Gulf Intracoastal Waterway
Aransas National Wildlife Refuge
Dredged Material Management Plan

Appendix A

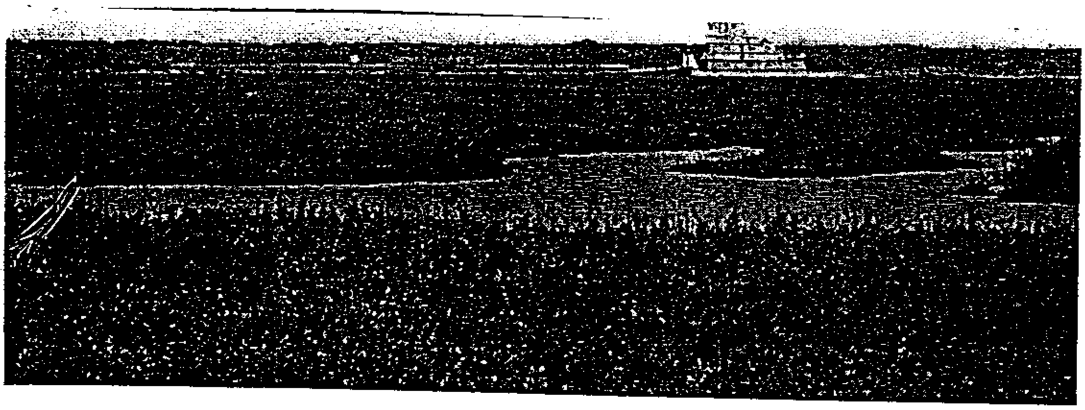
Goals of the Beneficial Use Sites

Purpose of this Report

This report provides planning information relevant to wetland creation using dredged material as part of the Gulf Intracoastal Water–Aransas National Wildlife Refuge 50-year Dredged Material Management Plan (DMMP). This document is divided into several sections:

- Summary of Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Measures for the Gulf Intracoastal Waterway-Aransas National Wildlife Refuge (ANWR) 50-year Dredged Material Management Plan;
- Investigations: Elevation, Vegetation, and Landscape-level Geomorphology;
- Testing Vegetation Performance Standards with Field Data
- Conceptual Design: Self-organizational Theory and Site Designs, Adaptive Management, Planting, Structures, and Coordinating dredging cycles;
- Specific designs for Beneficial Use Sites A, D, and K (as per *Gulf Intracoastal Waterway–Aransas National Wildlife Refuge, Texas, Feasibility Report and Final Environmental Impact Statement*); and
- Implementing Designs.

Figure 1 gives ground-level views of habitat at the project site.



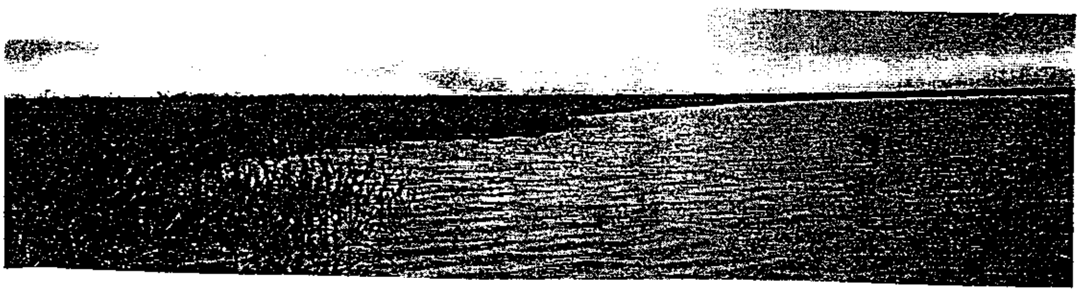


Figure 1. Marsh habitat in the project area. High marsh species dominate most of the project area (top), although *Spartina alterniflora* occurs in scattered patches, mostly along marsh edges (bottom).

I. Summary of Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Measures for the Gulf Intracoastal Waterway-Aransas National Wildlife Refuge 50-year Dredged Material Management Plan

This section summarizes the outcome of discussions of the Aransas Interagency Coordination Team (ICT) meetings on 3-4 November 1998 and 6 April 1999 regarding the creation of wetlands as part of the 50-year Dredged Material Management Plan (DMMP) for the Aransas National Wildlife Refuge stretch of the Gulf Intracoastal Waterway, including the Welder Flats area. Discussions began with the assumption that 1,613.5 acres of wetland habitat would be created from dredged material at specific locations labeled A-K (Figure 2), as per the *Gulf Intracoastal Waterway-Aransas National Wildlife Refuge, Texas; Feasibiilty Report and Final Environmental Impact Statement.* Furthermore, it was understood that marsh creation would occur in conjunction with maintenance dredging cycles scheduled throughout the 50-year life of the DMMP (Table 1).

ICT discussions focused on establishment of guidelines for the wetland creation portion of the

Table 1. Schedule for site creation*. See Figure 2 for site locations. The "year" is the year from beginning of 50-year DMMP. The parenthetical "cumulative acres" is the cumulative acres for each site. Bold type represents final planned acreage for each site. Total planned acreage for all sites combined is 1,613.5 acres.

Site	Year	Acres (Cumulative acres)	Site	Year	Acres (Cumulative acres)
A	2.5	42 (42)	D	4	90 **(90)**
A	5	42 (84)	E	4	49 (49)
A	7.5	18.5 (102.5)	E	12	49 (98)
A	10	42 (144.5)	E	20	49 **(147)**
A	12.5	42 (186.5)	F	12	24 (24)
A	17.5	42 (228.5)	F	20	24 (48)
A	20	42 (270.5)	F	28	24 (72)
A	22.5	18.5 (289)	F	36	24 **(96)**
A	25	42 (331)	G	4	24 **(24)**
A	27.5	42 (373)	H	4	10 **(10)**
A	37.5	18.5 **(391.5)**	I	4	37 (37)
B	12	47 (47)	I	12	37 (74)
B	20	90 (137)	I	28	74 (148)
B	28	90 (227)	I	36	74 **(222)**
B	36	90 (317)	J	12	74 (74)
B	44	90 **(407)**	J	20	74 **(148)**
C	12	43 **(43)**	K	4	35 **(35)**

*This information should be updated as final values are developed.

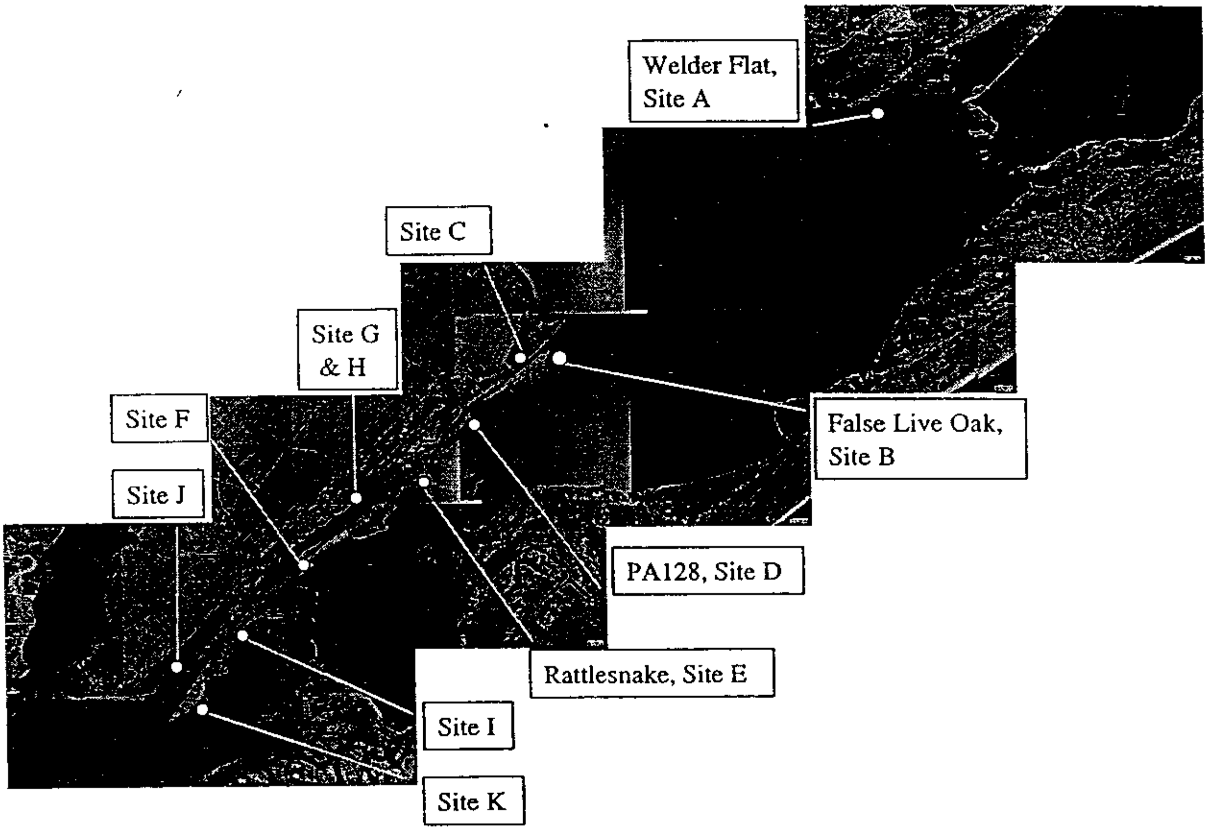


Figure 2. Planned marsh creation sites near Aransas National Wildlife Refuge, Texas.

50-year DMMP, including establishment of appropriate goals, objectives, performance standards, monitoring methods, and remedial measures. Topics such as justification of this project and funding opportunities were also discussed.

Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Measures

Table 2 defines goals, objectives, performance standards, monitoring methods, and remedial measures in the context used in this report.

Table 2. Definitions of terms used in wetland creation planning, in the context of this report.

Term	Definition
Goals	General statement about desired project outcomes; stating a goal allows all stakeholders to understand, in general terms, the desired direction of the project
Objectives	Specific statements about desired project outcomes; projects typically have more than one objective
Performance standards	Observable or measurable attributes that can be used to determine if a wetland creation project meets the objectives intended for the project; each objective will have one or more associated performance standards
Monitoring methods	Specific approaches to determining if performance standards have been met
Remedial action	Actions to be taken if performance standards are not met within the desired period

Goals, objectives, performance standards, monitoring methods, and remedial actions for the 50-year DMMP were discussed and agreed upon by ICT members attending the 3-4 November 1998 ICT meeting, which was largely dedicated to a workshop intended for development of these goals, objectives, performance standards, monitoring methods, and remedial actions. At the 6 April 1999 ICT meeting, minor changes to goals, objectives, performance standards, monitoring methods, and remedial actions were discussed and approved. Table 3 summarizes final goals, objectives, performance standards, monitoring methods, and remedial actions for wetland sites to be created as part of the 50-year DMMP. Note that two of the vegetation community performance standards (the Similarity Performance Standard and the Diversity Performance Standard) and approaches to aerial photography were modified based on testing described in this report (see "Section III. Testing Vegetation Performance Standards with Field Data"), as per the comments appended to Table 3.

Table 3. Summary of goals, objectives, performance standards, monitoring methods, and remedial measures from the 3-4 November ICT meeting.

Goal	Objectives	Performance standard	Monitoring method	Remedial measure
Use dredged material to create marsh similar to nearby natural marshes[1], including both high and low marsh, without adversely impacting critical habitats and while minimizing impacts to other natural habitats, and without adversely impacting navigation requirements	Provision of habitat for Whooping Cranes	Presence of at least one Whooping Crane per 200 ha of created marsh, on average, during the wintering season	Aerial counts of Whooping Cranes as part of USFWS routine weekly aerial counts and ground observations 7 years after marsh creation	Investigations designed to determine why Whooping Cranes are not using the habitat should be undertaken, including determination of similarity of created marsh to natural marsh, and results of these studies should be considered in marsh design as part of future dredging cycles
	Stabilization of dredged material	Areal loss of marsh should be no more than 10% of initial marsh area for the life of the project	DOQQs or equivalent photography at a scale of 1:1500 should be assessed at least once every 7 years to establish changes in area of marsh[2]	Erosion problems to be arrested by repairing or altering structures as needed, or by installation of additional structures
				Consider additional placement of dredged material on eroding site
			At least once each year, structural integrity of earthen dikes and other structures intended to stabilize dredged material will be assessed	Consider and correct design flaws that might impact sites created as part of future dredging cycles
	Accommodate required volume of dredged material	Projected capacity available as per maintenance dredging schedule[3]	Requirements established in preplacement surveys will be compared to design capacities stated in 50-year DMMP	Modify designs in DMMP as needed to accommodate changes in projected volume of dredged material

1. Natural marsh to be included extends about 1,000 feet inland from existing marsh edge.

2. During discussions with the ICT, use of photographs taken at a scale of 1:1000 were tentatively suggested. After further discussions with USGS remote sensing personnel, use of 1:1000 aerial photographs was discarded in favor of DOQQs, which have a resolution of 1 m.

3. Estimates of minimum and maximums of maintenance dredging needs are reported elsewhere in the 50-year DMMP.

Table 3. Summary of goals, objectives, performance standards, monitoring methods, and remedial measures from the 3-4 November ICT meeting **(continued)**.

Goal	Objectives	Performance standard	Monitoring method	Remedial measure
Use dredged material to create marsh similar to nearby natural marshes, including both high and low marsh, without adversely impacting critical habitats and while minimizing impacts to other natural habitats, and without adversely impacting navigation requirements	Support vegetation communities similar to those typical of nearby natural marshes	No *Phragmites australis* or obligate upland plants	Site visits to observe occurrence of undesirable plant species at least once per year, with upland plants as defined by USFWS plant lists	Removal or herbiciding of undesirable vegetation
		At least 1/5 of total cover (inclusive of bare ground) will be by *Batis maritima, Borrichia frutescens, Monanthochloe littoralis, Salicornia* spp., and *Lycium carolinanum*, and *Lycium carolinanum* will be present[4]	Collection of areal % cover data from at least 40 1-m^2 quadrats at created wetland 3 years after wetland planting, with quadrats placed randomly within the created wetland	Consider recontouring to support appropriate vegetation communities Consider remedial planting
		Similar patchiness in created and natural marsh sites as determined by achieving mean Shannon-Wiener Diversity Index values within 1-m^2 plots in created wetlands that is within the range of mean diversities for 1-m^2 plots in 5 nearby natural wetlands[5]	Collection of areal % cover data from at least 40 1-m^2 quadrats at created wetland and 5 nearby natural wetlands 3 years after wetland planting and computation of mean Shannon-Wiener Diversity index scores for created and natural wetlands	Consider and correct design flaws that led to low vegetation similarity or dissimilar patchiness
	Protect and preserve contiguous habitat	ICT members offer no negative observations or reports regarding impacts to contiguous habitat	Observations to be undertaken as part of routine site visits at least once per year	Seek ICT recommendations

4. This performance standard replaces the similarity performance standard discussed at the 3-4 November 1998 ICT meeting. The similarity performance standard was discarded after testing indicated that it was not appropriate. See "Section III. Testing Vegetation Performance Standards with Field Data" of the report.

5. ICT discussions led to suggestion of use of mean diversities as a measure of vegetation patchiness, or intermixing of species. ICT discussions suggested that diversity values should be wihtin 50% of those found in nearby natural wetlands, but testing of this method showed that it would be more appropriate to base the performance standard on attainment of a diversity within the range of those found in nearby natural wetlands. See "Section III. Testing Vegetation Performance Standards with Field Data" of this report.

Table 3. Summary of goals, objectives, performance standards, monitoring methods, and remedial measures from the 3-4 November ICT meeting **(continued)**.

Goal	Objectives	Performance standard	Monitoring method	Remedial measure
	Avoid creation of or increase in navigation problems or changes to dredging volume and frequency	No negative feedback through the ICT	Observations each year from Corps of Engineers conditions surveys, intracoastal waterway users, or others	Seek ICT recommendations
Use dredged material to create marsh similar to nearby natural marshes, including both high and low marsh, without adversely impacting critical habitats and while minimizing impacts to other natural habitats, and without adversely impacting navigation requirements	Develop habitat for fisheries support	Edge:area ratio equal to or greater than the median edge:area ratios of nearby natural marsh sites	Created wetland DOQQs or equivalent photography at a scale of 1:1500 should be interpreted once every 7 years and edge:area ratio compared to that typical of 5 nearby natural marshes	Where practicable, additional dredged material placement or recontouring should be used to obtain appropriate edge:area ratios, slopes, elevations, and open water habitat connected to tidal flushing, or edge:area ratios, slopes, elevations, and open water habitat connected to tidal flushing should be adjusted at marshes created as part of future dredging cycles for compensation
		Area of open water habitat with connection to tidal flushing is equal to or greater than median areas of open water habitat with connection to tidal flushing in nearby natural marsh sites	DOQQs or equivalent photography at a scale of 1:1500 will be used to measure area of open water once per 7 years and percent of marsh area comprised of open water habitat with tidal connections will be compared to that typical of 5 nearby natural marshes	For sites to be created as part of future dredging cycles, consider and correct design flaws that led to inappropriate edge:area ratios, slopes, elevations, and open water habitat connected to tidal flushing
		Slopes and elevations within the range of those typical of nearby natural marsh sites	A minimum of five transects will be surveyed at each created wetland and at 5 nearby natural wetlands once per 7 years, and slopes and elevations of transects at created wetlands will be within the range of those typical of nearby natural marshes	
		Mean overall density of blue crabs, transient fish species, and resident fish species in created wetlands are not to be significantly different from means for nearby natural wetlands[6]	Fish censusing via trapping (drop traps or throw traps, but not minnow traps, breder traps, or similar semi-quantitative methods) with a reasonably powerful sampling design will be used to compare mean densities 7 years after wetland creation at each site	Investigations should be undertaken to determine why differences exist in mean densities of blue crabs, transient fish, and resident fish

6. Measurement of blue crab and fish densities will require significant funding and will only be undertaken if funding is available. If measurements of blue crab and fish densities are not possible because of funding limitations, habitat structure variables will be accepted as a "stand-alone" measure of fisheries habitat development.

Development of goals, objectives, performance standards, monitoring methods, and remedial actions is not a simple process. It relies on professional judgement and experience from a number of fields. During the 3-4 November 1998 ICT meeting, a number of possible goals were discussed. After initial discussion, goals focused on using dredged material to 1) establish marsh similar to nearby natural marshes and 2) establish marsh generally similar to natural marsh, but with certain enhancements, such as increased areas of *Spartina alterniflora* edge habitat that would support certain fish species and provide some protection from wave energy to high marsh habitat. After further discussion, it was decided that the goal of marsh creation would be establishment of marsh similar to nearby natural marshes, but with an emphasis on emulating natural marshes with reasonably high levels of edge habitat. The emphasis on emulating natural marshes with reasonably high levels of edge habitat is reflected in performance standards related to the objective of fish habitat development (Table 3). During discussions of goals and objectives, it was also noted that marsh creation should not adversely impact existing critical natural habitat, should minimize impacts to other natural habitats, and should not adversely impact navigation requirements.

The guidelines generated by the ICT will require marsh construction efforts exceeding those routinely used in creation of salt marsh habitat as part of the beneficial use of dredged material, including efforts used in creation of the demonstration marshes at Placement Areas 127A and 128. Creation of marshes with characteristics described in guidelines will require 1) special care to achieve target elevations, 2) development of innovative techniques to cost-effectively create topographic characteristics similar to those of natural marshes, and 3) planting efforts focused on achieving the biodiversity, density, and species patchiness characteristic of nearby natural marshes. In addition, guidelines call for extensive monitoring.

