

Bellmural



FINAL REPORT

VEGETATION ANALYSIS IN THE C-111/TAYLOR SLOUGH BASIN

DOCUMENT 1: The Southeast Saline Everglades revisited: a half-century of coastal vegetation change.

DOCUMENT 2: Marine transgression in the Southeast Saline Everglades, Florida: rates, causes and plant sediment responses.

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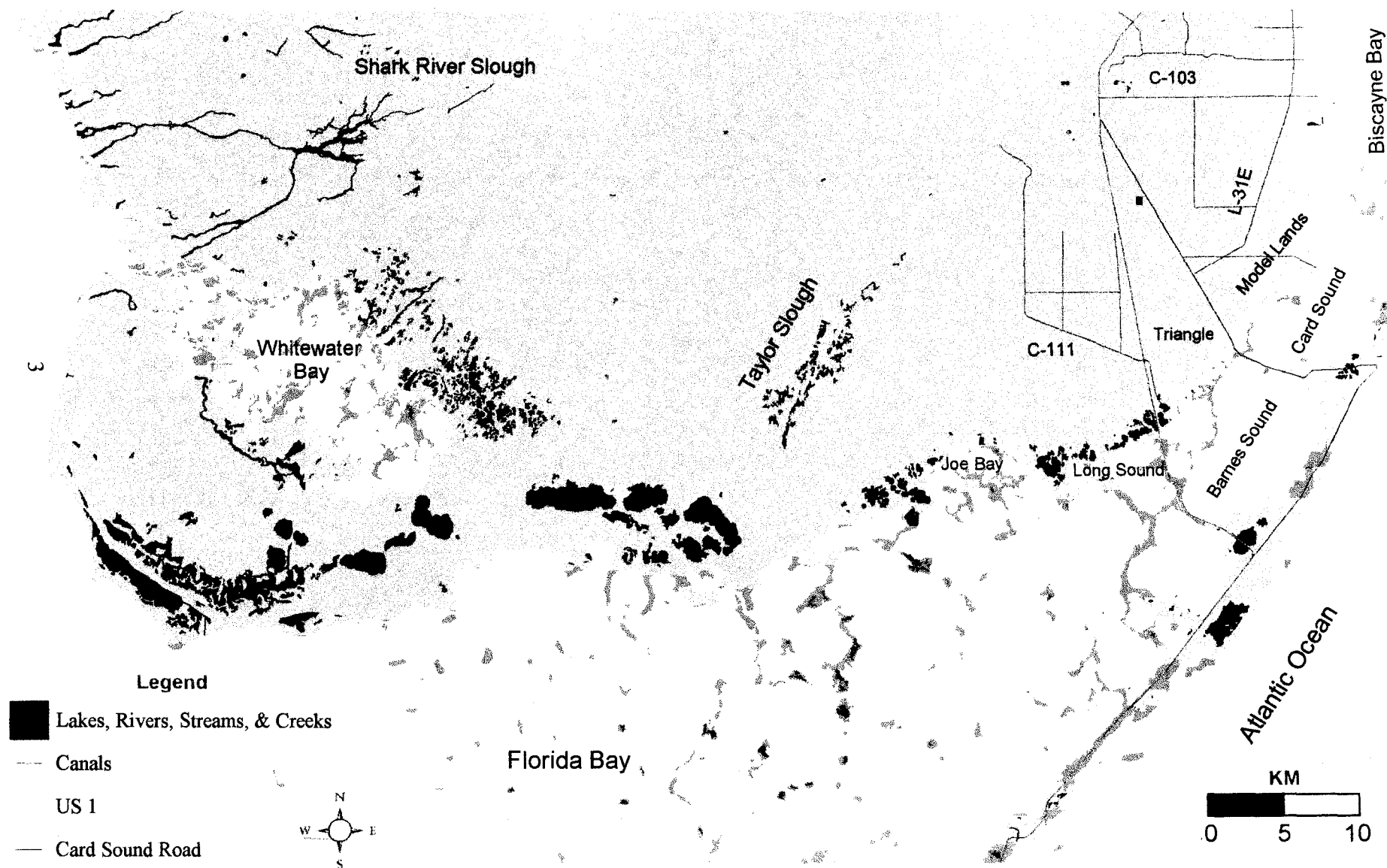
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DOCUMENT ONE

Figure 1: South Florida and the Southeast Saline Everglades



Slough; in the northeast these wetlands pinch out as the Coastal Ridge approaches the coast in southern Dade County. Our study concentrated on the C-111 basin, west of Card Sound Road and east of Taylor Slough, but also included sites in Taylor Slough and in the Model Lands basin south of Turkey Point.

Climate. At 25°N latitude, the SESE's climate is transitional between temperate and tropical environments. Mean annual temperature is about 25°C, with the difference between the warmest month (July) and the coolest month (January) less than 10°C. More significant is the frequency of freezing temperatures, which at the nearest longterm weather station in Homestead averaged one event per year between 1949-1987 (Duever et al. 1994). Freeze events in South Florida are usually of short duration, i.e., < 8 hours (Olmsted et al. 1993). Mean annual precipitation (1951-1980) at Homestead is 155 cm, with a strong seasonal cycle. Monthly means in the dry season (November - April) are less than 10 cm, but during May - October range from 17 cm to 26 cm. A large proportion of the rainfall which occurs during the latter half of the wet season is attributable to tropical storms and hurricanes. Based on narratives of North Atlantic hurricanes over a one-hundred year period (Neumann et al. 1981), any single location in the nearby Florida Keys is likely to receive winds exceeding 120 miles per hour about four times per century.

Physical environment. The SESE is a flat coastal plain which ascends from sea level to approximately one meter a.s.l. at the base of the uplands, which is more than 10 km distant throughout most of the region. Below the surface decimeter or so, soils are mostly marls produced under fresh water conditions, or peats, or some combination of the two (Leighty et al. 1965, Meeder et al. in prep). Carbonate surface layers in certain sections have been produced under brackish water conditions. The lower half of the SESE plain is dissected by ephemeral creeklets which range in depth from several inches in the upper reaches to several feet near the coast. Much of the variation in vegetation structure, including the profusion of tree islands, appears to be associated with these and smaller local undulations in topography.

The hydrology of the Southeast Saline Everglades is, as the name implies, wet and marine-influenced, but the extent or duration of wetness or saline conditions varies widely from one part of the region to another, and from one year to the next. Water levels at sites in the lower SESE are primarily responsive to fluctuations in the adjacent marine waters, while levels in the interior marshes are highly correlated with stage in the C-111 Canal. This mutual independence between forces affecting interior and coastal sites may produce conditions where water levels are higher at either end of the SESE coastal gradient than at intermediate locations (Bjork and Powell 1993). Both Egler (1952) and Tabb et al. (1967) emphasized that periods of elevated salinity in SESE are episodic, short-lived events, while background porewater salinities in most areas are low. As the results described below will demonstrate, however, hydrologic conditions in the SESE may have undergone considerable change in recent decades.

Vegetation. Several general treatments of South Florida vegetation included characterizations of marsh communities present in the SESE (e.g., Harshberger 1914; Harper 1927; Davis 1943; Craighead 1971; Duever et al. 1986). For the portion of the SESE south

and southwest of the C-111 Canal, Tabb et al. (1967) detailed the distribution of dominant macrophyte species in relation to salinity tolerance. Only Egler (1952) described the marshes or tree islands of the SESE as a group, and the following classification scheme is his.

Egler (1952) divided the vegetation of the SESE (excluding Taylor Slough) into seven concentric belts roughly parallel to the coast. The two most interior belts, the Pine Forest and the *Aristida* Grassland, was described only in passing, but the Upper Saline Everglades (Belt 3) was described in much greater detail. The dominant plant in Belt 3 marshes was sawgrass (*Cladium jamaicense*). Egler recognized two variants of this marsh type: a dry, interiorward, species-rich phase and a wet, coastward, species-poor phase. Red mangrove (*Rhizophora mangle*) was conspicuously absent from Belt 3, and spikerushes (*Eleocharis* sp) were not included in species lists of typical sites. Egler described the hydric *Persea*-dominated tree islands of Belt 3 in considerable detail.

Red mangrove was an important element in Egler's Belts 4-7. He described Belt 4 (the Lower Saline Everglades) as a narrow zone characterized by "... the general paucity of vegetation..." and "... the 'dwarfness' of many of the mangroves..." (Egler, 1952; p. 256). As presented by Egler, Belt 4 marshes were a mixture of sawgrass, red mangrove, and spikerush, with the former the dominant species on the basis of cover. Egler considered fire and propagule availability to be the primary factors affecting the importance of red mangrove in Belt 4 (as well as its absence in Belt 3). He characterized the tree islands of Belt 4 as similar in composition to more interiorward hammocks, but tending toward a more mesic, tropical species assemblage.

Belts 5-7 were treated in less detail by Egler (1952). He described Belt 5 (Mangrove-sawgrass vegetation) as a mosaic of sawgrass patches, mixed mangrove forest (including black mangrove, *Avicennia germinans*), and open water. According to Egler, the interiorward border of Belts 5 represented the coastward limit of fire. In Belt 6 (Mangrove - Tidal Marsh Vegetation), sawgrass was replaced by salt-tolerant plants such as *Batis maritima*, *Borrchia frutescens*, and *Juncus roemerianus*. The latter was most representative of interiorward portions of the Belt, while *B. maritima* was associated with more coastal areas. Red, black, and white mangrove (*Laguncularia racemosa*) were locally dominant. Finally, in the floristically simple Belt 7 (*Rhizophora* Border), the salt marsh species were less extensive, and *R. mangle* was the sole tree species of significance.

Craighead's (1971) classification of South Florida tree islands has been applied widely by South Florida researchers. His nomenclature is based on characteristic dominant species. Types described by Craighead (1971) which occur widely in the SESE are: Buttonwood Strands and Islands (characteristic species: *Conocarpus erectus*), Bay Heads (characteristic species: *Persea borbonia*, *Magnolia virginiana*), Tropical Hardwood Hammocks (characteristic species: many, including *Metopium toxiferum*, *Eugenia axillaris*, *Lysiloma bahamense*, *Bursera simaruba*, *Swietenia mahogani*, *Myrsine guianensis*, *Coccoloba diversifolia*), Cypress Domes (characteristic species: *Taxodium distichum*), and Willow Heads (characteristic species: *Salix virginiana*).

Land use. Human activities which may have had direct effects on the current condition of SESE plant communities are primarily those which altered the region's hydrology. Some of these were: (1) the establishment of the railroad bed along the current U.S. 1 in 1904; (2) dredge and fill operations involved with construction of the Ingraham Highway, Card Sound Rd., and the current ENP road system; (3) the establishment and management of the canals and structures associated with the Everglades National Park - South Dade Conveyance system, beginning in 1948; (4) modifications associated with the Turkey Point Power Plant in the 1960's and 1970's; and (5) flood protection associated with agriculture and, more recently, residential, commercial, and recreational development in the southern Biscayne Bay watershed.

METHODS

Sampling design. Vegetation and soils were sampled at 55 individual locations and along one coastal transect (Figure 2) during the winters of 1994-95 and 1995-96. Site names and locations are listed in Appendix 1. Access was by helicopter or, in a few instances, by foot. 22 sites were adjacent to hydrological stations in a network jointly maintained by Everglades National Park and the U. S. Geological Survey. Nineteen of these stations consisted of wells sunk to bedrock, outfitted with water level recorders that had been in operation since at least 1992. Another was a groundwater monitoring station which had been established in 1973, and two more were surface water wells only operative since 1995. 26 other sites were distributed along a network sampled in 1967 (Tabb et al. 1967). Seven additional sites were chosen to fill in gaps in sampling coverage, especially along the western and coastal periphery of the study area. In each case, latitude and longitude were pre-determined in the office with reference to topographic maps and other information, then located in the field with a global positioning system.

Vegetation sampling. We estimated relative species cover in the marsh or low swamp vegetation characteristic of our 55 individual sampling locations. In order to minimize observer bias among the four people involved in vegetation sampling, we used a ranking system instead of direct estimates of species cover. The vegetation sampler walked approximately 50 meters from the plot center, then tossed a 1.12 m diameter hoop (1 m² area enclosed) to his left. Vascular plant species rooted within the hoop were ranked in terms of shoot cover, with "1" being the most abundant species, "2" the next most abundant, etc. By pacing chords of 12° arcs clockwise from the initial point, we located and sampled thirty subplots in a broad circle around the plot center. Species relative abundance in each site was equal to 100 times the sum of species abundance in the 30 subplots divided by the total abundance of all species, where the species ranked first in each plot was assigned an abundance of 10, the species ranked second an abundance of 5, the species ranked third an abundance of 2, and species ranked fourth or higher an abundance of 1. Other species present in the marsh but not falling within any subplot were assigned a summed abundance of 1.

Figure 2: Sampling locations.

C111 SAMPLE STATION TYPES

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- TABB WITH BIOMASS
- BIOMASS
- COMPOSITION ONLY
- MODEL LANDS TRANSECT

The map displays the following sampling locations:

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- EVER 2B** (star symbol)
- EVER 3** (star symbol)
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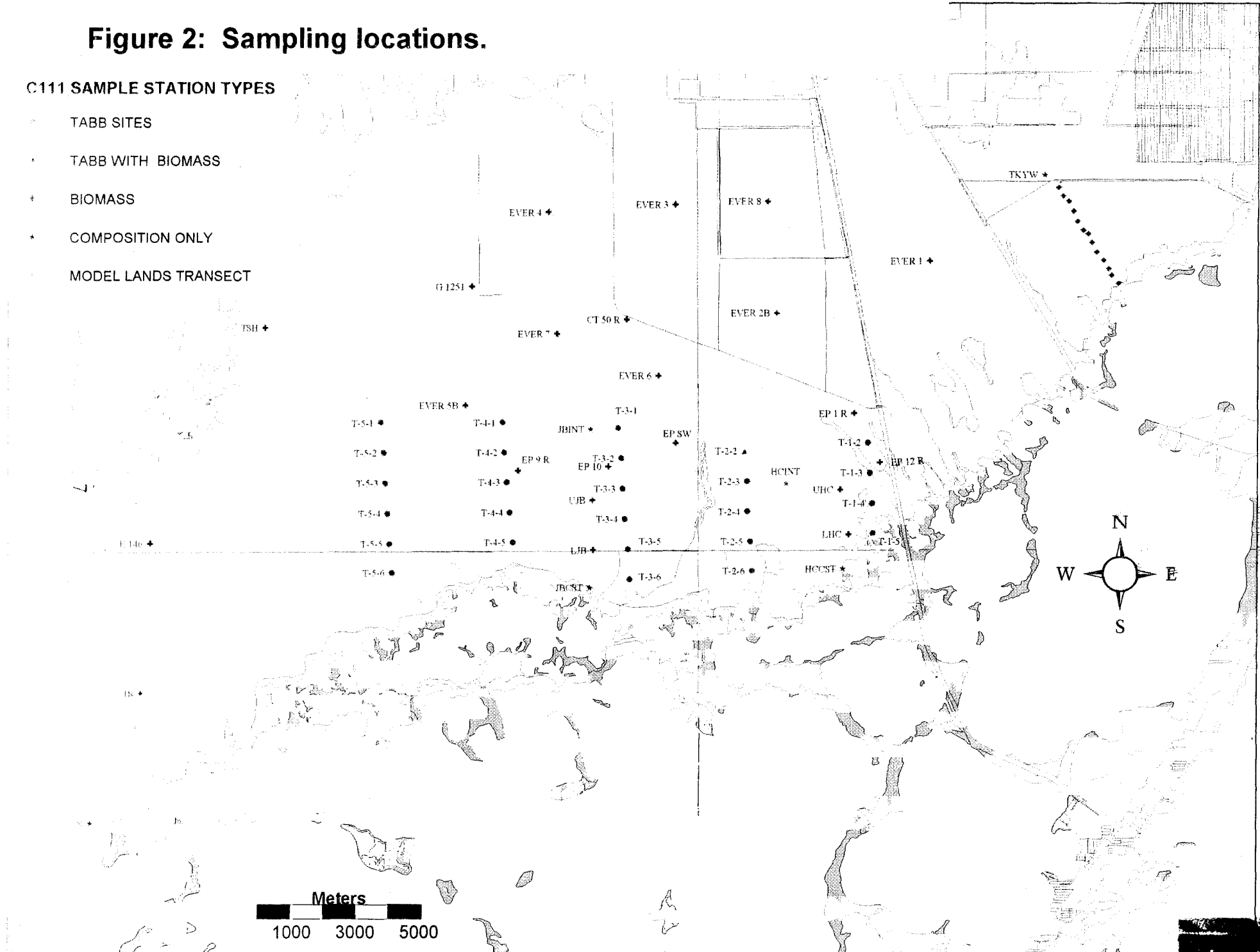
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- COMPOSITION ONLY
- MODEL LANDS TRANSECT

• TABB WITH BIOMASS

BIOMASS

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MODEL LANDS TRANSECT



We also estimated the relative abundance of tree species in the hammock closest to 54 of the marsh plots (no tree island was within 500 meters of the 55th site). One of us explored each hammock for 15-20 minutes, recorded the tree species present, and ranked them in terms of canopy coverage. Species ranked 1 through 4 were assigned an abundance of 10, those ranked 5 through 8 an abundance of 5, those ranked 9 through 12 an abundance of 2, and those ranked 13 or more an abundance of 1. Species abundances were relativized as described for the marsh.

Sampling at the 22 hydrologic stations also included estimation of aboveground community biomass and leaf area. A 100-meter transect was established, beginning within twenty meters of the monitoring well and oriented perpendicular to the apparent slope direction. Within each ten-meter segment of the transect, a single subplot location was located. We surveyed by theodolite from the water level recorder table (whose elevation was known) to ground surface at five-meter intervals along the transect and at the ten subplot centers, and calculated a site average. Finally, all material above the soil surface in a 0.25 m² square quadrat at each subplot was harvested and separated into the following components: live vascular plant tissue by species, dead standing vascular plant tissue, litter, mat periphyton, and epiphytic periphyton. Woody plant leaf and structural tissues were also separated. Harvested material was dried to constant weight at 65° C, and the weight recorded. Inorganic and organic fractions of periphyton components were separated by combustion at 500°C, and biomass expressed on the latter only. Leaf area index was calculated by multiplying live leaf biomass (woody plants) or live aboveground biomass (herbaceous plants) by specific leaf area for individual species, then summing for the plot as a whole. Estimates of specific leaf area for the three most abundant plants (*C. jamaicense*: 53.58 cm²/g, s=5.03; *R. mangle*: 45.22 cm²/g, s=8.39; and *E. cellulosa*: 121.79 cm²/g, s=8.69) were based on samples of 4-6 leaves per plant from ten individuals at several locations within the study area. A mean specific leaf area of 74 cm²/g was used for other species, which generally comprised less than 25% of total "green" biomass.

We gathered more detailed vegetation information from a single coastal transect in the Model Lands area in the eastern portion of the SESE (Figure 2). The transect was ca 4 km in length, extending from the L-31E canal to the coastline of Card Sound. Vegetation plots of 5-meter radius were established at 100-meter intervals, beginning 50 meters from the canal. Within each of the 40 plots, a single observer estimated crown cover by species, using cover categories of 0-1%, 1-4%, 4-16%, 16-33%, 33-66%, and >66%. Elevation of the plot centers were determined by surveying with theodolite beginning at a USGS benchmark near the canal. Soil cores were extracted at locations 1,000, 2,000, and 3,500 meters from the coast. Soil accretion rates were estimated from profiles of Pb-210 activity determined by Eugene Turner at the Coastal Wetlands Center at Louisiana State University.

Soil sampling. Soil depth was determined at each individual vegetation site as the average of 4-6 probings to bedrock with a 1-cm diameter aluminum rod. Bulk density and organic matter content were determined from surface samples (upper 3 cm) at 44 sites, according to methods outlined in DeLaune et al. (1987) and Dean (1974), respectively. We also used the same surface samples to calculate a site salinity index, which was the density-

weighted average of the salinity affinity of the fossil mollusk species present in the collection. The salinity affinities applied to the mollusk species, as well as the references on which those affinities are based, are listed in Table 1.

Current patterns in marsh and tree island communities - We used a combination of classification and ordination techniques to describe the current gradients in marsh and tree island composition in the SESE. Analyses of marsh and hammock data sets were identical, except that in the former we took steps to ensure that our definitions of SESE plant communities could be directly compared to Egler's (1952) study. As noted above, Egler included data from two transects representative of Belt 3 marsh vegetation and one transect representative of Belt 4 species composition. His tables listed the frequency of occurrence of each species in fifty 10-m² plots, and the proportion of occurrences in which it was "rare", "occasional", and "abundant". We assigned an abundance of 1, 2 and 10, respectively, to these descriptors, and calculated relative species abundance in his transects in a manner analogous to what we had done with our own data. We then applied the TWINSpan classification procedure (Hill 1979) and Detrended Correspondence Analysis (DCA) (ter Braak 1987) to a 58-site marsh data set (our 55 plots and Egler's three) and a 54-site data set including current hammocks only. After eliminating species that occurred in fewer than three sites, we transformed the relativized data into octave categories for the DCA analysis, and chose pseudospecies cut levels of 0, 2, 8, 33, and 66 for TWINSpan. Displaying potential classification units on the site ordination diagram helped us distinguish ecologically significant groupings.

Comprehensive, spatially explicit, appropriately scaled environmental information was extremely limited for the study area. We therefore considered only a few variables in our examination of vegetation-environment interactions: the three soil variables described above (depth, organic matter percentage, bulk density), salinity index, hydroperiod, and distance to the coast. The latter was a spatial variable intended to represent the composite effects of many unmeasured environmental factors. At the twenty sites for which continuous hydrologic data was available for the 1992-94 period, we calculated hydroperiod as the mean annual number of days that water was more than five cm above the average soil surface along our surveyed marsh transect. Interactions between the six environmental measures and SESE marsh vegetation were analyzed via Canonical Correspondence Analysis (CCA) (ter Braak 1992) and drawn using the CANODRAW program (Smilauer 1992). The CCA analysis was applied twice: (1) Distance to coast, the three soil variables, and salinity index were the environmental variables in a CCA analysis of a 42-site data set, and (2) Distance to coast and hydroperiod were environmental variables in a CCA analysis of nineteen sites. In order to determine the best model, we applied Monte Carlo permutation tests to variable combinations arrived at through a forward stepwise selection process (ter Braak 1992). The CCA analysis was limited to the marsh vegetation because environmental data specific to the tree islands were unavailable.

Table 1. Salinity rankings used to weight mollusk species abundances for calculation of salinity index. Rank 1 = freshwater, 1.5 = freshwater species with tolerance for low salinity, 2 = brackish species, 2.5 = brackish species that tolerate marine conditions, 3.0 = restricted marine with toleration for lower salinity, 4.0 = marine species with a tolerance for low salinity, and 5.0 = marine species. Based on descriptions in Ladd, 1957; Tabb and Manning, 1961; Moore, 1964; Turney and Perkins, 1972; Abbott, 1975; and Thompson, 1984.

Species no.	Species	Salinity rank
1	<i>Biomphalaria havanensis</i>	1
2	<i>Cylindrella</i> spp.	1
3	<i>Laevapex peninsulae</i>	1
4	<i>Physella cubensis</i>	1
5	<i>Planorbella scalaris</i>	1
6	<i>Polygyra</i> spp.	1
7	<i>Pomacea paludosa</i>	1
8	<i>Littoridinops monoroensis</i>	1.5
9	<i>Pyrogophorus platyrachis</i>	2.5
10	<i>Cerithidea beattyi</i>	3
11	<i>Batillaria minima</i>	4
12	<i>Brachidontes exustus</i>	4
13	<i>Cyrenoida floridana</i>	4
14	<i>Littorina angulifera</i>	4
15	<i>Melampus coffeus</i>	4
16	<i>Terebra dislocata</i>	4.5
17	<i>Turbonilla</i> spp.	4.5
18	<i>Alvania</i> spp.	5
19	<i>Anomalocardia auheriana</i>	5
20	<i>Bulla striata</i>	5
21	<i>Caecum pulchellum</i>	5
22	<i>Carditas</i> spp.	5
23	<i>Chione cancellata</i>	5
24	<i>Chione latilirata</i>	5
25	<i>Corbula contracta</i>	5
26	<i>Lima pellucida</i>	5
27	<i>Marginella</i> spp.	5
28	<i>Meioceras nitidum</i>	5
29	<i>Retusa sulcata</i>	5
30	<i>Rissoina catesbyana</i>	5
31	<i>Strigilla carnaria</i>	5
32	<i>Tricolia bella</i>	5

The results of the above analyses called for a more detailed examination of the relationship of the geographic variable "distance to the coast" with species composition in both marsh and hammock. Least-square regressions relating site DCA Axis 1 score with coastal distance were determined for linear, quadratic, cubic, power, and logistic functional forms, and the percent of variance accounted for by the various models compared.

Temporal change in marsh vegetation patterns - 1940 to 1994. Our analysis of changes in the position and species composition of SESE marsh communities were based on comparisons with Egler (1952) and with Tabb et al. (1967). Comparison with the former was primarily intended to document the distance and direction of movement, if any, in the landward border of a "... conspicuous white band, forming a smooth arc which parallels, and is inland from, the ocean shores." (Egler 1952; p. 256). Egler's manuscript included copies of several 1940 aerial photos (Soil Conservation Service, CJP series), whose captions clearly illustrated the zone to which he referred. In Egler's classification, the interior border of this white band demarcated the transition between Belts 3 and 4, and represented "... the upper limit of invasion by *Rhizophora* propagules sufficient to form a complete coverage..." (Egler 1952, p. 231). In documenting this interpretation, the author included vegetation data from the zones on either side of the interface. The white band remains remarkably prominent on current photos, with a landward boundary that remains "... distinct, but not knife-edge, definite enough so that the changeover usually occurs within half a kilometer..." (Egler 1952; p. 256). We therefore compared the 1940 and 1994 positions of this boundary, hereafter referred to as the "white zone", using our vegetation data as an aid in interpreting its ecological significance.

We first delineated the interface described above from Joe Bay to the eastern end of the study area, based on both 1940 and 1994 aerial photos. The former were from the same Soil Conservation Service (1:24,000, black and white) series used by Egler, and the latter were NAPP 18" x 18" 1:29,000 color infrared photos. The images were rectified utilizing natural or anthropomorphic landmarks as control points. Using ATLAS-GIS software (Strategic Mapping Inc.), the historical and current zone interfaces were digitized and superimposed on boundary files generated from U.S. Geological Survey 1:100,000 digital line graphs. Distances between the 1940 and 1994 zone interfaces perpendicular to the general direction of the coastline were calculated at *ca* 520-meter intervals along the coast, and examined graphically. Because the coastal boundary of the white zone was not clearly defined on either set of photos, we did not attempt to delineate its position.

Temporal change in marsh and tree island vegetation patterns - 1967 to 1995. A second historical benchmark against which we could compare current SESE vegetation was a study conducted for the National Park Service soon after the establishment of the C-111 Canal (Tabb et al. 1967). Tabb and his associates surveyed selected plant, faunal, and environmental variables in areas south and southwest of the Canal. Their report included marsh and hammock vegetation data along a network consisting of five N-S transects two miles apart, with sampling stations at approximately 0.5 mile intervals along each. Since the position of the northeast corner of the network was known, plot locations could be estimated in the absence of exact coordinates or permanently marked sampling stations. We sampled 26 sites within this network (Figure 2); however, comparable historical data for only 20 sites

were available because the earlier study did not include vegetation data from one of the western transects. Eight of these sites were south of the canal (Transects 1 and 2), and twelve were located to the southwest (Transects 3 and 5). Tabb and coworkers' marsh vegetation observations were limited to two important species, *Cladium jamaicense* and *Eleocharis cellulosa*. They recorded frequency, mean density and mean height of these graminoid species from samples of twenty randomly distributed 1-m² plots. Because our plot size was the same, our sample frequencies for *C. jamaicense* or *E. cellulosa* could be directly compared to theirs for the same sites.

Using these data, we tested a hypothesis of management interest, i.e., that the coastal marsh gradient south and southwest of the final leg of the C-111 Canal had undergone contrasting trajectories of change since the canal's completion in the late 1960's. Since the establishment of the canal, the marsh immediately south of the canal had received overflow through gaps in its southern levee during periods of high water, while areas to the southwest had not. We reasoned that if the amounts of water exiting the C111 canal for the southern marshes were ecologically significant, we should see a trend toward freshwater species in that area in comparison to the marshes to the southwest. Since both zones were likely to include sites experiencing a range of coastal influences, we analyzed the data using analysis of covariance, with Distance to Coast as the covariate, Position (South, Southwest) as the main effect, and Time (1967, 1995) as the repeated measure (within-site) effect. Data were first tested for homogeneity of slope using Wilk's Lambda as test statistic. The STATISTICA program (Statsoft, Inc.) was used for all analyses.

Egler (1952) documented the presence of woody plant species in twenty-five SESE tree islands, but many of these had been disturbed or cleared in the years since his study, and only six remained within the range of our sample locations. We therefore chose to assess changes in hammock species composition with reference to the common sites from the Tabb et al. (1967) study. In that study, species were rated as "abundant", "consistently present", or "seedlings only". We assigned abundances of 10, 5, and 1, respectively, to these ratings, then relativized species' abundances as we had for our own 54-site 1995 hammock data. We applied an octave transformation to the combined 1967 and 1995 data sets, then ordinated the data with DCA, treating the twenty 1967 samples as passive elements. As we had for *C. jamaicense* and *E. cellulosa* in the marsh, we assessed overall 1967-1995 vegetation change within the Tabb et al. network by applying analysis of covariance to the DCA Axis 1 scores for common sites. Interpretation of this analysis of course relied on an appropriate interpretation of the DCA ordination of hammock species composition.

RESULTS

Current marsh communities. The DCA ordination is presented in Figure 3, with the classification groupings suggested by the TWINSpan analysis. Axis 1 of DCA explained 21% of the variation in marsh species composition, and Axis 2 accounted for an additional 9%. The first and strongest division in the TWINSpan analysis (eigenvalue=0.43) divided Group 1 from Groups 2-4, largely on the absence or presence, respectively, of a significant component of *R. mangle*. Subsequent divisions in Group 1 were weak and not stable to slight

Figure 3: Biplots of DCA Axis 1 and Axis 2 scores for 58 marsh samples, with TWINSpan classification groupings. Sites EG3D, EG3W, and EG4 were ordinated from data supplied in Egler (1952), and represent dry and wet phases of his Belt 3, and his typical Belt 4 species assemblages, respectively. Group I = Sawgrass Marsh; Group II = Sawgrass - Spikerush - Mangrove Marsh; Group III = Mangrove Scrub; Group IV = Coastal Prairie.

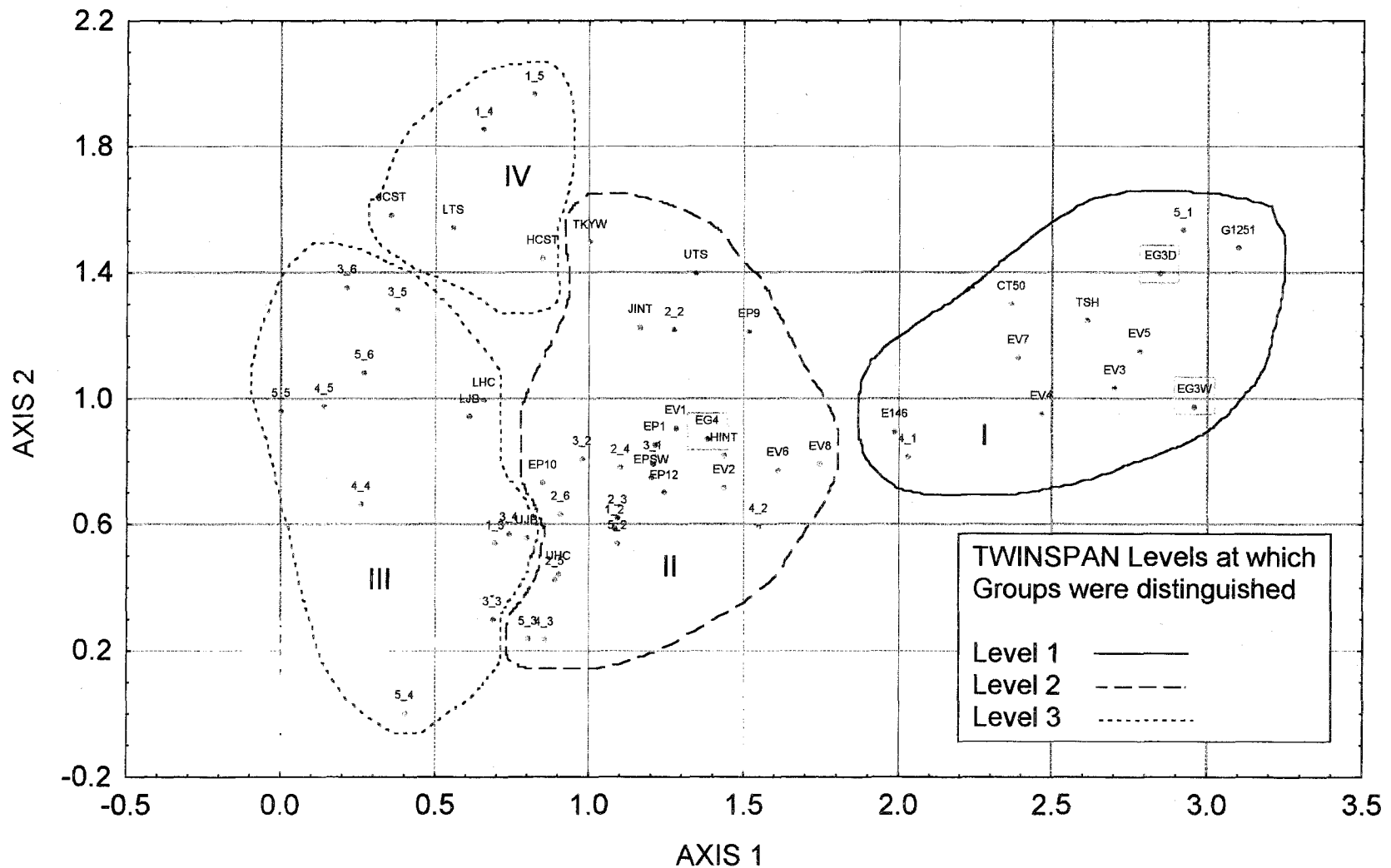


Table 2: Mean relative abundance of common plant taxa (i.e., present in ≥ 3 sites) in four SESE marsh community types. Parentheses enclose the number of sites in which species was recorded.

Name of Species	Species code	Community type			
		Sawgrass Marsh	Sawgrass-Spikerush-Mangrove Marsh	Mangrove Scrub	Coastal Prairie
<i>Proserpinaca palustris</i>	PRO PAL	0.56 (3)			
<i>Panicum tenerum</i>	PAN TEN	1.44 (4)			
<i>Taxodium distichum</i>	TAX DIS	1.22 (4)			
<i>Nymphaea aquatica</i>	NYM AQU	0.04 (3)			
<i>Bacopa monnieri</i>	BAC MON	2.30 (6)			
<i>Agalinis linifolia</i>	AGA LIN	0.17 (3)			
<i>Ludwigia</i> sp.	LUD SPP	0.13 (3)			
<i>Rhynchospora</i> sp.	RHY SPP	9.12 (8)	0.04 (1)		
<i>Oxypolis filiformis</i>	OXY FIL	1.41 (5)			
<i>Pluchea</i> sp.	PLU SPP	0.21 (3)			
<i>Sagittaria lancifolia</i>	SAG LAN	1.16 (8)			
<i>Schoenus nigricans</i>	SCH NIG	1.28 (5)	<0.01 (1)		
<i>Eleocharis interstincta</i>	ELE INT	0.28 (3)			
<i>Annona glabra</i>	ANN GLA	0.04 (4)			
<i>Crinum americanum</i>	CRI AME	0.77 (7)			
<i>Cassytha filiformis</i>	CAS FIL	2.56 (8)	0.12 (3)		
<i>Aster tenuifolius</i>	AST TEN	0.57 (6)	0.04 (3)		0.91 (3)
<i>Cladium jamaicense</i>	CLA JAM	49.44 (10)	43.73 (26)	0.04 (3)	0.75 (2)
<i>Conocarpus erectus</i>	CON ERE	0.06 (4)	0.75 (4)		4.93 (5)
<i>Eleocharis cellulosa</i>	ELE CEL	20.93 (10)	30.05 (24)	46.91 (13)	53.37 (5)
<i>Utricularia purpurea</i>	UTR PUR	5.94 (6)	6.28 (18)	19.06 (10)	2.02 (3)
<i>Utricularia foliosa</i>	UTR FOL	0.23 (4)	0.90 (6)	5.03 (8)	1.11 (2)
<i>Fimbristylis castanea</i>	FIM CAS		0.12 (1)		1.13 (2)
<i>Rhizophora mangle</i>	RHI MAN	0.13 (2)	16.83 (25)	17.87 (13)	31.76 (5)
<i>Tillandsia pauciflora</i>	TIL PAU	0.01 (1)	0.69 (11)	0.85 (7)	
<i>Tillandsia balbisiana</i>	TIL BAL		0.07 (6)	0.20 (3)	
<i>Tillandsia flexuosa</i>	TIL FLE		0.19 (8)	0.18 (7)	0.02 (1)
<i>Laguncularia racemosa</i>	LAG RAC				2.69 (4)
<i>Ruppia maritima</i>	RUP MAR			9.83 (7)	1.14 (3)

manipulations, i.e., the removal of individual sites commonly caused significant rearrangements in the subgroup assignments. Both of Egler's Belt 3 samples fell within Group 1. The Level 2 division of sites distinguished Group 2 from the remaining sites (eigenvalue=.24), based on the presence of *C. jamaicense* and the absence of *Ruppia*

maritima. Subsequent divisions within the group (eigenvalue < 2) were not recognized, leaving Egler's Belt 4 site located centrally within Group 2. Level 3 division of the remaining sites distinguished Groups 3 and 4 (eigenvalue = .31) on the left side of Figure 3; *R. maritima* and *Utricularia foliosa* were indicators of the former, and *Conocarpus erectus* and *Laguncularia racemosa* indicators of the latter group. Other divisions beyond Level 3 were not considered significant at the scale of the study area.

Based on the analyses described above, we recognized four vegetation units among SESE marshes and non-forested swamps. Mean species abundances within these units are listed in Table 2. Sawgrass Marsh (Group 1 in Figure 3) was compositionally equivalent to Egler's Belt 3. It was characterized by the overwhelming dominance of *C. jamaicense* and the common occurrence of *E. cellulosa*, in mixture with a suite of graminoids (e.g., *Schoenus nigricans*, *Rhynchospora* spp.) and forbs characteristic of freshwater marshes further north. Group 2, the Sawgrass - Spikerush - Mangrove Marsh, was equivalent to Egler's Belt 4. The two named graminoids and *R. mangle* were of roughly equal abundance in this transitional community, while other plants characteristic of Sawgrass Marsh were conspicuously absent. Three bromeliad species (genus *Tillandsia*) were common epiphytes in this unit, especially on *R. mangle*. Groups 3 and 4 included mangrove-dominated species mixtures that Egler divided among Belts 5 through 7. In both groups, sawgrass (*C. jamaicense*) was restricted to small patches in high areas adjacent to tree islands. Mangrove Scrub (Group 3) was a monotonous assemblage characterized by red mangrove shrubs, with *E. cellulosa* and/or several salt-tolerant aquatic herbs (*Ruppia maritima*, *Utricularia foliosa*, *U. purpurea*) in the large gaps between shrub clumps. Coastal Prairie (Group 4) was characterized by the presence of white mangrove (*L. racemosa*) and buttonwood (*C. erectus*) shrubs in mixture with *R. mangle*, and the scattered occurrence of several halophytic herbs (*Aster tenuifolius*, *Fimbristylis castanea*, *Distichlis spicata*).

Mean structural attributes of Sawgrass Marsh (8 sites), Sawgrass - Spikerush - Mangrove Marsh (11 sites), and Mangrove Scrub (3 sites) in the SESE are summarized in Table 3. Unfortunately, the 22 biomass sampling stations included no examples of Coastal Prairie vegetation. Mean aboveground biomass (including dead standing material, but not litter) averaged 619 g/m² in the Sawgrass Marsh, 800 g/m² in Sawgrass - Spikerush - Red Mangrove Marsh, and 1072 g/m² in Mangrove Scrub. Differences in standing crops among the three community types were largely attributable to the relative importance of the woody plant (e.g., red mangrove) component. However, leaf area index in the predominantly woody Mangrove Scrub (0.54 m²/m²) was only about half that in Sawgrass Marsh (0.96 m²/m²) and Sawgrass - Spikerush - Mangrove Marsh (0.99 m²/m²). The importance of the algal component also decreased with total standing crop: total periphyton constituted 29% and 23% of total aboveground biomass in the Sawgrass and Sawgrass - Spikerush - Mangrove Marsh, respectively, decreasing to 9% in the Mangrove Scrub. Finally, the high proportion of dead standing material in all three community types was at least in part the result of the winter sampling period and a recent (December 1989) freeze.

Table 3: Components of aboveground biomass (gm/cm²) and leaf area index (m²/m²) in three SESE marsh community types. n=8, 11, and 3, respectively for Sawgrass Marsh, Sawgrass-Spikerush-Mangrove marsh and Mangrove Scrub. No data are available from sites classified as "Coastal Prairie".

Materials	Community type		
	Sawgrass Marsh	Sawgrass-Spikerush-Mangrove Marsh	Mangrove Scrub
Litter	40.4	74.7	7.4
Dead Standing			
<i>Rhizophora mangle</i>	0.0	12.2	317.0
Others	260.6	258.3	79.8
Dead total	260.6	270.5	396.7
Live materials			
<i>Cladium jamaicense</i>	96.4	126.3	0.0
<i>Eleocharis</i> spp.	16.6	10.6	7.1
<i>Rhizophora mangle</i>	22.4	182.9	553.7
<i>Utricularia</i> spp.	5.2	7.1	8.7
Others	28.1	4.1	10.4
Live total	168.8	331.0	579.9
Periphyton			
Attached Periphyton	50.1	37.2	35.3
Mat Periphyton	139.2	161.7	59.6
Periphyton total	189.3	198.9	95.0
Leaf Area Index	0.99	0.96	0.54

The canonical correspondence analysis (Figures 4 and 7) indicated that SESE marsh vegetation was arranged primarily along a gradient of distance to the coast. For the 42-site data set, linear combinations of the five environmental variables illustrated in Figure 4 explained 29% of the variation in species composition. Distance to Coast alone explained 16% of total compositional variation ($p < .001$), and, according to the Monte Carlo permutation test, the addition of only Depth to Bedrock ($p = .002$) and Salinity Index ($p = .08$) improved the

single-variable model further. Both Depth to Bedrock and Salinity Index were highly correlated with Distance to Coast ($r=-.62$ and $r=-.52$, respectively). However, a plot of the former (Figure 5) exhibits a secondary trend of increasing soil depth toward the east, and a plot of the latter (Figure 6) shows several outlier sites, as well as considerable variation in the rate of decrease with distance among different SESE drainage basins. The CCA results indicate that these patterns are also reflected in the vegetation. Neither Bulk Density nor Organic Matter Content showed a strong spatial trend across the area as a whole (Appendices 2 and 3), and neither were significantly associated with marsh species composition. For the 19-site data set, Hydroperiod was uncorrelated with Coastal Distance ($r=-.20$), and its inclusion did not significantly improve ($p=.20$) a model based on Distance alone (Figure 7, Appendix 3).

Table 4: Summary of measured environmental variables in four community types. Range of values are in parentheses.

Environmental Variables	Community Type							
	Sawgrass Marsh		Sawgrass-Spikerush-Mangrove Marsh		Mangrove Scrub		Coastal Prairie	
	Mean (Range)	n	Mean (Range)	n	Mean (Range)	n	Mean (Range)	n
Distance to Coast (km)	8.13 (4.87-12.61)	10	4.46 (2.48-11.13)	26	2.10 (1.09-3.43)	13	1.04 (0.12-2.23)	5
Hydroperiod (no. of days)	259 (133-335)	8	303 (116-360)	9	300 (266-333)	2		
Depth to Bedrock (cm)	52 (16-73)	10	94 (38-145)	25	76 (34-101)	13	134 (107-170)	5
Bulk Density (g/cm ³)	0.22 (0.12-0.42)	6	0.28 (0.08-0.78)	20	0.35 (0.06-0.74)	13	0.23 (0.12-0.32)	5
Organic Content (%)	14.6 (8.5-22.6)	6	24.8 (6.4-83.4)	19	16.4 (4.7-43.9)	13	19.9 (11.8-30.8)	5
Salinity Index	1.0 (1.0-1.0)	6	1.2 (1.0-3.5)	20	2.3 (1.4-3.4)	13	2.7 (2.3-3.1)	5

The zonal arrangement of SESE marshes is illustrated in the distribution of marsh community types among our sampling locations (Figure 8), and in the summary of measured environmental variables in these four types (Table 4). The groups fell neatly into four parallel bands, with Coastal Prairie closest to the shore of the SESE interior bays, followed by Mangrove Scrub, Sawgrass - Spikerush - Red Mangrove Marsh, and Sawgrass Marsh toward the interior. Among the sampled sites, mean distance to the coast was 1.0, 2.1, 4.5, and 8.1

km for the four community types listed above, with some overlap between the latter two groups (Table 4). Salinity index was high in the two coastward community types, decreasing sharply in the two types interiorward of the Mangrove Scrub. Soil depth (mean =1.3 meters) in the Coastal Prairie type was more than twice that in Sawgrass Marsh (mean=0.5 meters), with intermediate values in the two intervening zones. The other three environmental variables did not exhibit substantive differences among community types (Table 4).

Within the range of sites included in our study area, the change in marsh species composition with distance from shore was essentially linear. Although variability in the DCA Axis 1 scores increased slightly beyond about 6 km from the coast (Figure 9A), polynomial, power, and logistic functions did not provided a better fit to the data than did the linear regression model ($R^2=0.57$; Table 5).

Table 5: Coefficients of determination of five alternative least square regression models for marsh and tree island. Models are: $y = a + bx$ (Linear); $y = a + bx + cx^2$ (Quadratic); $y = a + bx + cx^2 + dx^3$ (Cubic); $y = ax^b$ (Power); and $y = y_{max} \cdot \exp(a \cdot bx) / (1 + \exp(a \cdot bx))$ (Logistic), where y is the site Axis 1 score from the marsh or hammock DCA ordination, y_{max} is the maximum Axis 1 score among all marshes or hammocks, and x is perpendicular distance from the coast.

Types of Analysis	Vegetation type	
	Marsh	Hammock
Logistic	0.583	0.664
Power	0.576	0.662
Linear	0.574	0.605
Quadratic	ns	0.693
Cubic	ns	ns

Current forest assemblages. The DCA analysis of species abundances in SESE tree islands, with groupings suggested by the TWINSpan classification procedure, are presented in Figure 10. The first two axes of the DCA analysis explained 26% and 7%, respectively, of the variation in hammock composition. TWINSpan groupings were generally aligned from high to low on DCA Axis 1. The Level 1 division divides all tree islands into two broad groups (eigenvalue=.41) based on the dominance of freshwater swamp species or more salt-tolerant tree species. Four discrete groups emerged from the Level 2 divisions. Freshwater Swamp Forest and Mixed Swamp Forest (Groups 1 and 2, respectively) were distinguished on the right side of Figure 10 (eigenvalue=.39), and Mixed Upland Forest and Coastal Mangrove Forest (Groups 3 and 4) on the left side of Figure 10 (eigenvalue=.26). We did not recognize subsequent divisions because the proportion of within-group variation explained was relatively low, or because the subgroups were insufficiently represented.

Figure 5: Current distribution of Depth to Bedrock in the SESE.

