Establishment of Vegetation for Shoreline Stabilization in Galveston Bay

by
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The objective of this study was to determine which resident species of plants adapted to saline conditions can be used to control shore erosion in bays or estuaries.

Water salinity and soil physical and chemical characteristics were determined at the experimental planting sites at East Bay near Galveston, Texas. The soil was loam or clay-loam texture and was structurally unstable and subject to wave erosion. Soil salinity varied from 2,500 to more than 12,000 parts

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20. Abstract (Continued)

per million and water salinity from below 2,500 to 18,000 parts per million.

Twelve plant species were selected for evaluation of their ability to stabilize the shoreline. Giant reed (*Arundo donax*) is effective in the upper zone (above MHW). Black mangrove (*Avicennia germinans*) can establish in the middle zone (MLW to MHW) and lower zone (below MLW). Saltgrass (*Distichlis spicata*) may be used in the middle zone if wave action is low at planting time. Gulf cordgrass (*Spartina spartinae*) is adapted for use in the upper zone and smooth cordgrass (*Spartina alterniflora*) is well adapted for use in the middle and lower zones. Several combinations of species are suggested for different zones.

An inexpensive wave-stilling device to protect plantings from wave action is described.

PREFACE

This report is published to assist coastal engineers in shoreline stabilization through the establishment and maintenance of vegetation. The techniques for shoreline stabilization with vegetation discussed in this report are applicable to other low-energy estuarine areas. The work was carried out under the coastal ecology research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by J.D. Dodd, Professor of Range Science, and J.W. Webb, Research Assistant in Range Science, Texas A&M University, under CERC Contract No. DACW72-74-C-0002. Support was also received from the Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas 77843.

The authors express appreciation to personnel of the Anahuac National Wildlife Refuge, particularly Mr. Russel Clapper, Manager, for their cooperation; and to W.G. McCully for his advice and encouragement in the initiation of these studies. Special thanks are due A.T. Weichert and B.H. Koerth for their assistance in the field work; and to D.W. Woodard, CERC, for his advice and encouragement throughout the course of this study.

Comments on this publication are invited.

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JAMES L. TRAYERS
Colonel, Corps of Engineers
Commander and Director

CONTENTS

TABLES

CONTENTS

TABLES - Continued

CONTENTS

TABLES - Continued

FIGURES

CONTENTS

FIGURES - Continued

ESTABLISHMENT OF VEGETATION FOR SHORELINE STABILIZATION IN GALVESTON BAY

by

J. D. Dodd and J. W. Webb

I. INTRODUCTION

1. Purpose of Study.

Texas has 1,800 miles of bay and gulf shorelines and 2,100 square miles of shallow bays and estuaries. This coastal zone is inhabited by nearly one-third of the population of Texas and nearly one-third the total industry in Texas (Fisher, et al., 1972). Thus, a considerable concern exists for a solution to the shoreline erosion problem in the Texas gulf coast zone.

Structural solutions to eroding shorelines are expensive in cost and environmental impact. Use of vegetation to stabilize eroding shorelines should be less costly and of greater benefit to marine organisms, birds, and the associated environment than structures. Natural establishment of vegetation along the shorelines of Galveston Bay seems to be prevented by wave action. Thus, artificial revegetation is necessary.

This study was started to characterize available endemic plant materials and to determine growth requirements for establishment on representative shoreline sediments along the upper Texas coast. The four specific objectives were: (a) to isolate candidate planting materials known or believed to have utility for shoreline stabilization; (b) to field test candidate planting materials on sites typical of shorelines along the upper Texas coast; (c) to refine present knowledge on germination requirements, planting technology and stand management of selected plants; and (d) to compile a preliminary performance estimate equating time requirement and accomplishment for particular operations.

2. Previous Work.

Few reports are available on the establishment of vegetation along coastal shorelines. Two reports, Phillips and Eastham (1959) and Sharp and Vaden (1970), describe the sloping and planting of shorelines along tidal rivers in Virginia. These plantings were only partially successful. Sharp and Vaden concluded that smooth and salt meadow cordgrasses were the best adapted plants for stabilizing this eroding beach area. Other reports have dealt mainly with stabilization of dredged material and creation of salt marshes. Larimer (1968) reviewed the literature and discussed the possibilities for creating salt marshes in the estuaries of the Atlantic and gulf coasts but did no field work.

Chapman (1967) reported on attempts to vegetate a dredged-material island in Galveston Bay with sod, rhizomes, and seeds of *Spartina alterniflora*. Seed germination was not satisfactory, but transplants did appear to establish and spread. Woodhouse, Seneca, and Broome (1972) examined some of the aspects of reproduction, propagation, establishment, and growth of smooth cordgrass on dredged material in North Carolina. They concluded that establishment on some areas was possible with either seeds or transplants. However, transplants were more adaptable to a wider variety of conditions. Germination response of *Spartina alterniflora* to temperature and salinity as well as seedling response to salinity by three height classes was also investigated in North Carolina by Mooring, Cooper, and Seneca (1971). Broome, Woodhouse, and Seneca (1973) reported on the propagation and mineral nutrition required for establishment of *Spartina alterniflora*. They reported that productivity was probably limited by nutrient supply.

Research on establishment of vegetation on dredged material in San Francisco Bay was reported by Mason (1973). He found, based on the physical and chemical characteristics of the dredged material, that it was not a good growth medium for marsh plants. However, the root system of *Spartina foliosa* converted the anaerobic soil to aerobic soil and survived. Garbisch, Woller, and McCallum (1974) investigated salt marsh establishment and development on shores and dredged materials in the mid-Chesapeake Bay region. They reported no limitations for vegetation establishment above mean high water. Establishment of *Spartina alterniflora* in intertidal zones was restricted by wave action and coarse sediment stresses. Similarly to Woodhouse, Seneca, and Broome (1974), they reported increased production by *Spartina alterniflora* with fertilizer treatments. A review of available information on the establishment of marsh and aquatic plants on newly available substrates was compiled by Kadlec and Wentz (1974).

II. DESCRIPTION OF AREA

The shoreline of Texas consists of both a gulf shoreline and a bay shoreline. The bay shoreline generally lacks sand beaches and in many places is associated with low-lying marshes. Low bluffs exist wherever wave action has eroded the Pleistocene terrace deposits. Estuaries and consequently bay shorelines originated from the drowning of entrenched valleys as the sea level rose in the late Pleistocene age. Some estuaries filled, and deltaic plains formed at mouths of the Rio Grande, Brazos, and Colorado Rivers. A series of barrier islands have formed from the sediment in many areas along the coast. Smaller streams, i.e., the Nueces and San Jacinto Rivers, flow in narrow valleys and empty into bays or estuaries behind these barrier islands (LeBlanc and Hodgson, 1959).

Climate differs greatly along the 375-mile Texas gulf coastline. The Galveston area has a relatively high humidity and receives about 40 inches of rain annually (Table 1). Chambers County, immediately

Table 1. Climatological data for Galveston Island, located 25 air miles from study blocks.

Month	Temperature (°Fahrenheit)*				Precipitation (Inches)				
	102 Year Average			1974	102 Year Average	1974			
							Number of Days Greater Than		
	Maximum	Minimum	Average	Departure from Normal		Monthly	.10	.50	1.00
January	61.9	52.0	57.0	+3.1	3.46	3.28	7	2	1
February	64.5	53.0	58.8	+2.6	2.88	0.83	2	1	0
March	70.0	61.5	65.8	+4.8	2.86	2.79	3	1	1
April	74.5	66.3	70.4	+1.2	2.59	0.91	3	1	0
May	81.0	73.4	77.2	+1.3	2.79	7.84	5	3	3
June	84.8	76.6	80.7	-0.6	2.65	2.03	4	1	1
July	87.1	78.8	83.0	-0.2	4.79	2.18	2	1	1
August	86.4	78.8	82.6	-0.7	4.39	8.08	7	6	3
September	80.9	71.0	76.0	-4.0	5.09	3.31	2	2	1
October					2.86				
November					3.56				
December					3.89				
Total					41.81				

*National Oceanic and Atmospheric Administration, 1974.

north of Galveston has an annual rainfall of 51 inches. In general, a progressively drier climate exists southward until a semiarid condition with less than 25 inches of annual rainfall occurs near the Rio Grande. Since the vegetation and soil types change in a southerly direction this study was confined to the upper Texas gulf coast and more specifically to East Bay in the Galveston-Houston area.

Tidal ranges throughout Galveston Bay are generally less than 1.5 feet. Maximum tidal currents, excluding currents in the navigation channels, are about 1 foot per second (Bobb and Boland, 1970). Fisher, et al. (1972) state that "except within the area of significant salt-water wedge and flood-tidal delta deposition, tides are generally unimportant within the bay-estuary-lagoon system, except when amplified by wind."

Minimum water salinities in East Bay occur in conjunction with heavy rains, varying distances from Bolivar and San Luis Passes, and the tidal entrances to bays. Water surface salinities in the shallow bay areas are generally about 2 parts per thousand less than bottom salinities at the same locations (Bobb and Boland, 1970).

Marine processes have been the chief forces in shaping the shoreline and in forming many of the physiographic features of this region. Some of these features are: Galveston Island, a barrier island sheltering West Bay; Bolivar Peninsula protecting East Bay; Trinity River alluvial valley; Trinity Bay; San Jacinto River alluvial valley; and Galveston Bay. Trinity Bay and Galveston Bay are the seaward continuation of the Trinity and San Jacinto alluvial valleys, respectively. These two bays merge to form one of the largest estuaries of the Texas coast. The central part of the bays have a maximum depth of approximately 10 feet with soft mud bottoms. East Bay and West Bay are both shallow, usually less than 6 feet deep, and are 3- to 4-miles wide with soft mud bottoms (LeBlanc and Hodgson, 1959).

Shoreline accretion in the bay area has been limited to the immediate vicinity of the Trinity and San Jacinto deltas. These deltas are small in comparison to others along the Texas coast due to the small silt loads of the Trinity and San Jacinto Rivers.

The dominant process along the bay shoreline has been erosion. The shoreline from April Fool Point to Kemah in Galveston County has been recorded as eroding at the rate of 4 feet annually (U.S. Army, Corps of Engineers, 1954). Sixty miles of shoreline in East Bay, Galveston Bay, and Trinity Bay in Chambers County (Fig. 1) have also eroded at the rate of about 4 feet per year (Carroll, 1974). Fisher, et al. (1972) have compiled an active processes map of the Galveston Bay complex which show areas of active erosion. One of the critical areas is the north shore of East Bay in Chambers County.

Two principal wind directions dominate the East Bay area. Persistent, southeasterly winds occur from March through November and short

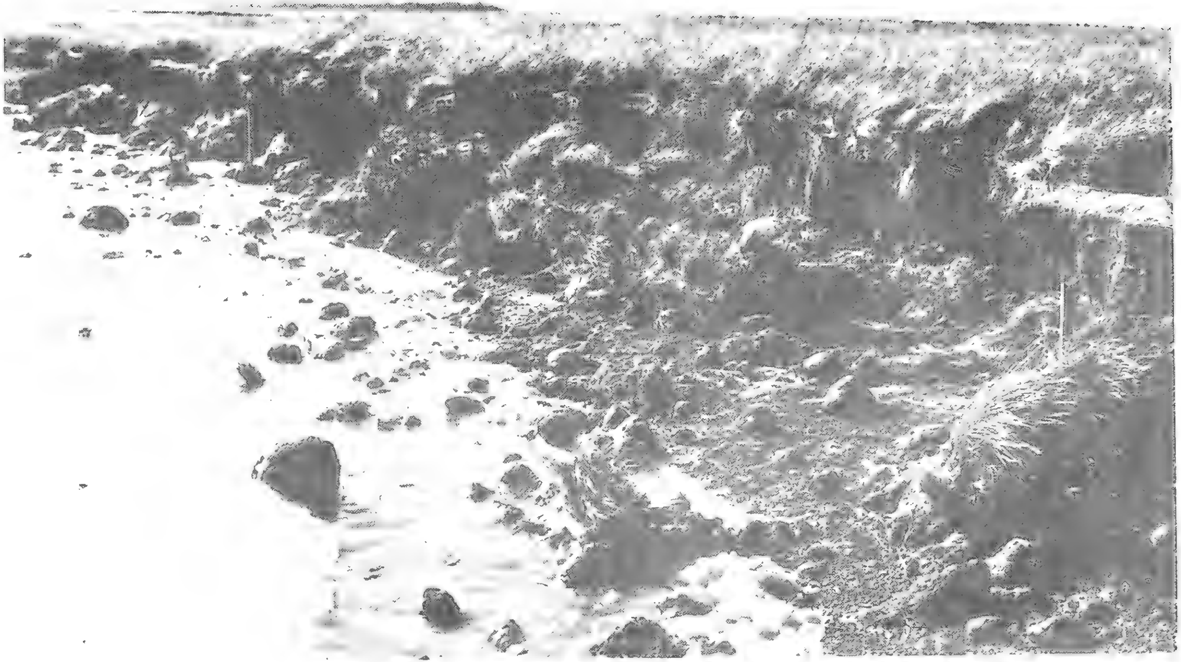


Figure 1. Eroding clay shoreline along the north shore of East Bay in Chambers County, Texas.

lived, but strong northerly winds from December through February (Fisher, et al., 1972). The dominance of winds from the southeast and the winter northers is even more significant when wind duration is multiplied by average hourly velocity.