Changing Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Actions

Information in Table 3 will allow the Corps to move forward with design of sites for the DMMP, but Table 3 should be revisited periodically by the ICT as the DMMP is implemented. Problems with project design, changes in technology, changes in the perceived desirable characteristics of created wetlands, or other developments may arise that will render some or all of the information in Table 3 obsolete. However, revision of goals, objectives, performance standards, monitoring methods, and remedial actions should not be taken lightly. Experience has shown that people can lose sight of guidelines midway through projects or after projects are completed, and that periodic review of guidelines can prevent wasted effort and contentious claims of success or failure. ICT members agreed that changes to goals, objectives, performance standards, monitoring methods, and remedial actions should be specifically approved by the ICT.

Justification of Effort

During discussions, the ICT recognized that the wetland creation effort under consideration as part of the 50-year DMMP was unusually ambitious. Because these sites will be created adjacent to the Aransas National Wildlife Refuge, the extra effort required to satisfy goals, objectives, and performance standards can be justified. The created wetlands are likely to provide habitat for endangered Whooping Cranes and will undoubtedly attract the attention of conservation organizations and the general public. Also, techniques developed for creation of these marshes can be used in future wetland creation programs at other sites and may contribute to substantial improvements in salt marsh creation using dredged material throughout the United States.

Funding Opportunities

ICT members expressed concern about the possibility of designs being "scaled back" because of increased costs associated with innovative design requirements. Until detailed designs are completed (i.e., when dredging is scheduled), it is impossible to estimate the magnitude of costs. However, if costs restrict the ability of the Galveston District to support the desired design, ICT members suggested that opportunities for cost sharing should not be overlooked. Because the project will extend over 50 years, ICT members believed that external support could be attracted for at least some aspects of the required work. ICT members supported the possibility of seeking funds from non-Corps sources, if necessary.

Several potential sources for funding or in-kind support were identified, including: 1) Section 204, 1135, and 206 funds, 2) Texas Coastal Management Program funds, via the Texas Coastal Coordination Council, and 3) in-kind support for site development as part of a compensatory mitigation requirement through Section 404 of the Clean Water Act. Other sources of funding may be available to supplement aspects of project construction. Corps of Engineers funding support mechanisms for wetland creation and restoration projects are summarized in Text Box 1. This summary of information was not discussed by the ICT, but is included here as supplemental information.

Immediate Needs Recognized by ICT

To proceed with design of sites based on identified goals and objectives in Table 3 and to test a number of points considered as part of project guidelines, the necessity of collecting limited field and photographic data was recognized. Critical requirements discussed were:

- high-accuracy (±5 cm) topographic measurements of selected areas, to gain a better understanding of the small elevation changes across natural marsh sites, especially in relation to changes in vegetation communities, changes from high to low marsh, and changes from marsh surface to marsh creeks and pools (collected 8-10 December 1998 in field, see Section II);

- measurement of slopes across the marsh surface and at the marsh edge (collected 8-10 December 1998 in field, see Section II);
- collection of vegetation quadrat data to test viability of similarity and diversity performance standards (collected 8-10 December 1998 in field, see Section II);
- aerial photographs that could be used for site design (obtained from ANWR 9 December 1998); and
- collection of data to increase knowledge of site foundation conditions and the quality of dredged material that is anticipated (to be collected as part of detailed design work).

Text Box 1. Funding Vehicles for Wetland Creation and Restoration Undertaken by the Corps

The Corps of Engineers has several vehicles for funding wetland creation and restoration projects. These vehicles are summarized here. Note that these funding vehicles are awarded on a nationally competitive basis. Official documentation should be consulted for detailed information.

- *Section 204—Implementing Ecosystem Restoration Projects in Connection with Dredging:* Section 204 funding is intended for projects that use dredged material to produce high value environmental outputs in a cost-effective manner, including projects that protect, restore, or create aquatic or wetland habitats in connection with dredging for construction, operation, or maintenance of a Federal project. No benefit-cost ratio is required, but the quantity and quality of the protection, restoration, and creation must be reconciled against costs associated with working beyond the dredging project's base plan. The base plan (the primary costs of dredging and associated activities) is fully funded from Federal sources, but costs above the base plan are funded via cost-sharing, with 75% of costs funded from Federal sources and 25% of costs funded from non-Federal sources (i.e., a local sponsor). Local sponsors must be legally-constituted public bodies.
- *Section 206—Aquatic Ecosystem Restoration:* Section 206 funding is intended to restore degraded ecosystem structure, function, and dynamic processes, usually through manipulation of hydrology. No relationship to a Corps project is required. No benefit-cost ratio is required, but the project's ability to improve the environment must be qualified and quantified. Total project costs are not to exceed $7.69 million, with no more than $5 million of these costs coming from Federal funding. Cost sharing allows for 65% Federal funding and 35% non-Federal funding. Work-in-kind can constitute part or all of the non-Federal 35% funding for the project, with the exception that work-in-kind is not applicable to the feasibility phase of the project. Local sponsors must be legally-constituted public bodies.
- *Section 1135—Project Modification for the Improvement of the Environment:* Section 1135 is intended for restoration of degraded ecosystem structure, function, and dynamic processes. Categories include modification of existing Corps projects, restoration where existing Corps projects contributed to environmental degradation, or restoration where construction or funding by the Corps or another Federal agency contributed to degradation of the environment. All Section 1135 restoration projects must have some connection to a Corps project. No benefit-cost ratio is required, but the project's ability to improve the environment must be qualified and quantified. Total project costs are not to exceed $6.6 million, with no more than $5 million of these costs coming from Federal funding. Cost sharing allows for 75% Federal funding and 25% non-Federal funding. Non-Federal sponsors may be public agencies, national non-profit groups, and private interests.

II. Investigations: Elevation, Vegetation, and Landscape-level Geomorphology

In this section, elevation, vegetation communities, and landscape-level geomorphology are each discussed. Information from this section is used in the Conceptual Design and Detailed Design sections of this report.

In wetland creation using dredged material, it is possible to design for and to some degree control three factors that will contribute to meeting goals, objectives, and performance standards established by the ICT. These factors are 1) elevation and topography, 2) vegetation community structure, and 3) site morphology. Appropriate elevations can be designed for and achieved through careful engineering, including application of appropriate models for consolidation of dredged material (which require detailed geotechnical data) as well as careful consideration of site area, existing bathymetry, and required volume of dredged material. The ICT determined that a performance standard for the objective "Develop habitat for fisheries" would require "Slopes and elevations within the range of those typical of natural marsh sites" in the project area (see Table 3). In addition, several other performance standards related to the objective "Support vegetation communities similar to those typical of Aransas National Wildlife Refuge" will require specific elevations. To identify appropriate target elevations and to quantify microtopographical variations in elevation, detailed survey work in natural marshes of the project area as well as a review of available survey data were required. Throughout this report, the project area includes Welder Flat and Aransas National Wildlife Refuge marshes.

While vegetation communities will evolve over time to reflect prevailing environmental (physical and biological) conditions, initial planting of appropriate vegetation assemblages can prevent or at least delay problems with establishment of nuisance plant species or dominance by one or a small number of species. Also, planting can contribute to accelerated consolidation of dredged material through evapotranspiration, protection from erosion by development of a root mat, rapid development of habitat structure to support birds and other wildlife, and potentially improved wetland functioning in terms of biogeochemical cycling and nutrient dynamics. One of the ICT's stated objectives for the wetland creation aspects of the 50-year DMMP was "Support of vegetation communities similar to those typical of Aransas National Wildlife Refuge." To understand vegetation community structure at the level required for design of appropriate planting schemes, vegetation survey work, linked to microtopographical elevation survey work, was required.

In a created wetland, appropriate use of structures, strategic placement of dredge discharge pipes, and post-consolidation contouring can lead to the desired landscape-level geomorphology. The ICT determined that performance standards for the objective "Develop habitat for fisheries" would require 1) "Edge:area ratio equal to or greater than the median edge:area ratios of natural marsh sites at Aransas National Wildlife Refuge," and 2) "Area of open water habitat with connection to tidal flushing is equal to or greater than median areas of open water habitat with connection to tidal flushing in natural marsh sites at Aransas National Wildlife Refuge." Both of these performance standards require consideration of landscape-level morphology of natural marshes in the project area. Note that here, and throughout this report, the term "landscape-level geomorphology" is used to describe the geomorphology that can be determined from aerial photographs, and does not include consideration of elevation and slopes. Elevation and slopes are considered separately from landscape-level geomorphology. High resolution, large scale aerial photographs, such as Digital Orthophoto Quarter Quadrangles (DOQQ), are required to better understand landscape-level morphology of sites. For this report, unrectified aerial photographs with an approximate scale of 1:6,000 (1 inch = 500 feet) were obtained from ANWR.

Elevation

Detailed survey work was undertaken at eleven sites in the project area (i.e., Welder Flat and Aransas National Wildlife Refuge marshes) on 8-10 December 1998. Approximate locations of sites are identified in Figures 3a (Welder Flat sites) and 3b (Aransas National Wildlife Refuge sites). Site choice was limited by the presence of Whooping Cranes.

Personnel from the Army Corps of Engineers Galveston District and the US Army Engineer Research and Development Center, Waterways Experiment Station, conducted surveys using a Real Time Kinematic On-The-Fly (RTKOTF) Global Position System (GPS) (Trimble 4000 SSI) (Figure 4). Base stations were established near the boathouse next to the Welder Flat channel (sometimes called Cliburn's Channel) and near the boat landing at Aransas National Wildlife Refuge. Base station coordinates were 2757027.887 (Easting) / 188731.242 (Northing) / 8.010 (elevation) for the Welder Flat sites, at a point permanently marked by a disc set in concrete near the boathouse. Base station coordinates were 2708880.425 (Easting) / 151163.915 (Northing) / 7.808 (elevation) for the Aransas National Wildlife Refuge sites, at a point permanently marked by a bolt near the boat landing.

Survey data were collected along transects and in grids (comprised of multiple parallel transects spaced at 1-m intervals), with coordinates collected at roughly 1-m to 2-m intervals along transects. The objective of surveying was to assess microtopography in a way that could provide insight for wetland creation design. As such, sites were chosen subjectively to cover a variety of situations within the constraints of avoiding wintering Whooping Cranes. Sites with different vegetation communities located at different distances from the Intracoastal Waterway, and with different densities of ponds and depressions, were included. One area selected from aerial photographs because of its high edge:area ratio, to the

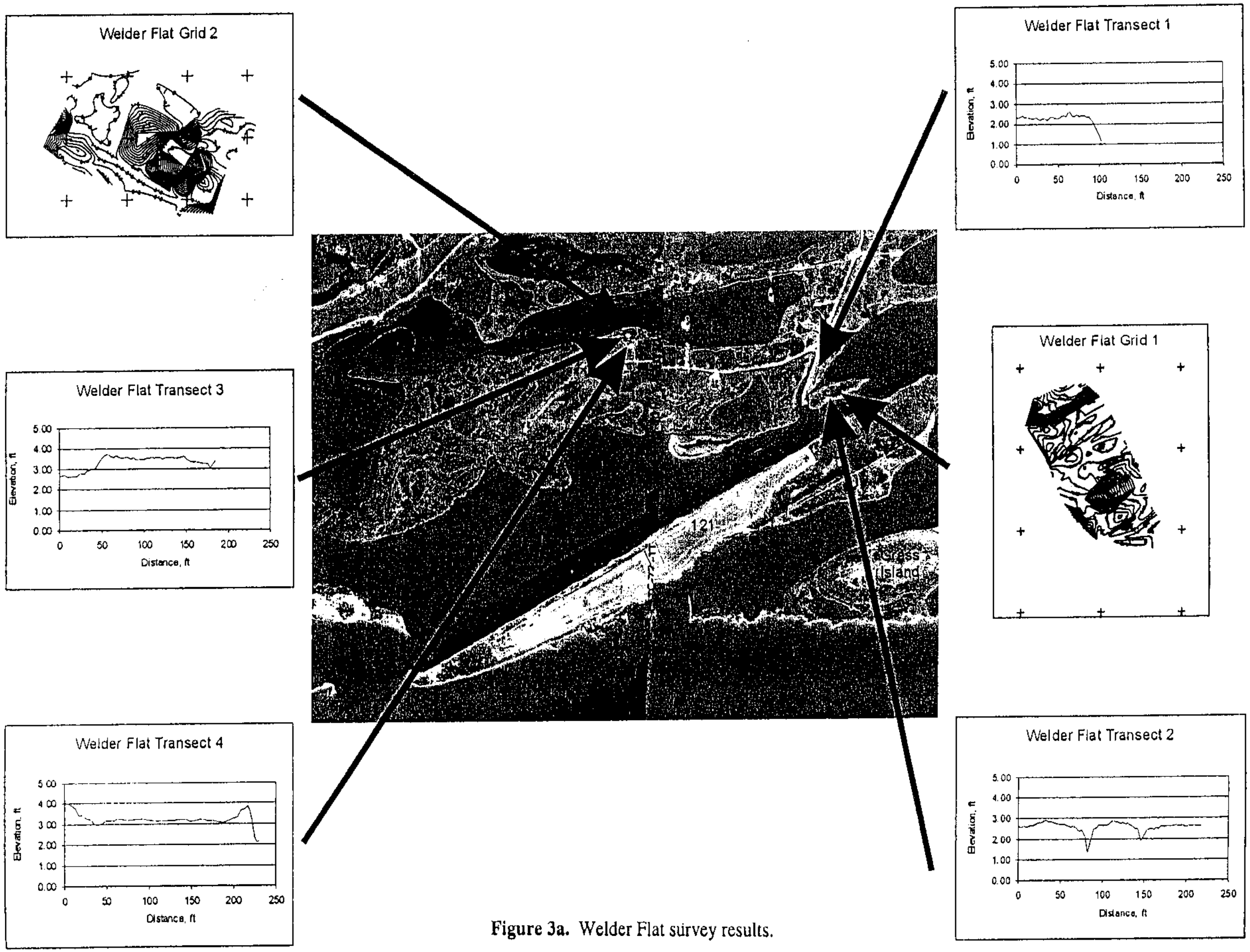


Figure 3a. Welder Flat survey results.

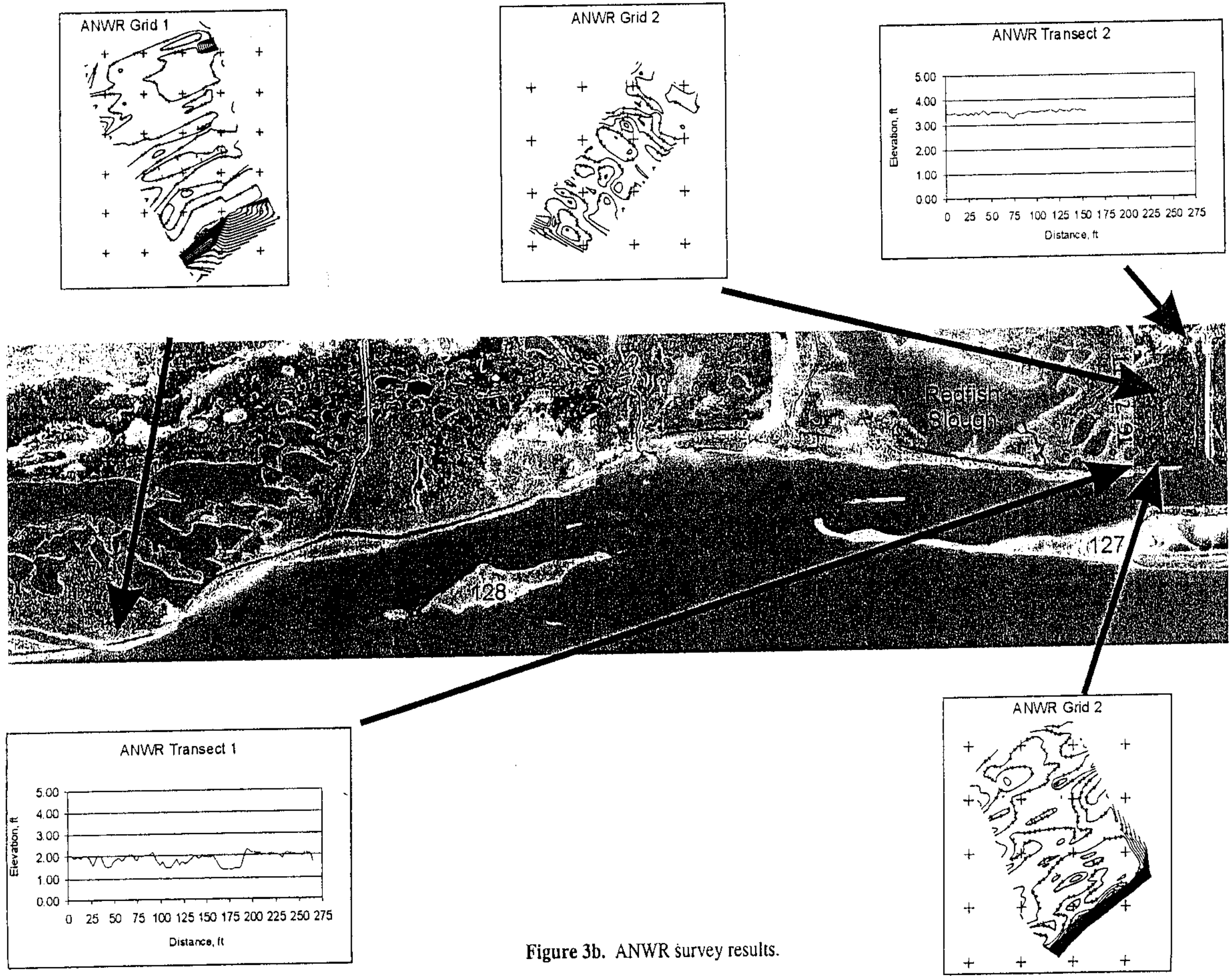


Figure 3b. ANWR survey results.

northeast of the Aransas National Wildlife Refuge boat landing, could not be surveyed because Whooping Cranes were present.

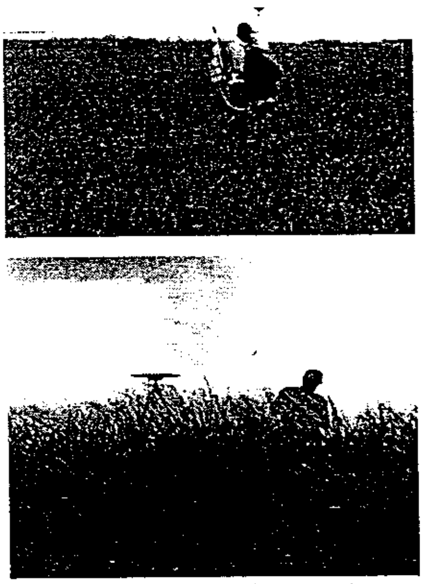


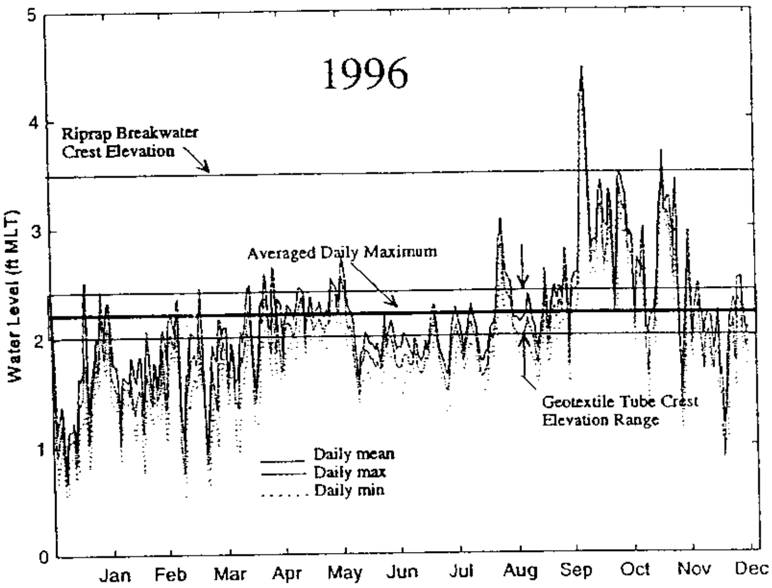
Figure 4. In bottom photograph, Cleo Dow establishes RTKOTF surveying base station at Aransas National Wildlife Refuge; in top photograph, Cleo Dow and Gail Stewart (right) collect survey data.