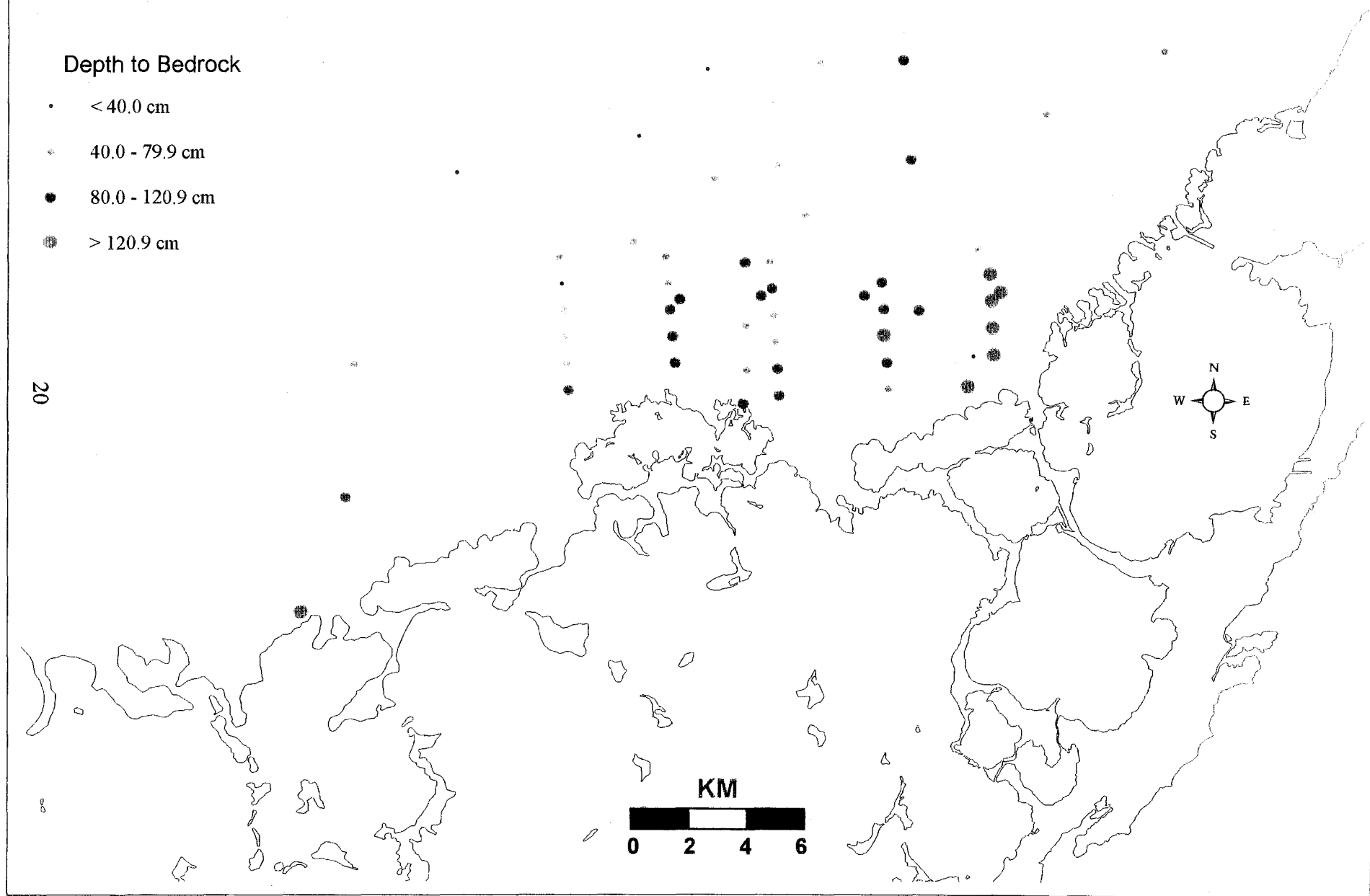


Figure 6: Current distribution of Salinity Index in the SESE. See text and Table 1 for method of calculation.

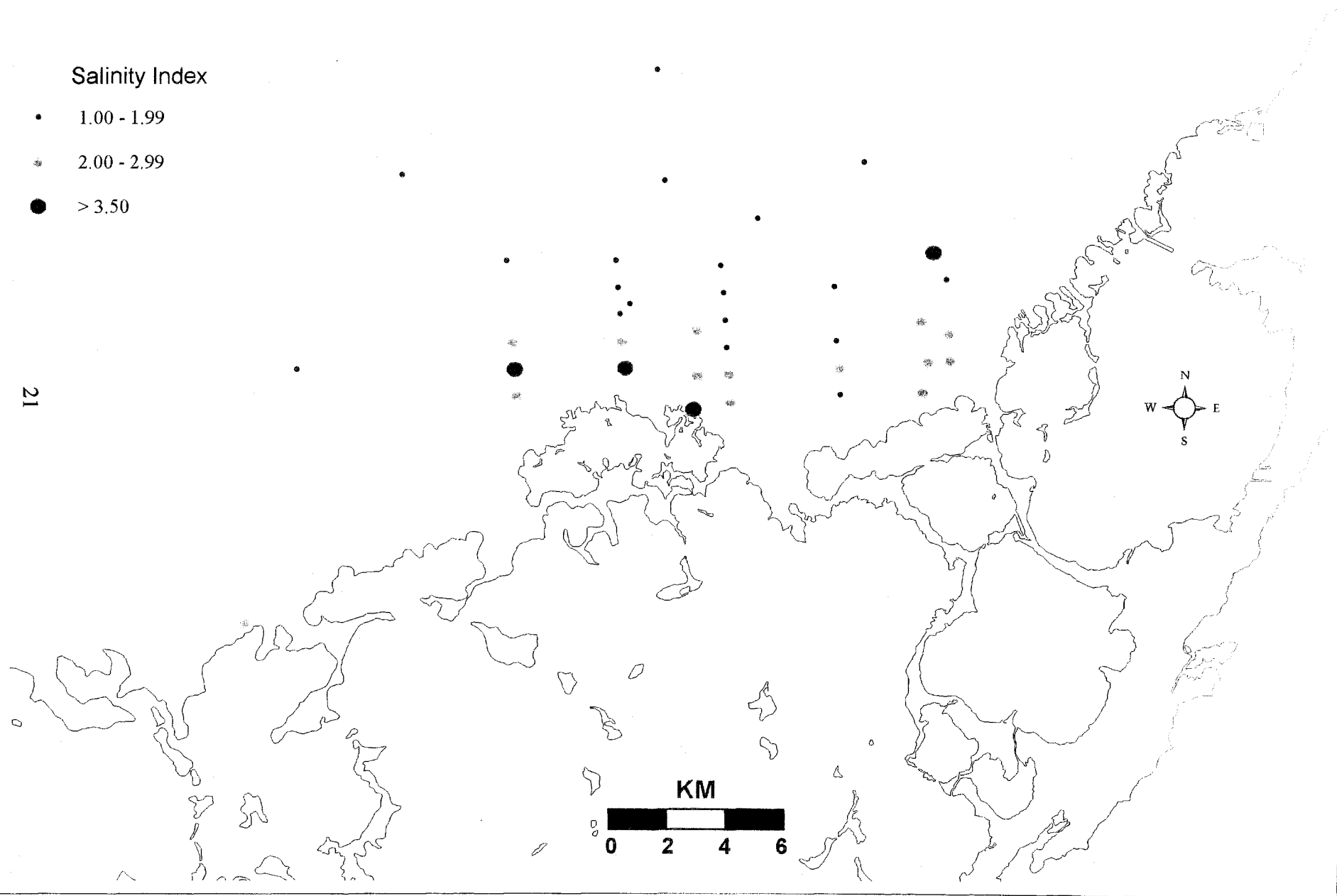


Figure 7: Triplots of CCA analysis of SESE marsh vegetation at 19 sites, based on two environmental variables. Vectors of variables indicated significant ($p < 0.1$) by a Monte Carlo permutation test (999 permutations) are represented by bold lines. Identification of species codes are included in Table 2.

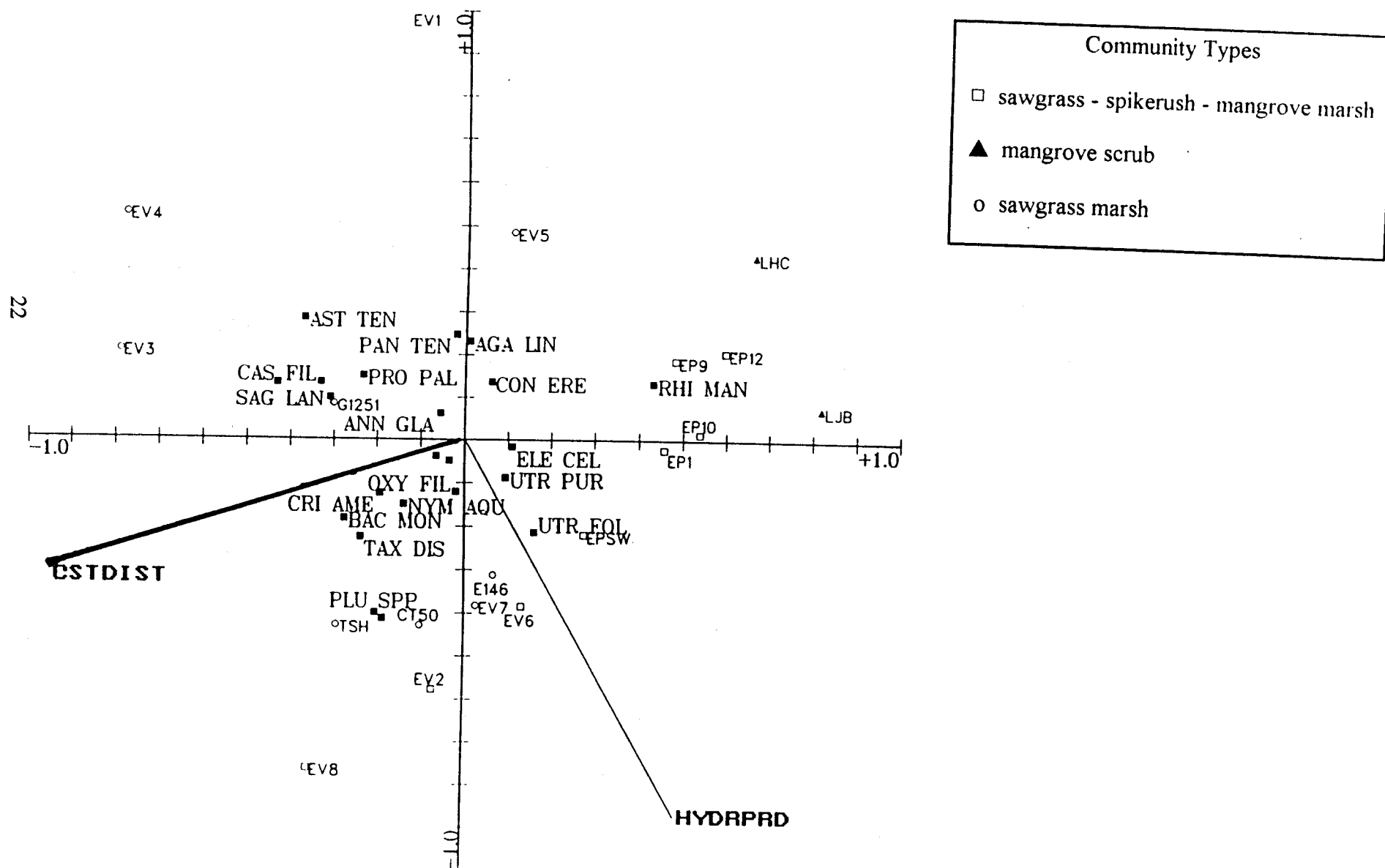


Figure 8: Current distribution of four marsh vegetation types in the SESE, with 1940 and 1994 position of white zone.

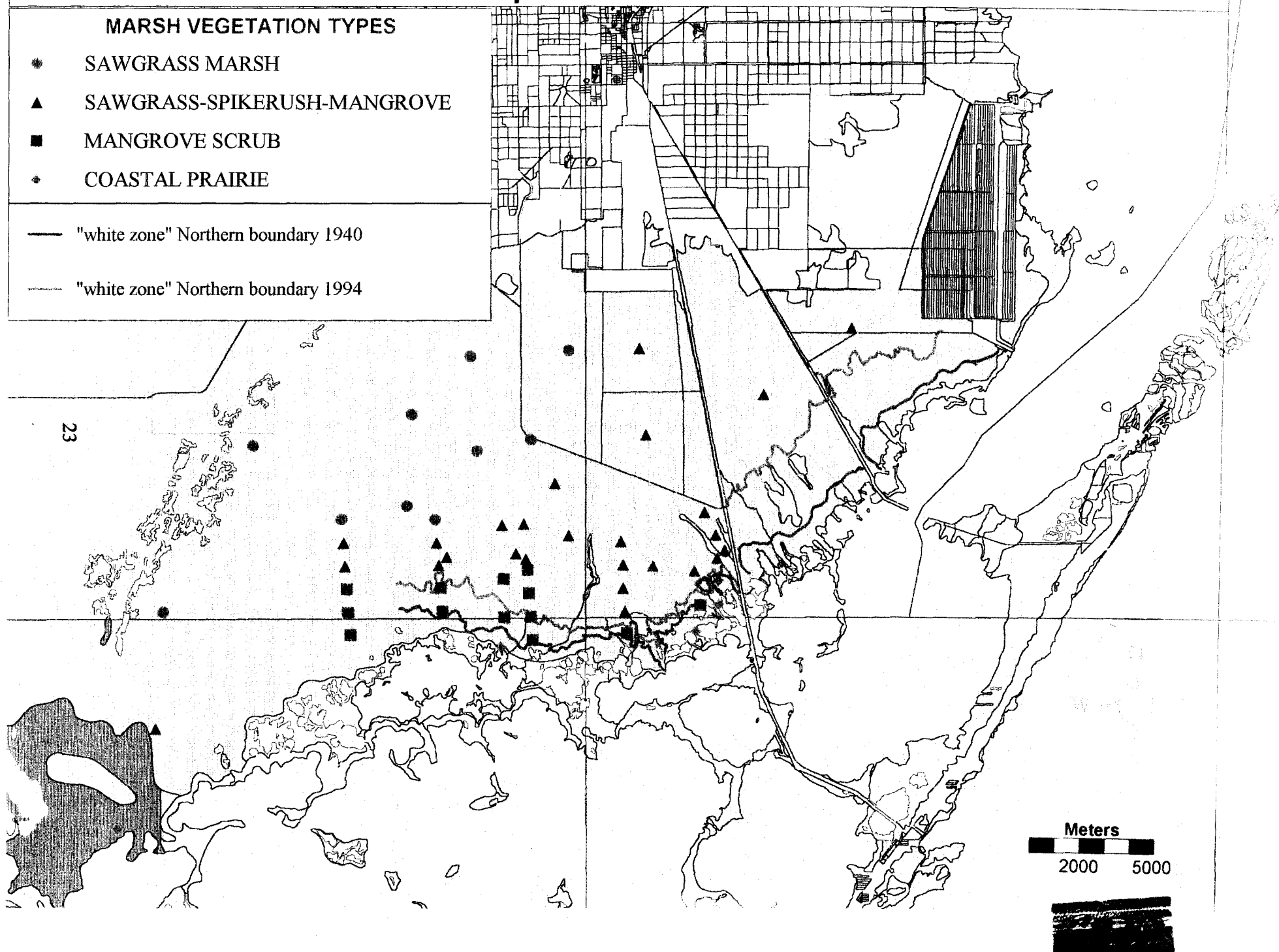


Figure 9: Scatterplots of Axis 1 DCA scores vs. Distance to Coast, with best fit regression line (see Table 5 for coefficients of determination for alternative models. (A) Marsh data from 55 sites, and (B) Tree island data from 54 sites.

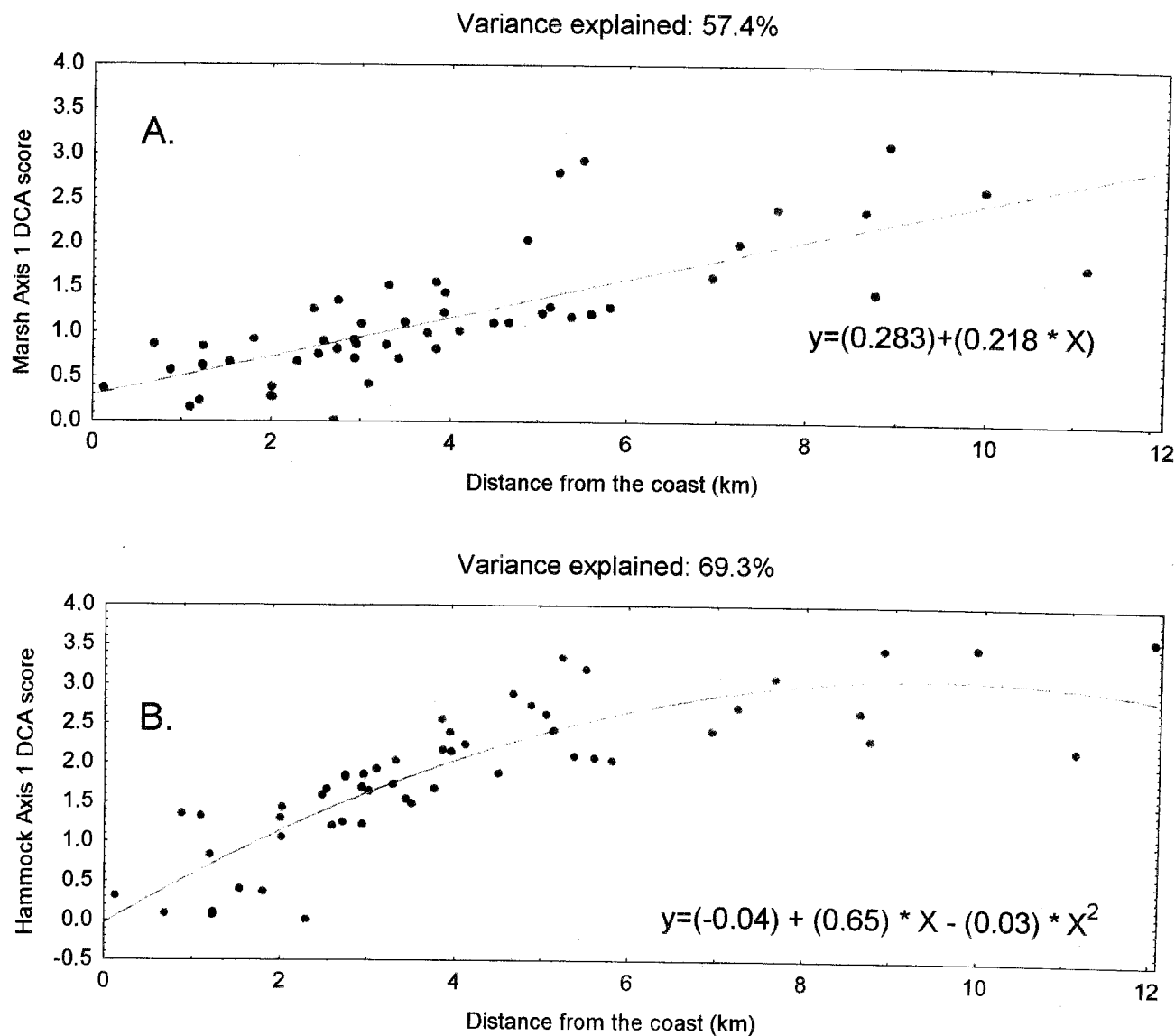
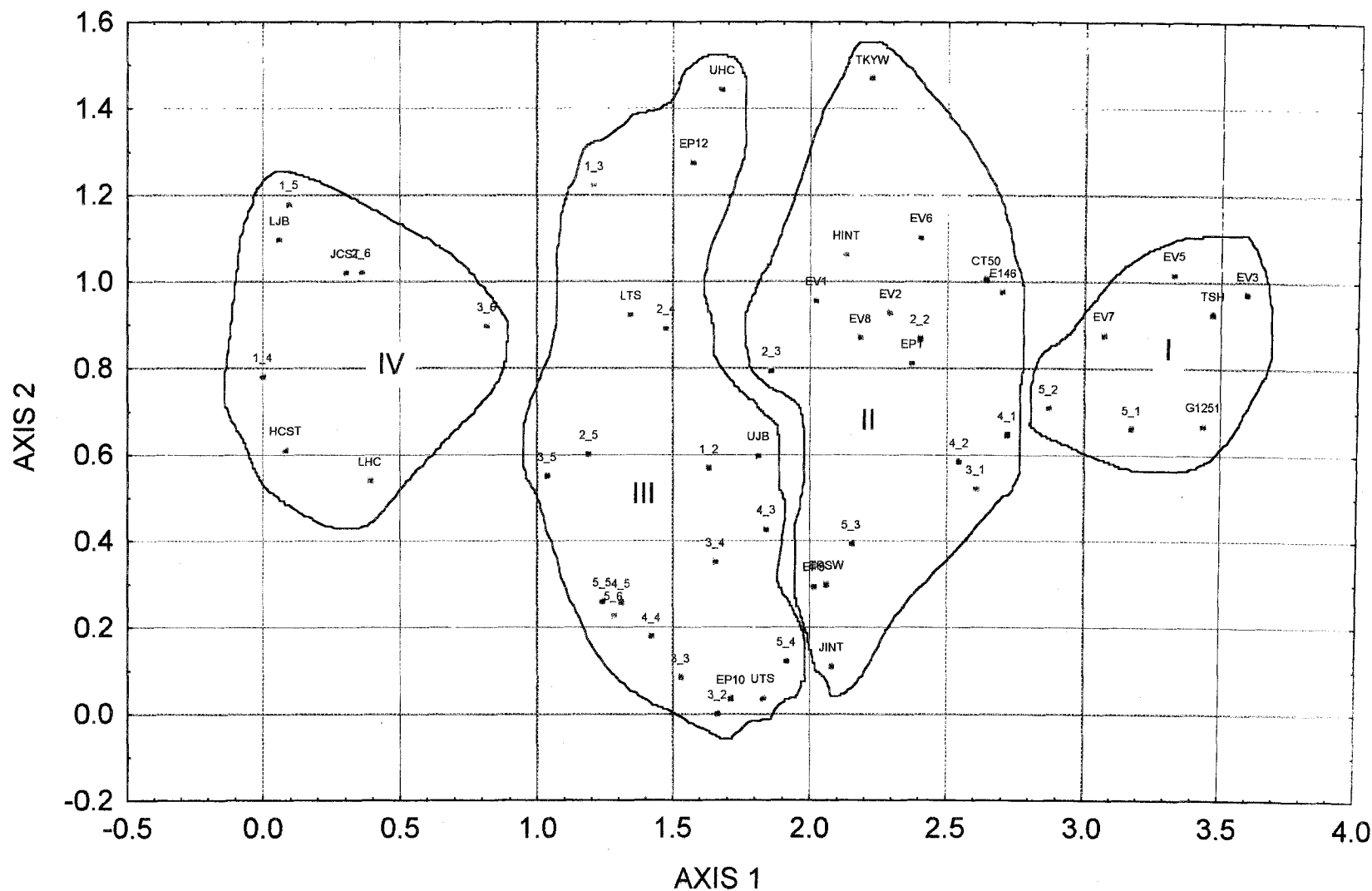


Figure 10: Biplots of DCA Axis 1 and Axis 2 scores for 54 hammock samples, with TWINSpan classification groupings. All four groups were distinguished at TWINSpan Level 2 divisions. Group I = Freshwater Swamp Forest; Group II = Mixed Swamp Forest; Group III = Mixed Upland Forest; Group IV = Coastal Mangrove Forest.



Freshwater and Mixed Swamp Forest units (Groups 1 and 2) share several of the same fresh water swamp species of more temperate distribution, e.g., *Persea borbonia* and *Myrica cerifera* (Table 6). The former forest type is distinguished by the relative abundance of willow (*Salix caroliniana*) and baldcypress (*Taxodium distichum*), as well as pondapple (*Annona glabra*). Mixed Swamp Forests typically include several species associated with more mesic conditions (e.g., *Metopium toxiferum*, *Eugenia axillaris*) and may include halophytes such as red mangrove and/or buttonwood along their flanks. While the Mixed Upland Forest category (Group 3) is a heterogeneous group in which nearly any SESE tree species may be found, it is characterized by mesic species whose center of distribution lies to the south, e.g., *M. toxiferum*, *Coccoloba diversifolia*, *Calyptanthese pallens*, *Eugenia foetida*, and *E. axillaris* (Table 6). Finally, tree islands categorized as Coastal Mangrove Forest (Group 4) include a much more diverse mixture of woody halophytes than are found in the zonal mangrove swamps of the SESE or other portions of South Florida. Besides buttonwood and the three mangrove species, common associates are *Lycium carolinianum*, *Bumelia celastrina*, *Jacquinia keyensis*, and *Randia aculeata* (Table 6).

The distribution of tree islands in the study area resembled that of SESE marsh vegetation, i.e., hammocks of similar composition were arranged in roughly concentric bands parallel to the coast (Figure 11). The compositional change in SESE hammocks with increasing distance to the coast is displayed more quantitatively in Figure 9B. Beginning at the coastline, hammock species composition along DCA Axis 1 changed in a more or less linear fashion for about 6 km inland; beyond that distance, variation was non-directional. When we fit these data to alternative regression models, the quadratic term provided an improvement to the linear model, but the cubic term did not (Table 5). Combined with the lack of improvement associated with the logistic function, these analyses supported the visual impression that an extensive zone of relatively constant tree island species composition occurred at the interior end of the study area, but not at the coastal end.

Historical changes in SESE vegetation. The 1994 and 1940 locations of the interior edge of the white band discussed by Egler (1952) are superimposed on the current classification of marsh sites in Figure 8. The white band was a narrow coastal feature in 1940; the mean distance from its inner edge to the northern coastlines of Joe Bay, Long Sound, Barnes Sound, and Card Sound at that time was 1.13 km (range 0.56-2.22 km). By 1994, aerial photos indicated that the interior boundary of this zone had shifted farther inland by an average of 1.46 km, with less movement in the area west of U.S. 1 (mean=0.82 km) than east of it (mean=2.24 km). West of U.S. 1, there was a trend of increasing movement with distance from the highway; the opposite was true on the east side of U.S. 1 (Figure 12). Finally, while Egler's observations indicated that in 1940 the interior boundary of the white zone separated pure Sawgrass Marsh to the north from the mixed Sawgrass/Spikerush/Mangrove community, today it is near (in places south of) the boundary between Sawgrass - Spikerush - Red Mangrove Marsh and Mangrove Scrub. The current boundary between the compositionally-defined Sawgrass and Sawgrass - Spikerush - Red Mangrove communities is now several kilometers north of the interiorward boundary of the white band (Figure 8).

Table 6: Mean relative abundance of common tree species (i.e., present in ≥ 3 sites) in four SESE hammock community types. Parentheses enclose the number of tree islands in which species was present.

Name of Species	Species code	Forest type			
		Freshwater Swamp	Mixed Swamp	Mixed Upland	Coastal Mangrove
<i>Taxodium distichum</i>	TAX DIS	15.29 (7)			
<i>Salix caroliniana</i>	SAL CAR	8.51 (4)	1.32 (2)	0.16 (1)	
<i>Magnolia virginiana</i>	MAG VIR	4.91 (3)	1.87 (4)		
<i>Ilex cassine</i>	ILE CAS	8.90 (6)	6.07 (12)	0.20 (2)	
<i>Persea borbonia</i>	PER BOR	11.81 (6)	7.37 (6)	0.63 (6)	
<i>Annona glabra</i>	ANN GLA	7.00 (6)	2.49 (7)	0.97 (7)	
<i>Chrysobalanus icaco</i>	CHR ICA	12.36 (6)	12.60 (16)	2.38 (10)	
<i>Ficus spp.</i>	FIC SPP	2.74 (3)	2.17 (5)	1.49 (7)	
<i>Sabal palmetto</i>	SAB PAL		1.51 (3)		
<i>Myrsine guianensis</i>	MYR GUI	6.29 (6)	6.93 (15)	4.22 (16)	
<i>Myrica cerifera</i>	MYR CER	15.16 (7)	13.06 (18)	7.72 (20)	2.27 (2)
<i>Metopium toxiferum</i>	MET TOX	3.12 (4)	10.09 (15)	10.38 (19)	0.98 (1)
<i>Schinus terebinthifolius</i>	SCH TER	0.41 (1)	2.32 (10)	4.88 (16)	
<i>Calyptanthus pallens</i>	CAL PAL		1.22 (6)	5.18 (13)	
<i>Eugenia axillaris</i>	EUG AXI		1.46 (3)	2.30 (10)	
<i>Casuarina equisetifolia</i>	CAS EQU		0.84 (2)	2.39 (4)	
<i>Coccoloba diversifolia</i>	COC DIV		0.54 (2)	3.75 (11)	
<i>Conocarpus erectus</i>	CON ERE	2.02 (3)	13.99 (17)	15.17 (20)	19.48 (8)
<i>Swietenia mahogani</i>	SWI MAH		0.40 (1)	2.00 (15)	
<i>Rhizophora mangle</i>	RHI MAN	1.48 (2)	11.16 (18)	13.45 (20)	19.48 (8)
<i>Eugenia foetida</i>	EUG FOE		0.79 (1)	5.29 (15)	
<i>Coccoloba uvifera</i>	COC UVI		0.41 (3)	2.84 (12)	1.53 (2)
<i>Randia aculeata</i>	RAN ACU		0.49 (3)	4.83 (15)	5.54 (4)
<i>Pithecellobium guadalupense</i>	PIT GUA		0.08 (1)	0.26 (2)	0.98 (1)
<i>Laguncularia racemosa</i>	LAG RAC		0.41 (3)	5.73 (15)	11.86 (7)
<i>Bumelia celastrina</i>	BUM CEL		0.39 (3)	3.23 (11)	12.96 (5)
<i>Avicennia germinans</i>	AVI GER			0.21 (2)	4.68 (3)
<i>Lycium carolinianum</i>	LYC CAR			0.34 (1)	11.09 (6)
<i>Jacquinia keyensis</i>	JAC KEY				9.16 (5)

Figure 11: Current distribution of four types of tree island in the SESE

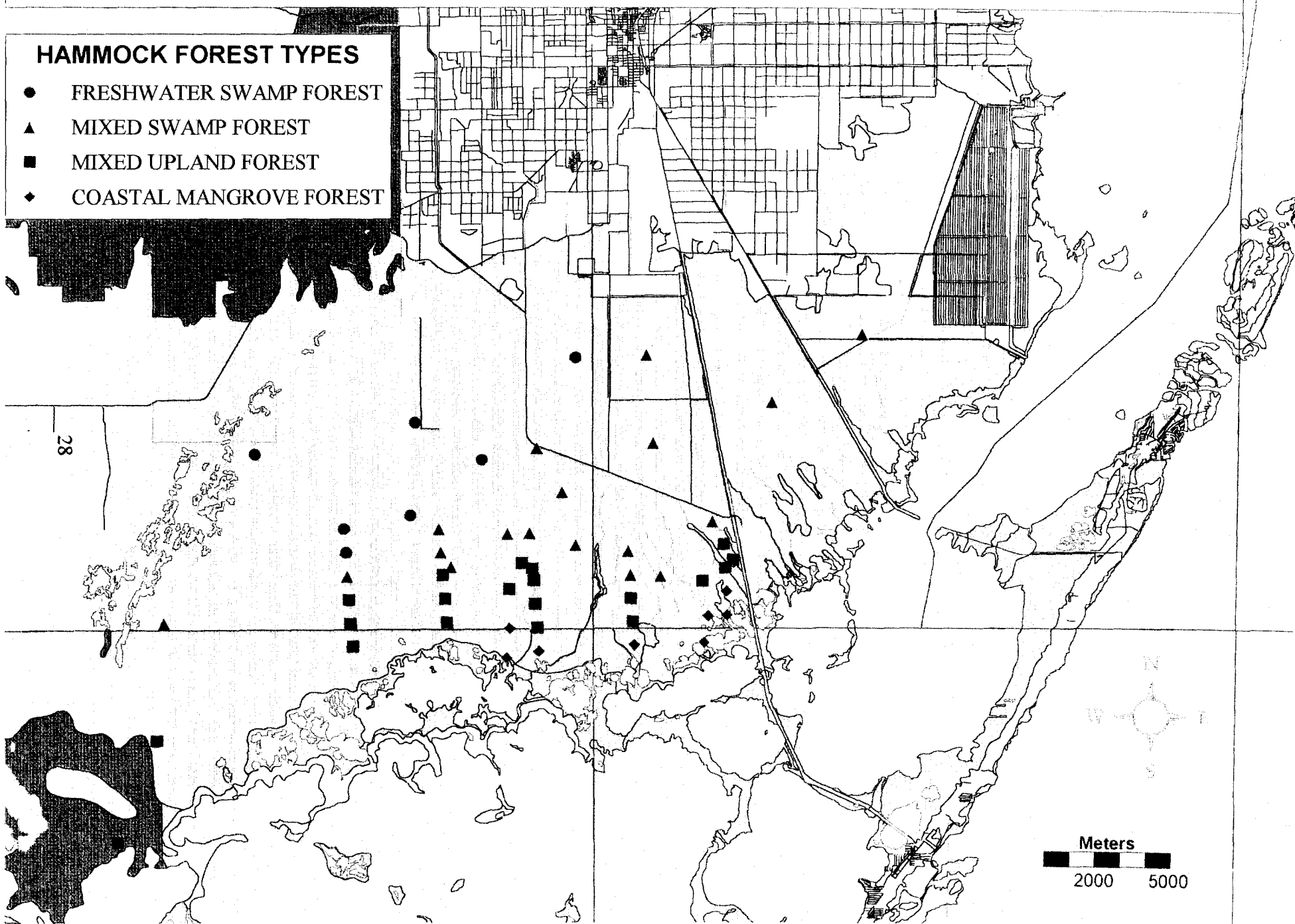
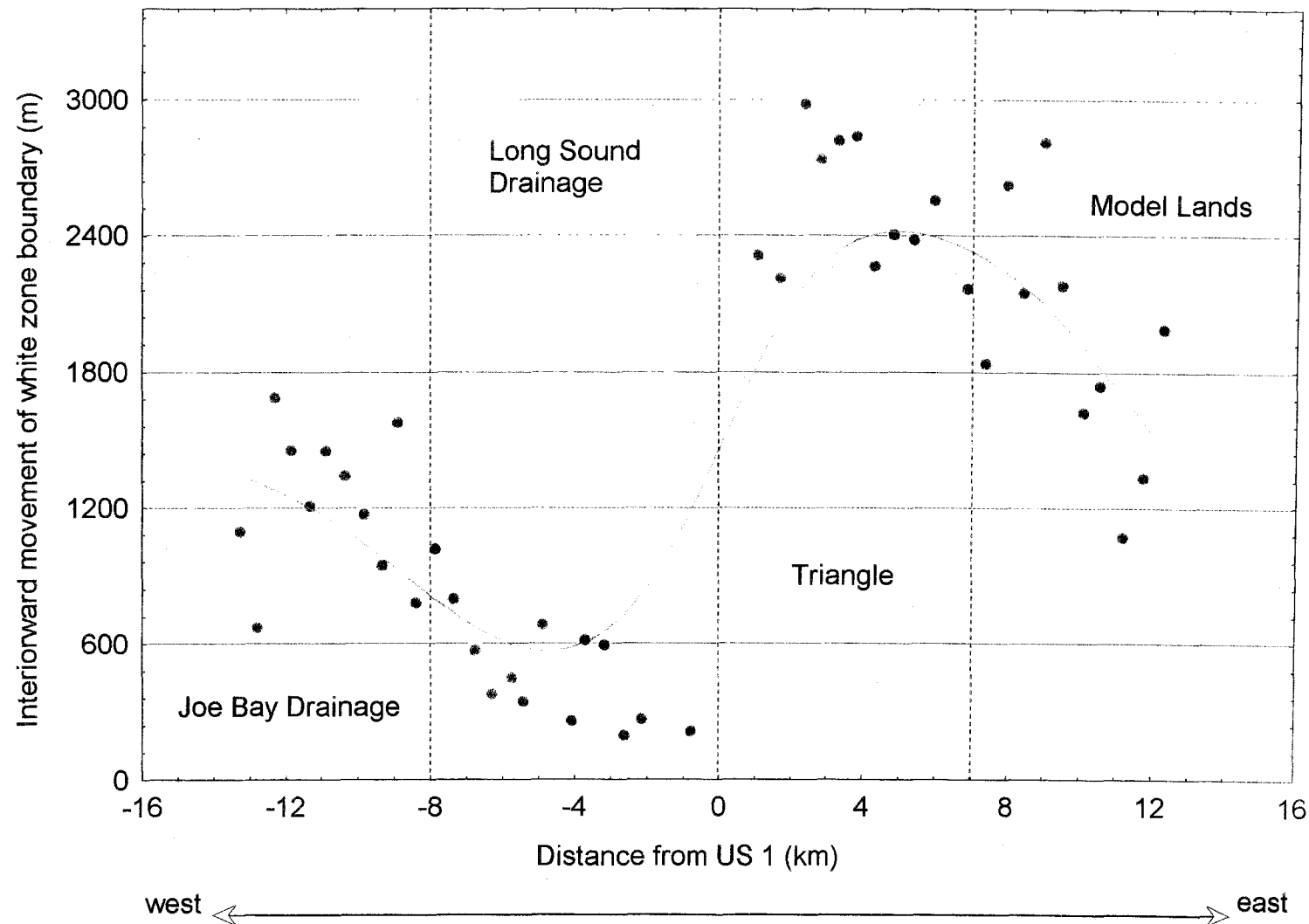


Figure 12: Movement of interior boundary of white zone between 1940 and 1994. Points represent distance measured along 45 transects perpendicular to the SESE coast and spaced at approximately 520 meter intervals along it.



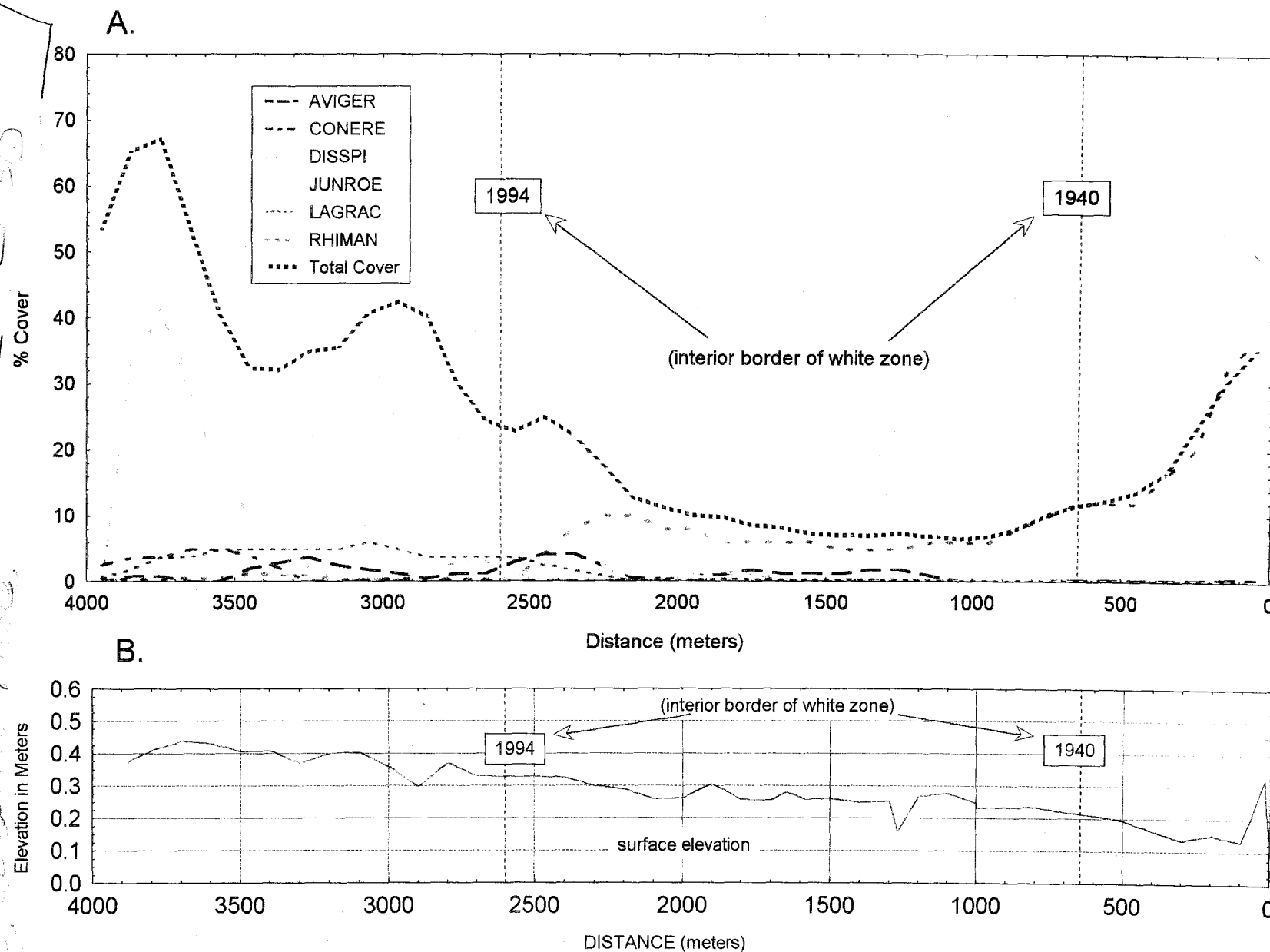
Some more focused evidence of the characteristics of the white zone emerge from closely-spaced observations along the Model Lands transect (Figure 13, Appendix 5), which differs compositionally from areas to the west in the SESE. The species gradient along this transect begins with a relatively dense, monodominant *R. mangle* stand at the coast, then passes through a zone in which *R. mangle* and *A. germinans* share dominance in a very open shrubland. At about 2500 meters from the coast, the vegetation changes quite abruptly to a predominantly graminoid form, with *Juncus roemerianus* and *Distichlis spicata* the leading species and mangroves (*A. germinans* and *L. racemosa*) present but in low abundance. The shift to a graminoid-dominated community coincides roughly with an increase in total macrophyte cover, as well as the interior limit of the current white zone. The white zone has transgressed inland by about 1950 meters since 1940, equivalent to an upslope movement of approximately 11 cm (Figure 13).

Table 7: Analysis of covariance for *C. jamaicensis* and *E. cellulosa* frequency, and hammock Axis 1 score at 20 sites sampled by Tabb et al. (1967) and again in 1995. Distance to Coast is covariate, Position (south or southwest of C-111 Canal) is among-site effect, and Time (1967 or 1995) is repeated measures effect.

Vegetation Paramenter	<i>C. jamaicense</i> frequency		<i>E. cellulosa</i> frequency		Hammock Axis 1	
Test of Homogeneity of Slope of Covariate						
Variable	Wilks' Lambda	P -value	Wilks' Lambda	P -value	Wilks' Lambda	P -value
Distance to Coast	0.95	0.66	0.57	0.01	0.98	0.85
Test of Main Effects						
Effects	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Position	2.22	0.15	n.a.	n.a.	52.90	< 0.01
Times	1.67	0.21	n.a.	n.a.	0.71	0.41
Position x Times	7.44	0.01	n.a.	n.a.	2.63	0.12

The results of the analysis of covariance for changes in marsh and hammock species composition below the C-111 Canal between 1967 and 1995 are summarized in Table 7. Overall, *C. jamaicensis* frequency did not differ by Position or Time. However, a significant Position x Time interaction indicated that over the 28-year period, *C. jamaicensis* decreased southwest of the Canal (compare diamonds and circles in Figure 14), while increasing directly to the south (compare squares and triangles in Figure 14). Analysis of covariance was inappropriate for *E. cellulosa*, because the effect of the covariate (Distance to Coast) differed between south and southwest positions (Table 7). Inspection of Figure 15, however, suggests that the response of this relatively salt-tolerant species was opposite to that observed for *C.*

Figure 13: 1940 and 1994 position of white zone along Model Lands transect, with (A) total macrophyte cover and cover of major species, and (B) elevation. Cover values and elevation are calculated as 3-plot moving averages at 100-meter intervals along transect.



08 R30 in hand S20 F7
 11-10 2-30
 9
 31

Figure 14: Scattergram, with least squares linear regression line, for four *C. jamaicense* data sets. Data are frequency of occurrence (in 1 m² plots) vs. Distance to Coast for sites south or southwest of C-111 Canal, as sampled in 1967 or 1995.

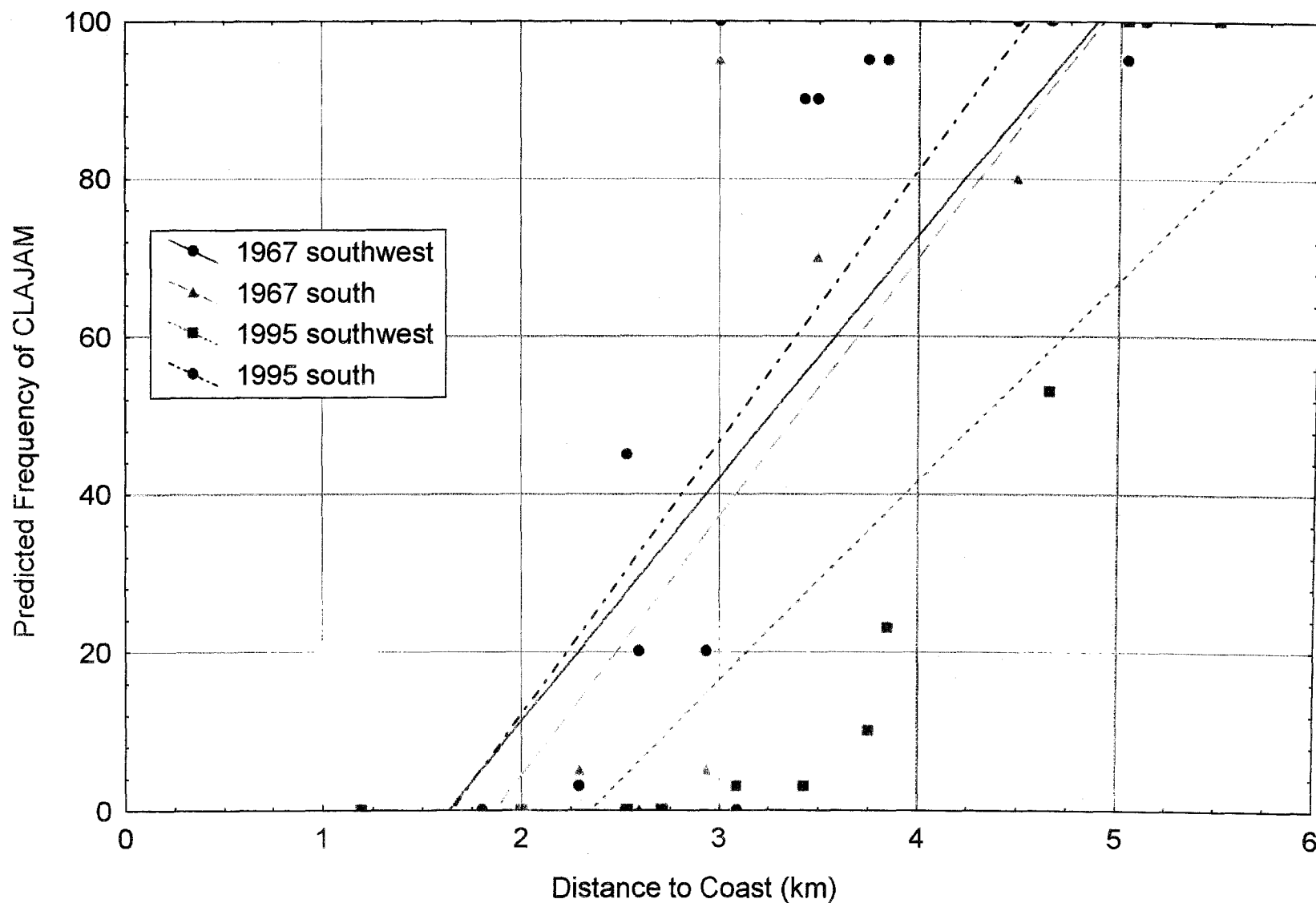


Figure 15: Scattergram, with least squares linear regression line, for four *E. cellulosa* data sets. Data are frequency of occurrence (in 1 m² plots) vs. Distance to Coast for sites south or southwest of C-111 Canal, as sampled in 1967 or 1995.