The study area was located on the north side of East Bay along the shoreline of Anahuac National Wildlife Refuge in Chambers County, Texas (Figs. 2 and 3). Blocks I and II have a general southeasterly exposure. The fetch ranges from less than 1 mile in Block I to about 2 miles in Block II. Block III is exposed to the southwest and the fetch exceeds 6 miles. Block VI, located behind the shoreline in a ditch, is protected from both wind and wave action. The only water action results from tidal fluctuations (Fig. 4).

Block I has a gentle sloping shoreline with a natural accumulation of shell that exceeds 2 inches in depth in some plots (Fig. 5). In contrast, Block II has a steep-cut bank forming the shoreline (Fig. 6) with the water level always at the base of the bank. Block III has a gentle sloping shoreline, but the surface has been covered by artificial placement of oyster shell to depths of at least 2 inches (Fig. 7).

The shoreline, in each block was divided into three zones based on length of inundation. The lower zone was considered to be below mean low tide and was constantly inundated. In contrast, the middle zone consisted of that part of the shoreline between mean low tide and mean high tide. The upper zone was above mean high tide and was inundated only by abnormally high tides.

III. PROCEDURES

Bay water samples were collected biweekly in each block. Samples were collected approximately 10 feet from shore and stored in airtight bottles until analyzed. Conductivity in micromhos per centimeter for each sample was measured on a wheatstone bridge. Conversion factors listed in U.S. Salinity Laboratory (1954) were used to convert micromhos per centimeter at 25° Celsius to parts per million (ppm).

Soil samples were collected on two different dates, 9 February and 24 May 1974 at three locations within each block (end plots and middle plots). An exception was Block IV in which only one location was sampled. At each location, soils were taken at three arbitrary depths, 0 to 2, 2 to 4, and 4 to 6 inches, and in three zones (upper, middle, and lower). Each soil sample was oven dried at 100° Celsius for 24 hours. Shells and rocks were removed and the samples were ground by a mechanical grinder and finally by a mortar and pestle to break up remaining particles. Particles that would not pass through a 2-millimeter screen were removed. Large quantities of shell were recorded by weight and expressed as a percent of total sample weight.

Soil textural analyses followed the procedures outlined by Bouyoucos (1962). Samples were run in duplicate and the average

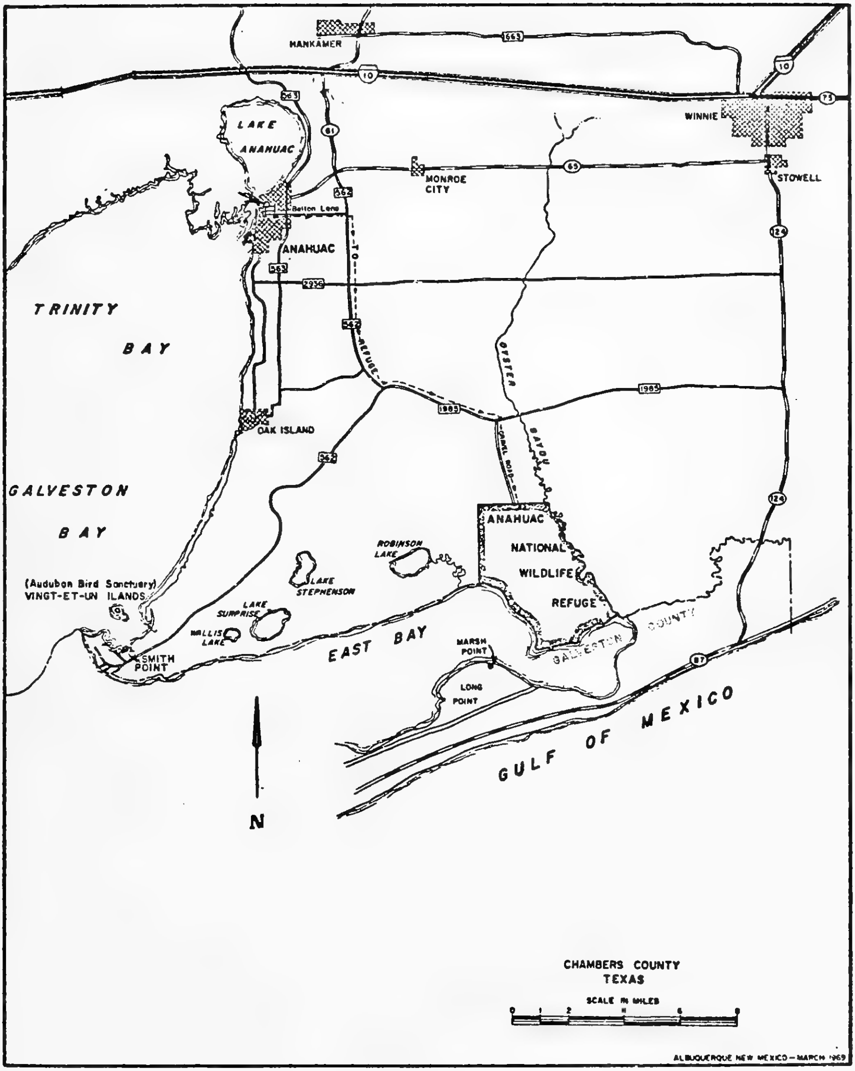


Figure 2. Location of Anahuac National Wildlife Refuge along the shoreline of East Bay (From U.S. Department of Interior).

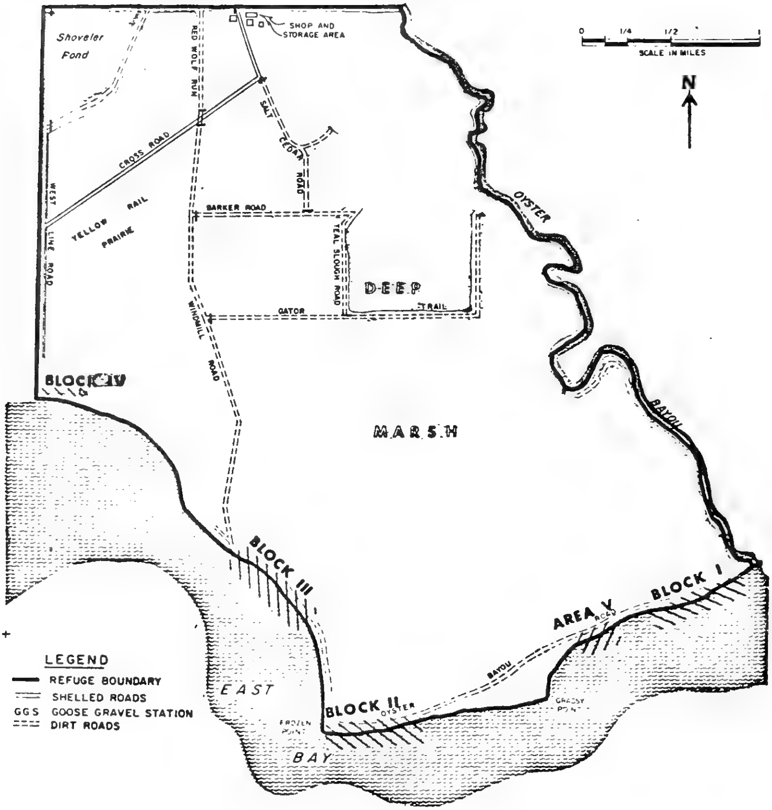


Figure 3. Location of Blocks I through V and smooth cordgrass *(Spartina alterniflora)* seed plot on Anahuac National Wildlife Refuge, Chambers County, Texas.

Figure 4. A general view of Block IV at low tide. Smooth cordgrass in foreground was planted 18 January 1974. Photo taken 22 February 1974.

Figure 5. A general view of study Block I at low tide. Note the occurrence of natural shell on the soil surface. Smooth cordgrass in foreground was planted 20 May 1974. Photo taken 20 September 1974.

Figure 6. A general view of study Block II. Note the sharp bank forming the shoreline. Plants in foreground are smooth cordgrass, transplanted in July 1974. Photo taken in September 1974.

Figure 7. A general view of study Block III. The occurrence and accumulation of artificially placed shell in this study block is shown in the foreground. Note the establishment, growth, and seed stalk production of giant reed *(Arundo donax)* above mean high tide. Planting was made on 9 January 1974. Photo taken 23 November 1974.

percent sand, silt, and clay was calculated. Textural classification was accomplished utilizing the textural triangle diagrammed by Jacobs, et al. (1971).

Soil salinity for each sample was determined by electrical conductivity of the saturation extract. Sample preparation and collection of extracts followed the procedures outlined in U.S. Salinity Laboratory (1954). However, only 100 grams of soil were used for the saturated paste. The pH (hydrogen-ion concentration) of each extract was determined on a pH meter. Four selected extractable cations were measured in the extract. Calcium (Ca), potassium (K), and sodium (Na) were measured by flame spectrophotometry and magnesium (Mg) by atomic absorption. Due to high concentrations it was necessary to dilute aliquots of the extract. Data in parts per million were converted to micrograms per gram (μg/gm) of soil.

Twelve plant species were selected for trial transplants as shoreline stabilizers (Table 2). A randomized complete block design was used with four blocks. Each study block was subdivided into 12 plots (Table 3), 1 for each species, and subsequently divided into 5 subplots. Subplots were planted on five different dates, 9-18 January, 1-2 March, 10-13 April, 20-24 May, and 8-10 July 1974. Subplots were further divided into three tidal zones (upper, middle, lower).

Each subplot was divided in eight rows, at 3-foot intervals, extending through the zones. Within rows the transplants were at 2-foot intervals and the number of transplants in each row was recorded. The transplant material was culms, stems, or rhizomes, and associated roots, except for saltcedar *(Tamarix gallica)* (cut stems). Winter plantings were primarily rhizomes and root systems and the spring and summer plantings utilized current green growth for each species. Tall plants, such as giant reed *(Arundo donax)*, common reed *(Phragmites communis)*, and big cordgrass *(Spartina cynosuroides)* were pruned to heights of 16 to 30 inches. Transplant material was dug, separated, and planted by hand. Man-hours to dig, separate, and plant were recorded for each species.

Block V was established 15-16 March 1974 to further delimit the zonation of plants and to explore the possibility of mechanical sloping before revegetation. A bulldozer was used to develop an approximate 10:1 slope on 200 feet of land at the shoreline. Three areas were established in this block with 13 plots each. Each plot consisted of a row for each study species. In addition, upper, middle, and lower zones were defined.