Survey data had a nominal precision of less than 1 inch. However, the sediments at many of the survey points were very soft, so surveyors had to subjectively identify a "true ground level," which introduced an unmeasured error in the vertical dimension (elevation) that probably exceeded the nominal precision of survey data in the vertical dimension; this error probably varied from 1-3 inches. A total of 1,264 points were surveyed. Elevations, not including those of base station points, ranged from 0.174 ft MLT to 3.97 ft MLT across all sites. Lowest elevations were from points at the edge of Intracoastal Waterway, in unvegetated open water. Highest elevations were from points near the Aransas National Wildlife Refuge boat ramp, in areas generally dominated by *Spartina patens*.

Tide ranges, based on data from the Copano Bay water level gauge (gauge maintained by the Texas Coastal and Ocean Observation Network) are plotted in Figure 5, and the location of the gauge is shown in Figure 6 (28.1145^0 N, 97.0242^0 W). Data suggest that the lowest elevations surveyed on the edge of the Intracoastal Waterway, at less than 1 ft MLT, are flooded at all times. Highest elevations, at greater than 3.5 ft MLT, would only be flooded by tidal water during extreme high tide events, such as occurred in late 1996 and late 1997 (Figure 5).

Elevations for individual transects and grids are summarized in Table 4 and plotted in Figures 3a and 3b. Within individual sites, elevations could vary by up to 2.4 feet. Darnell reported slopes of 0.5% in unvegetated habitat of Aransas National Wildlife Refuge marshes and 0.3% for areas with emergent vegetation in Aransas National Wildlife Refuge marshes. However, it should be noted that Darnell's surveys relied on a small number of survey points to compute slope and variability related to microtopographic relief may influence reported scores.

Differences in elevation between the vegetated areas surrounding ponds or flooded depressions and the unvegetated bottoms of ponds or depressions were typically less than 6 inches. Differences between the vegetated areas surrounding tidal channels and the unvegetated tidal channel bottoms were typically less than 9 inches. These differences are about 3 inches greater than differences reported by Darnell et al. (1997) for Aransas National Wildlife Refuge, based on interpretation of Darnell et al.'s Figure 7 (reproduced in this report as Figure 7).



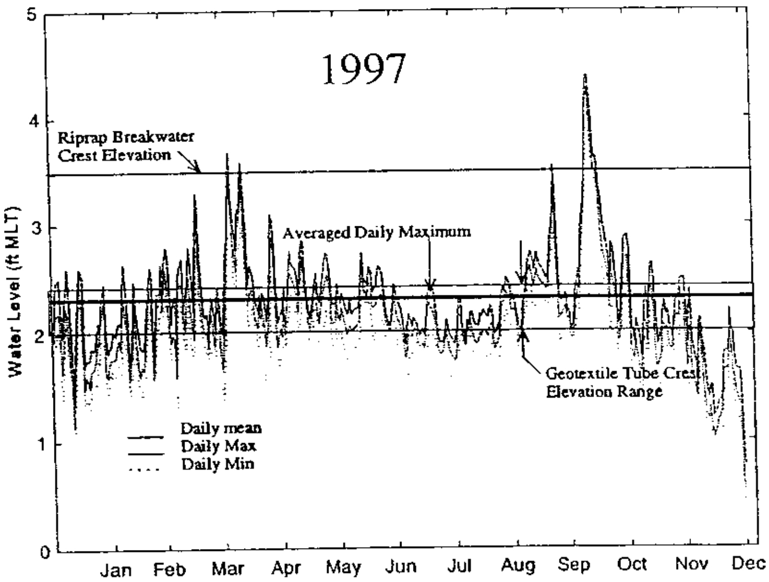


Figure 5. Water levels at study sites in 1996 and 1997, along with elevations of existing structures protecting PA 127a and 128. The highest survey elevations on natural marshes were 3.97 ft, while the lowest were 0.174 ft. Highest survey elevations were rarely inundated during 1996/97, while lowest survey elevations were almost always innundated. Lowest survey elevations were from unvegetated open water at the edge of the Intracoastal Waterway. Lowest vegetated elevations were typically around 1.7 feet. Data from Copano Bay Tide Gauge.

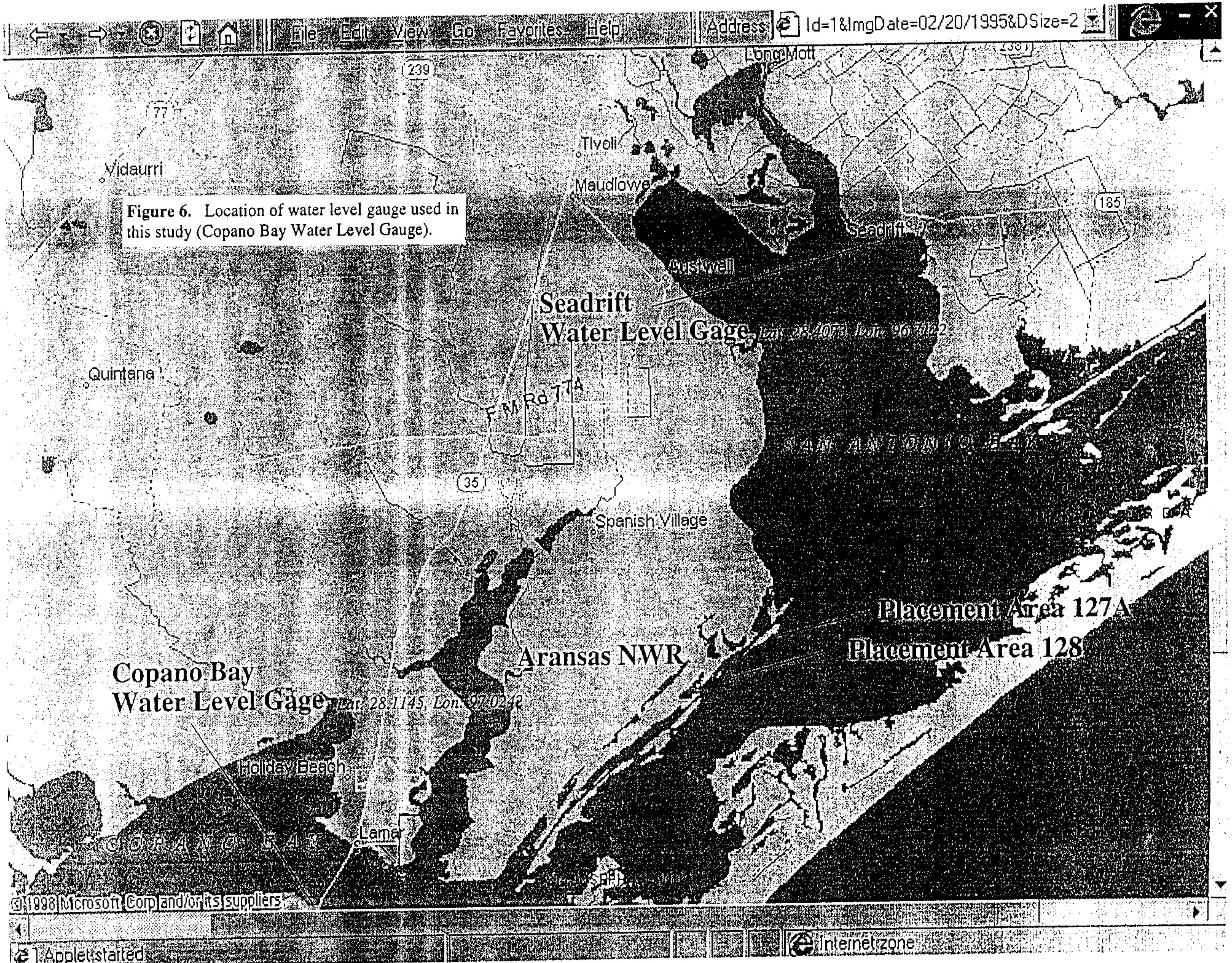


Figure 6. Location of water level gauge used in this study (Copano Bay Water Level Gauge).

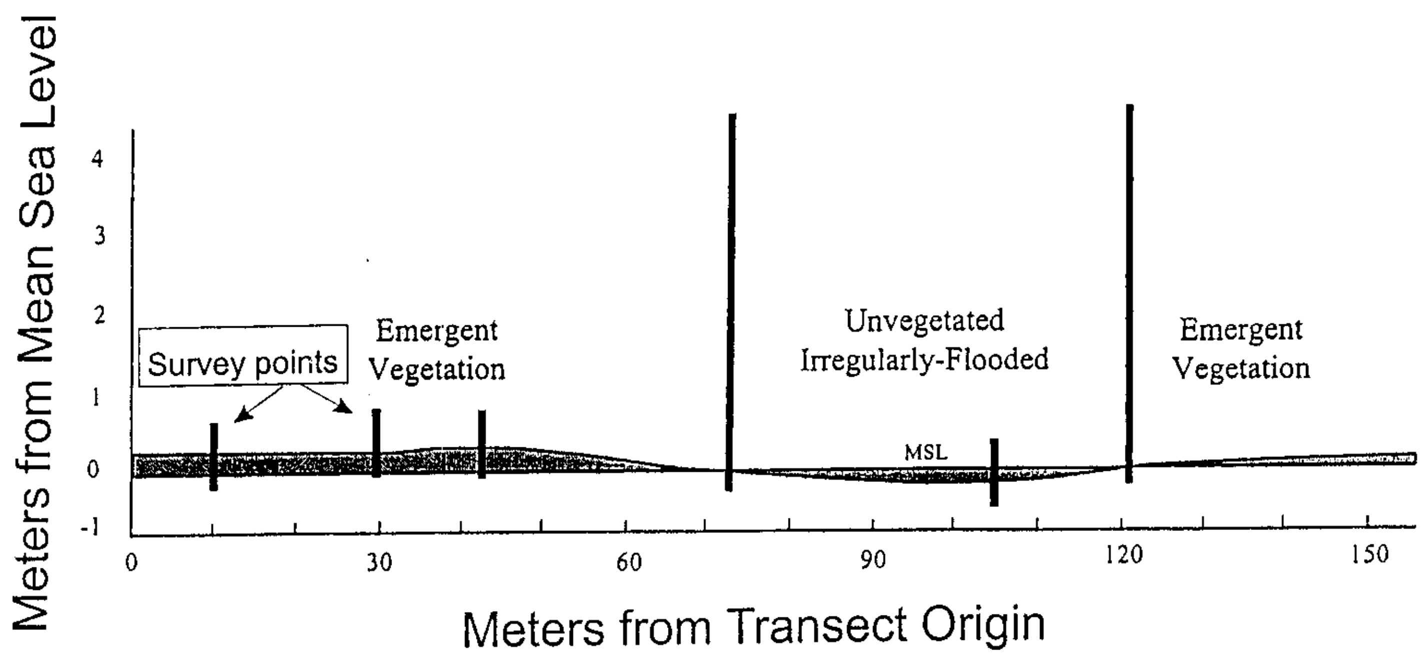


Figure 7. Contour profile, adapted from Figure 7 in Darnell et al. 1997. Note that the coutour profile is based against mean sea level, rather than mean low tide, and that the profile is based on a limited number of survey points.

Vegetation

Areal cover by plant species was estimated in 1-m^2 quadrats at each site where elevation surveys were conducted, concurrent with elevation surveys on 8-10 December 1998 (Figure 8). Quadrats were placed on the marsh surface at irregular intervals within surveying grids and transects. Because vegetation estimates required more time per quadrat than was required to measure surveying coordinates, there are fewer vegetation quadrats than elevation data points; in total, areal cover was estimated in 306 quadrats. Tables 5 and 6 describe vegetation from Welder Flat and Aransas National Wildlife Refuge sites, respectively. Figures 9 and 10 summarize percent contributions from the eight most abundant plant species and bare ground for each site at Welder Flat and Aransas National Wildlife Refuge sites, respectively.

At most sites, bare ground was the most abundant cover class. Although salt marsh vegetation in the project area generally persists through winter months, senescence and partial winter die-back (sampling was undertaken on 8-10 December 1998) may have resulted in larger percentages of bare ground than would be found during warmer months. Fifteen plant species were found in quadrats (see Tables 4 and 5), but only eight species occurred frequently enough to be considered important contributors to plant community structure at any of the sites: *Batis maritima*, *Borrichia frutescens*, *Distichlis spicata*, *Lycium carolinanum*, *Monanthochloe littoralis*, *Salicornia virginica*, *Spartina alterniflora*, and *Spartina spartinae*.

Figures 9 and 10, which summarize data on the nine most abundant cover types (bare ground and eight plant species) found in quadrats, suggest the variability between sites. Even sites that are geographically close and have similar elevations may have very different plant communities. For example, in Welder Flat Grid 1, *Batis maritima* was the most abundant vegetation cover class (i.e., the most abundant cover class not including bare ground), with *Distichlis spicata* as the second most abundant cover class. Nearby, at Welder Flat Transect 2, *Batis maritima* was considerably less abundant, and *Distichlis spicata* covered less than 1% of quadrat area. Elevations at the two sites were similar: elevations for Welder Flat Grid 1 ranged from 1.99-2.61 ft MLT, with a mean of 2.46 ft MLT, while elevations at Welder Flat Transect 2 ranged from 1.89-2.84 ft MLT, with a mean of 2.58 ft MLT (for elevations taken at plant quadrats, as per Table 5). Thus, differences in elevation are small and may not explain differences in vegetation. Similarly, at Aransas National Wildlife Refuge Transect 1, *Distichlis spicata* and *Batis maritima* were the most abundant vegetation cover classes, but at nearby Aransas National Wildlife Refuge Grid 3 *Borrichia frutescens* was the most abundant vegetation cover class, with *Batis maritima* covering less than 6% of quadrat area and *Distichlis spicata* covering less than 3% of quadrat area. Again, elevations at the two sites were similar: elevations at Aransas National Wildlife Refuge Transect 1 ranged from 1.71-2.22 ft MLT, with a mean of 1.99 ft MLT, while elevations at Aransas National Wildlife Refuge Grid 3 ranged from 1.94-2.45 ft MLT, with a mean of 2.21 ft MLT (for elevations taken at plant quadrats, as per Table 6). Just as in the previous example, differences in elevation may not explain differences in plant

Table 4. Elevation ranges for surveyed sites, in feet above MLT.

Welder Flat	Lowest elevation	Highest elevation
Transect 1	1.468	2.616
Transect 2	1.344	2.897
Transect 3	2.621	3.716
Transect 4	2.086	3.970
Grid 1	1.296	2.644
Grid 2	1.824	3.316
Aransas National Wildlife Refuge		
Transect 1	1.337	2.265
Transect 2	3.253	3.621
Grid 1	1.153	2.933
Grid 2	1.778	2.457
Grid 3	0.174	2.582

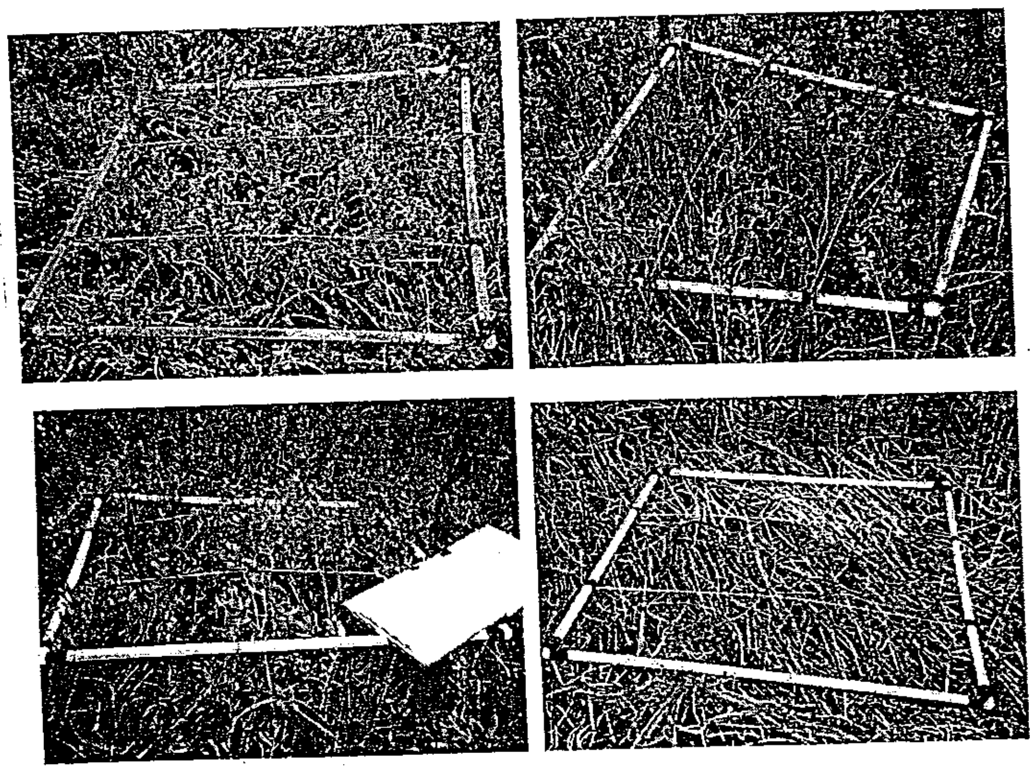


Figure 8. Plant quadrats (1 m^2) were used to assess vegetation communities at sites. Areal cover for each species and for bare ground was visually estimated for each quadrat.

Table 5. Summary of vegetation grids and transects for Welder Flat sites. Values are mean percent cover values from 1-m^2 quadrats. "P" indicates species present at less than 1% mean cover. In general, variances (not listed) were much greater than means, reflecting a high degree of patchiness (i.e., an aggregated dispersion pattern in plant distributions) within sites.

Scientific name	Common name[1]	Grid 1	Grid 2	Transect 1	Transect 2	Transect 3	Transect 4
bare ground	—	41.2	39.6	29.0	35.5	45.3	41.8
Aster tenuifolius	(Perrenial salt marsh aster)	0	0	P	P	0	0
Batis maritima	Saltwort	39.6	27.0	9.5	16.8	19.1	6.2
Borrichia frutescens	Sea-oxeye (Sea-oxeye daisy)	1.5	1.5	6.0	2.8	1.3	3.3
Cuscuta sp.	Dodder	0	0	0	0	0	P
Distichlis spicata	Spike grass (salt grass)	11.0	1.9	33.6	P	P	6.9
Lycium carolinianum	Christmas berry (wolf berry)	1.1	1.9	P	1.0	1.6	P
Monanthochloe littoralis	Key grass	6.7	9.4	P	13.5	1.6	4.4
Salicornia bigelovii	Annual glasswort	0	0	0	0	P	0
Salicornia virginica	Perennial glasswort	P	2.2	16.7	20.6	31.6	6.8
Spartina alterniflora	smooth cordgrass	0	18.1	6.1	10.5	1.3	30.0
Mean (and range) of elevation (in ft MLT)		2.46 (1.99-2.61)	2.25 (1.95-3.32)	2.24 (1.47-2.38)	2.58 (1.89-2.84)	3.42 (3.00-3.64)	3.27 (2.26-3.97)
Number of quadrats		46	40	10	20	16	17

[1]As per Godfrey and Wooten 1981; parenthetical common names are from local usage.

