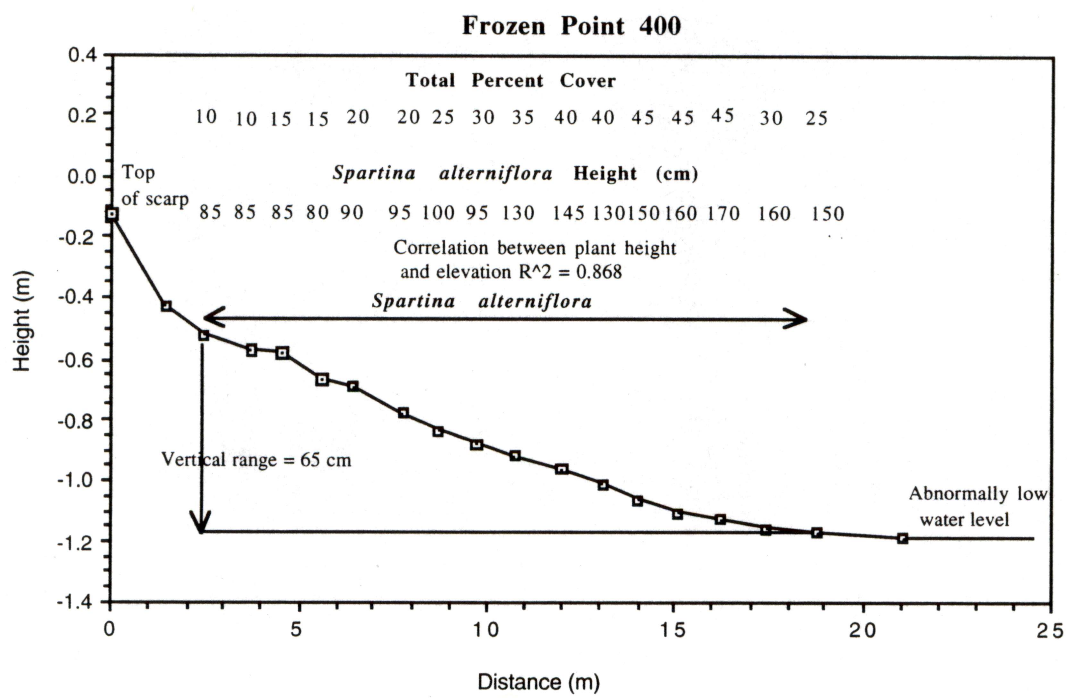


Figure 48. Transect 400, Frozen Point marsh.

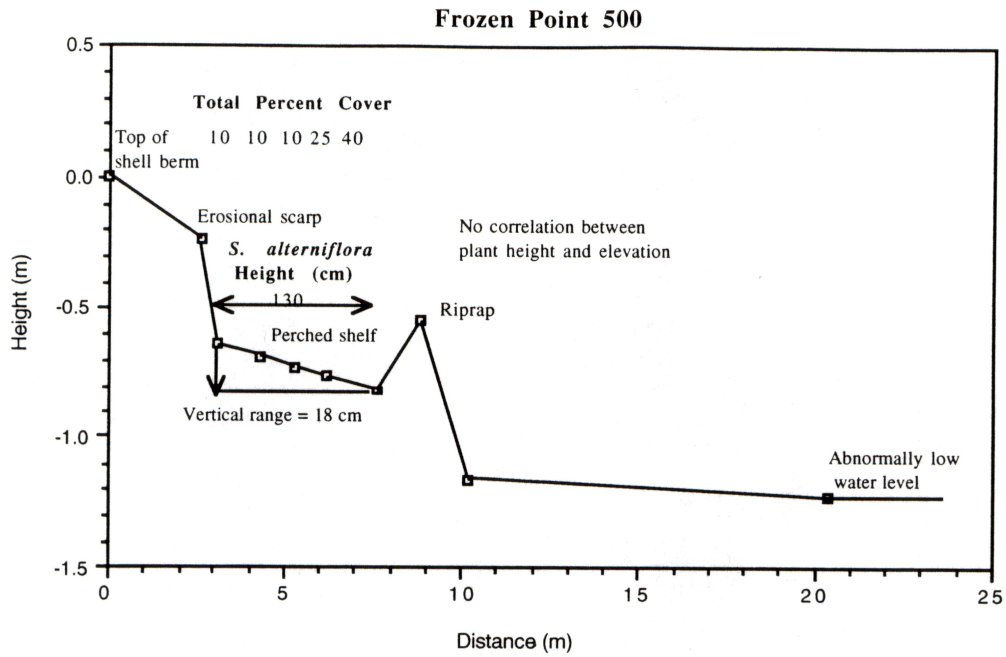


Figure 49. Transect 500, Frozen Point marsh.

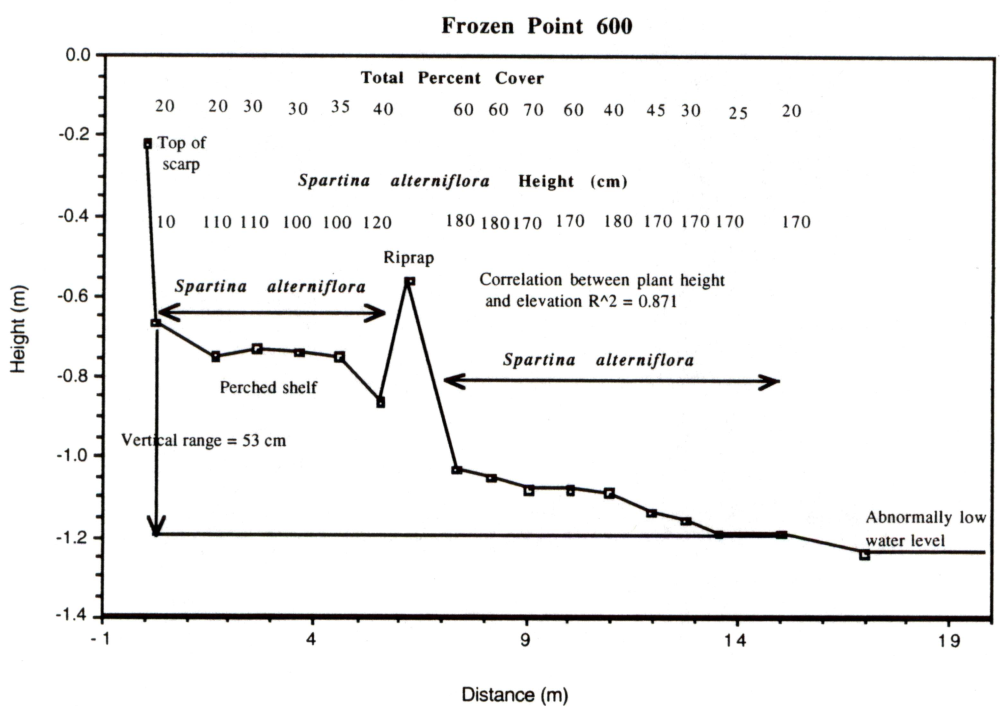


Figure 50. Transect 600, Frozen Point marsh.

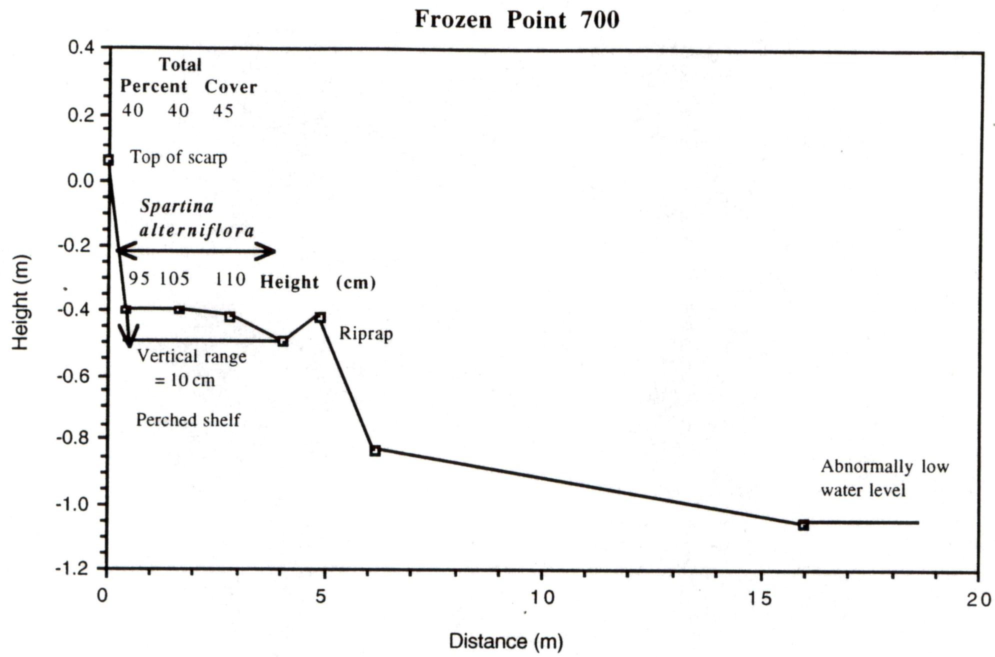


Figure 51. Transect 700, Frozen Point marsh.

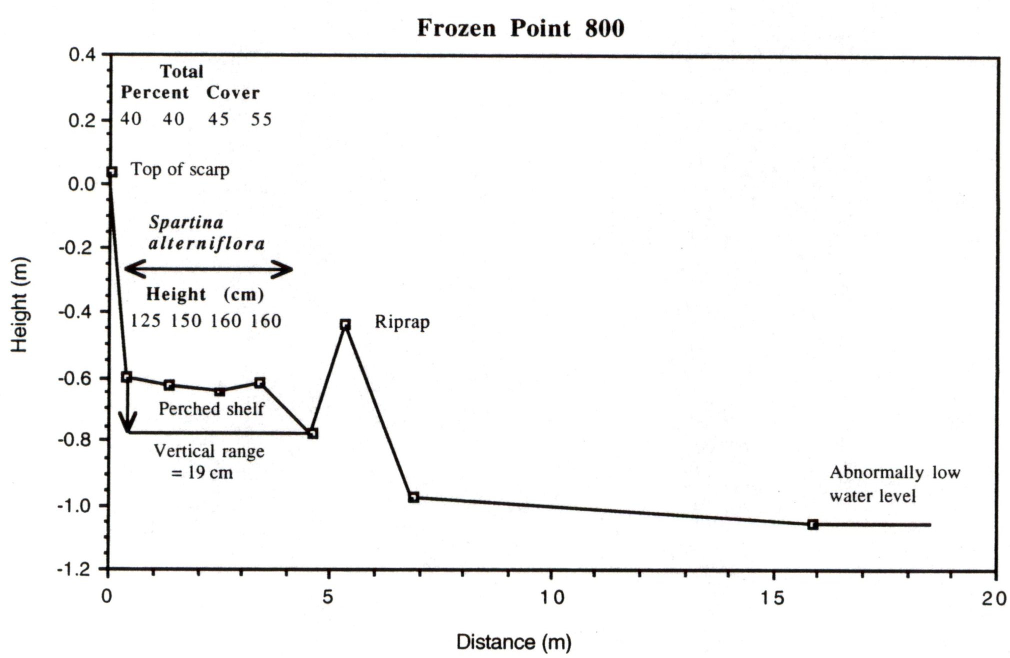


Figure 52. Transect 800, Frozen Point marsh.

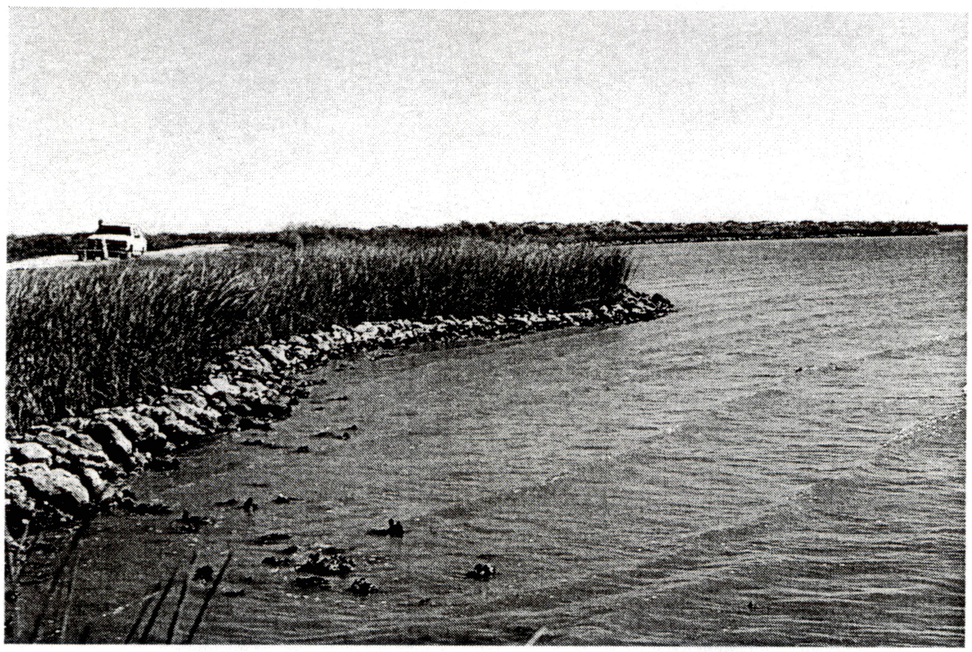


Figure 53. Photograph of riprap and *Spartina alterniflora* at one site at Frozen Point.