In Blocks I through V three separate evaluations of plantings were made. The first was on 10-18 June, prior to completion of all plantings. On 19-20 September, a fall evaluation was made. The winter evaluation was on 21-22 November 1974. Plants were recorded as alive if green, dead if present, but brown and absent if the

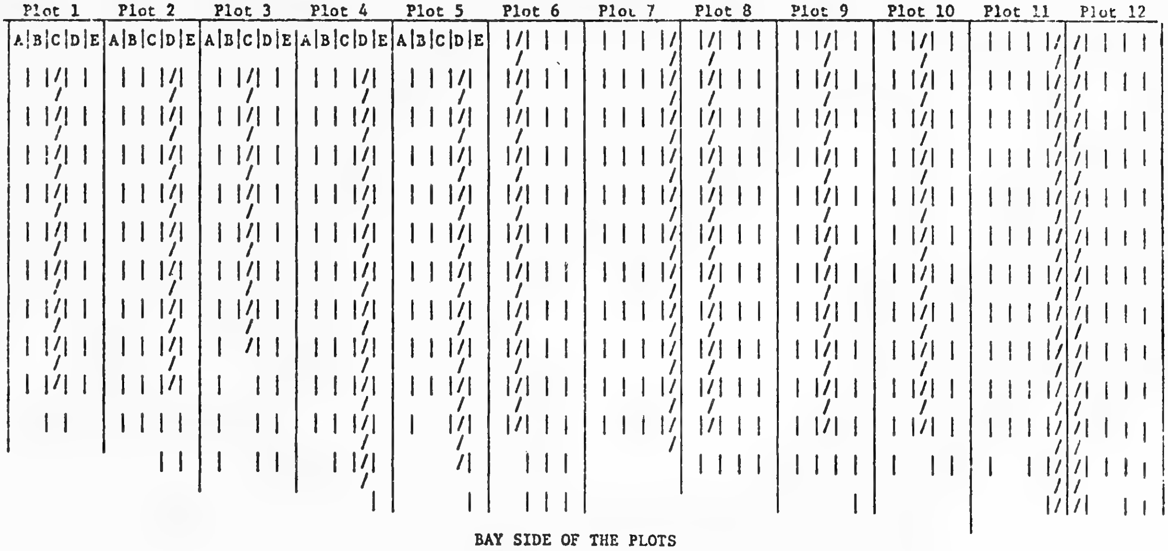
Table 2. List of selected species used in transplant studies in Blocks I through IV.

Common name	Scientific name	Synonyms
Giant reed	*Arundo donax*	
Black mangrove	*Avicennia germinans*	*Avicennia nitida*
Seashore saltgrass, saltgrass	*Distichlis spicata*	*D. spicata var. spicata*
Needlegrass	*Juncus roemerianus*	
Common reed	*Phragmites communis*	*Phragmites australis*
American bulrush	*Scirpus americanus*	
Olney bulrush	*Scirpus olneyi*	*Sciprus chilensis*
Saltmarsh bulrush	*Scirpus robustus*	*Scirpus maritimus*
Smooth cordgrass	*Spartina alterniflora*	*S. alterniflora var. glabra*
Big cordgrass	*Spartina cynosuroides*	
Gulf cordgrass sacahuista	*Spartina spartinae*	
Saltcedar	*Tamarix gallica*	

transplant could not be located. The number of tillers per surviving transplant, tiller height, and height of the original transplant was determined. Height classes were separated at 10 centimeter intervals with plants above 100 centimeters placed in class 11. Percent survival and percent absent were derived by dividing green or absent by the total number planted. The average number of tillers was derived by dividing number of tillers by number of green transplants.

Smooth cordgrass *(Spartina alterniflora)* seeds collected by hand on two different dates (10 November and 1 December) in the fall of 1973 were used to determine storage procedures and germination methods. All seeds were stored at 6° Celsius for at least 6 weeks before germination tests. Some seeds were stored dry while others were stored in seawater containing 8,000 ppm salinity (Mooring, Cooper, and Seneca, 1971). All seeds were checked for the presence of caryopsis within glumes before germination tests were conducted. Petri dish tops with filter paper were sterilized in an autoclave. One hundred seeds of a test type were placed in each petri dish and sealed with saran wrap and with a rubberband.

Table 3. A schematic drawing of the design used in each study block. Each block consisted of 12 plots and each plot was further subdivided into 5 subplots. Each species was randomly assigned to a plot and planting date was randomly assigned to each subplot. Hash marks illustrate one planting sequence.



Petri dishes were then placed on a metal tray and covered with black plastic to ensure darkness. All seeds were germinated in the dark with alternating thermal periods of 20° Celsius (16 hours) and 30° Celsius (8 hours) in a consol germinator (Mooring, Cooper, and Seneca, 1971). The following variables were tested: (a) dry seeds in glumes collected 10 November 1973, (b) wet seeds in glumes collected 10 November 1973, (c) dry caryopses (no glumes) collected 10 November 1973, (d) wet seeds in glumes collected 1 December 1973, and (e) wet seeds with gibberellic acid collected 10 November 1973.

A total of 33 soil samples (11 at each location) were collected 20 June 1974 at the shoreline, 50 and 150 feet from the shore. These samples were placed in plastic bags for transport to the laboratory. The soil was spread on shallow trays and observations for seed germination were made for 3 weeks. Soil was moistened as necessary with distilled water.

Four soil samples from the upper and middle zones and three samples from the lower zone were collected in July 1974 and placed in shallow pans. Twenty-five seeds of smooth cordgrass were placed in each sample and the soil was moistened with seawater as necessary. Seed germination was recorded for a 3-week period.

Smooth cordgrass seeds were planted 23 March 1974 in a 10- by 12-foot plot in a wave-protected area. Seeds were mixed with substrate by hand.

An experiment to compare survival of different transplant heights (4 to 15, 16 to 30, and over 30 inches) for black mangrove *(Avicennia germinans)* was planted 17 October 1974 (Fig. 8). Three replications (Blocks VI, VII, and VIII) were established. Blocks were designed to allow two additional monthly plantings of each height classes.

Block IX was designed to test the establishment and growth of plants when protected from wave action. A temporary wave-stilling device (Fig. 9) was constructed from baled hay, wire net, steel cable, and pipe. The maximum height of the device was about 36 inches. Twelve rows of black mangrove, saltgrass *(Distichlis spicata)*, needlegrass *(Juncus roemerianus)*, common reed, smooth cordgrass, and big cordgrass were planted behind the wave-stilling device.

IV. WATER SALINITY

Water salinity was variable at all study locations during 1974 (Fig. 10). Salinity at Block I was affected by influxes of freshwater from Oyster Bayou. Thus, the biweekly salinity values at this location were generally lower than for the others. An exception occurred in July, a period of low precipitation, when salinity was about 15,700 ppm. Lowest values were during the winter and following a heavy precipitation period in May. Salinity then was generally below 2,500 ppm.

Figure 8. Three height classes of black mangrove used to determine survival relationships between transplant height and water depth. Transplant heights ranged from over 30 inches (left) to 16 to 30 inches (center) to 4 to 15 inches (right).

Figure 9. A temporary wave-stilling device constructed in Block IX. The device is constructed of pipe, wire netting, cable, and baled hay.

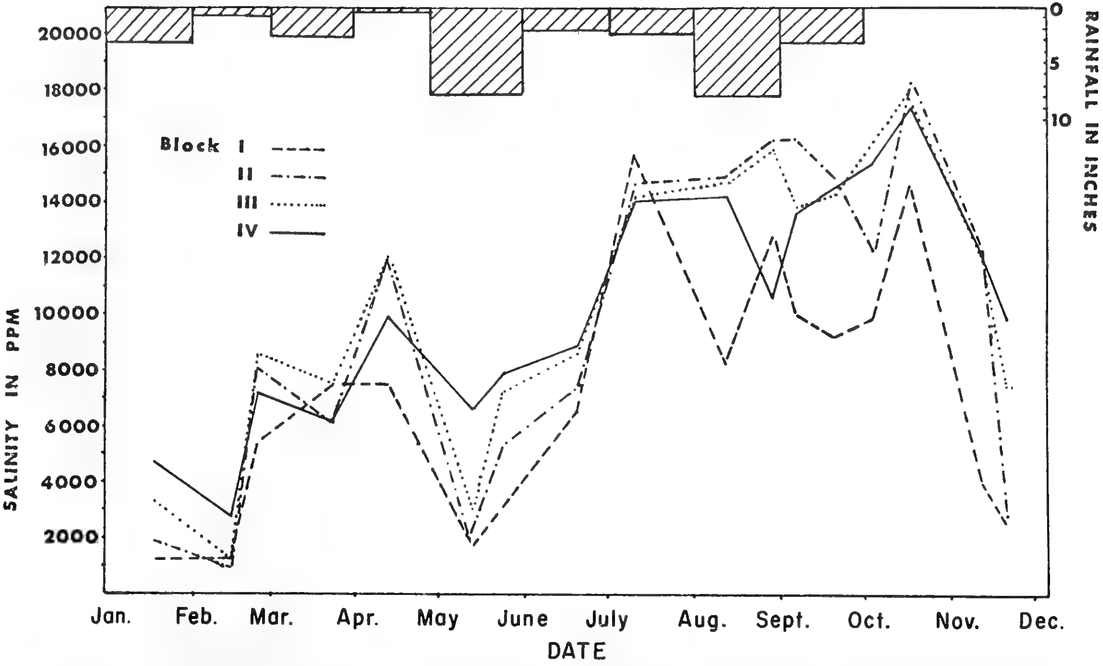


Figure 10. Water salinity in parts per million (ppm) for samples collected biweekly in study Blocks I through IV during 1974. Rainfall is also shown for the same period.

Salinities at Block II were similar to Block I during the fall-winter period (Fig. 10). However, during periods of low precipitation (April and October) salinity values were high, with the maximum of 18,500 ppm recorded in mid-October. Water salinity at the mechanically shaped Block V was similar in magnitude and trends to Block II.

Water samples from Blocks III and IV fluctuated widely throughout the year, but were similar in magnitude at most sampling intervals (Fig. 10). The major differences occurred in winter with water from Block IV higher in salinity than Block III. In late August, during a period of relatively high precipitation, water salinity in Block III increased, while in Block IV a decrease was recorded.

Water salinities fluctuated throughout the year irrespective of location, but mirrored the precipitation. In general, the lowest readings were in Block I, while the highest occurred as distance from Oyster Bayou increased. This resulted in three distinct periods of low salinity: winter 1973, early summer 1974, and fall 1974. In contrast, two periods of high salinity occurred. The first, of relatively low magnitude, was from mid-February to mid-May and the second, of higher magnitude was from June to November. Periods of low water salinity should be favorable for the establishment of transplants while the high summer salinity period should be considered as a poor period for establishment. The amount of precipitation received was an indicator of water salinity levels within East Bay.

V. SOIL CHARACTERISTICS

1. Soil Texture.

The shoreline on East Bay has been commonly referred to as clay. However, textural analyses of the soil in each block and in 3 zones (upper, middle, and lower) and at various depths to 6 inches indicated the soil was generally of a loam or clay loam texture (Table 4). The surface 2 inches of the upper zone, Block II; lower zone, Block III; and lower zone, Block IV were either sandy loam or sandy clay loam in texture. In general, the clay loam texture occurred at depths greater than 2 inches. Thus, the general sequence of soil texture was a surface layer (0 to 2 inches) of loam underlain by a layer (2 to 6 inches) of clay loam.

In most blocks the percent sand exceeded that of other particle classes and clay particles occurred in the smallest quantities. These textural properties result in a highly erodible soil, probably due to an unstable structure. The result of this unstable structure is a soil substrate that readily erodes with any form of disturbance. Thus, the continual wave action results in sloughing of the shoreline and a high annual loss. In addition, the disturbance associated with planting causes an unstable condition and again the continual wave action disperses the soil from around the planted material and ultimately the materials are washed out.

Table 4. Textural analyses of the 0-to 2-, 2-to 4- and 4-to 6-inch depths of the soil in the four study blocks by zone (U - upper, M - middle, L - lower). Data based on the mean of three samples.

