MAINTENANCE DREDGING EFFECTS ON VEGETATION ADJACENT TO THE GULF INTRACOASTAL WATERWAY - CEDAR LAKES SECTION

by

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ABSTRACT

The relationship of spoil deposition and bank erosion to habitat condition and vegetation is examined in six sites along the Gulf Intracoastal Waterway in Brazoria County, Texas.

Fourteen mappable plant assemblages were identified by cluster analysis of data obtained along 100-meter transects and verified in the field. Species frequencies for these plant assemblages are presented in histograms and compared with environmental data collected along these same transects. Vegetation maps of an abstract nature depict the pattern of assemblages for each site.

Vegetation and habitat data from the individual sites, viewed in the context of historical land use and modification in the general study area, indicate that soil moisture is the limiting factor for plant growth both past and present. Deposition of spoil on the canal banks has led to less uniform and more dynamic conditions of soil moisture and has increased the range of soil moisture potentials. Spray from passing boats and bank erosion has added a new dimension of wetting and drying along the canal. These effects are observable in the pattern of vegetation. Alternatives for the placement and management of spoil materials are presented which allow some control over the distribution and composition of vegetation.

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INTRODUCTION

The Gulf Intracoastal Waterway extends 426 miles along the entire coast of Texas. The Waterway which is generally twelve feet deep and one hundred and twenty-five feet wide cuts across a number of different habitats including: bays, river mouths, grass flats, mud flats, and salt and brackish water marshes.

The construction of the GIWW in Texas has had a major impact on the coastal marshes of Texas (U.S. Army Corps of Engineers, 1974). Changes in the pattern of drainage and tidal inundation were introduced to which the marsh vegetation has accomodated. Aside from the initial impact, the canal provides continuous disturbance to the marsh ecosystem. Disturbances result from heavy boat traffic and maintenance dredging. Among the disturbance events are: deposition of spoil materials, bank erosion, and the consequent drainage realignment.

The U.S. Army Corps of Engineers has the responsibility of maintaining the Gulf Intracoastal Waterway. Segments of the Waterway are maintained by periodic dredging to remove accumulations of sediment and siltation. Dredging frequencies vary from twelve to ninety-six months. In the past, spoil materials have been deposited on land, in open water, and in the marsh.

Traffic along the canal creates waves which break against the canal banks eroding them. Barges occasionally bump into the bank gouging out sizable portions of the bank which then erodes to some semi-stable equilibrium.

Drainage realignment in segments of the marsh is caused by locally changed base levels and impedance of flow due to deposition of dredged material. These modifications of drainage change the direction of sheet flow and may lower the water within the marsh, thus modifying salinities and surface soil moisture regimes.

The coastal marshes are a vital component of the coastal ecosystem because they serve to take up, convert, store, and supply basic nutrients. They also provide a necessary habitat for many birds and animals, grazing for cattle, and help reduce coastal flooding by absorbing storm waters.

The Army Corps of Engineers recognizes the strategic importance of the marsh ecosystem and has stated the intention of avoiding the use of marsh areas as disposal grounds. However, the Army Corps of Engineers foresees that deposition in marshlands cannot be entirely avoided. They estimate that 4,464 acres of marsh will be covered in future dredging operations in Texas (U.S. Corps of Engineers, 1974: 64). Furthermore, it is possible that edge effects from the deposition of spoil materials will be felt along the whole of the 426 miles of Intracoastal Waterway in Texas.

It is generally accepted that the maintenance and use activities associated with the GIWW are sources of disturbance to Texas coastal marshes. There is, however, a lack of information on the response of the Texas coastal marsh vegetation to particular disturbances. For this reason a study was initiated to examine along one section of the GIWW the response of salt marsh vegetation to spoil deposition and bank erosion.

The objectives of this study were: 1) to describe the vegetation of limited areas adjacent to the GIWW where it traverses coastal marsh; 2) to determine the environmental factors which are controlling with respect to the distribution of plants in the study areas; and 3) to examine the relationship of spoil deposition and bank erosion to habitat condition and vegetation.

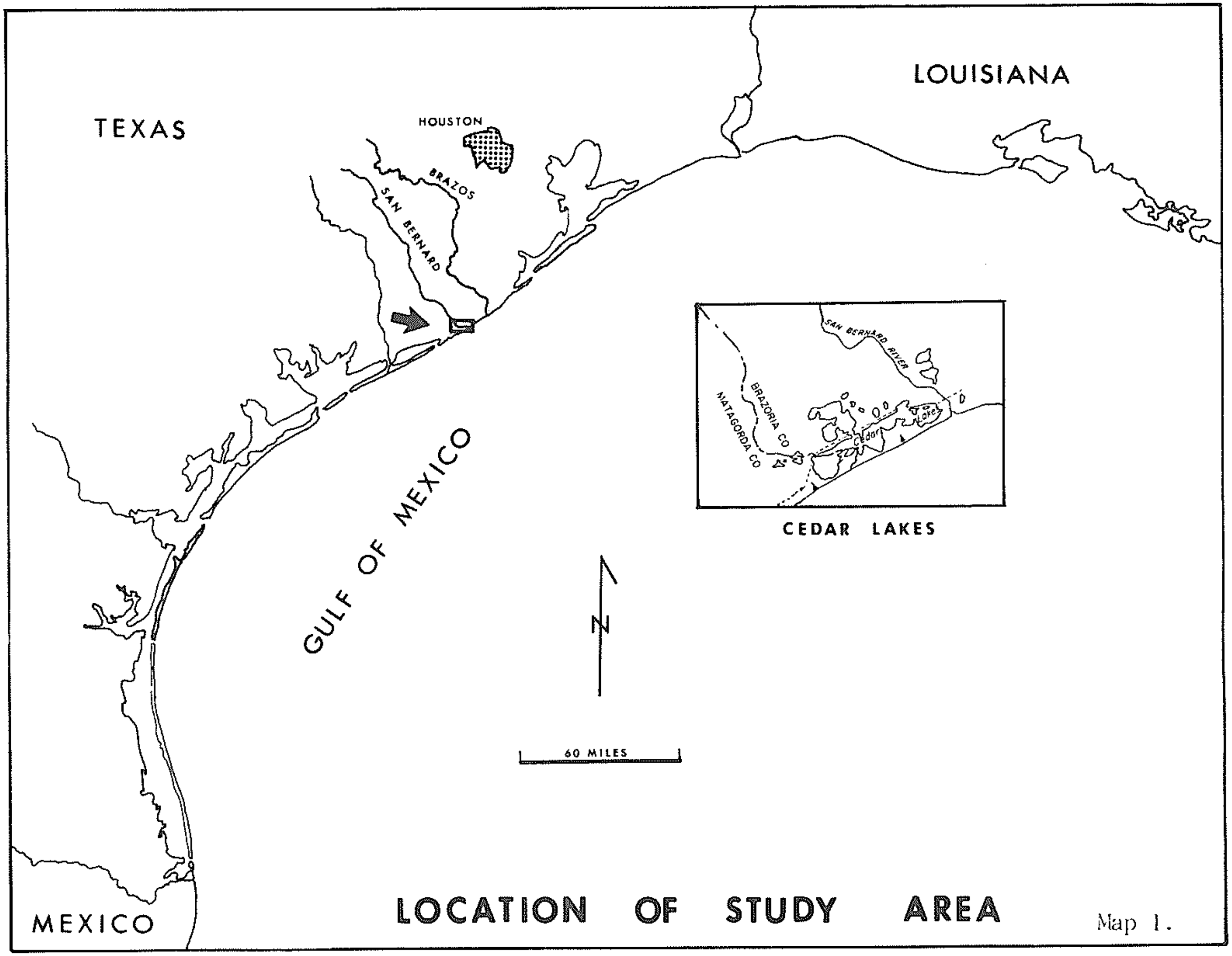
THE SETTING

An eight-mile segment of the Gulf Intracoastal Waterway between the San Bernard River and Cedar Lakes Creek was selected as the study area (see map 1). The area is approximately 70 miles southwest of Houston and is within the bounds of Brazoria County. The name Cedar Lakes is used locally to identify the area and refers to four large interconnected lakes which form a chain along the Gulf side of the present GIWW.

The area is a natural marsh basin enclosed by a levee of the San Bernard River and Cedar Lakes Creek and a barrier beach ridge on the Gulf side. Intermittently filled ponds and permanent lakes dominate the landscape. Cowtrap Lake, inland from the Waterway, is the largest of these and drains across the GIWW into Cedar Lakes. Elevations range from -3 feet in the bottom of Cowtrap Lake to +4 feet in the high marsh. There is a gentle slope of less than .001 from the adjacent coastal prairie to the sea.

The marsh substrate is Beaumont clay of Pleistocene age overlain by interdistributary sand, silt, and mud (Bureau of Sport Fisheries and Wildlife, 1974, p. 19). The "marsh soil" is a dark, mucky clay with a high organic content.

The vegetation of the high marsh is dominated by *Spartina patens* and *Spartina spartinae*, while in the low marsh the predominant species are *Spartina alterniflora*, *Distichlis spicata*, *Batis maritima* and *Salicornia* spp.



LOCATION OF STUDY AREA

Map 1.

Abundant rainfall and almost continuous growing season make the marsh an extremely productive biome. Net primary productivity for a Spartina salt marsh has been estimated to be over five times that of a South Carolina grass field (Crisp, 1972: 78). However, much less of the salt marsh is directly consumed by herbivores. Most of the salt marsh production remains as standing crop until it decays and finds its way into the estuarine food web. Locally collected data indicate the Texas Spartina dominated marshes are similarly productive (Ivy, per com. 1976).

Rainfall averages 49.16 inches in coastal Brazoria County and has a bimodal distribution. Precipitation peaks in the early spring and again in the fall. In terms of potential evapotranspiration, there is an average annual surplus of four inches (McGowen et al., 1976). However in the year 1975, which immediately preceded this investigation, there was an overall deficit of ten inches. This probably had important consequences with regards to the results of vegetation sampling in the area. The average mean free air temperature is about 70°F. Temperatures occasionally go higher than 100°F. Damaging freezes occur rarely.

Hurricane surge is a destructive agent in the area. A surge height of ten feet can be expected approximately every one hundred years with a maximum surge of thirteen feet (Morton and Peiper, 1975: 29). Hurricane Carla in 1961 was the last major storm to affect the area. A maximum surge elevation of

12 feet was recorded near the adjacent city of Freeport and completely inundated the study areas.

The topography of the study area has changed dramatically in historic time, not only by natural processes such as shoreline erosion and hurricane (Morton and Pieper, 1975), but also by the construction of the GIWW. Originally there were only two small drainage outlets and the marsh water stayed fresh to mildly saline, although periods of high salinity did persist after hurricanes. These periods of high salinity usually lasted until the next heavy rains (Bureau of Sport Fisheries and Wildlife, 1974). The two drainage outlets were at the mouth of the San Bernard River and where Cedar Lakes Creek emptied into the Gulf. The construction of the GIWW increased drainage within the marsh and concomitantly the effects of tides. Small ponds previously permanent are now drained occasionally during abnormally low tides and water salinity over the marsh is significantly higher (Bureau of Sport Fisheries and Wildlife, 1974).

A five-foot-deep, forty-foot-wide channel between Matagorda Bay and the Brazos River was the first canal cut through the Cedar Lakes area. It was completed in 1917. For the most part, this canal ran through the chain of Cedar Lakes themselves and required only minimal dredging. In 1942, a completely new channel 12 feet deep and 125 feet wide was completed. The new canal was cut through the marsh and mudflats rimming the north side of Cedar Lakes. The old canal was abandoned and allowed to fill.

It is still a visible part of the landscape. It is the vegetation adjacent to the new canal, particularly that which is on the inland side of the waterway, which is the focus of this study.

The land bordering the inland side of the twelve-foot-deep waterway has been administered by the federal government as a part of the San Bernard National Wildlife Refuge since 1968. The refuge serves as a wintering ground for migratory geese and management is directed primarily towards that end. Livestock grazing on a permit basis and controlled burning are part of the regular management practices on the refuge. Grazing has been the important economic use of the Cedar Lakes marsh area since the early 1900s, and burning has traditionally been used to improve the forage conditions.

Grazing and or burning can have a variety of impacts on the marsh vegetation. Cattle graze selectively which can change the composition of the marsh. Plant composition may also be altered by burning which reduces the cover of dominant plants and allows new individuals to emerge. Heavy burns or grazing followed by a hurricane can result in sterile mud flat conditions. The impact of burning and grazing on the salt marsh depends on timing, frequency, and intensity.

The average dredging frequency for the GIWW at Cedar Lakes is thirty months, (U.S. Army Corps of Engineers, 1974). Dredging operations along all portions of the GIWW in Texas range from twelve to ninety-six months. Thirty months is near the average dredging frequency for Texas. This results in an annual dredged volume of approximately 400,000 cubic yards (U.S. Army Corps of Engineers, 1974) in this stretch of the GIWW.

The pipeline cutter dredge is the standard equipment for maintaining the canal. Typically, the discharge line from the dredge is connected with a flexible pipe or ball joint to a floating pipeline. The dredged material is carried in the pipeline to the disposal site. In the Cedar Lakes area, materials have been deposited on both sides of the waterway. Sufficient material has been deposited on the Gulf side to create an almost continuous barrier island. On the inland side, spoil mounds occur singly or as continuous strings of material. Elevations range from less than a meter to over four meters. Materials have been dumped within a few meters of the waterway's edge and as far back as 100 meters. Although a few of the mounds are heavily vegetated the majority are scarcely vegetated. In the flat relief of the coast, these largely bare mounds appear as stark, yellow hills. It is in the vicinity of these inland spoil dumps that the sample sites for this study were chosen.