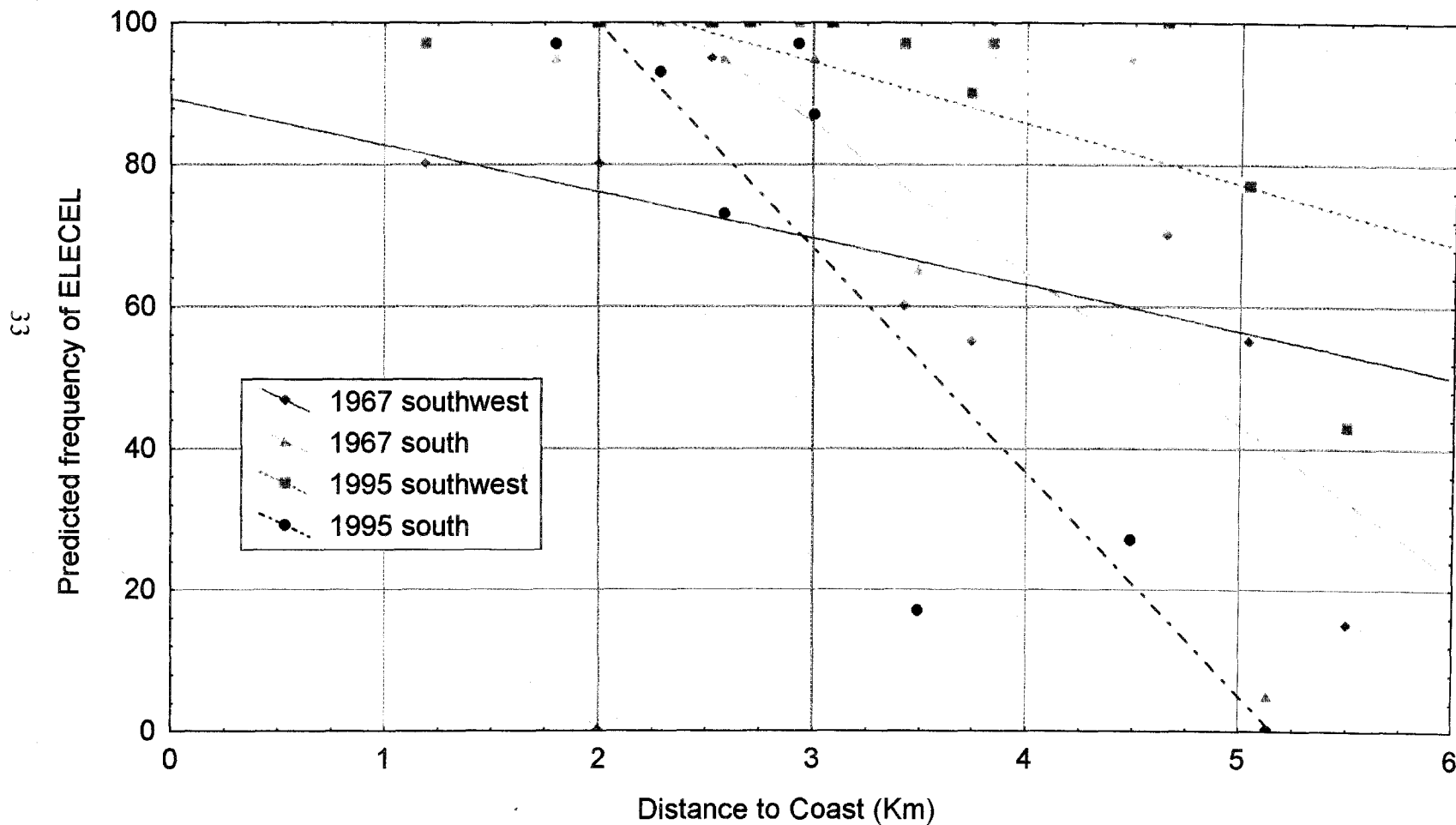
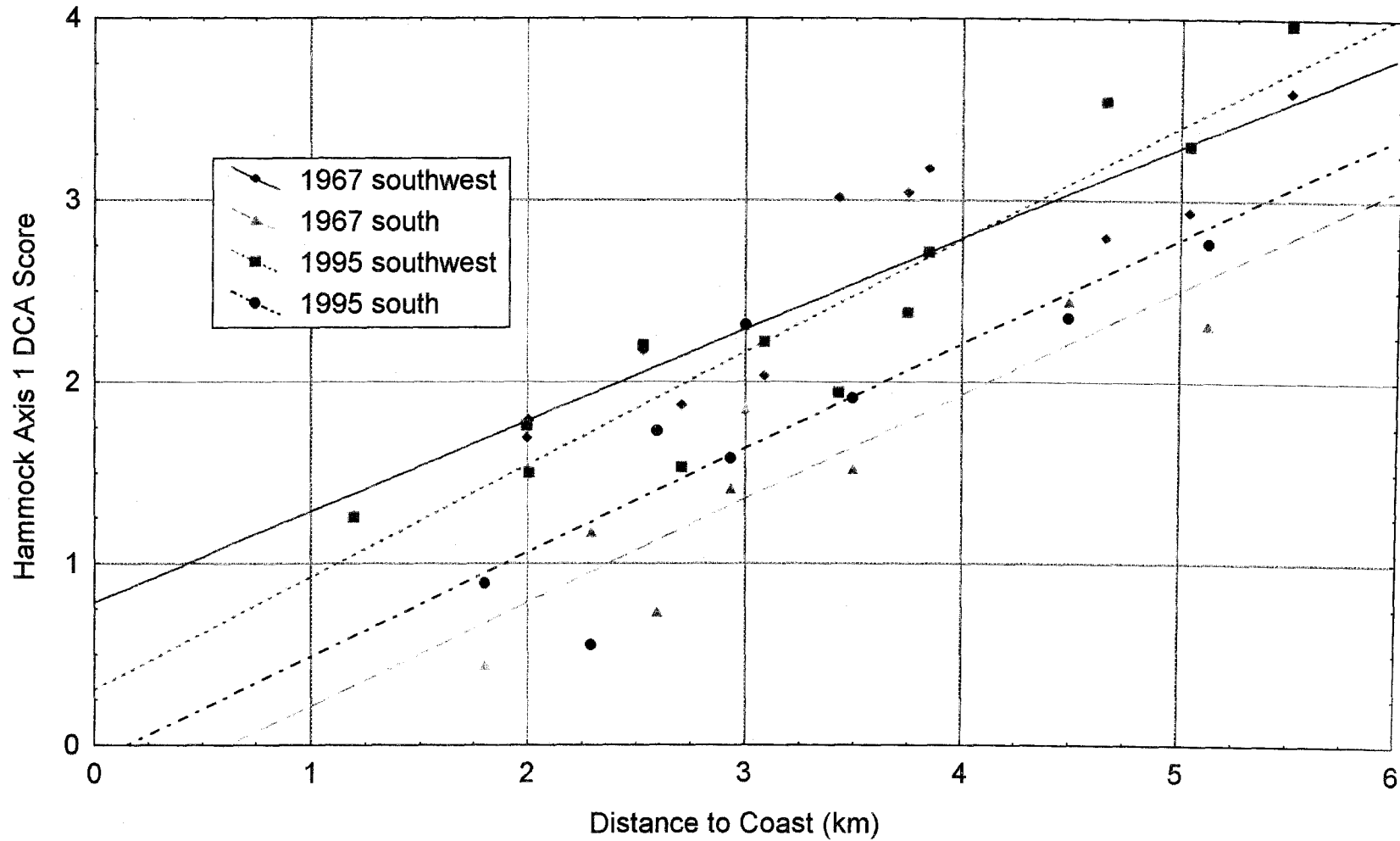


Figure 16: Scattergram, with least squares linear regression line, for four tree island data sets. Data are DCA Axis 1 scores vs. Distance to Coast for sites south or southwest of C-111 Canal, as sampled in 1967 or 1995.



jamaicense. Tree island composition showed a strong effect of Position, a non-significant Time effect, and a nearly significant Position x Time interaction. As illustrated in Figure 16, fresh water species are more important in tree islands south of the Canal than to its southwest (higher DCA scores in the former), and this contrast tended to become stronger with time.

Two naturalized exotic tree species displayed different levels of invasiveness in tree islands within the Tabb et al. (1967) network. *Casuarina equisetifolia* (Australian pine) was recorded in two of twenty tree islands in both samples. *Schinus terebinthifolius* was not recorded within the network in 1967, but is now present in fourteen of the twenty hammocks examined in both surveys. For the 1995 survey as a whole, *S. terebinthifolius* was present in 50% (27) of the 54 hammocks sampled, and there appeared to be little pattern to its distribution.

DISCUSSION

Current SESE marsh communities --- species composition and biomass

Like our predecessor (Egler 1952), we found the matrix of low vegetation in the SESE to be arranged in a long gradient perpendicular to the South Florida coastline. In his 1952 paper, Egler characterized seven discrete communities that occupied successive bands parallel to the southeast Florida coast, five of which comprised the Southeast Saline Everglades *per se*. We followed Egler's lead by classifying plant communities along this coastal gradient, in the process identifying four marsh species assemblages among the 55 samples included in the data analysis (Figures 3). Our groups were also distributed in distinct zones, with little geographic overlap between one group and the next (Figure 8). However, the low eigenvalues for TWINSpan divisions beyond Level 1, and the overlap in species composition evident in Table 2, suggest that these are not so much discrete units as nodal regions along a gradient from mangrove-dominated coastal shrublands to sawgrass-dominated interior grasslands.

Vegetation described in this study as Mangrove Coastal Prairie bears considerable similarity to Craighead's (1971) Marl or Coastal Prairie in species composition and in distribution, which is apparently limited to a narrow zone immediately interiorward of Long Sound, Joe Bay, and several of the lakes in the Taylor Slough drainage. In our study area, this slightly raised strip of land is continuous with but perhaps not as well-developed as the Buttonwood Embankment further to the west (Craighead 1964, 1971). Mangrove Coastal Prairie vegetation is distinguished from the much more extensive Mangrove Scrub by the presence of several herbs of open coastal settings, as well as small specimens of buttonwood and white mangrove (Table 2). The latter two usually occupy higher elevations than red or black mangrove (Davis 1940; Lewis et al 1985), although any mixture of the four species may be found in combination. Craighead (1971) reported that many Coastal Prairie sites were formerly wooded mixtures of buttonwood and upland species that were cut for charcoal. He predicted that they would eventually revert to upland forest, but we found no evidence of such a trend in our sites.

Craighead (1971) considered areas interior to the Buttonwood Embankment, with its characteristic Coastal Prairie vegetation, to be primarily fresh water systems, though salt water impacts occurred periodically. The three interior vegetation units recognized in our study --- Mangrove Scrub, Sawgrass - Spikerush - Mangrove Marsh, and Sawgrass Marsh --- represent regions along a gradient characterized by an inland decrease in the abundance of *R. mangle* and *E. cellulosa*, and an associated increase in the abundance of *C. jamaicense* and a fairly diverse group of fresh water herbs (Table 2). This gradient in species composition is accompanied by structural change: a decrease in the woody plant component from Mangrove Scrub through Sawgrass Marsh, an associated decrease in total aboveground vascular plant biomass, and a maximum in periphyton biomass in the intermediate Sawgrass - Spikerush - Mangrove zone (Table 3). Because of our small sample size, especially in the Mangrove Scrub, these trends are not statistically significant. However, they may reflect small but potentially important differences among community types whose vascular plant biomass totals are among the lowest reported for either mangrove or sawgrass communities in South Florida. For instance, Steward and Ornes' (1975) average monthly live standing crop of 1130 g/m² in a homogeneous sawgrass stand in Conservation Area 3B was more than six times greater than the total for all vascular plants in our Sawgrass Marsh sites (169 g/m²). While some of this difference may be attributable to our January - February sampling period, Browder's (1982) data from three sawgrass stations in Taylor Slough were not consistently low during this time of year. Biomass estimates for Florida mangrove communities vary dramatically, e.g., 787 g/m² in a scrub mangrove stand south of Turkey Point (Lugo and Snedaker 1974), and 17,932 g/m² in a paralic red mangrove forest in southwest Florida (Lugo and Snedaker 1975).

As discussed by several authors (Monteith 1972; Woodward 1987), primary production is largely a function of solar radiation intercepted. The estimates of leaf area index included in Table 3 may be a reasonable reflection of relative productivity across the ecological gradient discussed above, i.e., a trend of increasing vascular plant production away from the coast. Because these leaf area estimates were derived from biomass-based regressions for herbaceous plants, the much higher biomass reported for sawgrass marshes further north (Steward and Ornes 1975) suggests a continuation of this trend beyond the bounds of the SESE. Browder (1982) reports live macrophyte biomass as high as 800 g/m² at several East Everglades sites, but temporal and spatial variability of an order of magnitude or more were common. It should be noted that the taller plants in interior Everglades marshes probably contain a higher proportion of structural, non-photosynthetic tissue than plants from most C-111 locations. Like our biomass estimates, leaf area index means of nearly 1.0 in Sawgrass Marsh and in Sawgrass - Spikerush - Mangrove Marsh probably represent annual minima because of the winter sampling season. Even these minimum values approach the range of 1-3 reported for mid-latitude grasslands (Schulze 1982; Woodward 1987). In contrast, our mean leaf area index in Mangrove Scrub (0.54) is well below the value of 3 m²/m² generally found in shrubland ecosystems. In this context, we hypothesize that soil factors, especially the prevalence of heavy marl soils which were formed under sparse graminoid cover, temporarily prevent invading mangrove communities from reaching the production potential normally associated with the dominant plants' growth form. In sites that have been occupied long enough and in sufficient densities by mangroves for a layer of peat to have built up above the marl, however, much higher leaf areas may be attained. In coastal

portions of the Biscayne Bay watershed or the Florida Keys, gradients of several hundred meters length or less characterized by increases in mangrove leaf area index from <1 to >5 are common. Such transects invariably cross a sharp edaphic boundary between marl or rock at the low leaf area end and peat at the other (Ross et al., unpublished data).

Current marsh communities --- environmental underpinnings

To this point, our discussion has focused on four wetland communities that were defined on the basis of a classification analysis, an approach we followed for ease of presentation, and in order to compare our results with those of Egler (1952). However, the linear relationship observed between marsh species composition and coastal distance (Figure 9A, Table 5) seems to belie the notion of homogeneous communities separated by sharp boundaries, or ecotones. SESE marsh vegetation is instead arranged in a classic ecocline. Species present in low to moderate abundances near the coast (e.g., *Borrchia arborescens*, *Laguncularia racemosa*, *Conocarpus erectus*) gradually drop out inland. In the middle of the gradient there is a steady shift from *R. mangle*-dominated to *C. jamaicense*-dominated assemblages, with *E. cellulosa* an important associate throughout. At the most interiorward SESE sites, species characteristic of the deeper sloughs (e.g., *Bacopa monnieri*, *Nymphaea aquatica*) or of the wet prairies adjacent to the Coastal Ridge (e.g., *Schoenus nigricans*, *Rhynchospora* spp.) begin to increase in importance. What do our data indicate about the environmental factors controlling the long, smooth SESE gradient?

We used canonical correspondence analysis to assess the relationships of marsh plant species composition in the SESE to known environmental variables, but the analysis did not allow us to disentangle the many factors associated with the coastal gradient. Our results were limited by the unavailability of complete, spatially explicit data for potentially important variables likely to covary with proximity to the coast, such as elevation, disturbance history (e.g., fire, freeze, hurricane), and water quality parameters. Without these data, it was necessary to "blackbox" the complex coastal factor by including it in the analysis as "Distance to Coast", a spatial measure apt to integrate the effects of many unmeasured variables. CCA was nevertheless useful in 1) identifying a secondary axis of variation correlated with soil depth (Figure 4), and 2) identifying the weakness of association between hydroperiod and marsh species composition in the South Florida coastal zone (Figure 7). The absence of a significant secondary effect of hydroperiod is somewhat puzzling, because it is considered to be a primary control on plant species composition in the exclusively fresh water portions of the Everglades (Newman et al. 1996; Craighead 1971; Loveless 1959; Herndon et al. unpublished manuscript), and because it is not highly correlated with coastal distance. Such a result may suggest that vegetation is relatively slow in reaching an equilibrium with management-imposed deviations from the longterm hydrologic regime. In coastal South Florida, most plants are perennial, long-lived species with wide ecological amplitudes. Vegetation reaction to environmental change may be episodic rather than gradual, perhaps associated with the colonization period following disturbance. For instance, an established stand of *C. jamaicense* may be unaffected by high water or elevated salinity in the short term, but may be replaced by aquatic or halophytic plants, respectively, when similar conditions follow immediately on the heels of a fire. Alternatively, the absence of a hydroperiod effect

might be attributed to the limited size of the data set available for the analysis (only 19 sites), or the very wet set of years on which it was based.

If our data do not allow us to distinguish among the many environmental factors which may contribute to the SESE vegetation gradient, we can still offer informed hypotheses based on the autecology of the plants which are dominant at its opposite ends, *C. jamaicense* and *R. mangle*. From such considerations, detailed below, we hypothesize that salinity, fire, and freeze each have important, interacting roles in shaping the SESE vegetation gradient.

1. **Salinity.** Elevated surface and porewater salinities do occur at least seasonally at considerable distance from the coast in the SESE. Bjork and Powell (1993) reported surface salinities of 13 ppt at UJB, 2.2 km from the Joe Bay coastline in June, 1992, and similar salinity levels were recorded from a nearby well at EP9R in the spring of the following year (Everglades National Park, unpublished data). As expected, our salinity index was negatively correlated with coastal distance (Figure 4). However, the rate of decrease with coastal distance varied widely across the study area, with fresh water mollusk assemblages reached within a 2.5 km in Taylor Slough, and not until 5-7 km from the coast along transect north from Joe Bay and Highway Creek (Figure 6; see also Meeder et al. in prep.).

C. jamaicense is popularly considered the quintessential plant of the fresh water Everglades (Douglas 1947), though it may survive periodic exposure to salinity associated with hurricane storm tides, apparently by salt exclusion at the root-soil interface (Rejmankova et al. 1996). We were unable to uncover any accounts in the published literature concerning the response of *C. jamaicense* to controlled salinity conditions. However, in herbaceous wetlands in the Yucatan peninsula, Rejmankova et al. (1996) found that *C. jamaicense* biomass was maximum at sites with porewater conductivities of 4-8 mS/cm, while *Typha domingensis* was maximum at lower conductivities (0-4 mS/cm) and *E. cellulosa* at higher conductivities (8-20 mS/cm). In our own work in the Florida Keys, porewater salinities above 20 ppt were recorded throughout an annual cycle in one extensive sawgrass stand (Ross, unpublished data). However, *R. mangle*'s adaptation to salinity clearly extends further, as it apparently occurs at soil salinities up to 65 ppt (Cintron 1978). Like *C. jamaicense*, *R. mangle*'s principal means of salt tolerance is exclusion at the roots (Scholander 1968). In a greenhouse setting, *R. mangle* gas exchange was maximum at 4 ppt, and was relatively unaffected by salinities as high as 30 ppt (Lin and Sternberg 1993). Thus, Egler (1952) was probably correct in his contention that low salinity did not limit the northward expansion of *R. mangle*, but the reverse cannot be applied to the survival of *C. jamaicense* in the lower reaches of the SESE.

2. **Fire.** Variation in fire regime among different portions of the SESE are not well known, but fire return intervals are very likely to increase coastward because

of the decrease in fine fuels (i.e., graminoids) in that direction. Such zonal variation in fire frequency would interact with differences in susceptibility among species. On the one hand, the woody, thin-barked *R. mangle* seems to be extremely vulnerable to damage by fire. Lightning strikes which ignite small groups of red mangroves in coastal forests usually cause complete mortality of adults and initiate new cycles of regeneration (Smith 1994). *R. mangle* shrubs or trees retain almost no capacity to resprout after such damage because dormant buds do not maintain viability beyond a few years (Tomlinson 1980). Reestablishment of local populations therefore depends at least in part on successful colonization from distant seed sources. In contrast, fire does not cause widespread mortality in *C. jamaicense* under normal conditions. Most fires pass quickly over sawgrass stands, leaving a stubble of live tissue at the base of the culm, which resprouts and grows rapidly if not inundated soon afterward (Herndon et al., 1991). Egler (1952) believed that fire was important in limiting the northward expansion of *R. mangle* in Belt 3, and in allowing the survival of patches of *C. jamaicense* in Belt 4. In our judgement, fire is likely to be an important factor in the denser sawgrass swards in the northern one-third of the SESE, but of much lesser significance in the Sawgrass - Spikerush - Mangrove or Mangrove Scrub communities, where fuel loadings today are miniscule (Table 3).

3. **Freeze.** Freeze events are expected to be more frequent and severe with distance from the coast, but no empirical information on the subject are available from South Florida wetlands. Thomas' (1974) map of mean January isotherms for South Florida indicates a sharp decrease in temperature immediately inside the SESE coast, with less spatial variation in temperatures further inland. As a group, mangroves are very susceptible to low temperatures, with *A. germinans* somewhat better adapted to freeze damage than *R. mangle* or *L. racemosa* because of its ability to resprout with vigor (Odum and McIvor 1990). At least three freeze events have affected South Florida mangrove communities in the last decade. Olmsted et al. (1993) examined the effects of freezes in 1977, 1981, and 1989. The latter event was a severe late December frost that affected hundreds of hectares of Mangrove Scrub in the SESE and the northernmost Florida Keys. In much of the affected area, mortality of *R. mangle* was nearly total, and recovery of the original canopy from new colonizers has been slow. A much less severe freeze caused localized mortality on January 8-9, 1996. Even in severely affected areas, recovery has been rapid, primarily from small surviving *L. racemosa* and *R. mangle* individuals which constituted a "seedling bank" prior to the event (Ross et al. unpublished data). These two instances had no apparent effect on *C. jamaicense*, whose northern distribution extends as far as Virginia (Godfrey and Wooten 1979). A number of authors have cited freeze events as a potential causes of vegetation patterns in South Florida (Craighead 1971; Egler 1952; Olmsted et al. 1993). We agree, and think that these episodic occurrences may be particularly significant ecological factors within coastal ecoclines like the SESE.

Current tree islands --- species composition

We divided the tree islands of the SESE into four compositionally-determined groups, which are distributed in bands roughly parallel to the coast (Figure 11). The types of hammock we encountered have been described by others (Davis 1943; Egler 1952; Craighead 1971; Olmsted et al. 1981; Gunderson 1992), but ours is the first to describe their distribution across a coastal gradient. We named these groups on the basis of the dominant species' hydrologic affinities, but might equally have chosen a nomenclature which emphasized species' climatic habits, as suggested by their range distributions. More specifically, temperate species reaching their southern limit in South Florida are most prominent in the two bands furthest from the coast (Freshwater Swamp Forest and Mixed Swamp Forest), while the more coastal tree islands (Mixed Upland Forest and Coastal Mangrove Forest) are characterized by species whose distributions are centered further south in the tropics. These are heterogeneous units from either aspect, with temperate and tropical species intermingling in the two Swamp Forest types, and all combinations of upland and wetland species occurring together in the two Mixed Forest types. These four units are roughly equivalent to Willow Heads or Cypress Domes, Bayheads, Tropical Hardwood Hammocks, and Buttonwood Islands, respectively, in the terminology of Craighead (1971).

The similarity in the zonation pattern of marsh and tree island suggests that these two associated structural forms may respond to the same categories of the macroenvironment discussed above --- hydrology, climate, and disturbance. At the local landscape scale, the response of hammock and marsh may differ as a result of their distinctive growth forms and the microenvironments they create. The paucity of physical information about the hydrology, climate, or disturbance regimes of SESE tree islands limits such speculations.

Hydrology. We are unaware of any data concerning the hydrology or salinity regime of tree islands in the SESE or in Everglades National Park. The SESE tree islands we visited were almost without exception conspicuously raised above the level of the surrounding marsh. Their soils were generally saturated to the surface, but standing water was rarely present in more than an occasional depression during the January - February sampling period. In seeming paradox, many of these forests were islands located in the center of local drainage basins, and most were surrounded by conspicuous moats. Gleason and Stone (1994) outlined several mechanisms by which tree island initiation may occur. Following these initial steps, peat accretion may cause the island to become further elevated relative to the surrounding marsh, or fires may lower its level. In conjunction with the marsh hydrologic regime, then, the soil formation process determines the water level or salinity in the tree island itself, with potential feedback effects.

For the vast majority of the trees which occupy the SESE tree islands, no published information are available regarding species response to water level or salinity regime under experimental conditions. However, the realized niches of many of these trees with respect to hydrologic factors are known to range widely. In the Florida Keys, species like *Coccoloba diversifolia*, *Swietenia mahogani*, *Metopium toxiferum*, *Eugenia* spp. and *Calypttranthes pallens* are rarely found in sites which are inundated for more than a few weeks per year

(Ross et al. 1992), while *Salix caroliniana*, *Taxodium distichum*, and *Ammonia glabra* are important components of Big Cypress communities with mean hydroperiods of six months or more (Duever et al. 1979). Their apparent sensitivity to salinity also runs the gamut. In the Florida Keys, *Avicennia germinans* adults survive in sites where soil salinities exceed 60 ppt for several months during most years (Ross et al. unpubl. data), while several of the Big Cypress species cited above are not found where salinities exceed 1 ppt or so for more than a few weeks (Craighead 1971). It would appear on this basis that salinity and water level have at least the potential to contribute to the observed variation in hammock species composition.

Climate. On a regional or global scale, the southeast saline Everglades is situated within a sharp ecotone between forest types, one which is strongly associated with the frequency and severity of freezing temperatures. Species assemblages in the Florida Keys, where freezing temperatures have never been officially recorded, are most similar to forests of the Bahamas and Caribbean islands. Although there is some overlap between Keys forest composition and that of the southernmost counties of the Florida mainland, these similarities disappear rapidly northward, where freezing temperatures are reached much more frequently. Most Florida Keys species reach their northern range limits in the southern half of the Florida peninsula, usually in coastal locations where temperature extremes are moderated (Little 1978). Within the SESE, the Mixed Upland Forest type has strong affinities with Florida Keys forests, while the Freshwater Swamp Forest are most similar to swamp forests further north.

The climate of the SESE must be inferred from weather stations around its periphery. At the Homestead weather station northeast of the SESE, freezing temperatures were reached in 20 of 39 years between 1949 and 1987 (Duever et al. 1994). As discussed earlier, climatic models indicate that January temperatures are moderated along the Florida Bay coast relative to inland portions of the SESE (Thomas 1974). Consequently, the SESE probably encompasses a gradient in freeze frequency and severity, and such events may have a profound influence on the species composition of its tree islands. The sensitivity of the mangroves *R. mangle* and *L. racemosa* has been noted above, and Olmsted et al. (1993) observed clear differences in the susceptibility of temperate (*Quercus virginiana*) and tropical (*M. toxiferum*, *Bursera simaruba*) to damage from the freeze of 1989. In considering species' sensitivities to freeze, one should bear in mind the ameliorative effect of the tree islands themselves, and the structural niche of the species in question. For instance, for any given freeze event, cold temperatures experienced by understory species beneath the forest canopy are apt to be higher than those impacting species characteristic of the forest edge, or emergent trees.

Disturbance. Wildfires and hurricanes are the primary natural disturbances impacting SESE forests. As discussed earlier, strong hurricanes have a return interval of about 25 years (see Neumann et al. 1981). Fire frequency and intensity are affected by vegetation type and by the surrounding vegetation matrix, though these patterns are not well known for the remote SESE.

Hurricane and wildfire are unquestionably evolutionary forces which have shaped the flora of the south Florida hammocks by selecting for effective mechanisms of (a) initial

resistance, (b) reiteration of damaged crowns, or (c) population reestablishment from seed or vegetative means. However, the short-term successional variation created in the landscape by most hurricanes or surface fires are not responsible for the tree island zonation illustrated in Figure 11. Only disturbance types which produce relatively permanent changes in the underlying environment can contribute to such a broad and directional compositional pattern. One example may be storm surge, which in Hurricane Donna deposited two inches or more of salty mud on tree (mostly mangrove) roots several km inland from the Florida Bay shoreline west of our study area (Craighead 1964). Mortality was near-complete, regeneration from seed was slow, and the affected areas are still open-canopied, recognizable three decades later. The periodic occurrence of such storms may be responsible for substrate differences between Coastal Mangrove Forests and other tree island types. Robertson (1955) described succession after fire in several bayhead forests, which are equivalent to our two Swamp Forest types. While recovery could be rapid after a surface fire, bayheads in which most of the peat had been lost showed very little sign of recovery several decades later. Areas with a high longterm frequency of peat fires might therefore be characterized by low elevation (immature) tree islands, with species characteristic of such conditions. Clearly, not enough is known about the spatial and temporal distribution of different types of disturbance to adequately evaluate this possibility.

Historical changes in SESE ecosystems

The results described above document two significant vegetation-related changes in the SESE over the last half century: 1) the interiward movement of a band appearing white on both color infrared and black and white aerial photos, 2) shifts in vegetation composition below the C-111 Canal, with opposite trajectories of change in an area recipient of C-111 overflow and in an adjacent non-recipient area. In a companion manuscript, Meeder et al. (in prep.) traced a century-long increase in the proportion of marine-associated mollusk species preserved in SESE soil cores, an increase which varied dramatically among drainage basins of contrasting character and history. We believe these three trends are different manifestations of the same forces, i.e., the shifting balance between sea level and freshwater discharge in the SESE.

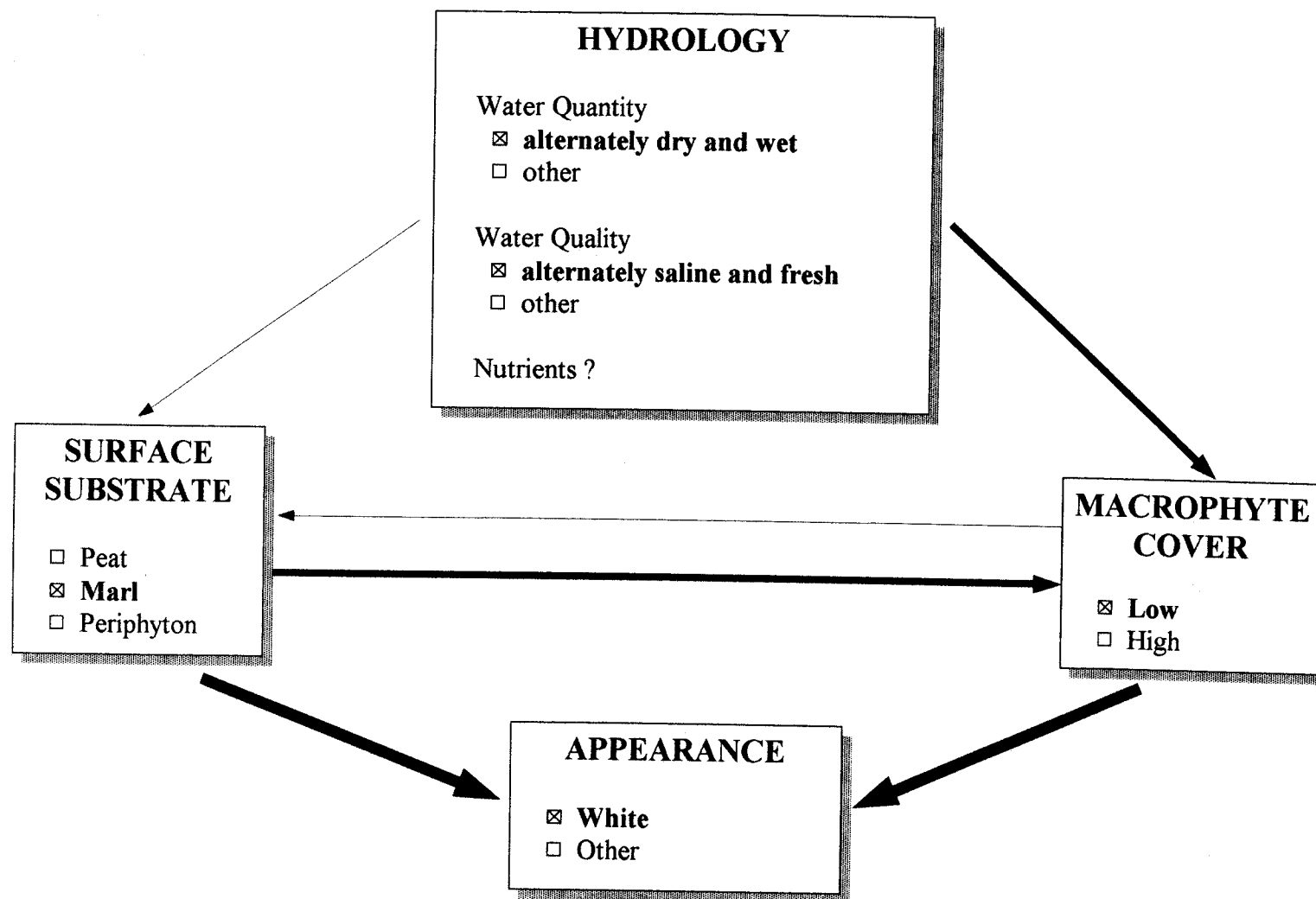
The white zone. Midway along the long, smooth SESE vegetation gradient, a sharp discontinuity between a sparsely speckled white zone toward the coast and a gritty, mostly unbroken, gray or pink area extending far into the interior are visible on both 1940 black and white and 1994 color infrared aerial photos. Based on his vegetation surveys within and on either side of it, Egler (1952) described this zone (his Belt 4) as a band of mixed vegetation including approximately equal proportions of *C. jamaicense*, *E. cellulosa*, and *R. mangle*; in the gray-appearing (on B&W aerial photos) communities bordering it on the interior (his Belt 3), *C. jamaicense* was the overwhelmingly dominant plant species. Today the white zone is a monodominant community of *R. mangle* (our Mangrove Scrub), with *C. jamaicense* virtually absent; in plant assemblages to the north (our Sawgrass - Spikerush - Mangrove Marsh, equivalent to Egler's Belt 4), *R. mangle* remains a very prominent component (Figure 8, Table 2). Because the vegetation within and north of the white zone of a half century ago comprised a different juxtaposition of plants than today, we surmise that the characteristic appearance of

this interface on aerial photos results from factors other than species composition.

An alternative interpretation better supported by available data is that the appearance of the white zone on aerial photographs results from the combined effects of a reflective substrate and low plant cover. South and southwest of the C-111 Canal, the current white zone lies entirely within Mangrove Scrub vegetation (Figure 8). The leaf area index mean of 0.54 in this community type (Table 3) is about 55% of that in the adjacent Sawgrass - Spikerush - Mangrove type, and this contrast probably becomes accentuated during late spring or summer when new shoots emerge. Given low macrophyte cover, the white appearance on CIR photos may be attributable to equal reflection in green, red, and near infrared bands by the surface substrate, which is a light-colored peaty marl (Meeder et al., in prep.), or, in the case of the Model Land transect (Figure 13) a recent storm deposit from Hurricane Andrew. In both cases, the white zone does not extend into the adjacent area in which a coherent periphyton mat is at least seasonally present. This is to be expected, since the periphyton is photosynthetic and therefore reflecting in the near infrared range. Hardisky et al. (1986) list a number of factors which affect spectral reflectance patterns of plant canopies. Several which may contribute to seasonal or annual variation in the current case are dead biomass in the plant canopy, salt accumulation on leaf surfaces, the wetness of the soil surface, and leaf moisture content. In the nearby Florida Keys, narrow white bands surrounding upland areas usually signify sparse buttonwood woodland or mangrove scrub vegetation on exposed limestone bedrock (Ross et al. 1992).

Observed spatial and temporal variation in the position of the SESE white zone are consistent with the hypothesis that hydrological variables associated with the balance of marine and fresh water sources are somehow implicated in the presence of this unproductive band of vegetation (Figure 17). Comparison of the 1940 and 1994 photo series indicates that the white zone has extended inland by about 1.5 km throughout the entire stretch of coastline between Joe Bay and Card Point on Card Sound. This interiorward movement has been greatest east of U.S. 1 in the Triangle and Model Land areas, least in the drainage north of Long Sound and immediately west of U.S. 1, and intermediate in the area north of Joe Bay (Figures 8 and 12). The relative movement of the white zone boundary among these four basins is well correlated with their access to fresh versus salt water. The Triangle and Model Lands are both entirely cut off by canals or roads from upstream sources of fresh water. When these areas are in whole or part tidally flooded, it is by Barnes or Card Sound waters of marine character. The intrusion of marine waters into the Triangle unit has been accelerated by the ditch along U.S. 1, which is open to Barnes Sound. In contrast, net outflow of fresh water from the C-111 Canal into marshes to the south (mostly Long Sound drainage) averaged about 175,000 acre-feet of water per annum during 1990-95. Here, the unculverted U.S. 1 serves to intercept fresh water flow and retain it within the basin. When flooded by wind-driven tides, both Long Sound and Joe Bay drainages are inundated by estuarine Florida Bay waters whose salinity is often (though not always) less than that of open sea water. Finally, the Joe Bay drainage is open at its upper end, but the effect of water management has been to shunt water which might have flowed in its direction either to the east or the west.

Figure 17: "White Zone" model



Such variations among basins have taken place in the context of a global rise in sea level that has been 9.9 cm since 1940 at Key West (Maul and Martin 1994). Over the same period, sediment accretion has been approximately 7.5 cm along the Model Lands transect illustrated in Figure 13 (Meeder et al., in prep). Given (a) the correctness of our hypothesis that white zone advance is the result of a balance between marine and fresh water input, and (b) no change in fresh water input, then sea level rise should have caused the white zone to move upslope in the Model Lands by approximately 2.4 cm since 1940. As the surveyed elevations in Figure 13 indicate, its interiorward movement of *ca* 2 km along the Model Lands transect is equivalent to a change in elevation of about 11 cm, or more than four times that expected on the basis of sea level alone. We think this result is not unreasonable considering the complete isolation of the area in question from upstream water sources which might previously have sustained it. In tracing the extension of marine-associated mollusk assemblages into the marsh interior over the previous century, Meeder et al. (in prep.) includes a much more complete treatment of these issues for the entire SESE. While the details vary considerably among drainage basins, all show signs of reduced fresh water input.

The relationship we have observed between fresh water input and the position of the white zone certainly support the hypothesis that the zone's low cover and consequent appearance on aerial photos is hydrologically based (Figure 17). Montague and Wiegert (1990) described several Florida coastal sequences in which a zone of low stature, sandwiched between taller marshes or swamps, occupied a belt coastward of the mean high tide line. Carter (1988) presented general marsh profiles for Britain and eastern North America in which the zone of sparsest vegetation occupied a region near the intersection of salt and fresh water bodies. In this position, one might expect intermediate mean but maximum variance in salinity. Similar distributions may be expected among other water quality parameters which differ between marine and terrestrial sources. Depending on topography, frequent wetting and drying are also likely. A plant in such an environment must function under a wide range of conditions, and the ability to do so may require physiological adaptations associated with slow growth. In developing this idea, Ball (1988) has pointed out that mechanisms of salt tolerance such as salt exclusion, conservative water use, and the associated need for control of leaf temperature through leaf display adaptations all incur carbon costs. Her studies show that mangrove species with the widest range of salinity tolerance have the slowest growth at optimal salinity. Ball's arguments were applied to interspecific variation, but similar reasoning may be relevant for variation within populations, or for variation in other environmental variables affecting gas exchange, i.e., drying. In a related study, Lin and Sternberg (1993) found that *R. mangle* grown at fluctuating fresh and saline conditions in the greenhouse had slower growth than individuals maintained at either extreme. At this time, too little is known about environmental variation within the SESE coastal gradient to assess whether fluctuation in salinity represents a viable hypothesis to explain low productivity in the white zone.

(Changes in species composition and community structure. If anything, our data suggest that marsh species composition has been more sensitive to changes in the balance between sea level and fresh water input than has the position of the white zone. As discussed earlier, Egler (1952) identified the interior border of the white zone as the boundary between his Belt 3 and Belt 4 vegetation units (equivalent to our Sawgrass Marsh and Sawgrass -

Spikerush - Mangrove Marsh, respectively). Today, along a transect north from Joe Bay, the same compositional interface is about 3.31 km further inland than in 1940, while the interior border of the white zone has moved north by only 1.25 km (Figure 8). The trend toward more salt-tolerant plant assemblages along the Joe Bay transect was generally borne out over the 1968-1995 period, while directly south of the canal supplementation of fresh water supply to the marsh may have mitigated and even reversed these changes for species like *C. jamaicensis* (Figure 14). Even in these marshes, the invasion by *R. mangle* has continued, and Sawgrass Marsh is no longer encountered until several km north of the C-111 Canal (Figure 8).

Craighead (1971) considered the Buttonwood Embankment, with its characteristic Coastal Prairie vegetation, to separate salt and fresh water vegetation types. The change in plant species composition documented in this study --- an advancing wave of replacement of *C. jamaicensis*-dominated marsh by low *R. mangle*-dominated mangrove swamp --- signifies an extension of marine and brackish water conditions into formerly fresh water wetlands, with enormous consequences for all organisms which must regulate their osmotic balance. Beyond this, the shift from herbaceous to woody vegetation will have its own broad ecosystem consequences. In shrubland ecosystems, a significant proportion of NPP and absorbed nutrients become tied up in a pool with a relatively slow turnover rate. To a significant extent, turnover in this pool results from periodic disturbances rather than predictable seasonal cycles. From the perspective of associated faunal groups, low swamp communities provide a very different vertical and horizontal structure than herbaceous marshes. Algal communities are also likely to be affected by structural differences which alter the light or nutrient environment at the soil surface, or which interrupt the cohesiveness of the periphyton mat. Structural impacts on hydrologic processes (e.g., evapotranspiration, resistance to surface water flow) are unexplored for these ecosystems, but quite possible. Differences in soil-forming processes between SESE mangrove and graminoid ecosystems are discussed in detail in Meeder (unpublished manuscript). Because the process of mangrove encroachment has been so extensive (Figure 8), significant relationships may have important impacts at the level of the south Florida ecosystem as a whole.

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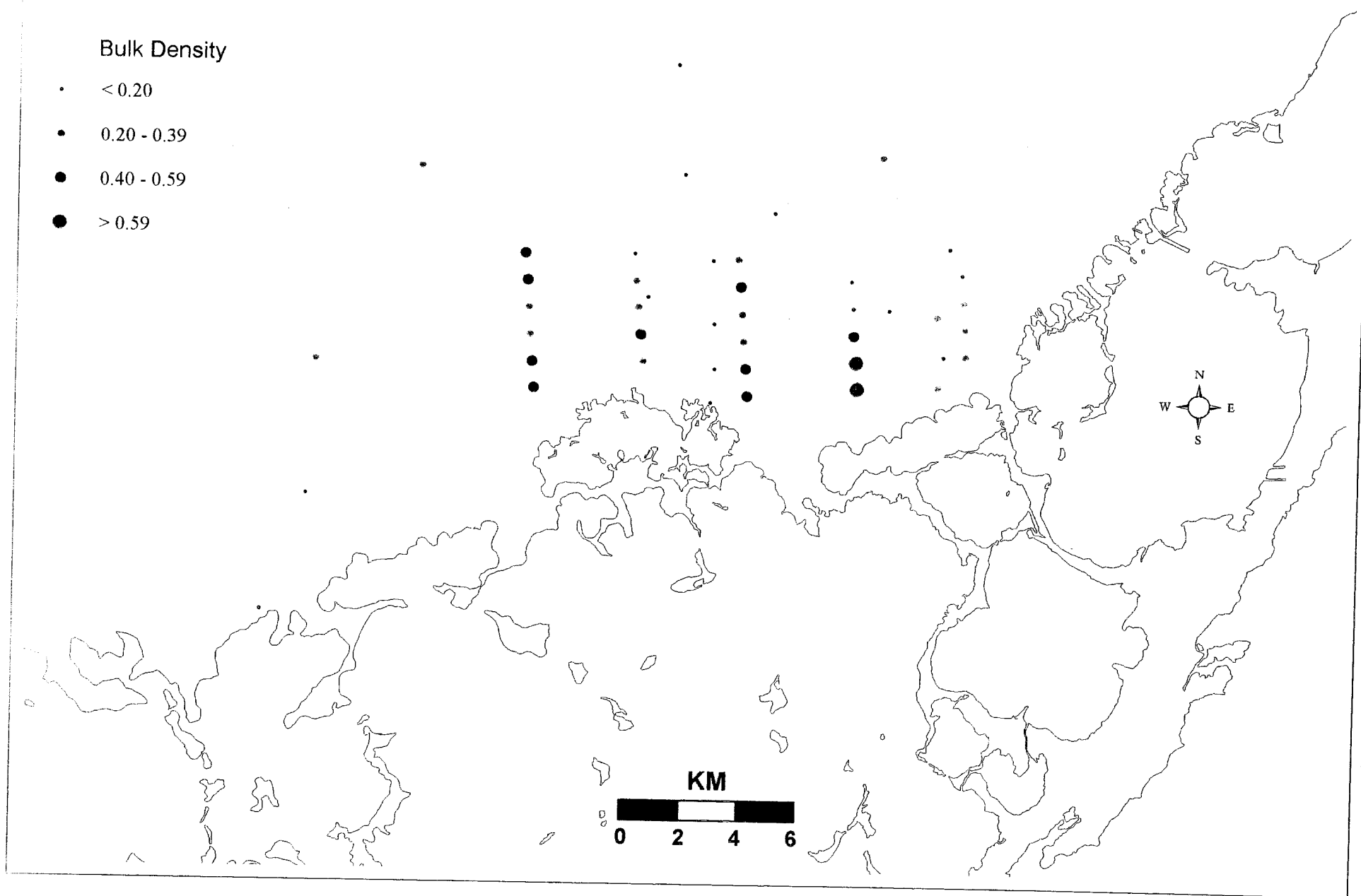
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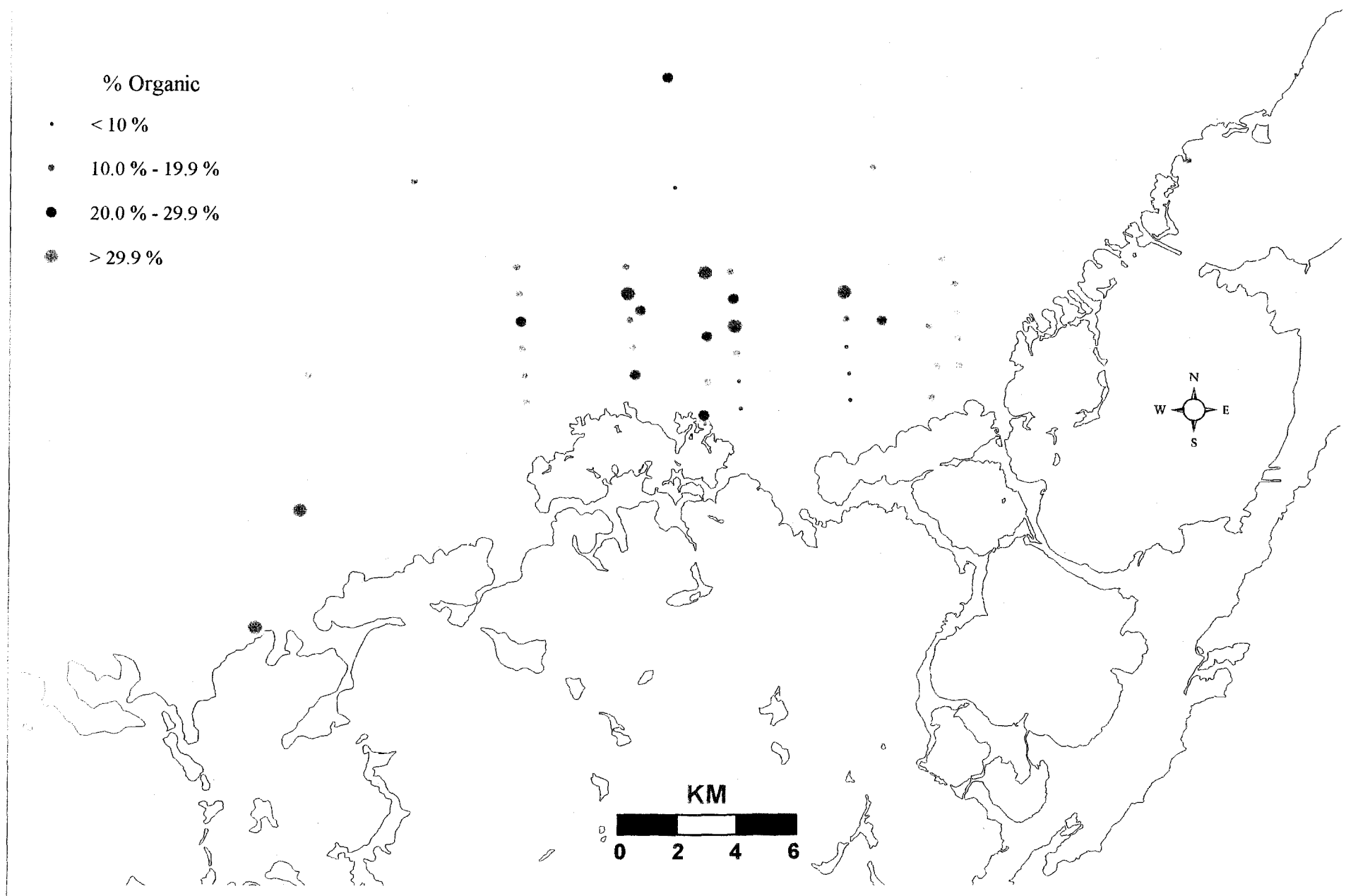
Appendix - 1

(longitude and latitude are in decimal degrees)					
SITE	LONGITUDE	LATITUDE	SITE	LONGITUDE	LATITUDE
CT 50 R	-80.521389	25.313611	T-1-2	-80.448900	25.279444
E 146	-80.666389	25.252222	T-1-3	-80.448300	25.271111
EP 10	-80.527222	25.273056	T-1-4	-80.447800	25.262778
EP 12R	-80.445278	25.273889	T-1-5	-80.447500	25.254444
EP 1R	-80.453056	25.287500	T-2-2	-80.486100	25.277222
EP 9R	-80.554722	25.271944	T-2-3	-80.485300	25.268889
EPSW	-80.506667	25.279444	T-2-4	-80.485300	25.260556
EVER 1	-80.430000	25.329444	T-2-5	-80.484400	25.252222
EVER 2B	-80.476111	25.315278	T-2-6	-80.483900	25.244167
EVER 3	-80.506667	25.345278	T-3-1	-80.524200	25.283611
EVER 4	-80.545278	25.343333	T-3-2	-80.523300	25.271111
EVER 6	-80.511944	25.298056	T-3-3	-80.522800	25.266944
EVER 7	-80.542778	25.309722	T-3-4	-80.522200	25.258611
EVER 8	-80.478889	25.346111	T-3-5	-80.521400	25.250278
EVER5 B	-80.570556	25.290000	T-3-6	-80.520800	25.241944
G1251	-80.568611	25.322778	T-4-1	-80.559400	25.285278
HCCST	-80.456500	25.244667	T-4-2	-80.558900	25.276944
HCINT	-80.473333	25.268333	T-4-3	-80.558100	25.268889
JBCST	-80.533167	25.239667	T-4-4	-80.557200	25.260556
JBINT	-80.532667	25.283333	T-4-5	-80.556400	25.252222
LHC	-80.454722	25.254167	T-5-1	-80.596100	25.285278
LJB	-80.531944	25.250000	T-5-2	-80.595300	25.276944
LTS	-80.684500	25.175000	T-5-3	-80.594700	25.268611
TKYW	-80.390278	25.349167	T-5-4	-80.594200	25.260278
TSH	-80.631111	25.311667	T-5-5	-80.593600	25.251944
UHC	-80.457167	25.266500	T-5-6	-80.592800	25.243889
UJB	-80.532167	25.263833			
UTS	-80.669333	25.210833			

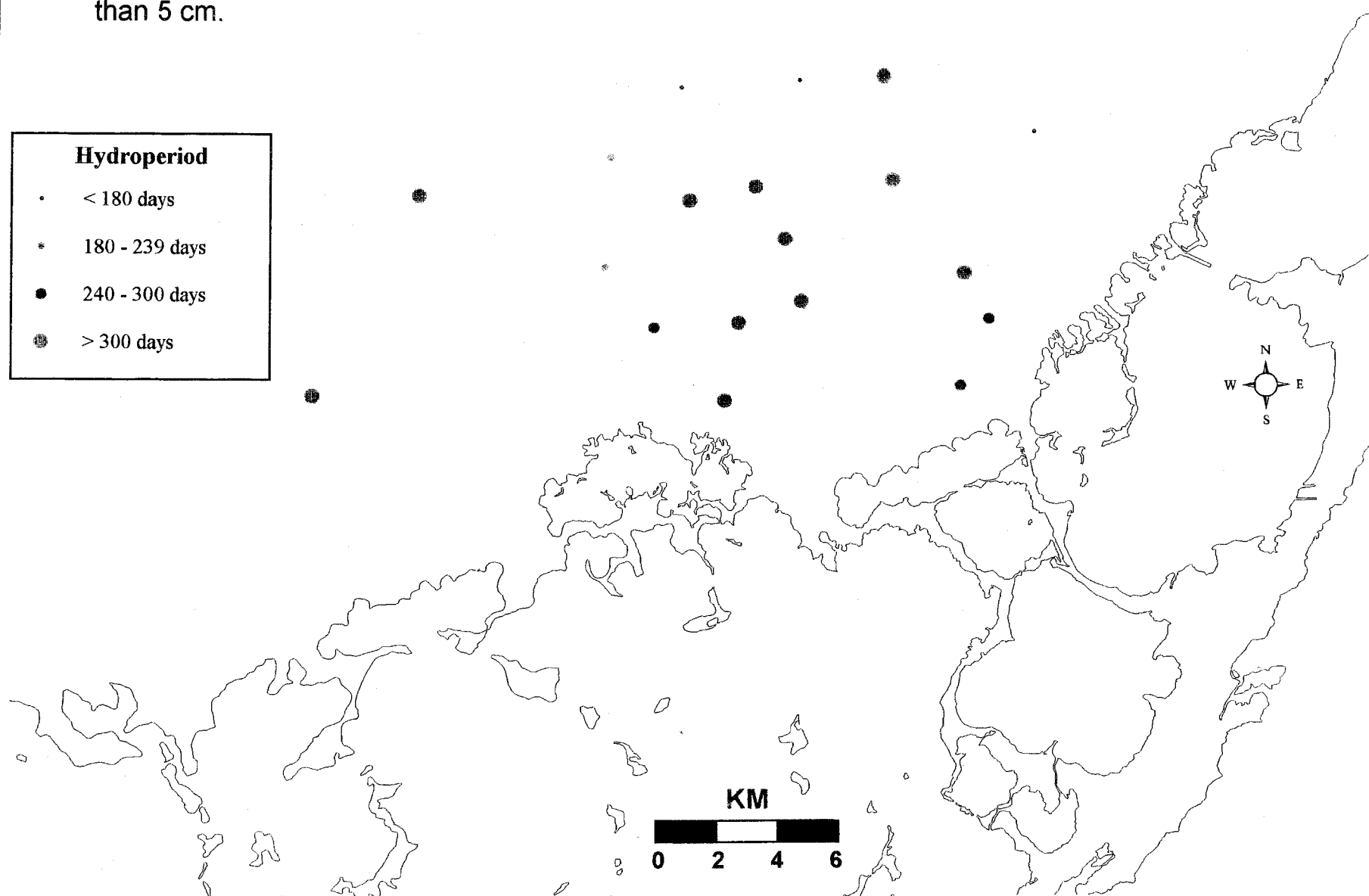
Appendix 2 : Current distribution of Bulk Density of surface soils in the SESE.