Hydrology and Salinity

Marshes are in regularly flooded intertidal environments. The hydroperiod is lowest in *Spartina alterniflora* located on the perched shelves behind breakwaters. Abnormally low tides during the field survey exposed a shallow shoreface bayward of the riprap along transects 500-800 (Figs. 49-52), whereas deeper nearshore areas along transects 100-300 placed the water's edge at the base of the riprap even during low tides (Figs. 45-47). Freshwater seepage from adjacent "highlands" was apparent along some transects, for example 700 and 800, where soils were moist and contained pockets of standing water.

Bay water salinity measured on the date of the field survey was 18 ppt. Standing water from seepage (see preceding paragraph) had a salinity of 3 ppt.

Shoreline and Site Stability

Project sites are along an erosional shoreline that has experienced long-term (1930s-1982) net retreat at average rates of up to about 0.9 m per year (Paine and Morton, 1986). The shoreline is exposed to waves from storms and prevailing southerly winds in East Bay. Subsidence in this area is part of the relative sea level rise equation. Subsidence along active faults has affected nearby marshes to the west and across East Bay on Bolivar Peninsula (White and others, 1985). Limestone riprap was placed alongshore to create a permanent breakwater to protect marshes from erosion (Fig. 53).

Vegetation

Foliar cover, maximum plant heights, and land surface heights were measured along eight transects. *Spartina alterniflora* was present landward of breakwaters along six transects and occurred both landward and seaward of a breakwater along one transect. It was also present along one transect without a breakwater (Fig. 48).

At 65 stations examined along transects, total foliar cover in areas dominated by *Spartina alterniflora* averaged 31.8 $\pm$ 13.1 percent, and ranged from 10 to 70 percent. There is a high inverse correlation between land surface height and percent cover along some transects if sites with low cover near the water's edge are excluded (Fig. 54a).

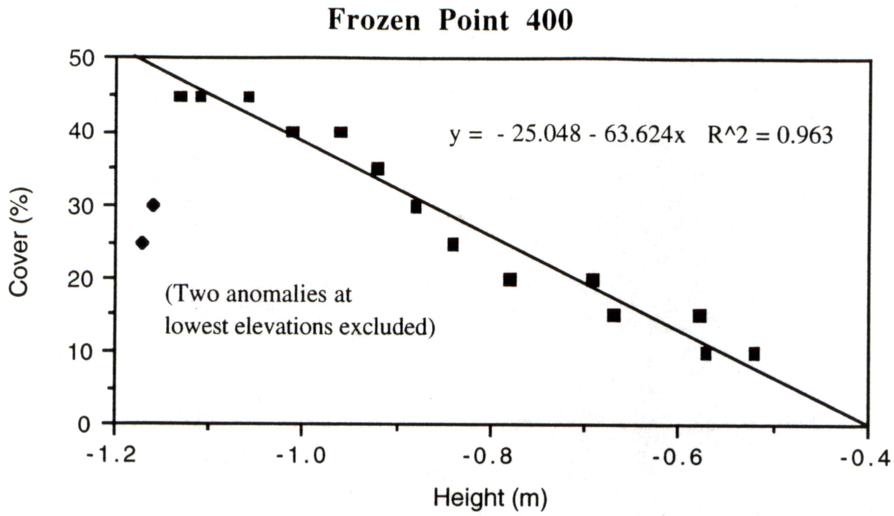
Maximum measured heights of *Spartina alterniflora* at 67 stations averaged 128 $\pm$ 29.5 cm and ranged from 60 to 180 cm. There is a strong inverse relationship ($R^2 = 0.713$) between height of *Spartina alterniflora* and land surface height as illustrated at 60 stations along transects 100-600 (Fig. 54b). The correlation is even higher along transect 400 (Fig. 54c). Height of *Spartina alterniflora* is lower on perched sediment shelves than along topographically lower slopes bayward of the riprap, but a high inverse correlation still holds for the entire transect (Fig. 50).

The vertical range in land surface height at which *Spartina alterniflora* occurred averaged 35 cm, but had a broad range from 10 to 65 cm (Figs. 45-52). The smallest vertical ranges occurred in *Spartina alterniflora* growing on perched sediment shelves located between wave cut scarps and riprap structures (Figs. 49-52). The largest vertical range of 65 cm occurred along transect 400, which had no riprap breakwater.

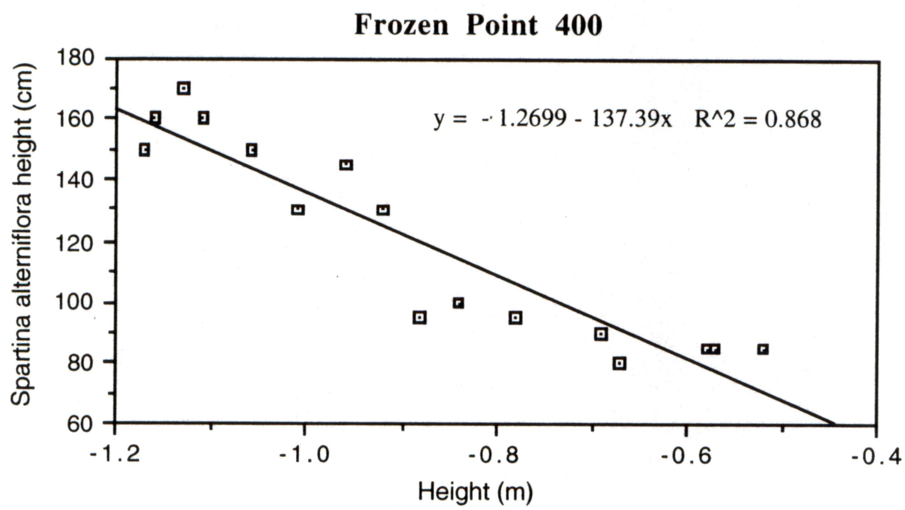
Success in Accomplishing Performance Goals

Project goals of marsh development and shoreline protection appear to have been successful over the short term. Riprap breakwaters and marsh vegetation parameters are

(a)



(b)



(c)

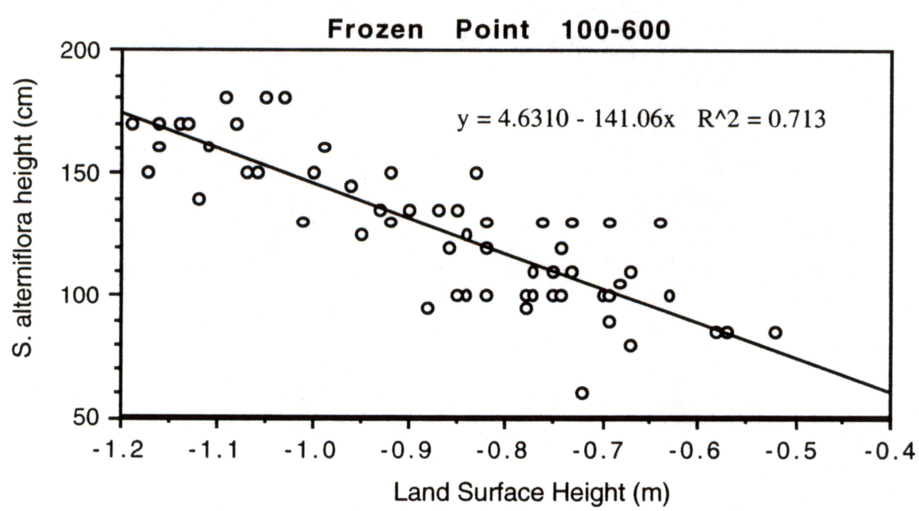


Figure 54. Correlation between (a) percent foliar cover and height of land surface at transect 400, (b) height of *Spartina alterniflora* and land surface at transect 400, and (c) height of *S. alterniflora* and land surface at stations along transects 100-600.

close to design specifications at the seven transects. Distances from shore of the riprap breakwaters, which define the width of *Spartina alterniflora*, generally exceed design specifications of 6.1 m. In addition, average widths of the breakwaters exceed specifications. However, based on seven measurements, the average breakwater height is approximately 0.39 m, which is about 0.4 m lower than that specified in design plans (USACE, 1992). It is possible that since construction, the riprap has settled, been partially buried by sediment, and reworked by large waves, thus reducing the effective height of the breakwaters. Along some unmeasured stretches, the riprap appears higher than that along transects.

The average cover of 32 percent for *Spartina alterniflora* is lower than in some other sites investigated, but it may be similar to natural fringe marshes in this area. Marsh vegetation appears healthy. The effectiveness of the riprap and marsh plantings as shoreline protection, however, can be better determined over the long term.

Criteria and Potential for Large-Scale Marsh Restoration and Creation

Among the criteria with potential for large-scale marsh development is the use of permanently established riprap breakwaters to help protect transplants and stabilize a retreating shoreline. Previous projects along this shore used temporary breakwaters made from material such as rubber tires to protect transplants but did not achieve long-term success. Still, planting fringe marshes that are about 6 m wide cannot themselves amount to large-scale marsh restoration. Two miles (3.2 km) of marsh this wide covers an area of about 2 ha. The most promising prospect is that these narrow shoreline features are helping protect and preserve existing large-scale marshes, like those on the Anahuac National Wildlife Refuge, from the effects of erosion and saltwater intrusion.

Bayland Park Marina Marsh

Wetlands at this site were established as part of marina construction in Bayland Park, located near the mouth of Cedar Bayou and adjacent to State Highway 146 in the City of Baytown. Four marsh areas were created in the park. The largest marsh, Wetland Area B (Fig. 55), was investigated during this study. The site is located at approximate Latitude 29° 42' 30" and Longitude 94° 59' 45".

Project Objectives

Among the objectives were to create salt marshes on graded fill material and to protect them from erosion by riprap.

Design/Restoration Criteria

The site plan (Randall-Porterfield Architects, Inc., 1995) presents a detailed layout of four wetland enhancement areas ranging in size from 0.03 to 2.3 ha and totaling 4.4 ha (Fig. 55). Design features for wetland area B included placing fill material along the bayward margins of an existing upland island and grading the fill to specified slopes of 5-10 percent along the upper margins and 1 percent along lower intertidal margins (Fig. 55). The intertidal surface was to have a minimum width of 30.5 m and elevations ranging from about 0.3 to 0.7 m above MSL for establishing salt marsh vegetation. Wave protection was provided by concrete-block riprap placed on a base of woven filter cloth along the bayward margin of the marsh and along a line farther offshore to form a wave breaker. Upland margins of the fill were to be stabilized by hydro-mulch and bermuda grass. The entire marsh habitat was to be created by planting approximately 45,000

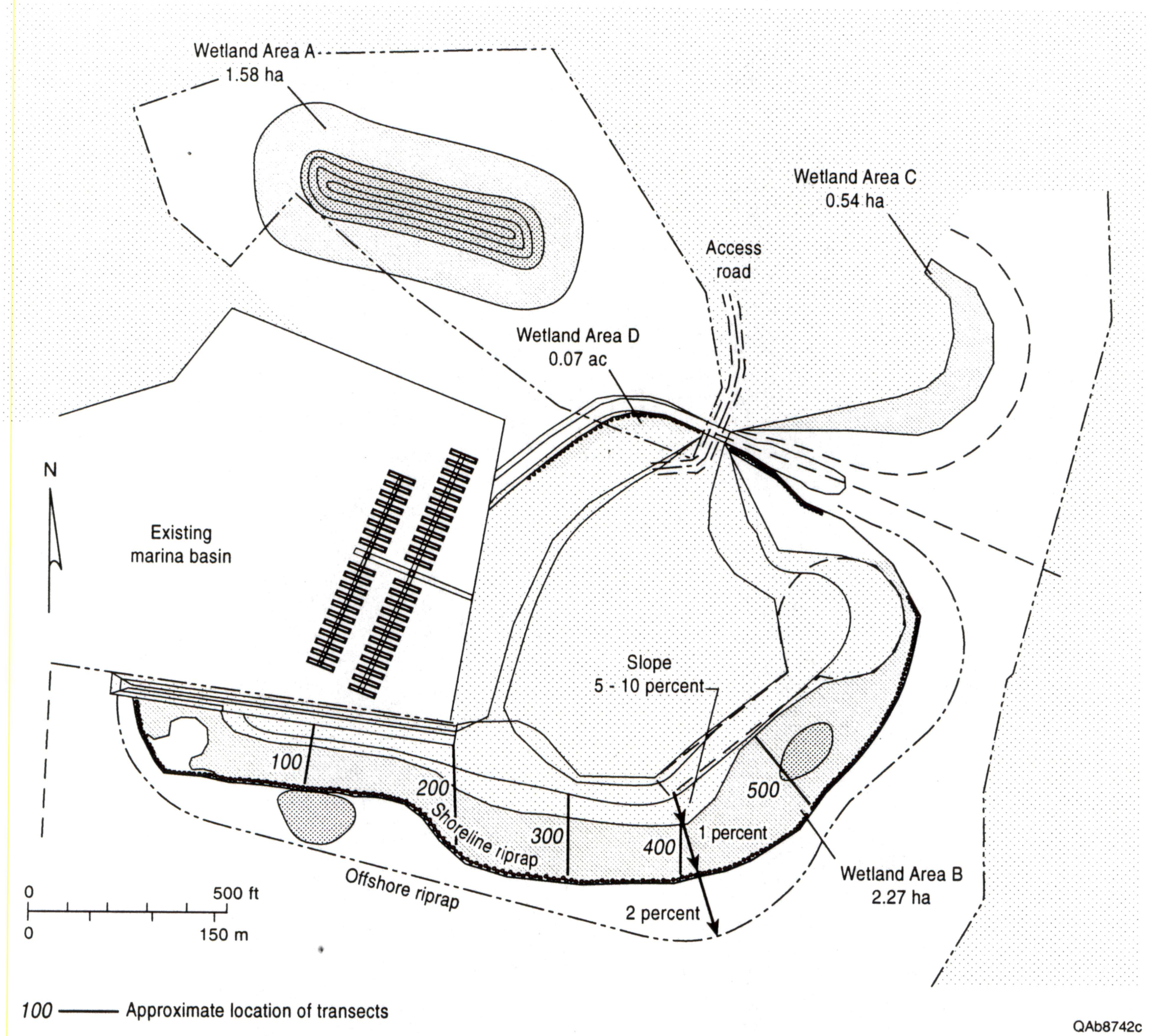


Figure 55. General design plan and approximate locations of marsh transects at Bayland Park Marina. Design plan from Randall-Porterfield Architects, Inc. (1995).

stems of *Spartina alterniflora* var. *vermillion*, at 1 m spacings. Vegetation was initially planted in 1996.