THE SALT MARSH

Salt marshes are characterized by the presence of a relatively few species of plants which are distributed in distinct zones. These zones are monotypic stands or, less often, assemblages of a few species of salt-tolerant grasses, rushes, or succulent dicotyledons. Despite the apparent order in the distribution of plants, a salt marsh is a highly dynamic community. Stands change rapidly in size and location, sometimes disappear or even merge.

The literature on maritime salt marshes is extensive and a variety of ecological studies have been undertaken. Two of the more comprehensive works are V. J. Chapman's Salt Marshes and Salt Deserts of the World (Chapman, 1960) and D. S. Ranwell's Ecology of Salt Marshes and Sand Dunes (Ranwell, 1972). Both works give extensive treatment of the structure and function of salt marsh communities as well as information on the autecology of marsh species.

The salt marsh environment is highly stressed. The high concentrations of salt in the environment affect the osmotic potential of plant tissue and the ionic mix of the soil solution is substantially different from that encountered by most terrestrial plants (Queen, 1974). Additionally, the periodic inundation of plants below the high-water mark and the generally saturated condition of marsh soil restricts the supply of oxygen to the upper part of the plant and shuts it off from the lower parts (Purer, 1942). Only a relatively small number of plants are capable of tolerating these conditions.

Marsh plants have evolved a number of mechanisms to cope with the stressed conditions. To insure their survival in saline environments marsh plants are frequently succulent, may have salt-secreting glands, a more vigorous transpiration or selective ion adsorption ability. Some plants, notably the Spartina species, have developed specialized vascular tissue which transports air to the root zone. In this manner they can survive periods of inundation.

Salt marsh species have not all adopted the same strategies nor to the same degree and so they vary in their ability to tolerate salinity and inundation. The variability of the plants to survive these stressful conditions helps to explain at least in part their distribution in the salt marsh.

A variety of studies have dealt with the complex physical factors which determine the distribution of plants in the marsh.

Johnson and York working at Cold Spring Harbor, New York, came to the conclusion that zonation in the salt marsh was related to small differences in submergence and emergence ratios determined by elevations and tidal inundations (Johnson and York, 1915).

Based on the conclusions of Johnson and York, Adams was able to develop a characteristic constant for each salt marsh species (Adams, 1963). The constant (K_j) is defined as the mean elevation of occurrence above mean sea level divided by one-half the mean tide range of the area. Adams identified two major zones in a North Carolina marsh: high marsh and low marsh. Low marsh with an average K_j of 1.13 included the species: Spartina alterniflora, Salicornia perennis, Limonium nashii, and Juncus roemerianus. High marsh with an average K_j of 1.43 included the species: Aster tenufolius, Distichlis spicata, Fimbristylis castanea, Borrichia frutescens, and Spartina patens.

Jackson investigating the tidal marsh of the Gulf coast of Florida found that soil water salinity is the most important single factor in limiting plant growth in the communities studied. Tidal inundation, rainfall, and evaporation control the salinity of free soil water. The degree of inundation is controlled by slight changes in elevation; and evaporation is influenced by temperature, wind, insulation , density of plant cover, and soil texture (Jackson, 1952). Jackson observed the following distinct zones: 1) Fimbrystylis species with a soil water salinity range of 2.3-5.2; 2) Salicornia species with a range of 5.6-9.8; 3) Distichlis species with a range of 1.7-2.5; and 4) Juncus species with a range of .06-1.4.

Miller and Egler have discussed the importance of tides, salinity, water table, mowing and ditching, precipitation, and temperature for a Connecticut salt marsh. They found tidal influences to be the most obvious correlate with the segregation of vegetation but point out that the tidal marsh ecosystem acts as a single integrated phenomenon and that it may be premature to propose any cause or effect relationships as the final answer. In conclusion, they suggest that historic catastrophy may often be the necessary explanation for the complicated mosaic of marsh communities they found (Miller and Egler, 1950).

Although a number of the species described in the previous marsh studies are found on the banks of the Texas Gulf Intracoastal Waterway, the physical conditions are often radically different, and represent historically catastrophic conditions. Elevations are generally well beyond the tidal range, and the gentle uninterrupted gradients associated with the marsh zonation elsewhere are rare.

In summary, no one factor is controlling in the salt marsh. It is a combination of interrelated factors including: elevation, soils, tides, climate, and the characteristics of the plants themselves. Physical factors are extremely dynamic in coastal environments insuring the dynamic character of the salt marsh vegetation. Additionally, salt marsh is susceptible to long-lasting modification by natural or man-induced catastrophy. Catastrophy may and generally does modify one or more environmental factors beyond the variability previously experienced by the plants. Deposition of dredge spoil is such a catastrophic event. It lacks the dramatic impact of a hurricane, but because of its frequency and persistence in the landscape beyond the impact of deposition it represents a greater than normal fluctuation in environmental conditions and can significantly modify the salt marsh vegetation.

PROCEDURES

Six sites were selected in the Cedar Lakes area for vegetation sampling. The six sites represent the typical and visible variations in habitat. These include: high, medium, and low elevations; heavily and lightly vegetated spoil mounds; as well as spoil mounds adjacent to and spoil mounds several meters inland from the canal.

Five of the study sites were sampled by means of a series of four parallel transects one hundred meters in length. One site because of its apparent homogeneity was sampled using only two transects. Every twenty centimeters along the transects a metal pin was dropped vertically and the first plant or artifact touched was recorded. Transects were placed perpendicular to the canal and were spaced twenty meters apart. A total width of 80 meters insured that some transects would intercept spoil materials in sites where they occurred. This point intercept methodology has been found to be an excellent technique for low herbaceous cover like that generally found along the Waterway. An excellent review of the history of the technique, its limits, and uses is provided by D. W. Goodall in his paper "Some Considerations in the Use of Point Quadrats for the analysis of Vegetation" (Goodall, 1951). A further review of the technique is provided by R. E. Winkworth in his paper "The Use of Point Quadrats for the Analysis of Heathland" (Winkworth, 1954).

Soil samples were taken intermittently along the transects. Due to limited resources and time for soil analysis, soil samples were taken from the top four inches of the ground surface only and primarily where there were visible differences in soil color, texture, drainage, or plant cover.

The samples were classified nonsaline, saline, and saline-alkali after the manner described in the U.S.D.A. handbook, Diagnosis and Improvement of Saline and Alkali Soils. The term saline is used for soils that have an electrical conductivity of more than 4 and an adsorption ratio less than 15; pH is usually less than 8.5. Saline-alkali soils have a conductivity greater than 4 and an adsorption ratio greater than 15; pH is seldom higher than 8.5 (U.S.D.A., 1954). Most field crops can tolerate conductivities of 4-8. Few plants will grow above an adsorption ratio of 16. A sodium adsorption ratio of 15 will adversely affect the growth of most crop plants. The sodium adsorption ratio (SAR), electrical conductivity in mmhos/cm and pH of the soil samples were determined by technicians of the Texas A&M University Soil Testing Laboratory.

Substrate classes were also established from the soil samples by this worker. Samples were classified as silt, clay, stiff clay, sand, sand and clay, sand and stiff clay, silt and sand, or sand and shell. This same classification was used for the materials obtained in cores made in the study area soils in 1927-28 by the U.S. Army Corps of Engineers and will therefore permit comparison between the two periods (U.S. Army Corps of Engineers, 1929).

Elevations were determined every twenty meters along the transects by direct measurement of the waterway banks and by indirect measurements with a hand level. These measurements were made during periods of high tide. Historical information on mean low tide elevations in the study area were derived from the 1929 Corps of Engineers survey.

Using the transect point intercept data, the vegetation types were described as discrete groups of plants. A cluster analysis of the data was used to facilitate this classification of plant assemblages. A distance measure,

$$C(I,J) = \frac{(1 - (SUM(X(I,K) - X(J,L))^{2})^{1/2}}{\text{No. of terms in sum}},$$

based on a Pythagorean treatment of relative frequencies of species was the algorithm employed in a separate cluster analysis of each site. The frequency data was first normalized on a scale of 0-30 to give more weight in clustering to the less frequent species. In habitats such as the salt marsh where there is a paucity of species, the rare or infrequent species may be excellent indicators of subtle changes in environment.

The basic taxonomic unit for clustering was a twenty-meter section of the transects defined by one hundred data points. Smaller sections were tested but the resultant clusters were too indistinct for efficient interpretation. The use of a section larger than twenty meters yielded only gross information on plant distribution.

This particular clustering technique is an agglomerative classificatory method. The agglomerative method proceeds by comparing a large number of taxonomic units and subsequently fusing these together into a small number of groups. The final fusion combines all groups into a single all-embracing group. A detailed description of the technique is provided by R. E. Frenkel and C. M. Harrison in their paper "An Assessment of the Usefulness of Phytosociological and Numerical Classificatory Methods for the Community Biogeographer" (Frenkel and Harrison, 1974).

Histograms were prepared to depict the species and their normalized relative frequencies in the assemblage units. The following terms are used to describe the normalized frequencies in the assemblage units: frequent for relative frequencies greater than 20; occasional for relative frequencies between 10 and 20; infrequent for relative frequencies between 2.5 and 10; and rare for species having relative frequencies less than 2.5.

Vegetation maps of an abstract nature were prepared for each site. The distribution of assemblages along transects is represented by coded strips laid along the transect line.

Comparisons were then made of the individual study sites as they vary in habitat conditions and vegetation. The primary instruments for comparison being the abstract vegetation maps of the sites, the assemblage histograms, and the environmental data collected along the transects.

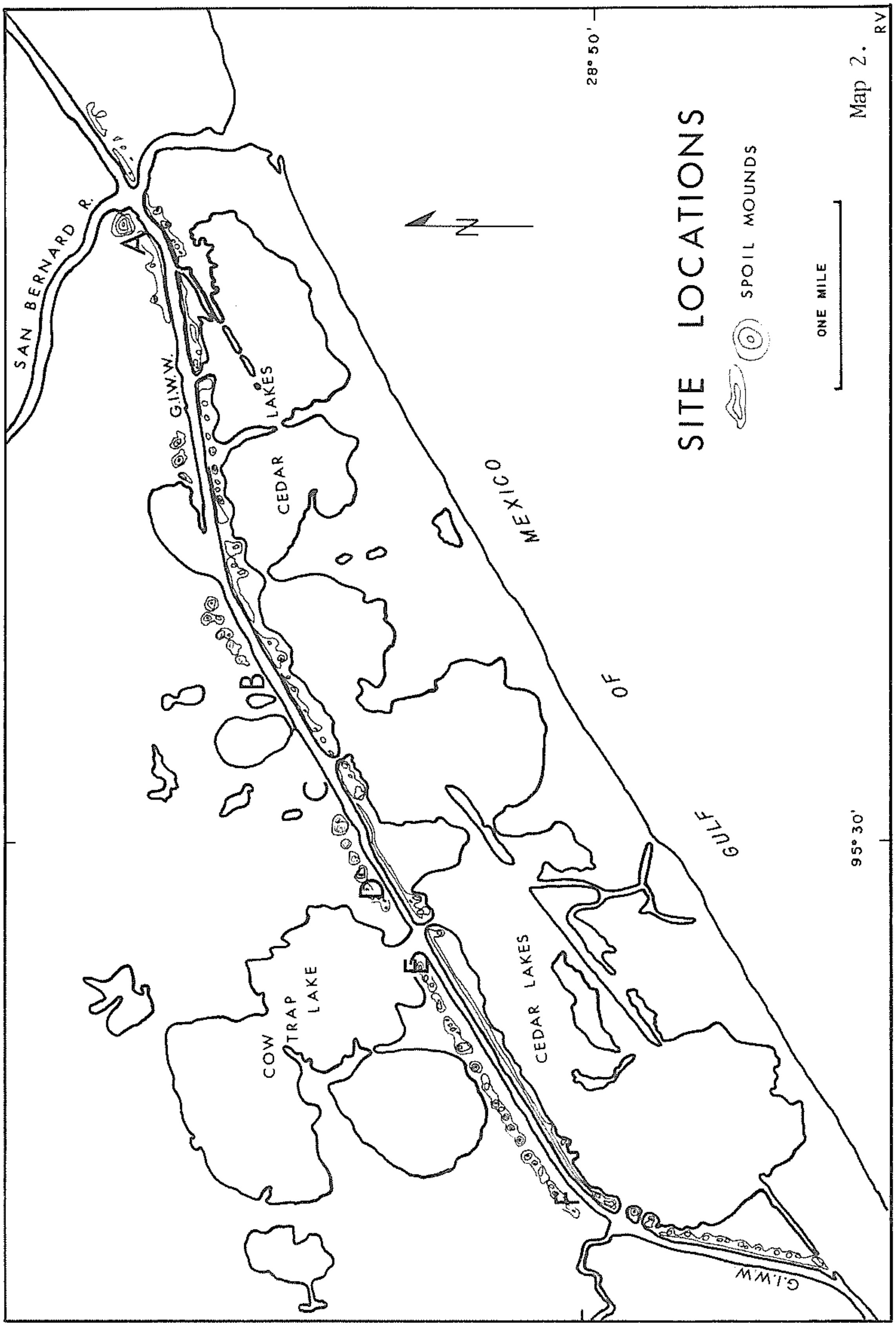
SITE DESCRIPTIONS

Site A lies immediately west and adjacent to FM road 2918 near the San Bernard River (Map 2). The area is not currently subjected to cattle grazing, but it is frequented by bank fishermen. General aspects of the site include two well-vegetated spoil mounds approximately 100 m apart and 40 m back from the canal. Sampling took place across the mound nearest the highway. The mound has a maximum elevation of 3.65 m and a length of 70 m. There is little evidence of surface erosion.

