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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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DOCUMENT ONE

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

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ABSTRACT

Marsh and adjacent tree island vegetation were examined in the Southeastern Saline Everglades (SESE), a broad zone between the Atlantic Coastal Ridge and the Florida and Biscayne Bay shorelines in SE Florida. The objective was to detect changes in the coastal gradient that had taken place since earlier descriptive studies by Egler (1952) and Tabb et al. (1967). Fifty-five sites were sampled in 1994 and 1995. SESE marshes were arranged in well-defined compositional zones parallel to the coast, with mangrove-dominated shrub communities near the coast giving way to graminoid-mangrove mixtures, and then sawgrass marsh. The compositional gradient was accompanied by an interiorward decrease in total aboveground biomass, and increases in leaf area index and periphyton biomass. Tree island composition also exhibited a zonal pattern along the coastal gradient, with stands dominated by salt-tolerant and tropical tree species gradually replaced by forest communities of more freshwater and temperate affinity. Since the earlier study by Egler (1952), the boundary of the mixed graminoid-mangrove and sawgrass communities had shifted inland by as much as 3.3 km. Moreover, the interior boundary of a low-productivity zone appearing white on both B&W and CIR photos had moved inland by an average of 1.5 km. A smaller shift in this "white zone" was observed in an area receiving fresh water overflow through gaps in one of the SESE canals, while greater movement had occurred in areas cut off from upstream water sources by roads or levees. Since the Tabb et al. (1967) study, patterns of change in the frequency of *Cladium jamaicense* and *Eleocharis cellulosa* in the marsh, and in tree island species composition were also consistent with historical differences in access to fresh water sources. These large scale vegetation dynamics are apparently the combined result of sea level rise --- approximately 10 cm since 1940 --- and the side effects of water management in the South Dade Conveyance system

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

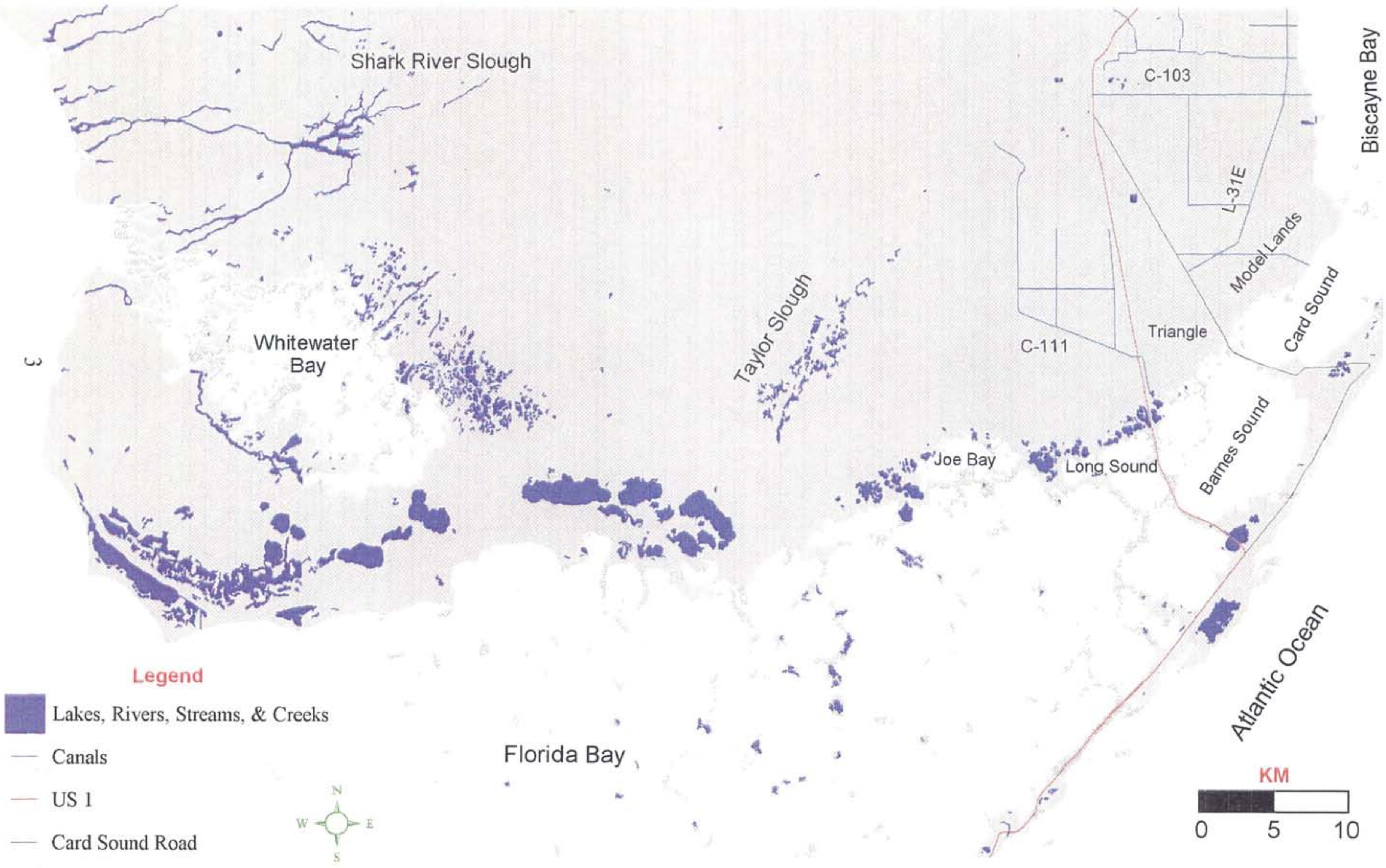
Nearly a half-century ago, Dr. Frank Egler described the vegetation of the area south and east of the Miami Rock Ridge in southernmost peninsular Florida, noting a conspicuous coastal zonation within the area he called "the Southeast Saline Everglades" (Egler 1952). Egler's description was based on 1938 and 1940 aerial photographs, and on field work undertaken in 1940 through 1948. He described the vegetation pattern in the coastal Everglades at the time of his study as "fossil", responding only slowly to a rapidly changing environment that included rising sea level, decline in the level of the surface freshwater aquifer, sharp alterations in fire regime, and a range of anthropogenic modifications to natural drainage patterns. Egler documented several examples of local vegetation change over the period of his study, including the invasion of the coastal halophyte red mangrove *((Rhizophora mangle)* into freshwater wetlands far from the coast. He anticipated continued change in community composition and structure, e.g., an interiorward shift in several vegetation zones and a loss of forest patches (tree islands) in fire-prone areas. Egler's work preceded the connection of the South Dade Conveyance system to the sea via the C-111 canal. Completed in the late 1960's, this project allowed more effective drainage of the agricultural and urban lands of southern Dade County during periods of high water, further altering the distribution of fresh water delivery to the wetland communities. Five decades after Egler's ecological studies and thirty years after completion of the C-111 canal, we reexamined the Southeast Saline Everglades. Our overall objectives were to determine recent changes in the coastal vegetation gradient, and to describe relationships between current vegetation patterns and known environmental or geographic variables. Documentation of temporal change in Southeast Saline Everglades vegetation took several forms, including comparison of present with past floristic surveys and aerial photographs, and paleoecological reconstructions from individual sites. In this paper we present results from vegetation analyses and photointerpretation; associated paleoecologic information based on soil constituent analyses are presented elsewhere (Meeder et al. in prep.).