Table 6. Summary of vegetation grids and transects for Aransas National Wildlife Refuge sites. Values are mean percent cover values from 1-m² quadrats. "P" indicates species present at less than 1% mean cover. In general, variances (not listed) were much greater than means, reflecting a high degree of patchiness (i.e., an aggregated dispersion pattern) in plant distributions within sites. Unknowns 1-3 were small forbs without flowers that could not be identified based on available plant material.

Scientific name	Common name[1]	Grid 1	Grid 2	Grid 3	Transect 1	Transect 2
bare ground	—	47.1	32.9	41.7	51.5	17.7
Aster tenuifolius	Perennial salt marsh aster)	0	0	P	0	0
Batis maritima	Saltwort	15.9	28.2	5.6	19.5	P
Borrichia frutescens	Sea-oxeye (Sea-oxeye daisy)	25.8	1.4	48.0	3.1	7.4
Cuscuta sp.	Dodder	P	0	P	0	0
Distichlis spicata	Spike grass (salt grass)	4.9	8.5	2.8	27.2	0
Lycium carolinianum	Christmas berry (wolf berry)	3.5	2.7	P	P	P
Monanthochloe littoralis	Key grass	3.6	28.2	P	0	51.0
Salicornia bigelovii	Annual glasswort	0	P	0	0	0
Salicornia virginica	Perennial glasswort	P	P	2.8	P	5.5
Scirpus c.a. *americanus*	Bulrush	0	0	P	0	0
Spartina spartinae	Gulf cordgrass	0	0	0	0	20
Unknown 1		0	0	0	0	P
Unknown 2		0	0	0	0	P
Unknown 3		0	0	0	0	P
Mean (and range) of elevation (ft MLT)		2.60 (2.41-2.83)	2.12 (1.87-2.44)	2.21 (1.94-2.45)	1.99 (1.71-2.22)	3.49 (3.25-3.60)
Number of quadrats		40[2]	41	46	20	10

[1]As per Godfrey and Wooten 1981; parenthetical common names are from local usage.
[2]Elevation data available from only 21 of 40 vegetation quadrats.

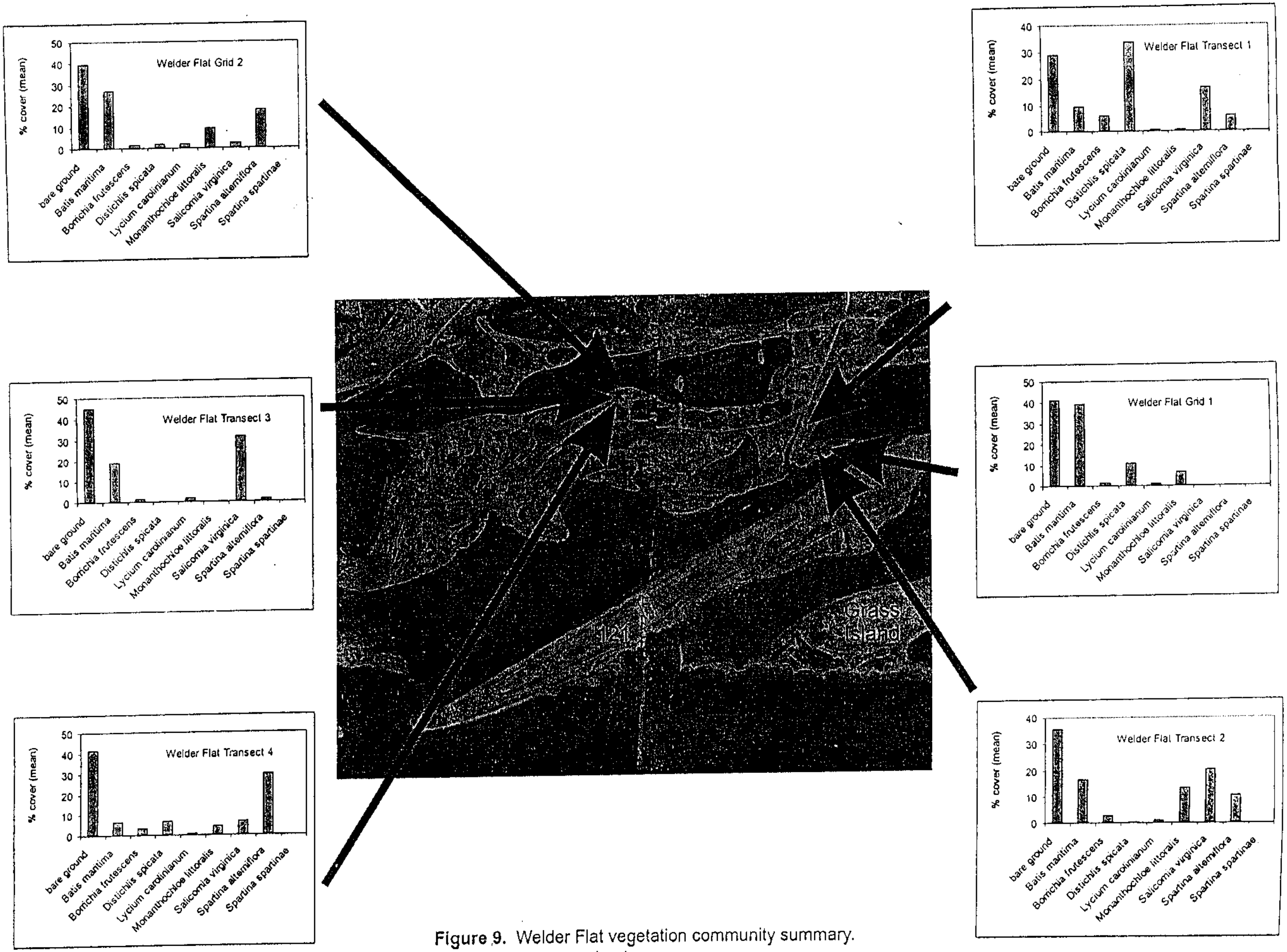


Figure 9. Welder Flat vegetation community summary. Locations are approximate.

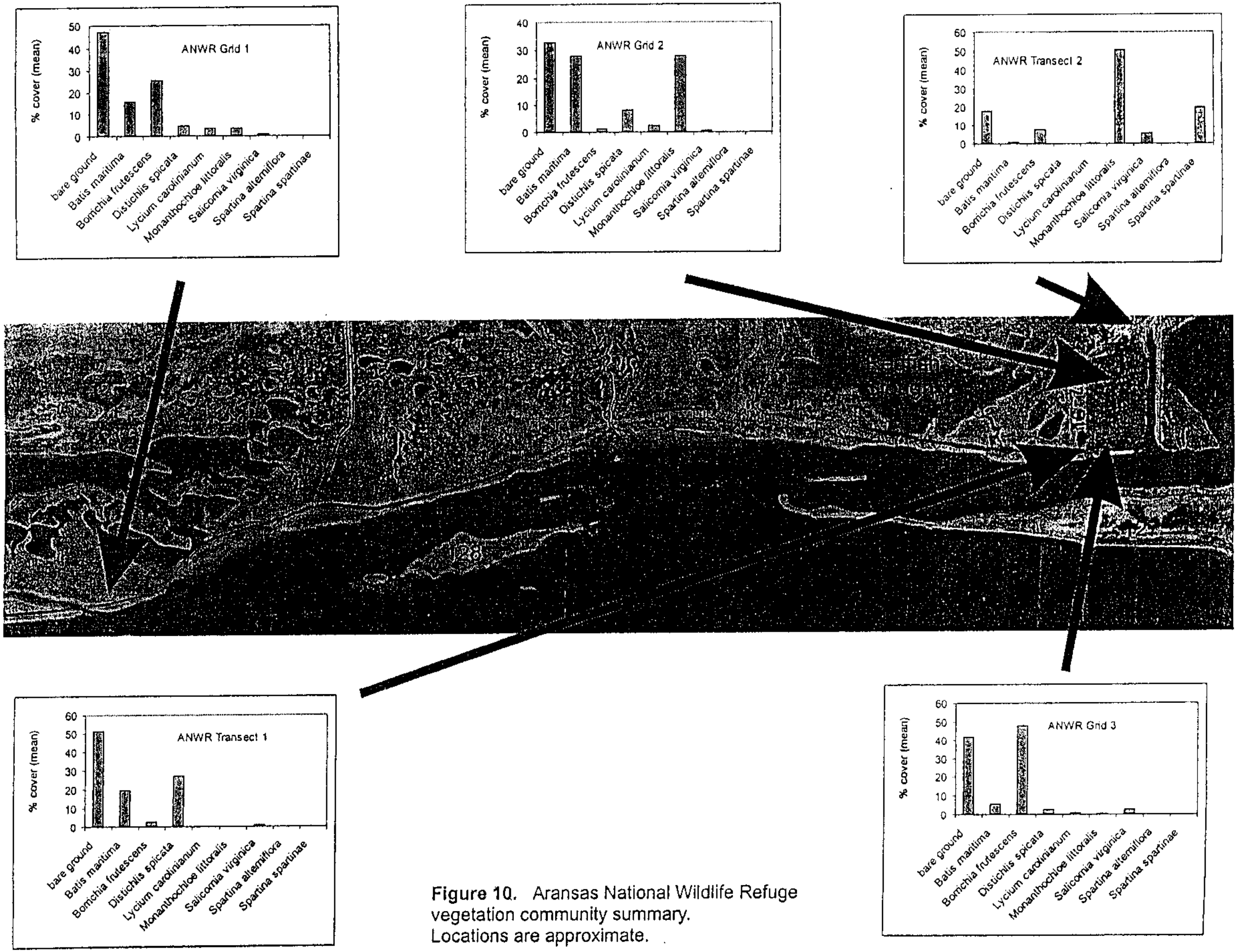


Figure 10. Aransas National Wildlife Refuge vegetation community summary. Locations are approximate.

communities. The point of this discussion is to suggest that within the marshes, differences in vegetation community structure may be driven by stochastic events that would be difficult or impossible to duplicate or predict. For example, factors such as grazing pressure and seed set may drive one part of the marsh toward dominance by *Borrichia frutescens* and another toward dominance by *Batis maritima*. The end result is a vegetation mosaic without clear zonation.

Cuscuta sp., a parasitic plant without chlorophyll that frequently occurs in salt marshes, was present in several quadrats. *Scirpus americanus*, a plant typically associated with brackish marshes or salt marshes with freshwater input via creeks or rain, was scattered through Aransas National Wildlife Refuge Grid 3, apparently growing from seed rather than via vegetative spread (based on the scattered occurrence of plants). Quadrats with *Scirpus americanus* had elevations of 2.0 to 2.3 ft MLT, and would therefore be frequently inundated by tidal flooding (see Figure 5). Rainwater may depress salinities sufficiently to allow germination and survival of *Scirpus americanus*, but the species may disappear during periods of drought. This is one example of a form of interannual variability in plant community structure that may occur in the project area. Both *Cuscuta* sp. and *Scirpus americanus* are two examples of species seldom seen in quadrats but known to occur in salt marshes.

Correlation analysis was used to further assess the relationship between various cover types (i.e., bare ground and plant species) and between cover types and elevation (Table 7). Of sixty-six relationships assessed, twenty-four were significant at the $p < 0.05$ level; of these significant relationships, only the negative relationship between *Monanthochloe littoralis* and bare ground had a correlation coefficient greater than $|0.5|$. Where *Monanthochloe littoralis* occurred, it frequently formed a dense ground cover that resulted in low percentages of bare ground. Correlation analysis did not suggest that any of the species considered had a mutually exclusive relationship; that is, the presence of one species within a 1-m^2 quadrat did not consistently mean that any other species would be absent. The weakness of correlations, both negative and positive, reinforces the suggestion that plant communities at these sites are best thought of as mosaic communities, rather than as communities with clear zonation (see, for example, Zedler et al. 1995). However, this is a small data set for assessment of infrequently occurring species and would not have allowed detection of relationships for some species. For example, *Spartina alterniflora* and *Spartina spartinae* never occurred in the same quadrat, but what would appear to be a strong negative relationship between the two species (probably related to elevation) was obscured by the large number of quadrats with neither species, and the relationship was not statistically significant.

Significant relationships between elevation and common cover types were plotted (Figure 11). Plots illustrate the weakness of relationships and serve as a reminder that significant relationships may not "explain" plant distributions or offer predictability useful for site design. For example, there is a significant relationship between bare ground areal cover and elevation, but the r^2 value suggests that elevation only explains 7% of the variability in the areal cover by bare ground. The scatter of points in Figure

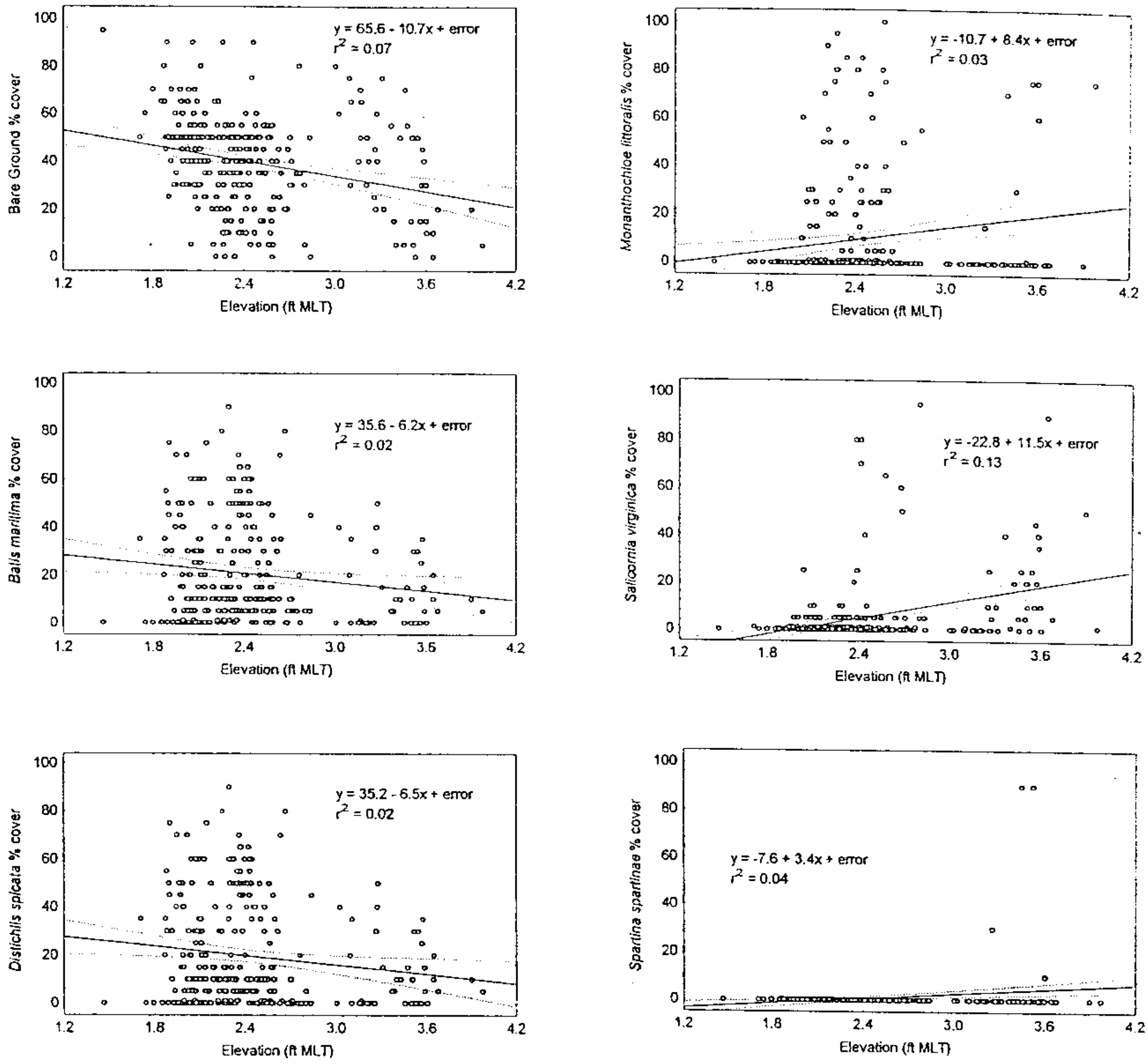


Figure 11. Relationships between elevations and areal cover by cover types (bare ground and plant species) significantly related to elevation. Low r^2 values suggest that the relationships between elevation and cover type, while statistically significant, is weak.

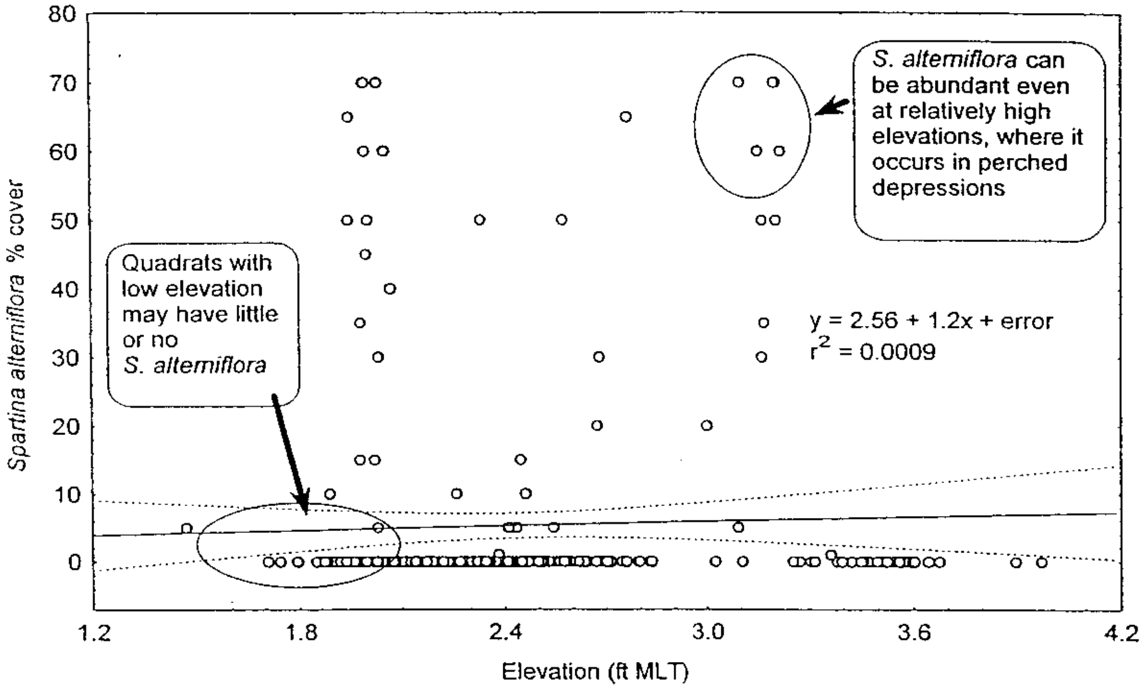


Figure 12. Although *Spartina alterniflora* is typically expected to grow at the lowest vegetated elevations within a marsh complex, there is no clear relationship between *Spartina alterniflora* and elevation for the marshes of the project area. The plot shown here illustrates this point. Note that the relationship depicted by the regression line is not significant at the $p < 0.05$ level (that is, there is no evidence to suggest that elevation, within the range of elevations examined, can predict *Spartina alterniflora* abundance). Circled and annotated data points reinforce the inconsistency of the paradigm linking low elevations with *Spartina alterniflora* abundance.