Two closely related vegetated zones are present in the sampled area. Zone 1 covers transect 1 and the first twenty meters of transects, 2, 3 and 4 (Fig. 1a). Zone 1 is coincident with the lower slopes of the mound which average 2.44 m. Elevation averages 1.23 m in Zone 1 (Fig. 1b).

In Zone 1 the vegetation assemblage is characterized by the following species and their relative frequencies (see Table 1). *Spartina patens* is frequent. *Borrichia frutescens* and *Rumex stenophyllum* are occasional and *Distichlis spicata*, *Salicornia* sp., *Melilotus officinalis*, *Oenothera speciosa*, *Ambrosia* sp., *Andropogon glomeratus*, and *Limonium nashii* are infrequent. Three unidentified herbs were also infrequent (Fig. 2).

Zone 2 assemblage is composed of frequent *S. patens* and *M. officinalis*; occasional *B. frutescens*, *O. speciosa*, and *A. glomeratus*; and infrequent *D. spicata*, *Batis maritima*, *Salicornia* sp., *Monthanochloe littoralis*, *Macheranthera phyllocephala*, *Labiatae* sp.,


SITE LOCATIONS
SPOIL MOUNDS
ONE MILE
RV
28° 50'
95° 30'
SAN BERNARD R.
G.I.W.W.
CEDAR LAKES
CEDAR LAKES
COW TRAP LAKE
GULF OF MEXICO
G.I.W.W
A
B
C
D
E
F

Map 2.

Fig. 1a. Abstract Map of Site A

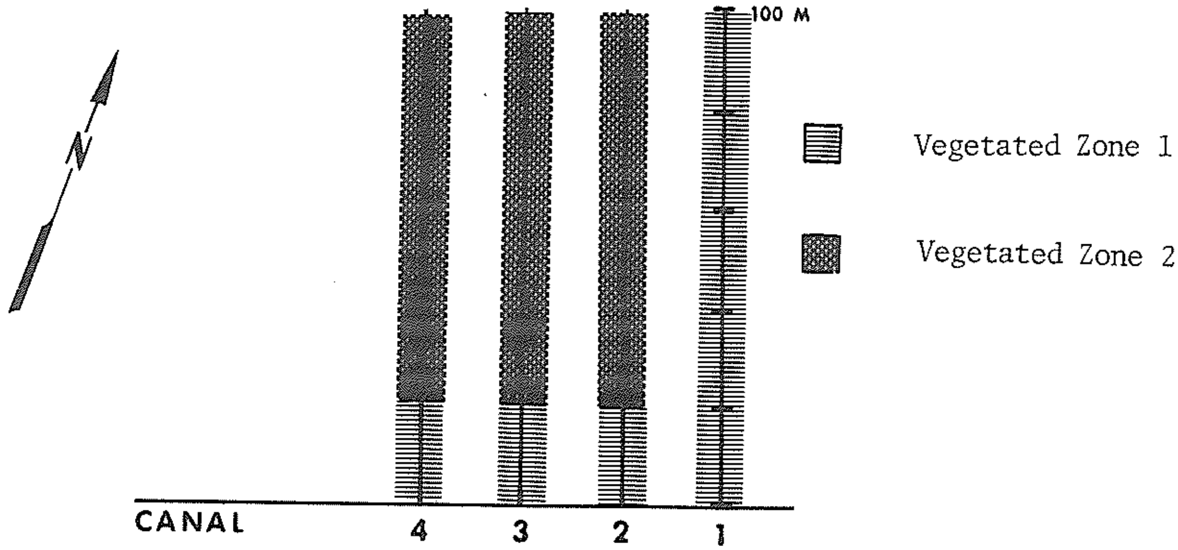
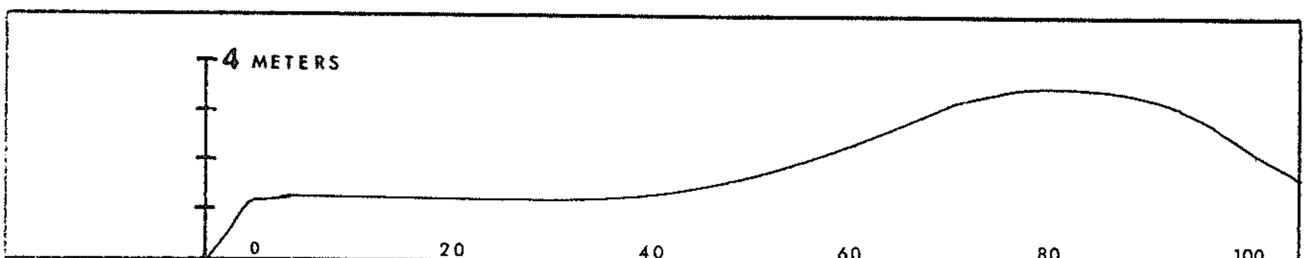


Fig. 1b. Transect 3 in Site A with Soils Analysis Data



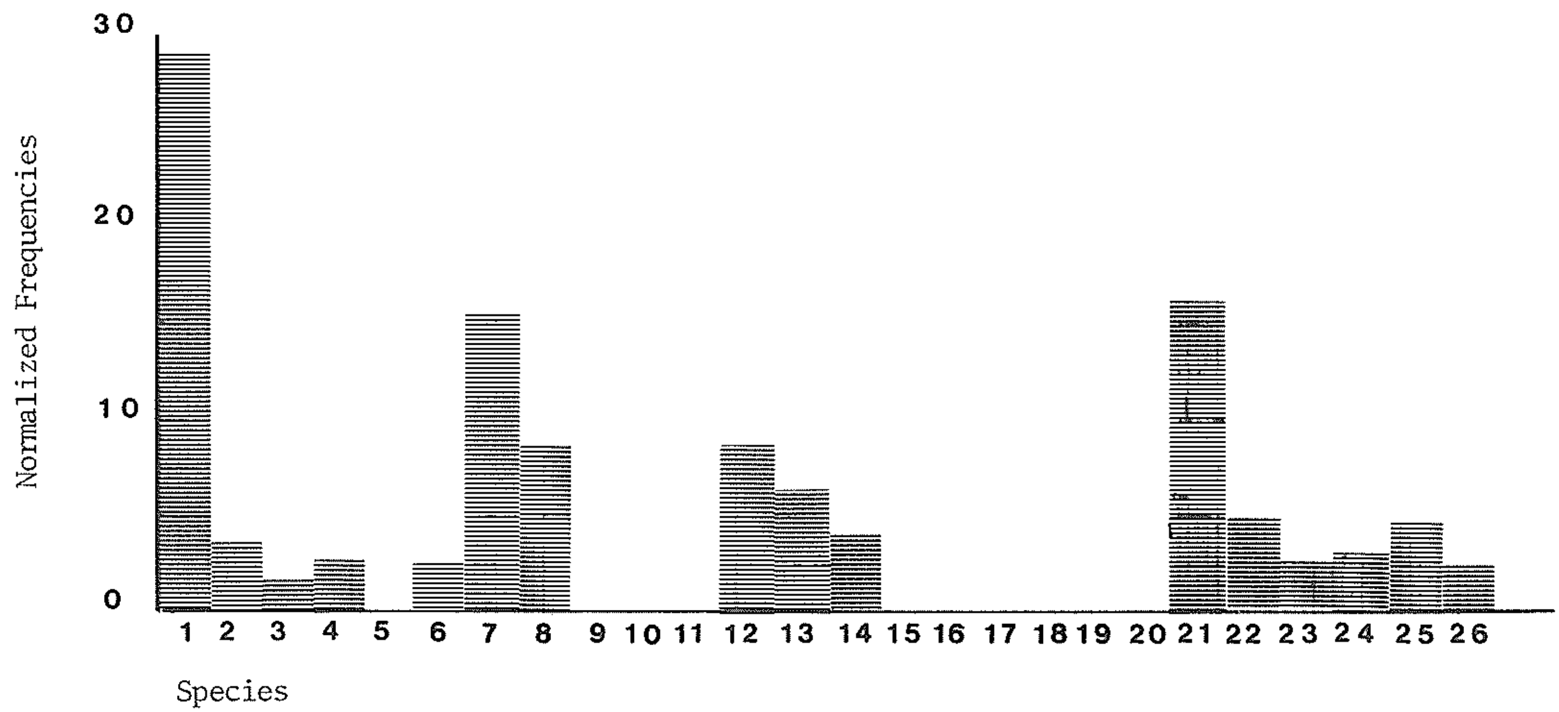
T-METER	20	64	100
S.A.R.	19.14	10.62	26.66
E.C.	5.62	2.92	7.78
pH	8.1	8.3	8.5
SUBSTRATE	shell clay	shell clay	shell clay
ELEV.	1.23	3.00	2.13

Source: Author field survey and Texas A&M University Soil Testing Laboratory

Table 1

CODE	SPECIES
1.	Spartina patens
2.	Distichlis spicata
3.	Batis maritima
4.	Salicornia sp.
5.	Spartina alterniflora
6.	Monthanochloe littoralis
7.	Borrichia frutescens
8.	Melilotus officinalis
9.	Macheranthera phyllocephala
10.	Sueada sp.
11.	unidentified shrub
12.	Oenothera speciosa
13.	Ambrosia sp.
14.	Andropogon glomeratus
15.	unidentified herb
16.	Labiatae sp.
17.	Setaria geniculata
18.	Sueada sp. 1
19.	Sueada sp. 2
20.	Sporobolis poiretii
21.	Rumex stenophyllum
22.	unidentified herb
23.	unidentified legume
24.	Limonium nashii
25.	unidentified compositae
26.	Baccharis sp.

Fig. 2. Species Frequencies for Site A, Zone 1



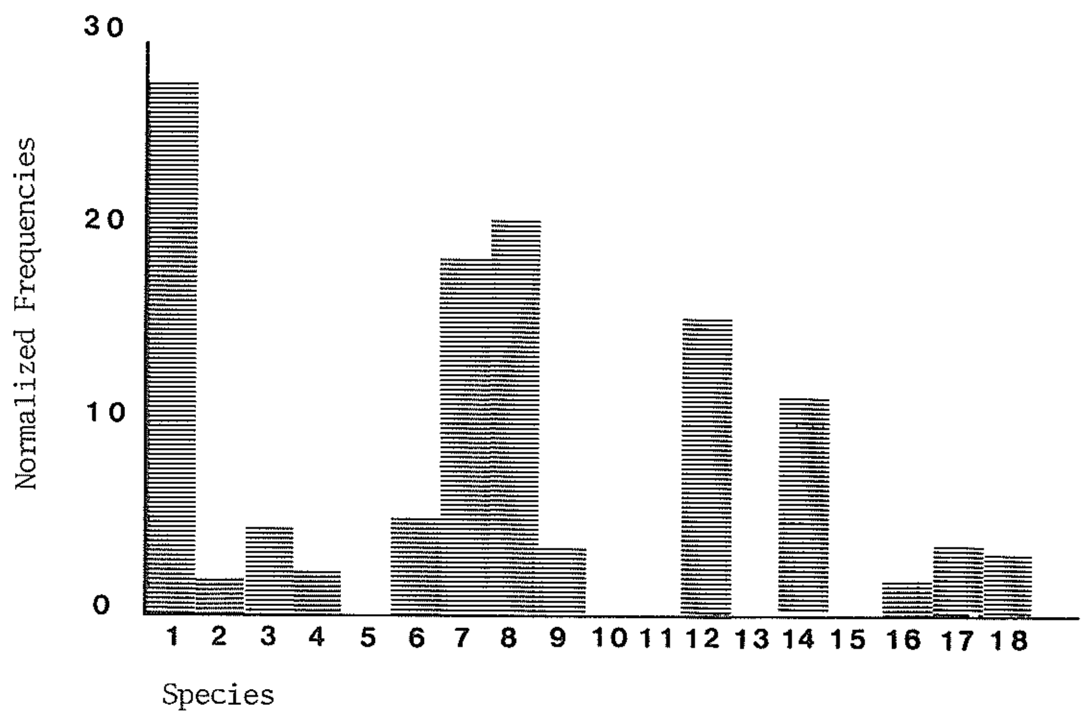
and three unidentified herbs (Fig. 3).

The substrate over the entire sampled area is shell mixed with clay. There is no zonation in the soils. Individual soil samples from both vegetated zones have been classified as ranging from non-alkali to saline-alkali. That is to say electrical conductivity (E.C.), sodium adsorption ratios (S.A.R.), and pH measures did not show any consistencies with plant zonation. For example, the E.C. within Zone 1 was 67.41 on transect 1 at 6 meters, 18.38 on the same transect at 10 meters, and 5.62 on transect 3 at 20 meters.

Elevation correlated well with zonation on site A. There are only small differences in the species makeup of the two zones. Differentiation rests primarily on the presence of R. stenophyllum and Ambrosia sp. in Zone 1 and the increased frequency of M. littoralis, B. frutescens, and M. officinalis in Zone 2.