As in most Everglades environments, the vegetation of the Southeast Saline Everglades (SESE) occurs in two structural forms: expanses of low graminoid or shrub-dominated wetland (for simplicity, referred to hereafter as "marsh"), interspersed with isolated patches of forest ("tree islands" or "hammocks"). This two-phase structure also sets the SESE vegetation gradient apart from those found in most other coastal systems. While a number of authors (e.g., Davis 1943; Egler 1952; Craighead 1971) have described the coastal marsh gradient in South Floridea in some detail, none have examined the compositional gradient in the forested phase in a quantitative manner. We therefore endeavored to do so for SESE tree islands, in the process contrasting current forest composition in one portion of the study area with that reported in a 1967 survey (Tabb et al., 1967).

STUDY AREA

As described by Egler (1952), the Southeast Saline Everglades (SESE) includes the broad band of wetlands extending from the southwest-curving Atlantic Coastal Ridge to the coast (Figure 1). The SESE is bordered in the southwest by the lower portions of Shark

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, Borrichia frutescens*, and *Juncus romoerianus*. 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 guienensis, Coccoloba diversifolia)*, Cypress Domes (characteristic species: *Taxodium distichum)*, and Willow Heads (characteristic species: *Salix virginiana)*.

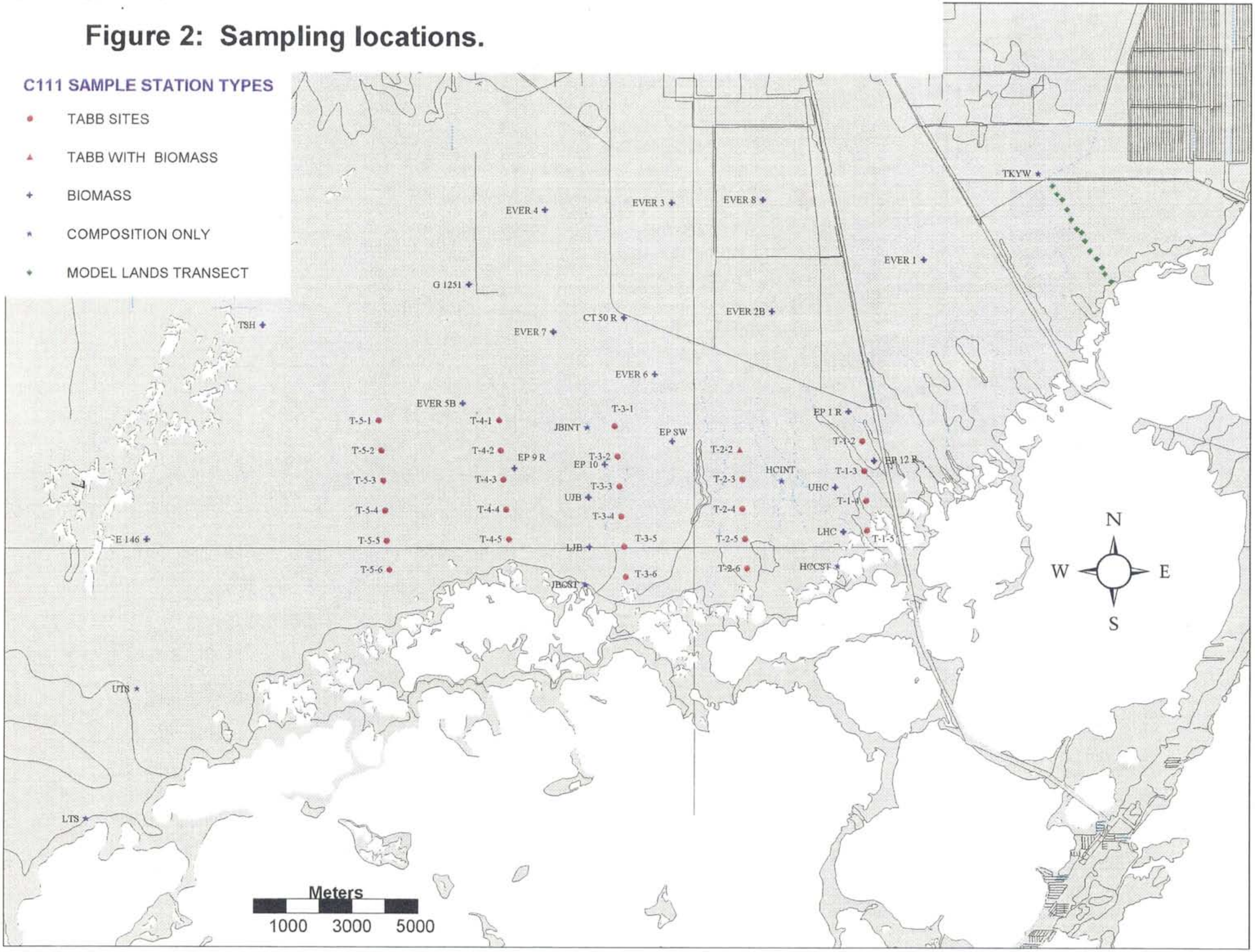
Land use. Human activities which may have had direct effects on the current condition of SESE plant communities are primarily those which altered the region's hydrology. Some of these were: (1) the establishment of the railroad bed along the current U.S. 1 in 1904; (2) dredge and fill operations involved 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 m^2 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.



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 m^2 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 cm^2/g, s=5.03; *R. mangle:* 45.22 cm^2/g, s=8.39; and *E. cellulosa:* 121.79 cm^2/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 cm^2/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 densityweighted 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-m^2 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	*Biomphalaria havanensis*	1
2	*Cylindrella* spp.	1
3	*Laevapex peninsulae*	1
4	*Physella cubensis*	1
5	*Planorbella scalaris*	1
6	*Polygyra* spp.	1
7	*Pomacea paludosa*	1
8	*Littoridinops monoroensis*	1.5
9	*Pyrogophorus platyrachis*	2.5
10	*Cerithidea beattyi*	3
11	*Batillaria minima*	4
12	*Brachidontes exustus*	4
13	*Cyrenoida floridana*	4
14	*Littorina angulifera*	4
15	*Melampus coffeus*	4
16	*Terebra dislocata*	4.5
17	*Turbonilla* spp.	4.5
18	*Alvania* spp.	5
19	*Anomalocardia auberiana*	5
20	*Bulla striata*	5
21	*Caecum pulchellum*	5
22	*Carditas* spp.	5
23	*Chione cancellata*	5
24	*Chione latilirata*	5
25	*Corbula contracta*	5
26	*Lima pellucida*	5
27	*Marginella spp.*	5
28	*Meioceras nitidum*	5
29	*Retusa sulcata*	5
30	*Rissoina catesbyana*	5
31	*Strigilla carnaria*	5
32	*Tricolia bella*	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, CJF 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 anthopomorphic 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-m^2 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.