Field Surveys

Field surveys as part of this project were completed in September 1997. Five transects were conducted in Wetland Area B along the southern side of the park (Figs. 55-60). The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based primarily on these transects and design plans.

Physical Characteristics

Width of *Spartina alterniflora* areas ranged from approximately 18 to 46 m and averaged 35 m. The seaward edge of *Spartina alterniflora* along its narrowest width of 18 m was estimated to be 15 m from the breakwater, yielding a total width of more than 30.5 m. Slopes on which *Spartina alterniflora* occurred ranged from 0.8 to 2.9 percent and averaged about 2 percent. Steeper slopes on the upland margin ranged from 8.9 to 9.6 percent.

Marsh substrates are predominantly silt and clay, and are locally capped by a sand veneer. Fill material on the steeper slopes consisted primarily of clay.

Geomorphology

Geomorphologically, the main part of this complex consists of a central concentric, topographically flat island with elevations > +3 m MSL, and a linear breakwater +2.4 m MSL located on the southwest corner to protect the marina (Fig. 55). The southern and eastern sides of the island have slopes of approximately 9 percent, skirted by an intertidal surface with slopes of approximately 2 percent. On the steeper slope, gullies have formed in the clay substrate. A smaller dredged-material island fringed by a *Spartina alterniflora* marsh is located immediately north of the main island complex (Fig. 55).

Hydrology and Salinity

The marsh area investigated appears to be regularly flooded along its lower reach, which grades into a higher slope that is flooded less frequently. The height of an apparent storm-tide drift line measured during the field survey was more than 1 m above the height of the bayward edge of *Spartina alterniflora*. Circulation for marshes on the north side of the island is provided in part by a riprap-lined tidal channel that connects to culverts under the access bridge to the island (Fig. 55). Runoff from precipitation has eroded gullies on the steeper slopes and deposited sediments on the topographically lower marshes. Bay water salinity at the time of the field survey was 18 ppt.

Shoreline and Site Stability

Marshes on the southern shore of the island complex are subject to waves from the wakes of ships in the Houston Ship Channel as well as wind-driven waves in the bay. High, short-period waves from a ship wake were observed breaking on the riprap and adjacent vegetation during the field survey. Dredged material islands along the ship channel offer some protection from ship wakes for the western portion of the southern shoreline, but the central portion is impacted. The larger waves break across the riprap and have scoured the bottom and uprooted *Spartina alterniflora* along stretches of the southern shore (Fig. 61). Marshes on the north side of the island are in an area protected from erosion but are susceptible to the effects of subsidence, as are all the marshes in this area.

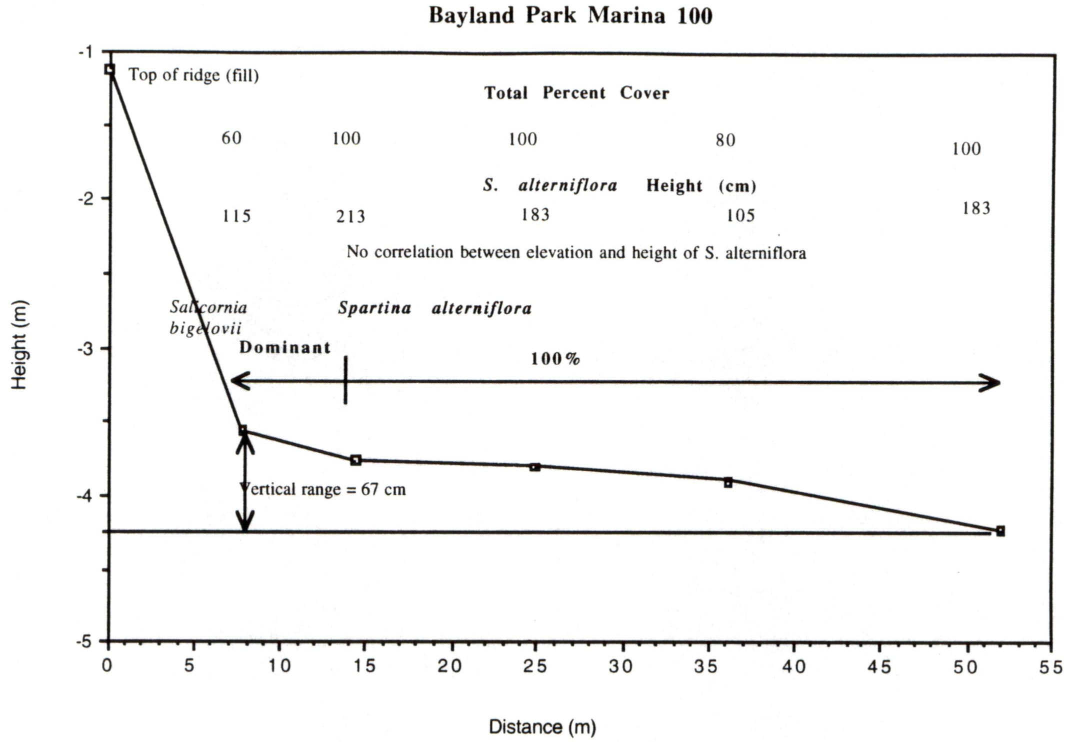


Figure 56. Transect 100, Bayland Park Marina marsh.

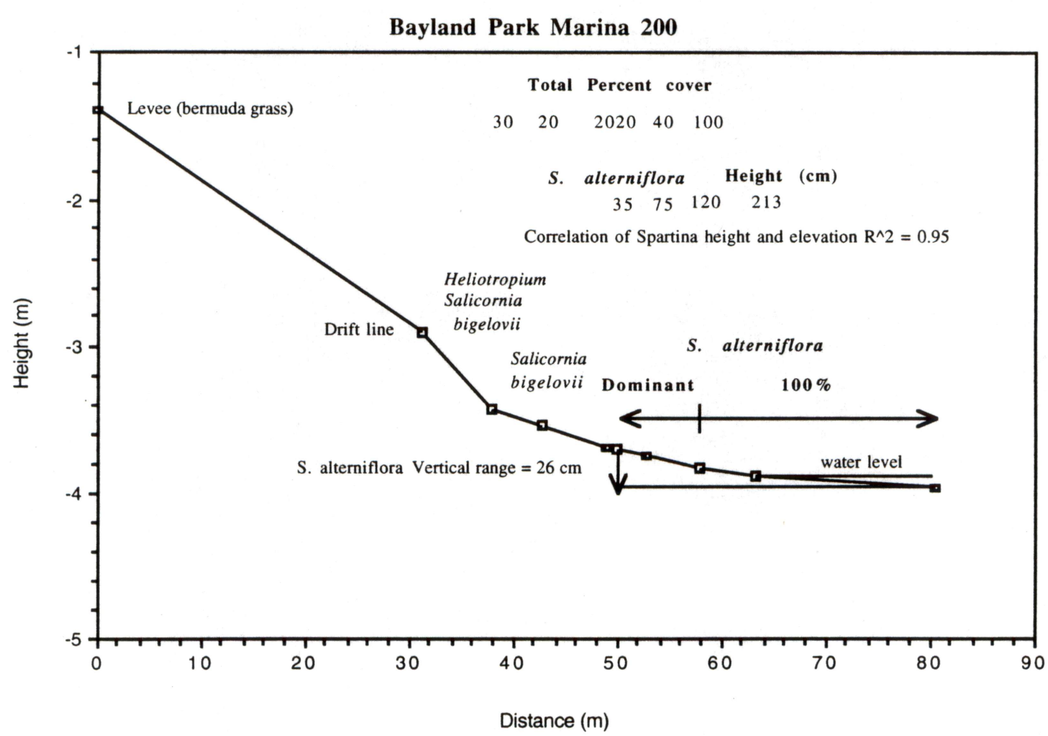


Figure 57. Transect 200. Bayland Park Marina marsh.

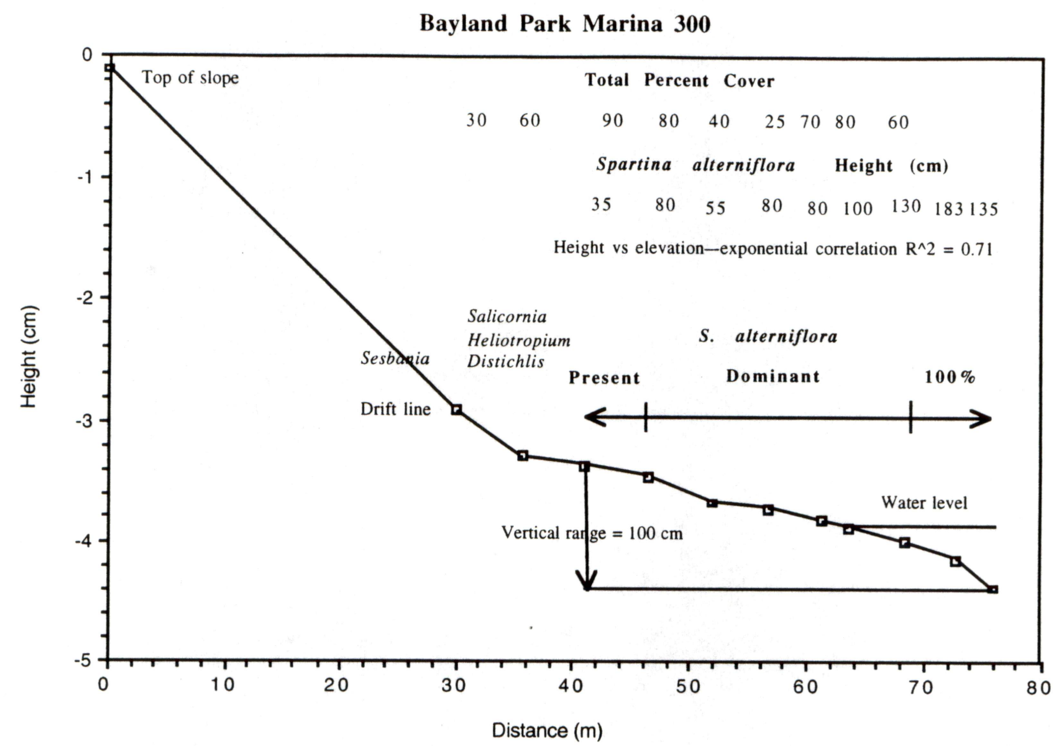


Figure 58. Transect 300, Bayland Park Marina marsh.

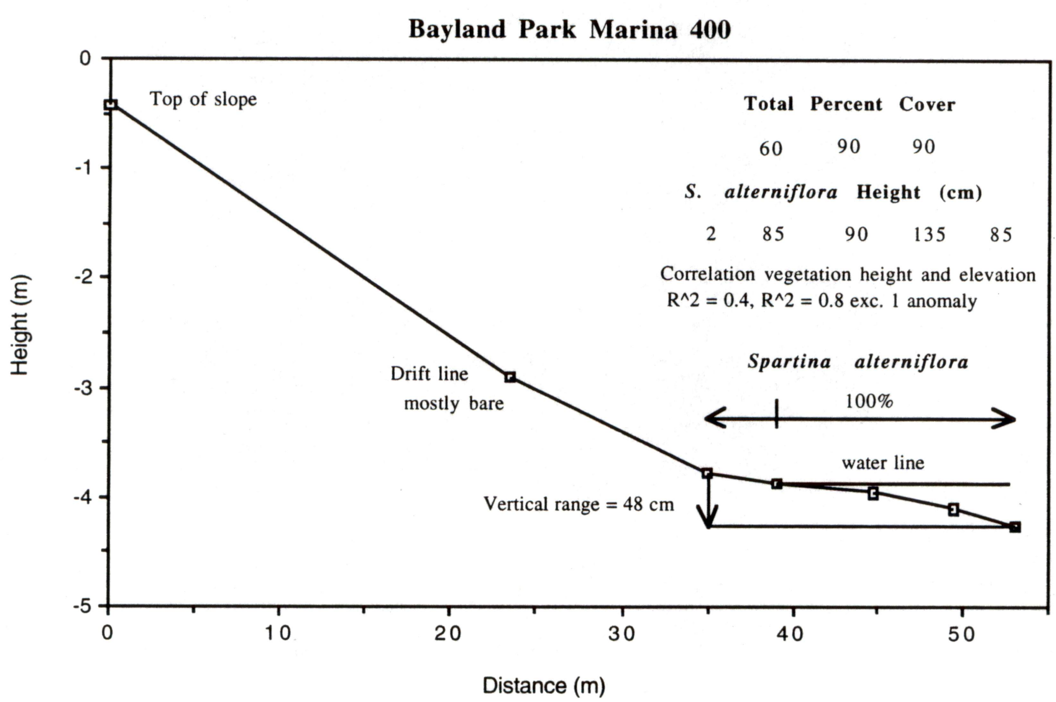


Figure 59. Transect 400, Bayland Park Marina marsh.