Site B is located approximately two miles northeast of the entrance to Cowtrap Lake (Map 2). The area is low lying and adjacent to a small salt pond. There is gradual rise from the canal edge over a sand and clay beach to the vegetated area. This beach varies from 10 to 15 m in width (Fig. 4b). At the vegetation line elevations range from .17 to .25 m. Elevations stay within this range over the remainder of the transects.

Fig. 3. Species Frequencies for Site A, Zone 2



Only two transects were sampled. This seemed reasonable because of the apparent homogeneity within the area. The site consists of one vegetated zone and vegetation assemblage (Fig. 4a). *Distichlis spicata* and *Monthanochloe littoralis* are frequent; *Salicornia* sp. is occasional; *Batis maritima* is infrequent; and *Spartina patens*, *Melilotus officinalis*, and *Oenothera speciosa* are rare (Fig. 5).

Soil samples taken at 10 m, 30 m, 50 m, and 70 m on the first transect were composed of sandy clays saturated with water. Conductivity ranged from 40.45 to 76.41 and sodium adsorption ratios ranged from 57.79 to 82.76. Soil pH ranged from 7.6 to 7.8. All soil samples are classified high saline-alkali. There is little field or laboratory evidence that the area was ever used for spoil deposition.

Site C is located approximately one mile east of the entrance to Cowtrap Lake (Map 2). The area is relatively level, heavily vegetated, and there is no obvious deposition of spoil materials. The elevation is .40 to .50 m at the Waterway's edge and rises from there to a mean elevation of .60 m within the first twelve meters of the transect (Fig. 6b). At the time of the sampling (May 3, 1976) there were 12 areas of standing water intercepted by the transects varying in size from one to five square meters. The depth of the occasional stands of water varied from .01 m to .04 m. Soils were saturated over the whole site.

Fig. 4a. Abstract Map of Site B

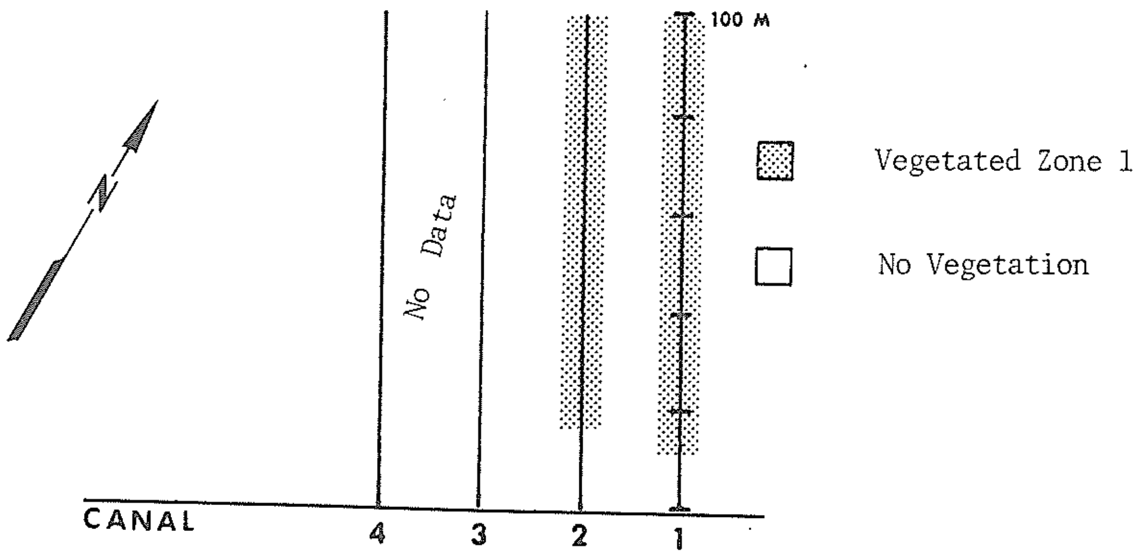
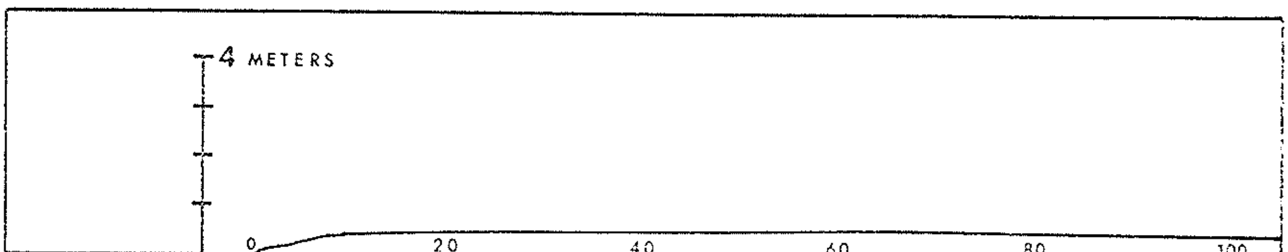


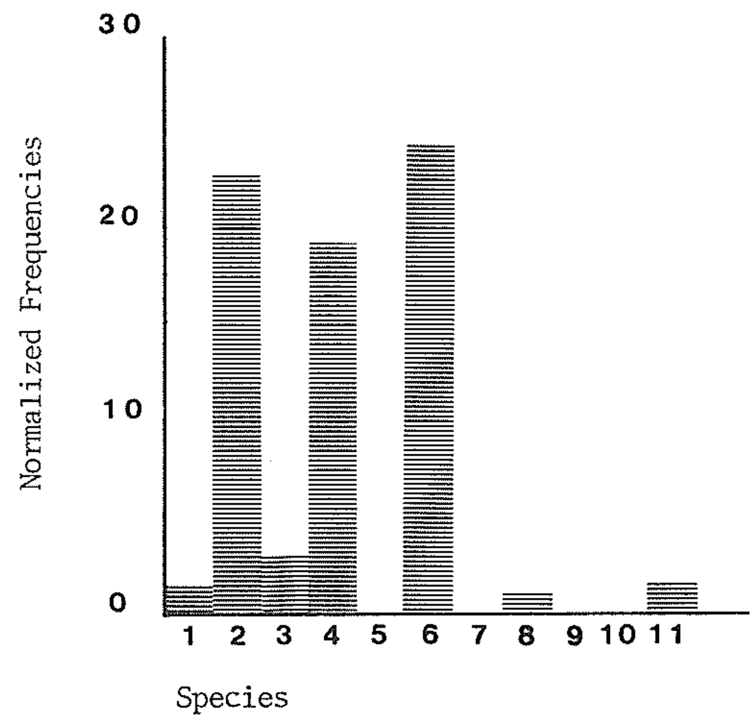
Fig. 4b. Transect 1 in Site B with Soils Analysis Data



T-METER	10	30	50	70
S.A.R.	82.76	57.79	70.15	60.63
E.C.	67.41	40.45	67.41	40.45
pH	7.6	7.7	7.7	7.8
SUBSTRATE	sand clay	sand clay	sand clay	sand clay
ELEV.	.20	.20	.20	.20

Source: Author field survey and Texas A&M University Soil Testing Laboratory

Fig. 5. Species Frequencies for Site B, Zone 1



Within the sampled area there were two distinct vegetated zones (Fig. 6a). Zone 1 occupies the first twenty meters of each transect from the canal water's edge. In Zone 1 the vegetation assemblage consists of Spartina patens, and Distichlis spicata which were frequent; Batis maritima and Salicornia sp. which were occasional; and Monthanochloe littoralis which was infrequent (Fig. 7a). It was observed that the interior edge of Zone 1 was the approximate limit of spray fall from passing boats and their washover.

In Zone 2 extending over the remainder of the transects only two species were encountered. S. patens was frequent and D. spicata was occasional (Fig. 7b). There were no observable differences between the vegetation of the inland standing water areas and the vegetation of adjacent dryer areas.

Soil samples taken at 8 m and 65 m on transect 2 had textures that were clay and sandy clay respectively. Both samples were classified as saline-alkali although there is a slight decrease in E.C. and S.A.R. between 8 m and 65 m along the transect.

Site D. is located one-half mile northeast of the entrance to Cowtrap Lake (Map 2). The site is dominated by a large spoil mound which begins approximately 60 m from the canal's edge (Fig. 8b). The mound reaches a maximum height of 4.25 meters and is 80 m at its greatest horizontal dimension. Numerous small gullies and rills are present on the actively eroding mound. Accumulations of sand are often found at the terminus of the gullies and clay nodules with diameters of .01 to .03 m

Fig. 6a. Abstract Map of Site C

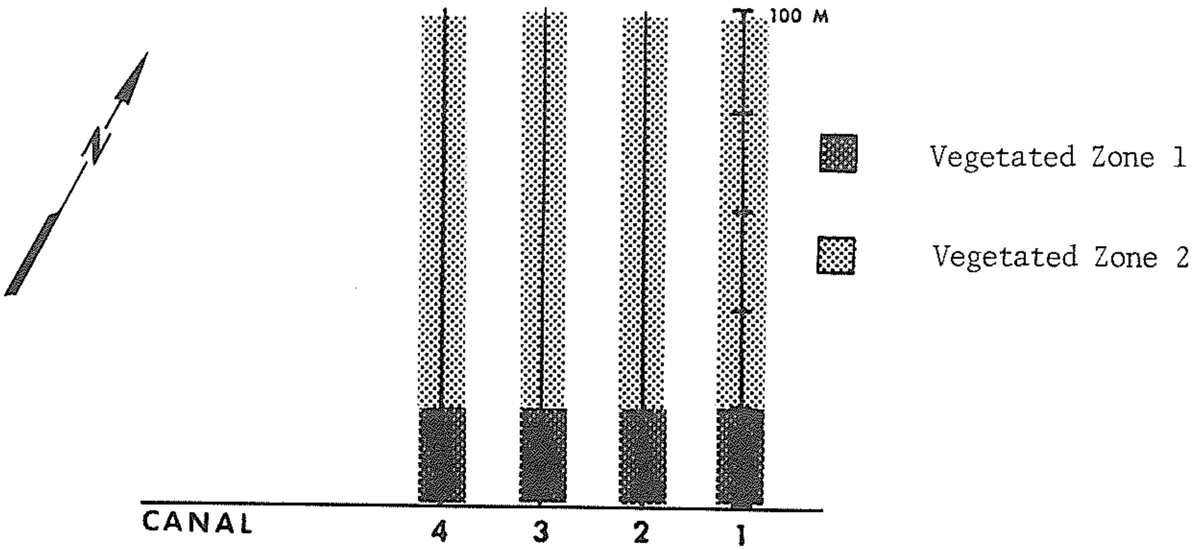
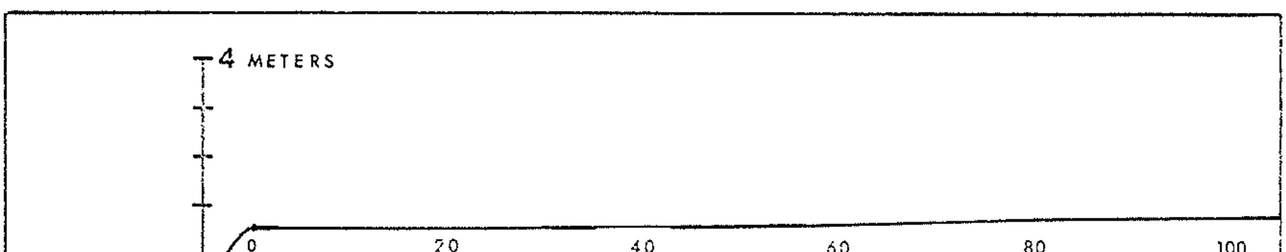


Fig. 6b. Transect 2 in Site C with Soils Analysis Data



T-METER	8	65
S.A.R.	45.22	36.14
E.C.	45.22	20.22
pH	8.0	8.1
SUBSTRATE	clay	sand clay
ELEV.	.45	.60

Source: Author field survey and Texas A&M University Soil Testing Laboratory

Fig. 7a. Species Frequencies for Site C, Zone 1

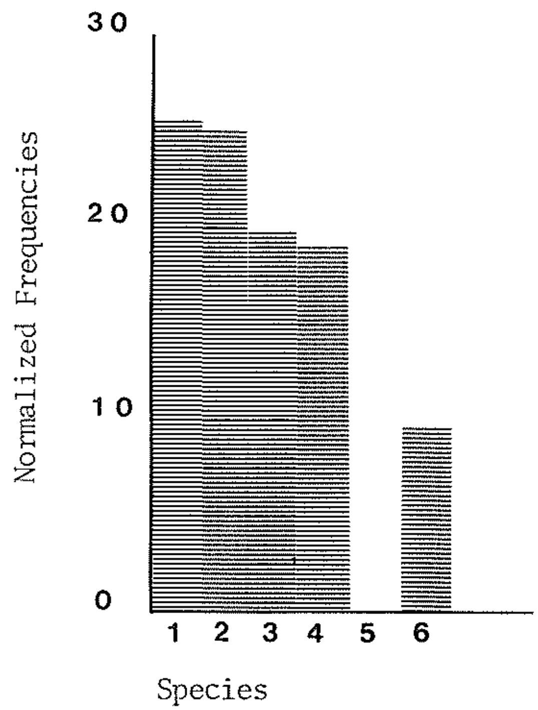
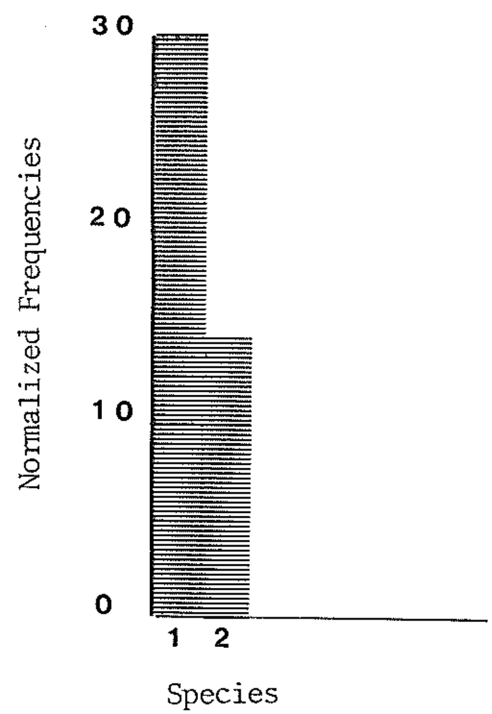


Fig. 7b. Species Frequencies for Site C, Zone 2



are found scattered on the surface of the mound. At the base of the mound is a ring of sand and very sandy clay varying in width from 5 m to 25 m. Vegetation is more dense on the level areas than on the mound.