Block	Zone	Depth (Inches)	Percent Sand	Percent Silt	Percent Clay	Texture
I	U	0 to 2	46.6	34.6	18.9	Loam
		2 to 4	46.7	33.9	19.5	Loam
		4 to 6	43.7	33.5	22.9	Loam
	M	0 to 2	44.7	30.1	25.3	Loam
		2 to 4	41.0	27.8	31.3	Clay Loam
		4 to 6	37.7	32.4	30.0	Clay Loam
	L	0 to 2	41.9	34.3	23.8	Loam
		2 to 4	37.9	33.1	29.0	Clay Loam
		4 to 6	36.4	35.3	28.3	Clay Loam
II	U	0 to 2	66.4	22.1	11.5	Sandy Loam
		2 to 4	34.5	38.0	27.5	Clay Loam
		4 to 6	32.0	36.9	31.2	Clay Loam
	M	0 to 2	36.3	36.0	27.7	Clay Loam
		2 to 4	36.8	35.4	27.8	Clay Loam
		4 to 6	34.6	37.5	28.0	Clay Loam
	L	0 to 2	50.6	31.6	17.9	Loam
		2 to 4	45.9	32.3	21.8	Loam
		4 to 6	45.0	31.6	23.5	Loam

Table 4. Textural analyses of the 0-to 2-, 2-to 4-, and 4-to 6-inch depths of the soil in the four study blocks by zone (U - upper, M - middle, L - lower). Data based on the mean of three samples-Continued.

Block	Zone	Depth (Inches)	Percent Sand	Percent Silt	Percent Clay	Texture
III	U	0 to 2	45.3	24.4	30.3	Clay Loam
		2 to 4	35.3	35.3	29.5	Clay Loam
		4 to 6	34.0	38.5	27.6	Clay Loam
	M	0 to 2	36.8	36.6	26.6	Loam
		2 to 4	29.7	42.4	27.9	Clay Loam
		4 to 6	34.6	36.4	29.1	Clay Loam
	L	0 to 2	62.8	27.3	9.9	Sandy Loam
		2 to 4	46.3	32.8	21.0	Loam
		4 to 6	45.3	30.2	24.6	Loam
IV	U	0 to 2	31.6	37.1	31.3	Clay Loam
		2 to 4	28.8	40.6	30.6	Clay Loam
		4 to 6	23.5	37.3	39.2	Clay Loam
	L	0 to 2	46.2	22.3	31.5	Sandy Clay Loam
		2 to 4	35.5	34.1	30.4	Clay Loam
		4 to 6	32.2	31.0	36.8	Clay Loam

Soil texture and the resulting unstable structural condition is a greater problem to shoreline stabilization than establishment of plant material. Any form of barrier that will reduce the wave action and its resultant dispersion of the soil will enhance vegetation establishment and stabilization of the eroding shoreline.

In comparing soil texture by blocks, disregarding both depth and zone, Blocks I, II, and III were classed as loam soils (Table 5). In contrast, Block IV, in the drainage ditch, was classed as a clay loam soil. Overall, the soils of Blocks I, II, and III were very similar with only minute differences in quantities of each particle class. In comparing the soil in Block IV to the other three, the percent contributed by the sand particles decreased while the clay significantly increased.

A change occurred in soil texture between zones of Blocks I, II, and III (Table 6). The upper, relatively undisturbed zone was of a loam texture to a depth of 6 inches and similar to the inundated lower zone. In contrast, the middle zone, had a significantly higher proportion of clay and a significantly lower proportion of sand resulting in a clay loam texture. This zone is exposed to more wave action than the others. As a result the surface soil has been removed.

The 0- to 2-inch depth contained significantly more sand in Blocks I, II, and III than either the 2- to 4- or the 4- to 6-inch depths (Table 7). This higher sand content was accompanied by a significantly lower clay content in the surface soil. The percent sand varied only slightly in the 2 to 4 and 4 to 6-inch depths, but was higher than either silt or clay. Silt content was similar at all depths and contributed about 33 percent of the soil particles.

2. Soil Salinity.

Soil samples for the determination of soil salinity were collected in February and May 1974 (Tables 8 and 9). Two collection dates provided data for comparison over time and under varying water salinity conditions and precipitation. Mean soil salinity in February ranged from over 11,000 ppm in the 4- to 6-inch depth of the upper zone to less than 2,600 ppm in the 4- to 6-inch depth of the lower zone (Table 10). The trend was decreasing soil salinity from the upper to the lower zones. In the upper zone, salinity in the surface 4 inches of soil was similar with an increase in the 4- to 6-inch layer. However, in the middle and lower zones, salinity varied only slightly with a change in depth. Water salinity at this time ranged from 1,100 to 3,200 ppm between blocks, indicating soil salinity was higher than water salinity.

In May following the relatively dry month of April, soil salinity values were higher than in February (Table 10). The lowest salinity, over 8,000 ppm, was in the 2- to 4-inch depth of the lower zone. While the highest, over 12,000 ppm, was in the 0- to 2-inch depth of the upper

Table 5. Comparison of textural classes between study blocks.

Block	Percent Sand	Percent Silt	Percent Clay	Texture
I	41.8 a*	32.7 b	25.5 c	Loam
II	42.5 a	33.4 b	24.1 c	Loam
III	41.1 a	33.7 b	25.2 c	Loam
IV	32.9 a	33.8 b	33.3 d	Clay Loam

*Means followed by the same letter are not significantly different at the 95 percent level.

Table 6. Comparison of textural classes between zones (Upper, Middle, Lower). Data combined for Blocks I, II, and III.

Zone	Percent Sand	Percent Silt	Percent Clay	Texture
Upper	42.7 ab*	33.0 c	24.3 de	Loam
Middle	36.9 b	34.9 c	28.2 e	Clay Loam
Lower	45.8 a	32.0 c	22.2 d	Loam

*Means followed by the same letter are not significantly different at the 95 percent level.

Table 7. Comparison of textural classes by depths (0 to 2, 2 to 4, 4 to 6 inches). Data from Blocks I, II, and III have been combined.

Depth (Inches)	Percent Sand	Percent Silt	Percent Clay	Texture
0 to 2	48.0 a*	30.6 c	21.4 d	Loam
2 to 4	39.3 b	34.5 c	26.2 de	Loam
4 to 6	38.1 b	34.6 c	27.3 e	Clay Loam

*Means followed by the same letter are not significantly different at the 95 percent level.

Table 8. Mean soil salinity, pH and extractable cations by study blocks, zone (U - upper, M - middle, L - lower) and depth. Samples collected 9 February 1974. Data based on a mean value of three samples in Blocks I, II, and III and two samples in Block IV.

Blocks	Zones	Depth (Inches)	Salinity (ppm)	pH	Extractable Cations (microgram per gram)			
					Ca	K	Mg	Na
I	U	0 to 2	7,854	7.4	25.0	37.1	174.3	1,234.4
		2 to 4	8,553	6.9	68.2	38.0	264.0	1,452.9
		4 to 6	8,819	7.2	78.3	45.2	251.1	1,509.3
	M	0 to 2	3,760	7.5	25.0	31.1	103.6	778.5
		2 to 4	3,417	7.2	16.9	46.4	83.1	773.7
		4 to 6	2,862	7.1	16.7	43.7	96.6	893.3
	L	0 to 2	3,095	7.3	15.6	30.9	80.3	635.9
		2 to 4	2,861	7.6	9.1	31.5	70.7	792.4
		4 to 6	2,178	6.8	12.1	4.8	191.9	971.3
II	U	0 to 2	11,048	7.0	79.1	36.7	241.9	1,357.6
		2 to 4	10,383	6.9	65.2	49.7	409.7	2,101.4
		4 to 6	13,422	6.8	104.8	59.0	515.9	2,421.6
	M	0 to 2	3,536	7.3	21.1	28.2	118.5	762.4
		2 to 4	4,359	6.8	20.3	31.6	47.1	892.6
		4 to 6	4,204	6.8	19.0	32.6	140.9	1,014.6
	L	0 to 2	1,974	7.3	10.1	24.5	49.9	348.9
		2 to 4	1,433	7.4	3.9	18.5	23.2	371.6
		4 to 6	1,710	7.2	4.9	20.2	26.9	428.8

Table 8. Mean soil salinity, pH and extractable cations by study blocks, zone (U - upper, M - middle, L - lower) and depth. Samples collected 9 February 1974. Data based on a mean value of three samples in Blocks I, II, and III and two samples in Block IV-Continued.

Blocks	Zones	Depth (Inches)	Salinity (ppm)	pH	Extractable Cations (microgram per gram)			
					Ca	K	Mg	Na
III	U	0 to 2	9,795	7.0	74.4	43.4	384.9	2,310.6
		2 to 4	11,515	7.0	69.5	43.3	427.9	2,049.0
		4 to 6	12,080	7.0	52.5	43.6	462.6	2,276.2
	M	0 to 2	2,462	7.7	12.8	24.1	57.4	546.2
		2 to 4	1,594	7.7	3.0	17.7	22.2	392.2
		4 to 6	3,148	7.0	11.5	25.7	77.8	628.1
	L	0 to 2	5,258	7.6	114.2	39.5	240.7	475.3
		2 to 4	3,982	7.2	37.4	43.6	147.2	872.9
		4 to 6	3,811	7.3	35.6	52.4	165.0	687.9
IV	U	0 to 2	7,188	7.6	85.2	68.0	456.8	1,317.1
		2 to 4	5,258	6.9	41.7	54.1	242.7	806.3
		4 to 6	9,984	6.0	140.7	132.6	860.8	1,994.8
	M	0 to 2	6,256	7.3	111.1	72.3	529.7	1,147.5
		2 to 4	4,725	7.9	57.5	67.0	240.8	661.7
		4 to 6	6,123	7.2	81.1	93.5	377.5	1,561.8
	L*	0 to 2						
		2 to 4						
		4 to 6						

*Data not available.

Table 9. Mean soil salinity, pH and extractable cations by study block, zone (U - upper, M - middle, L - lower) and depth. Samples collected on 24 May 1974. Data based on a mean value of three samples in Blocks I, II, and III and two samples in Block IV.

Blocks	Zones	Depth (Inches)	Salinity (ppm)	pH	Extractable Cations (microgram per gram) Ca	K	Mg	Na
I	U	0 to 2	13,703	7.5	50.5	13.9	246.5	1,185.0
		2 to 4	13,141	7.1	69.6	27.2	156.5	1,468.0
		4 to 6	15,878	7.1	74.8	33.8	204.0	1,654.1
	M	0 to 2	9,029	7.1	43.1	31.9	253.1	911.4
		2 to 4	9,927	7.1	85.8	39.0	213.2	917.6
		4 to 6	12,613	7.1	70.6	44.4	172.4	1,235.6
	L	0 to 2	5,570	7.3	35.1	32.1	135.1	732.5
		2 to 4	5,775	7.5	38.9	39.0	151.0	888.1
		4 to 6	5,382	7.1	30.5	34.9	162.3	927.8
II	U	0 to 2	8,570	6.7	65.9	44.7	514.0	979.6
		2 to 4	9,684	6.0	71.6	39.9	293.6	1,019.5
		4 to 6	4,259	6.5	19.4	30.9	89.7	689.5
	M	0 to 2	8,286	7.1	102.6	59.0	432.3	1,453.5
		2 to 4	9,318	6.8	146.4	95.0	599.3	2,071.8
		4 to 6	10,982	7.1	104.2	94.6	258.5	2,102.2
	L	0 to 2	10,161	6.9	117.7	111.4	173.7	1,528.4
		2 to 4	7,776	6.7	173.5	97.1	633.2	1,709.1
		4 to 6	7,732	7.0	35.6	83.8	605.4	1,761.2

Table 9. Mean soil salinity, pH and extractable cations by study block, zone (U - upper, M - middle, L - lower) and depth. Samples collected on 24 May 1974. Data based on a mean value of three samples in Blocks I, II, and III and two samples in Block IV-Continued.