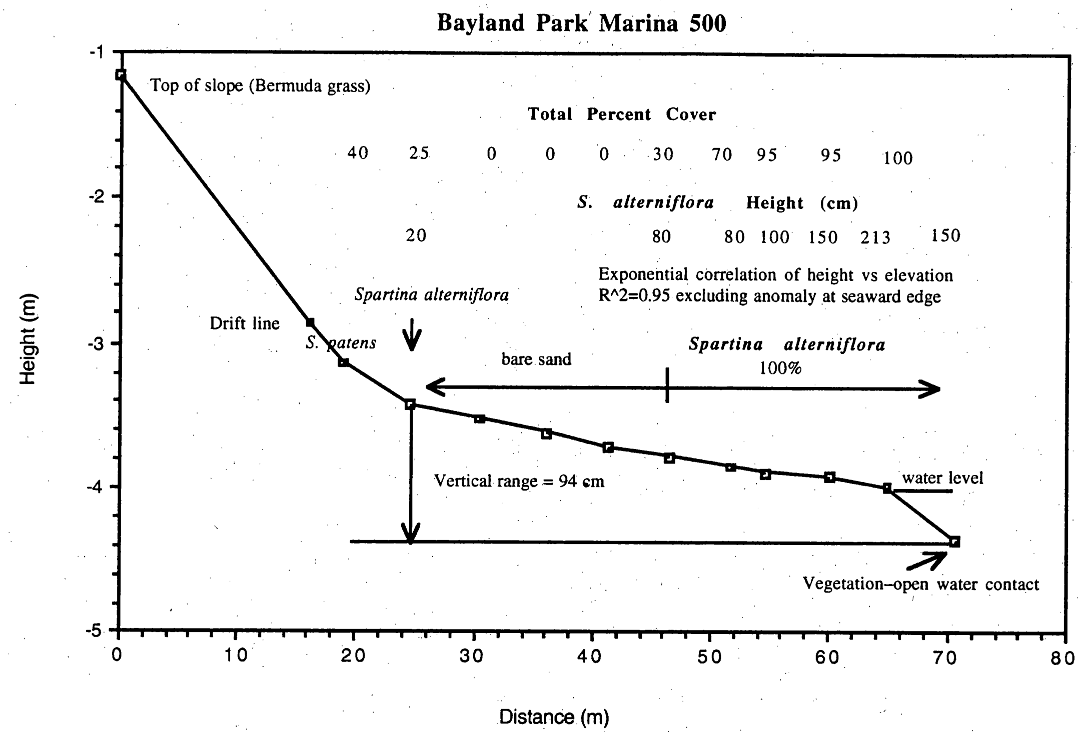


Figure 60. Transect 500, Bayland Park Marina marsh.

Figure 61. Photograph of scoured area and uprooted plants behind riprap between transects 300 and 400, Bayland Park Marina marsh.

The site is located near the center of maximum subsidence caused by groundwater pumpage (Gabrysch and Coplin, 1990). In past years, extensive upland and wetland areas, for example along Cedar Bayou adjacent to this site, have been submerged and replaced by open water (White and others, 1985). Subsidence rates have been greatly reduced since the late 1970s, however, and current rates of subsidence are a magnitude lower than the 1940s-1970s rates that exceeded 5 cm/yr. If subsidence rates remain low, rates of marsh vertical accretion probably can equal or exceed rates of relative sea level rise.

Vegetation

The intertidal marsh consists of *Spartina alterniflora*. Vegetation at higher elevations includes *Salicornia bigelovii*, *Heliotropium curassavicum*, *Distichlis spicata*, and *Spartina patens*.

Average foliar cover estimated at 33 transect stations was 56.4 ± 35.2 percent, with a minimum of 0 and a maximum of 100 percent. At 25 stations with *Spartina alterniflora*, the average percent cover was 68.8 ± 30.3; the minimum was 10 percent and the maximum 100 percent.

The height of *Spartina alterniflora* at 30 stations averaged 110 ± 57 cm and ranged from 2 cm to more than 213 cm. Along most transects, there is a strong inverse correlation between height of *Spartina alterniflora* and land surface height (Figs. 62-63). The correlation may be linear or exponential.

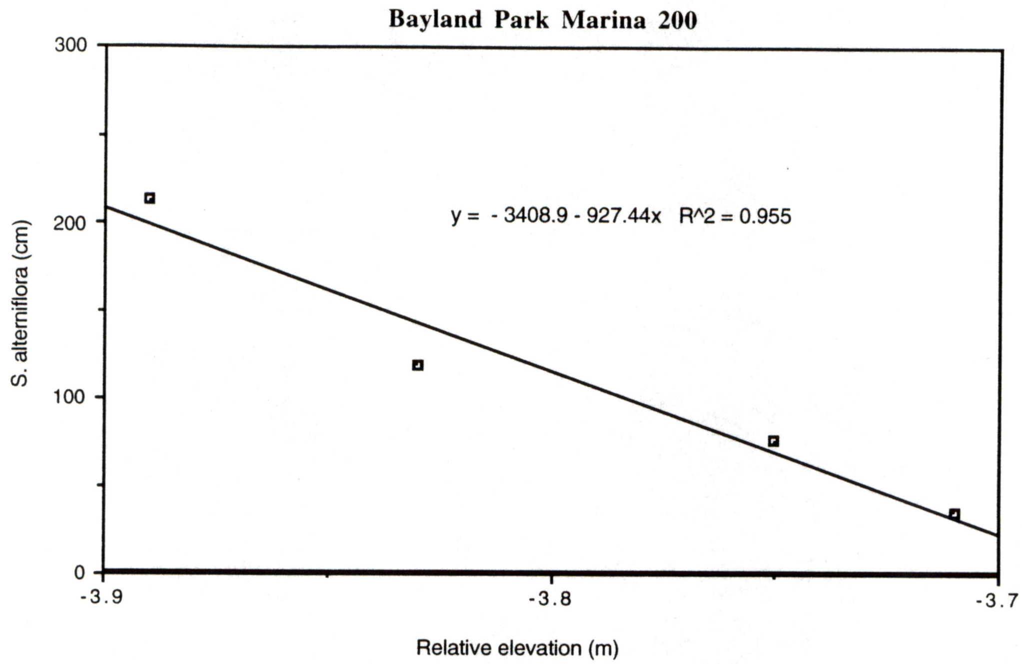
The vertical range in the land surface height on which *Spartina alterniflora* occurred varied on transects. The average vertical range was 67 cm, with a maximum of 100 cm and a minimum of 26 cm.

Success in Accomplishing Performance Goals

This site was visited in March and September 1997. The relative youth of this marsh site and the fact that it is still developing are a limiting factors in evaluating total success. Growth of *Spartina alterniflora* was substantial between March and September. Numerous closely spaced seedlings that were breaking ground in March had formed dense stands of vegetation by September. As a result, average total foliar cover in areas of *Spartina alterniflora* had reached 69 percent, compared to the average of 56 percent in all stations surveyed at this site. Barren areas persisted along the upper margins of the 2 percent slope, however, where *Spartina* was somewhat stunted and very short. This was in contrast to the bayward margin where *Spartina* achieved heights of over 2.1 m (Fig. 53).

Total marsh area was not determined during field surveys, but slopes, width of vegetation, percent cover, and vegetation heights were among the parameters investigated. Spacings of *Spartina alterniflora* transplants were about 1 m, which is in agreement with design specifications. Higher slopes of fill material matched specifications of 5-10 percent. The "intertidal area" had an average slope of 2 percent, which is more than the 1 percent specified. Minimum width of the intertidal area, i.e., from the base of the steeper slope to the riprap, is about 30.5 m, as designed; however, erosion and scouring behind the riprap in two areas narrowed the width of *Spartina alterniflora* to approximately 18 m (Fig. 61).

(a)



(b)

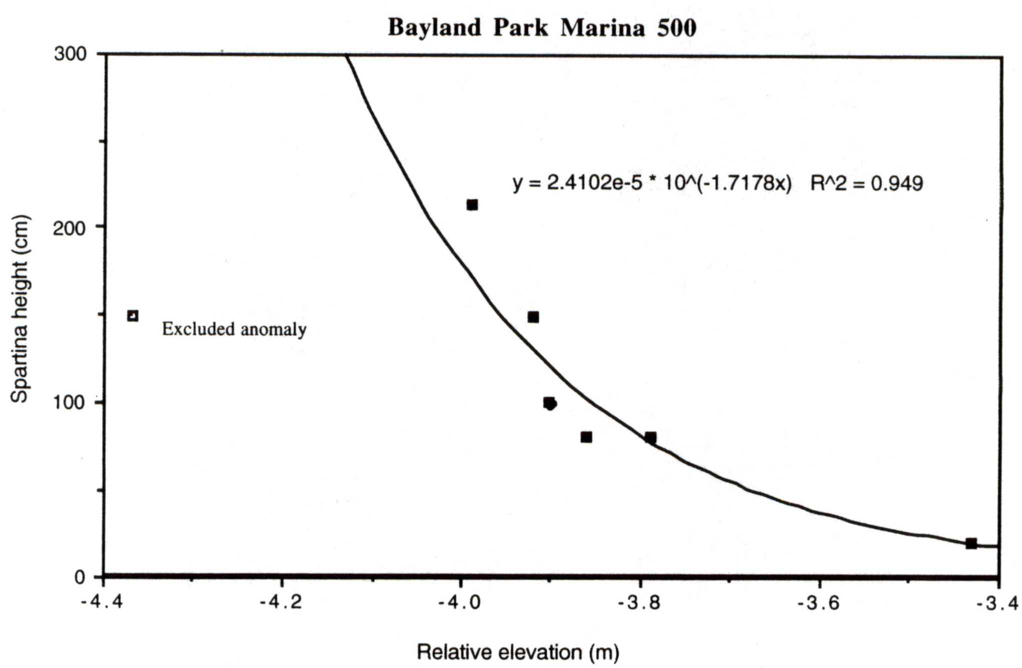


Figure 62. Correlation between height of *Spartina alterniflora* and height of land surface at (a) transect 200 and (b) transect 500.

Figure 63. Photograph of transect 500, Bayland Park Marina marsh. Note differences in vegetation height at water's edge in distance and on higher surface in foreground. There is a very high exponential correlation between *Spartina* height and surface height at this transect (see Fig. 62).

Success of the site in one area was demonstrated by expansion of *Spartina alterniflora* during one growing season. A designed open water and intertidal area near the end of the breakwater protecting the marina was the site of rapid spread of *Spartina alterniflora* seedlings between March and September.

A potential problem in accomplishing long-term goals throughout the complex is local erosion in the form of scouring behind the riprap structures and gullying along steeper slopes. In addition, *Spartina* had a vertical range of up to 1 m, which is unusually high and partly the result of the 2 percent slope on which it was planted. The intertidal range at this site is estimated at approximately + 0.3-0.46 m (Randall-Porterfield Architects, Inc., 1995). *Spartina* on most of the topographically higher surfaces was sparse and stunted, and it is doubtful that it will survive over the long term. Along the lower intertidal surfaces in areas where not uprooted, however, *Spartina* should continue to flourish and remain dense. The topographically higher zone could be the site for establishing higher marsh plants such as *Spartina patens,* and it could eventually be invaded by *Spartina alterniflora* if subsidence becomes a problem. A more complete evaluation of the success of this site can be made after it has reached maturity and vegetation has equilibrated with active processes.

Criteria and Potential for Large-Scale Marsh Restoration and Creation

Among the criteria with potential for large-scale marsh restoration and creation are (1) use of fill material that is compacted, shaped, and contoured to develop an intertidal surface, (2) construction of permanent wave barriers for erosion protection, (3) preparation of surfaces for the spread of seedlings, and (4) design of a circulation system for water exchange to inhibit stagnation.

Brownwood Marsh

The Brownwood Marsh Restoration Project was developed in response to a 1993 Natural Resources Consent Decree requiring the French Limited Task Group (FLTG) to undertake a marsh restoration project to provide for replacement of natural resources injured, destroyed, or lost as a result of releases of hazardous substances at or from the French Limited Superfund Site near Crosby, Texas. The Consent Decree required that an 8.5 to 10.1 ha site be acquired and that the site be suitable for marsh restoration. The decree also called for the site to be tidally linked to the San Jacinto River.

In 1994, the FLTG signed an agreement with the City of Baytown which allowed for the creation of an approximately 24.3 ha wetland system in the area formerly occupied by the Brownwood Subdivision. A Site Restoration Plan was developed that called for the establishment of approximately 16.2 ha of saline to brackish marsh, 4 ha of upland islands supporting freshwater pools, and 4 ha of tidally-influenced channels.

Project Objectives

The Brownwood Marsh Restoration Project was designed to enhance utilization of the area by wildlife by creating diverse habitats. Plant species were chosen for their wildlife habitat value, including forage, nesting material, cover, and resting areas for neotropical migrant birds. Site hydrology was designed to ensure fisheries enhancement and diversity. The design also included opportunities for public education and recreation.

Design/Restoration Criteria

The following discussion of design criteria is based primarily on French Limited Wetlands Mitigation monitoring reports (September 1995 to January 1998) prepared by Crouch Environmental Services, Inc. for federal and state natural resource trustees overseeing the project.

An approximately 24.3 ha wetlands/open water area was created by scraping down uplands on the site of the former Brownwood subdivision (Fig. 64). Concrete house foundations, debris, and most existing roads were removed. Concrete rubble from the house foundations was used to stabilize the shorelines around the channel cuts. Three tidal-exchange channels (one to the north and two to the south) were created to open into the bays surrounding Brownwood peninsula. The channels are 0.9 m deep and cover an area of approximately 5.7 ha. Topsoil excavated from the site was used for site contouring. Approximately 100,578 m^3 of soil was cut to create the tidal marsh and channels, and 42,943 m^3 of fill was used for island habitat, inlet breakers, and site recontouring. Two islands were created in the center of the wetlands, and primarily native tree/shrub species were planted on the islands and along the perimeter of the created wetlands.