11 also shows the variability in areal cover of bare ground that is unrelated to elevation. The *Salicornia virginica* plot shows the strongest relationship between a cover type and elevation, but even this relationship only explains about 13% of the variability in the data, and, again, the scatter of data points illustrates the weakness of this relationship. For other cover types with areal cover significantly related to elevation, elevation cannot explain (or predict) more than 7% of the variability. In short, within the range of elevations that occurred on study plots, a knowledge of elevation is of little value in predicting or explaining cover types.

This conclusion is difficult to reconcile with paradigms of marsh ecology that suggest a strong relationship between elevation and plant community structure. For example, *Spartina alterniflora* typically would be expected at the lowest elevations, followed by a mixture of species such as *Distichlis spicata*, *Borrichia frutescens*, *Monanthochloe littoralis*, and *Lycium carolinanum* at slightly higher elevations, and *Spartina spartinae* at the highest elevations. However, even a plot of *Spartina alterniflora* against elevation fails to show a clear relationship (Figure 12), and in fact the relationship that is present is not significant at the $p<0.05$ level.

Failure to find a strong relationship between elevation and plant community structure in the data set collected at the project site could be interpreted in several ways:

1. Elevation and/or plant data are not accurate.
2. The data set is too small to define relationships between elevation and plant community structure.
3. The paradigm linking elevation and marsh community structure is wrong, or does not apply at the project site.
4. The expected relationship between elevation and plant community structure is weakened when data from all sites are combined because similar elevations at different sites experience different inundation frequencies and duration.

Each of these possibilities is discussed below.

Elevation and/or plant data are not accurate. There is no *a priori* reason to suspect that elevation data are inaccurate. Elevation data were collected using standard methods, state-of-the-art equipment, and with the assistance of an experienced surveyor (Cleo Dow of the Army Corps of Engineers Galveston District). Similarly, vegetation data were collected by an experienced wetland ecologist (Bill Streever of Waterways Experiment Station) using standard quadrat methods. Although time constraints prevented assessment of quadrat measurement precision (that is, consistency of areal cover estimates) at the project site, past precision assessments of data collected using quadrats at other locations suggests that precision was well within practicable limits expected with this method (see, for example, Streever and Genders 1997). In short, data inaccuracy is not a reasonable explanation for the weakness in the relationship between elevation and vegetation communities.

The data set is too small to define relationships between elevation and plant community structure. Arguably, the data set may be too small to identify statistically significant relationships between vegetation and elevation. It is a basic premise of research design that increased sampling effort leads to increased statistical power, or the ability to detect significant relationships (in this case, relationships where $p < 0.05$ for the null hypothesis stating that the slope of the regression line is equal to 0) (see, for example, Streever and Portier 1994). In fact, a reasonably large number of samples were collected in this study ($n = 306$ for the total number of plant quadrats). Because all samples came from only eleven sites, each quadrat was not independent, and so some of the information used in the analyzes was redundant, or was "pseudoreplicated data," in the sense of Hurlbert (1984). Because one objective of field work was to identify microtopographic characteristics of the project site, true replication (i.e., independence of sampling) was sacrificed in favor of an approach relying on grids and transects; true replication would have required quadrat sampling of widely spaced, randomly selected points. However, for six of the most common species at the project site, the correlation between cover type and elevation was significant, and increased sample size would not have changed this outcome (except in the sense of making significant p values even smaller). In fact, the weakness of the relationships between cover types and elevation was not so much one of inability to find significance (i.e., low power) as it was one of low correlation coefficients for relationships that were statistically significant. That is, elevation was significantly correlated with vegetation cover but could only account for, or "predict," a small amount of the variability in cover type data. Increasing sample size would not have increased the ability of elevation to account for variability in cover type data. Scatter plots in Figures 11 and 12 illustrates this concept: more data points would have been scattered across the plots, just as existing points are scattered across the plots. In short, the data set is large enough to identify any ecologically important relationships between cover types and elevation, despite shortcomings related to one form of pseudoreplication.

The paradigm linking elevation and marsh community structure is wrong, or does not apply at the project site. It is possible, although unlikely, that the ecological paradigm linking elevation and plant community structure is wrong, although given the scrutiny that this paradigm has attracted over the past 20 to 30 years, this possibility is unlikely. The possibility that the paradigm does not apply at the project site is somewhat more likely. Most research supporting the paradigm relating elevation to plant community structure was undertaken in areas such as Sapelo Island, Georgia, where tide ranges exceed several feet and where variability in elevation is greater than that found at the project site. However, in the context of created wetland design, there is little conceivable benefit to abandoning this paradigm, and in any case the data set collected to support created wetland design would not, on its own, justify abandoning this well-established paradigm. Nevertheless, it seems likely that stochastic factors, such as grazing pressure and seed-set, may override the importance of elevation in controlling plant community structure, especially when elevation and tide ranges are narrow, as is the case in these sites. Even in sites where elevation and tide ranges are much larger than those of the project site, and where elevation is a good predictor of plant community structure, other factors, such as grazing pressure and interspecific plant competition (for example, see Bertness and Ellison 1987; Bertness et al. 1987; Taylor and Grace 1995; and Streever and Genders 1997), are known to play a role in zonation. That is, plant community zonation is not a direct response to elevation that excludes all other influences, even on sites with large tide and elevation ranges. In short, the paradigm linking elevation and plant community structure is not well supported by the data presented in this report, and elevation may have no more than a weak link to plant community structure.

The expected relationship between elevation and plant community structure is weakened when data from all sites are combined because similar elevations at different sites experience different inundation frequencies and duration. Elevation typically controls frequency and duration of inundation in tidal wetlands. Plants that are at higher elevations will generally be inundated less often, and for less time, then sites at lower elevations. The paradigm linking elevation and plant community structure uses elevation as a surrogate for inundation frequency and duration. Also, salinity and redox conditions related to duration and frequency of inundation are known to influence plant growth. Because elevation is typically linked to inundation, elevation can be measured and related to plant community structure in many instances. The weakness in the relationship between elevation and plant community structure for the data reported here may in fact reflect a poor relationship between elevation on the one hand and frequency and duration of flooding on the other hand for the surveyed sites. That is, a point at an elevation of 3 ft MLT, for example, at Aransas National Wildlife Refuge Grid 1 may not be inundated as frequently or as long as a point at an elevation of 3 ft MLT at Welder Flat Grid 2. As tides move past obstructions and through channels, tidal ranges can be attenuated. Alternatively, certain land forms can accentuate tidal ranges by funneling large volumes of water into small areas, as occurs, for example, along the Georgia Bight and the Bay of Fundy on the North American east coast. Aspect of openings to coves or inlets and associated fetch may also influence inundation duration and frequency in areas where wind plays a significant role in driving water levels. Areas at high elevations with depressions or areas blocked by wave berms (areas where wave-deposited sediment forms slightly higher ground at the interface between the Intracoastal Waterway and the marsh) may remain inundated longer than well-drained areas. Inundation frequency and duration can be further complicated by freshwater inputs.

Direct measurement of inundation duration and frequency is time consuming and expensive; it requires use of stage recorders deployed for long periods at many locations. Because direct measurement is usually impracticable, measurement of elevation is used as a surrogate. If inundation duration and frequency differs between sites for a given elevation, relationships between plant community structure and elevation should be stronger for data collected at individual sites (given the same sampling effort) than for data collected at multiple sites. With this in mind, relationships between elevation, bare ground, and areal cover for common plant species were examined using correlation analysis for two sites, the Welder Flat Grid 2 site and the ANWR Grid 2 site; that is, data from each site were looked at independently, so that site-specific differences in the relationship between elevation and inundation could be removed. Results of correlation analysis show that the relationship is stronger between elevation and plant community structure for each of these sites alone than for all sites combined (see Tables 7 and 8 to compare correlation coefficients), which is consistent with the hypothesis that inundation duration and frequency for a given elevation differs between sites. Plots of elevations and cover types for the Welder Flat Grid 2 site and the ANWR Grid 2 site also support the paradigm of a link between elevation and plant community structure much more strongly than plots for all sites combined, which is again consistent with the hypothesis that inundation duration and frequency for a given elevation differs between sites (Figure 13). However, even when individual sites are considered, r^2 values are relatively low, suggesting that elevation is at best a poor predictor of vegetation community structure.

While it is not possible to unequivocally state causes for the poor relationship between elevation and plant community structure, two explanations seem most reasonable: 1) While part of the variability in community structure at the project site may be driven by elevation differences, other factors, such as interspecific interactions, grazing, soil conditions, and seed set, are also involved, and 2) the expected relationship between elevation and plant community structure is weakened when data from all sites are combined because similar elevations at different sites experience different inundation frequencies and duration. These explanations gain further credence from data available in the scientific literature exploring the relationship between mean tide ranges and elevations at which *Spartina alterniflora* occurs at sites around the East and Gulf Coasts (Figure 14).

How can this information contribute to created marsh design? First, it suggests that target elevations should to be taken from nearby natural marshes that appear to have similar tidal exposure to the created wetland being designed. Second, it suggests that attainment of target elevations will not guarantee development of specific plant communities, and that performance standards should retain sufficient flexibility to account for this

Table 7. Correlation matrix for commonly occurring plant species and elevation. Correlation coefficients marked in bold are significant at $p < 0.05$ ($n = 288$). Analysis used case-wise deletion of missing data.

	Elevation	Bare ground	Aster tenuifolius	*Batis maritima*	*Borrichia frutescens*	*Distichlis spicata*	*Lycium carolinianum*	*Monanthochloe littoralis*	*Salicornia virginica*	*Scirpus c.a. americanus*	*Spartina alterniflora*	*Spartina spartinae*
Elevation	1.00											
Bare ground	**-0.26**	1.00										
Aster tenuiflius	0.00	-0.07	1.00									
Batis maritima	**-0.14**	0.01	-0.05	1.00								
Borrichia frutescens	-0.08	-0.02	-0.04	**-0.37**	1.00							
Distichlis spicata	**-0.14**	**-0.21**	0.00	**-0.16**	**-0.14**	1.00						
Lycium carolinianum	0.03	-0.10	-0.03	-0.04	-0.05	-0.06	1.00					
Monanthochloe littoralis	**0.18**	**-0.53**	-0.03	**-0.15**	**-0.18**	-0.08	**0.18**	1.00				
Salicornia virginica	**0.36**	**-0.22**	**0.25**	**-0.16**	-0.10	**-0.12**	-0.06	-0.10	1.00			
Scirpus c.a. americanus	-0.07	0.07	-0.01	-0.07	0.10	-0.04	0.02	-0.04	0.00	1.00		
Spartina alterniflora	0.03	0.06	-0.02	**-0.30**	**-0.19**	**-0.13**	**-0.12**	**-0.15**	-0.06	-0.03	1.00	
Spartina spartinae	**0.21**	**-0.17**	-0.01	-0.10	-0.02	-0.04	-0.03	-0.02	-0.01	-0.01	-0.03	1.00

Table 8. Correlation coefficients for dominant vegetation and elevation from Welder Flat Grid 2 and ANWR Grid 2. Correlation coefficients are all significant at $p < 0.05$ ($n = 40$). Comparison of correlation coefficients suggests that the relationships between the two dominant plant species for Welder Flat Grid 2 and Aransas National Wildlife Refuge Grid 2 and elevation are much stronger than relationships found for data collected throughout the project area (see Table 6), despite the smaller sample size. This is consistent with the hypothesis that "The expected relationship between elevation and plant community structure is weakened when all sites are combined because similar elevations at different sites experience different inundation frequencies and duration."

	Welder Flat Grid 2 Elevation	ANWR Grid 2 Elevation
Batis maritima	0.34	-0.61
Spartina alterniflora	-0.50	—
Monanthochloe littoralis	—	0.71

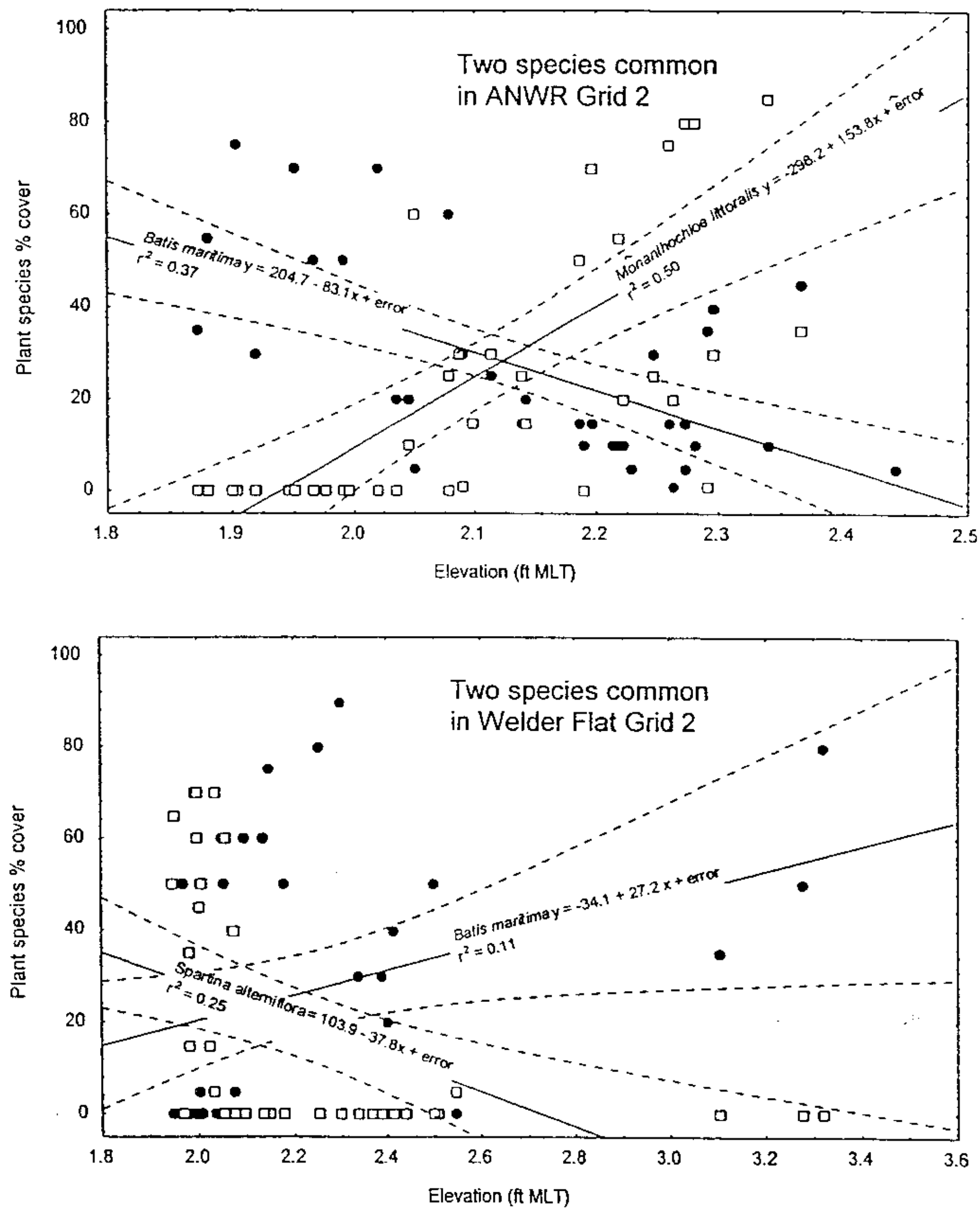


Figure 13. For individual grids (Welder Flat Grid 2 and ANWR Grid 2), data are more consistent with the paradigm linking elevation and plant community structure than is the case when data from all sites are compared. Nevertheless, r^2 values are low, indicating that factors other than elevation play a role in plant community structure. Circles represent *Batis maritima*, while open squares represent *Spartina alterniflora* (bottom) *and Monanthochloe littoralis* (top).

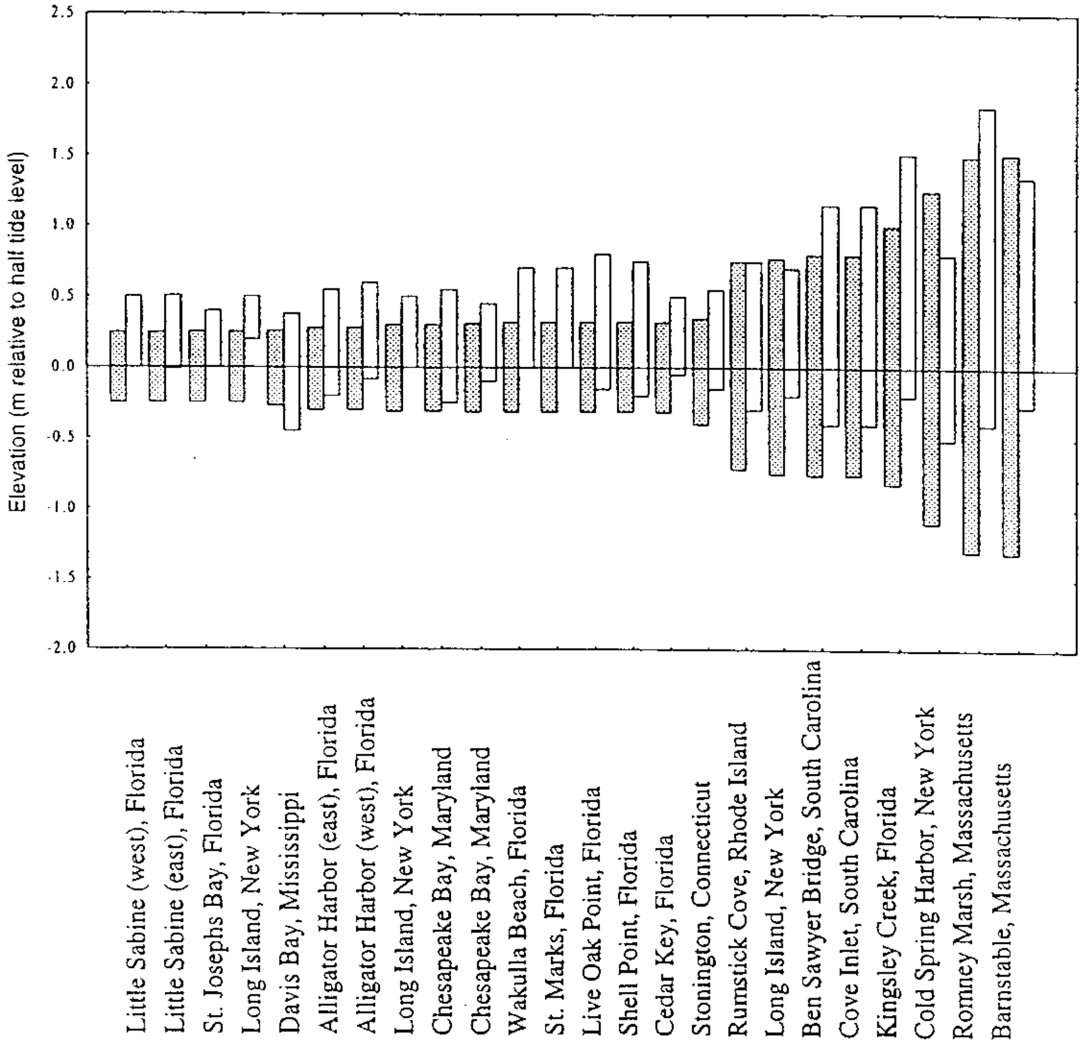


Figure 14. The Mean Tide Range (MTR) (filled bars) and the Growth Range for *Spartina alterniflora* (unfilled bars) from a number of sites around the East and Gulf Coasts. The Growth Range is the range of elevations where *S. alterniflora* occurs. The 0-m elevation is set to the half tide level, midway between mean high water and mean low water. Data are from various published studies. Mean Tide Ranges are based on tide gauge data, while Growth Ranges are from on-site observations using various surveying techniques. Data can be interpreted in at least two ways:

1. *S. alterniflora* growth ranges may vary, relative to Mean Tide Range, at different sites for a number of reasons, such as competitive interactions with other plants, intraspecific genetic differences in *S. alterniflora* from different areas, different soil conditions, and different salinities.
2. Mean Tide Ranges from tide gauge data may not be representative of conditions on the sites where Growth Ranges were measured. Estuarine geomorphology can funnel tides into some areas and restrict tides from other areas, and tidal attenuation will increase as distance from the main body of the estuary increases.