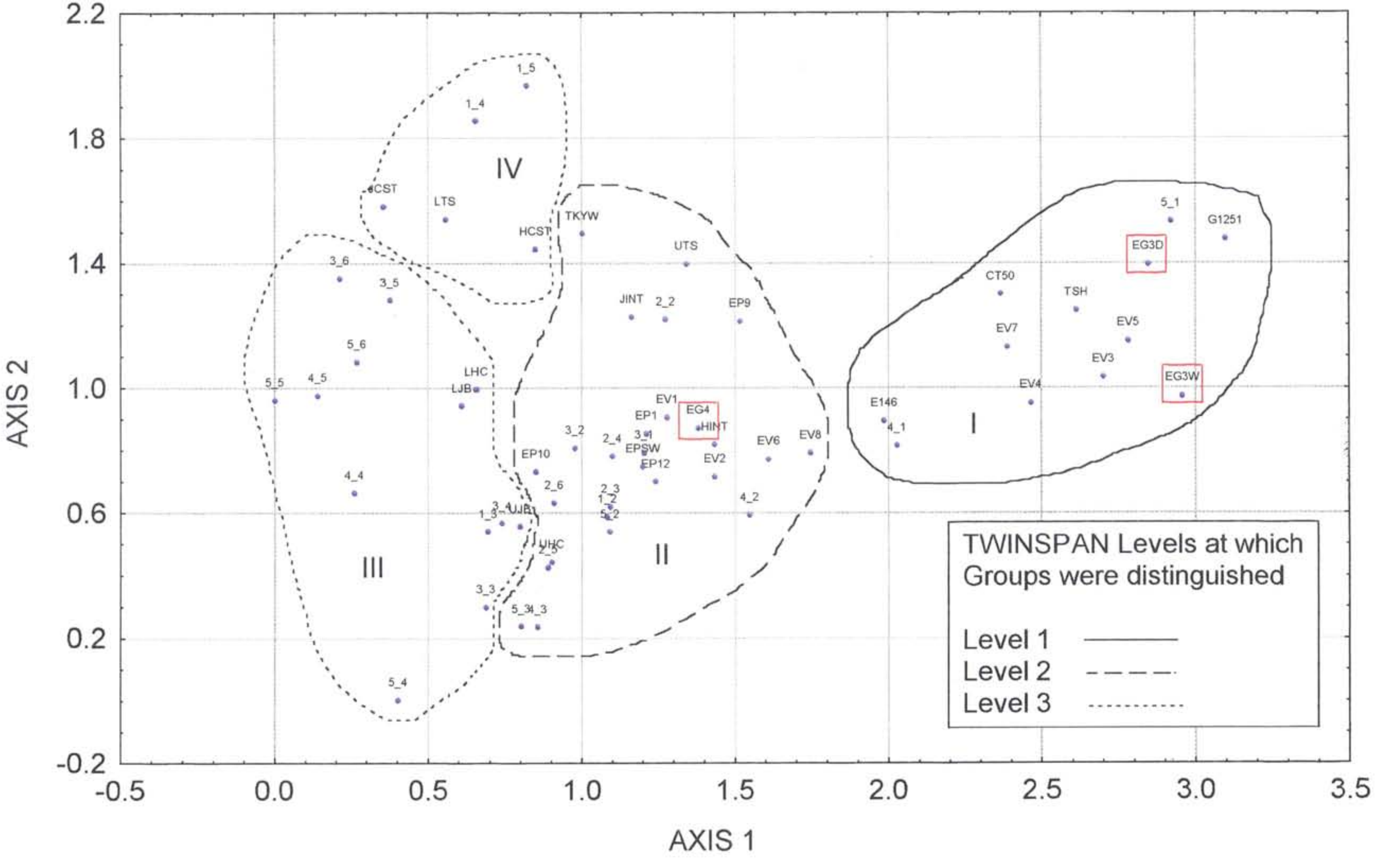


Table 2: Mean relative abundance of common plant taxa (i.e., present in ≥ 3 sites) in four SESE marsh community types. Parentheses enclose the number of sites in which species was recorded.

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

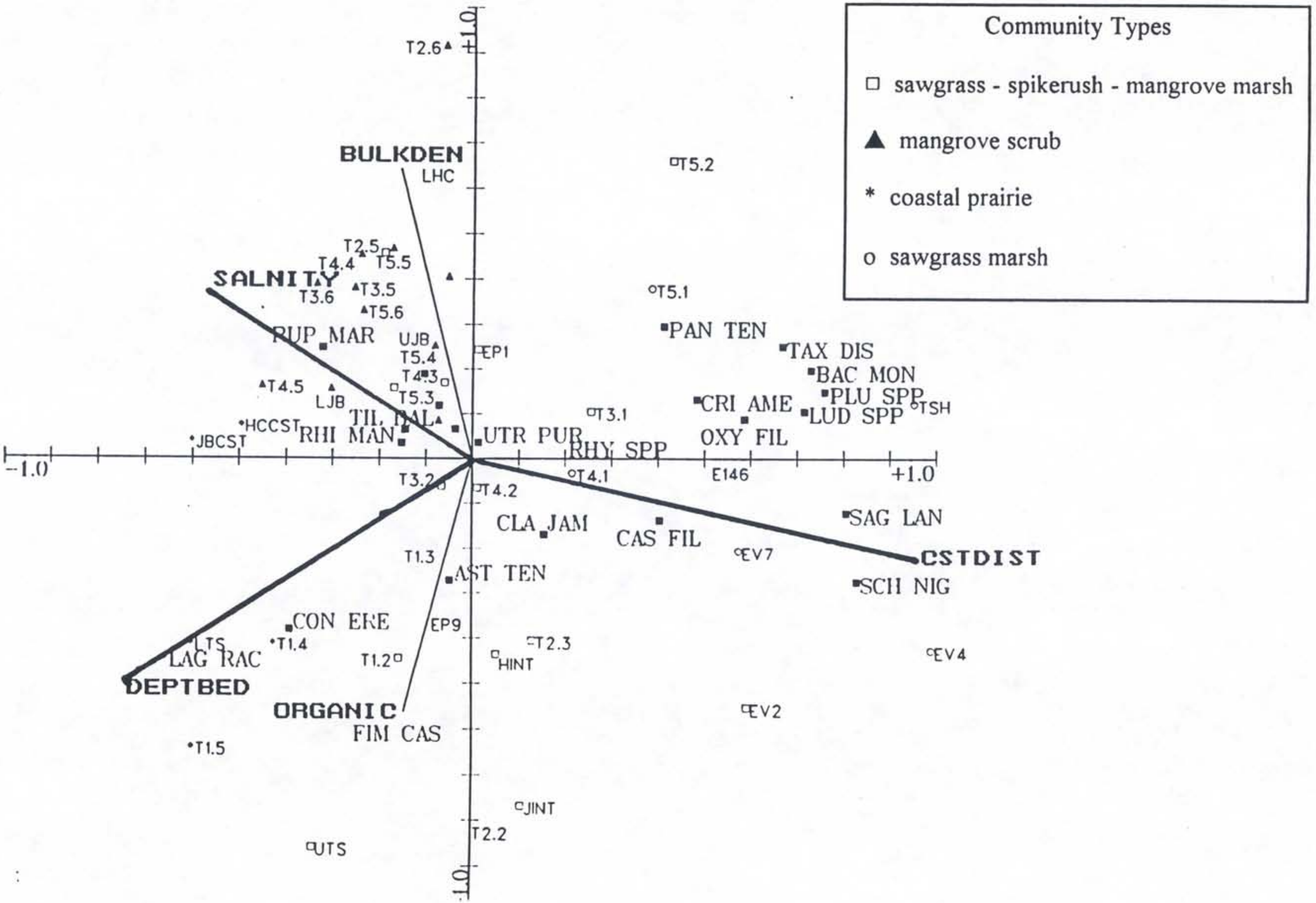
Mean structural attributes of Sawgrass Marsh (8 sites), Sawgrass - Spikerush - Mangrove Marsh (11 sites), and Mangrove Scrub (3 sites) in the SESE are summarized in Table 3. Unfortunately, the 22 biomass sampling stations included no examples of Coastal Prairie vegetation. Mean aboveground biomass (including dead standing material, but not litter) averaged 619 g/m^2 in the Sawgrass Marsh, 800 g/m^2 in Sawgrass - Spikerush - Red Mangrove Marsh, and 1072 g/m^2 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 m^2/m^2) was only about half that in Sawgrass Marsh (0.96 m^2/m^2) and Sawgrass - Spikerush - Mangrove Marsh (0.99 m^2/m^2) . 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 (Decmber 1989) freeze.