Blocks	Zones	Depth (Inches)	Salinity (ppm)	pH	Extractable Cations (microgram per gram)			
					Ca	K	Mg	Na
III	U	0 to 2	16,773	6.8	115.6	54.1	376.4	1,833.6
		2 to 4	9,163	6.7	67.6	36.9	358.2	1,272.8
		4 to 6	6,575	7.0	41.9	29.9	145.0	1,037.9
	M	0 to 2	8,064	7.1	54.9	50.2	140.2	1,409.7
		2 to 4	9,007	6.9	46.1	30.6	266.0	1,515.6
		4 to 6	7,805	6.9	36.4	38.3	111.9	1,303.1
	L	0 to 2	5,546	7.2	34.0	36.5	131.5	626.2
		2 to 4	7,931	6.9	52.1	40.7	131.9	1,164.6
		4 to 6	10,405	7.2	60.1	36.7	211.0	1,433.7
IV	U	0 to 2	9,551	7.0	358.8	56.9	538.0	1,525.6
		2 to 4	7,438	7.0	76.7	64.2	303.5	7,619.8
		4 to 6	9,834	7.0	128.8	82.1	470.8	1,730.1
	M	0 to 2	8,486	7.0	100.8	80.7	354.3	7,729.9
		2 to 4	5,408	6.9	44.6	49.8	268.9	1,065.8
		4 to 6	5,741	7.0	44.3	54.3	278.2	1,074.3
	L	0 to 2	13,644	7.1	376.5	108.4	880.0	1,653.3
		2 to 4	10,849	7.2	218.9	92.4	761.7	1,391.6
		4 to 6	12,979	7.3	315.5	116.6	967.2	1,707.5

Table 10. Mean soil salinity at two dates in parts per million by soil depth and zone. Data combined for Blocks I, II, and III. Data based on mean values of 9 samples.

Zone	0 to 2 inches	2 to 4 inches	4 to 6 inches	Mean
9 February 1974				
Upper	8,971	8,927	11,076	9,658
Middle	4,004	3,524	4,084	3,871
Lower	3,442	2,759	2,566	2,922
Mean	5,472	5,070	5,909	5,484
24 May 1974				
Upper	12,149	9,857	9,137	10,381
Middle	8,466	8,415	9,285	8,722
Lower	8,730	8,083	9,125	8,646
Mean	9,782	8,785	9,182	9,250

zone. The general trend was a decrease in salinity from the upper to lower zone, regardless of depth.

In the upper zone, a decrease in salinity occurred with depth (Table 10). In contrast, soil salinity increased slightly from the surface to the 6-inch depth in both the middle and lower zones. Water salinity in May ranged from 3,200 to 8,000 ppm between blocks.

Soil salinity in Block I, disregarding depth and zone, was lower (4,509 ppm) than in the other blocks in February (Table 11). The highest salinity was in Block IV, the protected ditch. By May, soil salinity had increased in all blocks with Blocks II and IV the lowest and Block I the highest (9,485 ppm). These data indicate a variation not only within blocks, but also between dates. For example, Block I had the lowest salinity in February and the highest in May while Block IV had the lowest in May and the highest in February.

Soil salinity was considerably higher on both dates than water salinity. Following the relatively dry month of April, both soil and water salinity values were higher than during February. This indicates that following below normal precipitation both soil and water salinities increase and could present a problem in vegetation establishment, particularly of the less tolerant plant species.

3. Soil pH and Extractable Cations.

Data on soil pH and extractable cations were collected in February and May 1974 (Tables 8 and 9). Two collection dates provided data for comparison of values over time of these normally stable soil characteristics.

In February, disregarding study blocks and zones, soil pH decreased slightly with increasing depth (Table 12). The range was narrow, fluctuating around a neutral pH. When soil depth and blocks were disregarded, soil pH increased slightly from the upper zone to the lower zone (Table 13). Again the mean pH values were near neutral.

Extractable cations, calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na) in February fluctuated in quantity with changes in soil depth and between zones (Tables 12 and 13). However, there was no significant difference between study blocks.

Maximum Ca concentration was in the surface 2 inches of soil with a decrease in the 2- to 4-inch layer. A corresponding increase was recorded in the 4- to 6-inch layer. In contrast, K increased in concentration from the soil surface to 6 inches. Both Ca and K occurred in similar quantities, but Mg occurred in larger quantities. The trend was a decrease in Mg concentration from the soil surface to 4 inches and an increase to the maximum in the 4- to 6-inch layer. Sodium concentration was high, regardless of soil depth. The range was from a low of

Table 11. Mean soil salinity as parts per million by study block and date. Data based on a mean value of 36 samples.

Block	Collection Date	
	9 February 1974	24 May 1974
I	4,509	9,485
II	4,632	8,674
III	6,129	9,030
IV	6,589	8,692

Table 12. Comparison of soil pH and extractable cations by depth. Data based on a mean value of 12 samples.

Depth (Inches)	pH	Extractable Cations (µg/gm)			
		Ca	K	Mg	Na
0 to 2*	7.4	52.1	39.6	221.6	992.3
2 to 4	7.2	35.7	40.1	179.9	1,015.2
4 to 6	6.9	50.7	53.7	287.9	1,308.0

*Soil samples collected 9 February 1974.

Table 13. Comparison of soil pH and extractable cations by zone (U - upper, M - middle, L - lower) in Blocks I, II, and III. Data represent the mean of 9 samples. (Block IV was not included since only two zones were analyzed for February).

Zones	pH	Extractable Cations (μ g/gm)			
		Ca	K	Mg	Na
U*	7.0	68.6	44.0	348.0	1,857.0
M	7.2	16.3	31.2	83.0	742.4
L	7.3	27.0	33.7	110.6	620.6

*Soil samples collected 9 February 1974.

about 992 μg/gm in the surface 2 inches to 1,308 μg/gm in the 4- to 6-inch layer. The highest extractable cation concentration was in the 4- to 6-inch soil layer.

In February, concentration of the four extractable cations varied between zones (Table 13). Maximum Ca concentration was in the upper zone. The concentration decreased in the middle zone with a slight increase in the lower. This same trend was reflected by K and Mg, but Mg was present in larger quantities than either Ca or K. Sodium concentration decreased from a high of about 1,860 μg/gm in the upper zone to approximately 620 μg/gm in the lower zone.

Soil pH in May, by depth, was similar to that recorded in February (Tables 12 and 14), with only slight differences between depths. By zones, soil pH was slightly lower in May than February (Tables 12 and 15). However, the values were still near neutral.

Calcium concentration decreased with an increase in depth from the soil surface to 6 inches (Table 14). The concentration, in general, was twofold higher in May than in February. Potassium concentration was uniform throughout the depth sampled and was lower than Ca, but had increased slightly from February. In general, Mg fluctuated only slightly with soil depth, but the concentration at all depths was considerably higher than in February. The maximum Na concentration (1,842 μg/gm) occurred in the 2-to 4-inch soil layer. This was only slightly higher than in the surface soil. A decrease of over 450 μg/gm occurred between the 2- to 4- and 4- to 6-inch layers. Sodium was the dominant extractable cation at all depths and occurred in higher concentrations than in February.

The four extractable cations varied in concentrations between zones in May (Table 15). Maximum Ca concentration was in the lower zone with the minimum in the middle. The trend exhibited an increase in K from the upper to the lower zones. This was a reversal of the trend exhibited in February. Magnesium content was highest (412 μg/gm) in soil of the lower zone while the minimum (279 μg/gm) occurred in the middle zone. This trend was a reversal of that exhibited in February. Sodium concentration was high in the upper and middle zones and declined in the lower. In February the high sodium concentration was restricted to the upper zone. In general, extractable cations occurred in larger quantities in May than in February.

Soil pH changed only slightly between February and May by depth and zones (Tables 16 and 17). Extractable cations did fluctuate by date, depth, and zone. All cations occurred in larger concentrations in May than in February at all three soil depths and were similar or greater in the three zones. This probably was a reflection of low rainfall and increased water salinity during the period before soil sampling in May.

Table 14. Comparison of soil pH and extractable cations by depth. Data based on a mean value of 12 samples.

Depth (Inches)	pH	Extractable Cations (μg/gm) Ca	K	Mg	Na
0 to 2*	7.1	121.3	56.7	347.9	1,797.4
2 to 4	6.9	91.0	54.3	344.8	1,842.0
4 to 6	7.0	80.2	56.7	306.4	1,388.1

*Soil samples collected 24 May 1974.

Table 15. Comparison of soil pH and extractable cations by zone (U - upper, M - middle, L - lower) in all study blocks. Data represent the mean of 12 samples.

Zones	pH	Extractable Cations (μg/gm) Ca	K	Mg	Na
U*	6.9	94.8	42.9	308.0	1,834.6
M	7.0	73.3	55.7	279.0	1,899.2
L	7.1	124.0	69.1	412.0	1,293.7

*Soil samples collected 24 May 1974.

Table 16. Comparison by date and soil depth of pH and extractable cations. Data based on a mean value of 12 samples from each of four study blocks.

	Depth (Inches)	9 February	24 May
pH	0 to 2	7.4	7.1
	2 to 4	7.2	6.9
	4 to 6	6.9	7.0
Ca	0 to 2	52.1	121.3
	2 to 4	35.7	91.0
	4 to 6	50.7	80.2
K	0 to 2	39.6	56.7
	2 to 4	40.1	54.3
	4 to 6	53.7	56.7
Mg	0 to 2	221.6	347.9
	2 to 4	179.9	344.8
	4 to 6	287.9	306.4
Na	0 to 2	992.2	1,797.4
	2 to 4	1,015.2	1,842.0
	4 to 6	1,308.0	1,388.1

Table 17. Comparison by date and zone (U - upper, M - middle, L - lower) of soil pH and extractable cations. Soils collected at three depths within zones. Data based on a mean value of 12 samples from each of the four study blocks at each date.

	Zones	9 February	24 May
pH	U	7.0	6.9
	M	7.2	7.0
	L	7.3	7.1
Ca	U	68.5	94.8
	M	16.3	73.3
	L	27.0	124.0
K	U	44.0	42.9
	M	31.2	57.7
	L	33.7	69.1
Mg	U	348.0	308.0
	M	83.0	279.0
	L	110.6	412.0
Na	U	1,857.0	1,834.6
	M	742.4	1,899.2
	L	620.6	1,293.7

VI. VEGETATION ESTABLISHMENT

1. General.

A survey of natural-occurring plant species along the upper Texas gulf coast as well as a literature survey resulted in the selection of 12 plant species for testing in this study (Table 2). These species appeared to possess the characteristics necessary for establishment and reproduction in the vigorous environment of East Bay. Establishment would provide for stabilization of the eroding clay shoreline.

Giant reed, an introduced species, has characteristics desired for erosion control. These include vegetative as well as sexual reproduction, rapid establishment, rapid growth, and an extensive root system that effectively holds soil against water erosion.

Black mangrove is a native tree that occurs along the shoreline from Texas to Florida.

Saltgrass is a low growing rhizomatous grass occurring along most shorelines of the world. This species propagates vegetatively and once established forms a protective mat over the soil surface. The rhizomes are effective in reducing soil erosion. In addition to vegetative reproduction, saltgrass produces seed throughout the growing season.

Needlegrass, a perennial rush, reproduces by short rhizomes and seed. It is widespread along the upper Texas gulf coast in fine textured soil. This species has a bunch growth form and produces an extensive root system that should retard water erosion.

Common reed is a tall perennial grass with a creeping rootstock. This species successfully reproduces from rhizomes as well as from seed. The extensive rhizome and root systems are effective soil binders. Common reed is common along the gulf coast.

American bulrush, a perennial bulrush, has wide distribution along the gulf as well as inland. This species reproduces both vegetatively and sexually and established plants are effective soil binders. In areas of establishment, this species forms a dense cover aboveground and an extensive root system in the upper soil layers.

Olney bulrush is a perennial bulrush of widespread distribution in salt marsh areas along the gulf and throughout North America. This species has most of the characteristics of American bulrush.

Saltmarsh bulrush *(Scirpus robustus)* is a perennial bulrush that frequently occurs in salt marshes of the upper Texas gulf coast. Characteristics of this species for reproduction, establishment, and erosion control are similar to those reported for American bulrush.

Smooth cordgrass is a perennial tall grass that reproduces both from rhizomes and seed. This species has a wide distribution along shorelines and in marshes of North America. It has been effectively used for salt marsh development and erosion control along the Atlantic coast.

Big cordgrass is a perennial tall grass that is similar to smooth cordgrass in growth habit, but it occurs at a higher elevation. Big cordgrass is not as abundant along the upper Texas gulf coast as smooth cordgrass.

Gulf cordgrass *(Spartina spartinae)* is a widespread perennial grass along the Texas gulf coast. It normally inhabits areas drier than either smooth cordgrass or big cordgrass. It is common in cordgrass flats, occurring at elevations above normal high tide. This species, like the others, reproduces readily from short rhizomes and seed. It forms a dense root and rhizome system in the soil.