The four sampling transects intercepted the mound variously at 60 m to 80 m from the canal (Fig. 8a). Elevations at the canal edge on transect 2 was .60 m (Fig. 8b). Within the next 60 m there is a slight rise in elevation to .74 m. After 60 m slope rises more rapidly and by 80 m the elevation is 3 m and at 100 m the elevation reaches 3.65 m (Fig. 8b).

Four vegetated zones are distinguishable in the area (Fig. 8a). Vegetation Zone 1 and its assemblage occupies the first 20 m to 40 m from the canal edge. This zone is composed of frequent Distichlis spicata and Salicornia sp. and occasional Spartina patens, Batis maritima, Monthanochloe littoralis, and Borrichia frutescens (Fig. 9).

Zones 2 and 3 occupy the central portions of the transects. Zone 2 assemblage is characterized by frequent Salicornia sp., occasional S. patens, and infrequent B. maritima and M. littoralis (Fig. 10a). Zone 3 assemblage is composed of frequent Salicornia sp. and frequent B. frutescens (Fig. 10b).

Zone 4 assemblages at the end of the transects are characterized by frequent D. spicata, M. littoralis, and Macheranthera phyllocephala. Sueada sp. is occasional. Infrequent species in

Fig. 8a. Abstract Map of Site D

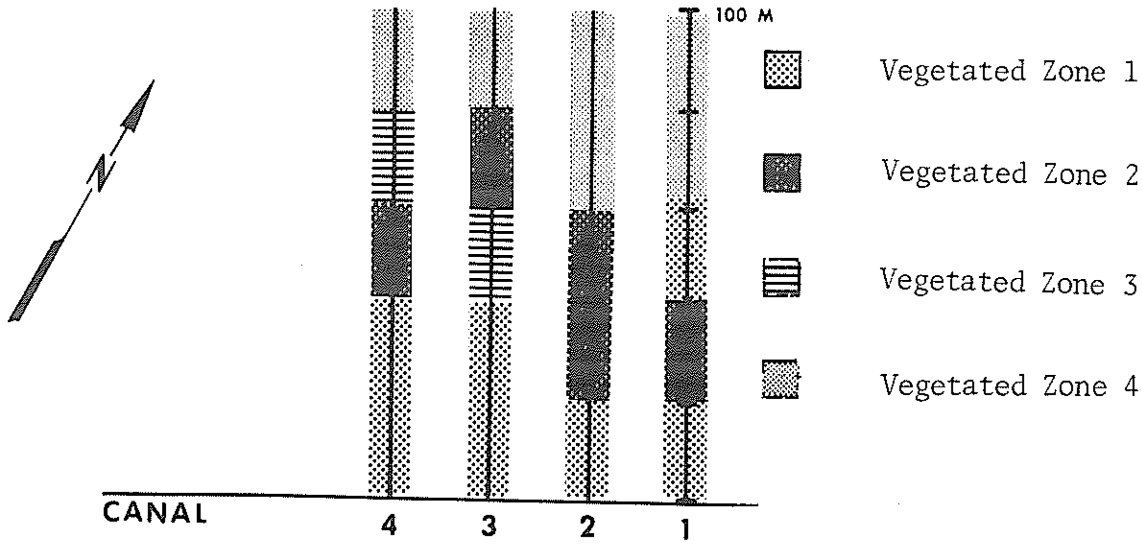
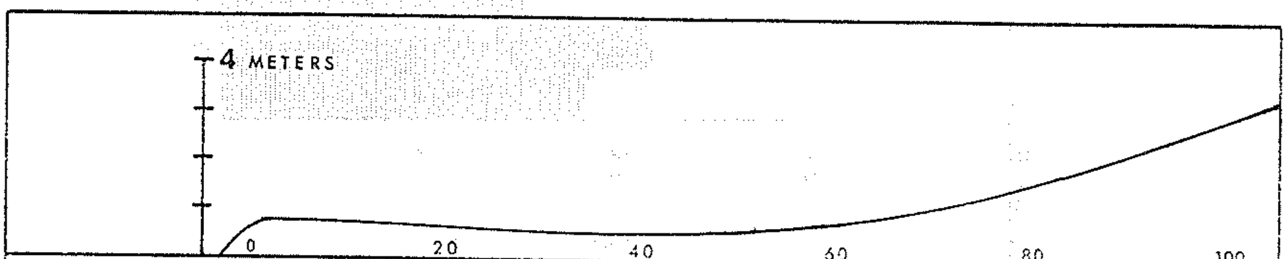


Fig. 8b. Transect 2 in Site D with Soils Analysis Data



T-METER	15	60	90
S.A.R.	57.54	52.17	64.00
E.C.	44.94	31.11	31.11
pH	8.0	7.2	7.8
SUBSTRATE	sand clay	sand	clay
ELEV.	.60	.74	3.35

Source: Author field survey and Texas A&M University Soil Testing Laboratory

Fig. 9. Species Frequencies for Site D, Zone 1

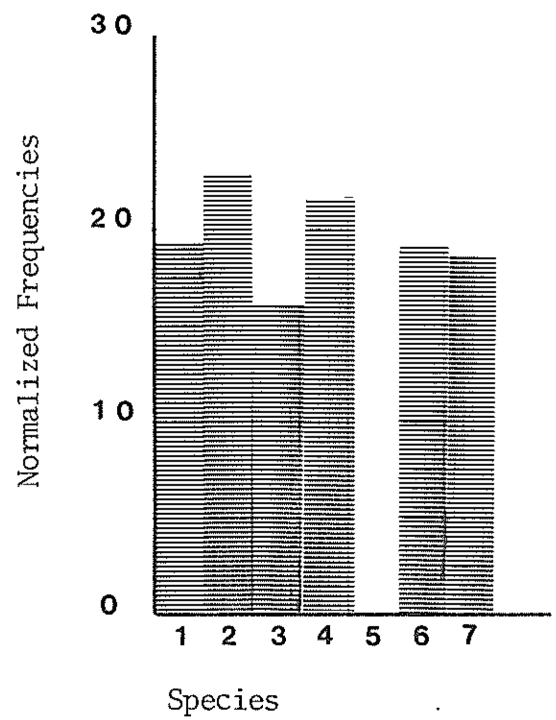


Fig. 10a. Species Frequencies for Site D, Zone 2

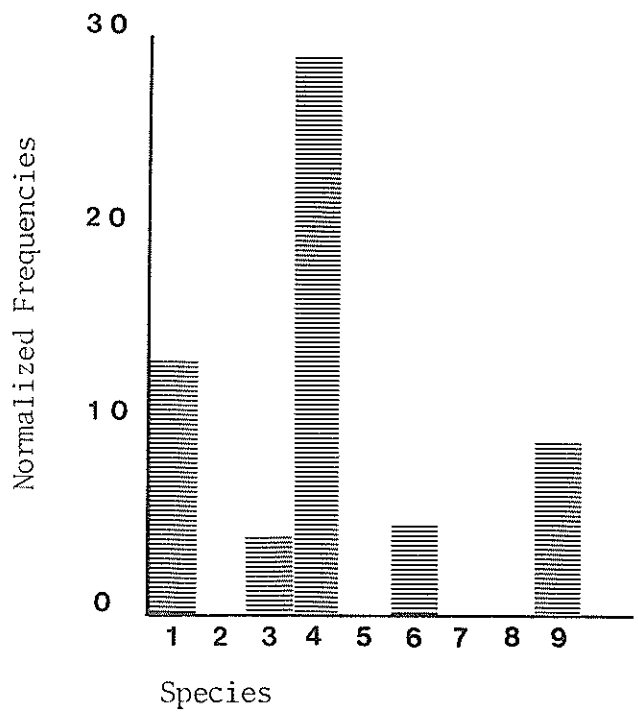


Fig. 10b. Species Frequencies for Site D, Zone 3

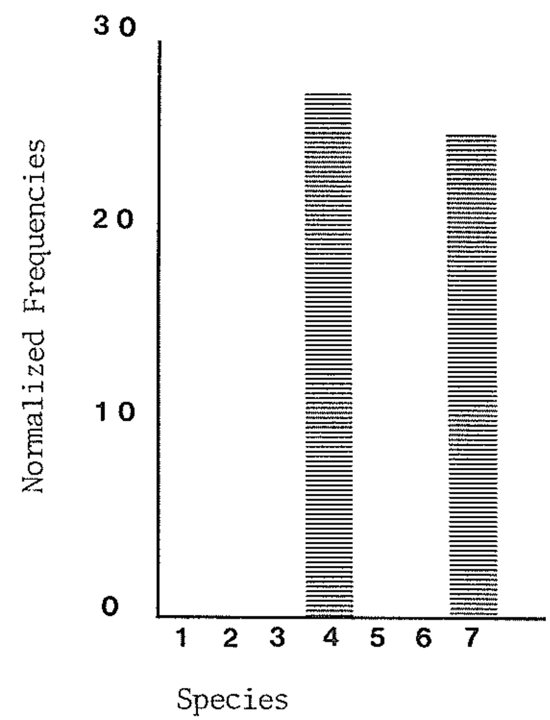
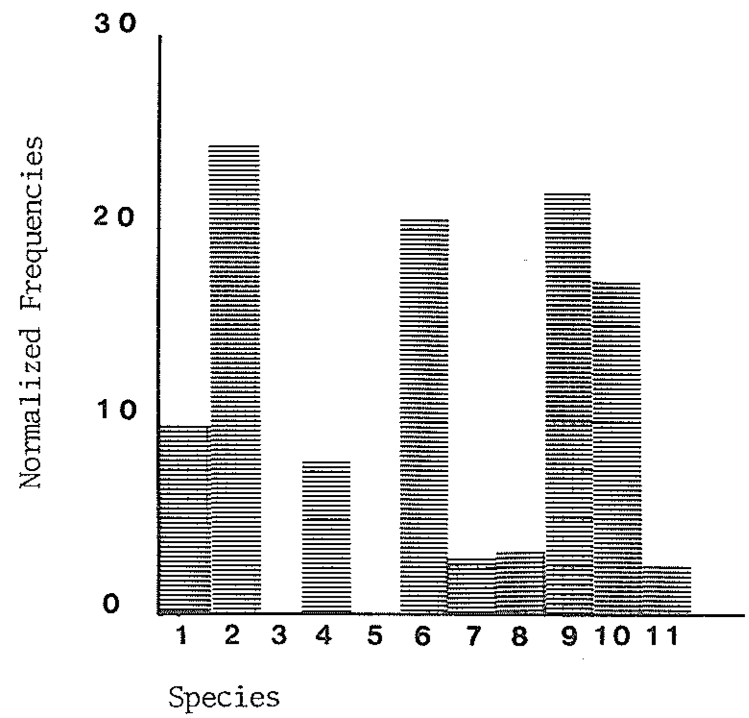


Fig. 11. Species Frequencies for Site D, Zone 4



this zone are S. patens, Salicornia sp., B. frutescens, Melilotus officinalis, and one unidentified shrub.

Three environmental zones can be differentiated in the study area which show some correlation with the vegetation zones. These are: 1) the level area preceding the spoil mound coincident with vegetation Zone 1; 2) the area at the base of the mound occupied by vegetation Zones 2 and 3; and 3) the spoil mound occupied by vegetation Zone 4.

The major differences in these environmental zones appear to be substrate, elevation, and slope. The substrate in the level non-spoil area is a sandy clay, at the base of the mounds the percentage of sand increases significantly and in some places is almost pure sand. The mound is composed of heavy, yellow clay. Elevations for the first two zones average .60 and .74 meters respectively. Most of the mound is over 2 m in elevation. Slope in the area at the base of the mound varies from 1% to 6%. Slopes on the higher portion of the mound often exceed 20% (Photo 1).

E.C., S.A.R. and pH are not significant factors in determining the three environmental zones. Soil samples taken across the environmental zones along the second transect over other parts of the site D are all high saline-alkali (Table 2). There is a slight decrease in E.C. and S.A.R. and pH values between the level area at 15 m and the base of the mound at 60 m on the second transect and no change in E.C. between 60 m and 90 m.