Table 3: Components of aboveground biomass (gm/cm^2) and leaf area index (m^2/m^2) 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			
Rhizophora mangle	0.0	12.2	317.0
Others	260.6	258.3	79.8
Dead total	**260.6**	**270.5**	**396.7**
Live materials			
Cladium jamaicense	96.4	126.3	0.0
Eleocharis spp.	16.6	10.6	7.1
Rhizophora mangle	22.4	182.9	553.7
Utricularia 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

Figure 4: Triplots of CCA analysis of SESE marsh vegetation at 42 sites, based on five 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.



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)	
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)	
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)	
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)	
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)	

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 $y = y_{max} \cdot exp(a + bx) / (1 + exp(a + bx))$ (Logistic), where y is the site Axis 1 score from the marsh or hammock DCA ordination, y_{max} is the maximun 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.

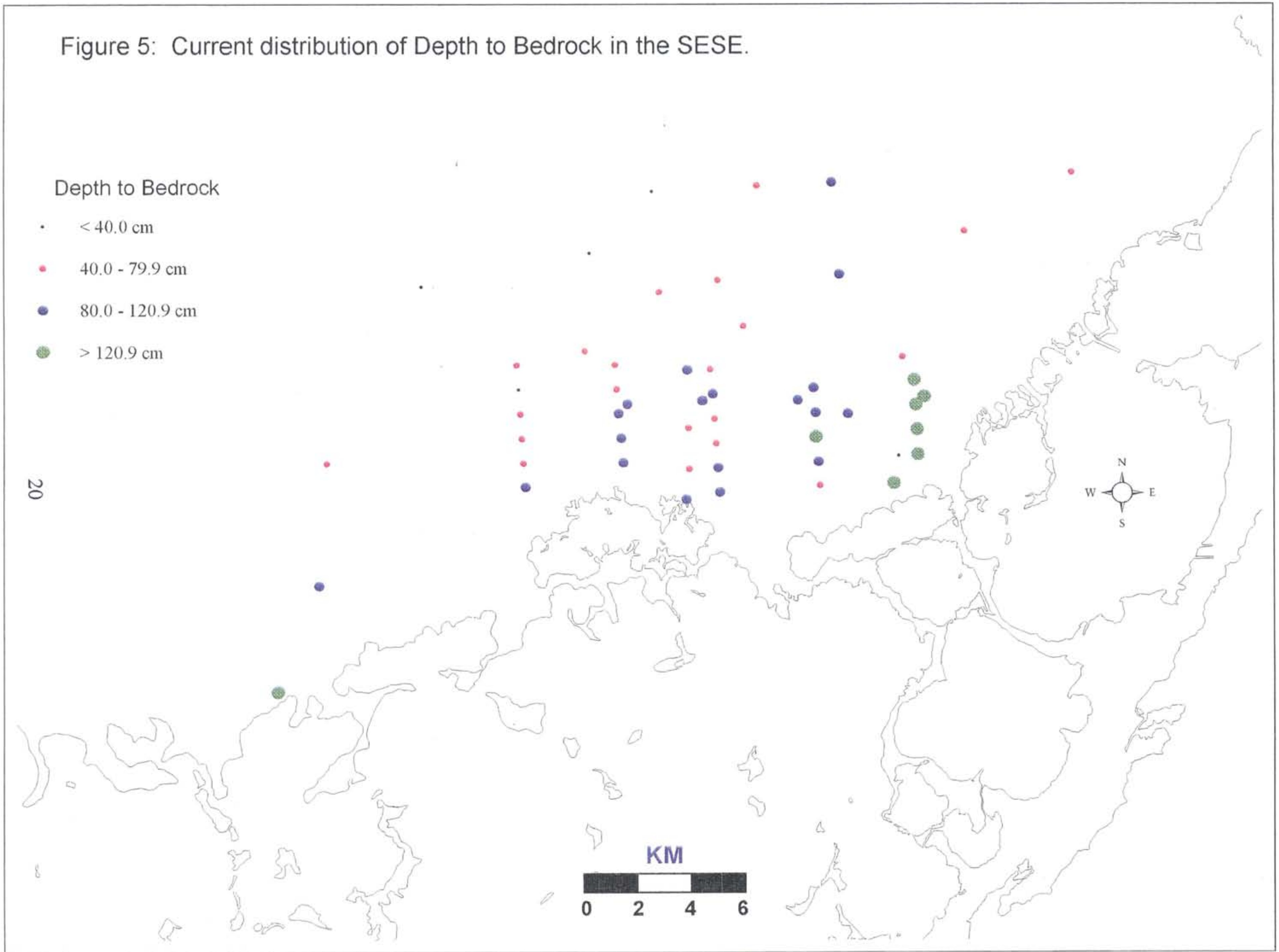
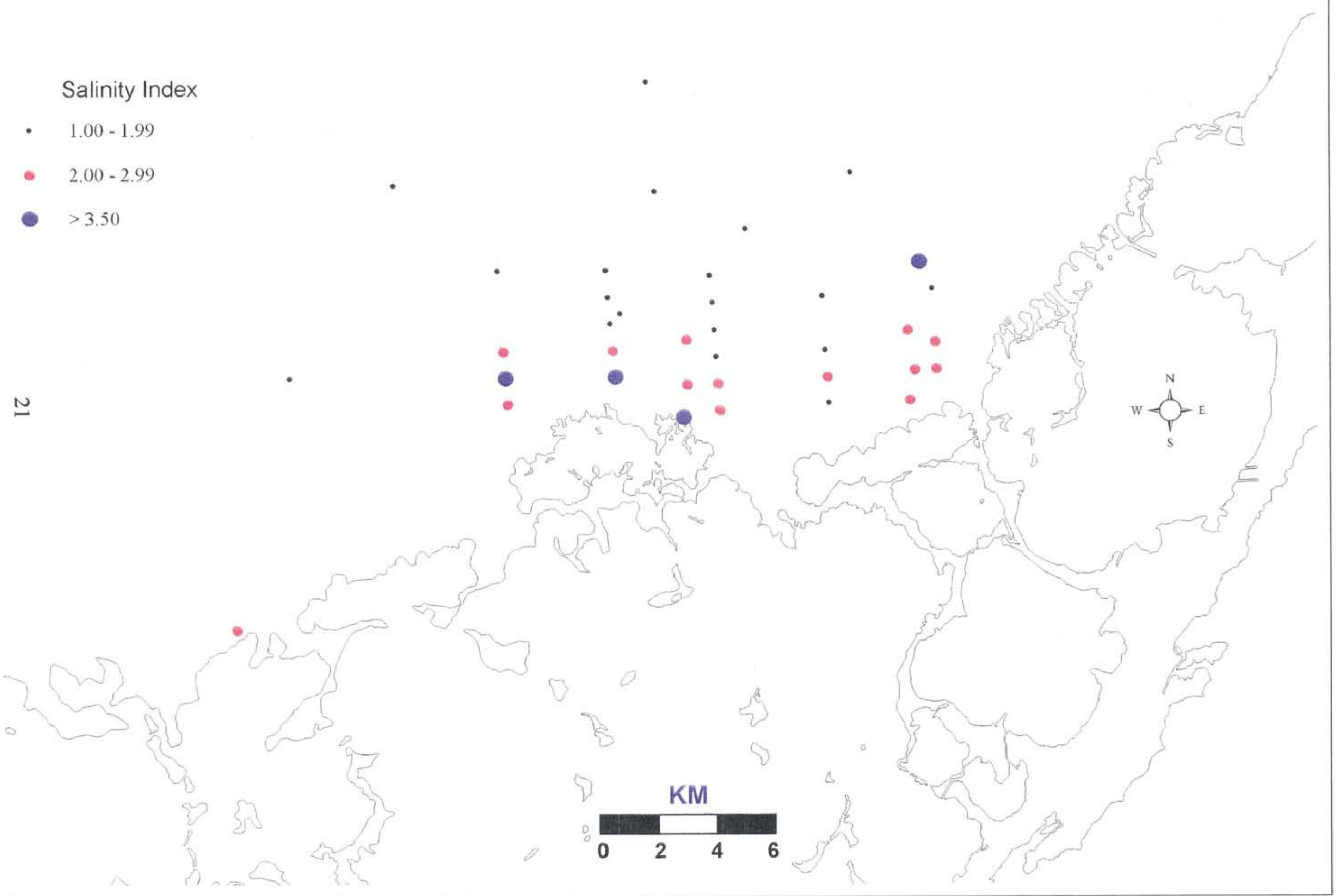