Appendix 3: Current distribution of percent organic matter in surface soils in the SESE.



Appendix 4: Distribution of mean annual hydroperiod over 1992-94 period in the SESE. Hydroperiod is calculated here as the mean number of days that average water depth at marsh surface was more than 5 cm.



Appendix 5 - Cover class estimates for all species along Model Lands transect. 1=0-1%; 2=1- 4%; 3=4-16%; 4=16-33%; 5=33-66%; 6=>66%. Species codes are as listed in Table 2, with addition of JUNROE (*Juncus roemerianus*), SALVIR (*Salicornia virginiana*), BORARB (*Borrichia arborescens*), AVIGER (*Avicennia germinans*), & DISSPI (*Distichlis spicata*).

Distance (m)	Species	Abundance	Distance (m)	Species	Abundance	Distance (m)	Species	Abundance
50	JUNROE	6	850	LAGRAC	3	1950	JUNROE	2
50	CONERE	2	850	AVIGER	2	1950	DISSPI	1
50	RHIMAN	1	850	RHIMAN	1	1950	AVIGER	1
50	CLAJAM	1	850	DISSPI	1	1950	RUPMAR	1
50	LAGRAC	1	850	RUPMAR	1	2050	RHIMAN	3
150	DISSPI	6	950	JUNROE	5	2050	DISSPI	1
150	JUNROE	2	950	LAGRAC	3	2050	RUPMAR	1
150	CONERE	2	950	DISSPI	1	2150	RHIMAN	3
150	LAGRAC	2	950	AVIGER	2	2150	AVIGER	2
150	AVIGER	2	1050	JUNROE	6	2150	DISSPI	2
150	FIMCAS	1	1050	LAGRAC	3	2150	LAGRAC	1
150	CLAJAM	1	1050	RHIMAN	1	2250	RHIMAN	3
250	DISSPI	6	1050	DISSPI	1	2250	DISSPI	1
250	JUNROE	6	1050	AVIGER	1	2250	AVIGER	1
250	RHIMAN	1	1150	JUNROE	6	2250	LAGRAC	1
250	LAGRAC	2	1150	LAGRAC	2	2350	AVIGER	2
250	CONERE	3	1150	RHIMAN	1	2350	DISSPI	1
250	ASTTEN	1	1150	AVIGER	1	2350	RHIMAN	3
350	DISSPI	5	1250	DISSPI	3	2450	RHIMAN	3
350	JUNROE	2	1250	JUNROE	3	2450	AVIGER	1
350	LAGRAC	3	1250	LAGRAC	2	2550	RHIMAN	3
350	CLAJAM	1	1250	RHIMAN	1	2550	LAGRAC	1
350	RHIMAN	1	1250	AVIGER	1	2550	AVIGER	1
350	ASTTEN	1	1350	JUNROE	4	2650	RHIMAN	2
350	CONERE	2	1350	DISSPI	2	2650	DISSPI	1
450	DISSPI	4	1350	LAGRAC	3	2650	AVIGER	2
450	JUNROE	4	1350	AVIGER	2	2750	RHIMAN	3
450	CONERE	3	1450	JUNROE	4	2750	DISSPI	1
450	LAGRAC	2	1450	LAGRAC	2	2750	AVIGER	2
450	ASTTEN	2	1450	DISSPI	1	2750	LAGRAC	1
450	BORARB	1	1450	RHIMAN	1	2850	RHIMAN	3
450	CLAJAM	1	1450	AVIGER	1	2850	AVIGER	1
450	RHIMAN	1	1550	JUNROE	5	2950	RHIMAN	3
550	DISSPI	4	1550	AVIGER	3	3050	RHIMAN	3
550	JUNROE	3	1550	LAGRAC	2	3150	RHIMAN	3
550	CONERE	3	1550	DISSPI	1	3250	RHIMAN	4
550	LAGRAC	3	1550	RUPMAR	1	3250	AVIGER	1
550	FIMCAS	1	1550	RHIMAN	1	3350	RHIMAN	4
550	ASTTEN	1	1650	RHIMAN	4	3450	RHIMAN	4
550	RHIMAN	1	1650	AVIGER	3	3450	AVIGER	1
650	DISSPI	3	1650	LAGRAC	2	3550	RHIMAN	4
650	LAGRAC	3	1650	JUNROE	3	3550	AVIGER	1
650	AVIGER	3	1750	JUNROE	1	3650	RHIMAN	4
650	RHIMAN	2	1750	RHIMAN	4	3750	RHIMAN	5
650	JUNROE	1	1750	RUPMAR	1	3750	AVIGER	1
750	JUNROE	6	1750	AVIGER	1	3850	RHIMAN	5
750	LAGRAC	2	1850	RHIMAN	3	3850	AVIGER	1
750	AVIGER	2	1850	AVIGER	1	3950	RHIMAN	6
750	SALVIR	1	1850	RUPMAR	1	3950	AVIGER	1
850	JUNROE	4	1950	RHIMAN	4			

DOCUMENT TWO

Marine Transgression in the Southeast Saline Everglades, Florida, USA: Rates, Causes and Plant and Sediment Responses.

Meeder, J.F., M.S. Ross, G.J. Telesnicki, and P.L. Ruiz. Southeast Environmental Research Program, Florida International University, Miami, FL 33199.

ABSTRACT

Holocene sea level rise has caused salt water encroachment into coastal areas during the last 6,000 yrs. Rising sea level in many low lying regions has resulted in a landward migration of marine or salt tolerant coastal vegetation types, soils and processes landward into freshwater ecosystems. All South Florida coastal basins studied exhibit evidence of salt water encroachment. However, the rate and distance of salt water encroachment differs considerably (by a factor of 8) between coastal basins although the rate of sea level rise throughout the study area has been the same. Coastal gradient, tidal range and especially the volume of freshwater discharge (or rather the change in historic discharge) appear to be responsible for most of the observed variability. Watersheds, such as Taylor Slough, have maintained sufficient freshwater discharge during the last century to minimize salt water encroachment.

Paleosalinities were established using mollusks which were abundant and well preserved at most sites and contained good indicator species of marine, brackish and freshwater habitats. Sediments containing fossil assemblages with a salinity index of greater than 1.5 are classified as marine influenced soils. Soil accretion rates, based upon Cs^{137} and Pb^{210} dating method, ranged between 1.0 mm/yr (brackish water marl soil producing areas) to 3.2 mm/yr (in *Cladium jamaicense* and coastal mangrove peat forming areas) for eight cores located along three transects. Time lines, based upon the soil accretion rates, were calculated for 1895, 1940, 1968 and 1995 along five transects crossing the fresh-to-marine gradient. Along these same transects the contact between marine influenced and freshwater soils were delineated permitting the calculation of the rate and distances of salt water encroachment between time lines. Joe Bay, Highway Creek and Turkey Point subbasins displayed the greatest rates of salt water encroachment during the last century, several times the rate indicated by sea level rise alone. Interestingly, the rates of saltwater encroachment varied in these three basins between time intervals (1895-1940, 1940-1968, 1968-1995) which are associated with different histories of anthropogenic alteration of freshwater deliveries. Taylor Slough subbasin exhibits less salt water encroachment than suggested by global sea level rise, probably because of adequate freshwater discharge which minimized salt water encroachment although historic flows have also been diminished. The Mowry Canal transect indicates that the rate of salt water encroachment was also high because of decreased freshwater discharge but was reversed in the late 1960's by the construction of the L-31E levee and water control structures in the coastal canals draining the freshwater interior areas.

A depositional model for the SESE is presented based upon vegetative and sediment analyses along the above five transects. Changes in sediment characteristics are associated with encroaching saltwater which changes the dominant depositional processes along the marine-to-freshwater gradient. The major sediment producing processes identified are: 1) peat formation, both marine influenced mangrove peats and *Cladium jamaicense* dominated fresh water peats, 2) marl development, 3) storm deposition of marine resuspended sediments, and 4) carbonate and silicate production by invertebrates. In most areas except, perhaps, Taylor Slough a marine transgressive sequence has developed. Taylor Slough appears to be under a more stable depositional environment. Predictions on the potential changes in estuarine productivity based upon the export of nutrient and organic carbon as transgression continues are formulated. In general, under conditions of continued or increased rate of salt water encroachment less freshwater derived organic carbon and nutrients will reach the coastal estuaries.

INTRODUCTION

The Southeast Saline Everglades (SESE) prior to development in the early 20th century comprised the area of wetlands east and south of the outcropping limestone (Figure 1a). This area of wetlands was comprised of a mixture of freshwater marsh types and intermittent wetlands along the uplands and graded sharply into brackish and salt marsh and mangrove swamps along the coast. The SESE wetland complex was narrow to the north where the rock ridge closes on the Biscayne Bay shoreline and broadens to more than 20 km in places to the south and to the west where the SESE ends abruptly at the Taylor River. In numerous areas the rock ridge was crossed by narrow "transverse glades" that more efficiently delivered Everglades surface water to base level via the shortest route. These glades delivered little water to the SESE in droughts and dry seasons but during high water conditions must have delivered large quantities of water to the coastal areas to compliment local rainfall to maintain the historic mangrove and salt marsh belt to a very narrow zone in comparison to present day conditions.

Prior to 1928 most of the SESE along the east coast and much of the area adjacent to the outcropping limestone ridge were drained and cross ditched for the dual purpose of farming truck crops and mosquito control (Figure 2). The area illustrated is about five miles north of Turkey Point Power Plant and displays worked fields, major drainage canals and cross ditching. Also note that the mangrove coastal belt is less than a few hundred meters wide. By the 1940's, saltwater intrusion destroyed many of these fields for agricultural purposes. Parker et al. (1955) outlined these problems in detail and proposed the establishment of water control structures along the coast. The coastal levee and a series of water control structures were completed in the 1960's to minimize saltwater intrusion and storm surges.

During this same time, Dade County was expanding very rapidly westward into the eastern Everglades which was being drained by channelization of the old transverse glades (Figure 1b). In the 1960's alone, the groundwater table in the eastern Everglades (west of the rock ridge) was lowered from 6.5 to 5.5 ft above mean sea level (Van Lent et al. 1992). In addition, the C-111 Canal and South Dade Conveyance System was completed in 1968 which was designed to facilitate water movement out of west Dade County to the south and east. The construction of these canals and levee systems has: 1) decreased freshwater sheet flow through the coastal wetland complex, 2) decreased maximum water depths and hydroperiod in the upper portions of coastal subbasins, 3) and has changed the times of delivery, decreased the water quality and increased the quantity of water delivered to the coastal estuaries.

In addition to the anthropogenic alterations of the freshwater delivery to the SESE and to the coastal estuaries the coastal estuaries and the SESE are being subjected to a relatively high rate of global sea level rise. The entire present day Florida Bay complex, Everglades and Big Cypress Swamp Ecosystems all have been formed under conditions of rising sea level during the past 6,000 yrs (Parkinson, 1989; Parkinson and Meeder, 1991; Stone et al. 1993; Gleason and Stone, 1994).

Parkinson (1989) revised the sea level curve of Scholl et al (1969) and concluded that we are presently undergoing a rapid acceleration in the rate of rise of sea level (Figure 3a). Maul and Martin (1993) produced a reliable sea level change curve for Key West, Florida based upon monthly mean tide data since 1875, continuous since 1910 (Figure 3b). Both Parkinson (1989) and Maul and Martin (1993) determined that sea level rise in south Florida for the last century is approximately 30 cm.

Eustatic and isostatic sea level rise for the coastal basins of this study are assumed to be the same with a high degree of probability based upon the known geology of the Florida Peninsula (Banks, 1972). However, we observe considerable differences in the distance and rates of salt water intrusion in different subbasins. Therefore, we must assume that differences in the rates of salt water intrusion are not caused by sea level rise alone but by other factors such as changes in freshwater delivery, differences in tidal range and coastal gradient. We have recognized changes in soil constituents, surface vegetation and molluscan assemblages along the marine-to-fresh water gradient. We have applied these trends with chronostratigraphic techniques to determine the distances and rates of saltwater intrusion beginning in 1895. We constructed time lines (1895, 1940, 1968 and 1995) and marine/freshwater influenced soil contact lines for each transect in order to quantify the rates and distances of salt water encroachment in the different subbasins of the SESE.

The objectives of this study are to: 1) document present spatial patterns of the fauna, flora, soils, and hydrologic conditions in the SESE in respect to the marine-to-freshwater gradient, 2) quantify the effects of saltwater intrusion on the fauna, flora, soils and hydrologic conditions, 3) quantify the rates and changes in rates of salt water intrusion over time at the same place and at five subbasins of the SESE, 4) determine if sea level rise or changes in freshwater delivery have had the greatest effect upon saltwater intrusion into the coastal freshwater wetlands, and 5) Produce a coastal depositional model based upon quantified changes in the five most important depositional process rates along the marine-to-freshwater gradient.

METHODS

Location. A GPS was used to record the exact location of each field station. Locations were recorded in degrees and minutes. Seconds were expressed as hundreds of a minute rather than true seconds. Either the GPS located in the Helicopter's navigation system (Biscayne Helicopter, Inc.) or a hand held Garmin was used. Distance from the coast was calculated using ATLAS GIS software after first plotting all station locations determined by GPS on a base map derived from USGS 7.5 minute topographic maps.

Our contract with SFWMD required that we incorporated pre-existing water level recorder stations into our research network, which resulted in the location of 23 stations. We added UTS, LTS, CJB, NUJB, CHC, NUHC, and the TP and MC stations after preliminary analyses of the original stations in order to fill gaps and create five complete transects along the fresh-to-marine gradient. Data from several stations not incorporated into our transects are not presented because of their locations.

Topographic Control. This is the area of greatest concern and potential inaccuracies in interpretation of soil core data. For water level recorder stations throughout the study area, except for the coastal and near coastal stations, table elevations were obtained from the Everglades National Park and from the United States Geological Survey. Elevations were recorded at 5 m intervals along a 100 m transect to establish average elevation of the surrounding marsh by the use of standard surveying methods and a SOKAL level with an accuracy of ± 2 mm in 100 m. The transects usually began 10 m from the water level recorder table to avoid disturbed soil elevations from installation and maintenance of the recorder and ran to the west in all cases but two. Transects were only run to the east when a slough or forested area lied to the west as was the case at LTS and LHC. The elevations for the UHC, LHC, UJB and LJB sites we were given by Gorden Anderson appear to be off considerably and estimates of elevation were determined by the water stages observed over seven years and provided to us by Jerry Lorenz (National Audubon Society). Elevations for sites not found at water level recorder stations were estimated from a contour map (0.5 ft intervals) provided to us by Dr. Robert Fennema (ENP) or determined graphically in areas of negligible slope. In most areas to the west and central to northern portions of the study area contour estimated and marsh elevations determined from table elevations were compatible. However, contour elevations and their control data are questioned in the Highway Creek watershed where elevations of -1.1 to 1.5 ft are frequently recorded in open marsh areas. We feel that this is unlikely because coastal topography is definitely much higher than this and areas of such negative relief would be permanent open water habitats. The contour map produced by Fennema must be used with caution, although it remains the best estimate of C-111 Basin topography at this time. The contour map was derived from numerous independent surveys made by several different contractors with little or no overlap. In addition, overall coverage of survey transects is poor. In defense of this limited data base it must be remembered that this area is extremely remote, bench marks rare and that the soils are frequently deep and very soft making surveys very difficult and costly. We have used several elevation scenarios at the JB and HC sites to determine the sensitivity of our salt water encroachment interpretations and have found that changes in elevation of less than 10 cm produce little change in rate and distance of encroachment as long as at least two station elevations can be assumed to be correct.

Vegetation Analyses. Relative abundance of plant species observed in 30-1 m² plots in a 100 m circle around each study site was recorded. In addition, plant biomass was determined by harvest method from 10- 1/4 m² plots along a 100 m surveyed transect starting approximately 10 m from all water level recorder stations in the C-111 Basin. Plant biomass was not determined for either the Turkey Point or Mowry Canal Transects. However, percent vegetative cover was calculated at 100 m intervals along the Turkey Point Transect. Detailed methodologies for vegetation analysis is found in a companion paper (Ross et al, MS).

Surface Soil Sampling. Surface soil sampling was accomplished by the careful removal of the active periphyton mat and collection of the upper 2 cm of soil which was placed in a labeled sample bag and refrigerated. Two splits were taken from each sample, one for soil and one for paleoecologic analyses. We had hoped that the collection of the upper two centimeters of soil would provide a time average of diatom assemblage at that site. That is, seasonality and unusual perturbation of diatom abundance's would be averaged out providing a long-term average of diatom distribution and abundance. If

changes in species composition and relative abundance could be correlated with salinity changes along the marine-to-freshwater gradient an analog model could be constructed to use in interpretation of downcore samples.

Although diatoms did not work out well for selective preservation reasons discussed elsewhere, mollusks fortunately worked quite well. Once it was determined that diatoms would not work, only one split was taken from each sample and processed for sediment constituents. (described below)

Soil Core Sampling. Soil coring was done by hand pushing a 7.5 cm diameter, thin walled aluminum pipe, with sharpened base into the soil. Depth to soil was measured inside and outside the core at intervals to determine compaction. Soil cores with more than 5% compaction were rejected. The cores were then excavated by hand from the surrounding soil eliminating the need for piston type coring devices. The cores were stored upright and frozen until time for analysis. Subsampling of the soil cores was done by carefully running water over the outside of the core tube until the outer most surface of the soil core was thawed. At this time the core slips easily from the core tube and is wrapped in newspaper to prevent additional surface contamination and to slow the thawing process. The cores were then placed in a miterbox and cut at one centimeter intervals and placed in preweighed and prelabeled petri dishes and stored in the refrigerator until processed.

Sediment analyses. Bulk density, percent organic and carbonate mud, and the major organic fractions identified and weighed for each one centimeter interval were recorded. Each centimeter subsample was split into two equal parts after weighing for the calculation of wet and dry bulk density. The first split was dried and weighed to obtain dry weight, then combusted at 500°C for one hour and reweighed to determine the weight loss (weight loss equals the organic content of the sample). The sample is then reheated at 1000°C for one hour to drive off the carbon dioxide from the carbonates (Dean, 1974). Clay minerals make up less than one percent of the total sediment in Florida Bay and adjacent areas (Manker and Griffin, 1971) and as a result all CO² produced during combustion is recorded as being derived from calcium carbonate decomposition. The second split was used to determine constituent composition. The samples were washed through a series of sieves (2 mm, 375 and 150 micron diameter). Constituent categories include: 1) above ground biomass (leaves, fruit, seeds and stems), 2) rhizomes (roots larger than 2 mm in diameter, 3) fibrous material (rootlets of less than 2 mm in diameter), 4) amorphous (fine grained, unidentifiable organic material), 5) carbonate mud, and 6) skeletal material. Skeletal material greater than 1 mm in diameter was collected, dried, weighed, counted and identified for use in paleoecologic analysis. The type of plant material was noted when identifiable.

Salinity Index Development. Originally we had hoped to utilize diatoms as salinity indicators but this was abandoned because of preservation problems of the diatom frustules. We decided to use mollusks, instead of foraminifera (monospecific except at coast) or ostracods (species diversity low and several complexities in identification) which proved to be a good choice because of their abundance, with several species being highly indicative of select salinity ranges. All mollusks over 1 mm in diameter were collected during the sediment analyses, identified using a Baush and Lomb 10-60 x binocular dissecting microscope, counted and recorded for each cm interval of each core to a depth of at least 30

cm, unless soil thickness was less. The salinity tolerances of the 32 molluscan species encountered were determined from the literature (Ladd, 1957, Tabb and Manning, 1961; Moore, 1964; Turney and Perkins, 1972; Abbott, 1974; Thompson, 1984). Many mollusk shells exhibited some signs of dissolution and skeletal fragmentation by root penetration. However, overall shell condition did not diminish down core below approximately 6-7 cm below the marsh surface. Periostracums were also lost at about this depth from most mollusks, especially the hydrobids. Methodology selected against larger shells (greater than 1 cm in diameter) causing considerable breakage. Most broken shell material was still identifiable based upon morphology of the protoconch, aperture, shell sculpture and columella.

To avoid counting two fragments of a single shell as two shells, only large fragments greater than one half of the complete shell or shell fragments with a diagnostic character such as the protoconch of *Planorbis* were counted. The most frequently broken shells (from sawing the 1 cm core subsamples) were the Pulmacea and Cerithids. Pulmacea, however, were not common, only six specimens in more than 700 samples.

In order to examine the compositional changes further, we used a weighted averaging procedure to calculate a sample salinity index (SI) for each 1-cm interval in all cores. The procedure used was similar to the specific conductance and ion indices created for use with diatoms (Blinn, 1993). The sample salinity index, SI_{xamp} was calculated according to the equation:

$$SI_{xamp} = (SI_{sp} * DEN_{sp}) / DEN_{xamp},$$

where SI_{sp} is a species salinity index based upon the literature, and DEN_{sp} and DEN_{xamp} are the density of individual species and all mollusks, respectively, in each sample. A SI of 1.0 represents freshwater and a SI of 1.5 or greater is interpreted as brackish, or marine influenced waters.

Radiometric dating of soil cores. Duplicate cores measuring 12.7 cm in diameter, were collected at eight sites. Two soil dating methods were utilized; Cs^{137} and Pb^{210} . The cesium method is based upon the contention that no atmospheric Cs was present prior to the first nuclear device surface detonation in 1947. Cesium rapidly spread throughout the atmosphere where it was incorporated into living tissue. Therefore the first appearance of cesium in a soil core can be dated 1947. The Cs^{137} optima was in 1962 which should form a well defined peak. However, Cs analysis of our cores found very low values and either no distinct peak or a very wide unusable peak. Soil accretion rates determined by Cs^{137} were discarded because of these interpretation problems, except at two sites: Ever 4 and Ever 7.

Pb^{210} dating method is based upon the fact that Pb^{210} is a decay product of the aerosol Radon²²². Therefore, Pb^{210} is found everywhere and because Pb^{210} has a half life of about 20 yrs, the procedure can be used to date soils up to 150 yrs old. Pb^{210} decays at a normal log method and therefore the slope of the decay curve can be used to predict the soil accretion rate (Lynch et al. 1989; Cutshall et al. 1983).

Transect Chronostratigraphy. Soil cores were collected along five transects (Figure 4) spanning from near the coast, through the brackish transitional zone well into pure freshwater habitat. The coastal third of the L-31E (3 cores) and the entire Model Lands (5 cores) transects are located along continuous surveyed lines. The Taylor Slough transect (4 cores) has only two control elevation points along it, whereas the Highway Creek and Joe Bay transects (6 cores each) had only two soil core stations without topographic control. However, the elevation data for the upper and lower stations are questionable. Stations without documented surface elevations were either graphically determined for sites lying between sites with known elevation that exhibited no substantial break in slope or were based upon ENP produced elevation contour map produced by Robert Fennema. Unfortunately, several sites (LTS, UTS, CJB, LJB, UJB, CHC, LHC and UHC) did not have reliable contour lines (stations are too far from any control points). The elevations at these sites were determined by field observations in relationship to the upper swash zone at coastal sites or by estimation of elevation in respect to the upper tide levels during dry season. Time lines based upon the radiometric dating of soil profiles, sediment type and constituents, and fossil flora and fauna assemblages were made.

Documentation of Anthropogenic Alteration History. A chronological history of anthropogenic alterations of the system was made based upon numerous documents (Parker et al. 1955; Klein et al. 1975; Van Lent et al. 1992; Bjork and Powell, 1993; Parker, 1975; U.S. Army Corp C-111 Basin Report, 1994)

Transect Interpretation. Rates of change in regards to the upland migration of salt tolerant organisms was established for each transect based upon time lines intersection with the marine-to-fresh water contact line. Both the distance of saltwater intrusion (m) and the elevation of the marsh surface at the point of time line intersection with the salt-to-fresh water interface lines (mm) were established. The effects of rising sea level (Maul and Martin, 1993), tidal range, coastal gradient and anthropogenic alterations of the hydrology were compared to the time lines to determine cause and effect.

RESULTS

Location. Field station positions, distance from the coast, elevation and a summary of other parameters are listed (Table 1). Field station locations are all plotted on the same map (Figure 4). Transects were established in order to address the salt water encroachment history in several subbasins of the SESE. Each subbasin is a distinct drainage basin under normal water levels but boundaries are much less distinct during extreme high waters. Each subbasin drains into a different estuarine body of water; 1) Taylor Slough (TS) discharges into Little Maderia Bay, 2) Joe Bay (JB) discharges into Joe Bay, 3) Highway Creek (HC) discharges into Long Sound, 4) Turkey Point into Card Sound, and 5) Mowry Canal (MC) into Biscayne Bay.

Taylor Slough Transect (TST) is 12, 681m in length and is based upon four stations: TSH, E146, UTS, and LTS, in order from north to south. All core stations are located on the east side of the major drainageway. LTS is the lowest station in this transect, lying 860 m from open water. Joe Bay lies just to the east of Taylor Slough and is 11.824 m in length. Coastal Joe Bay is located 122 m from the

coast. The JBT is made up of six core stations (Ever 4, Ever7, NUJB, UJB, LJB, and CJB). Highway Creek is located just to the east of Joe Bay and just west of the US1 Road right of way. HCT is 9,650 m in length and is made up to six core stations (Ever2B, EP1r, NUHC, UHC, LHC and CHC). Coastal Highway Creek is located approximately 678 m from the coast. Turkey Point Transect (TPT) is located approximately one half the distance between Card Sound Road and Turkey Point Power Plant. TPT is nearly 5,000 m in length and has five core stations (TPW, TPINT, TPE, TPEST, and CTP). CTP is located only 5 m from the coast. Mowry Canal Transect (MCT) is located parallel to and approximately 200 m north of the Mowry Canal. The MCT is approximately 2,650 m in length and has six core sites (10/10-6, 10/10-4, 10/10-2, TS-1, TS-2 and TF). The Treatment Fringe (TF) site is 15 m from the coast.

Topographic Control. Marsh elevations used in this study are found in Table 1.

Vegetation Analyses. The results of the vegetation analyses are found in a series of graphs (Figures 5a,b - 8a,b). A more detailed analysis of the vegetation is reported in a companion paper (Ross et al. MS). The data for each field station is displayed in a fence diagram, illustrating the differences in relative abundance and biomass (and percent cover, for Turkey Point) along the marine-to-fresh water gradient for each subbasin. A few general trends exist between both relative abundance and biomass and distance from the coast, for the major plant species of the study area. Mangroves, *Rhizophora mangle* in particular, have higher relative abundance and biomass than other plants species near the coast and both decrease inland. In contrast, *Cladium jamaicense* (saw grass, the dominant plant species in the freshwater Everglades marshes), exhibits the reverse trend. The point along the transect at which one species replaces the other varies from one transect to another as can be seen graphically (Figures 5a,b-8a,b).

Taylor Slough Transect (TST) (Figure 5a, b). The relative abundance of mangroves was 75 % 860 m from the coast and declined to near zero at 7500 m from the coastline. Mangrove biomass decreased from 540 mg/m² to zero between 7500 and 12,500 m from the coastline. Mangrove biomass is reported further from the coastline than the point where it statistically shows up in the relative abundance. This is mostly an artifact of the sampling techniques. A single mangrove plant usually has considerably more biomass than comparable numbers of graminoid plants whereas relative frequency methods decrease the significance of uncommon plants. *Cladium jamaicense* first appears nearly 2,000 m from the coast and rapidly makes up between 61 and 77 % relative abundance and biomass between 426 and 500 g/m² away from the coast. *Eleocharis cellulosa* is found along the entire transect, and may be slightly more abundant in the northern freshwater marshes and behind the coastal berm. Periphyton is also found along the entire transect. Other plant species combined are most abundant in the freshwater marshes between 7,500 and 12,500 m from the coast and on the coastal berm. Species diversity is lowest in the intermediate areas of the transect. Although obvious differences exist between biomass and relative abundance data, the same trends for each species exists.

Joe Bay Transect (JBT) (Figure 6a, b). Mangrove's relative abundance was 30% and biomass 1800 g/m² at 107 m from the coast and decreased to an insignificant relative abundance between 7,500 and 9650 m and biomass became insignificant at 5019 m from the coast. Insignificant amounts of *Cladium jamaicense* are found closer than 2,880 m from the coast but by 5,019 m reaches its relatively uniform

70 % relative abundance and 200 to 250 g/m² dry weight. *Eleocharis* is much more abundant along JBT than TST, especially near the coast. Two differences between JBT and TST is the greater abundance of *Utricularia* and many fewer plant species of significance in the JBT than in the TST.

Highway Creek Transect (HCT). (Figure 7a, b). Mangroves' relative abundance is 35 % at 678 m from the coast to zero just north of NUHC at approximately 5500m. Mangrove biomass ranged from a high of 1600 g/m² at 3279 m from the coast to zero also at approximately 5500 m. *Cladium jamaicense* makes its first appearance between 3279 and 5019 m from the coast and does not vary significantly in either relative abundance (35 to 45 %) or biomass (400 to 600 g/m²). *Eleocharis*, *Utricularia* and other plant categories are very similar to those of the JBT. The biggest difference between HCT and JBT is that JBT has mangroves much further from the coast than does JBT.

HCT.

Turkey Point Transect (TPT) (Figure 8a, b). Results of the vegetation analyses along the TPT exhibit the same general trends for *Rhizophora mangle* and *Cladium jamaicense* as found along the other transects in respect to relative abundance. However, no biomass data was collected along either the TPT or the MCT and percent cover estimates were collected at the same stations where relative abundance data was collected along the TPT. The TPT has mangroves along the entire 4500 m transect. Mangroves are 100 % of the relative abundance from the coastline to 1000m from the coastline. Percent cover of mangroves begins at 50% near the coast and decrease to less than 10 % by 100m from the coast but remain common until the L-31E Levee is reached at about 3800m. Two significant facts pertaining to this transect are worth attention. The first is other salt tolerant graminoids such as *Distichlis spicata* and *Juncus roemerianus* are both found on this transect between 2,000 and 4,000 m from the coast in an area between the marine mangrove zone and the freshwater *Cladium jamaicense* zone. These grasses are rarely found in the C-111 Basin just south of the ENP boundary. The second point is the percent cover is lowest in the transitional zone between the coastal mangroves and where the salt tolerant graminoids take over dominance. Although not quantified along the other transects, this area is frequently the area of the lowest percent cover of emergent vegetation and exhibits the thickest periphyton mat and largest periphyton biomass. This zone appears white in aerial photographs, probably because of the high reflectability of the marl soil surface and low vegetative cover.

Sediment analyses. Soil cores were sampled in one centimeter increments from the top to the bottom. Each sample was analyzed and the three topmost cm intervals lying below the active periphyton mat were averaged and the data plotted in graph form as fence diagrams (Figures 5c - 8c). Soil constituents plotted were: 1) root material both fibrous and rhizomes, 2) carbonate mud (derived from periphyton-water chemistry interaction and storm deposition, and 3) skeletal material. Root material was identified to species when possible, the primary species were *Rhizophora mangle* and *Cladium jamaicense*. Amorphous organics are fine grained, unidentifiable, organic, particulate material. Frequently fine fibrous material is observed breaking down into amorphous. Therefore, the amorphous weight was divided proportionately into the same species groups as the roots. The active periphyton mat was separated from the top of the soil profile by the presence of green color or green laminations. Live specimens of the mangroves, *Cladium jamaicense*, *Eleocharis cellulosa*, and other common plants were collected for use in identifying plant parts, especially roots, found in the soil samples. *Eleocharis* has a characteristic cellular structure of the stem but less than five samples had

Eleocharis material, all from the upper 2 cm of soil. The root biomass of *Eleocharis* is very small compared to *Rhizophora* or *Cladium jamaicense* and apparently decomposes much faster. *Rhizophora mangle* has a very characteristic reddish, fleshy rhizome with short, but numerous, coarse rootlets (less than 2 mm in diameter). *Cladium jamaicense* is frequently found in cores and the most commonly preserved plant parts are the base of the upright culm, the rhizomes, and characteristic vertical, near parallel, rootlets which are usually dark brown or black in color.

Taylor Slough Transect. (Figure 5c). Mangrove derived organics make up nearly 43% of the sediment at the LTS site and decreases to zero at 7,500 m from the coast. Mud content ranges between 28.2 and 35 % inland, but is slightly higher along the coast (56 %). Near the coast mud concentrations are slightly higher than the remaining portion of the transect because of mud deposition from storm tide deposition. *Cladium jamaicense* derived organics are not present in recognizable amounts until UTS station at 2,500 m where they comprise 39 % of the sediment and comprise between 59 and 65 % to the north. Skeletal material is comprised almost entirely of mollusk shells larger than 1mm in diameter.

Joe Bay Transect. (Figure 6c). Mangrove derived organics comprised 41% at 122 m, and varied considerably northward between 8 and 64 % until approximately the 5,500 m mark where mangrove materials are no longer observed. This distribution of mangroves materials in the soils are approximately 2,000 m further north on the JBT than along the TST. Mud makes up about 58 % of the soil constituents along the coast and decreases rapidly northward to between 19.6 and 43.6%. *Cladium jamaicense* derived organic material begins to be found in soils between 3,000 and 4,500 m from the coast. By 4,700 m *Cladium jamaicense* makes up 15 % of the total soil, but rapidly increases northward and ranges between 40 and 69 %. Skeletal material makes up only a small portion of the total soil constituents.

Highway Creek Transect. (Figure 7c). Mangrove derived organics comprised 41 % of the total sediment at 678 m from the coast and generally declined in respect to other soil constituents until approximately 9000 m where no mangrove material was observed in the soil. Between 3,500 and 4,500 m *Cladium jamaicense* begins to appear in soils and by 4,500 m *Cladium jamaicense* derived organics comprise 54 % of the sediment. Although *Cladium jamaicense*, in general, increases in abundance northward from this point, our randomly collected soil cores to the north of this point exhibit between 14 and 37 % *Cladium jamaicense* organics. Carbonate mud ranged from 45 to 75 % of total soil constituents along the transect. Average carbonate mud content along the transects increases nearly twofold between TST (38.9 %) and JBT (34.2 %) and the HCT (65.8 %).

Turkey Point Transect. (Figure 8c). Although mangroves are found much further inland along the TPT, mangrove derived organics make up only 21 % of soil constituents at the coast line and rapidly decrease to zero by 1000 m from the coast. Most of the mangroves in this area form a sparse cover of highly dwarfed individuals, probably exhibiting a decreased root biomass. *Cladium jamaicense* derived organics first appear along the transect between 2,000 and 3,000 m from the coast and gradually increase to 53 % of the total soil constituents at 4,500 m from the coast, well behind the coastal

protective L-31 E levee. Carbonate muds definitely exhibit an increasing pattern towards the coast from 33 % at 4,500 m to 74.8 % at the shoreline. The average carbonate mud value for the TPT is 70.7 %, even higher than the value calculated for the HCT. Mollusk shells make a higher percentage of the soil constituents along this transect than any others, varying from 0.2 to 10.7 %.

Mowry Canal Transect Only three soil cores from this transect were analyzed at the same level as previously described. However, careful core descriptions were made of all cores and our experience permits rather accurate interpretations of constituent analysis. Prior to the construction of the L-31 E levee a narrow red-white mature mangrove forest had developed upon a red mangrove peat more than 1.5 m in thickness along the coast. At approximately 200 m from the coast the coastal forest is replaced by a scrub mixed species mangrove community. The soils under the dwarf mangroves are a peaty marl to a depth of about 20 cm at which point they unconformably overlie a dense marl. West of the levee, a black wedge shaped peat with a maximum thickness of 12 cm thins to the west, disappearing at approximately 3,000 m from the coast. These peats unconformably overlie a dense marl.

Hurricane Andrew Storm Deposit Hurricane Andrew passed just to the north of the TPT, causing minor coastal erosion and deposition of storm suspended carbonate muds from Biscayne Bay and nearshore Atlantic Ocean bottoms. Three years after the storm, the effects of the mud deposition are still found: 1) dwarf mangroves buried by as much as 12 cm of mud remain dead or in poor condition, with minimal recruitment, and 2) an extensive surficial mud deposit is recognized and mapped along the TPT (Figure 9). The storm deposit is recognized by its different texture (lower bulk density), and color (highly oxidized as opposed to more reduced, darker colors below the contact, 3) a scalloped, but distinct contact between the surficial mud deposit and underlying peaty mud sediment, and 4) a fining upwards sequence where skeletal material is abundant closer to the coastline. The deposit is recognized for at least 2,000 m inland from the coastline and was observed in an area at least 700 m wide (between two parallel drainage courses on either side of the transect. In general, the deposit thins from a maximum thickness of between 12 and 16 cm near the coast to 1 cm at 2,000 m from the coastline. Storm deposited mud must have been transported further inland but the stratigraphy has been disturbed by the more dense vegetative growth found further inland. Our footprints, usually very deep in the soft substrate, from 4 weeks prior to our topographic survey were totally absent between the coast and 2,000 m whereas, between 2,000 and 4,500 m our tracks were highly visible. These observations suggest that the muds are still mobile within the area of frequent tidal inundation where they remain saturated. Inland from this point they have the opportunity to dewater and perhaps the vegetation helps to prevent wholesale transport.

Periphyton Distribution and Mat Composition.

a. Periphyton mat thickness. The thickness of the periphyton mat varied considerably along the transects (Table 2). The base of the mat was determined by the lack of green color and sudden increase in bulk density. Generally, periphyton thickness is lower in the densely vegetated freshwater sawgrass community, increases in the near coastal belt, and may decrease on the coastal berm. The thick (10 cm) mat reported at TPT at 5000 m may be abnormal because the site is semi-impounded, located within the apical area of two intersecting levees.

Table 2. Thickness of periphyton mat and biomass at core sites along the transects.

Distance from coast (m)	TST		JBT		HCT		TPT	
	Thick	Bio	Thick	Bio	Thick	Bio	Thick	Bio
0	-	-	12	-	-	-	2	-
1000	2	-	17	22	12	131	4	-
2000	-	-	-	-	16	138	7	-
3000	8	-	4	132	8	-	7	-
4000	-	-	-	-	-	-	-	-
5000	-	-	8	331	7	254	10	-
6000	-	-	-	-	7	102	-	-
7000	-	-	-	-	-	-	-	-
8000	2	243	3	265	-	-	-	-
9000	-	-	-	-	-	-	-	-
10000	-	-	-	-	7	123	-	-
11000	-	-	-	-	-	-	-	-
12000	-	-	4	133	-	-	-	-
13000	2	106	-	-	-	-	-	-
14000	-	-	-	-	-	-	-	-
15000	-	-	-	-	-	-	-	-

Data from transect stations are reported to the nearest 1000 m. Thick = Thickness (cm). Bio = Biomass (gm/m²).

b. Composition. Approximately 20 % of the entire active periphyton mat dry weight is carbonate mud. This is an average of 110 samples, five each from each surveyed transect throughout the C-111 Basin. Periphyton biomass ranged from 22 to 331 gm/m² dry weight. The highest biomass is usually found in the middle of the transects.

c. Mat vertical composition. In areas of little surface disturbance the annual periphyton mat accumulates over time producing a laminated texture with alternating layers of green-to-white and dark gray-to-black. In many such areas the laminations vary in thickness from 6-7 to 1-2 mm and invariably are thickest at the top. Bulk sediment analysis recognize distinct trends in dry bulk density, % carbonate mud and percent organic carbon (Figure 10). Average surface periphyton composition is 80 % carbon and 20 % calcium carbonate mud as previously mentioned. From the surface downwards we observe a gradual increase in dry bulk density, sediment dewaterers and denser muds concentrate, an increase from 20 % calcium carbonate mud at the surface to 80% at the base, and a decrease in carbon from 80 % at the top to 20 % at the base of the periphyton sequence.

Soil accretion rates and establishment of time lines. Drs. R.E. Turner and Charles Milan are responsible for our Cs¹³⁷ and Pb²¹⁰ analyses. Cs¹³⁷ method was found to be inadequate in this study area because of the low concentrations found, poor peak development, and indistinct base of Cs distribution curves. Results from the Pb²¹⁰ analysis were utilized. Eight soil cores were analyzed and the results are found in Table 3. In general, three regions of deposition were covered: the freshwater *Cladium jamaicense* dominated marsh sites, the mangrove coastal sites and the intermediate, brackish water areas with poor vegetative cover. *Cladium jamaicense* dominated marsh sites had sedimentation rates of 0.20 to 0.22 cm/yr, the mangrove sites ranged between 0.28 and 0.2 mm/yr and the intermediate brackish areas 0.10 mm/yr. Based upon this soil accretion data, projected elevations of the core sites and stratigraphic methodologies time lines were constructed along the transects. Time lines were constructed for 1895 (100 yrs before present, prior to anthropogenic alteration of the system), 1940 (age of earliest aerial photography with complete coverage of the study area and prior to any local system alterations except the construction of US 1 and the railroad right of way), 1968 (date of completion of most local system alterations), and 1995 (the present land surface).

Table 3. List of soil accretion rates. Cs-137 and Pb-210 analyses were performed by Dr. R.E. Turner, Institute of Coastal Studies, Louisiana State University. Pb-210 analysis of the soil cores provided a better assesment of soil accretion rate than did the Cs-137 because of the low levels and uncharacteristics profile of Cs.

Core Location	Cs-137	Pb-210	r2
TPE	*	0.14cm/yr	0.924
CJB	*	0.23cm/yr	0.822
LHC	*	0.10cm/yr	0.899
CHC	*	0.32cm/yr	0.940
Ever4	0.22cm/yr	not done	
Ever7	0.22cm/yr	not done	
UJB	*	0.14 cm/yr	0.928
LJB	*	0.21 cm/yr	0.933

* Insufficient Cs 137, ** Poor Cs 137 profile-data rejected.

Transect chronostratigraphy. Field stations along the designated transects are plotted with the X-axis distance from the coast, with the coast line on the left side, and with the Y-axis as elevation. This provided a transect across the marine-to-fresh water gradient. Based upon the soil accretion data we calculated the depth to different times (1895, 1940 and 1968) for each core so analyzed, 8 of 21 cores. The depth to the time intervals for cores without radiometric dating was done by one of two methods or a combination of them: 1) graphically determined between two known points with little change and 2) application of a soil accretion rate by habitat type (e.g. three of three *Cladium jamaicense* dominated study sites all have 0.22 to 0.28 cm /yr soil accretion rates, therefore the average of these values is applied along transects with no analysis of cores from this vegetative zone). Soil time horizons in each core are then linked to the same time horizons from all the cores in the transect to

form time lines. Most time lines parallel the present day surface except where breaks in slope occur. Complete time lines are only displayed in the insert of Figures 11-15. The enlarged portion of these figures is the segment of transect where the time lines are crossed by the marine-fresh water interface line (to be discussed next) in order to focus on the significant aspect of the time lines.

Along all transects the time lines had a very low or no detectable gradient towards the coast. The seaward slope of the time lines increased noticeably from the point of salt water encroachment (as defined by the presence of living mangroves) to near the coast, where the slope is reversed because of the positive topography of the coastal berm.

Salinity Index.

Salinity ranking. A list of thirty two species of mollusks, that were observed more than once, with their salinity rankings was made (Table 4). The salinity tolerances of the mollusk species as determined from the literature were used to assign a salinity rank to each species. Rankings are as follows: 1 = freshwater, 1.5 = basically freshwater species with tolerance for low salinities, 2 = brackish species, 2.5 = brackish species that tolerate marine conditions, 3.0 = restricted marine with toleration for lower salinities, 4.0 = normally marine species with a tolerance for low salinities, and 5.0 = marine species (Table 4).

Salinity Index. The results of the calculation of the SI for each one cm increment for each core studied are summarized in Table 5. The contact between marine influence sediments and freshwater sediments based upon the molluscan SI is designated by a dark line for each core. Salinity Indexes were not calculated for samples that did not contain at least two mollusk specimens because of the extreme shift one marine shell can have in a predominantly freshwater setting.

Marine-fresh water interface line. We can plot the elevations of these contacts between marine and freshwater influenced soils between cores and establish the marine-freshwater interface line for each core. Sediments above and to the left of these lines are marine influenced (Figures 11-15). Taylor Slough Transect (Figure 11) has the shortest and steepest sloped marine-freshwater interface line of the five transects. JBT, HCT and TPT all had similar very shallow slopes. The MCT is the only transect that exhibits a reversal in the direction of movement of the marine-fresh water interface line (Figure 15).

Salinity Index changes along the marine-to-fresh water gradient. When we plot the SI and distance from the coast from each field station we find that distance from the coast only explains 52 % of the variability in salinity (Figure 16). However, the relationship probably is much stronger than that because of design limitations. The major problem is that the transect lengths are unequal and that the distance of salt water encroachment is different for each transect. Individual transects have limited data points but graphically indicate a higher degree of correlation than that determined from the combined data. The major factor determining the distance of salt water encroachment is the change in volume of freshwater discharge. Freshwater discharge or the change in volume of freshwater discharge might account for the remaining variability. Unfortunately, freshwater discharge data is not available for each subbasin required for an analysis of this variable.

Rates of salt water encroachment. The distances of salt water encroachment can be measured directly from the chronostratigraphic profiles made for each transect (Figures 11-15) by measuring the horizontal distance between the intersections of the marine-freshwater interface line with two subjacent time lines. The length of time between times lines is known and therefore the rate calculated. The distances, elevations, times and rates of salt water encroachment are listed for each transect (Table 6).

In addition, the elevation, time interval and rate of sea level rise based upon Key West tide record (Maul and Martin, 1993) is also presented. The rates of salt water encroachment for each subbasin is plotted (Figure 17). TST exhibits the least salt water encroachment and the most consistent slope of all subbasins studied.

Table 6. Summary of saltwater encroachment and sea level change rates for three time intervals (1895-1940, 1940-1960, 1968-1995) along transects in SESE.

TIME PERIOD	DISTANCE (m/yr)				ELEVATION (mm/yr)			
	HIGHWAY CREEK	JOE BAY	TAYLOR SLOUGH	TURKEY POINT	HIGHWAY CREEK	JOE BAY	TAYLOR SLOUGH	TURKEY POINT
1995-1940	32.356	12.133	5.511	7.844	2.711	1.178	1.111	1.644
1940-1968	71.107	30.893	4.821	9.536	4.929	3.250	1.000	1.929
1968-1995	33.692	65.654	4.885	64.808	2.615	6.808	1.000	7.654

Anthropogenic impact history. Development and alteration of natural watershed characteristics have a short but dramatic history in South Florida. An abbreviated outline of the anthropogenic alterations of the Everglades Ecosystem and in particular impacts to the SESE are summarized below:

1882. The first major drainage activity was the use of the Disston Dredge to channelize the Calooshattee River (Duever et al., 1979). Although considered by many workers to be inconsequential in South Florida, the impacts of this activity may have been felt throughout the Everglades Ecosystem. Several million acre feet of surface water storage were eliminated, the level of Lake Okeechobee lowered from between 21 and 23 ft above mean sea level to below 14 ft before the turn of the century and the reduction of hydraulic head in the system by one third.