These interpretations are not mutually exclusive, and both may be valid. These data reinforce the limitations of marsh ecology paradigms that strictly link elevation relative to measured tide ranges with plant species distribution. Although similar data are not available for other plant species, the variability seen for *S. alterniflora* occurrence relative to tide ranges is likely to be found for other species as well, and this trend is consistent with field data from the project site. (Adapted from McKee and Patrick 1988.)

variability. (Note that performance standards as currently written will account for the degree of variability found in the field data.)

Landscape-level Geomorphology

As noted earlier in this report, the term "landscape-level geomorphology" is used to describe the geomorphology that can be determined from aerial photographs. A series of 1991 aerial photographs was obtained from Aransas National Wildlife Refuge. Cursory examination of aerial photographs shows that landscape-level geomorphology varies across the project site. For example, water-filled depressions and tidally connected pools make edge-area ratios higher in parts of Welder Flat than in parts of Aransas National Wildlife Refuge (Figure 15). To imitate the variability that exists across the project site, site design should be based on specific locations within the project site, rather than means of statistics summarizing landscape-level geomorphology based on the project site as a whole.

Various statistics that summarize landscape geomorphology, such as pond density and edge:area ratio, were not computed for this study. A study by Rozas and Zimmerman (1994) was identified in which a number of summary statistics were generated from three sites near Galveston Bay, and these statistics are presented in Table 9 for reference purposes. Similar statistics can be generated from project site aerial photographs or DOQQs if needed. Summary statistics will be needed to assess attainment of performance standards, but those statistics should be from recent DOQQs taken after site construction (as per Table 3). For design purposes, direct use of aerial photographs is more desirable than reliance on summary statistics, because summary statistics, which inevitably mask certain information and will not be fully representative of site conditions, may introduce design errors (see Conceptual Design and Detailed Design sections of this report).

Aerial photographs of parts of the project site suggest that at least some of the marsh habitat may be affected by subsidence (especially in parts of Welder Flat), and that open water areas and marshes with high edge:area ratios may reflect the results of subsidence (Figure 15). If open water areas and marshes with high edge:area ratios do reflect the results of subsidence, and subsidence has not stabilized, ongoing subsidence will lead to continued replacement of marsh with open water. Similarly, if created marshes are designed to mimic natural marshes affected by subsidence, created marshes may be replaced by shallow open water habitat over time. The time frame of subsidence at the project site is unknown. Analysis of a time series of aerial photographs, if aerial photographs are available, may indicate whether or not subsidence is in fact occurring and may allow an estimate of rates of marsh loss. Alternatively, installation of sediment-erosion tables (see Cahoon and Lynch 1997) would allow direct estimates of subsidence rates.

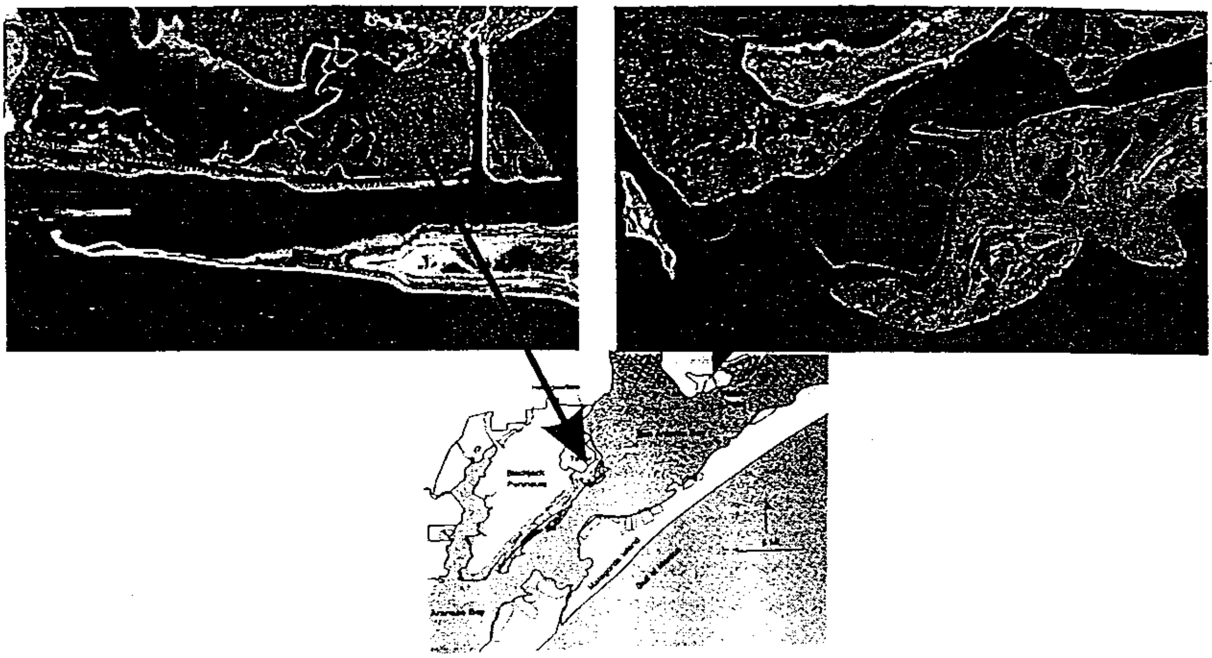


Figure 15. Aerial photographs show significant development of ponds and shallow depressions with few well-developed tidal creeks, especially at Welder Flat (top right). Development of scattered ponds suggests that sites may be undergoing long-term subsidence (see, for example, Gosselink 1984).

Table 9. Statistics summarizing landscape-level geomorphology of three Galveston Bay sites. Summary statistics are based on interpretation of aerial photographs. Adapted from Rozas and Zimmerman 1994.

	Site		
Statistic	Atkinson Island	Hog Island	Cedar Point
Total number of ponds	33	52	20
Total pond perimeter (m)	2,263	3,701	1,703
Total pond area (m^2)	18,389	57,780	14,583
Total number of channels	28	10	17
Total channel length (m)	1,241	1,043	1,037
Total channel area (m^2)	4,760	3,728	6,188
Total cove number	3	1	1
Total cove area (m^2)	79,248	26,377	12,259
Total length of shoreline (m)	8,009	6,489	5,491
Total area of site (m^2)	454,564	263,193	205,093
Total area of upland (m^2)	8,831	9,877	22,427
Total area of marsh (m^2)	343,335	165,430	149,636
Total area of open water (m^2)	102,398	87,886	33,030
Marsh:Open water	3.4	1.9	4.5
Pond density (ponds per ha of marsh)	1.0	3.1	1.3
Channel density (channels per ha of marsh)	0.8	0.6	1.1

III. Testing Vegetation Performance Standards with Field Data

Performance standards described in Table 3 of Section 1 in this report address a number of project features. Monitoring of most of the performance standards relies on standard methods. However, two of the vegetation performance standards suggested during the 3-4 November 1998 ICT meeting rely on methods that require testing. The first of these performance standards called for a similarity index of 0.6 or greater between created and natural marsh sites, based on computation of a similarity index using areal percent cover data from at least 40 1-m^2 quadrats at the created wetland and a nearby natural reference site (see Table 3, including footnotes). The second of these performance standards called for similar patchiness in created and natural marsh sites as determined by achieving mean diversity within 1-m^2 quadrats that is within 50% of mean diversity in natural wetlands, based on mean areal percent cover data from at least 40 quadrats and application of the Shannon-Wiener diversity index (see Table 3, including footnotes).

This section explains the rationale for these performance standards, explains why these performance standards require testing, and tests the performance standards using both actual data from the field and data generated on a computer.

The Similarity Performance Standard

A Primer on Similarity

Similarity indexes have long been used by ecologists to determine the degree to which two sets of samples share a common species list or a common species list and same-species abundances. Similarity indexes form the basis of more complex analyses, such as most forms of classification analyses (clustering) and most forms of ordination (such as Principle Components Analysis, Principle Coordinates Analysis, and Canonical Correspondence Analysis), but they can also be used to generate a similarity matrix that summarizes the degree to which two or more samples are "similar." Similarity indexes typically use an algorithm to generate a value between 0 and 1 for each comparison. Values approaching 0 suggest that the two sets of samples being compared have very little in common, while values approaching 1 suggest that the two sets of samples being compared have a great deal in common. Worded another way, values approaching 0 suggest that the two sets of samples come from different kinds of communities, while values approaching 1 suggest that the two sets of samples come from the same kind of community.

The simplest similarity index, sometimes called Sorensen's Similarity Index or the Coefficient of Sorensen, is based entirely on species lists; that is, the index only considers presence or absence of a species in each sample or set of samples. To compute the Sorensen's Similarity Index for sample sets A and B:

$$S = 2a / (2a + b + c),$$

where S is the Sorensen's Similarity Index, a is the number of species that occur in both sample set A and sample set B, b is the number of species that occur in sample set B but not A, and c is the number of samples that occur in sample set A but not B.

The following simple data set can be used as an example:

	Sample W	Sample X	Sample Y	Sample Z
Species 1	present	present	present	absent
Species 2	present	present	absent	present
Species 3	present	present	absent	present
Species 4	present	present	absent	present

Using presence and absence data from this data set, the following similarity matrix can be generated:

	-Sample W	Sample X	Sample Y	Sample Z
Species 1	-			
Species 2	1	-		
Species 3	0.4	0.4	-	
Species 4	0.86	0.86	0	-

Sample W and X are identical, and therefore have a similarity of 1. Sample Z shares three of four species with W and X, and has a similarity to both W and X of 0.86, suggesting that it is very similar but not the same as Samples W and X (i.e., the value 0.86 is close to 1, so the samples must be fairly similar). Sample Y shares one species with Samples W and X, and its similarity to these samples is only 0.4. Sample Y and Z share no species in common, and therefore have a similarity of 0.

Sorensen's Similarity Index is presented only as an illustration. Performance standards for the created wetlands require use of a quantitative similarity index-that is, an index that can account for both the species identity (which species are present or absent) and the number of individuals, or in this case the areal cover, of each species. An appropriate index for this purpose is the Simplified Morisita Index:

$$S = \frac{2\Sigma X_{ij} X_{ik}}{[(\Sigma X^2_{ij} / N^2_{j}) + (\Sigma X^2_{ik} / N^2_{k})]\, N_j N_k},$$

where S is the simplified Morisita Index, X_{ij} and X_{ik} are the number of individuals of species i in sample j and sample k, N_j is the total number of individuals in sample j, and N_k is the total number of individuals in sample k. The Simplified Morisita Index yields values from 0, for no similarity between samples, to about 1, for complete similarity. Note that many similarity indexes cannot be used with percent areal cover data, because they were designed for count data. The Simplified Morisitas Index is one of the few similarity indexes that can be used with percent areal cover data.

The Simplified Morisita Index value can be interpreted as a ratio of two probabilities:

probability that an individual drawn from sample j and from sample k will be the same species/
probability that 2 individuals drawn from either sample j or k will be the same species

A number of basic ecology text books discuss similarity indexes, including Krebs (1989) and Southwood (1978). In addition, many papers in the scientific literature discuss various similarity indexes and their behavior in different circumstances (for example, see Wolda 1981).

Rationale behind the Similarity Performance Standard

The similarity performance standard is intended to prevent creation of marshes with plant communities dramatically different (in terms of species present and their abundance) from those of natural marshes. Sites 127a and 128 are dominated by *Spartina alterniflora*. Although *Spartina alterniflora* marshes occur in the project area, they do not, in general, cover large areas. Concerns that created marshes might be dominated by *Spartina alterniflora* in particular drove the inclusion of a similarity performance standard.

Why the Similarity Performance Standard needs Testing

It is important to realize that two sets of randomly collected samples from a single community will not be identical to one another. This is because of the natural variability that exists within plant communities. Just as any one randomly selected sample is not going to be identical to any other randomly selected sample, any one set of randomly collected samples will not be identical to any other set of randomly collected samples. As the size of a sample set increases (that is, as the number of samples in the sample set increases), the ability of the sample set to represent the entire community increases. When two relatively small sample sets from the same community are compared, the natural variability in the community is likely to be reflected in a low similarity index value. With a sufficiently large set of pilot data, a self-similarity curve can be generated in which the similarity between progressively larger pairs of sample sets from the same community are compared until the similarity values begin to plateau, indicating that the sampling effort is sufficient to overcome most of the natural variability in the community (see Streever and Bloom 1993). Unless a self-similarity curve is generated, a predetermined sampling effort will have to be accepted, with the assumption that the sampling effort can adequately represent the natural variability of the marsh. While this is not necessarily an ideal approach, it is a commonly adopted approach in sampling design.

Stated more directly, sample size will affect similarity. When all else is equal, smaller sample sizes may yield lower similarity values than larger sample sizes. This is an important point, because low similarity may reflect differences between two communities (for example, between the plant community of a natural wetland and the plant community of a created wetland) or it may reflect variability within a community that is not captured by the sampling effort. However, it should also be noted that in the case of two distinctly different communities, increasing sampling effort will not increase similarity indefinitely. Once the sampling effort is sufficient to adequately capture the variability within a community, increasing sampling effort will not increase similarity values.

Prescribed similarity values are sometimes required as performance standards for compensatory mitigation required on Section 404 permits (see Streever 1999, example 18 in Table 1). The similarity value for these performance standards seems to be arbitrarily set or at least set on the basis of past experience rather than on the basis of well-reasoned analysis or trials with pilot data. In many cases, permits require attainment of specific similarity values but do not specify the required sampling effort or even the similarity index to be used. Similarly, a performance standard for the 50-year DMMP project wetlands was set at 0.6 (that is, a similarity of 0.6 between nearby natural and created wetlands) during the 3-4 November 1998 ICT meeting, based on past experience but without a well-reasoned analysis or trial. Without testing, the value of 0.6 set as a performance standard may be unreasonably high (i.e., it may be higher than the similarity typically seen between two areas of natural marsh sampled using the prescribed 40-quadrat method). Alternatively, the value of 0.6 may be unreasonably low, allowing created marshes that do not have reasonable similarity to natural marshes to meet the performance standard.

Testing the Similarity Performance Standard

Data from the three Aransas National Wildlife Refuge grids, the two Welder Flat grids, and three created data sets were used to test the similarity performance standard. For each grid, areal cover data from 40 1-m^2 quadrats were used. For grids with more than 40 1-m^2 quadrats, the first 40 1-m^2 quadrats were used. Created data sets consisted of cover values for 40 1-m^2 quadrats. "Monoculture" mock data is a created data set in which a single plant species (*Batis maritima*) and bare ground were present, with percent contribution of *Batis maritima* varying from 35% to 95% (with a mean cover of 50%); "monoculture" mock data represents a situation in which a single high marsh plant species survives. "Triculture" mock data is a created data set in which three plant species (*Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*) and bare ground were present, but only one plant species was present in any one quadrat, and with percent contribution of plant cover varying from 35% to 95% within a quadrat (each species had a mean cover of 16.66%, or 50% for the quadrats in which each species occurred); "triculture" mock data represents a situation in which plants are distributed with an unnatural zonation (or an aggregated distribution), as could occur following planting of mixed species. *Spartina alterniflora* monoculture mock data is a created data set in which *Spartina alterniflora* and bare ground were present, with percent contribution of *Spartina alterniflora* varying from 35% to 95% (with a mean of 50%);

Spartina alterniflora mock data represents a situation similar to that which has actually occurred across much of Sites 127a and 128.

Table 10 presents similarity values (Simplified Morisita Index similarity values) between the grids. Similarity values were created using Community Analyses System 5.0 software (Ecological Data Consultants, Inc.). Similarity values ranged from 0.42 to 0.96. Similarity values between the *Spartina alterniflora* monoculture grid and grids with actual field data ranged from 0.42 to 0.74. That is, similarity was not always below the required 0.6 set for the performance standard during the 3-4 November 1998 ICT meeting. Furthermore, several comparisons of actual data for wetlands in the project area also yielded similarity values below 0.6 (for example, Aransas Gird 2 and Aransas Grid 3 had a similarity of 0.48). With this in mind, it would not be reasonable to use the similarity performance standard without some modification.

Part of the reason for high similarity values among all sites was inclusion of the bare ground cover type in comparisons. Bare ground made a substantial contribution to areal cover at all sites, but because it can occur in any plant community its contribution to the assessment of created wetlands may be questionable. Re-analysis of the data with the bare ground cover class excluded was used to generate the similarity matrix in Table 11. With the bare ground cover class excluded, the *Spartina alterniflora* data set has a similarity of 0 to all actual grids except Welder Flat Grid 2, which was the only grid where *Spartina alterniflora* occurred;. comparison of the *Spartina alterniflora* monoculture data and the Welder Flat Grid 2 data was 0.41, lower than the 0.6 value required by the performance standard. However, many of the natural wetland comparisons also failed this performance standard. For example, ANWR Grid 1 and Welder Flat Grid 1 had a similarity value of 0.32, and ANWR Grid 2 and Welder Flat Grid 2 had a similarity value of 0.25.

Even when the bare ground cover class is excluded from the analysis, the similarity performance standard cannot consistently differentiate between comparisons of undesirable, unnatural plant communities and natural plant communities, on the one hand, and pairs of natural wetlands on the other hand. In short, there is little point in using the similarity performance standard.

If the similarity performance standard is abandoned, it should be replaced by a performance standard capable of identifying problems with vegetation community composition. The similarity performance standard was originally advocated (during the 3-4 November 1998 ICT meeting) as a means of preventing *Spartina alterniflora* monocultures, such as that of PA 127a, from being accepted as part of the ongoing wetland creation program. As explained in the following section, the diversity performance standard will prevent acceptance of monocultures of any species, including *Spartina alterniflora.* In addition to relying on the diversity performance standard to prevent acceptance of monocultures, the similarity performance standard was replaced with a performance standard requiring the presence of at least 20% cumulative cover by *Batis maritima, Borrichia frutescens, Monanthochloe littoralis, Salicornia* spp., and/or *Lycium carolinianum,* with the additional requirement that *Lycium carolinianum* should be present at all sites. This performance standard would be met by all transect data and grid data collected during 8-10 December 1998 field visits, but the three mock data sets would all fail. *Spartina alterniflora* monocultures such as those of PA's 127a and 128 would not meet this performance standard. Based on data presented in Darnell et al.'s (1997) Table 5, three additional natural wetlands would pass this performance standard, but PA's 127a and 128 would fail. (Of course, it would be unfair to judge PA's 127a and 128 based on this performance standard, because they were not designed to be similar to nearby natural marshes. They are simply cited here as examples of the kind of created wetlands that would not pass this performance standard.)