Table 2. Soils Analysis

STATION*	E.C.	S.A.R.	pH
A-1- 6	67.14	78.95	7.6
A-1- 10	18.38	43.30	7.3
A-1- 45	5.19	14.88	8.0
A-1- 60	44.94	59.66	8.0
A-1- 63	57.78	61.80	7.6
A-1- 76	2.30	8.00	7.8
A-2- 17	4.04	17.03	8.6
A-2- 60	16.85	31.30	8.1
A-2- 95	16.85	33.87	8.1
A-3- 20	5.62	19.14	8.1
A-3- 64	2.92	10.62	8.3
A-3-100	7.78	26.66	8.5
A-4- 33	1.93	4.08	8.2
A-4- 65	9.19	32.24	8.3
B-1- 10	67.14	82.76	7.6
B-1- 30	40.45	57.79	7.6
B-1- 50	67.41	70.15	7.7
B-1- 70	40.45	60.63	7.8
C-2- 8	45.22	45.22	8.0
C-2- 65	20.22	36.14	8.1
D-1- 8	57.78	61.43	7.6
D-1- 80	25.28	56.12	7.5
D-2- 15	44.94	57.54	8.0
D-2- 60	31.11	52.17	7.2
D-2- 90	31.11	64.00	7.8
D-4- 27	18.38	36.00	7.2
E-2- 20	6.74	23.68	8.4
E-2- 80	80.90	74.97	7.9
E-2-100	80.90	79.69	7.7
E-3- 60	11.24	26.33	8.4
E-4- 19	33.71	53.94	7.5
E-4- 36	12.64	43.55	8.2
F-1- 16	21.29	25.33	7.4
F-1- 36	6.74	16.01	8.0
F-1-100	2.02	11.67	8.6
F-2- 80	33.71	41.66	7.7

SOURCE - Field data analyzed by Texas A&M University Soil Testing Laboratory.

*Site-Transect-Meter

However, there is a general lack of consistency in the E.C., S.A.R. and pH measures for the same vegetation zones and environmental zones. Within vegetation zone 1 on transect 1 at 8 m the soil sample has an E.C. of 57.78, an S.A.R of 61.43, and a pH of 7.6. Within vegetation zone 1 on transect 4 at 27 m the E.C. is 18.38, S.A.R. is 36.00 and pH is 7.2. Ranges expressed in the soils analyzed in vegetated zone 1 bracket those of the soil in vegetated zone 4 since zone 4 on transect 1 at 80 m has an E.E. of 25.28, S.A.R of 56.12 and a pH of 7.5

Site E is a small well-vegetated peninsula on the west side of the entrance to Cowtrap Lake (Map 2). An eliptical spoil mound with a maximum elevation of 4 m rises 45 m southwest from the tip of the peninsula. Transects were laid across the peninsula and normal to the canal beginning 20 m west from the entrance channel to Cowtrap Lake (Fig. 12a). Succeeding transects were laid higher on the spoil mound until the fourth passed near the highest point on the mound. Maximum elevations ranged from .30 m on transect 1 to 3.65 m on transect 4.

Three vegetated zones are distinguishable in Site E. Vegetated zone 1 assemblage occupies the first and lowest lying transect and the lowest and last 20 m of transect 2. *Batis maritima* is frequent; *Salicornia* sp. and *Spartina alterniflora* are occasional; and *Spartina patens*, *Distichlis spicata*, and *Monthanochloe littoralis* are infrequent. *S. alterniflora* is clustered at the lowest end of transect 1 which is subject to tidal inundation from Cowtrap Lake (Fig. 13). Bare areas of up to seven meters in length were encountered in this zone (Fig. 12a).

Zone 2 assemblage occupies the central portion of transects 2, 3, and 4. The zone is distinguished by frequent S. patens, occasional Melilotus officinalis, and infrequent D. spicata, M. littoralis, Macheranthera phyllocephala, Oenothera speciosa, and Ambrosia sp. (Fig. 14).

Zone 3 assemblage is located at the beginning and the ends of transects 2, 3, 4 which lie on the lower slopes of the mound. The zone is characterized by frequent S. patens and D. spicata, occasional Salicornia sp., M. littoralis, M. officinalis, and infrequent M. phyllocephala, O. speciosa, and an unidentified shrub (Fig. 15).

There is little or no correlation between E. C., S. A. R., and soil pH with the distribution of vegetation zones (table 1) and (Fig. 12b). Zone 1 is associated with a substrate of sandy clay which occurs all along transect 1 and the last several meters of transect 2. Elevations for zone 1 are consistently below .30 m. The substrate for zones 2 and 3 is a dark clay. The differentiation of the vegetation may be related to elevation and or slope. Zone 2 is associated with the lower portions of the mound while zone 3 is associated with the high, central portion of the mound.

Site F is located 1.75 miles southwest of the entrance to Cowtrap Lake (map 2). The elevations at site F on the edge of

Fig. 12a. Abstract Map of Site E

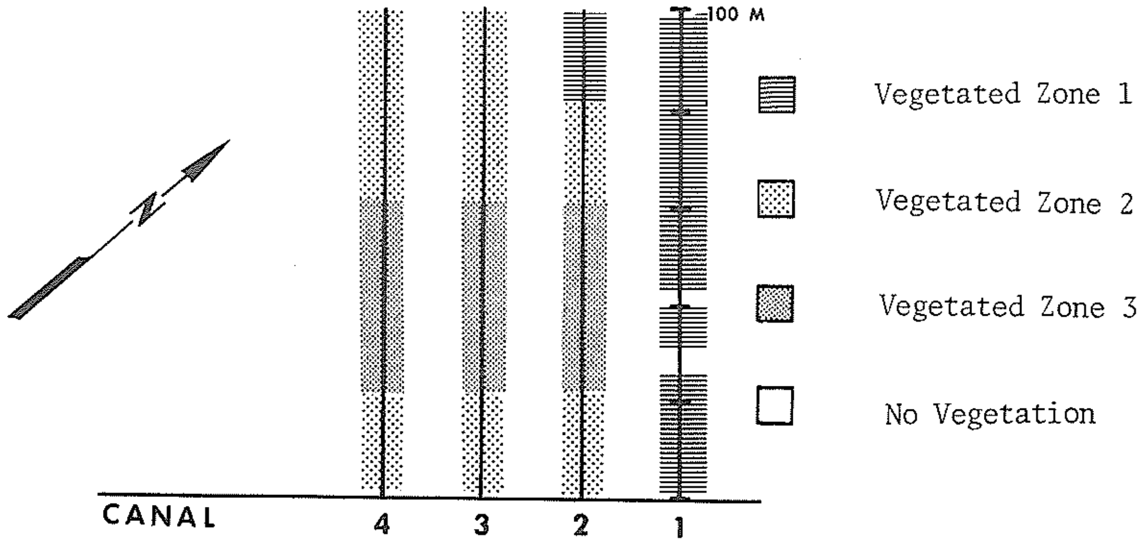
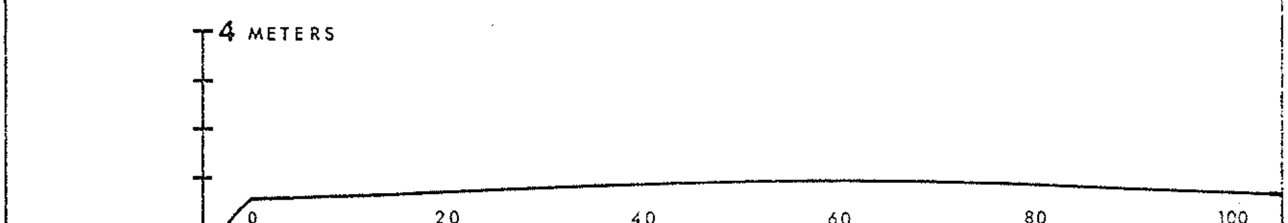


Fig. 12b. Transect 2 in Site E with Soils Analysis Data



T-METER	20	80	100
S.A.R.	23.68	74.97	79.69
E.C.	6.74	80.90	80.90
pH	8.4	7.9	7.7
SUBSTRATE	clay	clay	sand clay
ELEV.	.61	.43	.30

Source: Author field survey and Texas A&M University Soil Testing Laboratory

Fig. 13. Species Frequencies for Site E, Zone 1

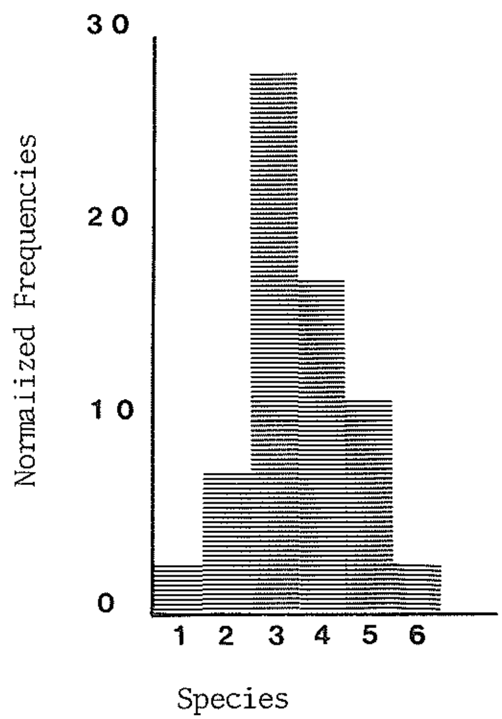


Fig. 14. Species Frequencies for Site E, Zone 2

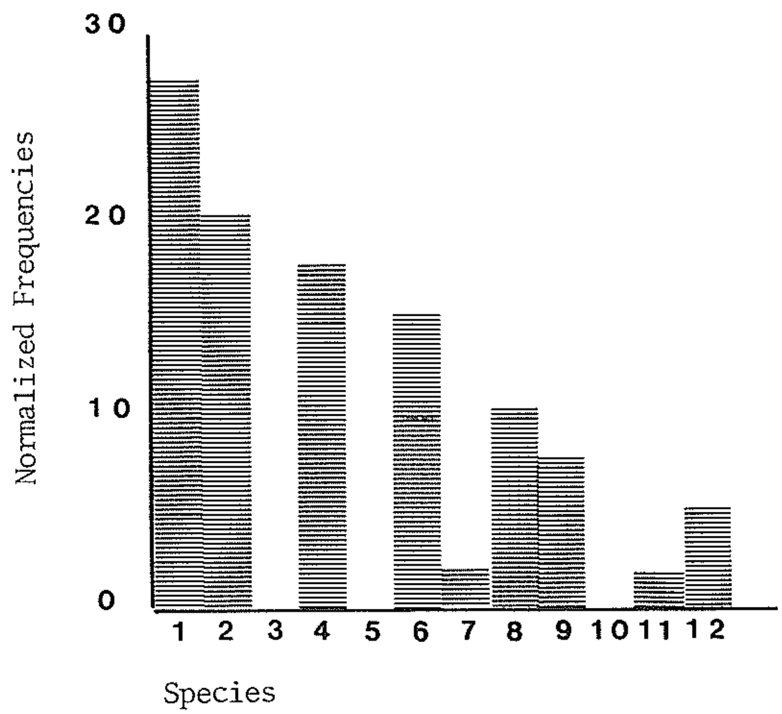
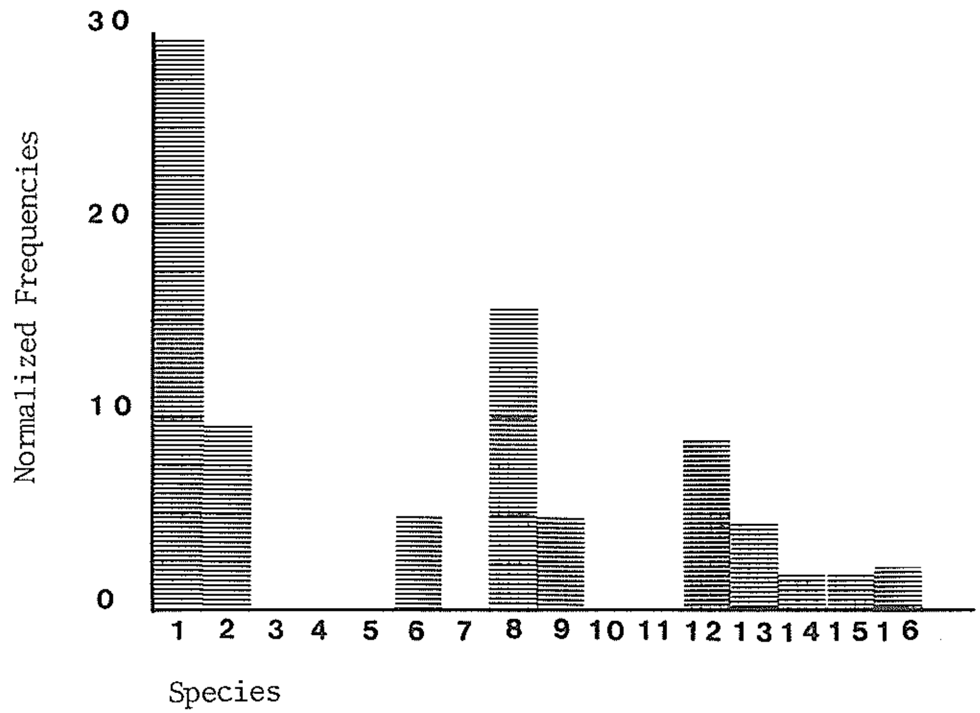


Fig. 15. Species Frequencies for Site E, Zone 3



the canal vary between .76 m and .86 m. From the edge inland elevations increase another 5 cm until a series of intermittent spoil mounds is reached. The mounds are located a distance of 60 m to 80 m from the waterway's edge, have diameters of 20 m to 50 m and reach elevations up to 4 m. The entire area was under moderate to heavy grazing at the time based upon evidence of trampling and the presence of a herd of cattle. Vegetation cover was heavy on the low-level areas and light on the mounds.