1905. Everglades Drainage District was formed. Under their jurisdiction, the Everglades were to be drained, "recovered" for agricultural development. Thus the second series of impacts were the construction of the major five drainage canals. By 1921 the Miami, North New River, Hillsboro, and West Palm Beach Canals were completed for land reclamation and by 1924 the St. Lucie Canal was also completed to help regulate Lake Okeechobee water levels. The St. Lucie canal was originally designed to handle 85 % of the Kissimmee River's peak discharge into Lake Okeechobee to prevent flooding (Stockbridge and Perry, 1926). This "Everglades" water was removed from the system and dumped into the Atlantic. These activities lowered south Florida water table by several feet (Parker et al., 1955) as well as soil elevations (Davis, 1946). The Miami Canal certainly affected the volume of water reaching the southern Everglades.

1912 The Florida Eastcoast Railroad (FEC) was completed to Key West, FL. Building the railroad bed required the dredging of an adjacent borrow pit (canal) that runs from Florida City to Key Largo. The construction of this borrow canal likely facilitated freshwater runoff and saltwater intrusion in adjacent marshes (Highway Creek subbasin).

1915 Homestead Canal and Ingram Highway was built to the Dade County Line which opened a large area for agriculture after further drainage by diking and cross-ditching. The Homestead Canal was connected to Flamigo in 1922. Considerable freshwater flow was captured from the C-111 Basin area and delivered directly into Florida Bay until the construction of a water control structure placed at Flamigo in 1962 to prevent over drainage of ENP and additional salt water intrusion. This canal likely decreased flow to Taylor Slough and the rest of the C-111 Basin and may have affected hydroperiod and salinity in the lower reaches.

1924 The Card Sound Road and bridge to North Key Largo was completed in 1924, 11 yrs before US1 was opened to Key Largo. The bridge over Steam Boat Creek was condemned in 1940 and the new road bed and bridges constructed. The roadway was made from dredge material from the adjacent borrow canal. The canal likely caused more rapid drainage of freshwater and salt water intrusion, especially in its lower reach.

1924 First Lake Okeechobee Dike was completed to protect Okeechobee rim farmers from seasonal flood waters of the Lake.

1928 Numerous local impacts are recorded. The Tamiami Canal and borrow canal were completed. In addition, by 1928, most of the east coast was drained by a network of canals and ditches for drainage and mosquito control resulting in salt water intrusion and abandonment of coastal fields in the 1940's (Hull and Myers, 1973). Most of the seasonal wetlands adjacent to the rock ridge for miles into the C-111 Basin were diked, cross ditched and reclaimed for agriculture.

Prior to 1935 Commercial mullet fisherman created numerous passes across banks in northern Florida Bay to increase access (eg. Dynamite Cut). These cuts act to decrease water renewal times in northern Florida Basins. Decreasing water renewal time increases the potential rate of sea water ingress and fresh water egress, resulting in increased salinity and lowered coastal marsh-swamp water table or hydroperiod.

1938 Hoover Dike was constructed to replaced the hurricane destroyed earthen dike. This is also the year that US1 was completed to Key West on the abandoned FEC roadbed. The FEC railway was also destroyed by hurricane in 1935.

1945 Coot Bay Canal completed.

1950 Four Canals to Biscayne Bay south of Tamiami Canal were completed draining the transverse glades and eliminating most sheet flow to Biscayne Bay.

1950-1967 Construction of impoundments for water storage in the WCA's was done to conserve water and to control flood waters. However, their construction was a response to the overdrainage of the regions peat soils which resulted in extreme marsh peat fires in the drought of 1943-5.

1960 The Adams Waterway was completed across Key Largo. This waterway has led to decreased water renewal times in parts of Florida bay.

1940's Central and South Florida Project. (origin of the concept of C-111 Canal and adjacent canals)

1947 South Dade County Comprehensive report was completed. This report recommended the construction of levees to the east and south to protect South Dade from storm tides and prevent salt water encroachment. The levee to the west was to protect the area from Everglades flood waters).

1959 Survey Review Report for South Dade County Project was revised. The C-107 through C-112 canals were proposed instead of the southern levee and were to go to tidewater: C-107 and C-108 to Card Sound, C-109 to Barnes Sound, and C-110 through C-112 to Long Sound with salinity control structures located between the 1 and 2 ft contours along each canal.

1962 General Design Memorandum was completed. The Aerojet General Corp demanded barge access and caused the present alignment of the C-111 Canal diagonal across the watershed and the placement of S-18C just downstream of US1

1968 ENP-South Dade Conveyance Canals was authorized to promote conservation and conveyance of water supplies to ENP and expanding agricultural and urban areas of south Dade County. Improvements to the L-31N and addition of S-331 and S-332 structures were added in order to deliver more water to TS and panhandle ENP. These activities lowered the groundwater 1.5 ft (Van Lent et al., 1992).

1983-1988 GDM was prepared which stated that a decrease flow to Barnes Sound and an increase northeast Florida Bay via C-111 is needed.

1989 Everglades National Park Protection and Expansion Act was passed. This Act dictates that more managed flow to the ENP is needed and construction of the cutouts might help to distribute water more evenly to northern Florida Bay.

1993 Experimental Program of Water Deliveries to ENP-Taylor Slough began with the design to increase flow to Taylor Slough via S-332.

DISCUSSION

The discussion is subdivided into three areas: 1) trends in vegetation, soil composition and salinity along the marine-to-fresh water gradient, 2) causes of differing salt water encroachment rates, and 3) a depositional model. The documentation of changes in vegetation, soil and salinity characters along the gradient are the basis (provide the necessary tools to) for a modern analog model for the SESE in order to interpret the effects of salt water encroachment and for the development of a depositional model. These trend analysis used in conjunction with chronostratigraphic and paleoecologic methods allow the calculation of the rates and changes in rates between time intervals for five different subbasins in the SESE. The depositional model recognizes five important soil building processes and demonstrates that these processes vary in rate along the gradient and therefore can be used to predict the effects of continued salt water encroachment on adjacent estuaries.

Trends along the marine-to-fresh water gradient.

Previous work: Compared to the "Sawgrass Everglades" little attention has been paid to the SESE. The C-111 Basin is the heaviest used part of the south Florida ecotone utilized by wading birds, especially the roseate spoonbills (90% of the nesting population), wood storks, and white pelicans (Bjork and Powell, 1993). This use by wading birds combined with the possible link of changing discharge patterns in the C-111 Basin and the decline of Florida Bay has generated interest in the last 10 years on water management issues, their relationships to wildlife and estuarine health (eg. Tropical Bioindustries, Inc. 1990, Cosby, 1994, Van Lent et al. 1992). Earlier works in the basin were descriptive in nature and focused on the vegetative characteristics of the area (Egler, 1952; Davis, 1940 and 1943, Tabb et al. 1968; Alexander and Crook, 1974; Ross et al. MS). Egler (1952) described in detail eight vegetation belts in the area ranging from the coastal prairies and mangrove belt to the innermost sawgrass belt and pine uplands using 1940 aerial photography for the entire basin. However, most of study plots and groundtruthing areas were close to US1 which may not be typical of the entire region (especially in respect to exotic plant presense and altered hydrology). Davis (1943) focused on the coastal mangroves but did not contribute greatly to the ecology of the basin. Tabb et al. (1968) characterized the vegetation at stations one half mile apart along transects that were 2 miles apart (five transects). In addition, Alexander and Crook (1974) described the vegetation in several sections of land to the east of US1 in the SESE. In the present study on the vegetation changes in the C-111 Basin these three data bases provide all the pre-existing vegetation data useful in determining how the system has changed (Ross et al. MS).

In general, freshwater species such as *Cladium jamaicense* are replaced by mangroves and other salt tolerant species as salinities increase along the gradient. A confusing complexity is plant communities are patchy wherever they are found along the gradient and most species have a wide range of salinity tolerances. For example, in the purely freshwater marshes, *Cladium jamaicense* and *Eleocharis cellulosa* both dominate their respective communities whereas *Cladium jamaicense* drops out along the increasing salinity gradient, *Eleocharis* does not drop out concurrently. In our analyses (Ross et al.

MS) of the vegetation changes in the C-111 Basin we addressed both marsh and hammock vegetation changes since 1940 (the earliest complete set of aerial photography of the study area). In this report we attempt to reconstruct vegetation and soil changes from 1895 (prior to major alterations of the hydrology) to the present using paleoecologic and chronostratigraphic methods.

Description of the vegetation types along the gradient is well documented in the companion paper (Ross et al. MS) in much greater detail than required for the purposes of this paper. Other trends we address in this paper are soil and salinity characteristics. Salinity characteristics are determined indirectly by the paleoecologic application of subfossil mollusk assemblages.

Previous work in South Florida wetlands soil characteristics and paleoecology are limited both in numbers and scope. Scholl et al. (1969) derived their sea level curve from radiometric dates of Holocene wetland and shallow marine soils, plant and skeletal material. Spackman et al. (1964 and 1966) describe the origin and constituent analysis of Everglades peats in a transect along Shark Slough and in areas further north using peat petrographic methods. This work was very focused, however, on the development of a coal forming environment. Wanless (1974) produced numerous coastal transects through the fringing mangroves and documented several different sediment sequences forming under the same Holocene rate of sea level rise. Stone et al (1993) described wetland soil sequences from Corkscrew Swamp and reconstruct the lateral expansion rate of the swamp and soil accretion rates. They found that the vertical accretion rates were nearly identical to those of coastal mangrove peats that are directly controlled by sea level rise although a 17 ft difference in elevation exists between them. Both coastal mangrove peats, Everglades and Big Cypress peat basal dates are nearly the same (Gleason and Stone, 1994). Gleason and Stone provide the best overall historic development of the Everglades Ecosystem available. Gleason (1972) and Gleason et al (1974) also described and documented the role of periphyton in the development of calcite crystals that make up the marl soils in the SESE. Craighead and Gilbert (1962) and Craighead (1964) describe depositional processes along the coast in the aftermath of Hurricane Donna. This is the first major study of soils and soil processes along the salt-to-fresh water gradient in the SESE.

Trends in these three parameters along the gradient are observed along all transects. Major problems in deriving a simple model for the trends is complicated by the facts that: 1) each transect has its peculiarities, 2) the length of the gradient from salt-to-fresh water ranges from 500 to 43000 m (making distance from the coast a significant parameter most difficult to utilize), and 3) too few core stations along transects and no repetition within subbasins limits interpretation. However, we will attempt in this discussion to derive a single simplified model of the vegetation, soils and salinity gradients for further development.

Vegetation trends. Several trends in plant distribution are observed along the transects as graphically illustrated (Figures 5a,b- 8a,b). In general, 1) mangrove abundance decreases away from the coast, 2) *Eleocharis* varies in relative abundance and biomass but is common along the entire transect, 3) *Cladium jamaicense* is rare near the coast and increases in relative abundance and biomass away from

the coast. 4) other plant species make up a small proportion of SESE plants, except locally, and 5) periphyton biomass and thickness usually increase towards the coast but decrease drastically near the coast. In the following section we will discuss the differences in trends along specific transects for each plant species.

Mangrove - The mangrove category in the figures and discussed here includes all three of the mangrove species, red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and black mangrove (*Avicennia germinans*) plus the buttonwood (*Conocarpus erecta*). The red mangrove is the most abundant at most sites and makes up nearly all the mangrove biomass. A regression between distance from the coast and relative abundance of mangroves was done for all transects except the MCT (Figures 18a-d). All regression lines had the same general negative slope. The shortest transect, TPT, had the steepest regression line slope indicating the greatest rate of decrease in abundance away from the coast of the four transects (Figure 18a). This may be a reflection of the fact that the coast along this transect has the heaviest mangrove cover of any transect and that the L-31 E levee has inhibited further expansion of mangroves inland. Taylor slough has the next steepest regression line slope (Figure 18b) which is not very different from the regression lines calculated for JBT and HCT. A regression line for the combined data of the three transects of the C-111 Basin with a 95 % confidence interval is presented (Figure 19a) and should be able to be used to predict mangrove relative abundance in the SESE in respect to distance from the coast. Most of our field sites are somewhat biased because of their locations in respect to water depth. Because service of recorders is done most frequently by airboat, the wellsites are not located in forested wetlands, deeper water sloughs or tidal creeks, nor in rocky or higher elevation sites because of limited access during low water periods. However, this bias has forced us to study sites rather similar in hydroperiod and water depth characteristics.

Mangroves definitely exhibit a decreasing pattern of abundance away from the coast although they do not have a physiological need for salt water to survive. Therefore, their distribution is probably not directly related to salinity. However, seed dispersal is by direct propagule drop or by water transport. Under conditions of sea water encroachment into a freshwater basin we expect a net movement inland of sea water frequently enough to transport propagules inland. Perhaps most propagule transport, in some years at least, is by storm tide (Craighead, 1964). Under conditions of a continuous rate of rising sea level the frequency of and height of storm tide transported propagules may always be slightly ahead of the true salt-fresh water soil contact. Mangrove migration inland is limited by the degree of salt water encroachment in the particular basin and other controlling factors such as, competition from other plants, and fire and freezing (Hoffstetter, 1974). Freezing is an obvious control of inland migration of mangroves in the SESE. Freezes in the southern Everglades occur infrequently but regularly (Duever et al, 1994). In 1981, 1991, and in small areas in 1995 winter freezes were observed to cause drastic dieback of mangroves in predominately freshwater areas. However, between freezes the mangroves appear to have regained their former positions in respect to distance from the coast within a few years. Mangroves close to the coast or waterways survived while mangroves in open marshlands died completely. The likelihood that fires control mangroves distribution in the lower SESE is doubtful for three reasons: 1) soil moistures are always high because of their proximity to the coast and low elevations, 2) the vegetation is very sparse and not likely to carry a fire well, and 3) the marl soils, unlike peats, also do not carry a fire well. However, in the upper portions of the basin

where *Cladium* is dense enough to carry a fire very few mangroves exist outside the tree islands. The likely hood of other, freshwater, vegetation outcompeting the mangroves also seems unlikely because 1) mangroves can outgrow most grasses, shrubs and many trees, and 2) mangroves are found growing well with many combinations of plants and even in tree islands or hammocks (Ross et al MS).

Usually, mangroves are much better developed along waterways in terms of structure and biomass. Along two of our transects biomass and relative abundance were actually higher inland some distance from the coastline. In these two areas, JBT and TST, the stations were located on or near the buttonwood embankment. This area has been described as a topographic high behind the coastline dominated by buttonwoods and other mangroves and in some areas by salt grass prairies (Davis, 1943; Egler, 1952; Craighead, 1964). Craighead and Gilbert (1962) made observations after Hurricane Donna on the development of the buttonwood berm. They observed that the berm is made or modified during storm tide events that deposit great volumes of mud behind the coastline as the waters recede, thus describing a storm overwash process. Infront of the buttonwood berm at these two sites and along the coasts of HCT and TPT the coastal mangroves are scrub mangroves of low cover. Offshore from these four locations we identified red mangrove peats exposed at the bay water-sediment interface for distances of more than 20 m. We conclude from this that a more extensive, better developed red and probably red and white mangrove fringing forest existed along these coasts in the recent past and that higher coastal energies associated with the Holocene rising sea level have produced an erosional and transgressive coastal sequence. An alternative theory is that the mangrove peat forming environment could not maintain itself in respect to rising sea level (Parkinson, 1994).

Cladium- *Cladium jamaicense* displays the reverse trend of the mangroves. *Cladium* is uncommon along the coast and increases dramatically inland (Figures 11-15). The slope of the regression lines of *Cladium*'s relative abundance and distance from the coast is positive (Figure 18a-d). The slope for the TST is very flat which suggests no change in relative abundance in respect to distance from the coast. However, the software program does not factor into the equation that no *Cladium* is found within 2,500 m of the coast. Therefore, at TST we have a situation where *Cladium* relative abundance remains high from its first appearance inland at 2,500 m for the distance of the transect (13,000 m). The slope of the regression line expressing the relationship between distance from the coast and relative abundance of *Cladium* for HCT, JBT, MC, and TP are extremely close to one another (Figure 18a,b,c,d). A curve representing the combination of the data from the three transects is presented with the 95 % confidence interval designated (Figure 19a).

The cause of the seaward decline in relative abundance of *Cladium* is generally related to increased salinity. However, we have observed *Cladium* growing in numerous areas with salinities between 16 to 30 ppt (Crocodile Refuge, Ross et al 1995 and Florida Keys (Ross et al 1992). The salinities of these two reported sites are higher than those usually found in the SESE. One major difference between the Keys sites and the SESE distribution of *Cladium* is that in the higher salinity sites *Cladium* is found at elevations above the ambient marsh surface on tussocks frequently more than 30 cm high. The tussocks appear to be made up of root and basal shoot material. In other areas, frequently adjacent to open bay waters, *Cladium* is found on elevated marl soils. Perhaps, these high salinity

Cladium sites are relict *Cladium* marsh fragments, reduced in abundance as sea level has continued to rise. We see no tussock development in the C-III Basin and must assume that relief does not exist in the lower basin to maintain outliers of relict *Cladium* or that conditions have changed so rapidly that the *Cladium* have not been able to produce tussocks in response to increasing salinity.

Eleocharis cellulosa. - *Eleocharis cellulosa* is found along the entire length of most transects. Relative abundance seems to vary considerably even within vegetation zones (Ross et al. MS). In the northern portion of the C-III Basin, where *Cladium* dominates, the marsh landscape actually consists of two patchy plant communities both nearly monospecific: *Cladium* and *Eleocharis*. To the south *Eleocharis* increases in relative abundance as salinities increase and *Rhizophora mangle* abundance begins to increase, although total percent cover decreases in the "white zone". The white zone is addressed in detail (Ross et al. MS). *Eleocharis* is found at the coast when the coastal berm is low or holds water but is replaced in higher coastal prairies by other salt grasses. Because *Eleocharis* has a relatively low biomass compared to its relative abundance we will not focus on *Eleocharis* in this paper.

Periphyton - Periphyton is dominantly composed of green and blue-green filamentous alga and diatoms. In some places *Chara* and other alga are abundant (Browder et al 1994). The organic component of the periphyton appears to decompose readily leaving behind amorphous organics and diatom frustules (silicate) and indirectly calcite mud. This important process is discussed later.

Other - (*Utricularia*, *Juncus roemarianus* and *Distichlis spicata*, and others). Other plant species rarely combine to make 20 % relative abundance and are insignificant as contributors to the soil.

Soil Constituent trends. Soils in the SESE are comprised of: organic material, skeletal material, and carbonate mud. Carbonate mud ranges between 93 to 40 % dry weight of soils in the SESE and averages approximately 60 %. The soils are classified in this paper by the relative percent of organic to carbonate mud as determined by the ashing method: 1) marl = 0 to 20 % organic which is not apparent. 2) peaty marl = 20 to 40 % organic much of which is usually visible as root material. 3) marly peat = 40 to 60 % organic material forms a fibrous matrix infilled with mud and amorphous organic material. 4) peat = greater than 60 % organic material forming a fibrous texture with no noticeable mud. Carbonate muds have two sources in the study area: 1) storm deposition of resuspended marine-estuarine bottom sediments and 2) calcite precipitation from the surface waters high in dissolved carbonates by the physio-chemical water column reactions initiated by periphyton productivity (Gleason, 1975).

Peats are only found at a few sites in the study area. Organic material is made up of less than one percent aboveground material (leaves, stems, seeds), mostly of root material and unidentifiable organic material. Unidentifiable organic material is either granular in nature (guppy) or fine grained amorphous material. Guppy has originates from deep marsh vegetation such as *Sagittaria* and *Nymphaea* (Gleason and Stone, 1994). The latter is probably highly decomposed vegetation with no identifiable microstructure. The fibrous organic material is usually rhizomes, rootlets or basal shoots. Most often these roots can be identified to species by characteristic characteristics such as color, size, nature of exfoliating epidermis, presence of nodes, distribution of rootlets along rhizome, and branching strategy.

of rootlets. The two dominant plant species are *Rhizophora mangle* and *Cladium jamaicense* both with easily identifiable root systems. Although *Eleocharis* is a numerically abundant species, below ground biomass is low compared to *Rhizophora* and *Cladium* as determined by field washing excavated plants. To support the field observations, only a few observations of identifiable *Eleocharis* material are reported from more than 700 sediment samples. *Rhizophora mangle* are red to orangish-brown in color, with thick, tapering rhizomes. The outer layers of the rhizomes tend to flake off in layers when washed. *Cladium* rhizomes, in contrast, are dark brown to black in color and are usually less than half the diameter of mangrove rhizomes. In addition, short shoots are much more common and likely to be found along rhizomes in *Cladium* than in *Rhizophora*. *Cladium* rootlets form small clumps located along the rhizome but also have thicker vertical rootlets (1-2 mm in diameter). The two major peat producing plants are *Rhizophora mangle* and *Cladium jamaicense*.

Rhizophora - The results of linear regression analysis between distance from the coast and weight percent of the soil for four transects are presented in Figure 20a-d. A negative relationship is documented for mangroves and the slopes are similar between TST, JBT and HCT. The data from these three transects are combined and a linear regression curve made with the 95 % confidence interval indicated in Figure 19b.

Cladium - The results of linear regression analyses between distance from the coast and weight percent in the soils of *Cladium* derived organics for four transects is presented (Figure 20a-d). A positive relationship is documented for all transects with similar slopes. The data from the transects are combined and a linear regression curve made with the 95 % confidence interval indicated (Figure 19b).

Skeletal material is comprised of silica (diatom frustules and sponge spicules) and aragonite mollusk shells. Other carbonate skeletal material is inconsequential in terms of dry weight percent and include foraminifera (*Ammonium beccarii*), ostracods (not identified), and vertebrate skeletal components (rare). Skeletal material averages about 1 % of the dry weight at most sites. Molluscan density seems to decrease considerably in the lower middle sections of most transects (Figure 16). The zero salinity values on this figure are actually sites with no mollusks found in the surface sediments.

Relationships between vegetation and soil constituents. A strong relationship exists between plant relative abundance and surface soil constituents along individual transects (Figure 21a,b). In the HCT example (Figure 21a) both mangrove relative abundance and percent soil constituent are negatively correlated with distance from the coast at nearly the same slope. In contrast, *Cladium* relative abundance and percent soil constituents correlate positively with distance from the coast with nearly the same slope. It is interesting to note that the relative abundance of mangroves is higher further inland than mangrove organics are found in the soil. Apparently there is a lag time between initial mangrove colonization and sufficient mangrove organic accumulation in the soils to be recognized. The same trends are displayed when combined transect data is compared between vegetation relative abundance and soil constituents (Figure 20a,b). Stronger relationship exists between plant species biomass and organic constituents in the soil at the few sites where biomass was measured. The paucity of biomass

sites has led to their exclusion in this discussion. Plant relative abundance was done at every sampling station and is therefore used for the purpose of discussing soil constituent relationships. *Rhizophora*, *Cladium* and periphyton are the vegetation that make the biggest contribution to the soils organic and inorganic components.

Salinity trends

Very limited data is available on the salinity levels in the study area. The data is collected from a few stations, frequently discontinuous and questionable from the analytical perspective. The most salinity data has been collected from the LJB, UJB, LHC and UHC stations. The salinity data base is inadequate for the purposes of this paper and therefore a surrogate for salinity was made. The SI was formulated at all stations in order to determine present and paleosalinity patterns along the five soil core transects and from the Tabb et al (1968) study sites (Figure 4).

In general, salinity index values decreased along the transects as the distance from the coast increased. However, distance from the coast only accounts for 52% of the variability of salinity (Figure 16). Although specific subbasin discharge values are not available for statistical analysis, we believe the remaining variability in salinity is probably associated with freshwater discharge volume.

Salt water encroachment.

Previous work - The emphasis in management of the Everglades during the last century, until quite recently, was to reclaim or drain it. However, reclamation is perhaps poorly used in this case, since the Everglades has been a wet land for the last 6,000 yrs (Gleason and Stone, 1994). However, after fifty years of reclamation, much of the reclaimed land along the coasts had to be abandoned because of salt water intrusion (Parker et al. 1955). Municipal water fields had to be abandoned and moved further inland, and ever expanding urban and agricultural expansion continually protected from flooding. Reclamation projects also changed the discharge patterns of the natural Everglades and has led to some estuaries receiving much more water and others less than historically, in turn impacting fisheries, tourism, and water quality. Recognition of the salt water encroachment problem associated with wetland drainage was widespread in the 1940's (Parker et al. 1955 and Klein 1957).

Different rates at different sites at different times.- Our analyses of the rate of salt water encroachment in the SESE along five transects has documented that the rate and extent of salt water encroachment has not been the same in different subbasins (Figure 17). Wanless (1974) reports the same for mangrove depositional packages on the larger scale of all south Florida. The changing elevation of sea level (Maul and Martin, 1993) and the elevation of the marsh-fresh water contact at different times for the transects are compared (Table 5). The rise of sea level is 1.91 mm/yr and the curve is nearly a straight line. Salt water encroachment along the TST exhibits about one half the increase in elevation of sea level rise. The elevation of salt water encroachment along the JBT, HCT and TPT are all approximately one half greater than the rise in sea level over the same one hundred year period. Interestingly these three transects exhibit different rates of rise in elevation of the salt-fresh water interface between 1895 to 1940, 1940 to 1968, and 1968 to 1995. In contrast, the horizontal distance of salt water encroachment varies between the transects by a factor of 9 as opposed to a factor of 3 for elevation. Also, none of the rates of salt water encroachment for the one hundred year period are similar (Figure 17b). The HCT has a steeper slope than all the other transects beginning in 1895. In

contrast TST has the lowest slope and the straightest line. The JBT, HCT and TPT initial slopes between 1895 and 1940 are very close to one another. Between 1940 and 1968 the rate of salt water encroachment increased dramatically for the JBT. Between 1968 and 1995 the rates increased for both the JBT and TPT while decreasing for the HCT.

Causes of salt water encroachment include sea level rise (combined isostatic and eustatic) and decreased freshwater runoff or lowered groundwater table. The rate of salt water encroachment is also dependent upon coastal gradient and tidal range. These factors are summarized for each transect (Table 6). The greater the coastal gradient the less affect observed in the horizontal distance of salt water encroachment. Coastal gradients varied by a factor of approximately 3.2 (Figure 22). Coastal gradient was calculated by establishing the elevation of the marine-freshwater contact (graphically from the transect profiles, Figures 9-14) and subtracting the lowest elevation point on the transect to determine the change in elevation. The change in elevation was then divided by the distance between the two points for each transect. Figure 23 shows the relationship between coastal gradient and distance of salt water encroachment during the last century. As gradient increases, the distance of salt water encroachment decreases. TST which had a negative coastal slope and should presumably exhibit the greatest salt water encroachment exhibits the least by far. Since the tidal ranges of the three subbasins are very close the low salt water encroachment rate for TST must be associated with the fact that adequate freshwater discharge must exist to minimize salt water encroachment in the Taylor Slough subbasin.

Table 6. Summary of factors affecting salt water encroachment in the SESE.

Transect	Dist (m)	Elev (mm)	Gradient	Tidal range (cm)	Runoff
TS	500	100	-2.837×10^{-5}	35	reduced, but still substantial
JB	3100	330	4.298×10^{-5}	40	reduced to local rainfall and
HC	4300	330	3.827×10^{-5}	35	reduced but some replenishment
TP	2300	330	6.342×10^{-5}	133	reduced to local rainfall
KW	-	191	-	97	-

Tidal range for JB and Long Sound (HC) are based upon three years continuous average daily water levels (Bjork and Powell, 1993) and TP and Key West are based upon predicted daily high and low water levels as taken from the Tide Tables for the Western Atlantic (Coast and Geodetic Survey, 1995). Tidal range for Little Maderia Bay (TST) is estimated to be similar to JB and HC, although the range might be even less. Runoff comments are very general and are based upon observed structures (Van Lent et al., 1992). Quantification of runoff in different subbasins could not be addressed in this study.

TP Tidal range
see Snyder
USGS
0100-516-001
60 ±

The greater the annual tidal range the greater the potential for salt water encroachment when other factors remain the same. The Maul and Martin (1994) sea level rise curve is based upon monthly mean tidal elevations which reduces the noise considerably for the calculation of long-term sea level rise. However, the potential effects of sea level rise based upon this curve are minimal because annual sea level variation is ± 47 cm (US Department of Commerce, 1992). Therefore, the coastal ecosystems in respect to salt water encroachment respond to high tidal elevations and not just the annual mean. For example, November spring tides are frequently the highest tides in the region reaching 66 cm higher than mean sea level at Government Cut, Biscayne Bay. During this period in basins with little freshwater discharge salt water can intrude much further than predicted by annual mean tidal elevation. Once salt water enters an area, flushing usually takes much longer than does the intrusion (Meeder, 1987, 1989). We assume this tidal range has been consistent for the record of tidal elevations at Key West and therefore we recognize that potential salt water intrusion is considerably higher than mean annual tide elevations would predict. This explains why the elevations of the marine-fresh water contact along HCT, JBT and TPT are so much higher than that of sea level (Figure 17b).

When determining the final causes of the various rates of salt water encroachment (Table 6) a comparison with the historic alterations to the system is necessary. Several major antropogenic alterations of the Everglades Ecosystem were completed prior to or very early in the 20th century. These activities lowered the head of the system by nearly one third, decreased the water table and soil surface several feet throughout the region, and rapidly removed a large quantity of the freshwater from the system. These activities are regional scale and all occurred in the headwaters region of the SESE. Therefore, subtle differences documented in these subbasins should not be associated with these activities even though they probably impacted the system to some degree. However, several major anthropogenic alterations to the system do correlate with changes in the rates of salt water encroachment in the different subbasins.

1. Construction of the F.E.C. railway and borrow canal to Key West was completed in 1912. This railway and borrow pit was constructed diagonally across the southeast sloping land surface, nearly parallel to the Highway Creek subbasin and HCT. This resulted in: 1) altered sheet flow patterns, 2) more rapid if not excessive drainage of the adjacent wetlands, and 3) increased salt water intrusion. In addition to our chronostratigraphic interpretation of extreme salt water encroachment in this subbasin exotic plant species have colonized much of this subbasin which also indicates that the hydrology of these wetlands was disturbed. *Schinus* (Brazilian pepper), *Casuarina* (Australian pines) and *Melehuca* (paper bark tree) are three species that frequently invade disturbed, especially decreased hydroperiod wetland sites (Myers, in Duever et al. 1979). The impact of the F.E.C. railway and adjacent borrow canal was limited in extent based upon the slight rate increase in salt water encroachment over this same time interval detected along the JBT, just to the west of the HCT.

2. The construction of the Homestead Canal to Flamingo was completed in 1922 and may have contributed to the decrease in water availability in the SESE west and to the south of US1. The canal was made for drainage and followed the old Ingram Highway built for access to the Dade County line. This system was made to open up agriculture and resulted in many square miles of wetlands and

transitional wetlands being diked, ditched and drained. Many of these fields can still be seen from the air. The impact of this project on the C-111 Basin is impossible to judge at present but the impact must have been basin wide and relatively minor because of the low rates of encroachment along the JBT and TST.

3 The Tamiami Canal and the Card Sound Roadbed and adjacent borrow canal were completed in 1928. The Card Sound roadbed and canal would not alter the watershed to the west of US1 and did not appear to affect TPT. The Tamiami Canal would have effected the subbasins west of US1 the same and apparently did not impact them significantly.

4 Between 1940 and 1950 the Water Conservation Areas (WCA's) north of Tamiami Trail were constructed and filled to conserve water and to act as storm water storage and groundwater aquifer recharge areas. These activities would effect the eastern SESE (east of US1) much less than to the west. Our graph shows that the salt water encroachment rate at TPT was minor compared to that of JBT or HCT. Of the latter two, the HCT had almost twice the rate increase of JBT. The early 1940's was also a time of severe drought (Duever et al, 1993) which might also play a short-term role in the increased rate of salt water encroachment.

5 In 1968 several significant projects were completed. The first was the L-31 E storm protection levee which runs parallel to the coastline (Figure 4). This levee stopped sheetflow to Biscayne Bay by way of the coastal wetlands and also stopped salt water encroachment. Construction of the L-31E reversed salt water encroachment by 2000 m along the MCT. Between the turn of the century and the 1940's the eastern SESE region had been drained for agriculture and fields came to within 1 km of Biscayne Bay in several areas. Most of these fields were lost to salt water encroachment prior to 1940. Loss of this area to salt water encroachment was the major reason USGS sent Gerald Parker to south Florida to assess the problem (Parker et al. 1955). In contrast, the construction of the L-31E further south at the TP site caused complete loss of sheet flow into the subbasin except that generated by local rainfall. This induced a very rapid rate of salt water encroachment between 1968 and present (the fastest rate observed in this study).

The other major project directly affecting the study area was the construction of the C-111 Canal and feeder system (the South Dade Conveyance System). This system was created to prevent the west Dade agricultural area from flooding by removing water to the east and to the south (Figure 4). These activities lowered the water table by 1.5 ft (Van Lent et al. 1992) just north of the study area. In addition to lowering the water table, the C-111 canal eliminated sheet flow that naturally would flow south and southeast to Florida Bay feeding the coastal subbasins. However, because of the alignment of the C-111 Canal diagonal across the natural slope of the land, water tends to move eastward more efficiently, drastically decreasing flow to Joe Bay subbasin and adding more water into Highway Creek subbasin. Water moving southeastward in the C-111 backs up against the lock just to the east of US1 and spills over into Highway Creek subbasin. This has resulted in an increased rate of salt water encroachment into Joe Bay but a decrease in rate in Highway Creek from its previous (1940 to 1968) higher rate. Several modifications to the system have been attempted such as the construction of gaps in the southern levee to increase outflow of water all along the reach of the canal and placing a water control structure along the northern reach. The gaps do not appear to be working as well as hoped and

the structure is used to deliver water to Taylor Slough. It is interesting that Taylor Slough exhibits the least saltwater encroachment during the last century. Management concerns for the last two decades has been that Taylor Slough needs more freshwater because of its reduced flow. Our data suggests that although historic flows may be greatly diminished, enough discharge exists and has existed during the recent past to minimize salt water encroachment. However, because JBT is just to the east of TST and the two subbasin watersheds are separated by insignificant higher elevations, significantly greater discharges down TS should also increase the contribution to JB. We might be able to estimate the maximum discharge down TS historically by pumping more water down Taylor Slough until spill over occurs in the JB subbasin. At present it appears that increasing the discharge to Taylor Slough is at the expense of JB.

Depositional Model. In the above two sections we have demonstrated that definite vegetation and soil constituent and salinity trends exist along the salt-to-fresh water gradient and that the rates at which these gradients migrate inland varies with changing balance between freshwater discharge and sea level rise. Several soil building processes are observed and constituents and rates of development documented. Both rates and processes are found to vary along the salt-to-fresh water gradient as well. In this section a depositional model is presented based upon these gradients and the rate changes of the processes in order to better estimate the effects of continued salt water encroachment on impacted marshes and on the adjacent estuaries.

A. Depositional Processes. - Of the eight recognized depositional processes in the SESE we recognize five as significant contributors to the soils, with three processes dominant. Depositional processes are recognized by careful constituent analysis of numerous soil profiles and comparison of results to vegetation patterns at the site and from conceptual modeling. A box diagram illustrates the soil constituents in weight percent along the gradient (distance from coast is the x-axis) generated from a summation of four transects (Figure 24). Major soil forming processes are identified by the soil constituents. The relative importance of individual processes is determined by constituent relative abundances (in terms of weight percent). The rate of different processes is determined by soil accretion measurements.

The depositional processes identified from the constituent analysis along the gradient are:

1. The dominant soil constituent is calcite mud which is the result of physio-chemical changes in the water column (containing waters near saturation in respect to calcium carbonate) caused by changing periphyton physiological diurnal processes (Gleason, 1972). Active periphyton mat averaged approximately 20 % (weight percent) calcitic mud and periphyton biomass ranged between 22 and 331 g/m² throughout the study area which compares well with previous work (Browder et al. 1981, Browder et al. 1982). Carbonate mud ranges from 40 to 91% of total sample dry weight, averaging approximately 60%. Compaction and organic diagenesis results in the change of periphyton composition from an average of 80% organic and 20% calcitic mud in surface mats to 20% organic and 80% mud while at the same time increasing in bulk density substantially (Figure 10). This diagenesis process must cause the release of most stored carbon with the soil dewatering process. The thickest periphyton mat observed is 16 cm thick and is laminated with individual laminae decreasing in thickness downward. The most recent, upper layer of the mat frequently reaches a thickness of 3 to 4 cm, whereas the lowest recognized periphyton layers are between 1 to 2 mm in thickness. Periphyton

layers are identified by their greenish color while the base of the mat is identified by the lack of green. Although these lower laminae are green, we believe they are photosynthetic inactive. The contact between the periphyton mat and underlying marl soil dated 27 yrs before present. The three Pb^{210} dated carbonate mud soil core dates had accretion rates between 0.10 and 0.14 mm/yr. This rate is one half to one third the rate of dated soil cores located along the coast or further inland in the more densely vegetated areas of mangroves or sawgrass, respectively.

2. The second important carbonate mud depositional process is storm resuspended mud deposition. Storm deposition is most pronounced along the coastal zone where resuspended estuarine mud (aragonite and calcite) is transported into the coastal wetlands during storm tides and deposited there as tide waters recede. This process is well documented (Craighead 1964; Craighead and Gilbert, 1962; Cotrell, 1987). In addition, we have quantified the volume and extent of one Hurricane Andrew storm deposit (Figure 9). Along the TPT Hurricane Andrew storm deposited mud was easily traced inland for a distance of 2 km and formed a wedge shaped blanket deposit ranging from 12 cm near the coast to 2 cm at the point where the deposit becomes indistinct because of the denser vegetation cover. No documentation of suspended carbonate mud sediments from the freshwater Everglades southward has been documented. Quantification of storm deposited mud is difficult because their mixed carbonate mineralogy (aragonite and calcite) is difficult to tell apart from freshwater calcite, especially in mixtures of the two and secondly root bioturbation frequently mixes thin layers.

3. Plant organic material forms the second biggest soil constituent. Peat forming processes are subdivided into two separate processes based upon soil constituents: a) mangrove organic accumulation and b) sawgrass organic accumulation. Both types of organic accumulation are dominated by below ground material with recognizable aboveground material making up less than 1 %. Mangrove organic accumulation will be addressed first. Mangrove organic accumulation rarely forms true peats in this area but forms highly organic carbonate muds (locally referred to as marls).

Mangrove peats are generally located only along the tidal creeks with well developed red mangrove growth also found in mangrove hammocks and along the coastline. However, most coastlines we studied are erosional which has resulted in the exposure of red mangrove peats at the shoreline and as far offshore as 40 m. The more typical fringing mangrove forests found in other areas are replaced with typical basin mixed black-red and white or dwarf red mangrove communities. The majority of red mangrove organic rich marl soils are found along the coast and inland as far as maximum (note, not sustained) salt water encroachment has occurred. Mangrove organic constituents range in percent weight from 35% along the coast to zero% between 8 and 9 km inland. However, mangrove organics decrease rapidly after 6 km inland. Coastal soils high in mangrove organics are nearly 60% carbonate mud of which we estimate as much as 20% is derived from storm deposition processes.

Coastal soil accretion rates ranged between 2.1 to 3.2 mm/yr for coastal stations (CJB, LJB and CHC). Red mangrove root biomass accumulation must be the major cause of contributions greater than that of carbonate mud deposition (1.0 mm/yr). This assumption is based upon the similar carbonate mud contents by percent weight between marl and mangrove peaty marl soils. These soil accretion rates are much slower than reported rates of mangrove peat accretion along more productive and stable coastlines (Parkinson, 1993).

4 The second organic accretion process is that of sawgrass organic accumulation. Sawgrass organics contribute up to 38% by weight to the soils. Because organic material has a much lower density than carbonate mud a soil composed of 38% organics displays a much larger volume of organics than of mud. Sawgrass organic constituents remain high (35% by weight) along the northern part of the transect and begin to decrease rapidly at about 6 km from the coast and disappear altogether by 2 km from the coast. As in the case of the mangrove organic rich sediments, the sawgrass organic rich sediments consist of 60% carbonate mud produced almost entirely by periphyton processes. Soil accretion rates in these northern areas are 2.2 mm/yr. As in the case with the mangrove peaty marls the sawgrass peaty marls contain 60% carbonate mud which produces a sedimentation rate of 1.26 mm/yr in the low emergent vegetation cover areas. The difference between the 2.2 and 1.26 (the average of the three marl soil accretion rates) is the result of sawgrass organic accumulation. These rates are lower than those reported from the true freshwater Everglades sawgrass peats much further north (Richardson et al. 1991) and in Shark Slough (Gleason and Stone, 1994).

Allochthonous organic deposition from reworked Everglades vegetation has been described in Shark Slough (Cohen, 1970) but we have not identified allochthonous organics in our samples. Therefore, we feel this process is insignificant in terms of overall deposition.

5 Skeletal accumulation resulted in an average of 1% by weight in most soils except those found along a narrow belt. This belt is well identified along the salinity gradient transects curves (Figure 6) as zero values. Zero values indicate no mollusks not zero salinity in this figure. Freshwater or zero salinity is represented by an SI of 1.0. In addition, peat soils rarely have mollusks preserved in this area. In a few near coastal sites skeletal material made up as much as 12% by weight. This skeletal material consisted mostly of offshore marine species that were well worn and broken suggestive of transport by storm tides.

B. Schematic ecosystem model. The following model is an attempt to establish the relationships between SESE ecosystem components in respect to changes in soils induced by increased salinity (Figure 25). Salinity and hydrology components of this model most influence vegetation processes as indicated by the two squiggly arrows. A wealth of literature permits these basic assumptions (Ball, 1988; Hoffstetter, 1974; Alexander and Cook, 1974 and Alexander, 1974; Ross et al. 1993 for effects of salinity and Craighead, 1971; Duever et al. 1979; Browder et al. 1995 for hydroperiod). The salinity regime is a summation of several processes, most of which are external to the ecosystem. Sea level rise rate influences tidal range and potential salt water encroachment rate. In addition, the balance between basin rainfall and evapotranspiration rates and the effects of channelization and water management on the volume of freshwater discharge into each subbasin effects the rate and intensity of salt water encroachment. The difference between rainfall and evapotranspiration in this region has been estimated to be a surplus of about 10% (Duever et al. 1994). For the most part, the balance between sea level rise and freshwater

discharge determine the rate of salt water encroachment. The rate of sea level rise is known and the rates of salt water intrusion for each basin is documented but the changes in the volume of freshwater delivered to each subbasin is not available. However, with additional data collection, freshwater discharges might be able to be calculated by modeling or mass balance methods.

Hydrologic parameters are locally influenced by basin rainfall, evapotranspiration, upland freshwater runoff volume and the tidal processes. The major process changing the hydrology parameters is the channelization of water and delivery via canal directly to the estuaries in the upper reaches resulting in the decrease of maximum water depth and decreased hydroperiod. In the lower reaches of the basin, tidal activities and freshwater runoff are the two most important components whose interaction determines the rate of salt water encroachment, as well as, effecting hydroperiod, water depths, and water quality. As hydrologic factors such as hydroperiod, water depth and salinity change, they influence plant species relative abundance, percent cover and biomass (and presumably productivity).

The vegetation component includes four subcomponents, one for each of the major plant species or groups of species (in the case of periphyton or other categories). We have verified the relationships of these four plant species in respect to decreasing salinity. In general, mangroves dominate the more saline habitats with *Spartina* in the least saline habitats. Periphyton plentiful everywhere, is most abundant in the area between the mangrove and sawgrass dominated areas. The most abundant higher plant in this area is *Eleocharis*, a minor contributor to the soils. An interesting relationship may exist between the areas of highest periphyton biomass and the lack of macrophalaginous mollusks (grazers component). Not enough data exists to fully document this relationship but at several sites the toe of the salt water encroachment wedge, lack of mollusks, low emergent vegetation cover and high periphyton biomass all coincide. Herbivory on higher plants seems negligible.

The different plant species contribute differently to the soils. Both mangroves (pathway labeled #3 in the Figure 25) and sawgrass (pathway 4) contribute from 0 to 35% by weight to soils, but contribute at opposite ends of the gradient. The periphyton mat which contributes only short-term to the organic content of the soils does contribute between 20 and 25% dry weight as calcite mud (pathway 1). Other plant species contribute little to the organic component of the soils except locally (pathway 5). Other soil processes include: skeletal accumulation which amounts to about one percent of the soil by weight throughout the study area except along the coast where some skeletal material is either transported into the system or concentrated by physical processes (pathway 6), suspended sediments transported from further upland (pathway 7, not observed), suspended sediments derived from the storm tide deposition (pathway 2, most significant along the coast with decreasing significance landward), and soil erosion (pathway 8, not observed).

The rate of soil accretion at any site is dependent upon the summation of soil processes active at that site. Soil accretion rates have been determined for three major habitats: coastal belt (stations CJB, LJB and CHC), brackish to intermediate salinity belt (stations UJB, LHC and TPE), and the freshwater belt (stations Ever 4 and Ever 7). These belts have average soil accretion rates of 2.5

mm/yr, 1.1 mm/yr and 2.2 mm/yr, respectively. Because each soil core composition was determined, the contribution from each soil process was determined and summarized (Figure 24) along the transects. This data permits the prediction of changes in soil components with changing salt water encroachment rates.

C. Effects of salt water encroachment on soils and adjacent wetlands and estuaries.

1. Changes in soil carbon storage potential. As salt water enters sawgrass marshes, the contribution of sawgrass organics to the soil is reduced from 36% to zero percent and is replaced by a calcite mud producing soil process that contain on an average of 20% organics. In addition, after a couple of decades the organics in the developing marl soil is reduced by half and remains stable after that indicating that after initial dewatering marl soils have long-term nutrient storage potential.

2. The transition from sawgrass organic to marl soil processes also results in a decreased soil accretion rate. Under the global conditions of sea level rise this decreased accretion rate further encourages salt water encroachment by the development of a small scale topographic basin. This topographic basin can develop into open water in an equilibrium stratigraphic situation (Figure 26 b) or under transgressive stratigraphic conditions the topographic low might just migrate landward with further salt water encroachment (Figure 26 c).

3. Under continued sea level rise or decreasing freshwater runoff a transgressive depositional sequence should develop (Figure 26). In this case, less productive, organic rich, and less permeable marl soil would develop over sawgrass organic rich marl soils. This should result in less organic material (carbon and plant derived nutrients) available for export to the adjacent estuaries. Potentially, in areas of significant freshwater discharge and low to high sediment loads, a regressive stratigraphic sequence might develop (Figure 26a). This condition does not exist at present in the SESE but does exist in other areas of the Gulf of Mexico region.

Areas undergoing salt water encroachment have a decreased productivity (as determined from percent cover, relative abundance and biomass data), different plant communities develop, soils become less organic rich and marl soils bury organic rich sediments causing long-term storage. In addition, salt water encroachment suggests that less freshwater discharge exists than prior to salt water encroachment and therefore export from the freshwater marsh complex to the coastal estuaries must have been reduced. Furthermore, emergent plant dominance is replaced by the periphyton which probably are much more efficient at assimilating nutrients than most rooted plants, thereby reducing nutrient export to the estuary as well.