Low (*Spartina alterniflora*) and high (*S. patens*) marsh species were planted in the intertidal zone. Total hectares for *S. alterniflora* is 8.6 ha and 4.6 ha for *S. patens*. Sprigs and plugs were planted on 2.4 to 3 m centers. Species were planted at elevations similar to adjacent natural marsh elevations. These elevations were derived by having a surveyor determine the elevation of a similar natural marsh relative to a stable location, such as the paved top of a road, at the Brownwood site. This relative elevation served as the baseline for site contouring. Tidal fluctuations were also measured onsite to determine the upper and lower boundaries of tidal influence within the wetlands boundary.

Construction of the wetland complex was completed in June 1995. The site was transplanted between July and August 1996 (Crouch Environmental Services, Inc., 1996).

Field Surveys

The site was visited three times in 1997. Field surveys as part of this project were completed in September 1997 and consisted of five transects in salt to brackish marsh habitats (Fig. 64). The following discussions of physical, geomorphological, hydrological, and botanical characteristics are based primarily on these transects, design plans, and French Limited monitoring reports (Crouch Environmental Services, Inc., 1996).

Physical Characteristics

Total areas of habitats were not determined during the field surveys, but observations indicated that the physical layout of the wetland complex (Figs. 64 and 65) was in agreement with design plans. Lengths of transects (Figs. 66-70) match well with estimated distances based on photographs and planning maps (Crouch Environmental Services, Inc. 1996). Slopes of graded surfaces vary from highs of 3 to 4 percent on

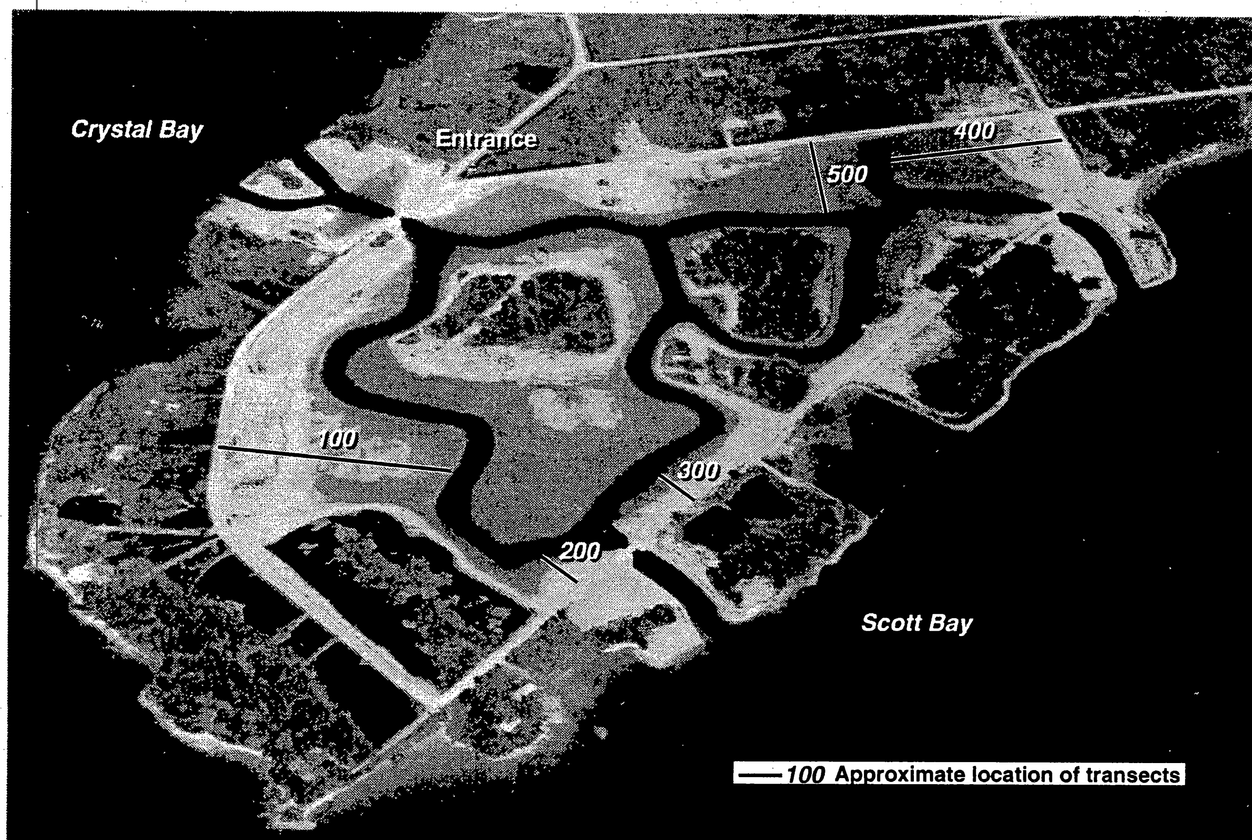


Figure 64. Photograph of Brownwood site taken in 1996, and approximate location of marsh transects. Photograph from Crouch Environmental Services, Inc.

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Figure 65. Photograph of Brownwood site taken in 1998. From Crouch Environmental Services, Inc.

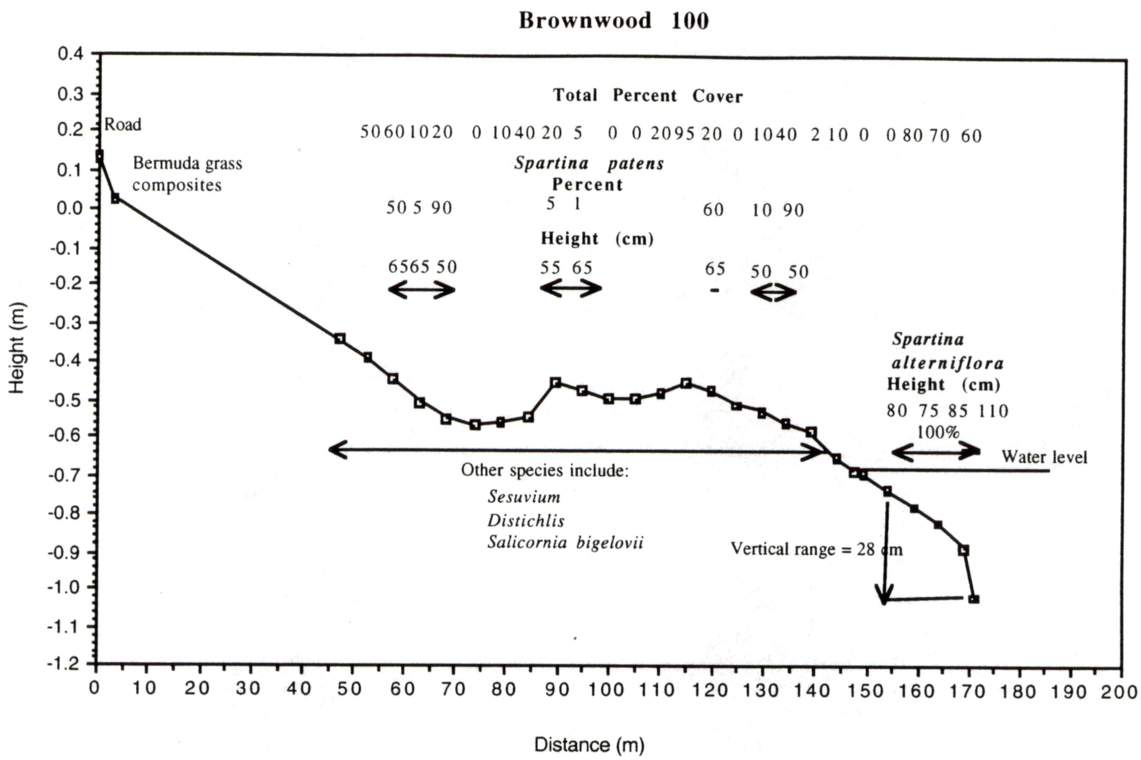


Figure 66. Transect 100, Brownwood marsh.

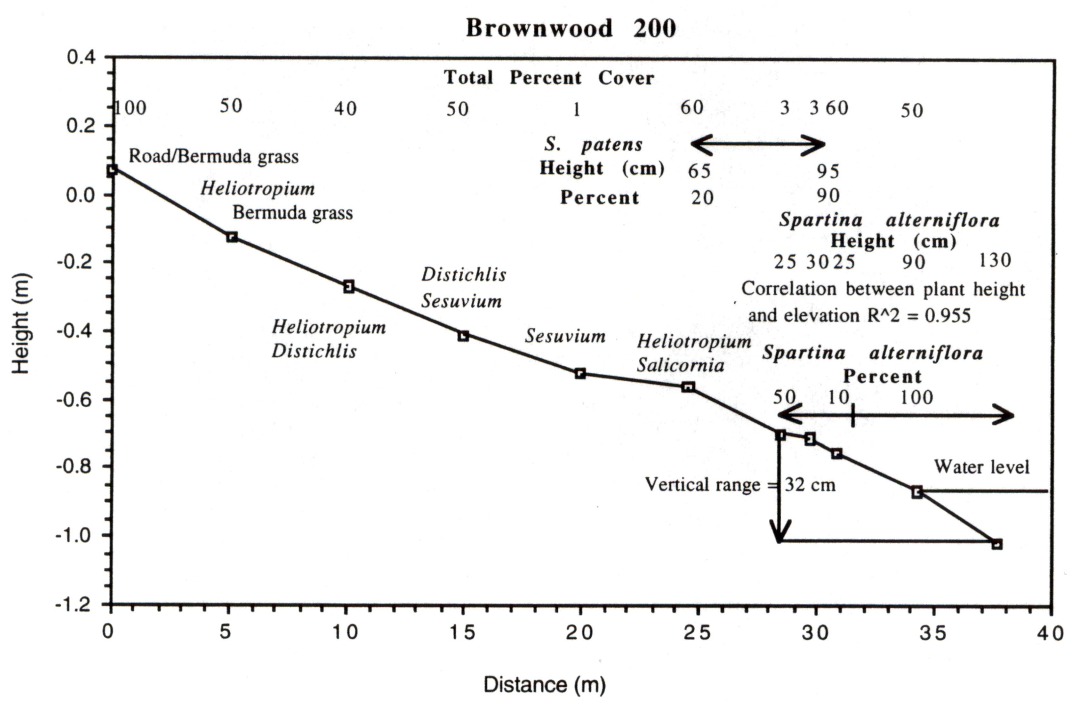


Figure 67. Transect 200, Brownwood marsh.

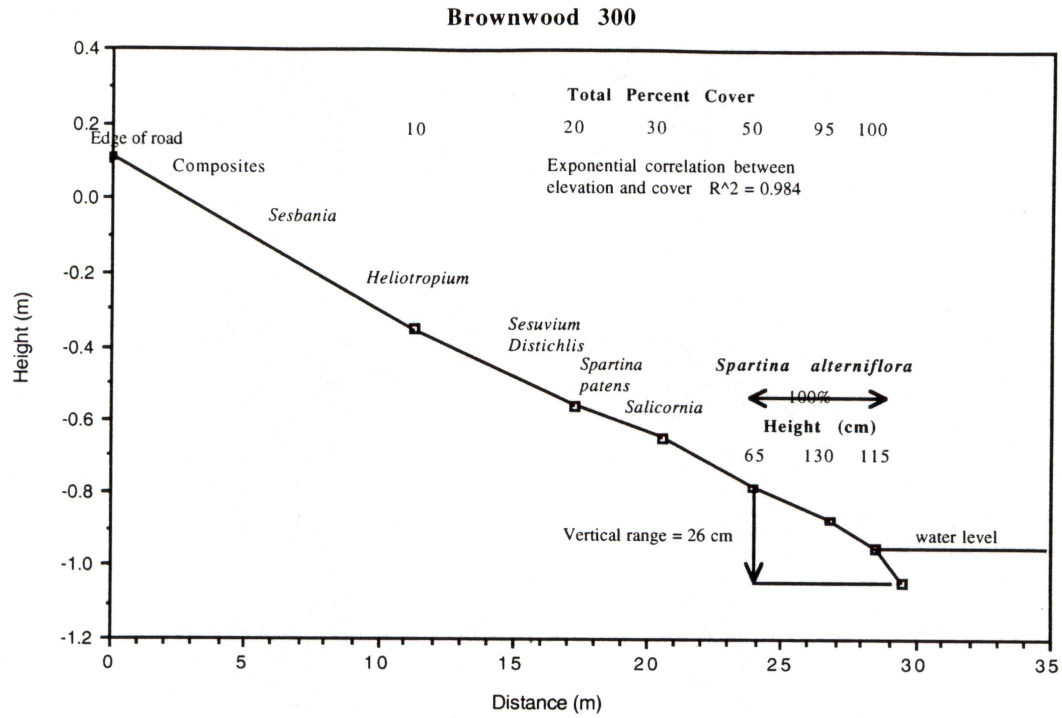


Figure 68. Transect 300, Brownwood marsh.