The first transect ran between two spoil mounds while the other three transects intercepted spoil mounds. Two vegetated zones are found in the study site. Zone 1 assemblage is found along all of transect 1 and those portions of the other transects that do not cross spoil mounds (Fig. 16a). *Spartina patens* and *Ambrosia* sp. are frequent; *Borichia frutescens*, *Oenothera speciosa*, and *Setaria geniculata* are infrequent. *Monthanochloe littoralis*, and one unidentified shrub are rare (Fig. 17).

In the zone 2 assemblage, *S. patens* and *M. littoralis* are frequent. *Salicornia* sp. and *Sueada* spp. are occasional. *Distichlis spicata*, *Batis maritima*, *B. frutescens*, *Macheranthera phyllocephala*, *Ambrosia* sp. and *Sporobolus poiretii* are infrequent (Fig. 18).

The mounds are composed of yellow and red clays and sand. There is much evidence of surface and gully erosion by water and sorting of materials. Sand accumulations in the form of small

Fig. 16a. Abstract Map of Site F

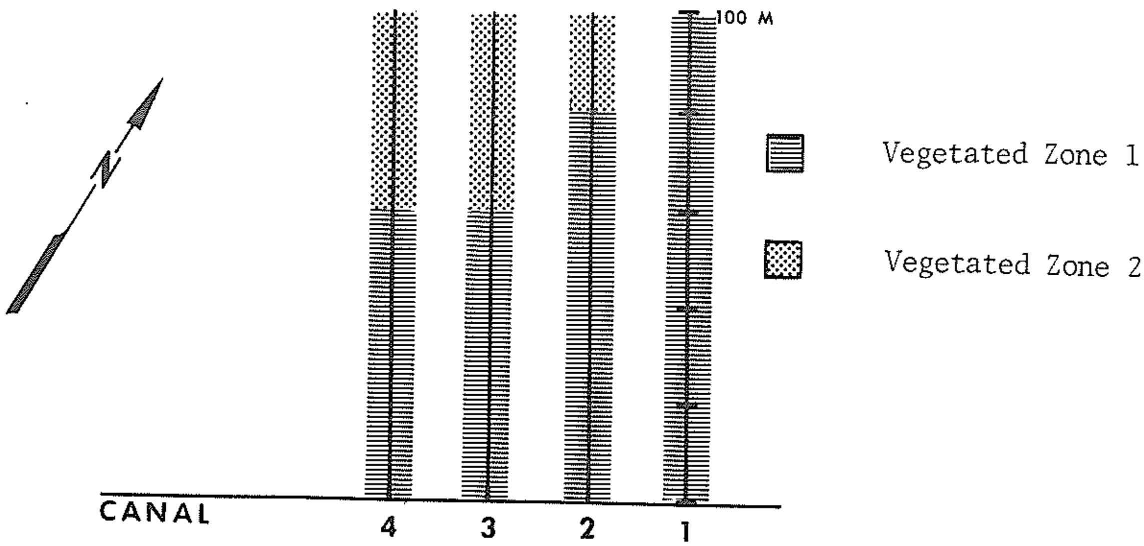
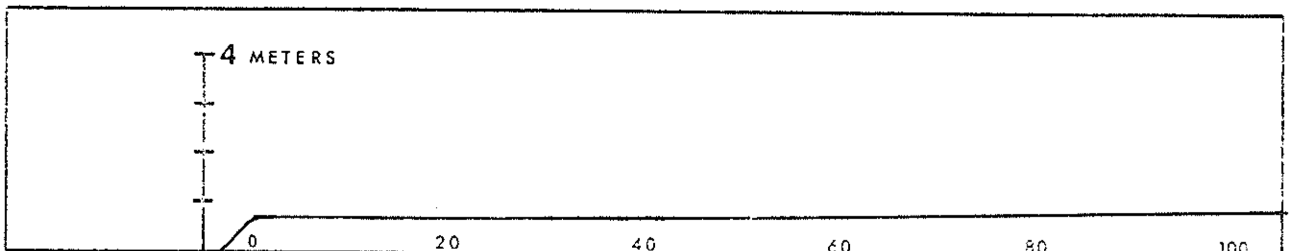


Fig. 16b. Transect 1 in Site F with Soils Analysis Data



T-METER	16	36	100
S.A.R.	25.33	16.01	11.67
E.C.	21.29	6.74	2.02
pH	7.4	8.0	8.6
SUBSTRATE	clay	clay	clay
ELEV.	.76	.77	.94

Source: Author field survey and Texas A&M University Soil Testing Laboratory

Fig. 17. Species Frequencies for Site F, Zone 1

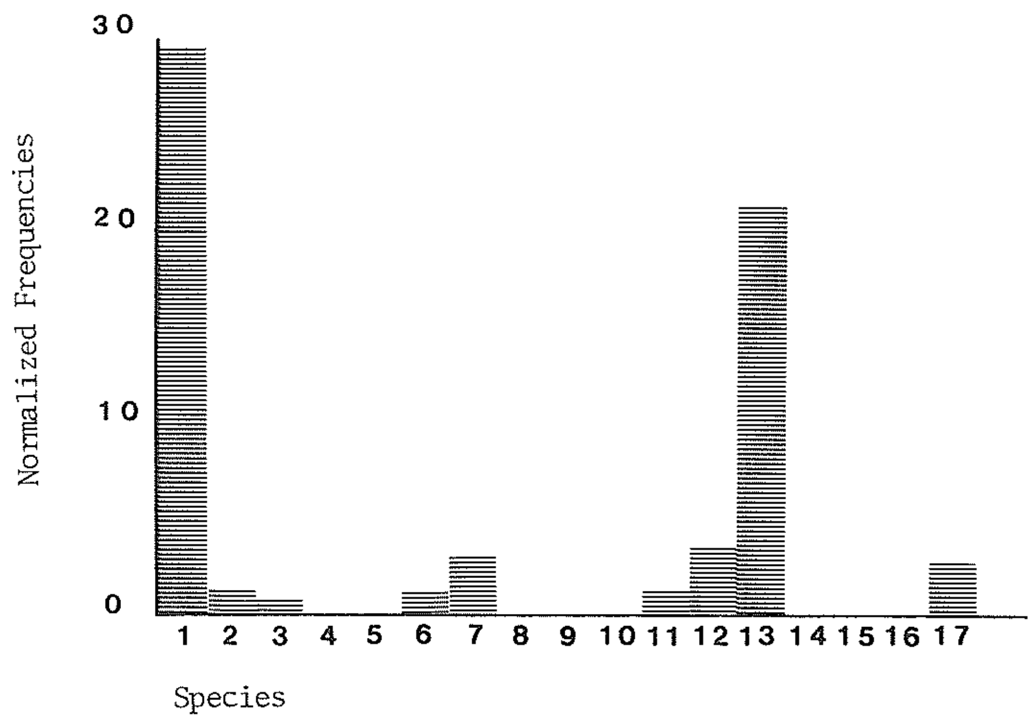
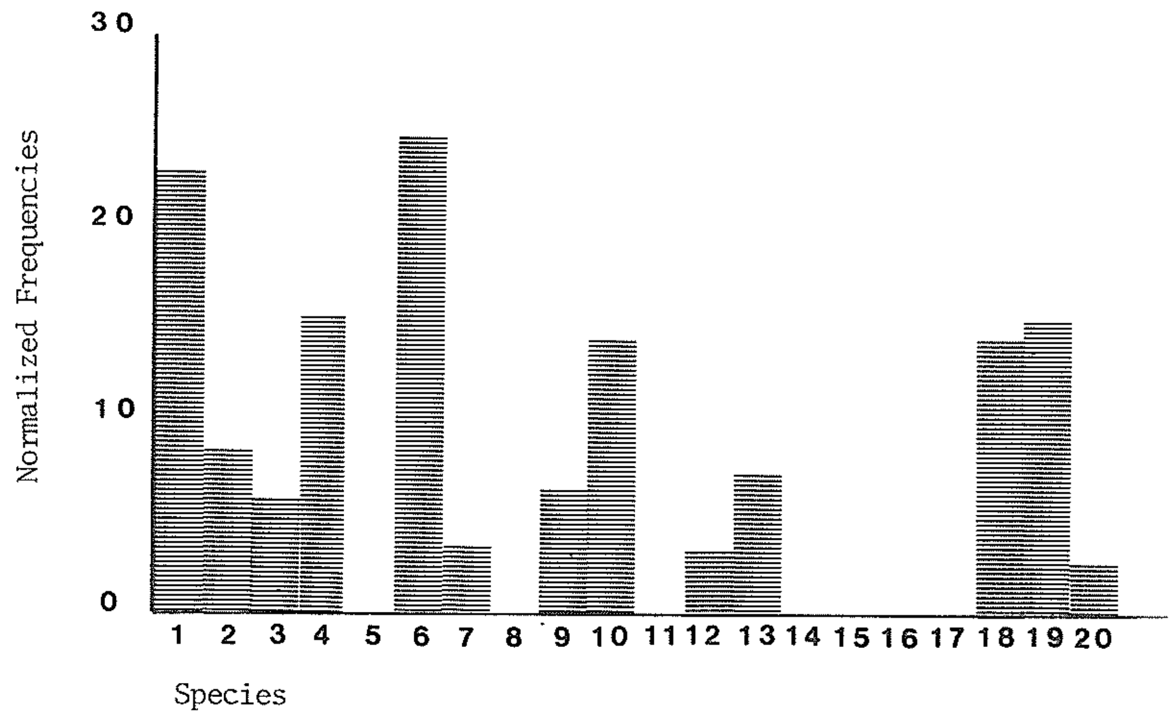


Fig. 18. Species Frequencies for Site F, Zone 2



alluvial fans and pockets are found in the gullies and rills and there is a general accumulation of sand ringing the base of the mounds (Photo 2). Clay nodules from 1 cm to 3 cm in diameter are scattered across the mounds and are also found accumulated in depressions and piled up against obstructions such as grass clumps.

E.C., S.A.R., and pH do not vary systematically with the distribution of vegetated zones. Soil samples taken with vegetated zone 1 along transect 1 had a generally decreasing E.C. and S.A.R. and an increasing pH (Fig. 16b). In sequential order, the soils can be classified saline-alkali, nonsaline-alkali, and nonsaline-nonalkali. A sample in vegetated zone 2 along the second transect at 80 m was saline-alkali with an E.C. of 33.71, and S.A.R. of 41.66, and soil pH of 7.7.

The vegetation zones are associated either with the level, non-spoil area or the spoil mound. The substrate of the level area was a dark clay; for the spoil mound it was a yellow-red clay. Elevation and substrate may control the vegetation zonation.

DISCUSSION

Vegetation on the banks adjacent to the GIWW (Cedar Lakes Section) is rarely distributed in the monotypic stands commonly associated with salt marshes. The exceptions are Spartina alterniflora which is rare in the area and which occurs only under conditions of tidal inundation and the ubiquitous Spartina patens. In the level, well-drained areas, S. patens can be found in dense stands. However, other species are often mixed in the stands such as the weedy Ambrosia sp. and Oenothera speciosa.

In most instances, the waterway's banks are a mosaic of heterogeneous stands of the more common halophytes such as Distichlis spicata, Salicornia sp., Borrichia frutescens, Batis maritima, Monthanochloe littoralis, and S. patens mixed with 21 other species in differing low abundances depending on the site. The canal's banks are usually at elevations which preclude any salinity gradients resulting from periodic tidal inundation. However, such areas do occur, and when this happens there is a segregation of plant species (Photo 3).

Soil moisture levels, though generally low on the waterway's banks, vary considerably. Conditions may be droughty or saturated depending on elevation, slope, and substrate. Materials taken from cores made within the Cedar Lakes area in 1928 indicate that the common substrate was sandy clay, the product of deltaic deposits (U.S. Army Corps of Engineers, 1929). This situation prevails today except where clay spoil has been deposited or there is an accumulation of sand from surface sorting. Data from the study sites indicate that these differences in substrate and accompanying changes in moisture conditions may be responsible for much of the zonation of vegetation.

Fourteen mappable plant assemblages were identified by means of a cluster analysis of the vegetation data from the Cedar Lakes area. These assemblages are differentiated by the dominance or lack of dominance of a very few species and the relative frequencies of other associated species. Site D contained the most assemblages with four; while the site B had only one mappable assemblage. Site D differed physically from site B primarily by the presence of mounded spoil. The zonation of assemblages is the result of differences in available soil moisture and competitive exclusion. The presence of mounded spoil on site D provided more and sharper gradients of soil moisture, and thus more zonation of vegetation.

At a larger scale, looking at the whole of the Cedar Lakes area, the dominance or even presence of particular species is indicative of the grosser changes in moisture-substrate conditions. The following correlations can be recognized in the Cedar Lakes area: 1) Salicornia sp. usually dominated the rapidly drying, sand substrate. 2) D. spicata but including M. phyllocephala and Sueada spp. is characteristic of the mounded clay spoil. 3) Batis maritima is typical of constantly wetted sandy clay, and 4) S. patens with Ambrosia sp. and O. speciosa present. The relations between the plant assemblages derived from phytosociological analysis and those intuitively derived are not altogether clear because there is overlap within and among the categories. Further work is needed to reconcile these differences resulting from analysis at different scales.