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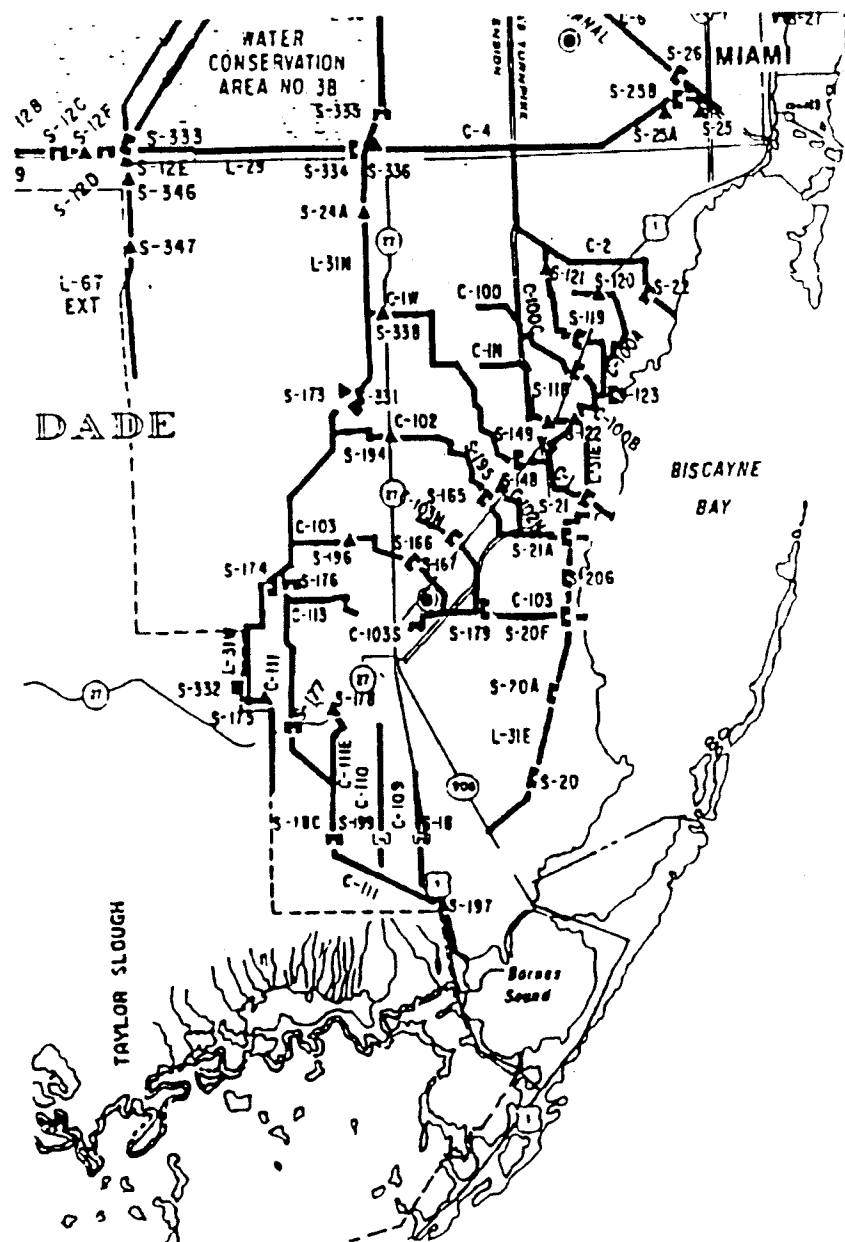
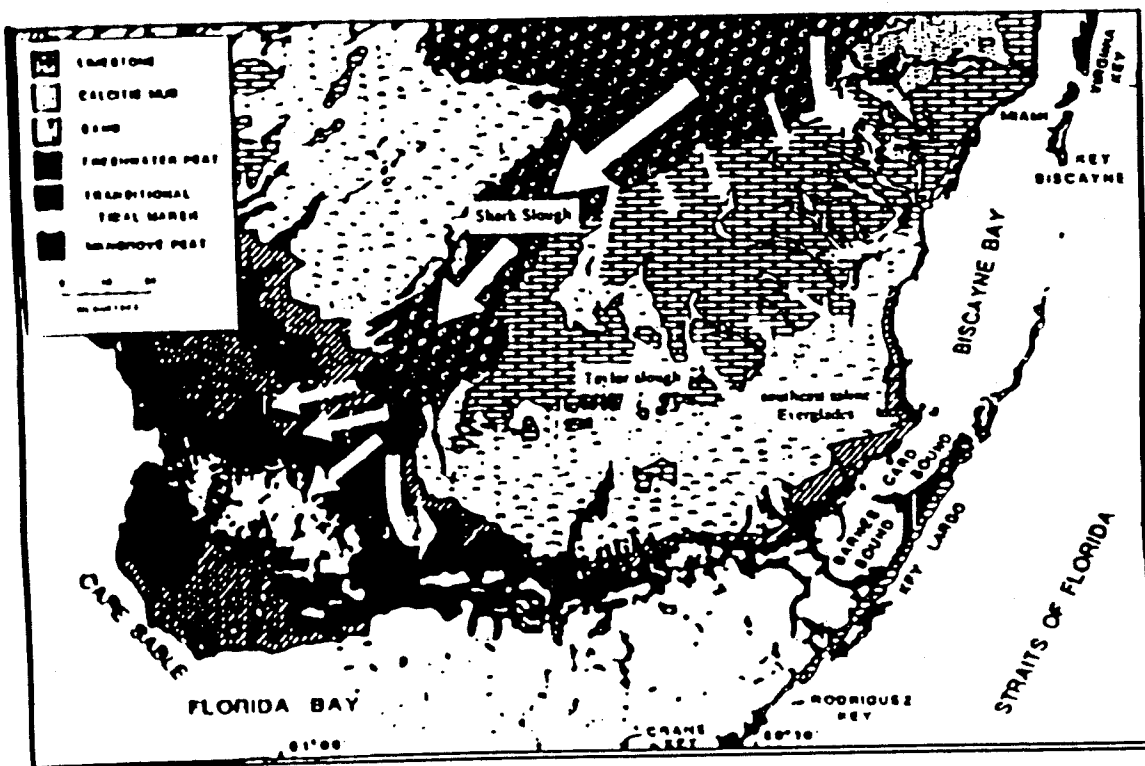


Figure 2. 1928 aerial photograph of the west coast of Biscayne Bay north of Fender Point. This photograph illustrates the degree of coastal wetland impact by 1928. Note the larger east-to-west drainage canals and the cross ditch systems which were constructed to drain the land for truck farming and mosquito control. At the time this photo was taken, nearly all tillable land with sweet soils were cultivated. Some cultivated fields were already abandoned because of inadequate drainage (those further from the coast still covered with dense vegetation) or because of salt water encroachment. Fields abandoned because of salt water encroachment are recognized by overgrown furrows in fields close to the coast. Many of these fields are within 400 m of the coast.

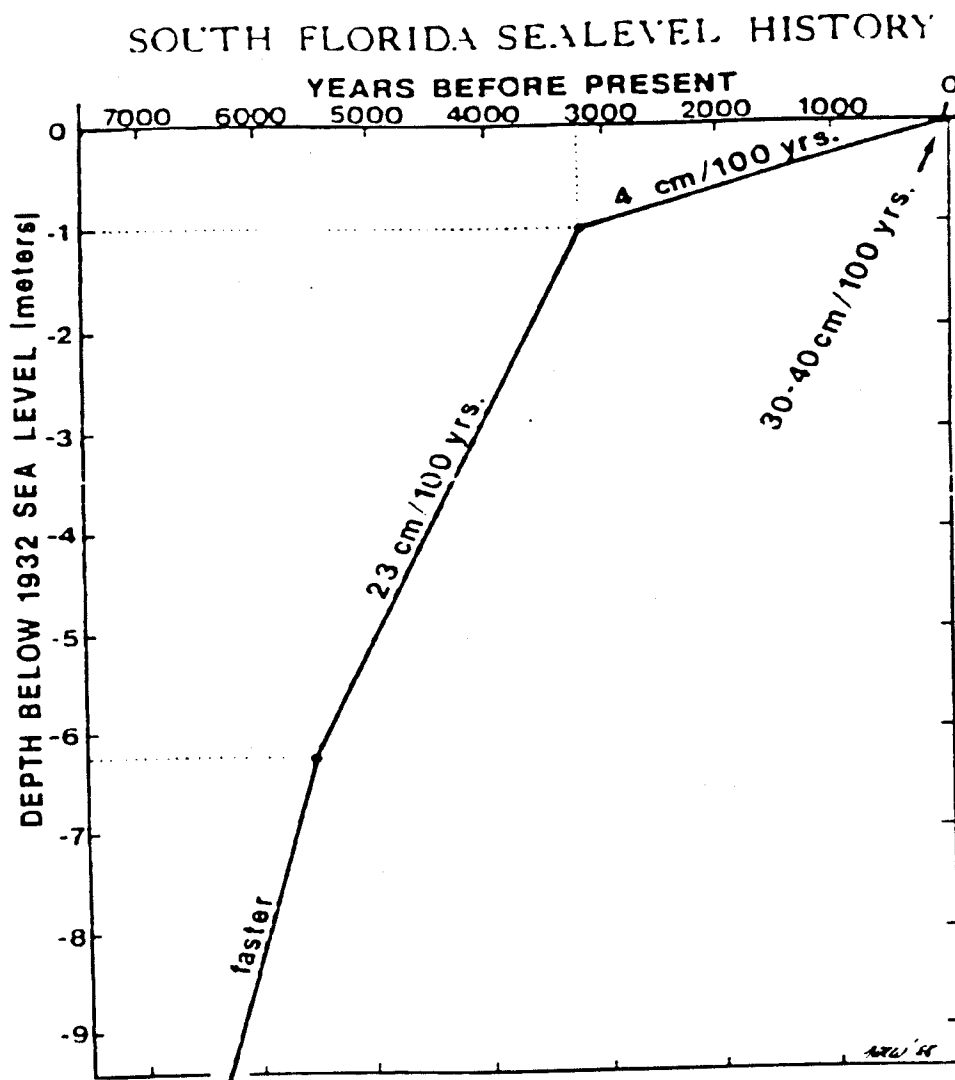


Figure 3. Sea level change.

a. Holocene sea level curve for South Florida for the last 6,000 yrs, the time interval during which the Everglades Ecosystem developed (from Parkinson and Wanless, 1992). Note the changing rate of rising sea level and their postulated recent rise in rate to approximately 30 cm/ 100 yrs.

b. Sea level change curve for Key West, Florida from 1846 to 1992 (Maul and Martin (1993). They document a sea level rate change of about 1.9 mm/yr for the duration of the record. Their analyses also finds sea level rose 1.5 mm/yr prior to 1925 and accelerated to 2.3 mm/yr afterwards.

A.



B.

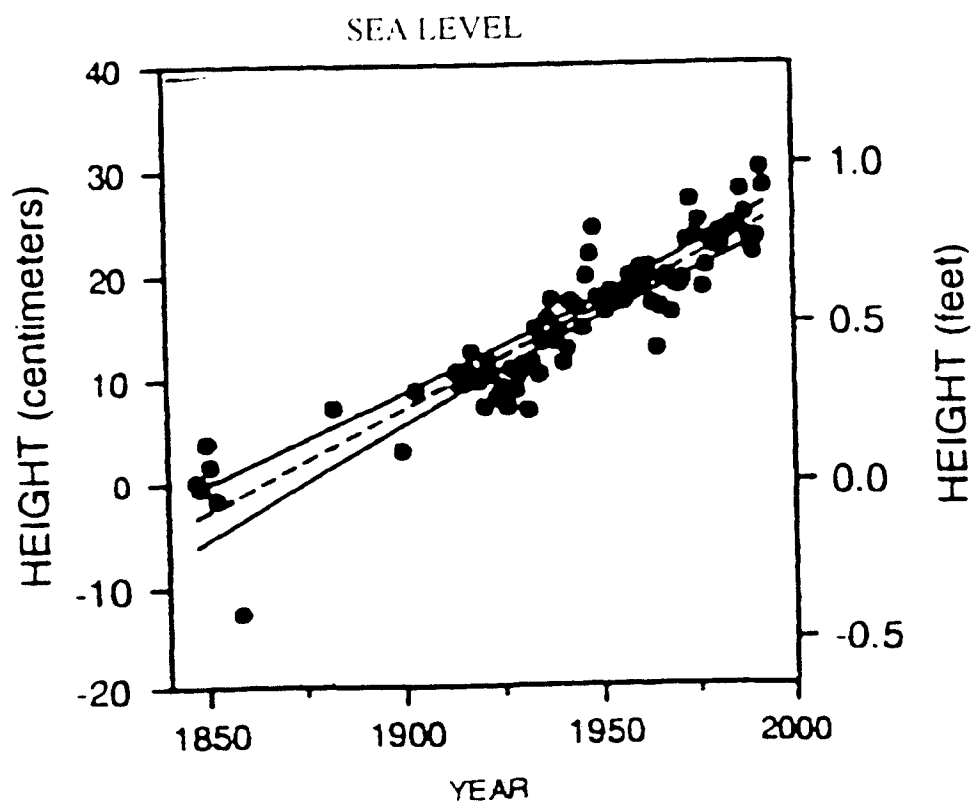


Figure 4. Map showing field stations and transect locations.

Sampling Sites and Transects in The C-111 Basin

Meters



2000 5000

L31-E
TRANSECT

TURKEY POINT
TRANSECT

HIGHWAY CREEK
TRANSECT

TAYLOR SLOUGH
TRANSECT

JOE BAY
TRANSECT

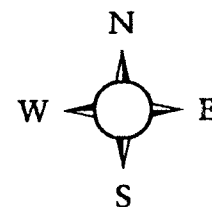


Figure 5. Vegetation and soil parameters plotted with distance from the coast along the Taylor Slough Transect. Station locations along the transect are noted at the top: LTS = Lower Taylor Slough, UTS = Upper Taylor Slough, E146, and TSH = Taylor Slough Hilton. Distance from the coast is found at the bottom of the page and is in meters.

- a. Plant species relative abundance versus distance from the coast.
- b. Plant species biomass versus distance from the coast.
- c. Soil constituent percent dry weight versus distance from the coast.

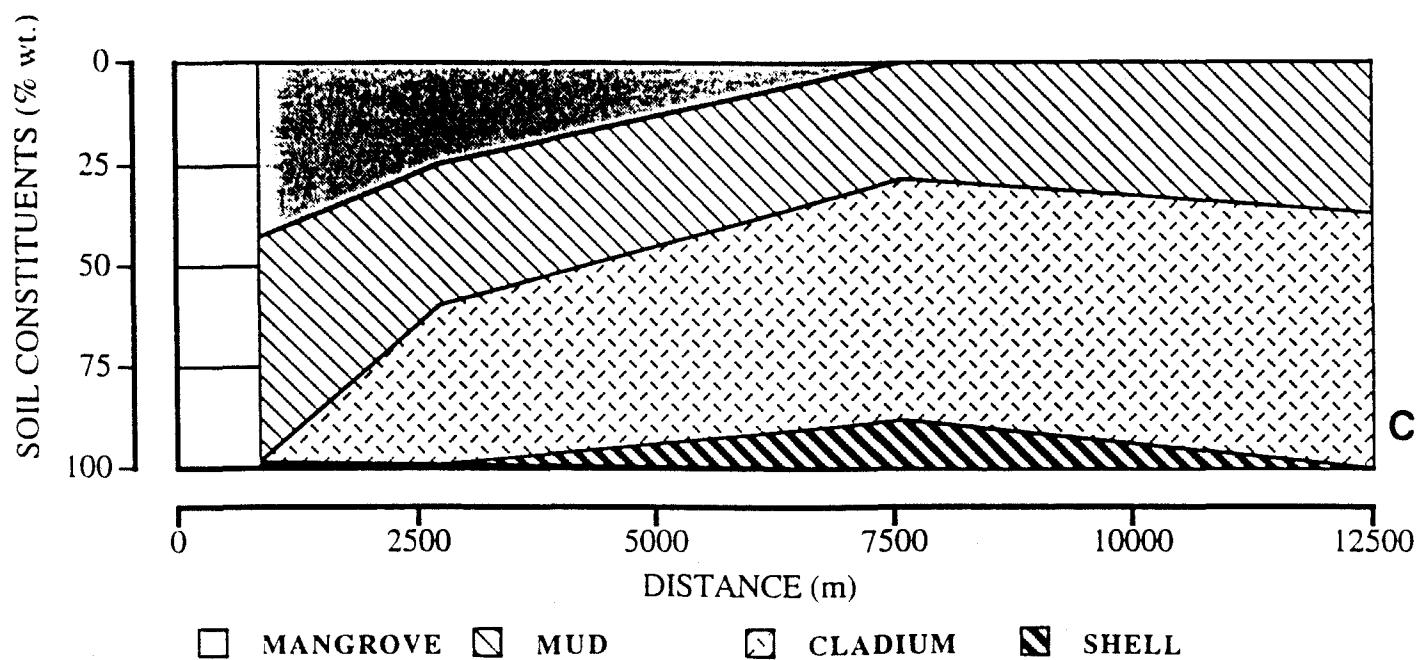
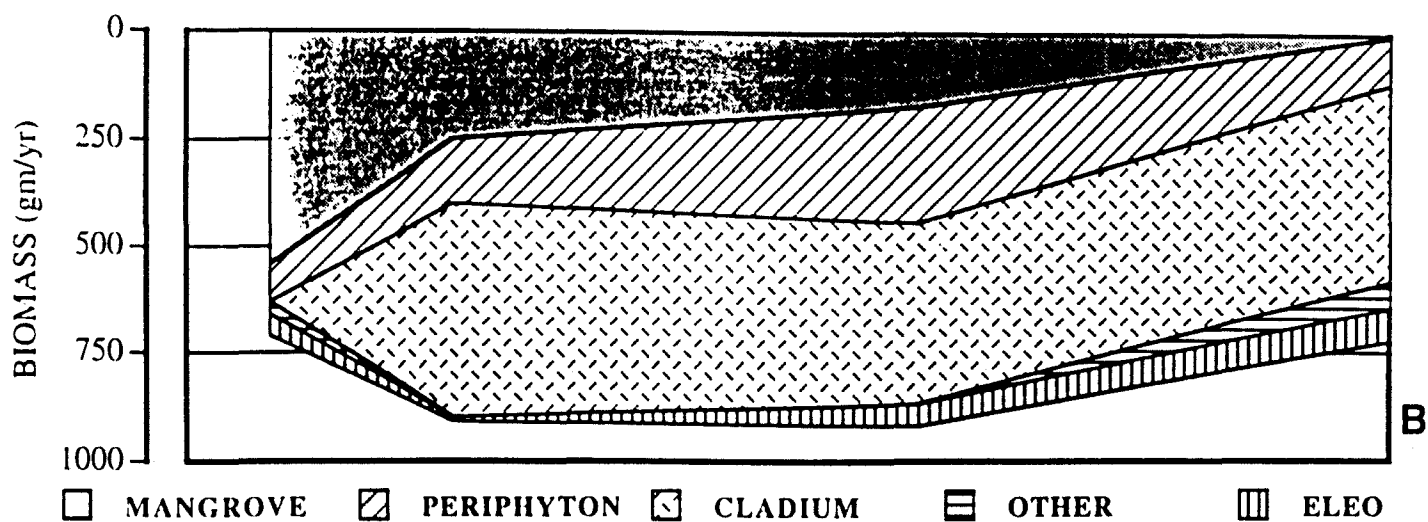
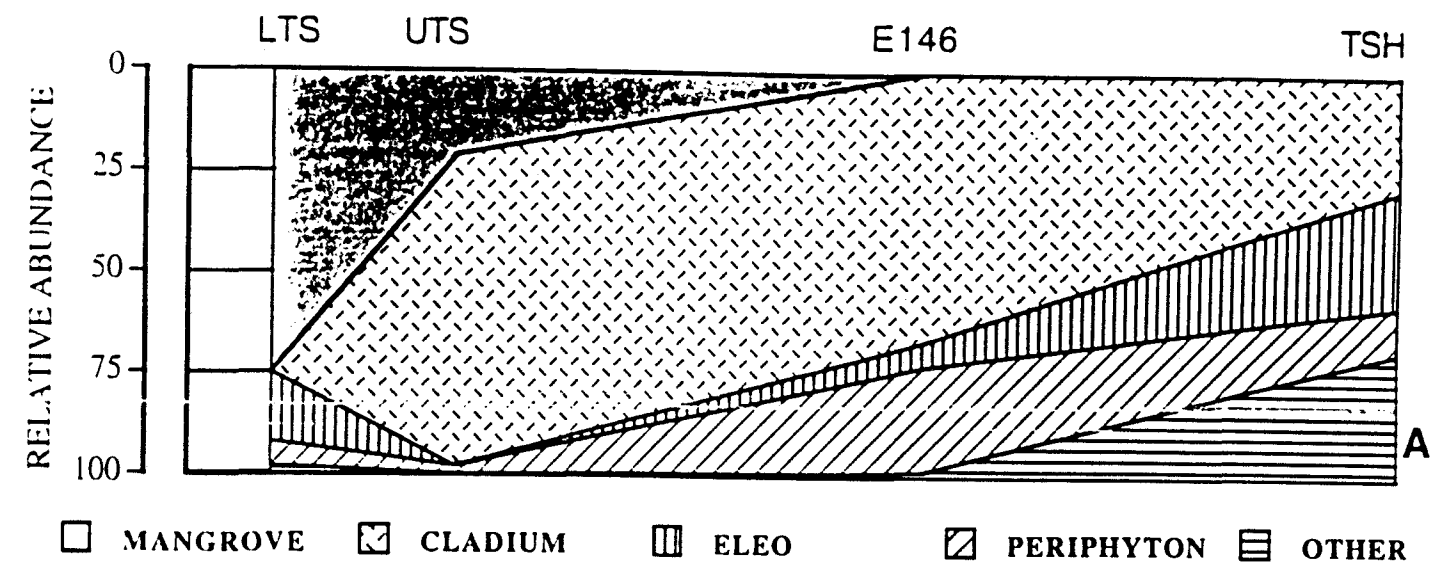


Figure 6. Vegetation and soil parameters plotted with distance from the coast along the Joe Bay Transect. Station locations along the transect are noted at the top: CJB = Coastal Joe Bay, LJB = Lower Joe Bay, UJB = Upper Joe Bay, NUJB = North of UJB, Ever7 and Ever 4. Distance from the coast is found at the bottom of the page and is in meters.

- a. Plant species relative abundance versus distance from the coast.
- b. Plant species biomass versus distance from the coast.
- c. Soil constituent percent dry weight versus distance from the coast.

JOE BAY

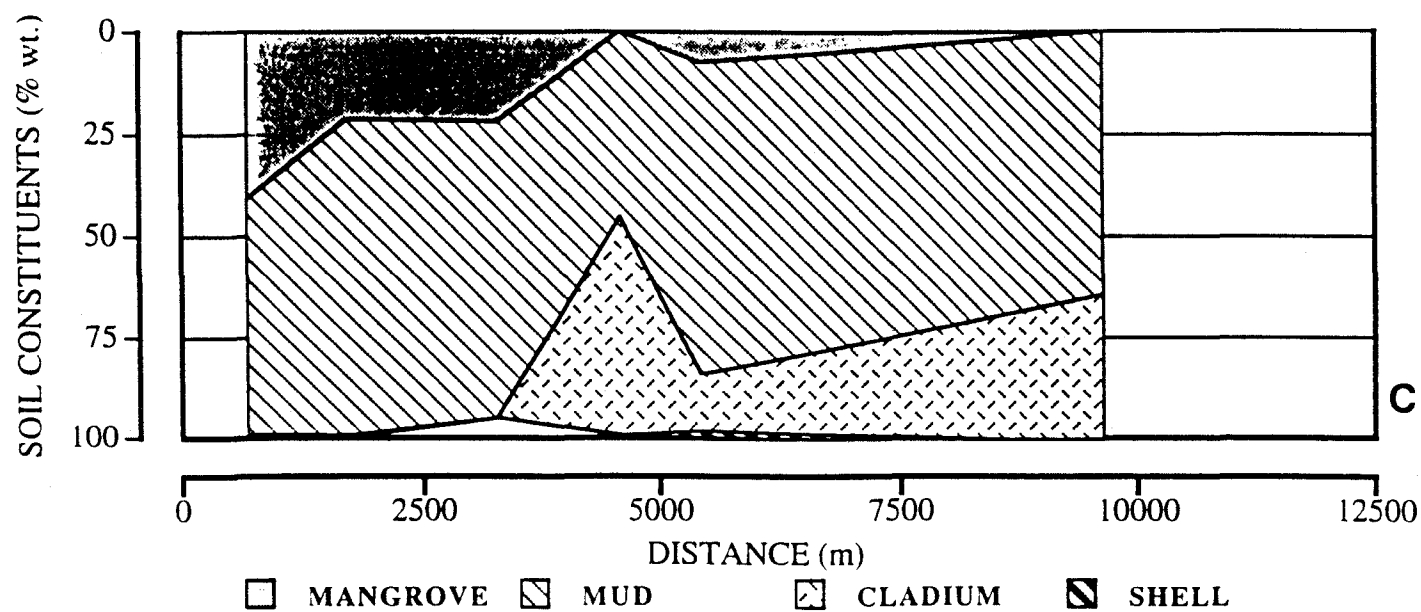
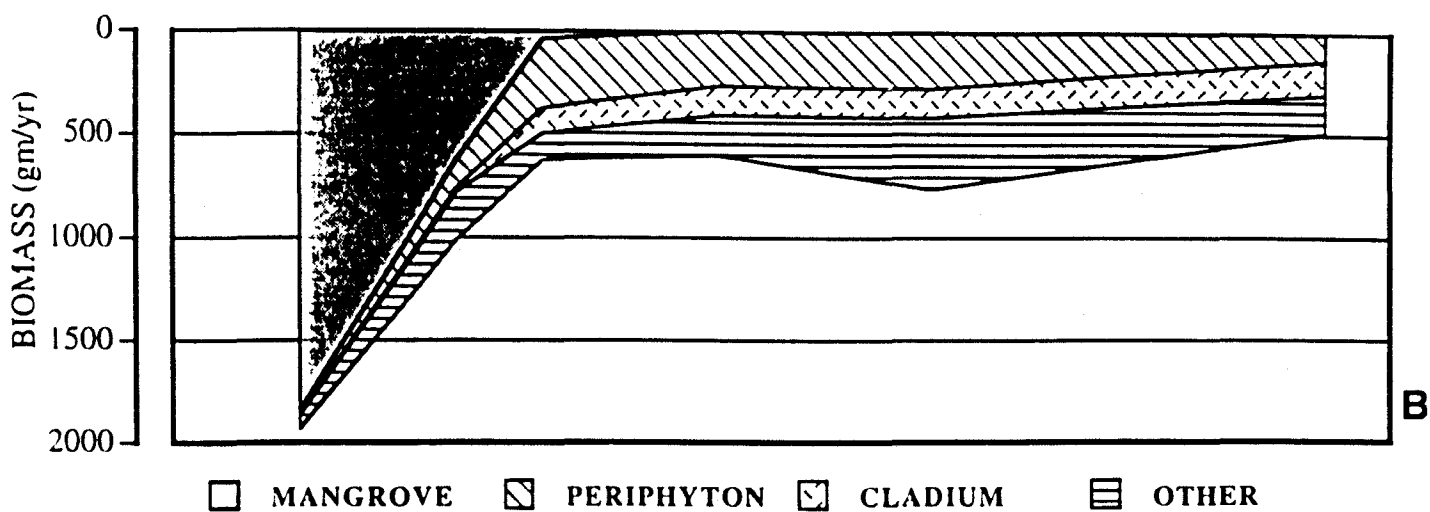
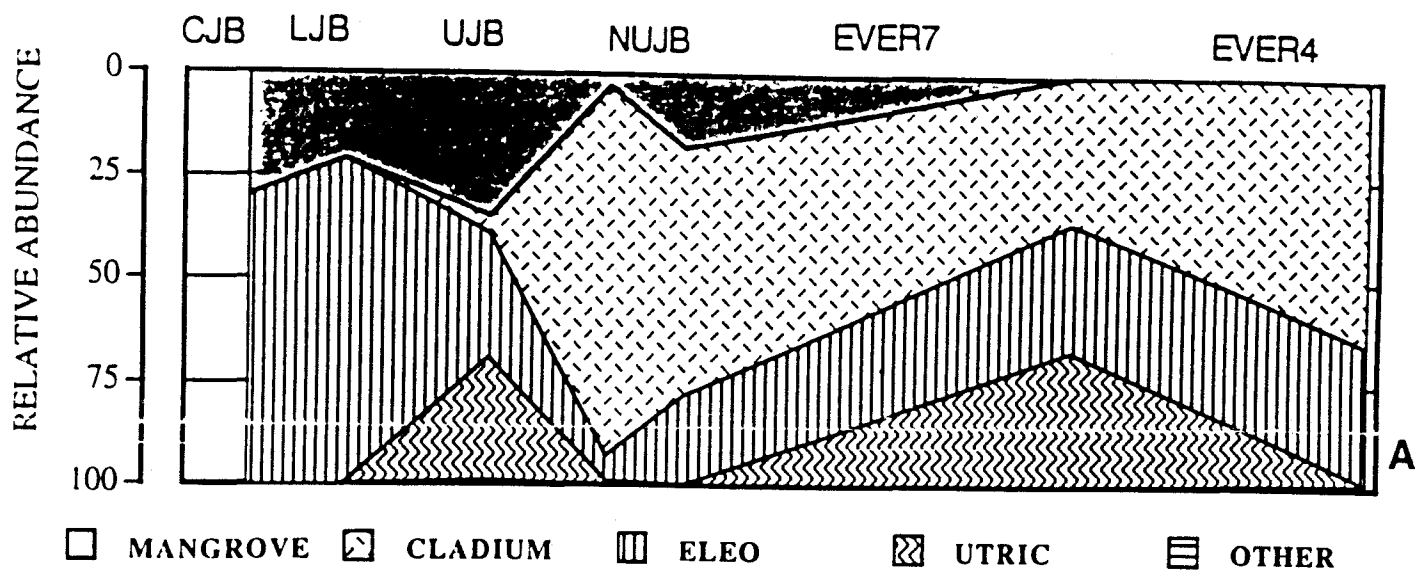
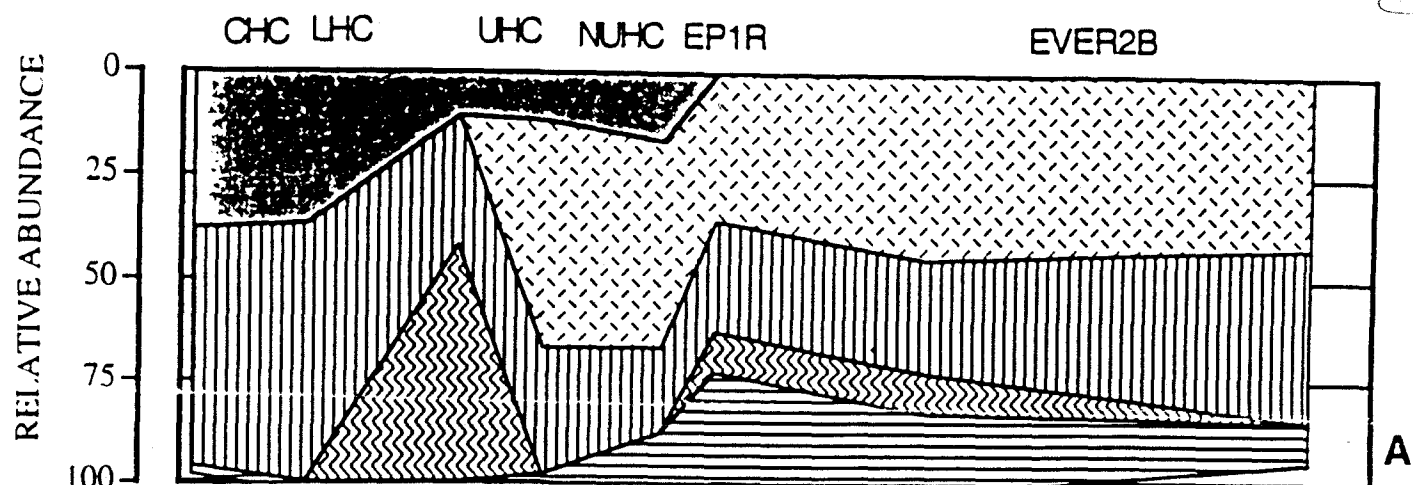
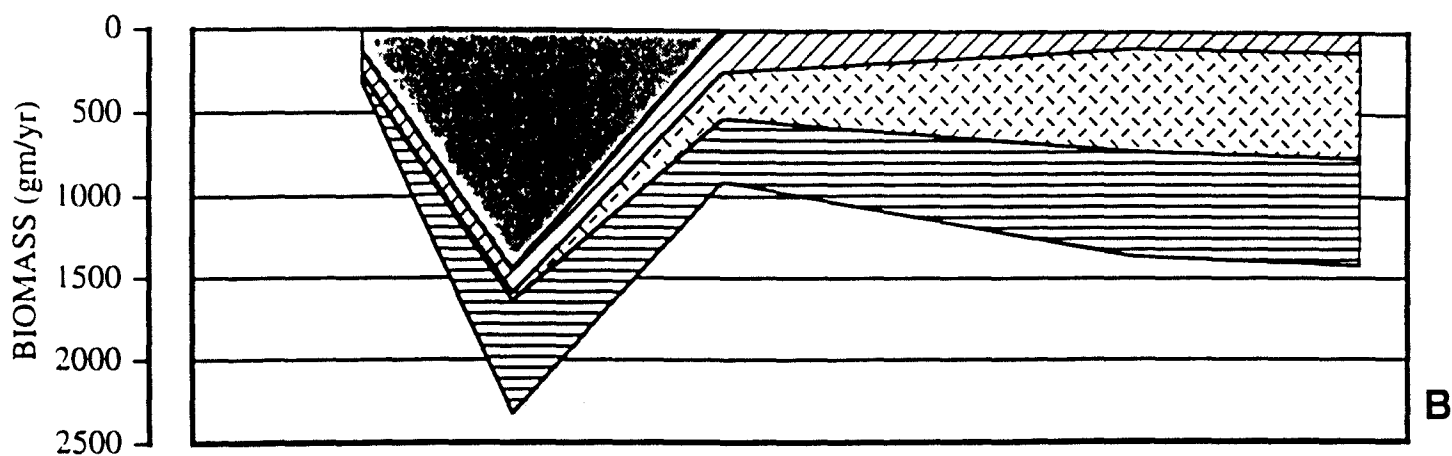


Figure 7. Vegetation and soil parameters plotted with distance from the coast along the Highway Creek Transect. Station locations along the transect are noted at the top: CHC = Coastal Highway Creek, LHC = Lower Highway Creek, UHC = Upper Highway Creek, NUHC = North of UHC, EPIr and Ever 2b. Distance from the coast is found at the bottom of the page and is in meters.

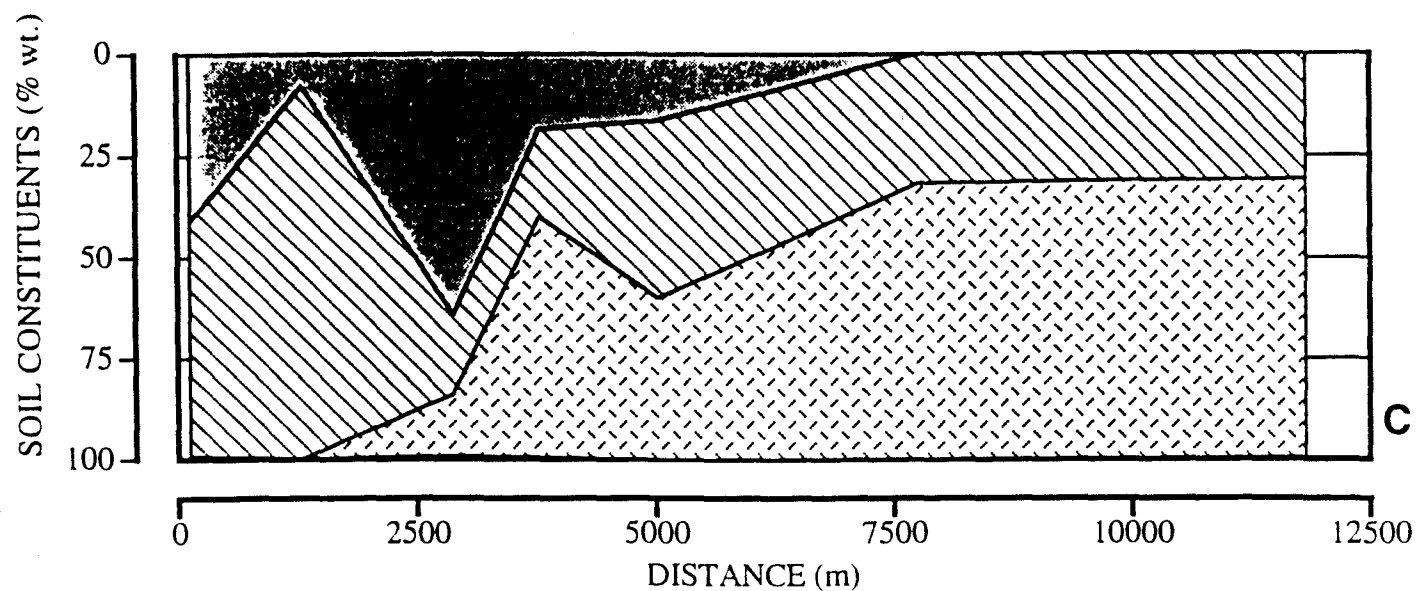
- a. Plant species relative abundance versus distance from the coast.
- b. Plant species biomass versus distance from the coast.
- c. Soil constituent percent dry weight versus distance from the coast.



☐ MANGROVE
 ☒ CLADIUM
 ☒ ELEO
 ☒ UTRIC
 ☒ OTHER



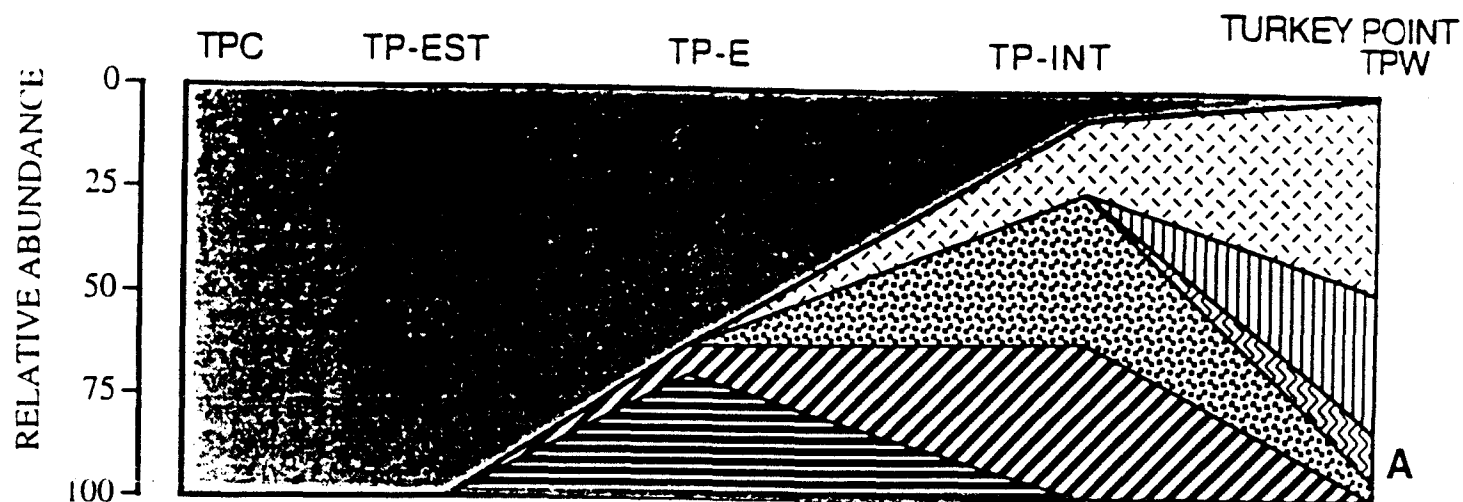
☐ MANGROVE
 ☒ PERIPHYTON
 ☒ CLADIUM
 ☒ OTHER



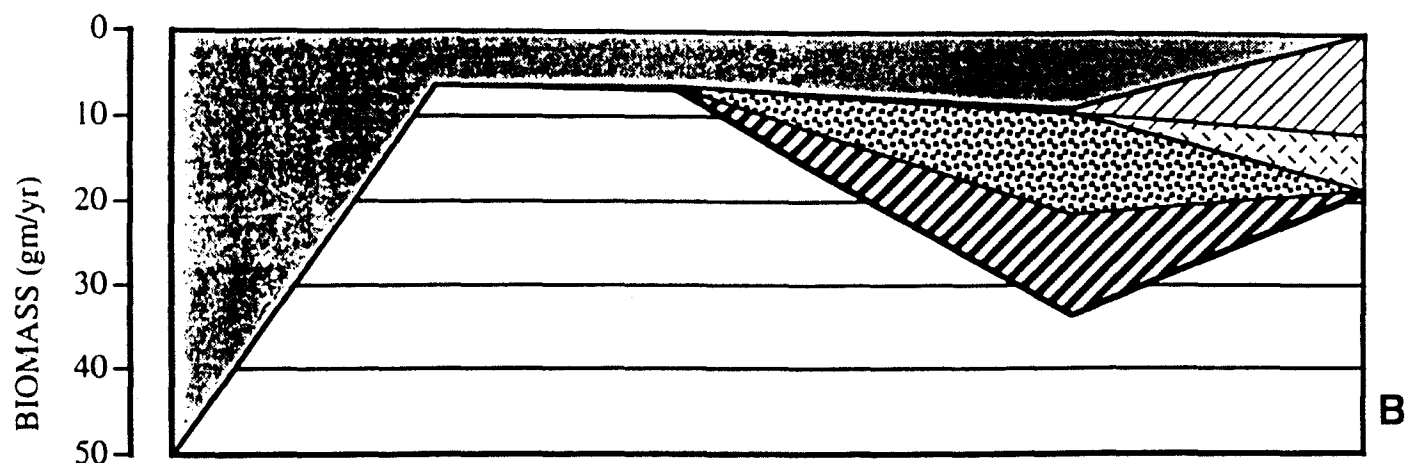
☐ MANGROVE
 ☒ MUD
 ☒ CLADIUM
 ☒ SHELL

Figure 8. Vegetation and soil parameters plotted with distance from the coast along the Turkey Point Transect. Station locations along the transect are noted at the top: TPC = Turkey Point coastal, TP-EST = Turkey Point extreme east, TP-E = Turkey Point central, TP-INT = Turkey Point interior, and TPW = Turkey Point west. Distance from the coast is found at the bottom of the page and is in meters.

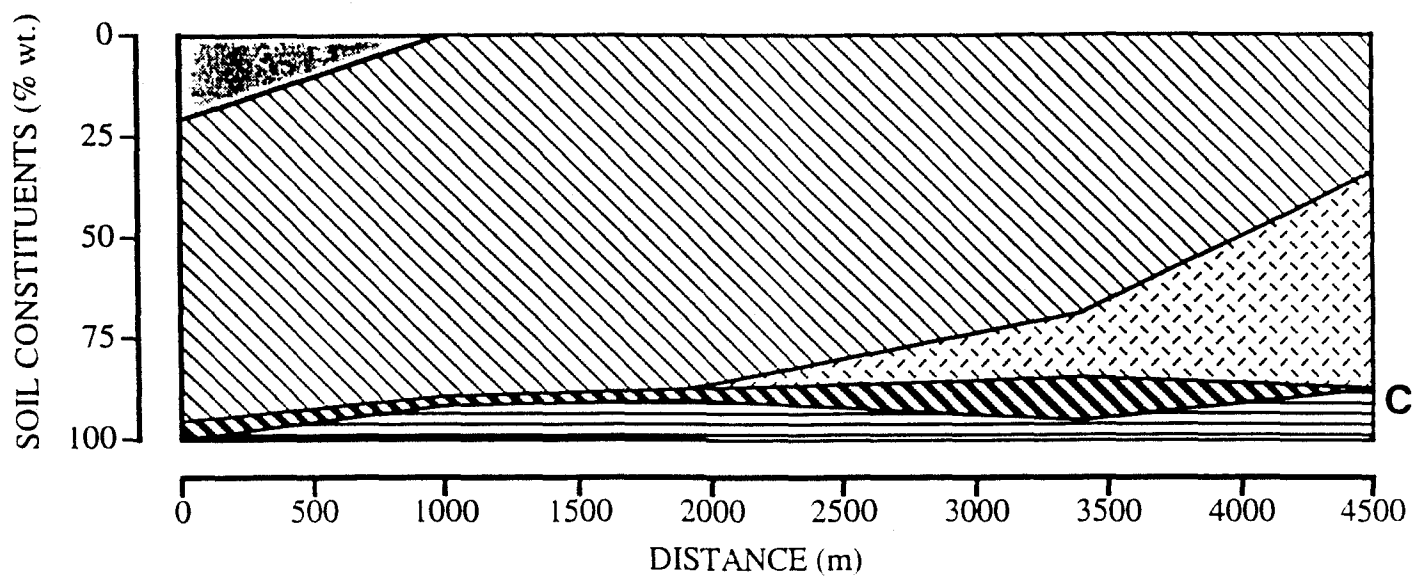
- a. Plant species relative abundance versus distance from the coast.
- b. Plant species biomass versus distance from the coast.
- c. Soil constituent percent dry weight versus distance from the coast.



MANGROVE CLADIUM ELEO UTRIC JUNC
 DIST RUPP



MANGROVE PERIPHYTON CLADIUM JUNC DIST
 RUPP OTHER



MANGROVE MUD CLADIUM SHELL OTHER

Figure 9. Detailed relief map of the Turkey Point Transect illustrating the micro-relief, thickness of the Hurricane Andrew Storm deposit, and the amount of impounded water observed in the micro-relief. An identifiable Hurricane Andrew Storm mud deposit is easily recognized along the surveyed transect by the excavation of shallow trenches. The thickness ranges from 12 to 16 cm along the coast to less than 2 cm at 2,500 m from the coast. Muds were transported and deposited further inland but are more difficult to identify because of the higher vegetation cover. Standing water was found in distinct "ponds" in steplike increases in elevation away from the coast. These observations were made during the lower half of the daily tidal range when bay water was not observed inundating the coastal wetlands. This survey documents the inadequacies of using surface water elevations as reference elevation in field ecology work.

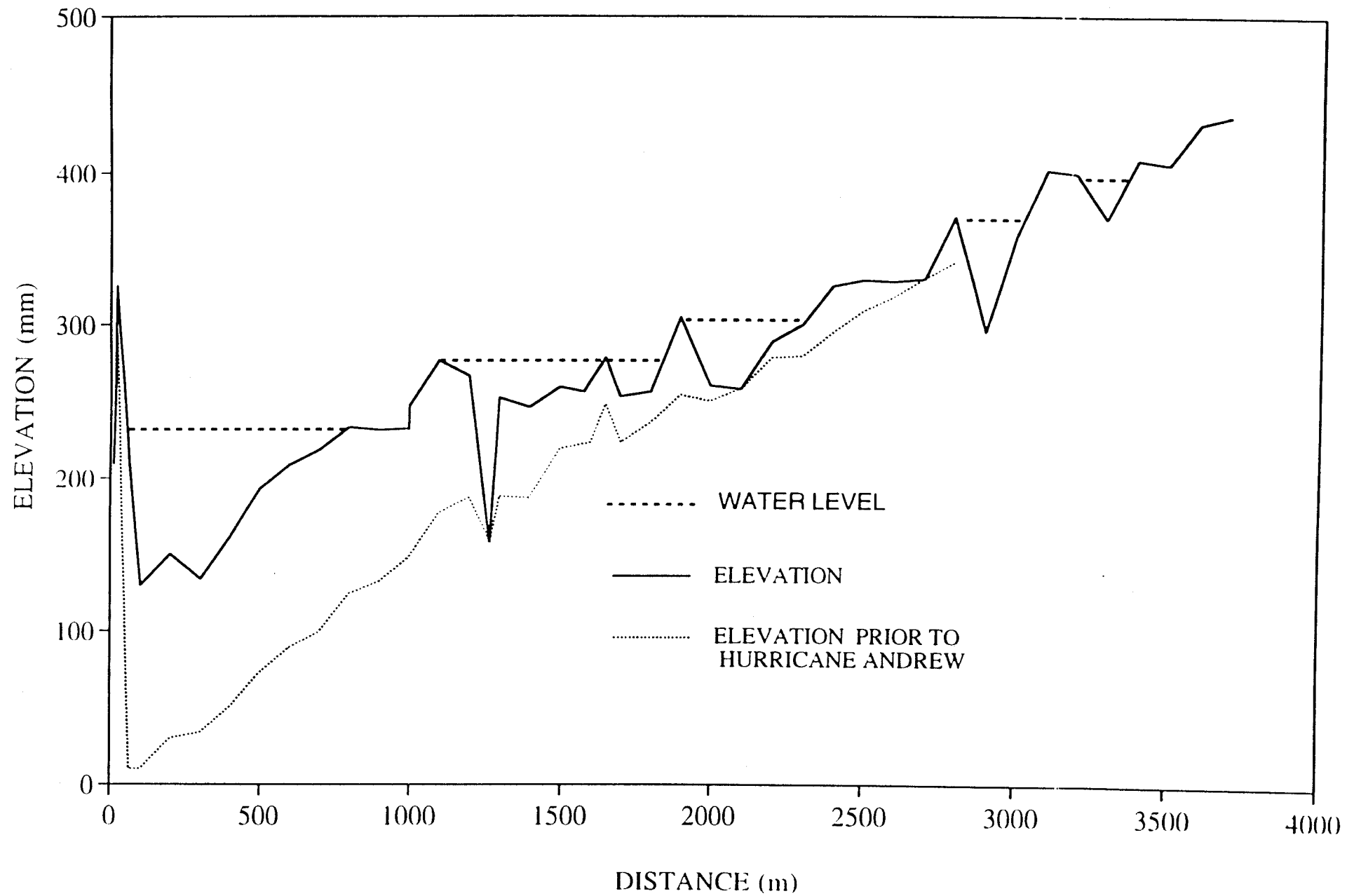


Figure 10. Vertical profiles of periphyton mats from two locations: CHC and NUJB. The periphyton thickness at CHC was 12 cm and 16 cm for NUJB.

- a. Percent total organic soil constituents versus depth. In both cores a negative correlation exists between increased soil depth and decreased organic content.
- b. Percent carbonate mud soil constituent versus depth. In both cases a positive correlation exists between increased soil depth and increased carbonate mud.
- c. Dry bulk density of soil versus soil depth exhibits a linear positive correlation. the bulk density increases with increased soil depth.