In Table 3, the similarity performance standard suggested during the 3-4 November 1998 ICT meeting was replaced with the performance standard stating that "At least 1/5 of total cover (inclusive of bare ground) will be by *Batis maritima, Borrichia frutescens, Monanthochloe littoralis, Salicornia* spp., and/or *Lycium carolinanum*, and *Lycium carolinanum* will be present."

The Diversity Performance Standard

A Primer on Diversity

Biological diversity in the context intended here is a measure of community complexity based on species, or, put another way, the species variability in a community. In a very diverse community, the likelihood of finding the same species in two randomly selected samples is very low. In a community with very low diversity, the likelihood of finding the same species in two randomly selected samples is very high. In a monoculture, which has the lowest possible diversity, every sample will have the same species (that is, every sample will have the only species that occurs in the community).

The simplest measure of diversity is simply species richness, or the number of species that occur in an area. Using this measure of diversity, a community with ten species is considered more diverse than a community with three species. However, this simple approach makes no provision for relative abundance of species. For example, consider two communities, each of which has 10 species and 1,000 individuals. Community 1 has 991 individuals of species a, and one individual representing each of the other nine species. Community 2 has 100 individuals of each species. Based only on species richness, the two communities have the same diversity, but anyone sampling the two communities would probably find Community 2 to be more complex. Also, an organism in Community 2 would tend to have more complex interactions, in the sense that it would have a higher likelihood of encountering different species than would its counterpart in Community 1.

With this in mind, diversity indexes were developed that account for species abundance as well as species

Table 10. Similarity matrix comparing similarity of vegetation grids from project site and three mock data sets. The "monocutlure" mock data set was constructed as a monoculture of *Batis maritima* (mean = 50%) with some bare ground (mean = 50%), such as might occur if only *Batis maritima* survived on the created sites. The "triculture" mock data set was constructed to represent a site with bare ground (mean = 50%) and several monocultures (*Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*, each with a mean of 16.6%), divided across the marsh in such a way that any one quadrat would only sample one species, such as might occur if vegetation grows in clearly defined zones rather than as a mosaic. The *Spartina alterniflora* monoculture data set was constructed to represent a site with only *Spartina alterniflora* (mean = 50%) and bare ground (mean = 50%), similar to parts of the existing created wetlands at sites 127a and 128. The similarity index used was the Simplified Morisita Index (also known as "Horn's Modification of the Morisita Index"), which can be applied to percent areal cover data.

	Aransas Grid 1	Aransas Grid 2	Aransas Grid 3	Welder Flat Grid 1	Welder Flat Grid 2	"Monoculture" Mock Data	"Triculture" Mock Data	*Spartina alterniflora* monoculture
Aransas Grid 1	1							
Aransas Grid 2	0.71	1						
Aransas Grid 3	0.93	0.48	1					
Welder Flat Grid 1	0.77	0.89	0.54	1				
Welder Flat Grid 2	0.77	0.86	0.55	0.91	1			
"Monoculture" Mock Data	0.72	0.79	0.52	0.96	0.86	1		
"Triculture" Mock Data	0.93	0.75	0.81	0.87	0.82	0.79	1	
Spartina alterniflora monoculture	0.55	0.42	0.46	0.49	0.74	0.50	0.6	1

Table 11. Similarity matrix comparing similarity of vegetation grids from project site and three mock data sets, with bare ground cover class data removed. Mock data sets are the same as those described for Table 10, but with the bare ground cover class data removed.

	Aransas Grid 1	Aransas Grid 2	Aransas Grid 3	Welder Flat Grid 1	Welder Flat Grid 2	"Monoculture" Mock Data	"Triculture" Mock Data	*Spartina alterniflora* monoculture
Aransas Grid 1	1							
Aransas Grid 2	0.73	1						
Aransas Grid 3	0.91	0.47	1					
Welder Flat Grid 1	0.32	0.63	0.11	1				
Welder Flat Grid 2	0.25	0.54	0.09	0.81	1			
"Monoculture" Mock Data	0.29	0.53	0.09	0.86	0.65	1		
"Triculture" Mock Data	0.50	0.42	0.48	0.72	0.54	0.56	1	
Spartina alterniflora monoculture	0	0	0	0	0.41	0	0	1

richness. Over time, the Shannon-Wiener Diversity Index (sometimes incorrectly called the Shannon-Weaver Index) became the most popular of the many diversity indexes available. The Shannon-Weiner Diversity Index is:

$$H' = \Sigma (p_i) (\log_{10} p_i) \quad ,$$

where H' is the Shannon-Wiener Diversity Index value and p_i is the proportion of the total sample belonging to the ith species. In this representation of the Shannon-Weiner Diversity Index, base 10 logarithms are used, but base 2 or base *e* logarithms have also been used, and comparisons of Shannon-Weiner Diversity Index values from different studies may need to standardized to a common base. This can be done through standard conversion factors available in many texts. Shannon-Weiner Diversity Index values derived using base 10 logarithms are sometimes reported in units called "decits."

Shannon-Weiner Diversity Index values will range from 0 (for a community with one species) to some larger value, although data from actual community sampling seldom leads to Shannon-Weiner Diversity Index values exceeding about 2 decits.

A number of basic ecology text books discuss diversity indexes, including Krebs (1989) and Southwood (1978). In addition, many papers in the scientific literature discuss various diversity indexes and their behavior in different circumstances (for example, see Hurlbert 1971 and Washington 1984).

Rationale for the Diversity Performance Standard

In many instances, diversity is of interest as a community attribute. For example, the diversity of benthic invertebrate communities can be used as an indicator of water quality; in freshwater streams, relatively high diversity of benthic invertebrates indicates clean water, while low diversity indicates polluted water (to be more precise, high diversity indicates high dissolved oxygen levels, while low diversity indicates low dissolved oxygen levels, which are usually associated with organic sewage in freshwater streams). As a performance standard for wetlands created under the 50-year DMMP, diversity in itself is <u>not</u> of interest as a community attribute. Instead, the Shannon-Weiner Diversity Index is used as a means of assessing the degree to which planted species occur in mixed stands in areas less than 1 m^2.

In natural marshes of the project area, three or more species and bare ground are likely to occur in a single 1-m^2 quadrat. The ICT expressed some concern that marshes planted on dredged material would not have the same level of intermixing of species. In fact, given standard planting techniques of no more than 1-m centers for planting, it seems unlikely that plant communities will have the same degree of intermixing until enough time has passed to allow spread of plants (vegetative spread and spread via seeds) even if initial plantings are intentionally mixed.

To measure the degree of intermixing of species in areas less than 1 m^2, some quantitative index had to be developed. After some consideration, it was suggested that mean diversity could be compared between created and natural marshes to determine if created marshes had the same degree of intermixing that occurred in created marshes. That is, the diversity of each 1-m^2 quadrat of a grid would be computed and a mean diversity for the grid would be computed based on the diversity of all quadrats in the grid. Initially, the ICT suggested that the performance standard should require the mean diversity of created sites to be within 50% of that of natural sites.

Why the Diversity Standard needed Testing

To the knowledge of ICT members, no standard methods are available to assess intermixing of herbaceous plant species on this scale (although various methods are available at other scales). Use of mean diversities in 1-m^2 quadrats as a measure of intermixing of species is a new method. As such, it should not be used without testing.

Testing the Diversity Performance Standard

Data from the three Aransas National Wildlife Refuge grids, the two Welder Flat grids, and three created data sets were used to test the diversity performance standard. For each grid, areal cover data from 40 1-m^2 quadrats was used. For grids with more than 40 1-m^2 quadrats, the first 40 1-m^2 quadrats were used. Created data sets consisted of cover values (cover values were included for each plant species and bare ground) for 40 1-m^2 quadrats. "Monoculture" mock data is a created data set in which a single plant species (*Batis maritima*) and bare ground were present, with percent contribution of *Batis maritima* varying from 35% to 95% (overall mean = 50% cover); "monoculture" mock data represents a situation in which a single high marsh plant species survives. "Triculture" mock data is a created data set in which three plant species (*Batis maritima, Borrichia frutescens*, and *Distichlis spicata*) and bare ground were present, but only one plant species was present in any one quadrat, and with percent contribution of plant cover varying from 35% to 95% within a quadrat (with a mean of 16.66% for each species, or 50% for each species within the quadrats that the species occurs); "triculture" mock data represents a situation in which plants are distributed with an unnatural zonation (or an aggregated distribution), as could occur following planting of mixed species. *Spartina alterniflora* monoculture mock data is a created data set in which *Spartina alterniflora* and bare ground were present, with percent contribution of *Spartina alterniflora* varying from 35% to 95% (with an overall mean of 50% cover); *Spartina alterniflora* mock data represents a situation similar to that which has actually occurred across much of Sites 127a and 128.

Shannon-Wiener Diversity Index values (base 10 logarithms) were computed for each quadrat; thus, there

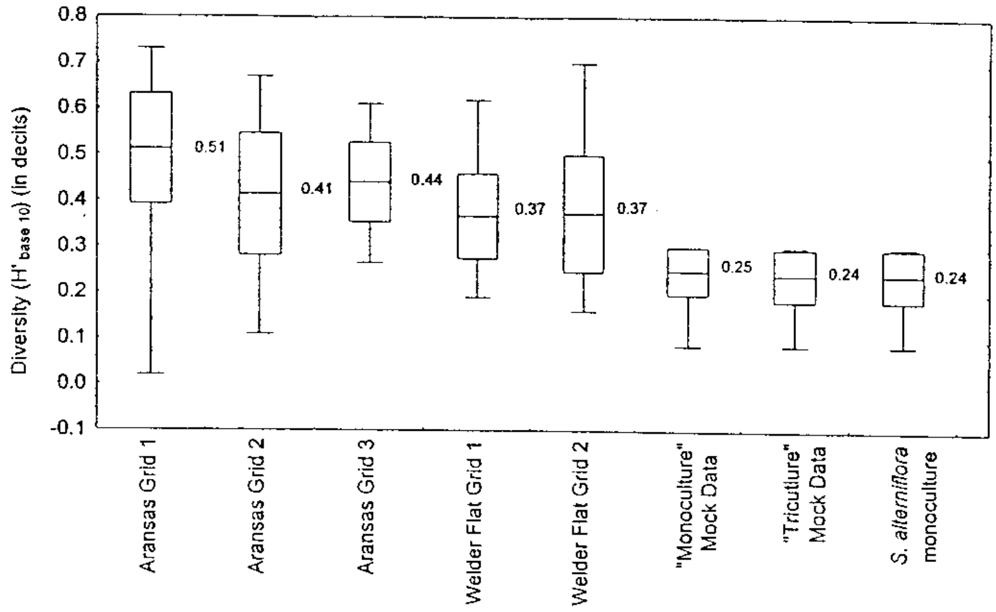


Figure 16. Diversity comparisons of grids and mock data. Horizontal line represents mean diversity, boxes represent standard deviations, and whiskers represent ranges. Means, standard deviations, and ranges are based on 40 1-m^2 quadrats from each grid. The diversity index used is the Shannon-Wiener (also called Shannon-Weaver) diversity index, with base 10 logs. "Monoculture" mock data is a created data set in which a single plant species (*Batis maritima*) and bare ground were present, with percent contribution of *Batis maritima* varying from 35% to 95% (mean = 50% cover by *Batis maritima*); "monoculture" mock data represents a situation in which a single plant species survives. "Triculture" mock data is a created data set in which three plant species (*Batis maritima, Borrichia frutescens*, and *Distichlis spicata*, each occurring with mean = 16.66%) and bare ground were present, but only one plant species was present in any one quadrat, and with percent contribution of plant cover varying from 35% to 95% within a quadrat; "triculture" mock data represents a situation in which plants are distributed with an unnatural zonation (i.e., an aggregated distribution). *Spartina alterniflora* monoculture is a created data set in which *Spartina alterniflora* occurs with cover varying from 35% to 95% (mean = 50%). A comparison of diversity values from the mock data sets with those of the actual data sets shows that mean diversity can act as an indicator of patchiness for assessment of created wetland plant communities.

were 40 Diversity Index values for each grid, and a total of 320 Diversity Index values. Diversity Index values were computed using Community Analyses System 5.0 software (Ecological Data Consultants, Inc.). For each grid, means, standard deviations, and ranges were computed. Summarized Diversity Index values are presented in Figure 16. Mean Diversity Index values for data from actual grids ranged from 0.37 to 0.51, while mean Diversity Index values for mock data, representing situations where species patchiness was less than that of natural marshes, ranged from 0.24 to 0.25. The similarity of Mean Diversity Index values for mock data is not surprising, since diversity in individual quadrats of the mock data sets would have been similar (because no quadrat in the mock data had more than one species and bare ground).

The diversity performance standard initially advocated during the 3-4 November 1998 ICT meeting called for "Similar patchiness in created and natural marsh sites as determined by achieving mean diversity within 1-m^2 plots in created wetlands that is within 50% of mean diversity in natural wetlands." Mean Diversity Index values from mock data sets were not below the 50%-difference threshold required in this performance standard. This performance standard, as initially stated, would not adequately address problems with low intermixing of species. A better performance standard would be "Similar patchiness in created and natural marsh sites as determined by achieving mean diversity within 1-m^2 plots in created wetlands that is within the range of mean diversity in natural wetlands." Based on this assessment, the performance standard was changed as noted here (see Table 3).

IV. Conceptual Design: Self-organizational Theory, Adaptive Management, Planting, Structures, and Coordinating Dredging Cycles

In this section, several issues relevant to design of all sites to be created as part of the 50-year DMMP are discussed. These issues include self-organizational theory, adaptive management, planting, structures, and coordinating dredging cycles.

The U.S. Army Corps of Engineers and others have been creating marshes on dredged material and other substrates for three decades (see, for example, Kusler and Kentula 1990, Landin et al. 1989). During this time, a great deal has been learned from both experience with marsh creation projects and research. Approaches to wetland creation are still evolving, as are generally accepted beliefs regarding the acceptability of end products and the certainty with which project outcomes can be predicted. For example, a salt marsh that was created on dredged material in the early 1970s may have been considered a resounding success, but by today's standards the same marsh may be considered little more than a marginal success. In the past, establishment of a plant community that resembled natural marsh plant communities frequently constituted a success. Currently, for a created marsh to be considered successful it should 1) support a plant community that is similar to natural marsh plant communities, 2) support invertebrate and vertebrate (fish and bird) communities similar to those of natural marshes, 3) have soils with characteristics similar to those of natural marshes, and 4) have a geomorphology similar to that of natural marshes, including occurrence of tidal creeks and pools and the absence of high ground.

This section summarizes a number of issues that will affect the design of all wetland sites to be created as part of the 50-year DMMP. Information in this section is drawn from the scientific literature as well as experience with existing sites. Experience from sites created near the Aransas National Wildlife Refuge is emphasized. These sites include three wetlands created by Mitchell Energy Corporation (MEC) in 1991, 1993, and 1995, and two sites created by the US Army Corps of Engineers in 1993. The MEC sites were built by placing dredged material inside of earthen dikes protected by articulated concrete mattresses near Mesquite Bay, about 60 m from Bludworth Island (at N 28^{0}09.337', W 96^{0}52.756'). Wynne Channel, near the northeast end of Bludworth Island, and a nearby drilling basin were the sources of dredged material for the MEC sites (Darnell et al. 1997). In general, grain size of the dredged material used to create the MEC sites was larger than the grain size that is expected in material resulting from maintenance dredging of the Gulf Intracoastal Waterway in the project area. The two sites created by the US Army Corps of Engineers, Sites 127a and 128, were constructed using material from maintenance dredging of the Gulf Intracoastal Waterway. Site 127a, located near False Live Oak Point in San Antonio Bay (at N 28^{0}13.540', W 96^{0}47.320'), was created by pumping dredged material into an area confined by an earthen dike and protected by a riprap breakwater. Site 128, located about 1 km northeast of Rattlesnake Island in Ayers Bay (at N 28^{0}12.763', W 96^{0}48.856') was created by pumping dredged material into an area confined by geotextile tubes and an existing dredged material island. Because Sites 127a and 128 were created from sediment that is similar to that which is expected to result from further proposed maintenance dredging, they provide a reasonable model for sites that will be built as part of the 50-year DMMP in terms of sediment characteristics. However, portions of the vegetation communities of Sites 127a and 128 are dominated by *Spartina alterniflora*, and are not representative of the desired plant communities for wetlands planned as part of the 50-year DMMP, apparently because elevations at Sites 127a and 128 are too low to support high marsh species such as *Batis maritima*, *Borrichia frutescens*, and *Lycium carolinianum*. In the relatively high elevations of Sites 127a and 128, as well as high elevations of the MEC sites, high marsh species do occur.

Self-organizational Theory and Site Designs

The definition of "success" and ways of measuring "success," in the context of wetland creation, is an area of ongoing discussion within the scientific and conservation literature. For the wetlands established as part of the 50-year DMMP, success will be assessed on the basis of performance standards established by the ICT and described in Section 1 of this report. Nevertheless, discussion of William Mitsch's (Mitsch and Wilson 1996) theory of self-design is warranted here because it is relevant to site design, and especially to those parts of site design related to site topography and planting strategies.

Attitudes about wetland creation can be categorized along a continuum. At one end of this continuum is the "designer" approach, in which sites are planned, constructed, planted, and maintained as static systems, intended to duplicate a particular initial vision. At the other end of this continuum is the "self-design" or "self-organizational" approach, in which initial conditions are established at a site and sites evolve over time in response to natural colonization by plants, erosion and deposition of material, and other events. The designer approach can be likened to gardening or landscaping, while the self-organizational approach can be likened to old field succession (i.e., development of a forest in an abandoned pasture). In reality, most wetland restoration and creation projects adopt an attitude that is somewhere between the designer and the self-organizational approach, and the marsh creation projects that are part of the 50-year DMMP are no exception.

How do these theoretical approaches or attitudes translate to practical matters? If the 50-year DMMP projects strictly follow the designer approach, sites would be created so that a stable topography was present before planting was undertaken, and plant species would be allocated across the created sites in zones believed to provide suitable conditions for these plant species. Detailed site designs, including vegetation communities, would be designed on paper before site construction, and considerable effort would be expended in matching actual site conditions to detailed designs, including activities such as post-compaction contouring, planting, and excavation of tidal channels and pools. On the other hand, if the 50-year DMMP projects strictly follow the self-organizational approach, designs would call for little more than placement of dredged material at an elevation approximating that of nearby natural salt marshes. No detailed site designs would be prepared, and site characteristics would develop on their own, including characteristics such as contours and plant community structure. Along the Texas coast, including the project area, there are numerous examples of old dredged material sites that were not planned as wetlands but that are at least superficially similar to natural wetlands. The existence of these sites suggests that it is possible and even likely that reliance on a self-organizational approach will result in at least some marshes that are similar to natural marshes, but development may take years or decades and not all sites will develop to be similar to natural marshes. Furthermore, even though some old dredged material sites appear to be similar to natural marshes, development of specific features, such as tidal creeks, tidal pools, and irregular marsh edges (rather than straight marsh edges), seldom occurs.