Saltcedar, an introduced woody plant, readily reproduces by transplant. It now occurs throughout much of central North America where it was introduced for erosion control. Along the lower Texas gulf coast it readily establishes in beach sand and is effective in dune stabilization.

2. Survival and Reproduction.

A total of five experimental plantings were made during 1974 at all four study blocks. The January planting was during a month of above normal precipitation and relatively low water and soil salinity levels. The March planting was during a month of near normal precipitation, but rainfall during February had been only 0.83 inches, over 2 inches below normal. Thus, on the 1 March planting date elevated water salinity was encountered. In April, precipitation was more than 1.5 inches below normal, following near normal precipitation in March. However, water salinity at the time of planting was at maximum for the spring. May precipitation was over 5 inches above normal and water salinity on the 20 May planting date was low, except in Block IV. In July, water salinity at all blocks, exceeded 14,000 ppm probably due to below normal precipitation and high summer temperatures.

a. Giant Reed. This species readily established in the upper zone (Table 18). The highest percent survival (58) was with the January planting with minimum survival during the late spring and summer. The surviving transplants readily reproduced vegetatively (Table 19) The number of new tillers per surviving transplant ranged from a low of over one in the April and May plantings to over four in the January planting. The transplants produced seed during the fall.

Transplants of giant reed were not successfully in either the middle or lower zones. This species apparently cannot tolerate inundation or water salinity. In addition, the large corms planted were frequently washed out by wave action. The only survival in these two zones occurred

Table 18. Mean percent survival of planted species. Data combined for the four study blocks by zone (upper, middle, lower) and planting date.

	Species	Planting Dates (Month and Day 1974)*					
		9 Jan.	1 Mar.	10 Apr.	20 May	8 July	Mean
Upper Zone	Giant reed	58.0	13.8	12.0	12.1	13.2	21.8
	Black mangrove**	----	----	2.2	16.8	1.9	7.0
	Saltgrass	0.0	0.0	3.8	0.0	0.0	0.8
	Needlegrass	0.0	0.0	0.0	0.0	0.0	0.0
	Common reed	0.7	0.0	0.0	0.0	0.0	0.1
	American bulrush	0.0	0.0	0.0	0.0	0.0	0.0
	Olney bulrush	2.2	2.1	0.0	1.9	17.3	4.7
	Saltmarsh bulrush	0.6	0.0	0.0	0.0	0.0	0.1
	Smooth cordgrass	0.0	0.0	11.3	34.3	14.0	11.9
	Big cordgrass	0.0	0.0	0.0	0.0	0.0	0.0
	Gulf cordgrass***	0.0	0.0	0.0	0.0	0.0	0.0
	Saltcedar	6.6	0.0	4.3	0.0	0.0	2.2
Middle Zone	Giant reed	0.0	0.0	0.0	0.0	5.3	1.1
	Black mangrove**	----	----	10.9	11.4	14.4	12.2
	Saltgrass	2.7	2.0	0.0	3.4	6.8	3.0
	Needlegrass	4.1	2.9	2.6	2.1	0.0	2.3
	Common reed	0.6	1.1	0.9	1.1	10.8	2.9
	American bulrush	0.0	0.0	0.0	0.0	1.9	0.4
	Olney bulrush	1.8	0.0	0.0	2.6	16.9	4.3
	Saltmarsh bulrush	2.4	0.0	0.0	2.0	10.6	3.0

*Data collected 19 to 21 September 1974.
**Black mangrove was not included in early plantings.
***Normally a natural occurring dominant in this zone and was not planted.

Table 18. Mean percent survival of planted species. Data combined for the four study blocks by zone (upper, middle, lower) and planting date-Continued

	Species	Planting Dates (Month and Day 1974)*					
		9 Jan.	1 Mar.	10 Apr.	20 May	8 July	Mean
Middle Zone	Smooth cordgrass	14.6	5.7	24.4	44.8	44.2	26.7
	Big cordgrass	3.2	1.2	0.0	2.0	3.2	1.9
	Gulf cordgrass***	1.2	6.3	7.7	0.0	8.2	23.4
	Saltcedar	1.6	0.0	0.0	0.0	0.6	0.4
Lower Zone	Giant reed	0.0	0.0	0.0	0.0	0.0	0.0
	Black mangrove**	----	----	2.7	4.6	33.9	13.7
	Saltgrass	0.0	0.0	0.0	0.0	0.0	0.0
	Needlegrass	0.0	0.0	0.0	0.0	0.0	0.0
	Common reed	0.0	0.0	1.6	0.0	10.0	2.3
	American bulrush	0.0	0.0	0.0	0.0	0.0	0.0
	Olney bulrush	0.0	0.0	0.0	0.0	17.3	3.5
	Saltmarsh bulrush	0.0	0.0	0.0	0.0	0.0	0.0
	Smooth cordgrass	0.0	0.0	0.0	11.9	34.5	9.3
	Big cordgrass	0.0	0.0	0.0	0.0	0.0	0.0
	Gulf cordgrass***	0.0	0.0	0.0	3.4	0.0	0.7
	Saltcedar	0.0	0.0	0.0	0.0	0.0	0.0

*Data collected 19 to 21 September 1974.

**Black mangrove was not included in early plantings.

***Normally a natural occurring dominant in this zone and was not planted.

Table 19. Mean number of tillers produced by surviving transplants by species, planting date, and zone. Data combined from the four study blocks.

	Species	Planting Dates (Month and Day 1974)*				
		9 Jan.	1 Mar.	10 Apr.	20 May	8 July
Upper Zone	Giant reed	4.3	2.9	1.4	1.7	3.4
	Black mangrove**	----	----	0.0	0.0	0.0
	Saltgrass	0.0	0.0	7.7	0.0	0.0
	Needlegrass	0.0	0.0	0.0	0.0	0.0
	Common reed	7.0	0.0	0.0	0.0	0.0
	American bulrush	0.0	0.0	0.0	0.0	0.0
	Olney bulrush	1.0	1.0	0.0	1.0	1.2
	Saltmarsh bulrush	4.0	0.0	0.0	0.0	0.0
	Smooth cordgrass	0.0	0.0	1.9	3.4	0.8
	Big cordgrass	0.0	0.0	0.0	0.0	0.0
	Gulf cordgrass***	0.0	0.0	0.0	0.0	0.0
	Saltcedar	0.0	0.0	0.0	0.0	0.0
Middle Zone	Giant reed	0.0	0.0	0.0	0.0	1.3
	Black mangrove**	----	----	0.0	0.0	0.0
	Saltgrass	0.0	19.0	0.0	8.3	2.8
	Needlegrass	20.9	6.0	11.2	6.8	0.0
	Common reed	1.0	1.0	1.5	0.5	1.3
	American bulrush	0.0	0.0	0.0	0.0	1.5
	Olney bulrush	1.8	0.0	0.0	1.8	2.7
	Saltmarsh bulrush	2.8	0.0	0.0	1.3	0.8

*Data collected 19 to 21 September 1974.
**Black mangrove was not included in early plantings.
***Normally a natural occurring dominant in this zone.

Table 19. Mean number of tillers produced by surviving transplants by species, planting date, and zone. Data combined from the four study blocks-Continued

	Species	Planting Dates (Month and Day 1974)*				
		9 Jan.	1 Mar.	10 Apr.	20 May	8 July
Middle Zone	Smooth cordgrass	22.0	13.2	14.2	10.8	4.6
	Big cordgrass	7.2	7.0	0.0	6.0	1.0
	Gulf cordgrass***	0.0	0.0	0.0	0.0	0.0
	Saltcedar	0.0	0.0	0.0	0.0	0.0
Lower Zone	Giant reed	0.0	0.0	0.0	0.0	0.0
	Black mangrove**	----	----	0.0	0.0	0.0
	Saltgrass	0.0	0.0	0.0	0.0	0.0
	Needlegrass	0.0	0.0	0.0	0.0	0.0
	Common reed	0.0	0.0	5.0	0.0	1.7
	American bulrush	0.0	0.0	0.0	0.0	0.0
	Olney bulrush	0.0	0.0	0.0	0.0	1.9
	Saltmarsh bulrush	0.0	0.0	0.0	0.0	0.0
	Smooth cordgrass	0.0	0.0	0.0	8.7	3.0
	Big cordgrass	0.0	0.0	0.0	0.0	0.0
	Gulf cordgrass***	0.0	0.0	0.0	0.0	0.0
	Saltcedar	0.0	0.0	0.0	0.0	0.0

*Data collected 19 to 21 September 1974.

**Black mangrove was not included in early plantings.

***Normally a natural occurring dominant in this zone.

with the July planting with a survival rate of over 5 percent and an average of over one new tiller per surviving transplant.

This species is well adapted for transplantation, establishment, and vegetative and sexual reproduction above the normal high tide zone. In the upper zone, considering all planting dates and all study blocks, this species had the highest survival and reproduction rate of all transplants (Tables 18 and 19). Highest survival and reproduction was associated with winter planting.

b. Black mangrove. A source of transplant material for this species was not available for the first two planting dates. In the upper zone, survival was low for the April and July plantings (Table 18). However, survival for the mid-May planting was about 17 percent. Vegetative reproduction did not occur at any of the planting dates or in any of the zones (Table 19).

Survival in the middle zone was more consistent, between dates, than in the upper zone. It ranged from a low of about 11 percent in April and May to over 14 percent in July. Maximum survival for this species occurred with the July planting in the lower zone (33.9 percent). However, survival at the two earlier planting dates was less than 5 percent.

This species may be adapted for use along eroding shorelines of the upper Texas gulf coast in either the low or middle zones. However, in both of these zones washout did occur. In addition, based on observation, chances for establishment were increased if the transplant material was tall enough so that 2 to 4 leaves extend above the water surface. Based on the data available, this species is adapted for late spring or summer planting.

c. Saltgrass. Single rhizomes of this species were used as planting material. Survival in the upper zone was recorded for only the April planting and was less than 4 percent (Table 18). However, each surviving transplant produced over seven runners during the summer growing season (Table 19).

In the middle zone saltgrass established on all planting dates, except April. However, survival was low, ranging from 2 to 7 percent. This low rate reflects a large loss due to washout from the continual wave action with dispersal of the unstable soil from around the transplants. Vegetative reproduction in this zone was erratic ranging from 0 in January to 19 in the March planting. In the lower zone no transplants survived. This indicated not only loss due to washout, but also that saltgrass was not adapted for areas continuously inundated.

Saltgrass is adapted for use in the middle zone. It can tolerate frequent inundation due to tidal action and readily reproduces vegetatively forming a mat over the soil surface. Transplanting would be successful during the spring or summer, provided the wave action is reduced sufficiently to prevent washout. In addition, planting blocks of sod rather than individual rhizomes may enhance establishment.

d. Needlegrass. This salt marsh species did not establish on any of the planting dates in the upper zone (Table 18). However, in the middle zone, establishment did occur at all planting dates, except July. It reproduced rapidly and at a desirable rate (Table 19). The surviving January transplants had an average of about 21 new tillers per transplant. It should be noted that much of the survival and reproduction of needlegrass occurred in Block IV where protected from wave action. This species did not survive, regardless of planting date in the lower zone. It apparently will not tolerate continuous inundation.

Needlegrass could be of value for use in the middle zone if wave action is reduced during establishment. It can be planted during the winter or spring with about equal chance of establishment. Vegetative reproduction was much greater with winter transplants.

e. Common reed. The January planting of this species was the only one with any survival in the upper zone (Table 18). Reproduction from the surviving transplants averaged seven tillers (Table 19). In the middle zone survival occurred at all planting dates. The range was from 1 percent in January to 11 percent in July. Reproduction was low, one and one-half tillers or less per surviving transplant. In the lower zone, survival occurred in only the April and July plantings. The high survival rate for July could be misleading due to the short time interval between planting date and evaluation. Reproduction from the April planting was five tillers per surviving transplant.

This species does not appear to be adapted for use in either the upper or lower zones. It apparently cannot survive the high soil salinity in the upper zone nor the inundation or salinity in the lower zone. Transplants of this species were one of the least susceptible to washout. The value of common reed for stabilization is limited to the middle zone. Due to low survival rate it may have limited use. It can be planted anytime during the winter, spring, or summer in this zone.

f. American bulrush. This salt marsh species did not survive in either the upper or lower zones (Table 18). Survival in the middle zone occurred only with the July planting and the rate of reproduction was over one tiller per surviving transplant (Table 19).