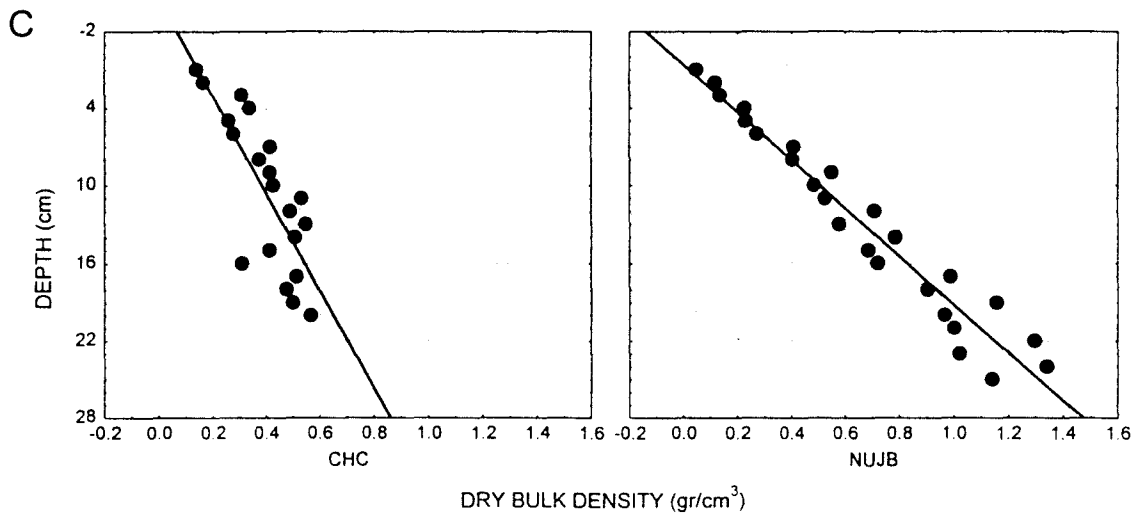
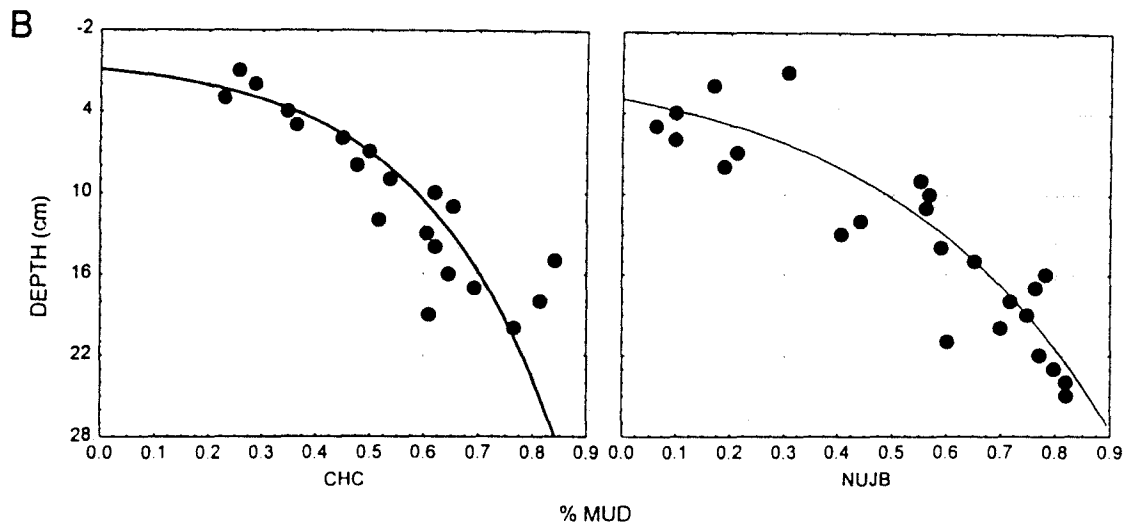
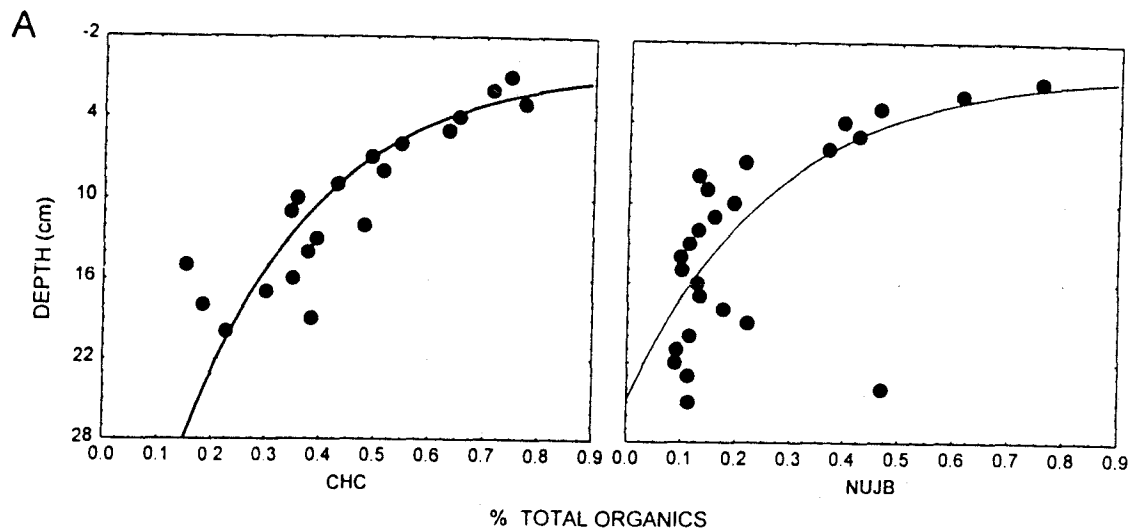


Figure 11. Chronostratigraphy and paleosalinity profile for the Taylor Slough Transect. The small enclosed box contains the entire transect to scale. The major point of interest is the area where the time lines cross the marine-to-freshwater contact line. This area is blown up to a larger scale to make the graphic determination of the rates of salt water encroachment more accurate and easier to accomplish. The intersections of the time lines with the marine contact line are indicated with labeled arrows. Taylor Slough has undergone approximately 500 m of marine encroachment during the last century (from 2,100m to 2,600 m from the coast).

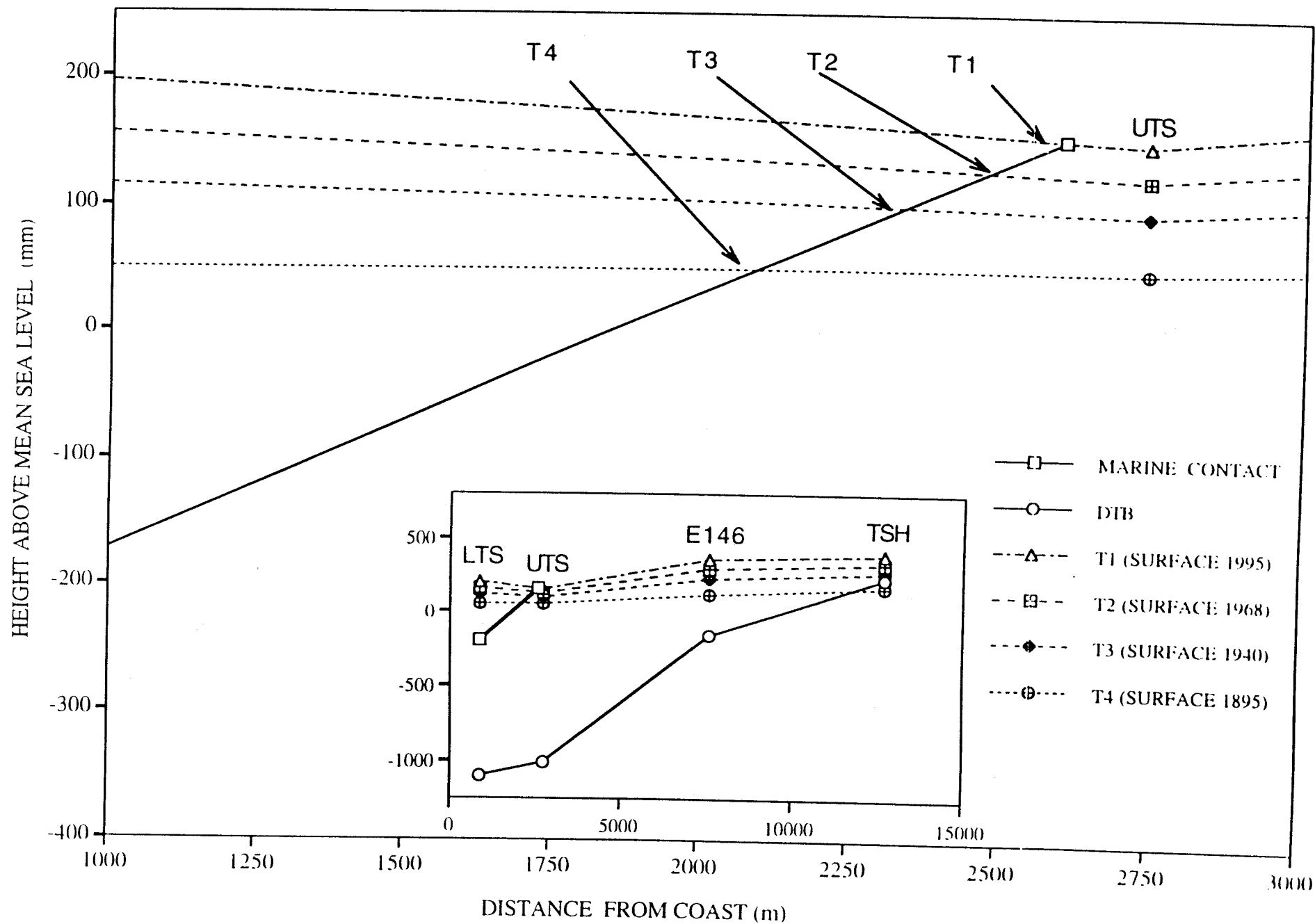


Figure 12. Chronostratigraphy and paleosalinity profile for the Joe Bay Transect. The small enclosed box contains the entire transect to scale. The major point of interest is the area where the time lines cross the marine-to-freshwater contact line. This area is blown up to a larger scale to make the graphic determination of the rates of salt water encroachment more accurate and easier to accomplish. The intersections of the time lines with the marine contact line are indicated with labeled arrows. Joe Bay subbasin has undergone approximately 3,100 m of marine encroachment during the last century (from 1,900 m to 5,000 m from the coast).

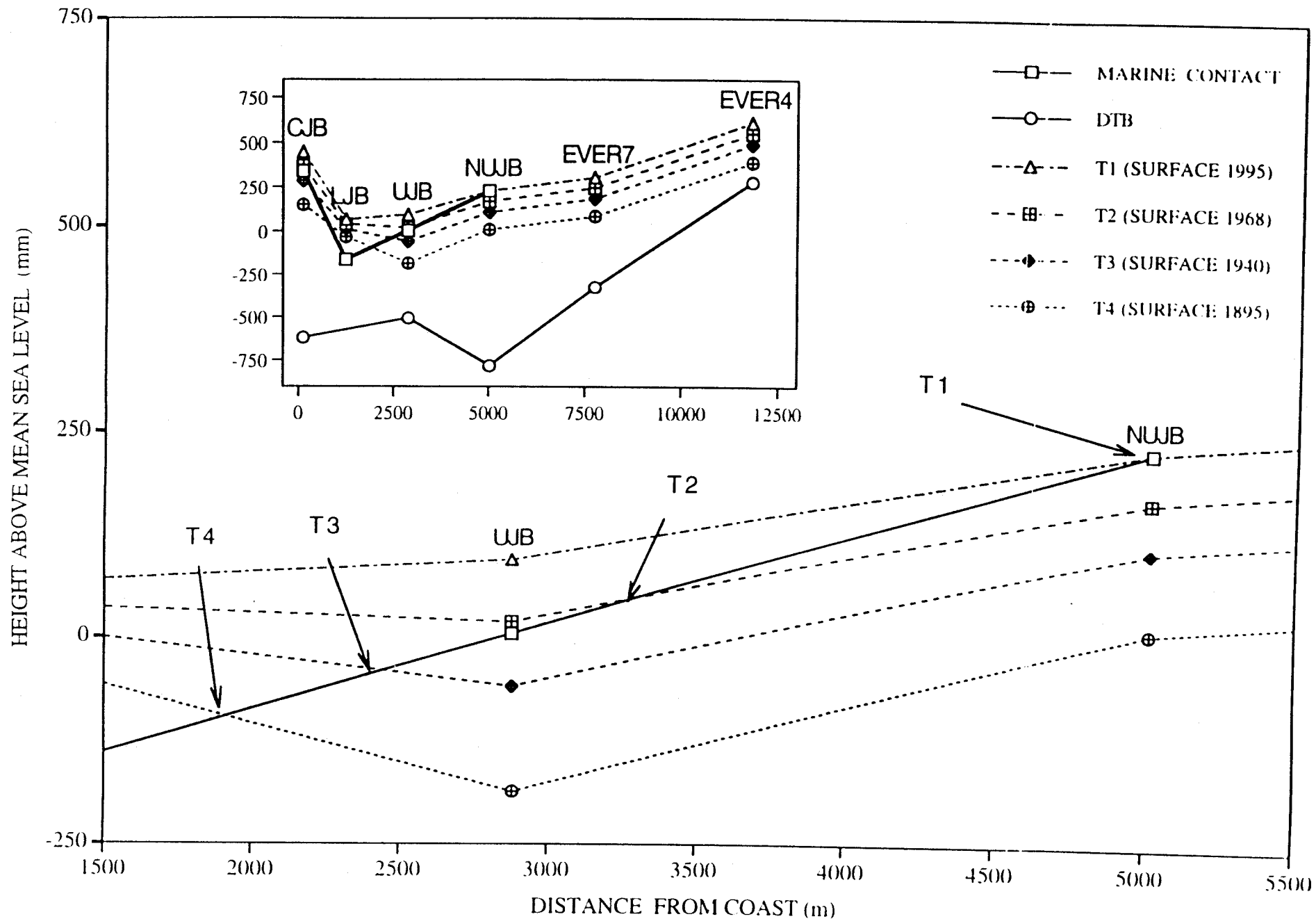


Figure 13. Chronostratigraphy and paleosalinity profile for the Highway Creek Transect. The small enclosed box contains the entire transect to scale. The major point of interest is the area where the time lines cross the marine-to-freshwater contact line. This area is blown up to a larger scale to make the graphic determination of the rates of salt water encroachment more accurate and easier to accomplish. The intersections of the time lines with the marine contact line are indicated with labeled arrows. Highway Creek subbasin has undergone approximately 4,200 m of marine encroachment during the last century (from 2,700m to 7,000 m from the coast).

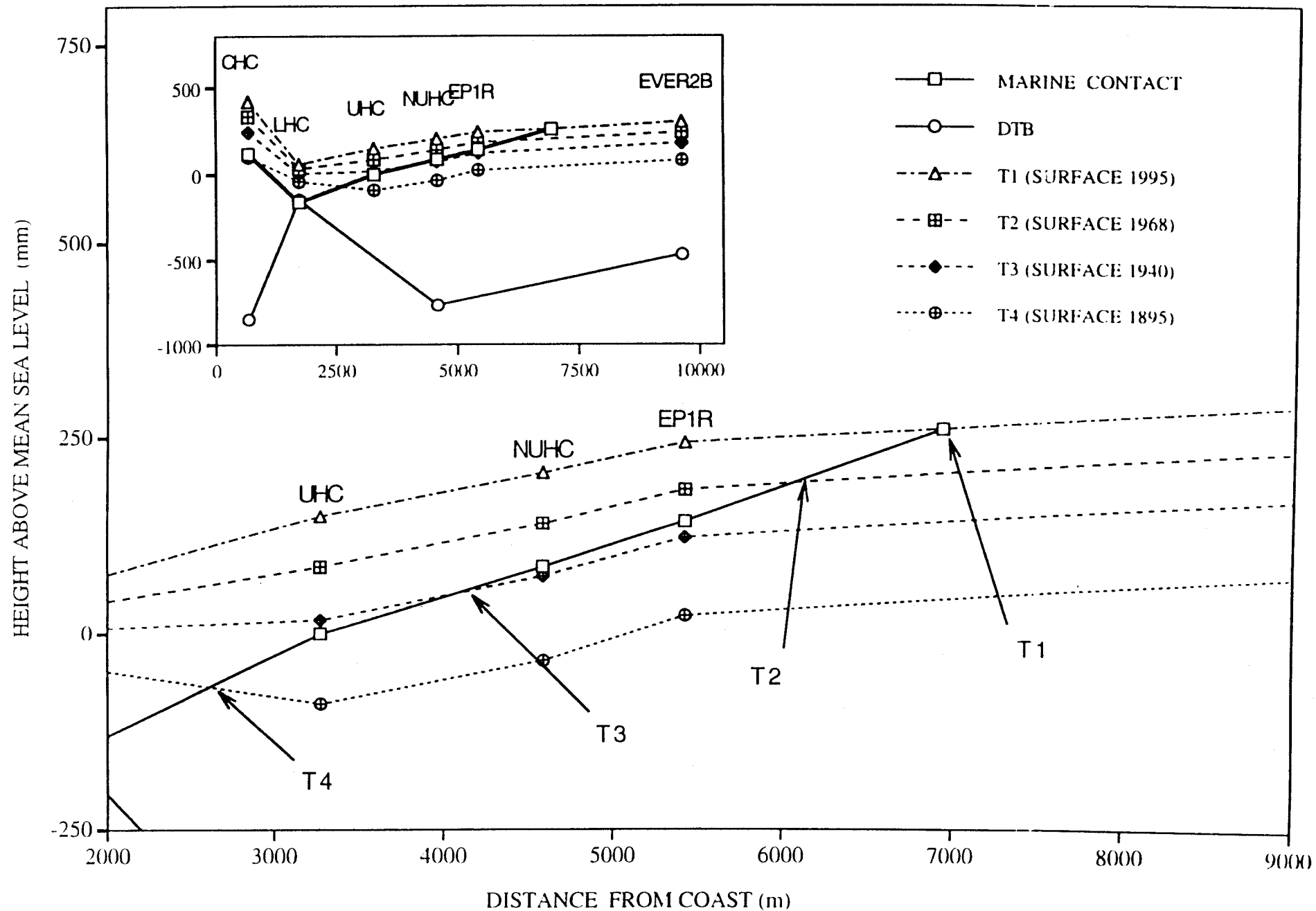


Figure 14. Chronostratigraphy and paleosalinity profile for the Turkey Point Transect. The small enclosed box contains the entire transect to scale. The major point of interest is the area where the time lines cross the marine-to-freshwater contact line. This area is blown up to a larger scale to make the graphic determination of the rates of salt water encroachment more accurate and easier to accomplish. The intersections of the time lines with the marine contact line are indicated with labeled arrows. Turkey Point subbasin has undergone approximately 1,700 m of marine encroachment during the last century (from 1,900 m to 3,600 m from the coast).

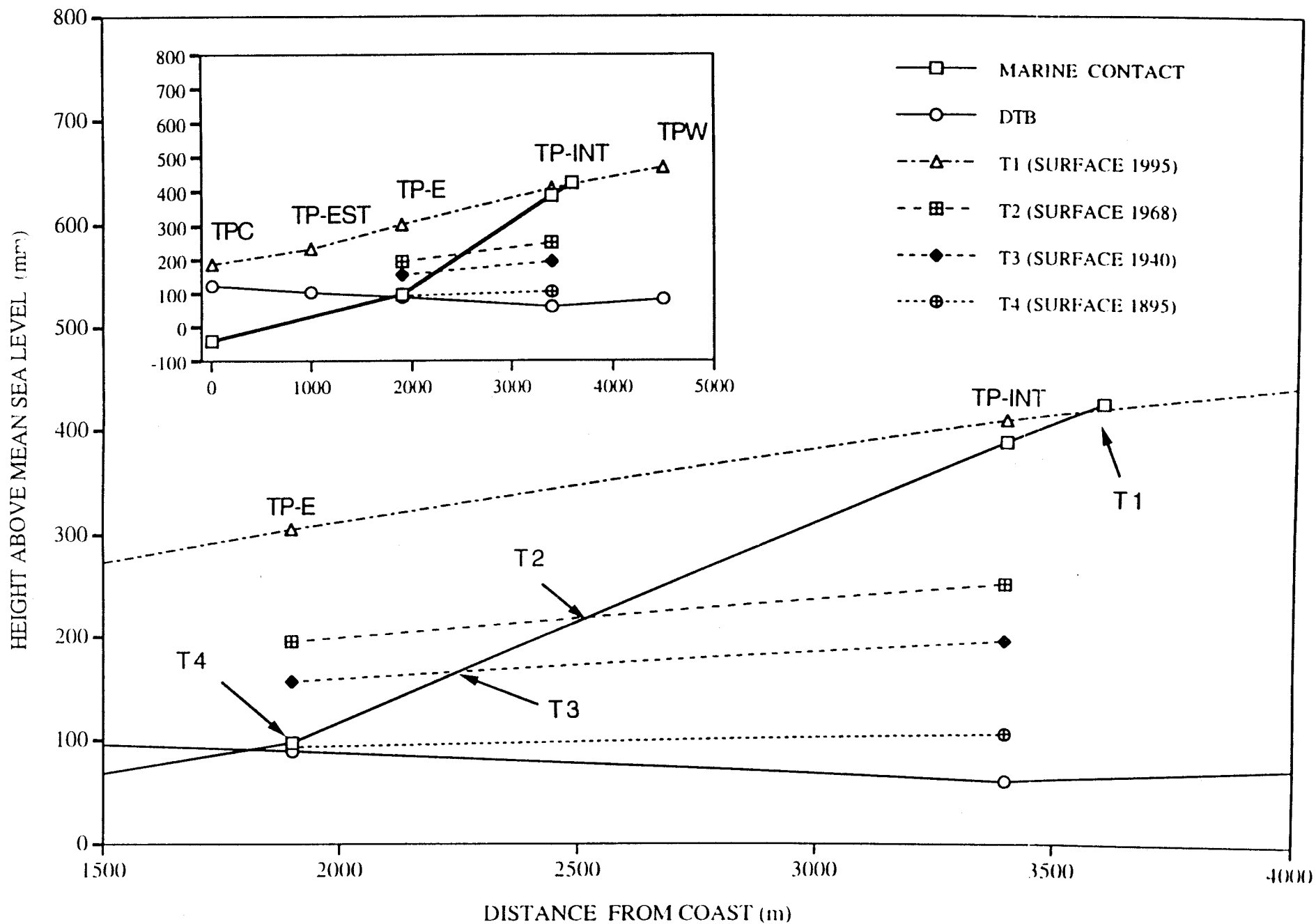


Figure 15 Chronostratigraphy and paleosalinity profile for the Mowry Canal Transect. The small enclosed box contains the entire transect to scale. The major point of interest is the area where the time lines cross the marine-to-freshwater contact line. This area is blown up to a larger scale to make the graphic determination of the rates of salt water encroachment more accurate and easier to accomplish. The intersections of the time lines with the marine contact line are indicated with labeled arrows. Mowry Canal subbasin has undergone approximately 1,600 m of marine encroachment during the last century (from 500 m to 2,100 m from the coast). Since the construction of the L-31E levee, however, the marine-to-fresh water contact has been reestablished at approximately 650 m from the coast at the foot of the levee.

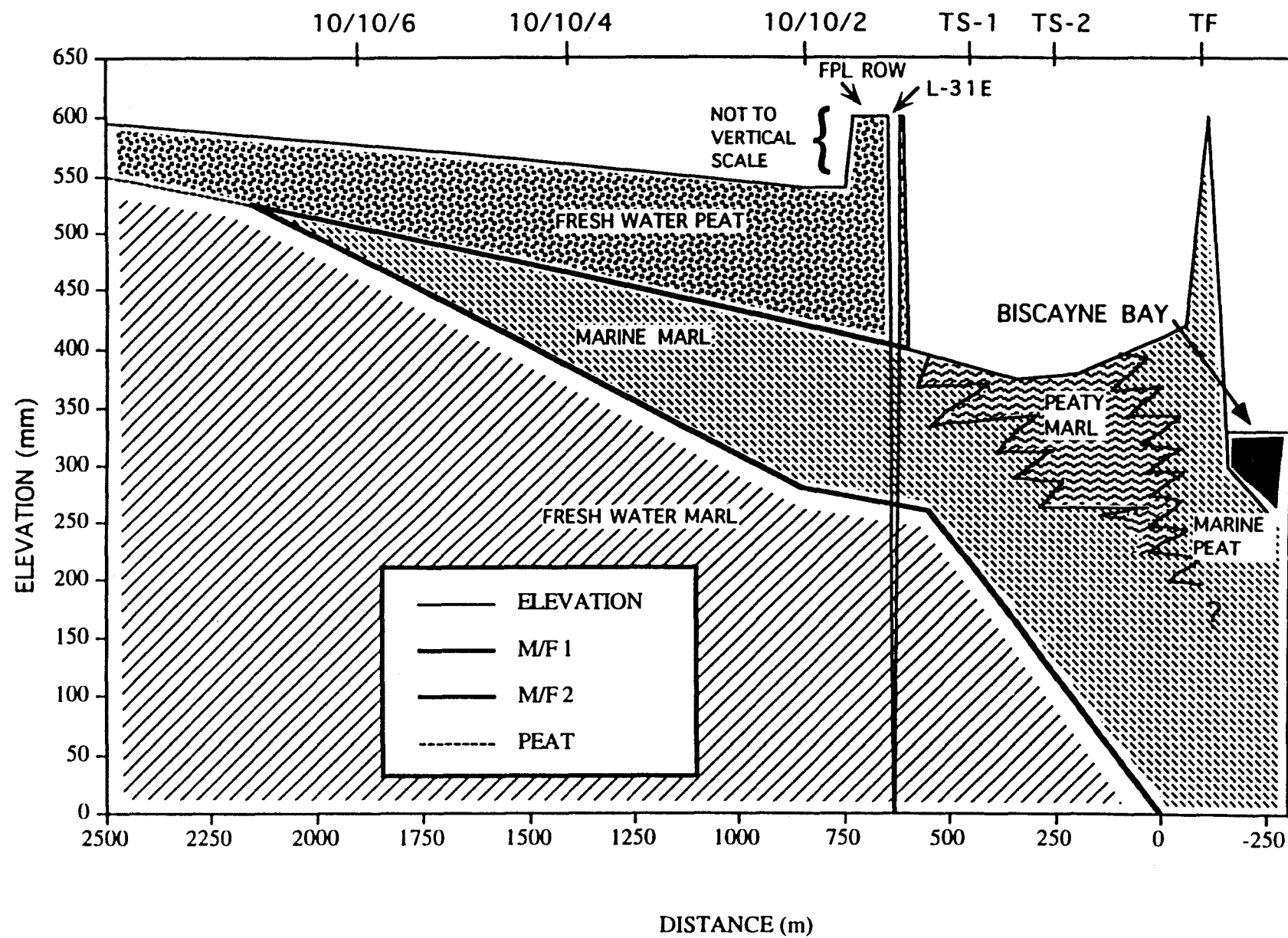
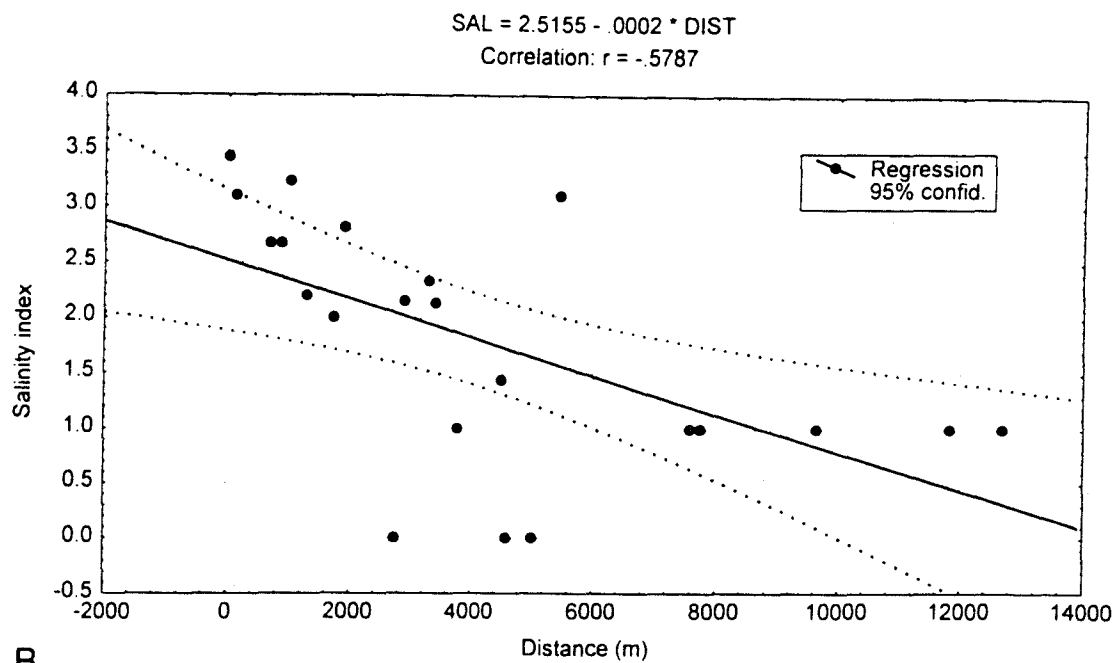


Figure 16 Relationship between salinity and distance from the coast.

- a. Salinity indexes were calculated for surface 2 cm of sediment beneath the periphyton mat. All stations with salinity index data (except for the Tabb et al. 1968 stations) were plotted in respect to distance from the coast. A linear regression with 95 % confidence interval has a r^2 of 0.5787.
- b. Salinity index data from all Tabb et al. 1968 study sites are plotted. Zero values are stations that recorded no mollusks in the soil and are not zero salinities. Zero salinity has a salinity index of 1.0. Note the weak sinusoidal curve along each of the five transects. The transects with the most pronounced sinusoidal curves have zero values at approximately the same relative position along the curve. Perhaps this area along the transects is a low productive area based upon molluscan macrophalaginous alga grazer paucity or absence.

A



B

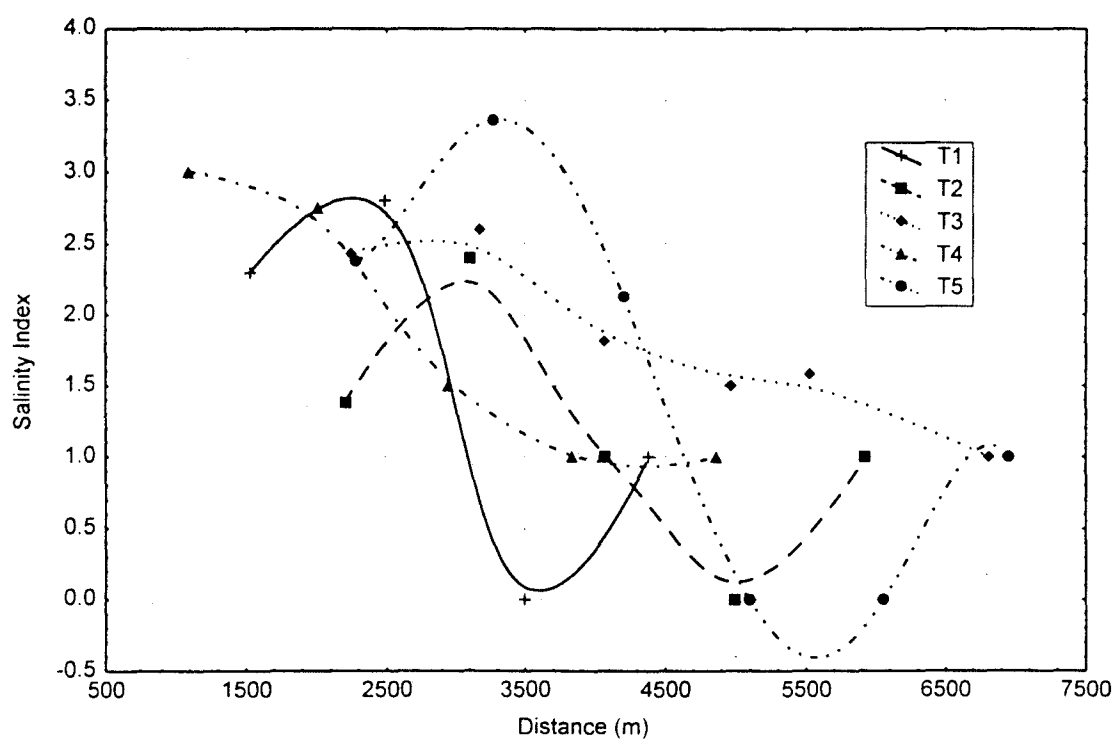
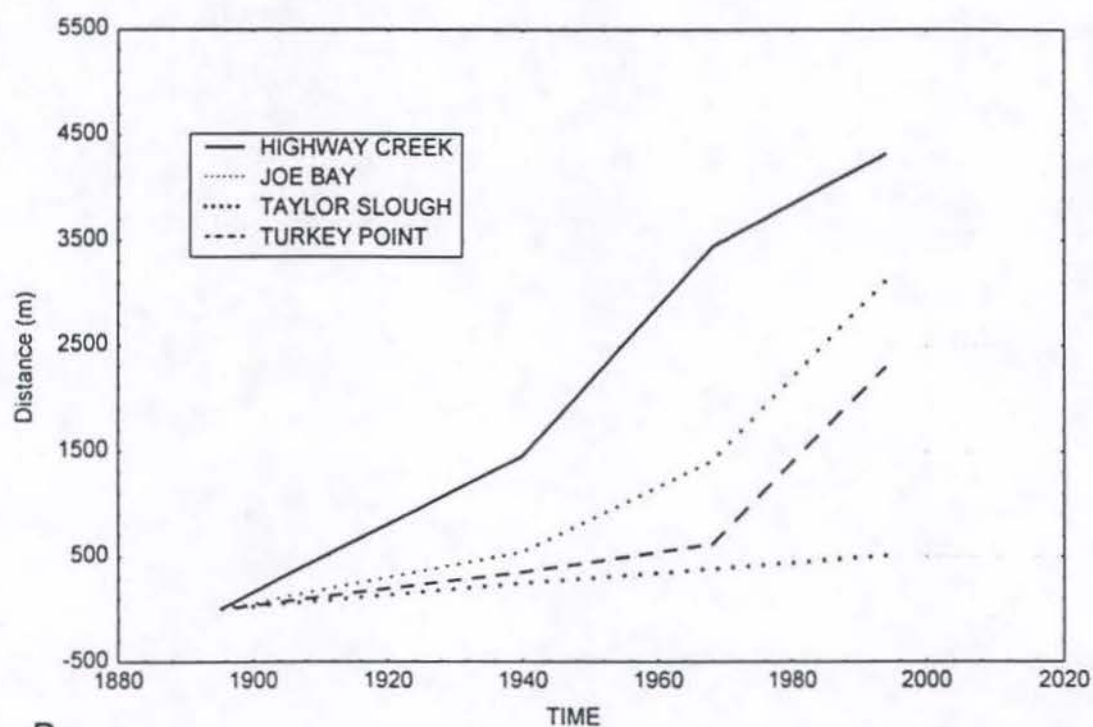


Figure 17 Salt water encroachment rates for each transect.

- a. Illustrates the change in elevation of the marine contact line with time. The change in sea level based upon Maul and Martin (1993) is also shown for comparison.
- b. Illustration of the change in distance of salt water encroachment with time.

A



B

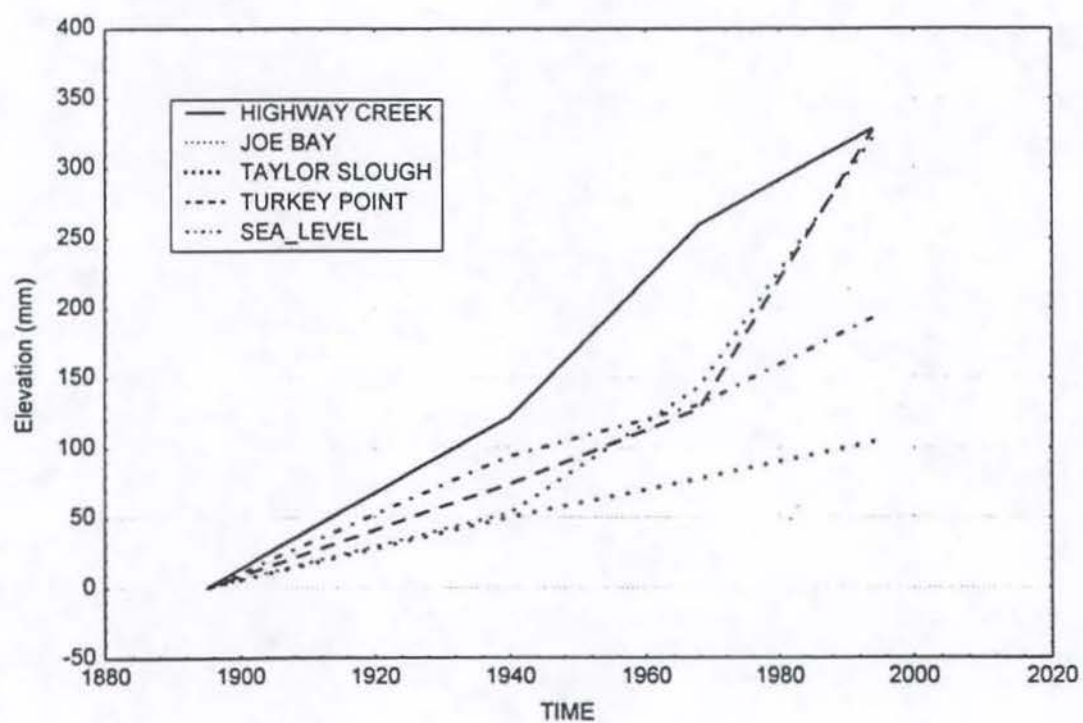
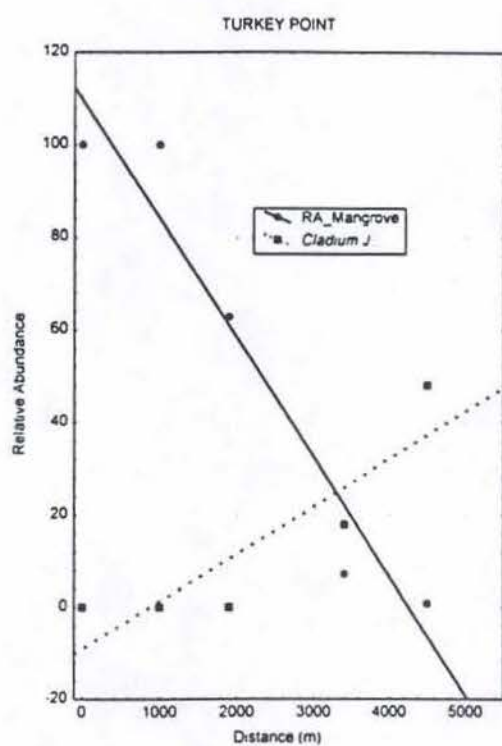


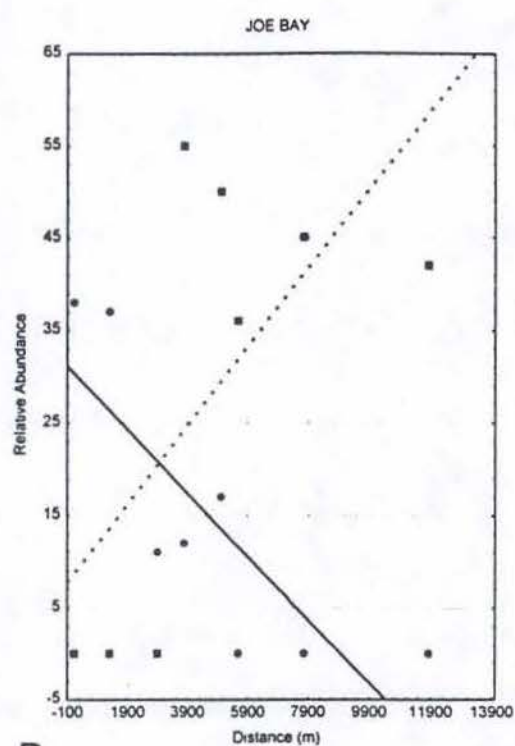
Figure 18 Comparison between the relative abundance of *Rhizophora mangle* and *Cladium jamaicense* with respect to distance from the coast

- a. Turkey Point Transect
- b. Joe Bay Transect
- c. Taylor Slough Transect
- d. Highway Creek Transect

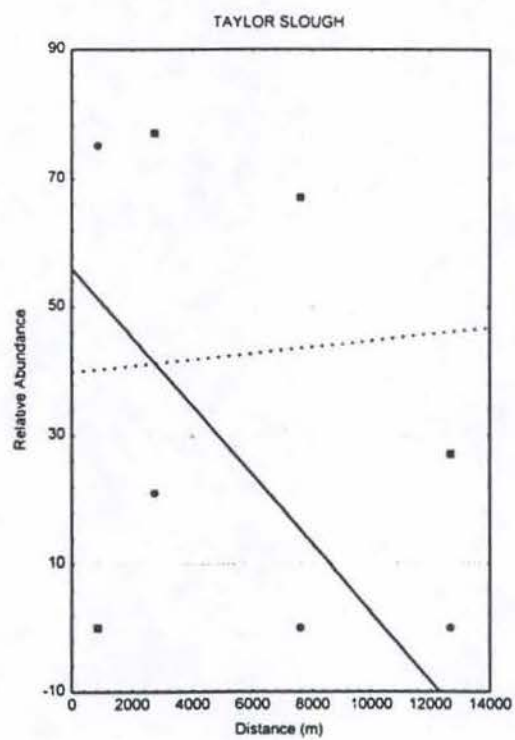
A



B



C



D

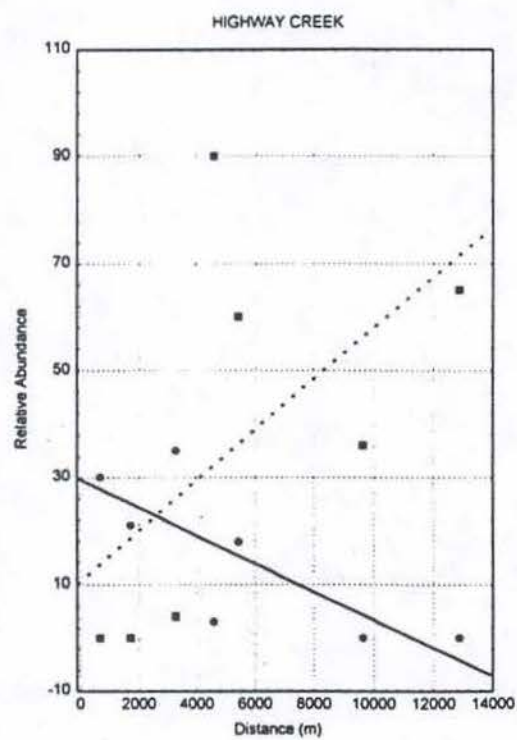


Figure 19 a Comparisons between the combined relative abundance data, from all transects, of *Rhizophora mangle* and *Cladium jamaicense* with respect to distance from the coast.

b Comparison between the combined percent mangrove and sawgrass soil constituents with respect to distance from the coast.

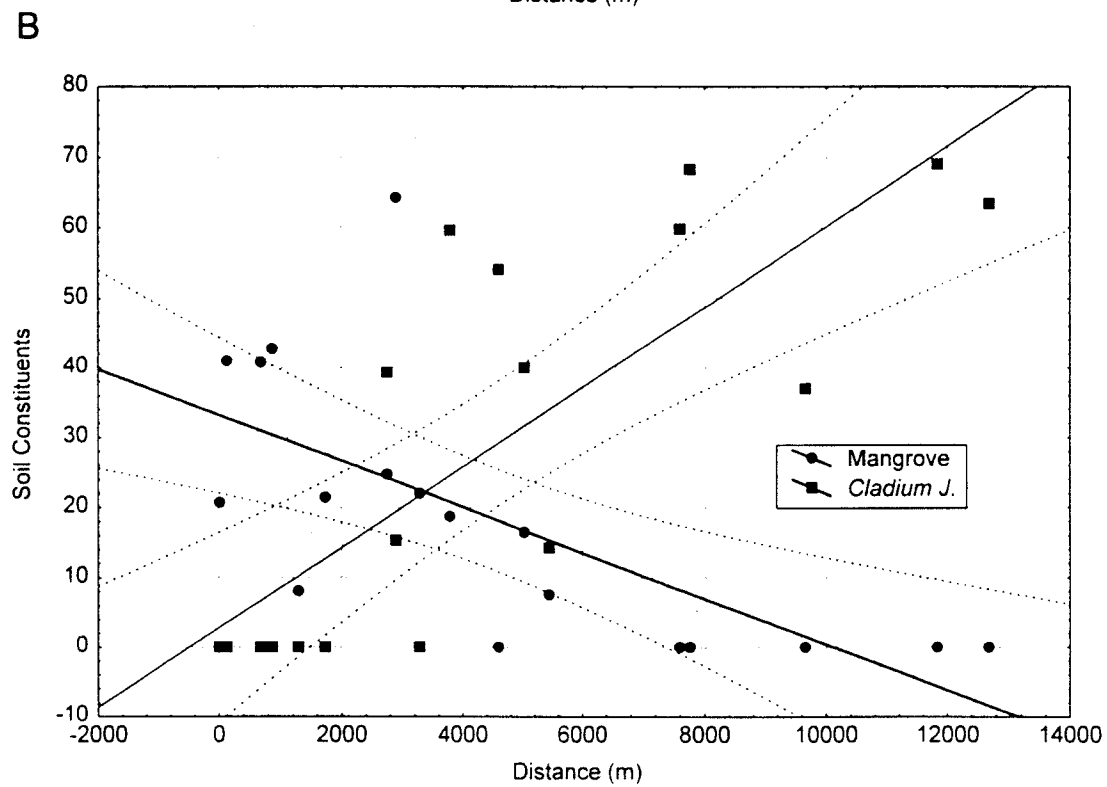
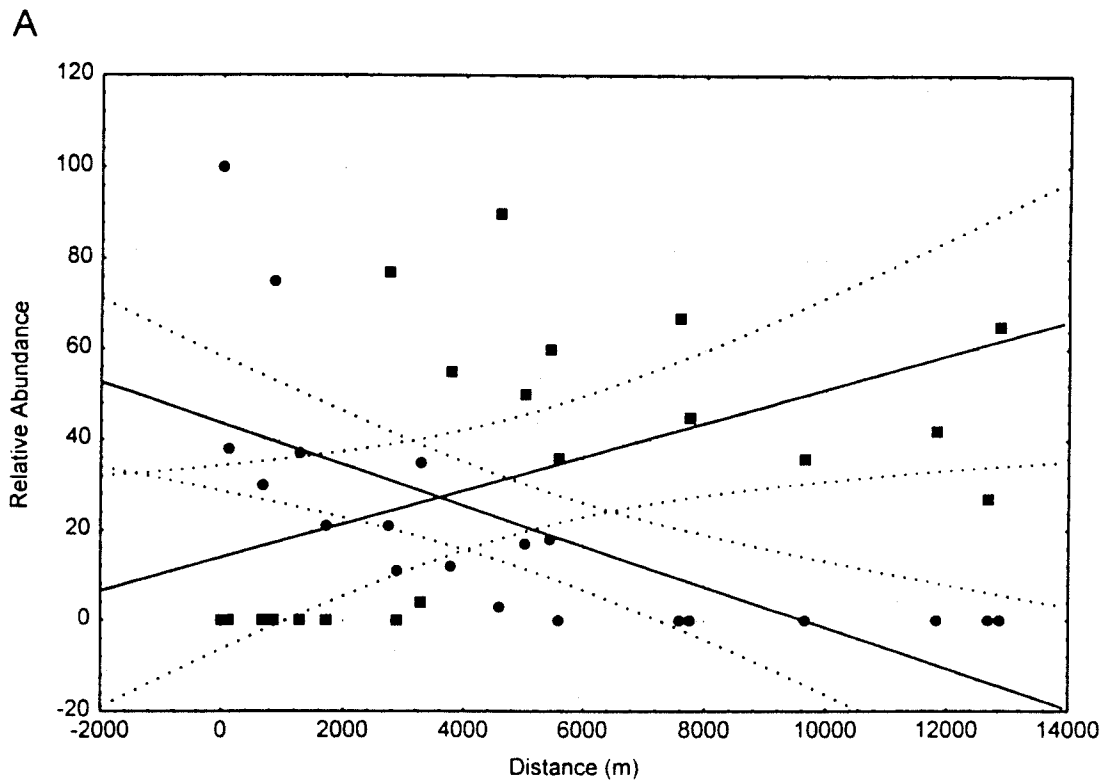
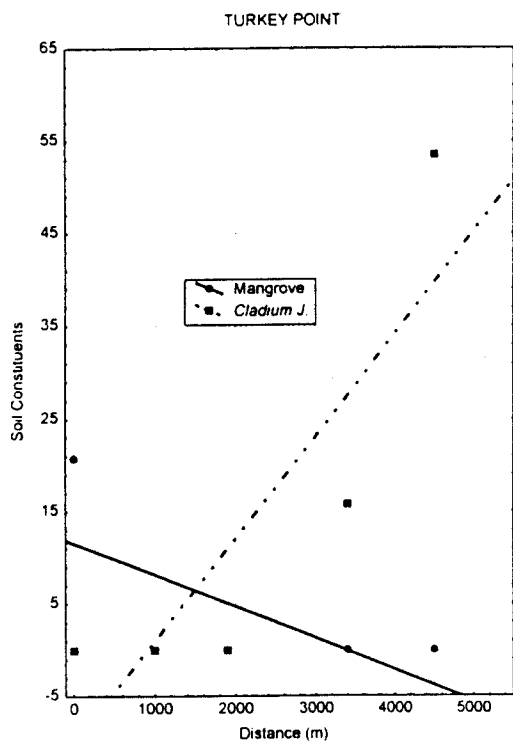


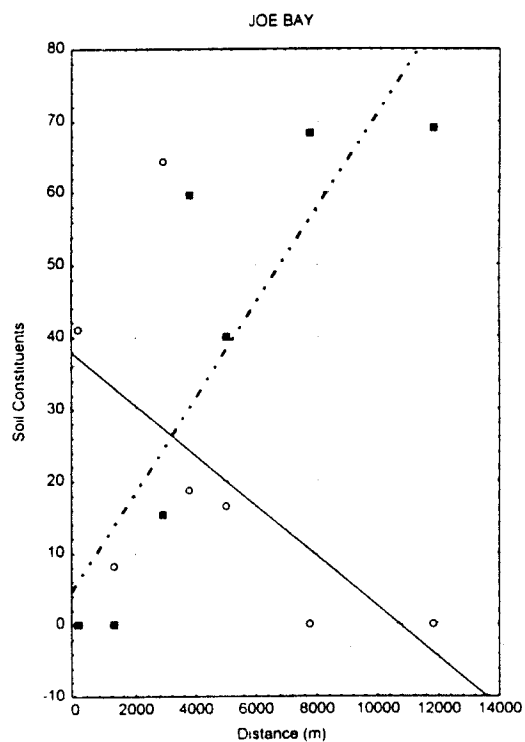
Figure 20 Comparison between the percent of *Rhizophora mangle* and *Cladium jamaicense* soil constituents with respect to distance from the coast.