Figure 6: Current distribution of Salinity Index in the SESE. See text and Table 1 for method of calculation.



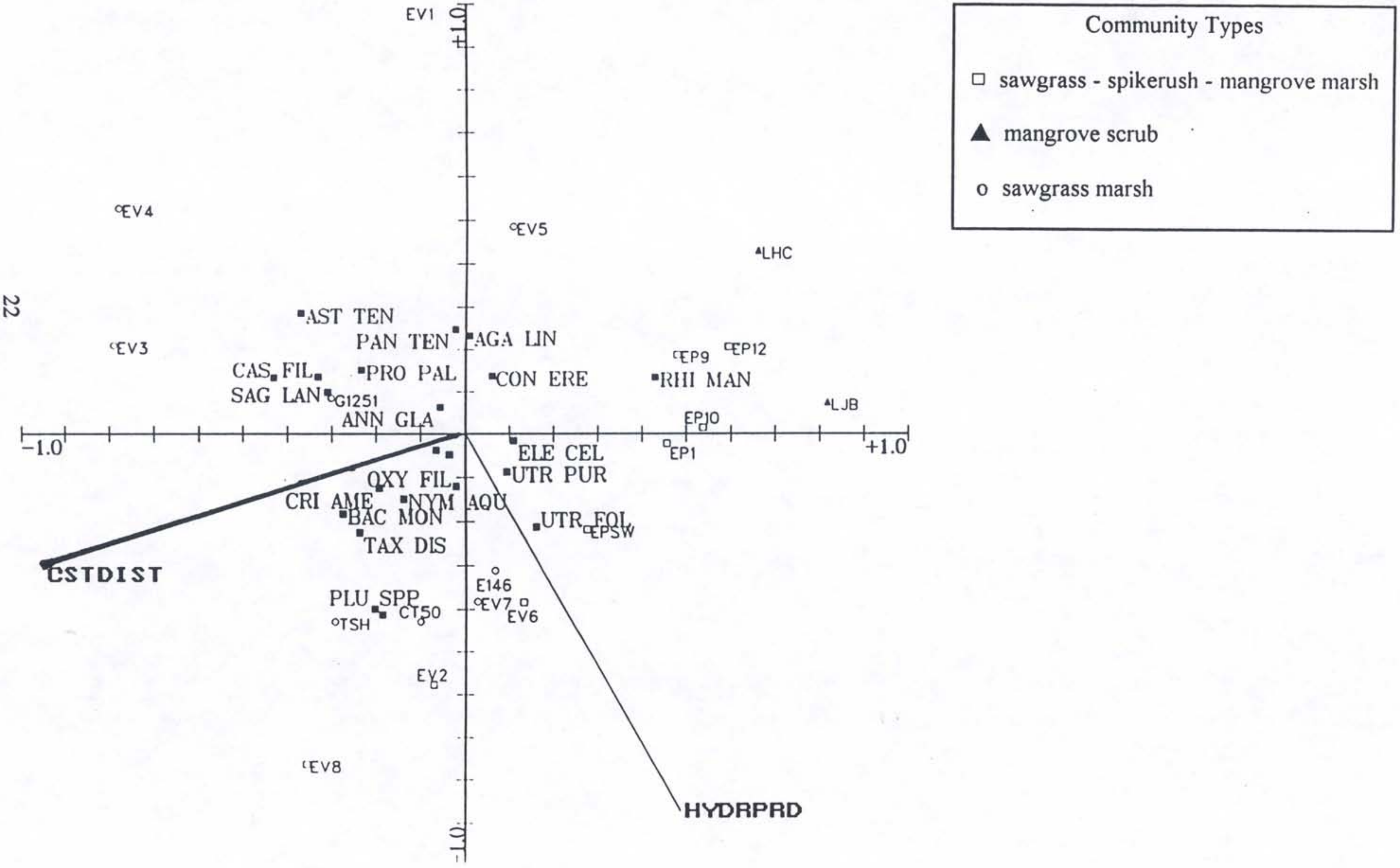


Figure 7: Triplots of CCA analysis of SESE marsh vegetation at 19 sites, based on two environmental variables. Vectors of variables indicated significant ($p < 0.1$) by a Monte Carlo permutation test (999 permutations) are represented by bold lines. Identification of species codes are included in Table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