It must be noted that the Cedar Lakes area represents a particular set of circumstances of topography, frequency of spoil deposition, soils, and climate. Care should be exercised in applying the above generalizations to other parts of the canal. The most important consideration according to our study is the annual precipitation amount and its seasonal distribution which is not duplicated along other parts of the canal. On the other hand aspects such as elevation and substrate are found along other parts of the canal.

CONCLUSIONS

Prior to the construction of the canal, the bank area of the present GIWW at Cedar Lakes, except for a few instances such as the area around site B, was well above tidal inundations. It is reasonable to assume that surface moisture changes from tidal action were the same or less than those at present. Changes in soil moisture were and are associated with inputs from precipitation. Then as now available moisture was probably the limiting factor. The salinity hazard may have been less earlier than today, certainly it was not higher. Conditions now, even though high-saline and high-alkali over most of the area, are still within the upper range of tolerances for most salt marsh species as discussed above. Thus factors which affect soil moisture such as slope, texture, and elevation become critical to plant growth in this area, rather than salinity as found by Jackson for Florida or submergence-emergence ratios as found by Johnson and York for New York.

Deposition of spoil on the marsh led to less uniform and more dynamic conditions of soil moisture and increased the range of soil moisture potentials. Soil moisture conditions fluctuate more rapidly and over a wider amplitude, and at finer scales. This is so because of constant erosion of mound materials and the consequent creation of new, small-scale, local drainage patterns as well as of materials sorting. Furthermore, the spray from passing boats and bank erosion has added a new dimension of wetting and drying for areas immediately adjacent to the waterway.

Besides the increased fragmentation of vegetated zones, three other changes can be attributed to the disruption of soil moisture regimes in the areas of spoil deposition. These are: 1) an increase in species diversity; 2) an increase in the occurrence of weedy species such as *Melilotus officinalis* and *Ambrosia* sp.; and 3) a reduction of the area covered by high biomass-producing species such as *S. patens* and *S. alterniflora*.

RECOMMENDATIONS

Deposition of spoil materials on the banks of the Intracoastal Waterway in the Cedar Lakes area has had only minimal effects on local plant geography. The amount of vegetation on the spoil mounds is less than on adjacent non-spoil areas but the vegetation does exhibit more diversity of species. Most spoil material has been placed in sites where existing elevations were and are well beyond the tidal influences so critical to the development of salt marsh. There is at least one exception. At site E there is a relict population of *Spartina alterniflora*. This population may be the remains of a previously larger area of *S. alterniflora* and associated low marsh which has been reduced by spoil deposition. Comparisons made of aerial photographs taken before the construction of the canal with the field conditions suggest that over twenty acres of low marsh may have been destroyed or altered in that area (Tobin Research Inc., 1930). This type of spoil placement should be avoided to prevent destruction of highly productive areas.

Additionally, placement of spoil materials immediately adjacent to the canal near site D has accelerated bank erosion. This is the result of an increased slope near the bank and consequent bank cutting action by surface runoff. The flow of materials back into the canal is also more rapid because of the proximity of the mound to the waterway (Photo 4).

Potentials for vegetation management exists in the manipulation of soil moisture regimes. Soil moisture, and conjunctively the amount of vegetation, may be increased by the leveling of spoil mounds. This would spread the materials over a larger area and might be undesirable in areas below the threshold elevations of tidal influence. However, in higher areas, this leveling would slow drainage, increase infiltration, and reduce erosion and materials sorting.

As an alternative, stabilization of the mounds can be accomplished by artificial plantings of the more drought-resistant plants. Salicornia perrenis may be an excellent species for such plantings. This plant, which is found throughout the Cedar Lakes area, has largely been ignored by researchers interested in artificial plantings of marsh vegetation, but should be investigated more thoroughly. The plant is a deep-rooted perrenial that spreads by woody stems that root at the nodes. Seedling development on the mounds does not appear feasible but, planted at maturity, perhaps in the form of clumps of sod, Salicornia would form a dense, growing mat capable of stabilizing soil and trapping eroding detritus. The plant would be largely ignored by cattle.

Weedy species of the coastal salty prairie might also be investigated for their potential in seeding projects. The banks of the Waterway are generally deficient in plants that have food value for much of the wildlife in the area. There may be plants of the salt prairie, which could be planted on the spoil materials which would improve the value of the area as habitat for wildlife.

While the spoil deposition itself has had only local and minimal effects, the original construction of the canal at Cedar Lakes had a major impact by lowering water levels and increasing salinity in the marsh basin. The marsh would benefit by consistently higher water levels (Ivy, per. comm., 1976). Some future consideration might be given to strategies designed to impede surface drainage from the marsh into the canal. Suggested strategies are 1) the judicious placement of spoil materials along the canal in areas where surface drainage into the canal is significant, and 2) the transporting of spoil materials for the construction of levees and containment dikes within the near marsh area.

BIBLIOGRAPHY

Adams, David A., "Factors Influencing Vascular Plant Zonation in North Carolina Salt Marshes," Ecology, Vol. 44, No. 3, (1963), 445-455.

Bureau of Sport Fisheries and Wildlife, Proposed Acquisition of Lands Within San Bernard National Wildlife Refuge, Unpublished Environmental Assessment, (U.S. Department of the Interior, March 1974).

Chapman, V. J., Salt Marshes and Salt Deserts of the World (New York: Interscience Publishers, 1960).

Crisp, D. J.,"Secondary Productivity in the Sea," in Productivity of World Ecosystems, Proceedings of the International Biological Program Symposium (Washington, D. C.: National Academy of Sciences 1975), 71-90.

Frenkel, R. E. and Harrison, C. M., "An Assessment of the Usefulness of Phytosociological and Numerical Classificatory Methods for the Community Biogeographer," Journal of Biogeography, Vol. 1, (1974), 25-26.

Goodall, D. W., "Some Considerations in the Use of Point Quadrats for the Analyses of Vegetation," Australian Journal of Science and Research, Vol. 5, (1952), 1-40.

Ivy, Larry, Manager San Bernard Wildlife Refuge, personal communication, January, 1976.

Jackson, Curtis R., "Some Topographic and Edaphic Factors Affecting Plant Distribution in a Tidal Marsh," Quarterly Journal of the Florida Academy of Science, Vol. 15, No. 3, (1952), 137-139.

Johnson, D. S. and York, H. H., The Relation of Plants to Tide Level (Washington, D. C.: Carnegie Institute, 1915).

McGowen, J. H., Brown, L. F., Evan, T. J., Fisher, W. L. and Groat, C. G., Environmental Geologic Atlas of the Texas Coastal Zone - Bay City - Freeport Area, (Austin, Texas: University of Texas, Bureau of Economic Geology, 1976).

Miller, W. R. and Egler, F. E., "Vegetation of the Wequetequock-Pawcatuck Tidal Marshes, Connecticut," Ecological Monographs, Vol. 20, (1950), 143-172.

Morton, R. A. and Pieper, M. J., Shoreline Changes in the Vicinity of the Brazos River Delta, (San Luis Pass to Brown Cedar Cut), an analysis of historical changes of the Texas Gulf shoreline, (Austin, Texas: University of Texas, Bureau of Economic Geology, 1975).

Purer, Edith A., "Plant Ecology of the Coastal Salt Marshlands of San Diego County, California," Ecological Monographs, Vol. 12, No. 1, (1942) 83-111.

Queen, W. H., "Physiology of Coastal Halophytes," in Robert J. Reimold and William H. Quenn eds., Ecology of Halophytes, (New York: Academic Press, 1974), 345-355.

Ranwell, D. S., Ecology of Salt Marshes and Sand Dunes, (London: Chapman and Hall, 1972).

Tobin Research Inc., Aerial photographs of Cedar Lakes, (1930).

U. S. Army Corp of Engineers, "Intracoastal Waterway: Section 8, Brazos River to Pass Cavallo, Survey of 1927-28," Sheet No. 2, (Galveston: U. S. Engineer Office, May 18, 1929).

U. S. Army Corp of Engineers, Maintenance Dredging-Gulf Intracoastal Waterway Texas Section: Main Channel and Tributary Channels, Draft Environmental Statement, (Galveston: U. S. Army Corps of Engineers District, 1974).

U. S. Salinity Laboratory Staff, L. A. Richards ed., Diagnosis and Improvement of Saline and Alkali Soils, Handbook No. 60, (Washington, D. C.: United States Department of Agriculture, 1969).

Photo 1. View of spoil mound from the base of site D. The mound is composed of heavy, yellow clay with increasing percentages of sand at the base. Clumps of Salicornia sp. occupy the sandy substrate at the base of the mound. The effects of storm surges are evidenced by the drift wood (A) located at approximately three meters elevation on the mound. Gulleying is also taking place on the mound (B).

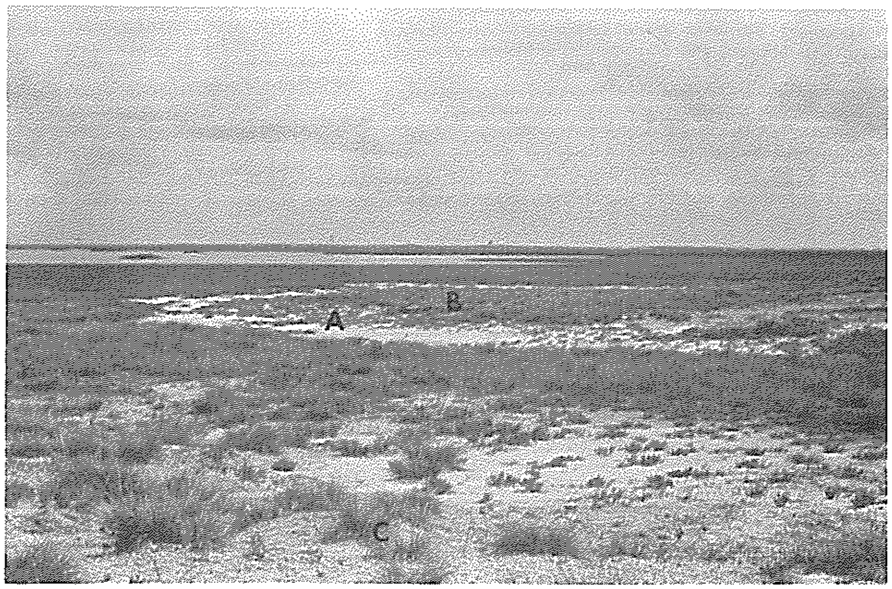


Photo 2. Typical sand ring at the base of a spoil mound adjacent to site D with Cowtrap Lake in the background. Salicornia sp. (A) is the first inner ring of vegetation on the sand followed by S. patens (B). S. patens (C) is in the foreground with an accumulation of clay nodules from the mound at site D. Patches of bare ground are frequent in the area.

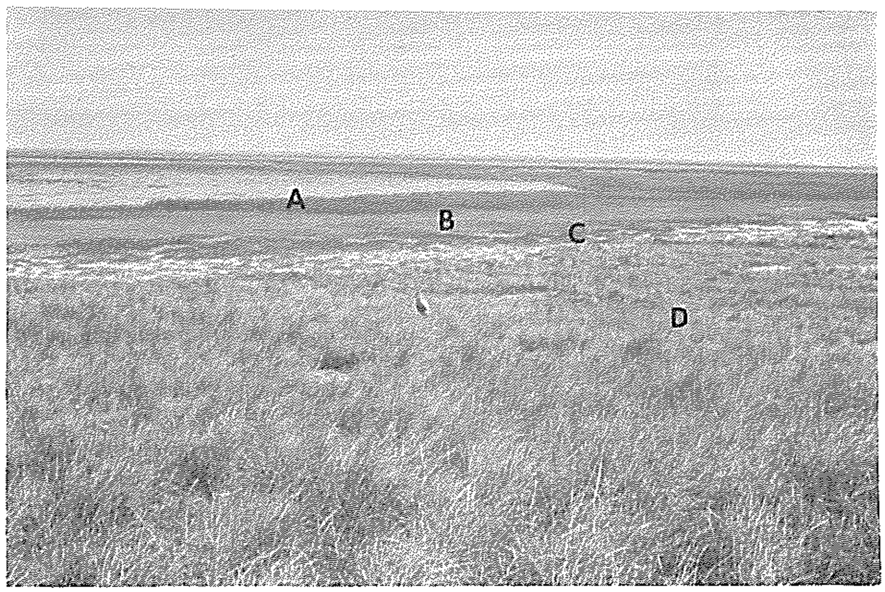


Photo 3. Plant zonation at the edge of Cowtrap Lake near site E. The following zones of vegetation are visible from the water's edge: S. _alterniflora_ (A), _Batis maritima_ (B), Salicornia sp. and _Monthanochloe littoralis_ (C) and _S. patens_ (D). A blue heron is present in the center of the photograph.

Photo 4. Spoil located near the edge of the canal in the vicinity of site D. Spoil material and vegetation are visibly eroding and are being carried into the canal. The vegetation cover is primarily *Salicornia* sp. and *S. patens*. In the lower right of the photograph is a small, possibly emerging colony of *S. alterniflora* (A). Drift wood from the canal is scattered over the area.