- a. Turkey Point Transect
- b. Joe Bay Transect
- c. Taylor Slough Transect
- d. Highway Creek Transect

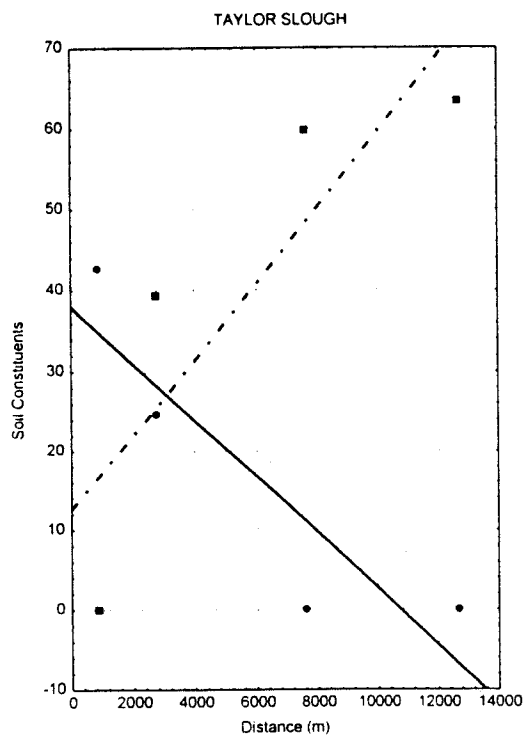
A



B



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D

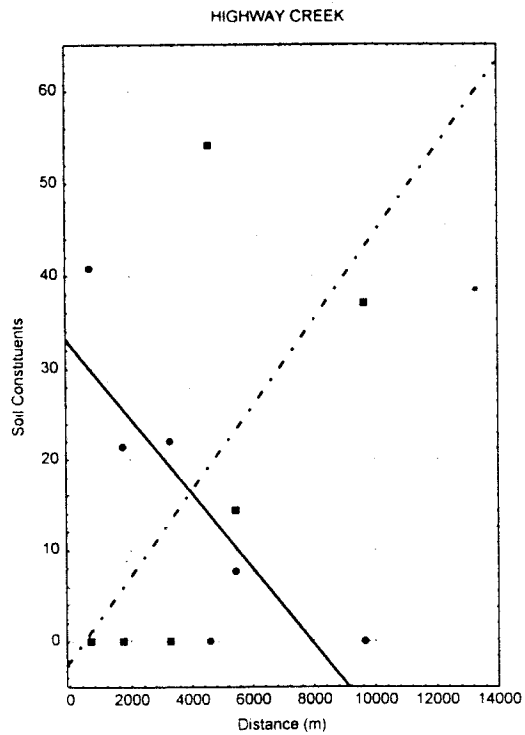
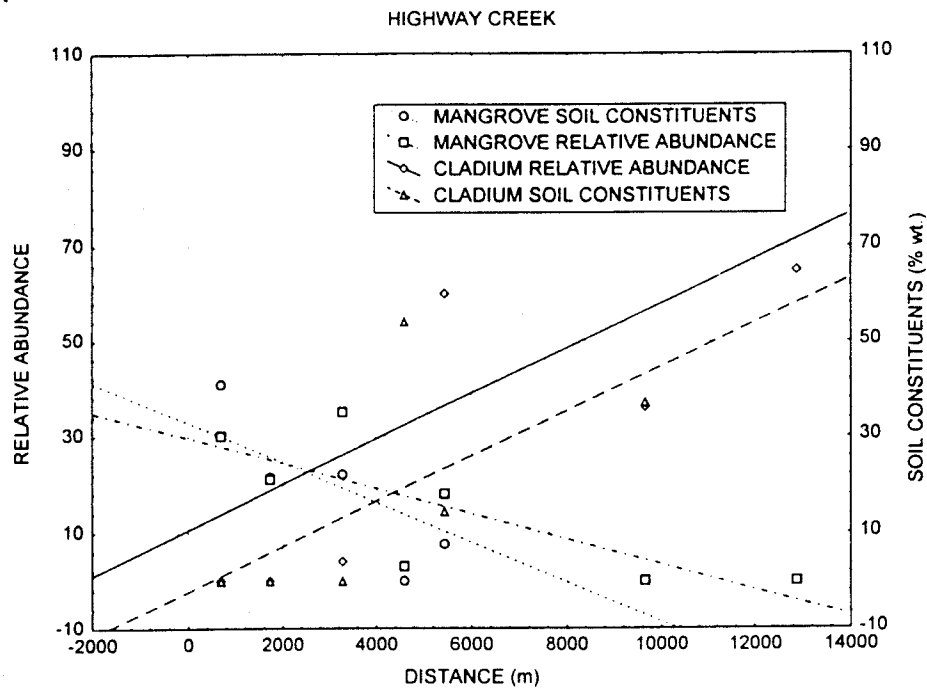


Figure 21. Graphs illustrating the relationships between mangrove and sawgrass soil constituent and plant relative abundance in respect to distance from the coast.

a. Highway Creek Transect

b. Joe Bay Transect

A



B

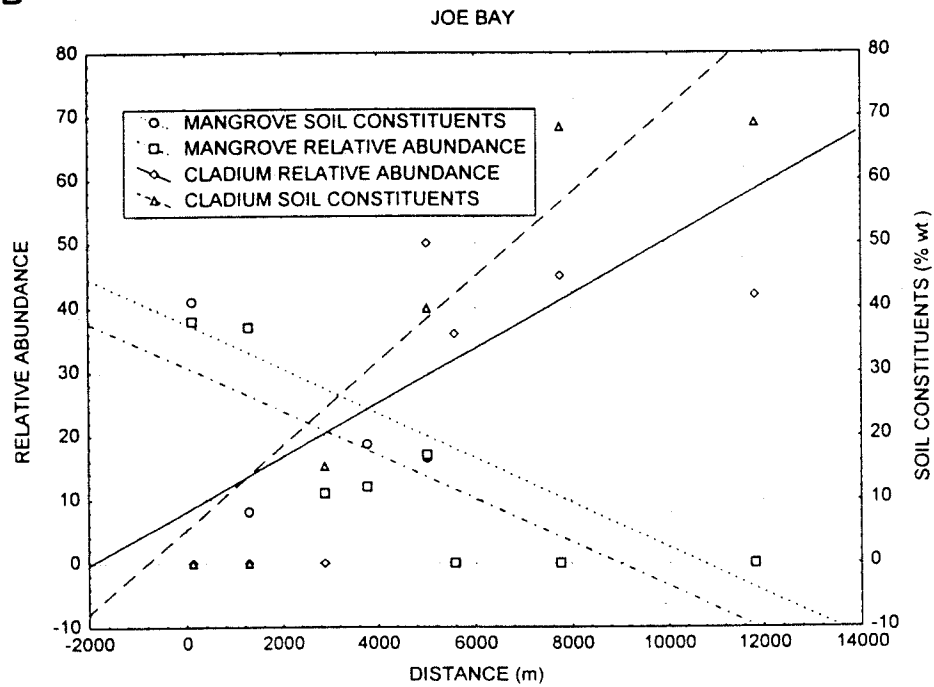


Figure 22. Coastal slopes for each transect

SITE: HC=-5.978+0.038*x+eps
SITE: JB=12.272+0.043*x+eps
SITE: TS=227.73-0.028*x+eps
SITE: TP=186.683+0.063*x+eps

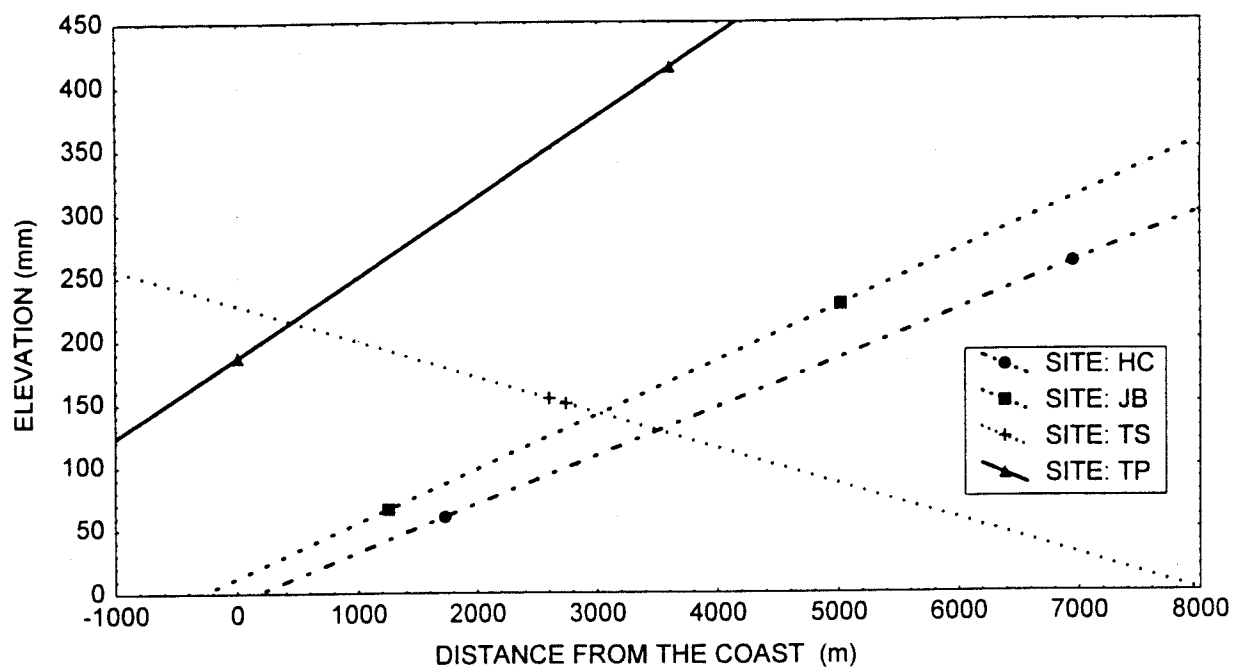


Figure 23 illustrates the relationship between coastal gradient and the change in distance of salt water encroachment during the last century. Note the relatively good correspondence of three of the four data points. The outlier, Taylor Slough Transect, does not fit the curve because of its adequate freshwater discharge which has minimized salt water encroachment in this subbasin.

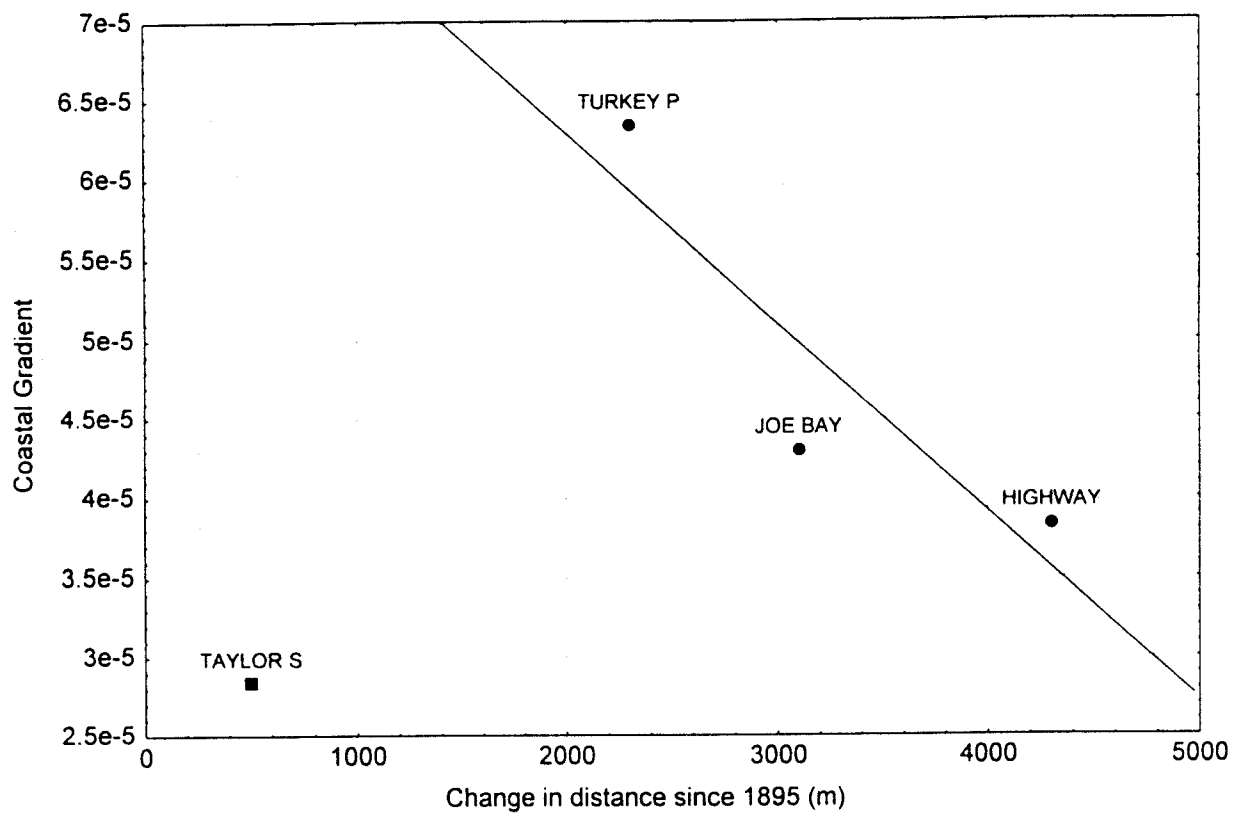
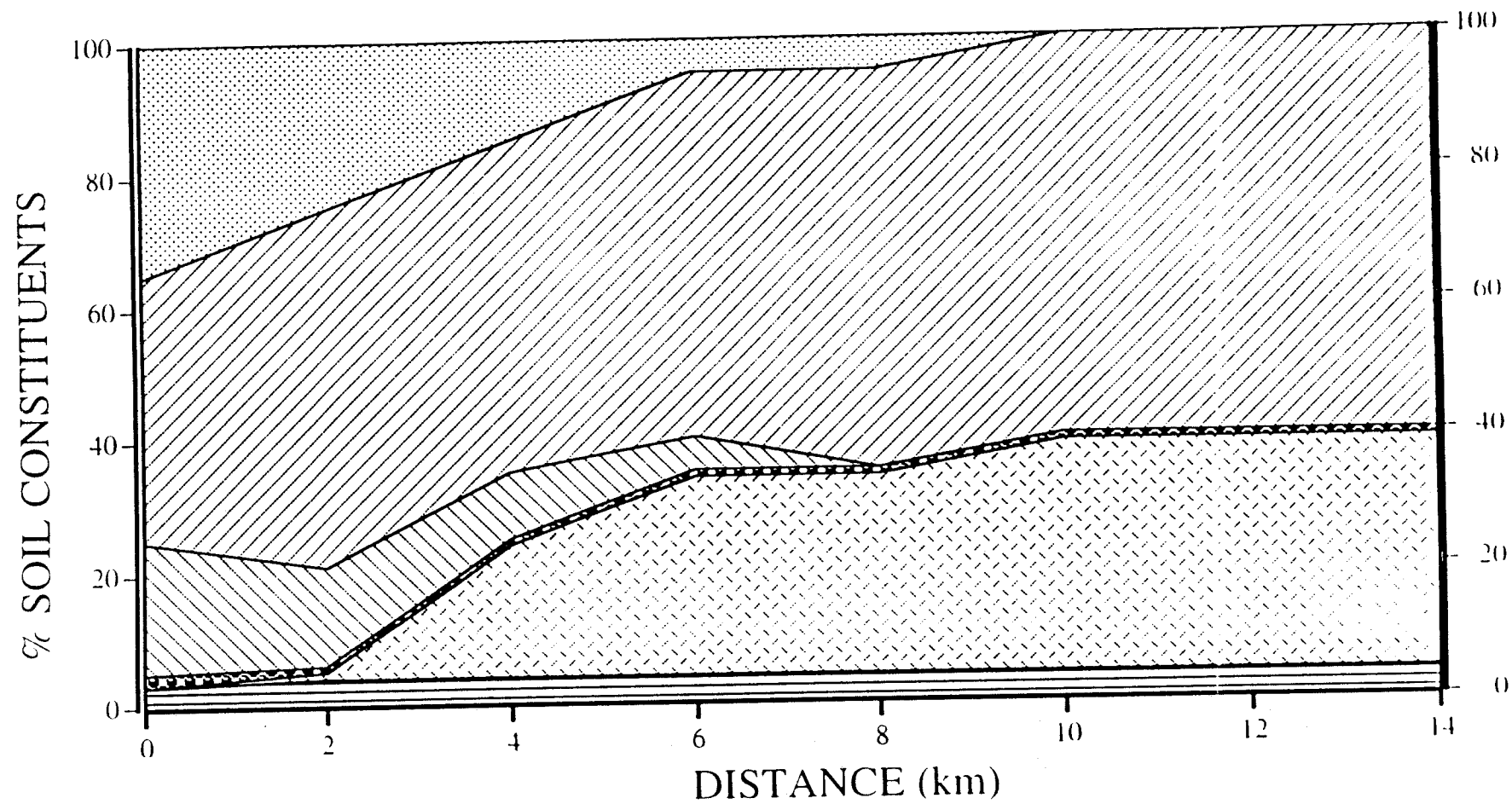


Figure 24 Box diagram illustrating the relationships between the dominant soil constituents and distance from the coast. Based upon soil constituent data from four transects (TST, JBT, HCT and TPT)



 OTHER	 CLADIUM
 MULLUSCS	 STORM MUD
 CARBONATE MUD	 MANGROVE

Figure 25 Depositional model of the SESE. The dashed box indicates the boundary of the SESE ecosystem. External components include global sea level rise, tides, canal construction, rainfall and runoff from adjacent basins or from headwaters. The arrows indicate how changing sea level and canal construction interact with the other components to changes the salinity and hydrology regimes. The vegetation component is subdivided into individual vegetative components based upon their salinity tolerances. The contribution of the different soil processes to soil accretion are indicated by arrows numbered arrows (1 through 8)

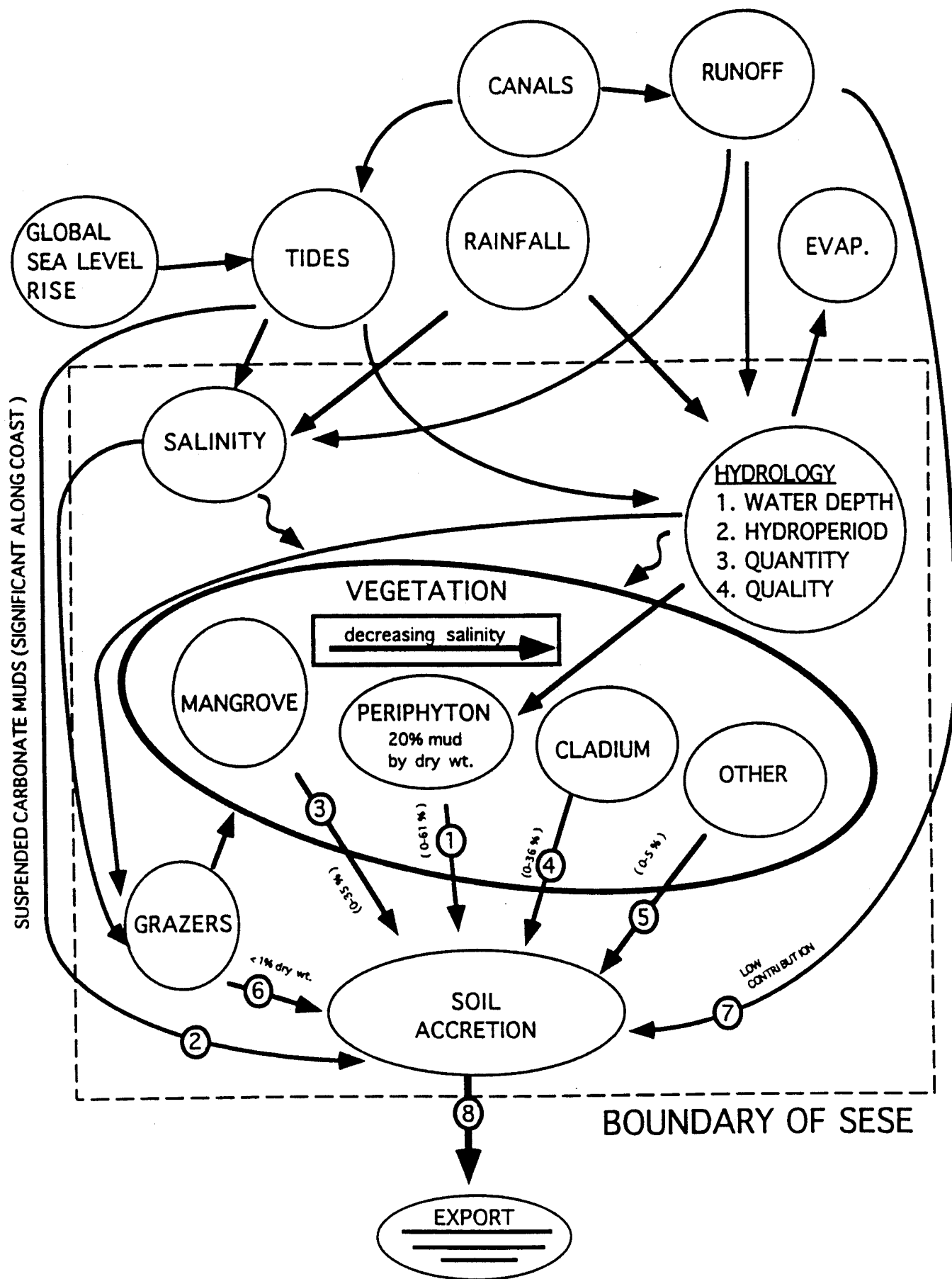
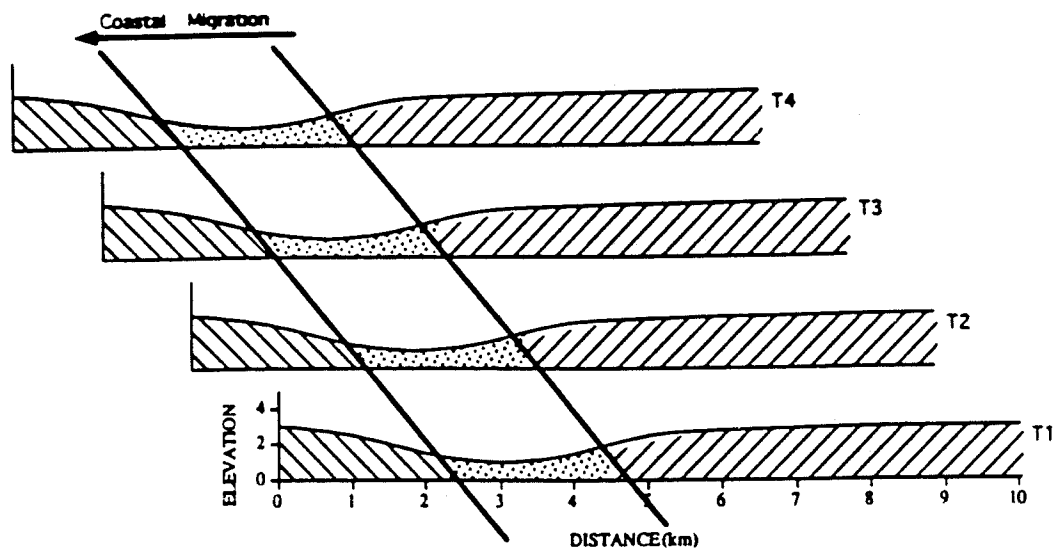


Figure 26 Model of coastal wetland responses under different salt water encroachment scenarios.

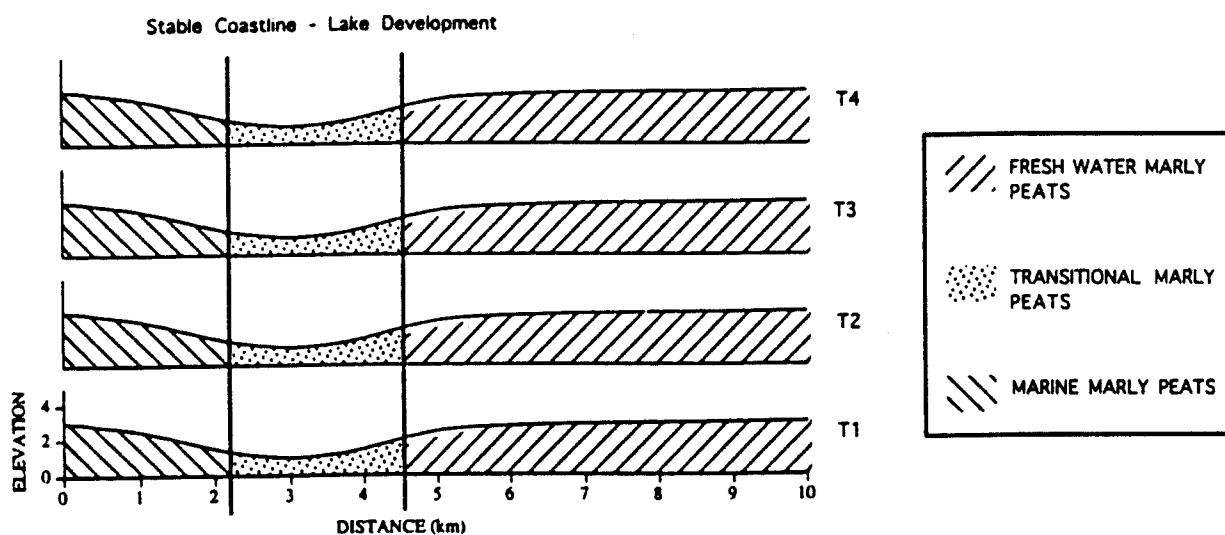
A. Progradation or a regressive sequence develops under conditions of falling sea level or during periods of ample freshwater discharge contributing sediments or encouraging coastal wetland productivity resulting in sedimentation building (coastal migration) outward into the marine environment.

B. Stable coastline results when the rate of sea level rise is minimal, coastal soils are accreting at the same rate as sea level rise, or when the effects of sea level rise are nullified by ample freshwater discharge.

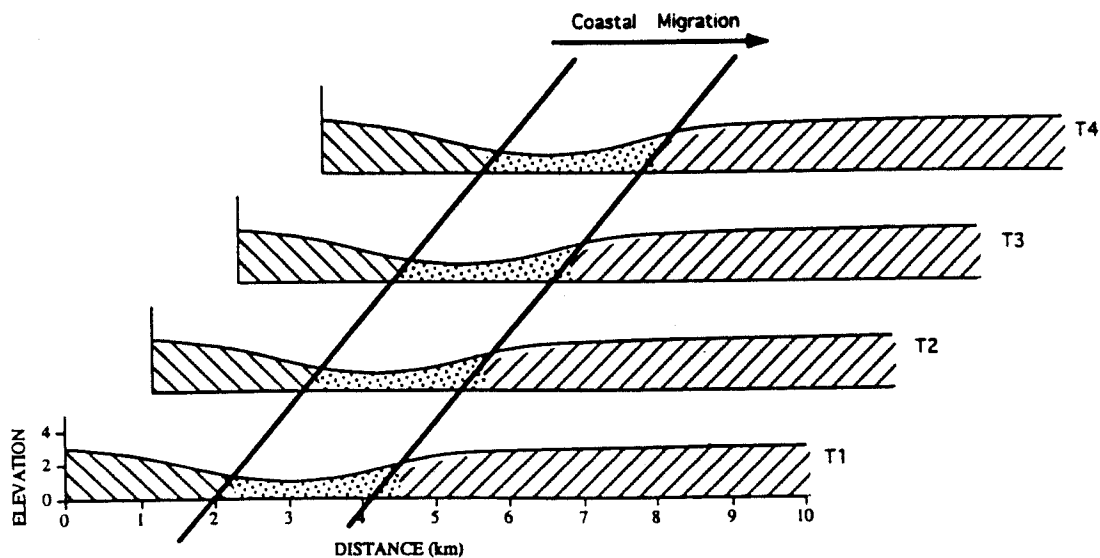
C. Transgressive stratigraphic sequence is produced when coastal migration is landward as salt water encroachment continues.



A. Progradation: regressive sequence



B. Equilibrium



C. Transgress sequence

TABLE 1. Summary of field station information, including location, elevation, soil depth, distance from the coast, salinity index, invertebrate and vegetation characteristics.

NAME	ABRV	LONG	LAT	elev. (mm)	dtb (cm)	dist (m)	bulk den	% org	S.I.	#1moll	peri BIO (g/m2)	dominant plant species				tot mang
												#1plant	#2plant	#3plant	#4plant	
N upper highway ck	NUHC	80 2840	25 1610	205*	112	4592	0.127	22.4	0	crenfla*	nd	clajam90	elecel6	rhiman3		3
N upper joe bay	NUJB	80 3196	25 1700	228*	101	5019	0.126	53.7	0	crenfla*	nd	clajam50	elecel21	rhiman17		17
coastal joe bay	CJB	80 3199	25 1438	450*	107	122	0.184	22.4	3.1	cerith	nd	elecel58	rhiman38	rupmar2		38
coastal highway ck	CHC	80 2739	25 1468	420*	120+	678	0.32	11.8	2.67	pyroplat	nd	elecel65	rhiman24	conere6		30
coastal turkey point	CTP	80 3705	25 3170	187	123	5	nd	11.7	3.45	batmin	nd	aviger60	rhiman40			100
turkey point-2	TP-2/TKYEST	80 3817	25 3375	233	103	999					nd	nd				nd
turkey point central	TP-1/TKYE	80 2223	25 1902	305	89	1900					nd	rhiman57	rupmar30	disspi7	aviger6	63
turkey point int	TP-3/TKYINT	80 3778	25 3306	409	60	3400					nd	disspi38	junroe37	lagrac18	conere4	22
turkey point west	TPW/TKYW	80 3903	25 3492	470	83	4500					nd	clajam48	elecel34	utrfo12	junroe5	0
taylor slough interior	TSI/UTS	80 40 54	25 12 30	150*	116	2740	0.187	83.4	0	0	nd	clajam77	conere18	rhiman3		21
taylor slough coast	CTS/LTS	80 4016	25 1263	200*	130	860	0.123	30.8	2.67	crenfla	nd	rhiman66	elecel17	lagrac9	utrpur6	75
ever 7	A	80 5428	25 3097	305*	63	7760	0.136	8.5	1	physa	270	clajam45	elecel28	rhyspp8	utrpur8	0
EVER 4	B	80 5453	25 3433	610	33	11824	0.12	22.6	1	biomhav	133	elecel48	clajam42	schnig3	casfil3	0
ujb	C	80 5322	25 2638	94*	60	2882	0.154	20.1	2.15	crenfla	132	utrpur58	elecel31	rhiman11		11
EP-9R	D	80 5547	25 2719	186	105	3779	0.12	25.9	1	plansca	331	clajam55	elecel31	rhiman12		12
EVER8	E	80 4789	25 3461	345	84	12875					123	clajam65	elecel34			0
EVER3	F	80 5067	25 3453	589	60	15445					305	clajam48	rhyspp30	casfil10	elecel5	0
EP11	G	80 4919	25 2731	275	111	3000					115	nd				nd
EP10	H	80 5272	25 2731	221	83	4494					277	elecel66	rhiman32	clajam1		32
EVER6	I	80 5119	25 2981	140	59	8949	0.14	nd	1	physa	214	clajam86	elecel7	utrpur7		0
EVER2B	J	80 4761	25 3153	300*	84	9650	0.208	16.6	1	physa	102	clajam36	utrpur33	elecel31		0
EP12R	K	80 4453	25 2739	272	145	3614					286	elecel40	utrpur34	clajam19	rhiman7	7
GWSW	L	80 5067	25 2794	277	93	8094					175	clajam47	rhiman25	utrpur24	elecel6	25
UHC	M	80 4572	25 2665	150*		3279	0.272	15.6	2.33	littmon	138	rhiman35	elecel30	utrpur30	clajam4	35
EVER5B	N	80 5706	25 2900		71	5581					265	clajam36	elecel27	rhyspp11	utrpur10	0
CT50R	O	80 5214	25 3136	362	73	10171					97	clajam61	elecel32	criame3		0
EVER1	P	80 4300	25 3294	459	74	7462					172	clajam76	rhiman15	elecel5		15
LHC	Q	80 4547	25 2542	60*	34	1724	0.063	11	2	littmon	131	elecel79	rhiman21	utrfo1		21
LJB	R	80 5319	25 2500	66	78	1287	0.067	19	2.2	pyropla	22	elecel63	rhiman37			37
E146	S	80 6664	25 2522	357*	52	7594	0.204	10.8	1	physa	243	clajam61	utrpur26	elecel6		0
TSH	T	80 6311	25 3117	390	16	12681	0.288	14.6	1	physa	106	elecel30	clajam27	bacmon18	utrpur11	0
G1251	U	80 5686	25 3228	575	28	9345					96	clajam62	rhyspp22	propal5		0
10/10/94=1R	V	80 4531	25 2875	243*	54	5437	0.153	12.4	3.1	hydrob/cre	254	clajam60	elecel22	rhiman18		18
1-1-2	na	80.4489	25 2794	nd	134	4385	0.16	11.3	1	physa	nd	clajam43	elecel26	rhiman22	utrpu7	22

NAME	ABRV											dominant plant species				
		LONG	LAT	elev (mm)	dtb (cm)	dist (m)	bulk den	% org	S l	#1moll	BIO (g/m2)	#1plant	#2plant	#3plant	#4plant	tot mang
t-1-3	na	80 4483	25 2711	nd	132	3499	0.373	12.8	0	crenfla*	nd	rhimaqn48	elecel35	clajam10	utrfo13	48
t-1-4	na	80 4478	25 2628	nd	141	2490	0.264	15.7	2.8	crenfla	nd	elecel61	rhiman13	limcas5	conere4	20
t-1-5	na	80 4475	25 2544	nd	170	1532	0.243	18.7	2.3	cerith	nd	elecel66	rhiman18	conere11		29
t-2-2	na	80 4861	25 2772	nd	106	5922	0.082	48.9	1	helisom	nd	clajam90	utrfo17	rhiman2		2
t-2-3	na	80 4853	25 2689	nd	112	4993	0.185	18.6	0	0	nd	clajam61	rhiman30	elecel4		30
t-2-4	na	80 4853	25 2606	nd	124	4071	0.512	6.4	1	helisom	nd	rhiman61	clajam35	elecel4		61
t-2-5	na	80 4844	25 2522	nd	109	3105	0.778	7.6	2.4	crenfla	nd	elecel40	rhiman39	clajam9	utrpup9	39
t-2-6	na	80 4839	25 2442	nd	74	2212	0.74	4.7	1.38	littmon	nd	utrpur50	elecel45	rhiman5		5
t-3-1	na	80 5242	25 2836	nd	72	6813	0.32	14.4	1	helis	nd	clajam58	rhiman22	elecel18		22
t-3-2	na	80 5233	25 2711	nd	101	5528	0.432	25.2	1.58	helis	nd	elecel77	rhiman21	clajam2		21
t-3-3	na	80 5228	25 2669	nd	70	4966	0.391	43.9	1.5	littmon	nd	elecel44	utrpur29	rhiman25		25
t-3-4	na	80 5222	25 2586	nd	57	4071	0.238	18.6	1.81	littmon	nd	utrpur43	elecel38	rhiman18		18
t-3-5	na	80 5214	25 2503	nd	97	3174	0.522	9.8	2.6	pyropla	nd	utrpur32	utrfo130	elecel19	rhiman12	12
t-3-6	na	80 5208	25 2419	nd	101	2250	0.465	8.4	2.43	littmon	nd	rhiman33	elecel24	rupmar20		33
t-4-1	na	80 5594	25 2853	nd	70	4865	0.18	19.2	1	physa	nd	clajam67	elecel26	utrpur5		0
t-4-2	na	80 5589	25 2769	nd	69	3837	0.256	43.6	1	helisom	nd	clajam71	elecel23	rhiman3		3
t-4-3	na	80 5581	25 2689	nd	81	2944	0.306	19.6	1.5	littmon	nd	elecel77	clajam10	rhiman7		7
t-4-4	na	80 5572	25 2606	nd	83	2014	0.49	14.1	2.75	crenfla	nd	elecel83	rupmar8	rhiman7		7
t-4-5	na	80 5564	25 2522	nd	94	1090	0.302	24.5	3	crenfla	nd	rupmar45	rhiman21	elecel19	utrfo17	21
t-5-1	na	80 5961	25 2853	nd	52	6953	0.416	11.8	1	helis	nd	clajam45	rhyspp18	panten11	elecel6	0
t-5-2	na	80 5953	25 2769	nd	38	6056	0.45	12.2	0	0	nd	elecel68	clajam25	rhiman7		7
t-5-3	na	80 5947	25 2686	nd	76	5097	392	20.6	0	crebfla*	nd	elecel75	clajam10	rhiman7		7
t-5-4	na	80 5942	25 2603	nd	79	4205	327	12.8	2.13	littmon	nd	elecel68	rhiman22	utrpur2		22
t-5-5	na	80 5936	25 2519	nd	69	3273	0.42	12.3	3.36	crenfla	nd	elecel61	rupmar31	rhiman6		6
t-5-6	na	80 5928	25 2439	nd	90	2283	0.425	13.7	2.38	crenfla	nd	elec36	utrpur24	rupmar17	rhiman14	14

NOTES

1 crenfla*

only mollusk present at these sites, but less than three specimens

2 sal

0 in cases with less than three specimens per 1cm interval

Table 4 Salinity rankings used to weight mollusk species abundances for calculation of salinity index. Rank 1 = freshwater, 1.5 = freshwater species with tolerance for low salinity, 2 = brackish species, 2.5 = brackish species that tolerate marine conditions, 3.0 = restricted marine with toleration for lower salinity, 4.0 = marine species with a tolerance for low salinity, and 5.0 = marine species. Based on descriptions in Ladd, 1957; Tabb and Manning, 1961; Moore, 1964; Turney and Perkins, 1972; Abbott, 1975; and Thompson, 1984.

Species no.	Species	Salinity rank
1	<i>Biomphalaria havanensis</i>	1
2	<i>Cylindrella</i> spp.	1
3	<i>Laevapex peninsulae</i>	1
4	<i>Physella cubensis</i>	1
5	<i>Planorbella scalaris</i>	1
6	<i>Polygyra</i> spp.	1
7	<i>Pomacea paludosa</i>	1
8	<i>Littoridinops monoroensis</i>	1.5
9	<i>Pyrogophorus platyrachis</i>	2.5
10	<i>Cerithidea beattyi</i>	3
11	<i>Baillaria minima</i>	4
12	<i>Brachidontes exustus</i>	4
13	<i>Cyrenoida floridana</i>	4
14	<i>Littorina angulifera</i>	4
15	<i>Melampus coffeus</i>	4
16	<i>Terebra dislocata</i>	4.5
17	<i>Turbonilla</i> spp.	4.5
18	<i>Alvania</i> spp.	5
19	<i>Anomalocardia auberiana</i>	5
20	<i>Bulla striata</i>	5
21	<i>Caecum pulchellum</i>	5
22	<i>Carditas</i> spp.	5
23	<i>Chione cancellata</i>	5
24	<i>Chione latilirata</i>	5
25	<i>Corbula contracta</i>	5
26	<i>Lima pellucida</i>	5
27	<i>Marginella</i> spp.	5
28	<i>Meioceras nitidum</i>	5
29	<i>Retusa sulcata</i>	5
30	<i>Rissoina catesbyana</i>	5
31	<i>Strigilla canaria</i>	5
32	<i>Tricolia bella</i>	5

Table 5. Salinity index for soil cores

DEPTH (cm)	Plot Depth	TSH	E146	UTS	LTS	Ever4	Ever7	NUJB	EP9r	UJB	LJB	CJB	Ever2b	EP1r	NUHC	UHC	LHC	CHC	TPW	TPINT	TPE	TPEE	CTP	1a31e	1b31e
0-1	1	1.00	.00	.00	.00	.00	1.00	.00	.00	.00	.00	1.92	.00	3.20	.00	1.50	2.00	.00		.00			3.79	4.00	2.75
1.1-2.1	2	1.00	1.50	.00	.00	.00	.00	.00	.00	4.00	.00	3.10	.00	3.06	4.00	3.00	1.50	2.67		.00			3.11	3.55	2.50
2.2-3.2	3	1.00	1.00	.00	2.67	1.00	1.00	.00	.00	4.00	.00	2.14	.00	3.09	.00	4.00	2.06	.00		.00			2.84	3.12	2.56
3.3-4.3	4	1.00	1.00	.00	1.50	1.00	1.00	.00	.00	.00	.00	3.28	.00	3.08	.00	1.00	1.50	2.50		1.00			2.61	2.51	2.14
4.4-5.4	5	1.11	1.00	.00	1.81	.00	1.20	4.00	1.00	.00	2.20	3.53	1.00	3.07	.00	.00	1.86	2.83		1.30			2.45	2.45	2.69
5.5-6.5	6	1.14	1.00	.00	2.08	1.25	1.17	.00	1.33	2.15	2.19	3.11	.00	3.10	.00	3.17	2.40	3.08		.00			2.38	2.21	2.54
6.6-7.6	7	1.00	1.00	.00	1.50	1.13	1.30	.00	1.61	3.17	2.41	2.61	1.25	3.10	.00	1.25	1.80	3.04		.00			2.32	1.50	2.79
7.7-8.7	8	1.11	1.00	.00	2.50	1.29	1.28	.00	1.23	2.04	2.52	1.38	1.25	2.76	4.00	1.70	3.00	3.75		1.00			1.70	1.50	2.45
8.8-9.8	9	1.00	1.11	.00	1.70	1.19	1.29	.00	1.36	1.76	2.15	1.95	1.25	2.58	.00	1.29	2.22	3.73		1.00			1.85	.00	2.09
9.9-10.9	10	1.13	1.00	.00	2.45	1.13	1.24	1.00	1.15	1.27	2.54	2.03	1.25	3.16	.00	1.25	2.40	3.21		1.28			1.50	.00	2.04
11.0-12.0	12	1.10	1.21	.00	2.13	1.47	1.24	.00	1.18	1.07	2.00	1.57	1.64	.00	4.00	2.00	2.37	2.18		1.27			1.78	2.25	1.69
12.1-13.1	13	1.00	1.00	.00	2.17	1.23	1.31	1.00	1.13	1.17	2.04	1.30	1.50	.00	2.50	1.62	2.16	2.11		1.24			1.79	2.00	1.98
13.2-14.2	14	1.13	1.09	.00	1.60	1.19	1.29	1.00	1.10	1.25	2.46	.00	1.33	.00	1.00	1.50	2.20	2.36		1.17			1.50	2.08	1.82
14.3-15.3	15	1.00	1.06	.00	2.03	1.19	1.45	1.00	1.13	1.29	3.13	1.29	1.38	.00	1.50	2.15	1.89	1.89		1.50			1.78	2.28	2.15
15.4-16.4	16	.00	1.19	.00	1.75	1.30	1.25	.00	1.22	1.00	3.25	1.45	1.50	.00	.00	1.79	1.96	2.43		1.19			1.52	1.75	1.64
16.5-17.5	17	1.00	1.10	.00	.00	1.31	1.31	1.25	1.29	1.21	1.92	1.00	2.83	.00	1.00	1.44	1.90	1.74		1.06			1.53	2.02	1.91
17.6-18.6	18	.00	1.05	.00	.00	1.26	.00	1.17	1.07	1.25	1.72	1.33	1.50	.00	2.13	1.53	1.99	2.33		1.21			1.67	2.33	1.71
18.7-19.7	19	.00	1.03	.00	1.67	1.25	1.45	1.25	1.40	1.31	2.14	1.27	2.31	.00	.00	1.39	1.73	2.42		1.35			1.52	1.74	1.92
19.8-20.8	20	1.50	1.00	.00	1.60	1.27	1.30	1.13	1.36	1.17	1.75	1.00	1.50	.00	1.00	1.42	1.72	2.40		1.08			1.52	1.81	1.56
20.9-21.9	21	.00	1.50	.00	2.01	1.35	1.33	1.33	1.33	1.50	1.38	1.12	1.48	.00	1.13	1.20	1.67	2.34		1.38			1.25	1.67	1.45
22.0-23.0	23	.00	1.21	.00	1.61	1.23	1.32	1.19	1.29	1.13	1.50	1.00	1.50	.00	1.25	1.53	1.95	2.48		1.37			1.38	1.63	1.54
23.1-24.1	24	.00	1.13	.00	1.56	1.09	1.19	1.25	1.20	1.25	1.42	1.00	1.25		1.00	1.32	1.50	2.16		1.37			1.29	1.48	1.42
24.2-25.2	25	.00	.00	.00	1.53	1.27	1.10	1.00	1.33	1.30	1.83	1.00	1.30		1.00	1.35	1.43	2.50		1.34			1.28	1.82	1.60
25.3-26.3	26	.00	1.25	.00	1.67	1.25	1.31	1.17	1.27	1.40	1.40	1.00	1.43		1.00	1.38	1.39	2.27		1.44			1.42	1.74	1.54
26.4-27.4	27	.00	1.27	.00	1.92	1.19	1.25	1.40	1.20	1.20	1.32	1.00	1.44		1.06	1.27	1.38	2.22		1.38			1.39	1.61	1.42
27.5-28.5	28	.00	1.17	.00	1.75	1.17	.00	1.21	1.38	1.28	1.35	1.00	1.38		1.14	1.38	1.47	.00		1.41			1.50	1.52	1.51
28.6-29.6	29	.00	1.24	.00	1.67	1.14	.00	1.25	1.34	1.26	1.11	1.30	1.42		1.25	1.27	1.52	.00		1.34			1.48	1.58	1.45
30.7-31.7	31	.00	1.26	.00	1.68	1.50	.00	1.17	1.10	1.22	1.46	1.00	1.33		1.00	1.25	1.44	.00		1.28			1.32	1.59	1.46
31.8-32.8	32	.00	1.24	.00	1.50	1.00	.00	.00	1.33	1.22	1.44	1.00	1.50		1.50	1.43	1.57	.00		1.31			1.33	.00	1.46
32.9-33.9	33	.00	1.31	.00	1.42	.00	.00	.00	1.33	1.17	1.06	1.25	1.42		1.00	1.33	1.30	.00		1.27			1.39	.00	1.47
34.0-35.0	35	.00	1.25	.00	1.80	.00	.00	.00	1.33	1.26	1.25	1.00	1.31		.00	1.20	1.36	.00		.00			.00	.00	1.49
35.1-36.1	36	.00	1.39	.00	1.50	.00	.00	.00	1.40	1.24	1.17	1.00	1.21		.00	1.25	1.44	.00		.00			.00	.00	.00
36.2-37.2	37	.00	1.33	.00	1.67	.00	.00	.00	1.25	1.23	1.25	1.00	1.33		.00	1.38	1.50	.00		.00			.00	.00	.00
37.3-38.3	38	.00	1.33	.00	1.66	.00	.00	.00	1.25	1.23	.00	1.00	2.00		.00	1.37	1.50	.00		.00			.00	.00	.00
38.4-39.4	39	.00	1.27	.00	1.94	.00	.00	.00	1.29	1.25	.00	1.00	1.31		.00	1.36	1.28	.00		.00			.00	.00	.00
39.5-40.5	40	.00	1.22	.00	1.60	.00	.00	.00	1.25	1.25	.00	1.19	1.28		.00	1.25	1.44	.00		.00			.00	.00	.00
40.6-41.6	41	.00	1.23	.00	1.88	.00	.00	.00	.00	1.22	.00	1.00	.00		.00	1.31	1.20	.00		.00			.00	.00	.00
41.7-42.7	42	.00	.00	.00	1.64	.00	.00	.00	.00	1.32	.00	1.00	.00		.00	1.36	.00	.00		.00			.00	.00	.00
42.8-43.8	43	.00	.00	.00	1.97	.00	.00	.00	.00	1.21	.00	1.00	.00		.00	.00	.00	.00		.00			.00	.00	.00
43.9-44.9	44	.00	.00	.00	1.69	.00	.00	.00	.00	.00	.00	1.00	.00		.00	.00	.00	.00		.00			.00	.00	.00
45.0-46.0	45			.00	.00		.00	.00	.00	.00	.00	.00	.00		.00	.00	.00	.00							.00