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

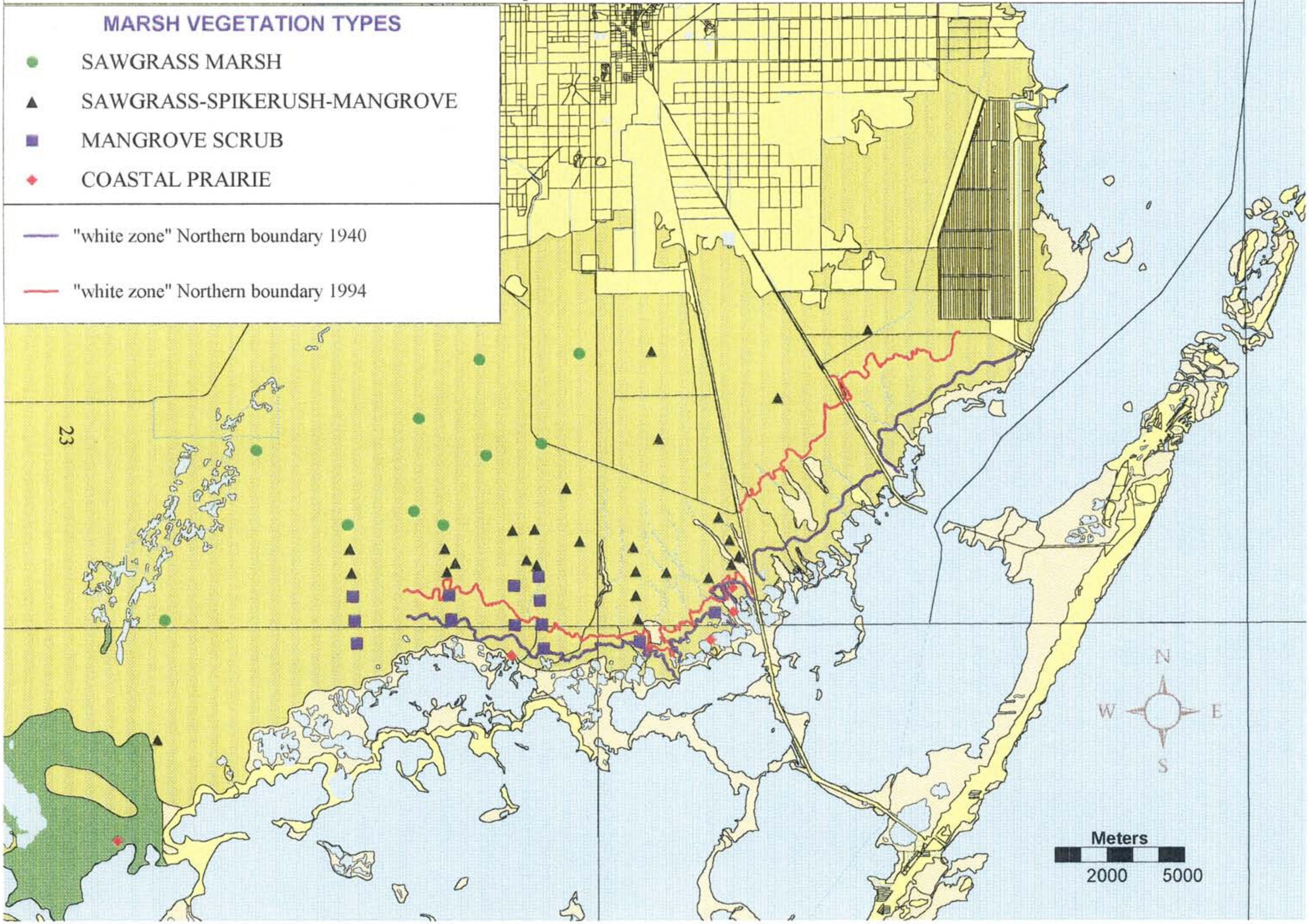


Figure 9: Scatterplots of Axis 1 DCA scores vs. Distance to Coast, with best fit regression line (see Table 5 for coefficients of determination for alternative models. (A) Marsh data from 55 sites, and (B) Tree island data from 54 sites.

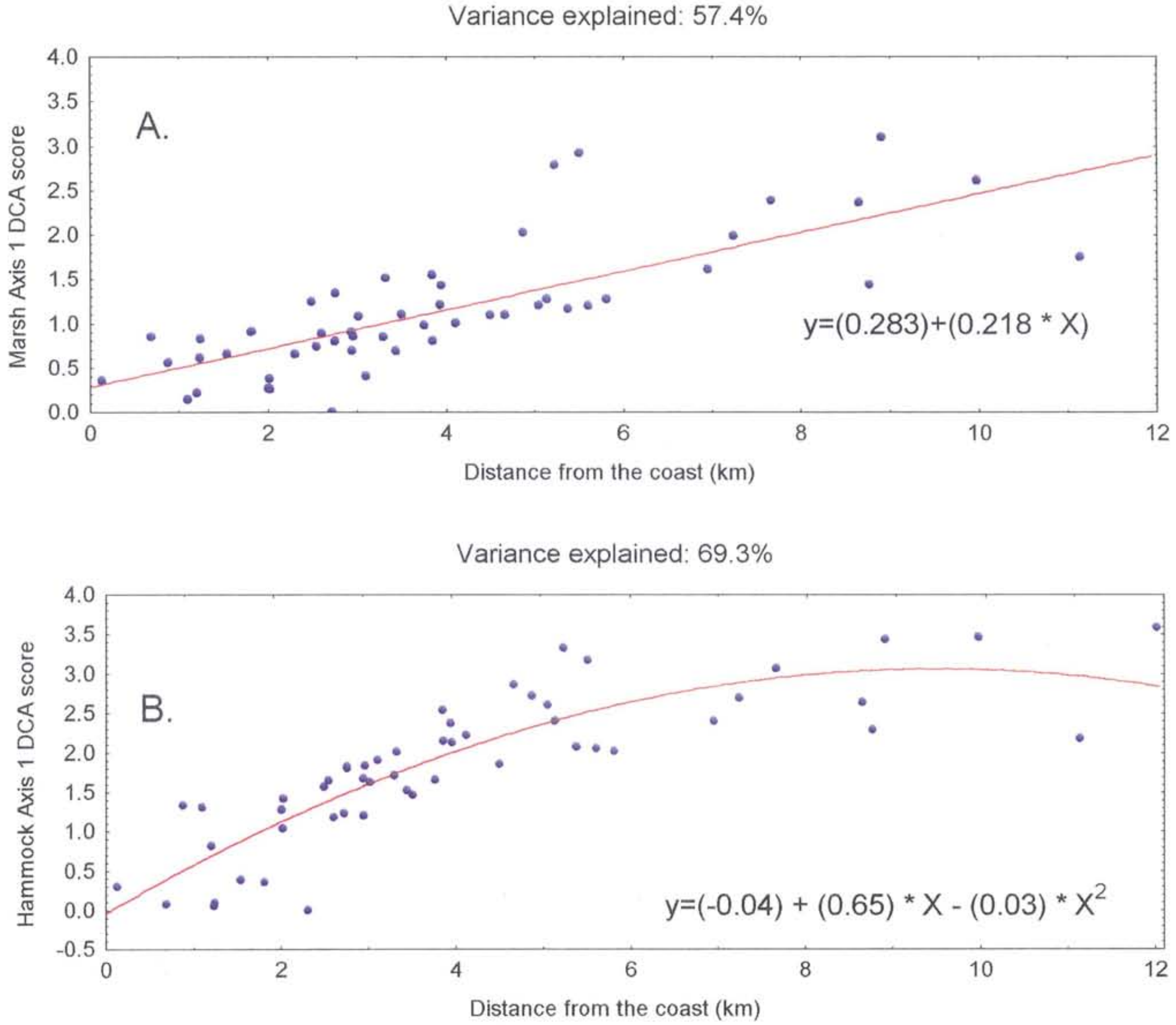
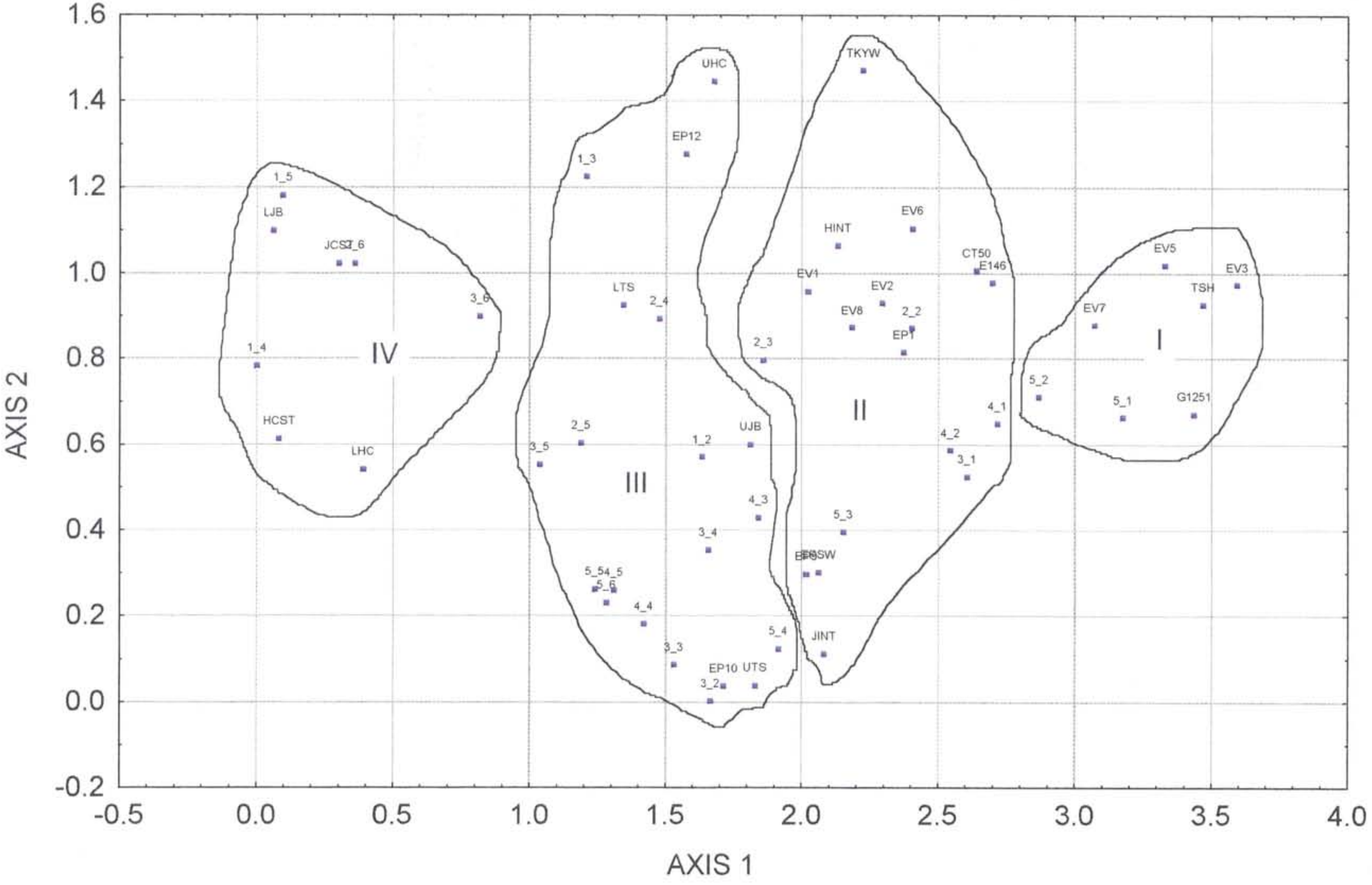