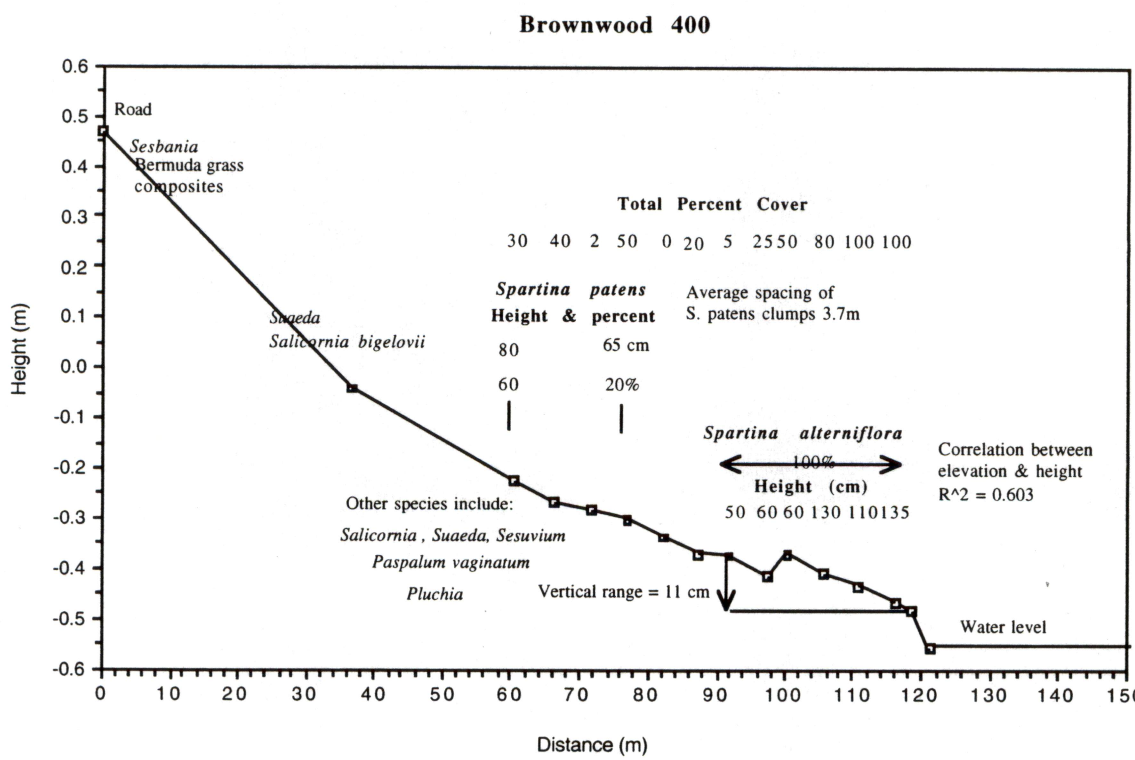


Figure 69. Transect 400, Brownwood marsh.

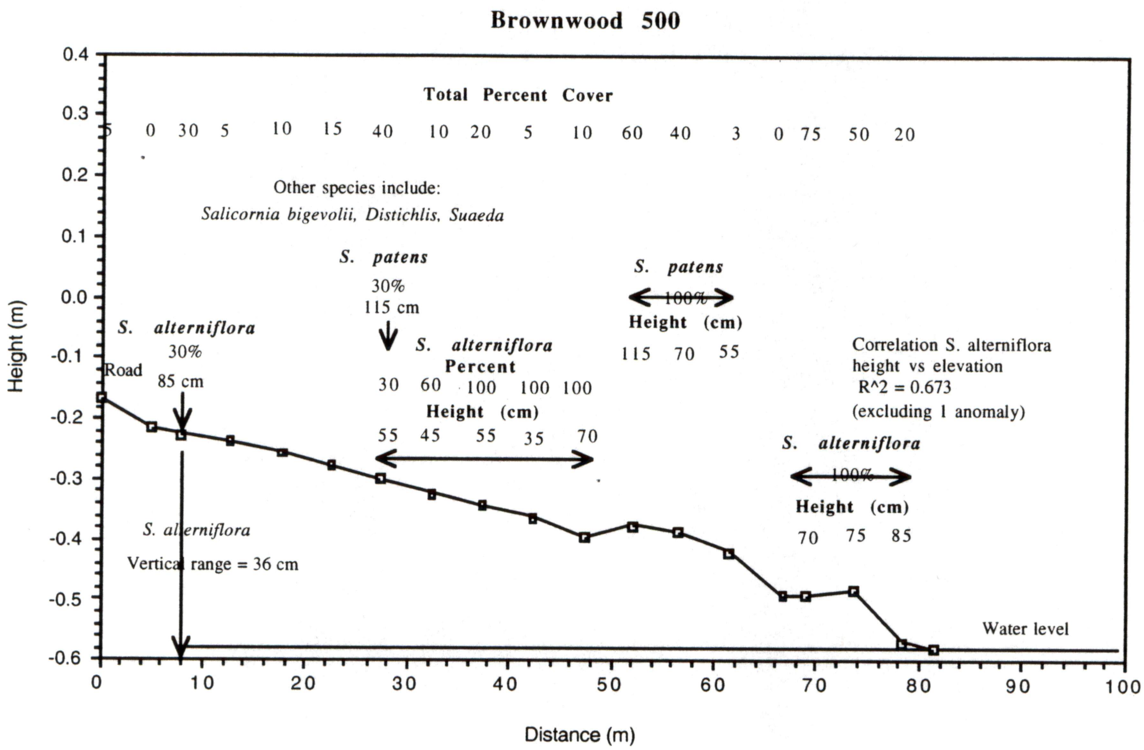


Figure 70. Transect 500, Brownwood marsh.

transects 200 and 300 to lows of less than 1 percent along transects 100, 400, and 500 (Figs. 66-70).

Substrates are primarily mud (silt and clay), and locally sandy mud.

Geomorphology

The marsh creation complex consists of two centrally located islands, the largest of which is bounded by sinuous channels that connect to tidal inlets (Fig. 64). The site is bordered by an upland ridge and gravel road that along the southern and eastern margins is more than a meter higher than *Spartina alterniflora* at the water's edge (Fig. 68). Marsh topography ranges from that characterized by broad relatively flat surfaces with local topographical reversals and mounds, to narrow steeper surfaces (for example, compare transect 300 with 500). Transect 100 has varying slopes along its profile, including a central mound with depressions (Fig. 66).

Hydrology and Salinity

Topographically low regularly flooded marshes and higher irregularly flooded marshes are inundated by flood tides along sinuous channels that are hydrologically connected to Scott Bay on the south and Crystal Bay on the west (Fig. 64). Circulation is provided by three riprap-armored tidal inlets that connect to the bays through concrete culverts. Low topography on the northeast corner of the complex provides communication from precipitation runoff and spring tides with an existing fresher marsh system north of the road.

The proximity of the site to the mouth of the San Jacinto River helps moderate salinities. Measurements of salinity in channels at the site during the field survey were 17 and 18 ppt. Salinity of bay water on the south side of the complex was 16 ppt.

Shoreline and Site Stability

This wetland creation complex is afforded protection from erosion by its central location and an erosional buffer of uplands and local hardened shorelines. Riprap placed along tidal channels provides additional stabilization for the site. Of more concern is the fact that this site lies at the heart of the subsidence bowl that encompasses much of Harris and adjacent counties. Historically, this area was a residential complex that was condemned because of subsidence and associated flooding. Rates of subsidence from the 1940s to 1970s exceeded 6 cm/yr (Gabrysch and Bonnet, 1975). Since the 1970s, however, subsidence rates are as much as a magnitude lower (Gabrysch and Coplin, 1990). If subsidence remains this low, it is probable that rates of marsh vertical accretion can keep pace with rates of relative sea level rise.

Vegetation

Vegetation communities are quite diverse and include forested areas, freshwater marshes, and saltwater marshes. The focus of field surveys as part of this study were areas planted with *Spartina alterniflora* and *Spartina patens*. Other species noted during surveys included *Sesuvium portulacastrum, Distichlis spicata, Salicornia bigelovii, Heliotropium curassavicum, Suaeda linearis, Pluchia* sp., and *Paspalum vaginatum.*

Sprigs and plugs of *Spartina alterniflora* were planted on 2.4 m to 3 m spacings, and the plants had spread and coalesced in many areas. Spacings between *Spartina patens* transplants were measured at 35 locations on transects 100, 400, and 500. The average distance between transplant centers was 3.9 m. Diameters of *Spartina patens* clumps averaged 1.6 m and ranged from 0.3 to 4.6 m at 35 stations. Clumps were largest at transect 100, where the average diameter was more than 2.1 m; at transects 400 and 500, averages were 1.1 m and 1.2 m, respectively. Predation was a problem for some transplants, particularly on the smaller island (Fig. 64).

Average foliar cover at 62 stations along 5 transects was 36 $\pm$ 30 percent, with a maximum of 100 percent and minimum of 0 percent. Average foliar cover at 27 stations where *Spartina alterniflora* was present was 47 $\pm$ 32 percent; the maximum was 100 and minimum 3 percent. Average foliar cover at 16 stations along transects where *Spartina patens* was present was 35 $\pm$ 19 percent, and ranged from 3 to 60 percent. Along some transects there is a strong inverse exponential correlation between percent cover and land surface height (Fig. 71a).

Maximum heights of *Spartina alterniflora* averaged 76 $\pm$ 34 cm and ranged from 25 to 135 cm at 27 stations. Maximum heights of *Spartina patens* averaged 70 $\pm$ 34 cm and ranged from 20 to 115 cm at 16 stations. An inverse linear correlation exists between *Spartina alterniflora* height and land surface height along several transects (Fig. 71b, for example).

Average vertical range of the land surface for *Spartina alterniflora* was 27 cm, with a minimum of 11 cm and a maximum of 36 cm.

Success in Accomplishing Performance Goals

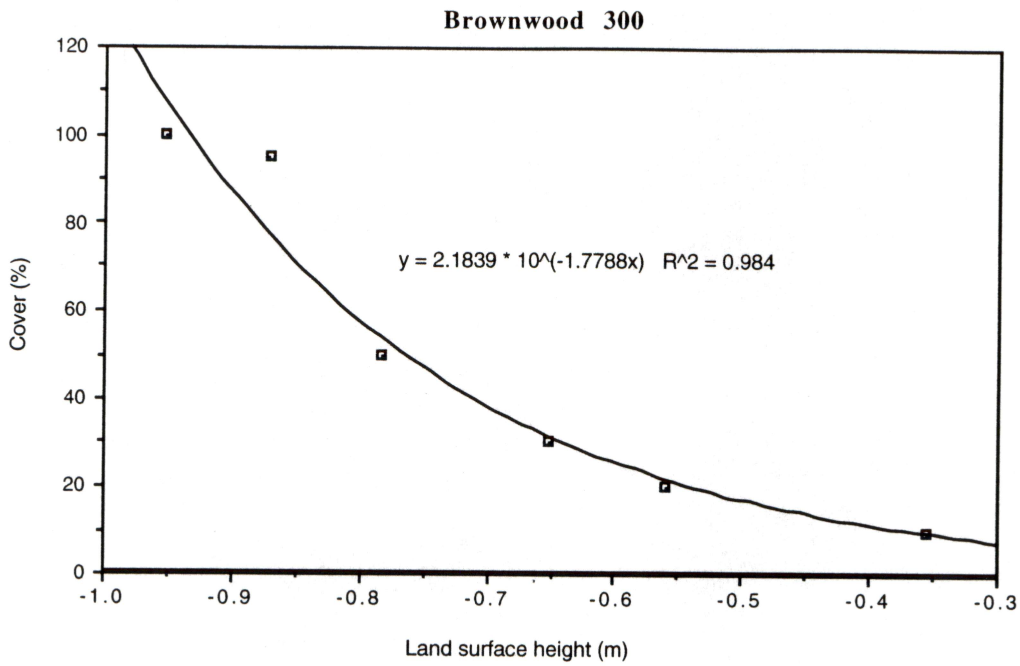
Success in accomplishing performance goals can be only partly determined because the site is relatively new and still developing. From a design perspective, goals were met. The overall layout matches well with plans including tidal inlets and channels, marshes, and forested islands. Field observations and aerial photographs indicate that the upper reaches of graded slopes are occasionally flooded, suggesting that the marsh surfaces are intertidal (Figs. 64 and 65). Comparison of Figures 64 and 65 shows extensive development of marsh vegetation to 1998. The varying topography – from tidal channels to fresh-water ponds to uplands – provides a setting for habitat diversity.

According to monitoring reports, 85-90 percent of transplants survived and were viable after the first year (Crouch Environmental Services, Inc., 1996). Field surveys show that the average spacing of *Spartina patens* transplants was approximately 3.6 m, which is close to design specifications. *Spartina alterniflora* has spread more rapidly than *Spartina patens* and foliar cover is more dense. In many areas, *Spartina alterniflora* plugs have expanded and coalesced (Fig. 65). Average cover in *Spartina alterniflora* areas is approximately 47 percent, and in *Spartina patens* areas, approximately 35 percent. Vegetative growth of *Spartina patens* was also apparent, as 10 cm diameter plugs (Crouch Environmental Services, Inc., 1996) had expanded to an average diameter of > 1.4 m . Along one transect, average diameters of *Spartina patens* clumps exceeded 2.1 m. Predation was a problem in some areas, especially on one island where transplants along the eastern shore did not appear to survive. If subsidence rates remain low, the overall prospects for the site to continue to develop look good.