This species is not adapted to the vigorous environment of the eroding clay shorelines along East Bay.

g. Olney bulrush. Establishment occurred in the upper zone at all planting dates, except April (Table 18). The highest rate, over 17 percent, occurred with the July planting. However, vegetative reproduction was low, about one tiller, regardless of planting date (Table 19).

In the middle zone, establishment occurred with each planting date, except March and April. Survival was greatest for the July planting and was less than 3 percent for the other two planting dates. Reproduction ranged from less than two tillers per surviving transplant in January and May to less than three in August. Olney bulrush survived only in the July planting in the lower zone and reproduction was less than two tillers per surviving transplant.

This species was susceptible to washout in both the middle and lower zones. Thus, if wave action is reduced, this species might have limited value in the middle zone. Either a winter or summer planting date should be used.

h. Saltmarsh bulrush. This marsh species established only in the January planting in the upper zone (Table 18) and at a rate of less than 1 percent. However, those surviving transplants did produce an average of four tillers (Table 19). In the middle zone, saltmarsh bulrush survived at all planting dates, except March and April. Survival ranged from 2 percent in May to over 10 percent in July. Reproduction was low, ranging from less than one tiller per surviving transplant in July to less than three in the January planting. This species did not survive at any of the planting dates in the lower zone.

Saltmarsh bulrush may be of limited value in the middle zone. It was not adapted to the harsh conditions of either the upper or lower zones.

i. Smooth cordgrass. This species is not adapted for winter or early spring planting in the upper zone (Table 18). However, survival for the late spring and summer planting dates ranged from over 11 percent to over 34 percent. Each surviving transplant produced over three tillers in the May planting, but less than one tiller in the July planting (Table 19). This low number for July may reflect the short time interval between planting and evaluation.

Survival was good for smooth cordgrass in the middle zone, ranging from a low of less than 6 percent in March to about 45 percent in May and July. These high survival rates were complemented by tiller production rates that ranged from about 5 tillers in July to 22 tillers per surviving transplant for the January plantings (Fig. 11).

Smooth cordgrass did not survive the winter and early spring planting dates in the lower zone. However, survival for May and July ranged from about 12 percent to 35 percent. Surviving transplants produced up to about nine tillers.

This species is well adapted for use in the middle zone. It rapidly establishes at a reasonable survival rate. Smooth cordgrass could be utilized in the middle zone with planting dates anytime during the winter, spring, or summer. However, indications were that late

Figure 11. Growth and tiller production of smooth cordgrass in the middle zone, Block IV. Transplants were made in January 1974; photo taken September 1974.

spring or summer transplants would have a higher survival rate. In the lower zone it is of questionable value because of low survival during the early spring period.

j. Big cordgrass. This cordgrass species did not survive at any of the planting dates in the upper zone (Table 18). Survival in the middle zone occurred at each planting date, except April. However, the survival rates were about 3 percent or less, regardless of planting date. Vegetative reproduction was approximately seven tillers per surviving transplant in January and March plantings (Table 19). Reproduction was slightly less for May and was reduced to one for the July planting. Big cordgrass transplants did not survive in the lower zone, regardless of planting date.

This species is not adapted for use in clay-loam shoreline stabilization. Survival did not occur in either the upper or lower zones. In the middle zone survival rate was erratic and low.

k. Gulf cordgrass. This species is the dominant plant of the vegetative cover in the upper zone. Thus, efforts were not made to establish transplants. In the middle zone, gulf cordgrass survived at all planting dates, except May (Table 18). Survival ranged from a low of about 1 percent in January to over 8 percent in July. Even though this species survived, it did not vegetatively reproduce (Table 19). Gulf cordgrass survived in only the May planting in the lower zone. The surviving transplants did not vegetatively reproduce.

This species does provide good cover and forage in the upper zone. However, results to date, indicate it is of little or no value in either the middle or lower zones.

l. Saltcedar. This introduced species of widespread occurrence has been difficult to establish by cuttings along the shoreline. Saltcedar survived in only the January and April plantings in the upper zone (Table 18). Survival was less than 7 percent and vegetative reproduction did not occur (Table 19). Survival of less than 2 percent was recorded for January and July plantings in the middle zone. Vegetative reproduction was not observed. This species did not survive in the lower zone, regardless of planting date.

3. Zonation.

The objectives of the planting studies were to determine planting dates and species adaptation by zones along East Bay. Thus, by orienting rows perpendicular to the shoreline, each species could be evaluated with regard to survival and reproduction at any point along this line.

Based on the data available three species, gulf cordgrass, giant reed, and smooth cordgrass are adapted for use in the upper zone (Table 20). Since gulf cordgrass occurs naturally, other species for use in

Table 20. Planted species arranged in order of decreasing mean survival percentage within zones. Survival percent based on data from the four study blocks and five planting dates.

Upper Zone		Middle Zone		Lower Zone	
Species	Survival (%)	Species	Survival (%)	Species	Survival (%)
Giant reed	21.8	Smooth cordgrass	26.7	Black mangrove	13.7
Smooth cordgrass	11.9	Gulf cordgrass	23.4	Smooth cordgrass	9.3
Black mangrove	7.0	Black mangrove	12.2	Olney bulrush	3.5
Olney bulrush	4.7	Olney bulrush	4.3	Common reed	2.3
Saltcedar	2.2	Saltgrass	3.0	Gulf cordgrass	0.7
Saltgrass	0.8	Saltmarsh bulrush	3.0	Giant reed	0.0
Common reed	0.1	Common reed	2.9	Saltgrass	0.0
Saltmarsh bulrush	0.1	Needlegrass	2.3	Needlegrass	0.0
Needlegrass	0.0	Big cordgrass	1.9	American bulrush	0.0
American bulrush	0.0	Giant reed	1.1	Saltmarsh bulrush	0.0
Big cordgrass	0.0	American bulrush	0.4	Big cordgrass	0.0
Gulf cordgrass*	0.0	Saltcedar	0.4	Saltcedar	0.0

*Species was not planted in this zone. It was the dominant plant in the native vegetation.

this zone may not be needed. Giant reed did readily establish, vegetatively reproduce, and produce seed. Thus, if needed, it could be utilized for stabilization in this zone.

In the middle zone, smooth cordgrass, gulf cordgrass, black mangrove, and saltgrass had good survival rates (Table 20). Smooth cordgrass appeared to be the best plant material for this zone, based on survival and vegetative reproduction rate. It appears to provide a rapid cover for erosion control. Black mangrove shows promise of providing long-term cover, based on survival, and could provide long-term protection with growth. Although the survival rates for saltgrass in the present plantings were low, it may be that by utilizing sod blocks instead of single rhizomes, this species would provide good erosion protection in this zone. Thus, in the middle zone, combination plantings of smooth cordgrass, black mangrove, saltgrass, and gulf cordgrass will provide for both rapid and short-term as well as long-term protection.

In the lower zone, black mangrove and smooth cordgrass should be planted in combination (Table 20). Smooth cordgrass would provide protection from erosion while black mangrove would provide a barrier against wave action.

4. Other Studies.

During this initial phase, other studies have been initiated in an attempt to gain information that would be of value in stabilization of eroding clay shorelines along the upper Texas gulf coast.

a. Block V. This study block consisted of a short section of shoreline that was mechanically sloped. After sloping, the block was utilized for a planting site.

Soil salinity was lowest in the upper zone, and within this zone decreased with depth (Table 21). There was very little difference in soil salinity between the middle and lower zones. In the middle zone the minimum (9,651 ppm) was in the surface 2 inches of soil while the maximum was in the 2- to 4-inch layer. In contrast, in the upper zone soil salinity increased with depth to a maximum of over 16,000 ppm in the 4- to 6-inch layer.

Soil pH varied only slightly within this block (Table 22). All readings, regardless of depth or zone, were near neutral.

Sodium was the most abundant cation in this block (Table 23). In the upper zone, Na concentration was highest in the surface 2 inches of soil and decreased with depth. In the middle zone it was twofold to threefold greater than in the upper zone and increased with depth. Sodium concentration in the lower zone was similar to that of the middle zone and exceeded 1,190 ppm at all depths.

Table 21. Mean soil salinity (ppm) by depth and zone for Block V.

Depth (Inches)	Upper Zone	Middle Zone	Lower Zone	Mean
0 to 2*	4,126	9,651	10,649	8,142
2 to 4	3,328	15,508	14,144	10,993
4 to 6	3,095	14,643	16,373	11,370
Mean	3,516	13,267	13,722	10,168

*Soil samples collected 24 May 1974.

Table 22. Soil pH for Block V by depth and zone.

Depth (Inches)	Upper Zone	Middle Zone	Lower Zone	Mean
0 to 2*	7.1	7.4	7.1	7.2
2 to 4	7.3	7.1	7.0	7.1
4 to 6	6.7	7.3	7.0	7.0
Mean	7.0	7.3	7.0	7.1

*Soil samples collected 24 May 1974.

Table 23. Mean quantities of extractable cations (μg/gm) (Ca - calcium, K - potassium, Mg - magnesium, Na - sodium) in the soil of Block V by depth and zone.

Cation	Depth (Inches)	Upper Zone	Middle Zone	Lower Zone	Mean
Ca	0 to 2*	21.5	47.5	80.4	48.1
	2 to 4	11.8	149.0	78.2	79.7
	4 to 6	11.5	136.6	156.3	101.5
	Mean	14.9	109.4	105.0	76.4
K	0 to 2	14.1	17.9	27.8	19.9
	2 to 4	12.9	23.5	23.1	19.8
	4 to 6	13.8	34.1	32.3	26.7
	Mean	13.6	25.2	27.7	22.2
Mg	0 to 2	58.9	251.0	180.1	163.3
	2 to 4	37.5	608.0	390.3	345.3
	4 to 6	44.9	427.7	375.9	282.8
	Mean	47.1	428.9	315.4	263.8
Na	0 to 2	518.2	1,029.1	1,199.5	915.6
	2 to 4	458.3	1,768.7	1,651.8	1,292.9
	4 to 6	453.2	1,761.2	1,556.5	1,257.0
	Mean	476.6	1,519.7	1,469.3	1,155.2

*Soil samples collected 24 May 1974.

Magnesium concentration was lowest in the upper zone, ranging from about 38 ppm in the 2- to 4-inch layer to about 59 ppm in the surface 2 inches. In the middle zone Mg occurred in larger quantities than in upper zone with the largest quantity in the surface 2 inches of soil. In general, Mg increased with soil depth in the lower zone.

Potassium occurred in small quantities in all zones and did not exceed 34.1 ppm in any zone or at any soil depth. In comparison to K, Ca occurred in larger concentrations with a maximum of over 156 ppm recorded in the 4- to 6-inch soil layer of the lower zone.

Plantings along East Bay are subjected to continual wave action and are in a soil of low structural stability. Thus, survival within this area cannot be based solely on the adaptability of the plant species to the saline environment. The conditions that control washout immediately after planting must be considered (Figs. 12 and 13).

In the lower zone of Block V, washout accounted for most of the mortality (Table 24). The range was from a low of about 29 percent for saltcedar to 100 percent for American bulrush, saltmarsh bulrush, gulf cordgrass and seeded smooth cordgrass. Thus, after washout and mortality only transplants of black mangrove and smooth cordgrass established.

Washout accounted for most of the transplant losses in the middle zone. Of the 12 species transplanted, 100 percent of 10 species were lost and less than 12 percent of the other 2 species survived washout. In addition, the seeded plot in this zone was eroded.

In the upper zone, the area seeded to smooth cordgrass was badly eroded and no germination was observed. In addition, all transplants of American bulrush were washed out. Species most resistant to washout in the upper zone were: gulf cordgrass, giant reed, black mangrove and saltgrass (Table 24). These same species ranked high in survival percent (Table 25).