Figure 10: Biplots of DCA Axis 1 and Axis 2 scores for 54 hammock samples, with TWINSPAN classification groupings. All four groups were distinguished at TWINSPAN Level 2 divisions. Group I = Freshwater Swamp Forest; Group II = Mixed Swamp Forest; Group III = Mixed Upland Forest; Group IV = Coastal Mangrove 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, Calyptranthese 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**
Taxodium distichum	TAX DIS	15.29 (7)			
Salix caroliniana	SAL CAR	8.51 (4)	1.32 (2)	0.16 (1)	
Magnolia virginiana	MAG VIR	4.91 (3)	1.87 (4)		
Ilex cassine	ILE CAS	8.90 (6)	6.07 (12)	0.20 (2)	
Persea borbonia	PER BOR	11.81 (6)	7.37 (6)	0.63 (6)	
Annona glabra	ANN GLA	7.00 (6)	2.49 (7)	0.97 (7)	
Chrysobalanus icaco	CHR ICA	12.36 (6)	12.60 (16)	2.38 (10)	
Ficus spp.	FIC SPP	2.74 (3)	2.17 (5)	1.49 (7)	
Sabal palmetto	SAB PAL		1.51 (3)		
Myrsine guianensis	MYR GUI	6.29 (6)	6.93 (15)	4.22 (16)	
Myrica cerifera	MYR CER	15.16 (7)	13.06 (18)	7.72 (20)	2.27 (2
Metopium toxiferum	MET TOX	3.12 (4)	10.09 (15)	10.38 (19)	0.98 (1
Schinus terebinthifolius	SCH TER	0.41 (1)	2.32 (10)	4.88 (16)	
Calyptranthes pallens	CAL PAL		1.22 (6)	5.18 (13)	
Eugenia axillaris	EUG AXI		1.46 (3)	2.30 (10)	
Casuarina equisetifolia	CAS EQU		0.84 (2)	2.39 (4)	
Coccoloba diversifolia	COC DIV		0.54 (2)	3.75 (11)	
Conocarpus erectus	CON ERE	2.02 (3)	13.99 (17)	15.17 (20)	19.48 (8
Swietenia mahogani	SWI MAH		0.40 (1)	2.00 (15)	
Rhizophora mangle	RHI MAN	1.48 (2)	11.16 (18)	13.45 (20)	19.48 (8
Eugenia foetida	EUG FOE		0.79 (1)	5.29 (15)	
Coccoloba uvifera	COC UVI		0.41 (3)	2.84 (12)	1.53 (2
Randia aculeata	RAN ACU		0.49 (3)	4.83 (15)	5.54 (4
Pithecellobium guadalupense	PIT GUA		0.08 (1)	0.26 (2)	0.98 (1
Laguncularia racemosa	LAG RAC		0.41 (3)	5.73 (15)	11.86 (7
Bumelia celastrina	BUM CEL		0.39 (3)	3.23 (11)	12.96 (5
Avicennia germinans	AVI GER			0.21 (2)	4.68 (3
Lycium carolinianum	LYC CAR			0.34 (1)	11.09 (6
Jacquinia keyensis	JAC KEY				9.16 (5