Criteria and Potential for Large-Scale Marsh Restoration and Creation

Among the criteria with potential for large-scale marsh creation are (1) grading and shaping existing consolidated material to achieve appropriate elevations and intertidal surfaces, (2) adding dredged material and contouring to create upland islands and

(a)



(b)

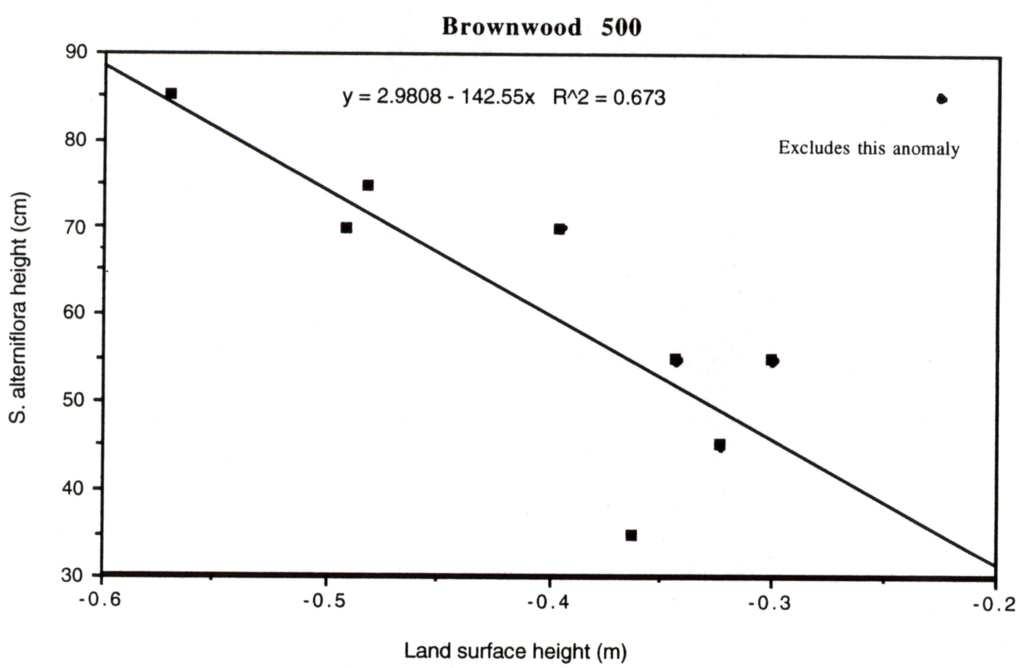


Figure 71. Correlation between (a) percent cover and height of land surface at transect 300, and (b) height of *S. alterniflora* and height of land surface at transect 500.

associated habitats, (3) planting high and low marsh vegetation to promote expansion in both regularly and irregularly flooded areas, (4) developing sites in interior settings and building a peripheral ridge or levee to provide added protection from erosion, and (5) constructing sinuous channels and stable tidal inlets with dimensions that assure adequate tidal circulation.

Bayport Demonstration Marsh Project

Field surveys of the Bayport Demonstration Marsh Project were not conducted as part of this investigation. Because the site is a demonstration marsh, it is being intensively studied, and periodic monitoring reports on its development have been completed. The information presented below is from existing reports.

The Port of Houston Authority and the Corps of Engineers (COE), in conjunction with an Interagency Coordination Team and the Beneficial Uses Group (BUG) (also an interagency working group), helped plan and implement a 89 ha demonstration marsh as part of the Houston-Galveston Navigation Channels, Texas Project (HGNC). A disposal plan was developed that utilizes dredged materials from the proposed widening and deepening of the Houston Ship Channel in "an environmentally sound and economically acceptable manner" (Port of Houston Authority, 1996). A component of the disposal plan is to eventually construct 1,720 ha of salt marsh to partially restore historic losses of wetlands in the Galveston Bay system and provide nursery habitat for fish and shrimp. As part of the overall marsh construction goal, a 89-ha demonstration marsh was constructed on Atkinson Island, on an existing dredged material disposal area in upper Galveston Bay in and adjacent to Bayport Channel (Fig. 2).

Project Objectives

The large-scale, Bayport Demonstration Marsh is intended to test various marsh development techniques prior to creating future marshes for the HGNC.

Design/Restoration Criteria

The demonstration marsh was created by using dredged material from maintenance dredging of the Bayport Ship Channel Flare and a portion of the Houston Ship Channel (HSC). The demonstration marsh attempted to replicate physical and biological features found in natural marshes. A data base on selected physical and biological attributes was developed on three natural marshes near the demonstration site (Rozas and Zimmerman, 1994). The data base was used to develop design parameters for constructing an ecologically functional marsh at the demonstration site.

Physical Characteristics

Information on physical characteristics, hydrology, vegetation, and shoreline stability is primarily from Turner Collie & Braden Inc./Gahagan & Bryant Associates, Inc., 1996 and 1997 and monitoring reports (September and December 1997) prepared for the Port of Houston Authority by Turner Collie & Braden Inc./Gahagan & Bryant Associates, Inc. The demonstration marsh is an enclosed 89-ha system protected by a 2,073 linear m confinement levee that was constructed of dredged material from the HSC and the Bayport Ship Channel Flare. Large-scale cutterhead dredging equipment was used for dredging the maintenance material from the Bayport Ship Channel. Approximately 641,760 m^3 of dredged material was used for constructing the levee and 1, 222,400 m^3 of fill material for the interior of the marsh site (Kindle, 1994). The site was filled to an approximate elevation of +2.0 m Mean Low Tide (MLT). Levee materials were new work materials composed of stiff clays, sand, and shell; the marsh substrate was fine-grained materials associated with maintenance dredging, such as soft clays, sands, and silts. Initial filling and dewatering resulted in a level fill surface required to achieve the microtidal environment of natural marshes in Galveston Bay.

Elevation characteristics of nearby reference marshes were selected as target elevations for the demonstration marsh. The ideal range in elevation would permit intertidal fluctuations and the development of tidal creeks and ponds. Computer modeling was used to predict the settling characteristics of the dredged material used for marsh creation.

The demonstration marsh became intertidal in the spring of 1995. The target elevation range of +0.6 to 0.8 m MLT was achieved in March 1995, 675 days after filling was complete (Port of Houston Authority, 1997). In December 1996, 50 percent of the marsh was within the target elevation range, 10 percent contained ponds and open water and had elevations less than + 0.6 m MLT, and the rest was characterized as mid- to high marsh (greater than + 0.8 m MLT). Computer modeling predicted the marsh would settle 7.6 cm over the next 6 to 12 months, potentially replacing high marsh with low marsh and low marsh with open water.

Two large ponds remained after settling of the fill material. The ponds have been incorporated into subsequent plans for ditching and are being designed into future layout of tidal creeks and ponds (Rozas and Zimmerman, 1994).

Hydrology

Rozas and others (1994) and Rozas (1995) characterized the hydroperiod, or flooding duration, of existing marshes on Atkinson Island and Hog Island, near the demonstration marsh site. Flooding durations were estimated from data from a tide gauge at Morgans Point, just west of Atkinson Island. Tide gauges at the demonstration marsh were only recently installed, in January 1998; therefore, hydroperiod information is not currently available for the demonstration marsh.

To improve tidal circulation, thereby improving fishery productivity, design modifications had to be made to provide ingress and egress for organisms, such as finfish and shrimp. Initially, tidal flow to and from the site was restricted to eight 76.2 cm pipes in temporary spillboxes placed during initial site construction. This design not only limited tidal flow, but also inhibited ingress and egress of potential user organisms. Development of tidal channels within the created marsh was inhibited by restricted tidal flow. Sheet flow over the mid-marsh was also inhibited since the perimeter ditch carried the majority of intertidal exchange from the spillboxes to the ponds on either end of the site. Also, dense marsh vegetation growth resulted in almost complete vegetative coverage of the site, further inhibiting circulation.

After conducting a circulation modeling study, ditching and levee breaching to improve tidal circulation was undertaken in the spring of 1997. The plan included two 76.2 m levee breaches, two perimeter ditch plugs, two ponds, and approximately 4.8 km of channels. As previously mentioned, a system of tide gauges was installed to monitor the effects of the breaching and ditching on circulation and flooding patterns. The results will be considered in future improvements.

Shoreline or Site Stability

The site is located near the western shore of the Galveston-Trinity bay system (Fig. 1) and is susceptible to high rates of erosion by waves and currents. Thirteen erosion-protection alternatives were evaluated to determine the best, most cost-effective methods to protect the levees from erosion. After evaluating different shoreline protection measures, three protection mechanisms were selected and installed in 1994: (1) a woven geotextile or Geotube, 762 m long; (2) a cellular confinement or Geoweb system composed of a filter fabric and confinement system filled with coarse aggregate and/or in-situ materials; and (3) an erosion enforcement or Pyramat matrix formed into a uniform configuration with a strong and stable matrix in all directions. In addition, a 762 m fringe marsh was created along the lower slope of the levees to provide additional erosion protection.

Monitoring of the Geotube, Geoweb, and Pyramat erosion protection measures indicated the Geotube offered the most promise for levee protection. Failure of part of the Geoweb sections and slumping of the Pyramat at the crown of the levee were observed during the first year following installation. Evaluation of the Geotube and fringe marsh continues.

Vegetation

A marsh-planting study was undertaken to determine which planting spacing and propagule type were most effective, in terms of cost and results, for obtaining at least 60 percent plant cover by the end of the second growing season (Port of Houston Authority, 1997). The interior of the demonstration marsh is divided into fifty 0.4 ha or 64 m X 64 m test plots to help evaluate the statistical differences of the various planting treatments. The total area planted was approximately 28.3 ha of *Spartina alterniflora* var. *vermillion* and 8.1 ha of *S. patens*. *Spartina alterniflora* var. *vermillion* was chosen because this variety exhibits resistance to the fungus *Rhizoctonia* which has produced widespread damage to native stands of *S. alterniflora* in the Galveston Bay system. The planting treatments included planting spacings of 0.9, 1.8, 3.6, 7.3, 11, and 14.6 m centers and propagule types of single-stem sprigs, peat pots, and one-gallon containers. Each treatment was replicated three or four times. Plantings were completed in July 1995 (Port of Houston Authority, 1997). The marsh was planted after the dredged material dewatered and consolidated to elevations of + 0.6 to 0.8 m MLT (Turner Collie & Braden/Gahagan & Bryant Associates, Inc., 1997). The goal was to create a marsh with a minimum of 60 percent cover by the end of the second growing season while using the most-cost effective planting methods. The planting effort began in February 1995 and was completed in July 1995. More details on the planting scheme and treatments for each study area can be found in Turner Collie & Braden/Gahagan & Bryant Associates, Inc. (1997).

Comprehensive monitoring was conducted in the spring and fall for two years following planting. The monitoring was to document changes in percent plant cover of *S. alterniflora* among different propagule types and planting spacings. *Spartina patens* was not monitored, as it did not survive after planting. Statistical analyses of the monitoring data indicated no significant propagule-type effects on plant cover, but there were significant plant-spacing effects (Port of Houston Authority, 1997). After two growing seasons, in October 1996, there were no differences in total plant cover among all plant spacings. However, plots planted at 14.6 m centers had less old-growth plant cover than plots planted at other spacings. Overall, results showed that planting sprigs at 11 m centers is the most cost-effective method. Also, augmenting sprigs by seeding may accelerate establishment of *S. alterniflora*, however, at this site seed germination was less than five percent (Turner Collie and Braden/Gahagan & Bryant Associates, Inc., 1996).

Success in Accomplishing Performance Goals

So far, the Bayport Demonstration Marsh is a successful restoration/creation site and can serve as a model for other large-scale marsh restoration/creation projects in the Galveston Bay system. Successful, cost-effective marsh transplanting techniques may be used in future marsh restoration projects. After two growing seasons, in October 1996, there were no differences in total plant cover among all plant spacings. Plots planted at 14.6 m centers had less old growth plant cover than plots planted at all other spacings. Planting of sprigs on 11 m centers was the most cost-effective planting method.

Monitoring of marsh development continues. Much of the current success can probably be attributed to the attempt to replicate the elevation, circulation, hydroperiod, and other characteristics of nearby, functioning reference marshes. Approximately 50 percent of the marsh is currently within target elevation ranges, based on elevations of the most productive areas of nearby natural marshes. The marsh is expected to settle another 7.6 cm over 1998, potentially replacing higher marsh with low marsh, and low marsh with open water. Newly created circulation channels, ditches, and levee breaches will also enhance marsh productivity and provide additional access for marine organisms. Flood duration and patterns are currently being monitored in the marsh. Hydrographs of the demonstration marsh will be compared with those of natural marshes on Atkinson Island.

Criteria and Potential for Large-scale Marsh Restoration and Creation

Among the criteria with potential for large-scale marsh creation are (1) selecting an appropriate site, which in this case was an existing embayment along a chain of dredged material islands near a ship channel, (2) filling the site with dredged material to an elevation that assures intertidal conditions after dewatering and compaction, (3) protecting the site from erosion by "armoring" the shoreline, (4) planting at spacings that assure eventual coalescence of vegetation but are also cost effective, which in this case was on 11 m centers, and (5) constructing channels and tidal inlets to enhance circulation and provide access for marine organisms.

Criteria used at the Bayport Demonstration Marsh can be used for other large-scale marsh restoration/creation projects, especially those projects where dredged material is used to create marshes. Future large-scale marsh restoration/creation projects, for example those associated with the HGNC, will benefit greatly from the knowledge gained in this demonstration project. Certainly, gathering extensive information on nearby natural marshes and then modeling design parameters after functioning reference marshes would help make any marsh restoration/creation project a success.

SUMMARY AND CONCLUSIONS

Field surveys provided an interesting comparison of design types, criteria, and site characteristics. Of the sites analyzed, two were primarily fill sites, two were fill and shape sites, two were scrape-down sites, and one was a natural substrate with shore protection (Table 1). The Bayport Demonstration Marsh, which was not surveyed, is a fill site. With the exception of this site, which has a 73 ha intertidal marsh, the largest marsh sites were the scrape-down sites, Highland Bayou and Bayland Park Marina, both with areas of more than 12 ha (Table 1). The smallest marsh investigated was the Sandefer site at less than 2 ha.

Accomplishment of performance goals could not be evaluated in all cases because of the "youth" of some sites and the fact that some are still under development. Overall, however, design specifications were followed closely at most sites. With few exceptions, such as slight variations in transplant spacings and slope, it appeared that vegetation was planted as specified.