By following a path that is somewhere between the designer approach and the self-organizational approach, the chance of meeting performance standards without incurring unnecessary costs is maximized. With this in mind, there will be no detailed site plans indicating the exact locations of tidal creeks, depressions, and vegetation community boundaries. Instead, plans will show:

- a general site outline (corresponding in part to earthen dikes or other structures required to confine dredged material);
- approximate boundaries and elevations of two plant communities, a relatively low-lying Spartina alterniflora monoculture, and a high marsh community consisting of a mix of *Batis maritima*, *Borrichia*

frutescens, *Distichlis spicata*, *Lycium carolinanum*, *Monanthochloe littoralis*, and *Salicornia virginica* (additional species, such as *Spartina patens* and *Paspalum distichum*, may be used to stabilize earthen dikes);

- guidelines for planting;
- an overlay of an aerial photograph of a nearby natural marsh, showing the general distribution of tidal creeks, depressions, and vegetation boundaries, but with the understanding that actual tidal creeks and depressions will follow contours that result from differential settling and erosion of dredged material with limited or no post-placement contouring, and that actual vegetation community boundaries will develop and change over time in response to environmental conditions and ecological interactions (i.e., factors similar to those that affect vegetation community development in natural marshes);
- temporary physical structures (including elevations) required for confinement of dredged material (such as earthen dikes) and an approximate time line for contouring of confinement structures to the level of the marsh; and
- permanent physical structures (including elevations) needed for protection from wave energy.

Adaptive Management

Adaptive management is a form of natural resource management that is responsive to ongoing developments and that is not locked into a pre-established plan. Although the phrase "adaptive management" is somewhat new, adaptive management is a common sense approach that has been practiced throughout history by farmers, business managers, and others who have to make decisions on the basis of incomplete information in a dynamic environment. Although wetland creation undertaken as part of the 50-year DMMP is driven by the goals and objectives established during the 3-4 November 1998 ICT meeting, these goals and objectives may be changed in response to various develpments. As noted in Section 1 of this report:

> ". . . Table 3 [the table of goals, objectives, performance standards, monitoring methods, and remedial actions] should be revisited periodically by the ICT as the DMMP is implemented. Problems with project design, changes in technology, changes in the perceived desirable characteristics of created wetlands, or other developments may arise that will render some or all of the information in Table 3 obsolete. However, revision of goals, objectives, performance standards, monitoring methods, and remedial actions should not be taken lightly. Experience has shown that people can lose sight of guidelines midway through projects or after projects are completed, and that periodic review of guidelines can prevent wasted effort and contentious claims of success or failure. ICT members agreed that changes to goals, objectives, performance standards, monitoring methods, and remedial actions should be specifically approved by the ICT."

Goals, objectives, performance standards, monitoring methods, and remedial actions recorded in Table 3, along with conceptual and detailed designs presented in this report, will guide management of this project, but with the concurrence of the ICT this guidance can be altered as needed to adapt to new information or perceptions.

Planting

This section provides a discussion of the rationale used to develop the suggested planting scheme, as well as a text box summarizing planting guidelines.

Salt marsh plants frequently colonize dredged material islands without active planting. Even when planting is undertaken, natural recruitment subsidizes planting efforts, leading to increased densities of vegetation, introduction of species that were not intentionally planted, and possibly increased genetic diversity. However, active planting programs are generally believed to accelerate development of plant communities similar to those that occur in natural salt marshes. This is especially true for sites that may be isolated or partly isolated from sources of seeds, such as sites surrounded by earthen dikes designed to confine dredged material. Also, active planting may prevent a single species from becoming established and excluding other species for an indefinite period, a phenomenon described in initial floristics theory (Egler 1954). Within the 50-year DMMP salt marsh creation program, there is scope for experimental trials of natural recruitment, but in general plans should include establishment of plant communities through a planting program.

Planting Methods

The U.S. Army Corps of Engineers and others have experimented with many salt marsh planting methods, including use of seeds, use of sprigs (individual plants or parts of plants, including root stock and stems, grown in nurseries or harvested from donor marshes), use of plugs (cores of plant and soil material, both transplanted directly from a donor marsh to the created site and transplanted from a donor marsh to a nursery before being transplanted to the created site), and use of containerized plants grown in nurseries. Most experimental work has focused on *Spartina alterniflora* plantings, but *Spartina patens, Batis maritima, Borrichia frutescens, Distichlis spicata, Lycium carolinanum, Monanthochloe littoralis,* and *Salicornia virginica* have all been established on dredged material and limited experimental data are available for some of these species.

Seeding: Sowing seeds of *Spartina alterniflora* has led to mixed success. Although sowing of seeds has been shown to be the most economical approach for establishment of *Spartina alterniflora* under some conditions (Woodhouse 1979), in areas subjected to frequent flooding by tides (that is, the lowest vegetated elevations of *Spartina alterniflora* marshes) seeds appear to wash away before plants take root. At slightly higher elevations, seeding has been more successful (see, for example, Webb et al. 1984 for an example from Bolivar Peninsula, in Galveston Bay, Texas). However, on the 50-year DMMP sites, active establishment of *Spartina alterniflora* will focus primarily on low areas along the edges of dredged material sites; most areas with slightly higher elevations, where seeding has been more successful, will be planted with high marsh species. The only exception to this may be around the edges of depressions that occur at higher elevations and that hold water trapped during extreme high tides or that hold rain water; these depressions are known to support *Spartina alterniflora* on natural salt marshes in the area, and it may be useful to seed some of these areas with *Spartina*

Planting Guidelines Summary

1. The most certain route to successful establishment of the targeted plant community is through transplanting of sprigs, harvested from nearby donor marshes. Sprigs should be transplanted to 1-m centers. *Spartina alterniflora* should be planted at the lowest vegetated elevations and around depressions that retain tidal water at relatively high elevations, while a mix of high marsh species (*Batis maritima, Borrichia frutescens, Distichlis spicata, Lycium carolinanum, Monanthochloe littoralis,* and *Salicornia virginica*) should be planted at higher elevations. Elevations for these two "zones" should be determined by surveying plant elevations at natural reference wetlands occurring close to each 50-year DMMP site. Natural reference wetlands should also have tidal exposure similar to that of the planned 50-year DMMP site. As noted elsewhere in this report, the same species can occur across a wide range of elevations in the project area, but this range decreases when individual sites are considered. Therefore, cost-effective planting will require knowledge of plant species elevation ranges under conditions found at nearby natural reference wetlands with exposure similar to that of the site being planted. To use this information effectively, elevations of the dredged material sites and nearby natural reference sites will have to be known with reasonable precision (at least ±5 cm). Once a benchmark is established at dredged material sites, a laser level can be used to insure that elevations and species are appropriately matched. Species mixes should be determined based on species mixes at a nearby natural reference marsh. To the degree possible, the combination of species mix and elevations at the nearby natural reference marsh should be duplicated at the dredged material site. Follow-up monitoring should be used to determine if all species survive and spread after transplanting at similar rates. Species mixes should be adjusted to account for differential survival and spread. Species mixes should not be determined based on species availability at the donor marsh.

2. Dramatic cost savings can be realized if plant spacings can be reduced from 1-m centers to 2-m centers or greater. It will be useful to undertake trials on the first sites to be planted to determine if spacing can be increased from 1-m centers without dramatically altering plant community density or structure after two years of growth. Standard agricultural experimental designs (ANOVA designs) should be used to test the effect of spacing.

3. Cost savings can be increased further if plants can be established from seeds. It will be useful to undertake trials on the first sites to be planted to determine if seeding can be used successfully to establish plant communities. Standard agricultural designs (ANOVA) designs should be used to test the viability of seeding. Results of hydroseeding and aerial broadcast seeding (if space is available for reasonably large plots) should be compared to establishment via transplanting.

alterniflora.

Spartina patens can be established by sowing seeds provided that the area to be seeded will not be flooded by high tides before plants can establish roots (Webb et al. 1984). However, storm events or sustained winds can drive tidal levels to high marsh elevations, where *Spartina patens* is found, during any time of the year at the 50-year DMMP sites (see Figure 5). With this in mind, it would not be prudent to rely exclusively on sowing seeds as a method of establishing *Spartina patens*.

For high marsh species other than *Spartina patens*, (*Batis maritima*, *Borrichia frutescens*, *Distichlis spicata*, *Lycium carolinanum*, *Monanthochloe littoralis*, and *Salicornia virginica*), experimental seeding could be considered, especially if costs of planting plugs or sprigs is prohibitive. Seeding appears to be a common means of natural establishment for *Batis maritima* in the project area. However, because seeding is not routinely used for high marsh species, it should be undertaken experimentally, with the understanding that planting of plugs or sprigs may be needed if seeding fails. Also, it should be noted that seeding is not likely to succeed because of the combination of typical weather conditions and tidal levels in the project area: seeds need moisture to germinate and survive, so seeding is most likely to succeed during periods of reasonably high rainfall, but periods of reasonably high rainfall in the project area coincide with high tide levels, which would wash seeds away. With all of these points in mind, large-scale experimental seeding should not be undertaken unless small-scale experimental seeding indicates that success is possible.

Several methods of seeding are possible, including hydroseeding, broadcast seeding, mechanical direct seeding, and hand direct seeding:

- Hydroseeding is spreading of seeds in a slurry. Fertilizer and mulch can be added to the slurry. Stabilizers or binders that protect the soil surface from erosion and bind the seed to the sediment surface can also be added to slurries. Hydroseeding can be accomplished from boats (including airboats) or from equipment stationed on dikes, and is frequently used to vegetate sites where access is difficult, as will be the case on the soft sediments that will be characteristic of the 50-year DMMP sites. Adding mulch to the slurry at a rate of 5.5 kg/ha or more may result in improved moisture retention across the site, and therefore lead to improved germination and survival. However, if the site is inundated by high water before seedlings are well established, both mulch and seedlings are likely to be washed away.
- Broadcast seeding is the spreading of dry seeds over the soil surface. Broadcast seeding is sometimes followed by mechanical rolling or other methods intended to increase contact between soils and seeds. Seeds can be broadcast from tractor-mounted seeders, from aircraft, or by hand. Use of tractor-mounted seeders will probably not be practical at the 50-year DMMP sites because sediments will probably not support the weight of a tractor. Aerial seeding may offer a viable alternative, depending on costs. However, aerial seeding will result in seeds having poor contact with sediments,

which may reduce germination and survival rates. Broadcast handseeding is probably of limited usefulness because of labor costs and site size; however, broadcast handseeding may be useful in specific areas and situations, such as around depressions at higher elevations where patches of *Spartina alterniflora* are to be planted.

- Direct seeding is the placement of seeds directly on the site at specified locations and specified depths in the soil. In mechanical direct seeding, drills or modified planters (modified from planters used for soybeans, corn, or cotton) can be used. Drills would not be necessary or appropriate for the soft dredged material that will comprise the 50-year DMMP sites. Mechanical direct seeding with modified planters is probably not a good option for the 50-year DMMP sites for at least two reasons. First, soft sediments may make access with equipment difficult or impossible. Second, a species mix will be used on the site, and modified planters may not function well with seeds of different sizes and shapes (seeds could be separated in the planter, leading to an undesirable patchiness of vegetation).
- Direct hand seeding is placement of seeds directly into the soil at the desired depth. Unlike broadcast seeding by hand, direct seeding by hand increases the contact between seed and soil and does not require follow-up rolling or other approaches to increase contact between seeds and soil. However, it is labor intensive, and probably does not offer enough cost reduction relative to use of plugs to justify the increased risk of failure.

If seeding is used, it should be noted that pregermination requirements must be met to increase seed viability. Falco and Cali (1977) summarize pregermination requirements for *Spartina alterniflora* and *Spartina patens*. Pregermination requirements for other species are poorly known. Also, it should be noted that seed availability is unknown for high marsh species, but that it is unlikely that viable seeds for all species would be available at the same time during the year. Unavailability of all seeds at the same time will add to logistical difficulties and costs of seeding.

Because little is known about pregermination requirements or seed viability, high densities of seeds should be used with any of the methods discussed above. A reasonable starting point for seed densities is 200 seeds per square meter. This density can be adjusted based on the results of experimental seeding, if experimental seeding is undertaken. Assuming that germination and survival rates are similar for all species, relative numbers of seeds for different species should be based on relative areal cover of species found on nearby reference marshes. However, it is unlikely that germination and survival rates are similar for all species, and results of experimental seeding, if it is undertaken, should be used to adjust species ratios in seed mixes.

Timing of seeding should coincide with optimal weather and tidal conditions. If experimental seeding is undertaken, seeds will have to be collected, treated for pregermination, and stored until optimal conditions are available. Appropriate storage methods for seeds of high marsh species are poorly known; experimental trials will be needed to determine appropriate storage methods.

In short, if seeding is used, it should be used experimentally with the understanding that it may result in total failure and a need for planting using some other method, such as transplanting of plugs or sprigs. Seeding methods with the greatest possibility of success, in terms of lowering planting costs and leading to rapid development of a salt marsh, are hydroseeding and aerial broadcast seeding. If seeding is seriously considered, experimental seeding should be undertaken using standard agricultural plot experimental designs comparing hydroseeding, aerial broadcast seeding, and other methods of plant establishment, as well as different seed densities.

Transplanting: Plants can be obtained as plugs by coring into existing marsh, and plugs can be separated into sprigs, or individual ramets (i.e., individual "plants"), from plugs. This approach was used with reasonable success at the Mitchell Energy marsh creation sites, as well as at Sites 127a and 128 (personnal communication, Tom Stehn and Charles Belaire). Plants obtained from sandy substrates may be more easily separated than plants obtained from finer substrates. Plants should be collected from areas similar (in terms of tidal and salinity ranges) to the planned created marsh. After collection, plants should be kept moist and replanted within 24 hours of collection.

Past experience suggests that a substantial number of plants can be collected from donor marshes without causing long-term damage to donor marshes (personal communication, Tom Stehn and Charles Belaire). Nevertheless, the effect of plant collection on the donor marsh should be closely monitored, and collection methods should be altered or abandoned if donor marsh recovery is slow. ICT members and land managers should be consulted regarding the acceptability of collection of plants and recovery rates of donor marshes.

Previous plantings in the project area have relied on densities of one plant per m^2 (personal communication, Charles Belaire), or 4,047 plants per acre. Spread by rhizomatous growth and establishment of plants by naturally occurring seeding generally fills in sites planted at this density within 2 years or less under normal conditions. Unusual conditions, such as sustained drought, can increase the time needed for complete vegetation of sites or lead to a need for replanting. Planting in densities of one plant per m^2 has become common practice for high marsh species at other sites in U.S. coastal waters. However, experimental plantings undertaken at different densities suggest that it may be possible to rely on lower planting densities. For example, planting trials at Atkinson Island, in Galveston Bay, Texas, led to the suggestion that planting of *Spartina alterniflora* on 11-m centers was more cost effective than other planting densities, including 0.9-, 1.8-, 3.6-, and 7.3-m centers. In all cases, 60% cover was attained by the end of the second growing season (White et al. 1998). It should be noted that the Atkinson Island setting offered good conditions for establishment of plants by seed, because it was protected from tidal flooding and is in an area that often receives sufficient rainfall for seedling establishment. Thus, at least part of the reason for successful establishment after two growing seasons with widely spaced planting can be attributed to seeds germinating on bare ground between transplants.

No attempt has been made to test lower densities of planting in the vicinity of the 50-year DMMP sites or with the high marsh species that will make up most of the planting effort at the 50-year DMMP sites. Because considerable cost savings could be realized if lower planting densities are successful, experimental trials of lower densities may be justified in the 50-year DMMP sites. For example, reduction of planting densities from 1-m centers to 2-m centers would result in a 75% reduction in the number of plants required, leading to dramatically lower costs and lower impacts to donor marshes. If experimental planting is undertaken, standard agricultural plot experimental designs should be used to compare different densities.

Timing of planting can be critical to successful establishment of a salt marsh plant community. Optimal timing for planting of plugs or sprigs appears to be in early autumn, just before the onset of autumn high water (personal communication, Charles Belaire). However, planting should not be undertaken while the marsh surface is under water. Also, planting should not be undertaken during periods of drought, because survival of planted stock will be low. Lastly, planting should not be undertaken until dredged material has dewatered for several months. In general, it should be possible to plant sites within six months of dredged material placement. Within these constraints, timing of planting should be flexible enough to provide planting contractors with the opportunity to use their professional judgement and to work within logistical constraints.

Genetic Integrity of Planted Stock

A number of U.S. Army Corps of Engineers Districts have guidelines that limit use of seeds and transplant stock from areas beyond a prescribed radius from the restoration site. This radius is usually set at between 50 and 200 miles. These guidelines are intended to insure that the genetic integrity of planted sites is similar to that of nearby natural sites. That is, these guidelines are intended to prevent introduction of individual plants that are genetically distinct from local plants. There are no research results to support use of a specific radius for any plant species. However, current research using amplified fragment length polymorphism (AFLP) technology (a method of looking at DNA signatures) indicates that sites planted with imported *Spartina alterniflora* maintain a unique DNA signature for at least several years following planting (Streever, unpublished data). Anecdotal information and a number of published scientific papers suggest that genetically distinct *Spartina alterniflora* plants respond differently to various environmental conditions.

Little information is available for plant species other than *Spartina alterniflora*, but basic principles of population genetics suggest that concerns regarding regional genetic integrity should apply to high marsh species.

In many created wetland sites, plant stock is imported from outside the immediate project area, primarily because plant suppliers cannot provide local stock. For example, a dredged material wetland in Mobile, Alabama, was planted with stock from Virginia. Furthermore, a number of sites in Texas, and particularly around Galveston Bay, have been planted with the Vermillion strain of *Spartina alterniflora* (for example, the Atkinson Island demonstration project and parts of the Bayland Marina site in Galveston Bay are planted with *Spartina alterniflora*). The Vermillion strain of *Spartina alterniflora* was originally harvested in Louisiana and is now available from nurseries in Texas. Proponents of the use of Vermillion strain *Spartina alterniflora* believe that it is resistant to infections that sometimes plague stands of *Spartina alterniflora* and that it grows more quickly than most other *Spartina alterniflora*. However, no data are available on belowground (root mat) growth of Vermillion strain *Spartina alterniflora*, and no comparative data are available on the performance of Vermillion strain *Spartina alterniflora* under various environmental conditions. With all of this in mind, it would not be prudent to use Vermillion strain *alterniflora* on the 50-year DMMP sites. If Vermillion strain *Spartina alterniflora* is used, it should be used experimentally. Follow-up measurements of experimental planting should include assessments of belowground biomass measurements, since root mats protect dredged material marshes from erosion.

Guidelines for planting of 50-year DMMP sites that are presented in this report call for use of transplants or seeds collected near the planned 50-year DMMP sites (see text box "Planting Guidelines Summary"). If these guidelines are followed, there is little risk of establishing sites with compromised genetic integrity. However, if planting is undertaken using other approaches, issues related to genetic integrity should be considered.

Soil Nutrient Conditions and Fertilizers

Past marsh creation at Sites 127a and 128 and the Mitchell Energy sites have resulted in successful establishment of vegetation on a variety of dredged material substrates, including maintenance dredged material, in the vicinity of the planned 50-year DMMP sites. These successes suggest that planting will be possible on dredged material in the project area, and that soil testing may not be necessary. However, inexpensive soil testing for macronutrients (phosphorus, nitrogen, and potassium) and other soil conditions (pH, salinity) is available. Soil testing may identify suboptimal conditions in specific areas that could be rectified through addition of soil amendments or fertilizers. Soil testing should be considered for all areas, and should be used in areas where plant establishment fails.

A number of researchers have assessed the use of fertilizers in dredged material wetland planting (see, for example, Woodhouse et al. 1972, Garbisch et al. 1975, Webb et al. 1984). Some results suggest that fertilizer can increase growth rates, but there is no evidence that suggests a need for fertilizers. That is, fertilizer may lead to more rapid plant growth, but plants grew on dredged material with or without fertilizer. Also, at least one fertilizer trial appeared to result in plant stress (Webb et al. 1984). With this information in mind, fertilizer should not be routinely used as part of the 50-year DMMP planting program. However, experimental fertilizer trials may be warranted, especially in areas with poor plant growth. Also, if soil tests indicate deficiencies in macronutrients, use of fertilizers should be considered.

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