A comparison of survival and washout by zone in Block V shows over 26 percent of the transplants in the upper zone survived, regardless of species. This was significantly higher than from either the middle (0.0 percent) or lower (4.1 percent) zones. Percent washout was 52.2, 98.6, and 77.4 for the upper, middle, and lower zones, respectively.

b. Height plantings. Based on observations, survival of black mangrove improved if two to four leaves of the transplants were exposed above the water. Thus, in October 1974, three blocks were planted to black mangrove of various heights to determine the relationship between height, water depth, and survival. Two additional plantings will be made, one in the winter and one during the spring 1975.

Figure 12. A general view of Block V, approximately 4 weeks following mechanical sloping.

Figure 13. A general view of Block V,7 months after mechanical sloping. Wave action eroded most of the 100 feet sloped.

Table 24. Mean percent survival (S), dead (D) and washout (WO) in Block V. Data presented by species and zone.

Species	Upper Zone			Middle Zone			Lower Zone			Combined Zones		
	S	D	WO	S	D	WO	S	D	WO	S	D	WO
Giant reed*	50.0	34.6	15.4	0.0	0.0	100.0	0.0	41.6	58.4	9.4	3.0	61.2
Black mangrove	35.7	17.9	46.4	0.0	5.5	94.5	18.9	25.3	55.7	17.5	18.9	63.6
Saltgrass	34.5	6.9	58.6	0.0	0.0	100.0	0.0	36.2	63.8	8.9	16.9	74.1
Needlegrass	0.0	40.0	60.0	0.0	0.0	100.0	0.0	7.6	92.5	0.0	13.5	86.6
Common reed	24.0	44.0	32.0	0.0	0.0	100.0	0.0	44.4	55.6	6.2	27.8	66.0
American bulrush	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
Olney bulrush	23.1	19.2	57.7	0.0	0.0	100.0	0.0	14.0	86.0	5.3	10.6	84.0
Saltmarsh bulrush	12.0	36.0	52.0	0.0	0.0	100.0	0.0	0.0	100.0	3.0	9.0	88.0
Smooth cordgrass	31.0	0.0	69.0	0.0	0.0	100.0	1.3	2.6	96.1	7.0	1.4	91.6
Big cordgrass	14.3	25.0	60.7	0.0	0.0	100.0	0.0	8.1	91.9	2.9	9.4	87.7
Gulf cordgrass	74.9	3.5	20.7	0.0	0.0	100.0	0.0	0.0	100.0	19.6	0.9	79.5
Saltgrass	11.5	34.6	53.9	0.0	11.1	88.9	0.0	71.1	28.9	1.9	51.6	46.5
Seeds (Smooth cordgrass)	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0

*Planting was on 23 March 1974 and evaluation was on 18 June 1974.

Table 25. Mean percent survival of each species by zone in Block V. Species are arranged in descending order of survival.

Upper Zone		Middle Zone	Lower Zone	
Gulf cordgrass	74.9 c*	No	Black mangrove	18.9 d
Giant reed	50.0 b	Survival	Smooth cordgrass	1.3 d
Black mangrove	35.7 ab			
Saltgrass	34.5 ab			
Smooth cordgrass	31.0 ab			
Common reed	24.0 ab			
Olney bulrush	23.1 ab			
Big cordgrass	14.3 a			
Saltmarsh bulrush	12.0 a			
Saltcedar	11.5 a			
American bulrush	0.0 a			
Needlegrass	0.0 a			
Seeds (Smooth cordgrass)	0.0 a			

*Means followed by the same letter within zones are not significantly different at the 95 percent level.

c. Wave-stilling device. Indications were that wave action combined with the structurally unstable soil was responsible for most of the low survival rates measured for the five planting dates. In November 1974, a wave-stilling device was installed. To date it has been effective in eliminating losses of transplants due to washout.

5. Germination.

Approximately 24 percent of the seed collected in November and December 1974 contained caryopsis. Smooth cordgrass seeds, in glumes, germinated under laboratory conditions (Table 26). Seeds with glumes removed had the lowest germination percentage. Mechanical damage or excessive drying with glume removal may cause the lower germination percentage. Germination of seeds stored under dry and cold conditions was slower than for seed stored wet and cold. However, total germina-

Table 26. Percent seed germination of smooth cordgrass seeds stored dry and in seawater at 6° Celsius. Other treatments were seeds with glumes, glumes removed, collection date, and effect of gibberallic acid. Germination was in dark at alternating thermal periods of 20° Celsius (16 hours) and 30° Celsius (8 hours).

Treatment	Collection date	Imbibing medium	% Germination* 7 days	9 days	16 days	18 days
Dry seeds in glumes	10 Nov. 73	Distilled water	4	18	65	73
Dry seeds in glumes	10 Nov. 73	Distilled water	7	31	86	87
Wet seeds in glumes	10 Nov. 73	Distilled water	72	82	87	89
Wet seeds in glumes	10 Nov. 73	Distilled water	78	82	84	88
Dry caryopses, no glume	10 Nov. 73	Distilled water	2	21	64	69
Wet seeds in glumes	1 Dec. 73	Distilled water	61	69	75	77
Wet seeds in glumes	1 Dec. 73	Distilled water	74	78	80	81
Wet seeds in glumes	1 Dec. 73	Distilled water	67	79	83	86
Wet seeds in glumes	10 Nov. 73	100 ppm GA_3	70	75	79	81
Wet seeds in glumes	10 Nov. 73	100 ppm GA_3	81	85	88	88
Wet seeds in glumes	10 Nov. 73	100 ppm GA_3	63	70	79	79
Wet seeds in glumes	10 Nov. 73	25 ppm GA_3	75	79	87	88

*Germination tests were conducted January 1974.

tion after 18 days was similar, regardless of storage conditions. Gibberellic acid did not affect germination after cold storage treatments. Seeds stored under wet and cold conditions remained viable through July 1974.

Seeds planted 23 March 1974 in a 10- by 12-foot wave-protected plot (Block IV) failed to establish. Many seeds were germinating at time of planting. Seeds planted the same date in rows in Block V also failed to establish.

Soil samples collected at the shoreline, 50 and 150 feet from shore, on 20 June were returned to the laboratory. After 3 weeks no seedling plants were observed in any of the samples. If viable seeds were present in the soil samples they should have germinated within this time interval. Smooth cordgrass seeded into 11 soil samples collected from the study blocks and moistened with seawater had a 33 percent germination rate. Thus, the soil or its inherent salinity was not a factor in seed germination.

VII. TIME AND COST

Saltcedar required the least amount of time to transplant. The stems could be pushed into the ground without digging (Table 27). Saltgrass was easily dug, separated, and planted. Seedlings of black mangrove could be pulled from the soft mud with little trouble. Separation was not necessary, reducing the time requirements for transplanting. Needlegrass grew in large bunches with rhizomes. The material was not difficult to dig, but did require separation which was not difficult. Many culms of smooth cordgrass could be pulled from soft mud or easily dug, and separation by hand was usually easy. Gulf cordgrass was hard to dig during dry conditions but the large clumps could be separated by hand. Saltmarsh bulrush was hard to dig in most instances because individual plants had to be removed from masses of saltgrass roots. Pulling was more efficient time-wise then digging but stems often broke. Common reed was difficult to dig because of the massive root structure and rhizomes. Separation and cutting of stems were also necessary. Big cordgrass possessed a deep root system and grew in a soil that required extensive digging. Separation of plants and cutting of stems also took time. American bulrush grew in a location often covered by water. Extensive digging was necessary to extract the root system. Giant reed required picks and shovels to dig, but plants were collected relatively fast. Cutting of rhizomes by axe, pick axe, or edge of shovel was necessary for separation of plants. Large holes were necessary to plant the rhizomes. Olney bulrush was difficult to dig, separate, and plant and required the greatest amount of time.

Planting required more time than digging or separating, regardless of species. Mechanical instead of manual operations could greatly change time requirements for each species. Man-hours and vehicles required to transport each species from source to planting site were not compiled since that time was variable.

Table 27. Man-hours required to dig, separate, and transplant 1,000 plants of each species used in five monthly plantings. Species are arranged in order of total man-hours required to handle. Data are based on total man-hours recorded and number of plants planted in the monthly plantings.

Species	Planting material	Man-hours required			
		To dig	To separate	To plant	Total
Saltcedar	cut stems 15 to 30 inches	3.0	0.0	5.0	8.0
Saltgrass	1 to 5 culms w/roots	1.4	1.3	8.6	11.3
Needlegrass	1 to 5 culms w/rhizomes	1.5	1.3	8.9	11.7
Black mangrove	seedlings 6 to 24 inches	3.7	0.0	8.3	12.0
Smooth cordgrass	1 culm w/roots	1.7	0.8	10.9	13.4
Gulf cordgrass	small clumps	1.5	1.8	9.9	13.2
Saltmarsh bulrush	1 culm w/roots	5.7	1.5	10.7	17.9
Common reed	1 culm w/roots	5.2	1.8	11.5	18.5
Big cordgrass	1 culm w/roots	5.0	1.7	14.4	21.1
American bulrush	1 culm w/ roots	9.3	0.9	14.4	24.6
Giant reed	1 culm w/rhizomes	7.1	2.1	18.4	27.6
Olney bulrush	small clumps	4.1	4.9	20.3	29.3

Sloping of long stretches of shorelines with a bulldozer does not appear to be feasible. Draglines or other equipment may be more practical. Sloping of the shoreline in Block V took approximately 14 hours and the total cost for 200 feet was $350. This did not include transportation costs. Techniques for rapid establishment of vegetation or for shoreline protection until vegetation is established must be perfected before sloping can be justified.

Cost of wave-stilling devices could be variable. A 140-foot wave-stilling device was constructed for only the cost of labor, fencing, wire, and hog rings. If costs of hay bales, steel posts, and cable were added, the cost would be considerably higher. Approximately 15 man-hours were required for actual construction. Time to load, transport, and unload hay bales at the site was not included. A 150-foot roll of 3-foot and a roll of 4-foot chicken wire was required. Thirty metal posts 5 feet tall or more plus additional shorter stakes were used. A total of 105 bales of hay were used in construction.

VIII. SUMMARY

This study, started fall 1973, was conducted along the north shoreline of East Bay on the Anahuac National Wildlife Refuge, Chambers County, Texas.

Water salinity fluctuated throughout the year. Two peaks of high salinity occurred, the first, of relatively low magnitude, was from mid February to May 1974 and the second, of higher magnitude, was from June to November. In general, water salinity was related to monthly precipitation and distance of collection point from a source of freshwater.

Soil physical and chemical characteristics were determined. The soil was generally classified as loam or clay loam texture, and was considered structurally unstable and susceptible to erosion. Soil salinity ranged from about 2,500 to over 11,000 ppm in February 1974. In May the salinity values were higher in all blocks than in February. Soil salinity in February and May 1974 was consistently higher than water salinity. Soil pH was consistent and near neutral in all samples. Extractable cations (Ca, K, Mg, Na) fluctuated in concentration by date, depth and zone. Sodium was the most abundant cation, followed in decreasing order by Mg, Ca, and K. In general, all cations occurred in larger quantities in May than in February.

Twelve plant species were selected to evaluate for use in shoreline stabilization. Giant reed is adapted for use in the upper zone, above normal high tide. Black mangrove established in both the middle and lower zones and apparently has value in these zones. Saltgrass may be adapted for use in the middle zone if wave action is reduced at the time of planting. Common reed may have limited value in the middle zone. American bulrush does not appear to be adapted for use in shoreline stabilization. Olney bulrush could be of value in the middle zone with a reduction in wave action during establishment. Saltmarsh bulrush is not adapted for use. Smooth cordgrass is well adapted for use in both the middle and lower zones. Big cordgrass is not adapted for use. Gulf cordgrass is well adapted for use in the upper zone. Saltcedar does not appear to be adapted for use along East Bay. Valuable species for use in the upper zone are gulf cordgrass, giant reed, and smooth cordgrass. In the middle zone a combination planting of smooth cordgrass, black mangrove, and saltgrass should provide both long and short term protection and stabilization. In the lower zone a combination planting of smooth cordgrass and black mangrove should reduce shoreline erosion.

Mechanical sloping was not successful. Within 7 months most of the 100-foot-sloped area had eroded to a cutbank. Studies of smooth cordgrass seed indicated that germination occurred following either a cold and wet or a cold and dry treatment. A recently constructed temporary wave-stilling device successfully prevented washout of transplants.

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