Analyses of vegetation characteristics and land surface profiles indicate that the fill, and fill and shape sites had achieved the densest foliar cover, with percentages ranging in the 60s, followed by scrape-down sites with percentages in the 40s (Table 2, Fig. 72). The Frozen Point marsh, which is on a natural substrate along an erosional shoreline, had an average percent cover in the 30s (Table 2). Heights of *Spartina alterniflora* also varied. The maximum *Spartina alterniflora* heights exceeding 213 cm (7 ft), were at Armand Bayou and Bayland Park Marina, where the *vermillion* variety of *Spartina alterniflora* was planted. Highest average maximum heights of *Spartina alterniflora* were at Armand Bayou and Frozen Point (Table 2, Fig. 73). At many sites there was a high inverse correlation between height of the land surface and height of *Spartina alterniflora*. Along some transects this relationship was exponential, and along others linear. On some transects there was an inverse linear correlation between percent foliar cover and land surface height. These trends were often broken at the seaward edge of the marsh transect where the land surface was lowest and water depth highest. Percent cover and vegetation height usually decreased in these areas, producing anomalous points.

The average vertical range in land surface height on which *Spartina alterniflora* occurred varied from 25 cm at Highland Bayou to more than 60 cm at Bayland Park Marina (Table 2). The scrape-down sites (Highland Bayou and Brownwood) had the lowest vertical range, possibly indicating lower daily tides in these interior settings. The abnormally high vertical range at Bayland Park Marina suggests that transplants have not equilibrated with the tidal range. It is likely that transplants at the higher elevations at this site will eventually be replaced by high marsh species, and *Spartina alterniflora* will be restricted to a lower, regularly flooded vertical range. Variations in vertical range from site to site indicate that the height of the intertidal zone varies. It is important to define intertidal elevations at the project area or to use nearby natural marshes as reference sites to determine the vertical range in elevation of *Spartina alterniflora* for the created marsh. Planting of *Spartina alterniflora* outside the intertidal range will lead to failure. Although not as cost-effective, vegetation could be planted beyond its expected range and allowed to equilibrate with the mean intertidal range. A more cost-effective approach would be to plant at a narrower range with the expectation that transplants will spread and cover the normal tidal zone. At sites where organically-rich fill material is used, wider spacings, as much as 11 m between transplants, appear to work and are the most cost effective as shown at the Bayport Demonstration Marsh.

There were differences in development of vegetation in fill sites and scrape-down sites. At scrape-down sites the surface is cut down to achieve intertidal and subtidal elevations, whereas at fill sites, fill material is used to elevate the surface to intertidal levels. Fill sites, in general, achieved a higher density of vegetation over a shorter period of time, in part due to relatively flat intertidal surfaces. At scrape-down sites, however, more precise and intricate geomorphic and hydrologic features in aquatic and marsh habitats could be developed. Among the advantages of working with older, relatively stable sedimentary substrates at scrape-down sites is that sediment is less susceptible to compaction and dewatering compared to loosely consolidated fill. The foundation strength of this material when dry allows heavy equipment to be used on site to cut or excavate the surface to meet specifications. The land can be scraped to more exact elevations and slopes, and channels can be cut to more precise widths, depths, and courses to assure

Table 2. Comparison of vegetation characteristics including foliar cover, height, and vertical range of *Spartina alterniflora*, and water salinities.

Marsh Site	Total Foliar Cover (%)	Total Foliar Cover Where Smooth Cordgrass Present (%)	*Spartina alterniflora* Average Maximum Height (cm)	Maximum Height (cm)	Average Vertical Range in Surface Height (cm)	Maximum Vertical Range in Surface Height (cm)	Water Salinity (ppt)
Sandefer (Fill and shape)	63 ± 20	69 ± 30	87 ± 38	150	49	50	35
Highland Bayou (Scrape down)	42 ± 30	48 ± 28	95 ± 39	175	25	35	26
Swan Lake (Fill)	68 ± 22	64 ± 22	104 ± 23	155	37	39	28
Armand Bayou (Fill)	68 ± 17	67 ± 17	149 ± 44	225	29	43	
Frozen Point (Natural substrate)	32 ± 13	32 ± 13	128 ± 30	180	35	65	18
Bayland Park Marina (Fill and shape)	56 ± 35	69 ± 30	110 ± 57	213	67	100	18
Brownwood (Scrape down)	36 ± 30	47 ± 32	76 ± 34	135	27	36	17

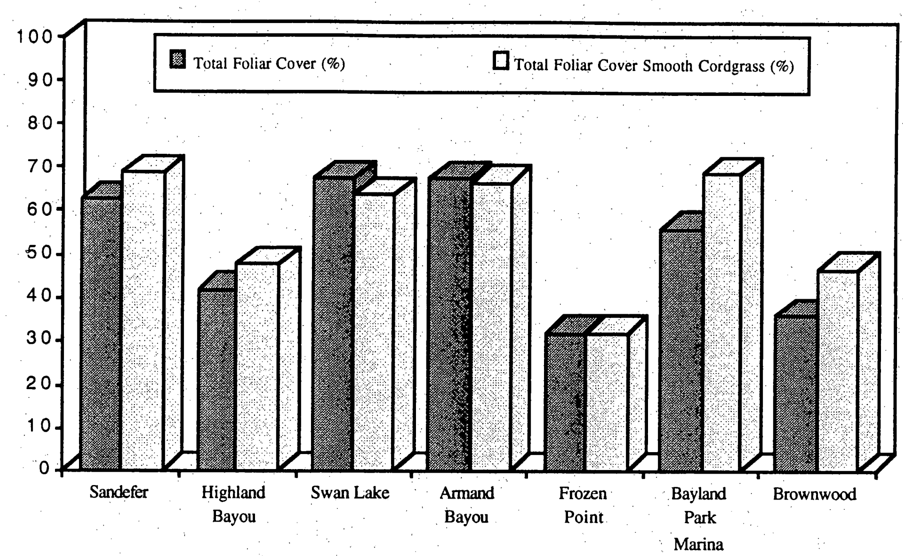


Figure 72. Percent foliar cover of all vegetation and of *Spartina alterniflora* at surveyed sites.

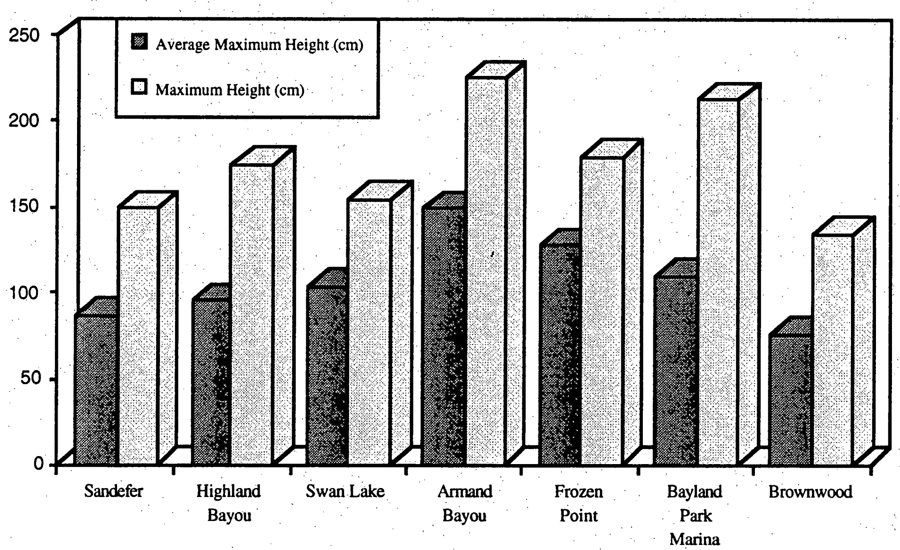


Figure 73. Average maximum height and maximum height of *Spartina alterniflora* at surveyed sites.

adequate circulation. In less consolidated fill substrates, compaction and dewatering of fill material may exceed or be below desired elevations, and tidal inlets and channels maybe more difficult to construct and maintain. On the other hand, without good knowledge of the tidal range, the land may be scraped too low or too high to achieve optimum intertidal elevations for colonization and growth of emergent vegetation. Such was the case at a creation site in the Nueces River delta where a high marsh of *Spartina spartinae* was scraped to lower elevations to create an intertidal marsh. Final elevations, however, were too low, and transplanted *Spartina alterniflora* did not survive (Nicolau, 1995).

In terms of substrates, frequently inundated organically-rich muds (silt and clay) seemed to have the most potential for relatively rapid growth and development of vegetation. This was exemplified at Armand Bayou, which was one of the youngest sites but still had one of the highest percentages of foliar cover. The fill material was obtained from the floor of Armand Bayou, where it is assumed that accumulated sediments were rich in organics and nutrients. In contrast, low-organic, dewatered Pleistocene clays at scrape-down sites, such as at Highland Bayou, may take time to become fertile enough for a more rapid spread in vegetation.

Subsidence could be a threat in all areas if rates do not remain low, but, in terms of shoreline stability, all sites had design criteria to guard against erosion. Three sites that were exposed directly to open bay water and high wave energy (Swan Lake, Frozen Point, and Bayland Park Marina) had permanent riprap breakwaters or wave barriers. At Armand Bayou a brush fence backed by an earthen berm served as a temporary wave breaker until vegetation became established. The earthen berm also served as a containment dike for dredged material. At the Swan Lake site a large permanent breakwater was constructed along the edge of Galveston Bay, but two rows of parachute netting were also used to provide transplants with temporary protection from lake waves. The interior nature of scrape-down sites at Highland Bayou and Brownwood provided a measure of protection from wave and current erosion. In addition, at the Brownwood site, tidal inlets leading to open bay waters were armored with riprap. The location of the Sandefer site in a shallow protected lagoon helps protect it from wave erosion.

Among the criteria with potential for successful large-scale restoration based on sites surveyed are:

- achievement of intertidal elevations and appropriate water regimes for transplanted vegetation based on intertidal elevations of local natural marshes to account for variations in the vertical range of *Spartina alterniflora* at different sites

- protection of transplants from wave and current erosion using permanent wave barriers, or development of sites in interior protected settings

- establishment of adequate water circulation, including channels large and deep enough to provide good tidal exchange

- location of sites near existing sources of dredged material to provide a cost-effective source of material for fill

- development at sites with potential for expansion, including marginal upland and transitional areas to allow for the possibility of subsidence

- placement of transplants at cost-effective spacings, which may be as much as 11 m in intertidal fill material, but at closer spacings in irregularly flooded high marsh areas to achieve denser percent cover over the short term

- utilization of organic rich fill material for sites where rapid colonization is a goal

- creation of an on-site nursery to provide a local source of transplants and an on-site laboratory for observing plant health and survivability

Both scrape-down and fill sites, plus combinations of the two, have potential for large-scale development. Scrape-down sites are usually developed in uplands so there is the potential of adding wetlands without displacing aquatic (bay bottom) habitats, and thus expanding the overall area of wetland habitats in a bay system. In fill sites, vast quantities of dredged material from navigation channels provide a potential source of fill for large-scale development. Most of these sites displace bay bottom habitats, but in many cases in the Galveston Bay system, the sites are former marshlands that have been lost to subsidence. In currently subsiding zones, acquisition of adjacent transitional areas and uplands can provide an elevated substrate for the growth and expansion of wetlands in response to relative sea-level rise.

The criteria and techniques identified for large-scale marsh development in the Galveston-Trinity Bay system have potential for application in other bay-estuary-lagoon systems. For example, the TPWD has recently acquired several thousand hectares of estuarine habitat on the upper Texas coast in the Neches River valley. Thousands of hectares of marsh habitat have been lost in this area over the past four decades (White and others, 1987). Staff of the TPWD are in the preliminary stages of planning marsh restoration for the area. Criteria and techniques identified as part of this study would provide valuable assistance for large-scale marsh creation and restoration in the Neches River valley, as well as in other estuarine systems. The Neches River system is complex, and marsh losses have been attributed to a number of factors including faulting and subsidence, erosion, channelization, disposal of dredged material on natural levees preventing overbank flooding, and reservoir development upstream. Because of these factors, it is unlikely that natural marsh sedimentation from river and tidal sources will ever equal or exceed rates of relative sea-level rise; thus, artificial techniques will be necessary to restore submerged marshes. Among the possibilities for large-scale restoration are the use of new fill material to build up submerged areas to intertidal levels and to shape and contour existing dredged material that has been deposited on levees. The use of fill material at these sites, of course, is contingent upon its being free of contaminants that would be detrimental to marsh development. Because of the possibility of additional subsidence, terraced areas at higher elevations than intertidal could serve as future wetland sites should submergence continue. Analysis of elevations of existing natural marshes in the area, similar to those conducted at the Brownwood and Armand Bayou sites, would provide data on intertidal elevations. Substrates in the Neches River valley are rich in organics, so fill material should support relatively rapid growth of planted vegetation similar to the Armand Bayou and Bayport Demonstration Project sites. Marsh designs should incorporate areas of existing open water habitat to enhance circulation and prevent stagnation of developed marshes. As the area of existing open water is reduced, erosion in this shallow system should also be reduced. The use of earthen berms and levees could help stabilize and protect planted areas. An on-site nursery, similar to the one in Highland Bayou, could be constructed to provide a source of local transplants. Restoration sites could be planned and developed in stages, such as at Swan Lake. Sites on the northern side of the valley, where Pleistocene substrates occur, could be considered for scrape-down marsh development, as in the Highland Bayou and Brownwood sites. There is evidence that rates of subsidence and marsh loss are declining in this valley (White and others, 1996) and that developing sites at elevations that will support both topographically high and low marsh communities could succeed.

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