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

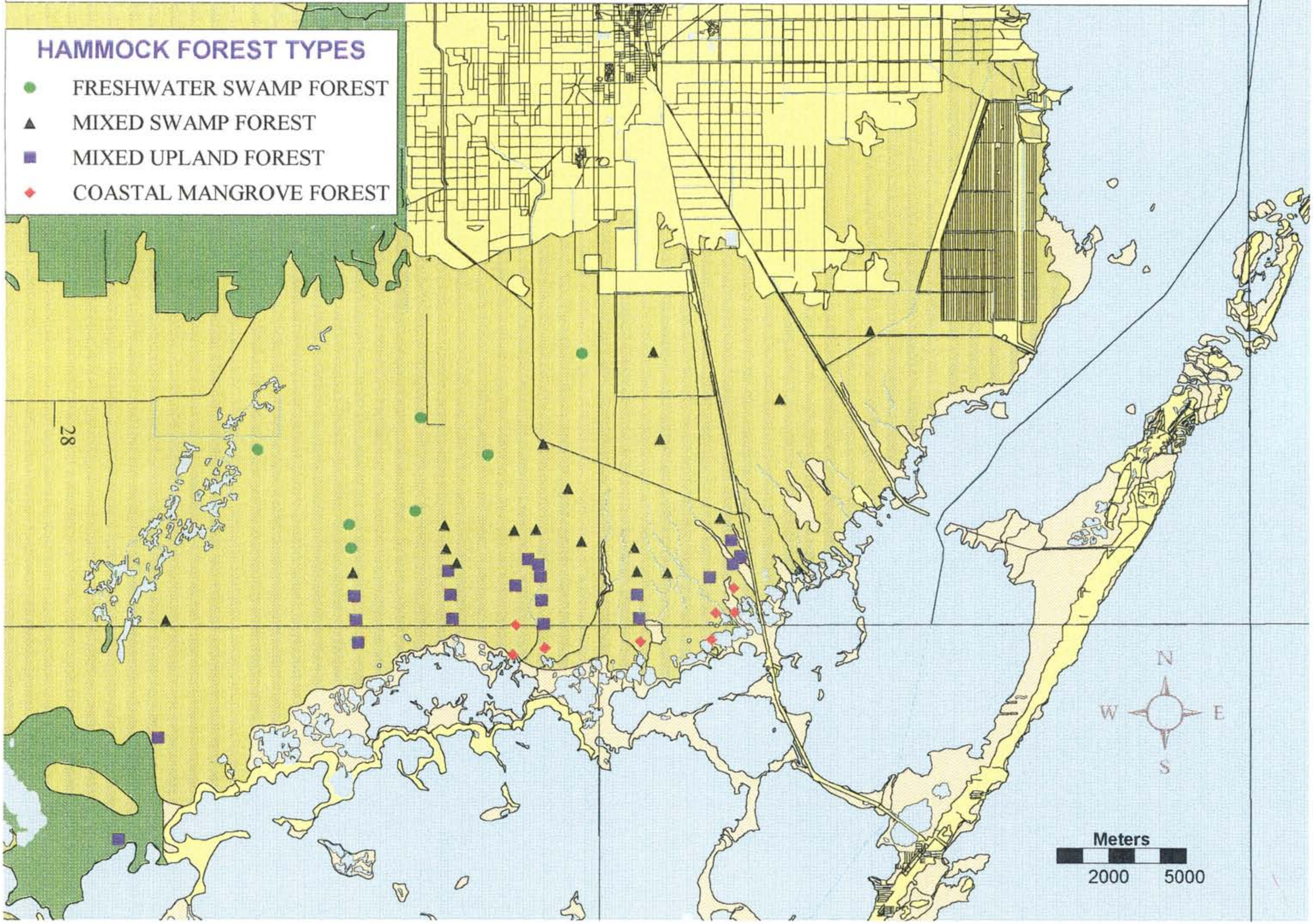
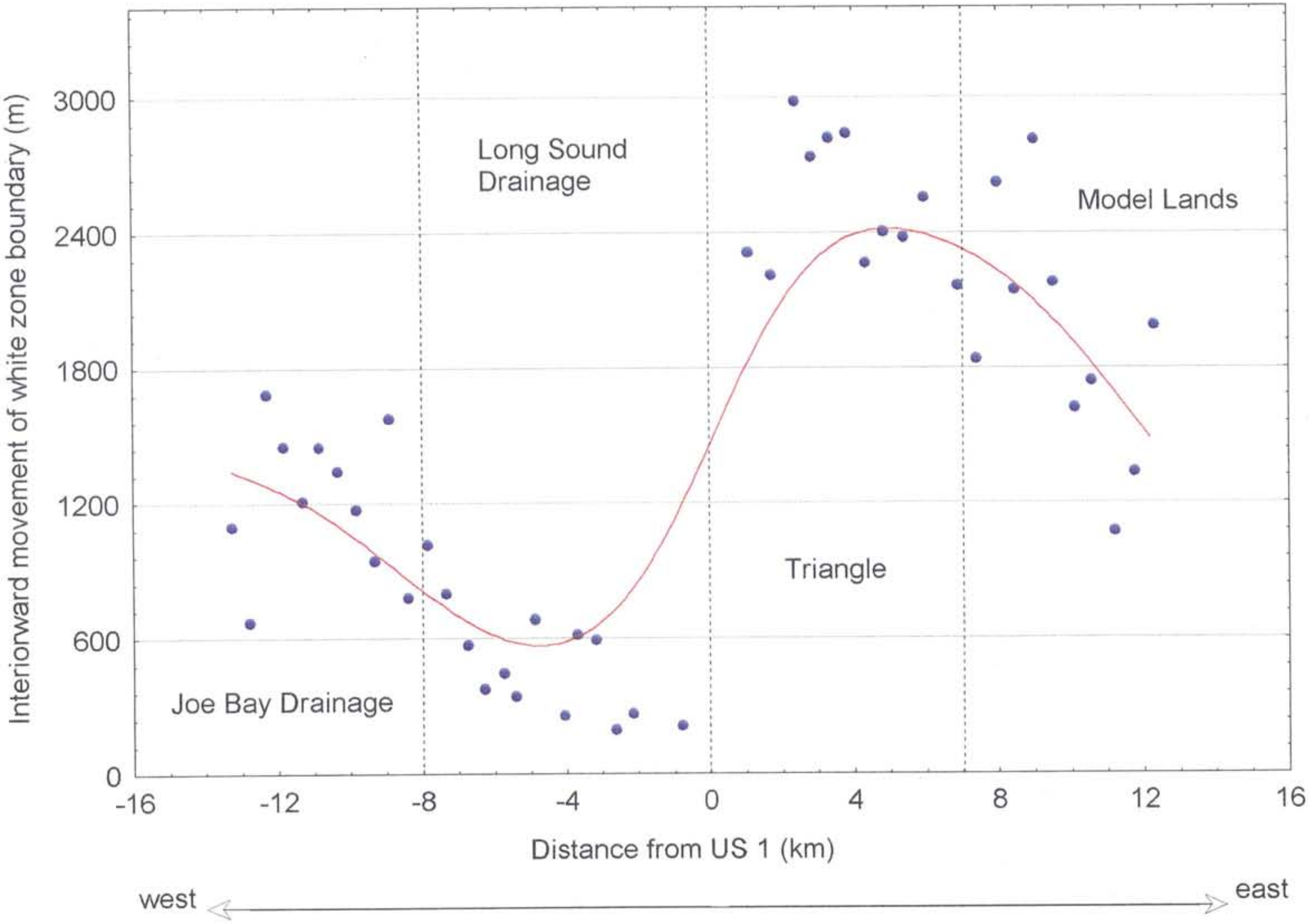


Figure 12: Movement of interior boundary of white zone between 1940 and 1994. Points represent distance measured along 45 transects perpendicular to the SESE coast and spaced at approximately 520 meter intervals along it.



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 romoerianus* 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. jamaicense* 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	***C. jamaicense* frequency**		***E. cellulosa* frequency**		**Hammock Axis 1**	
Test of Homogenity 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. jamaicense* frequency did not differ by Position or Time. However, a significant Position x Time interaction indicated that over the 28-year period, *C. jamaicense* 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.

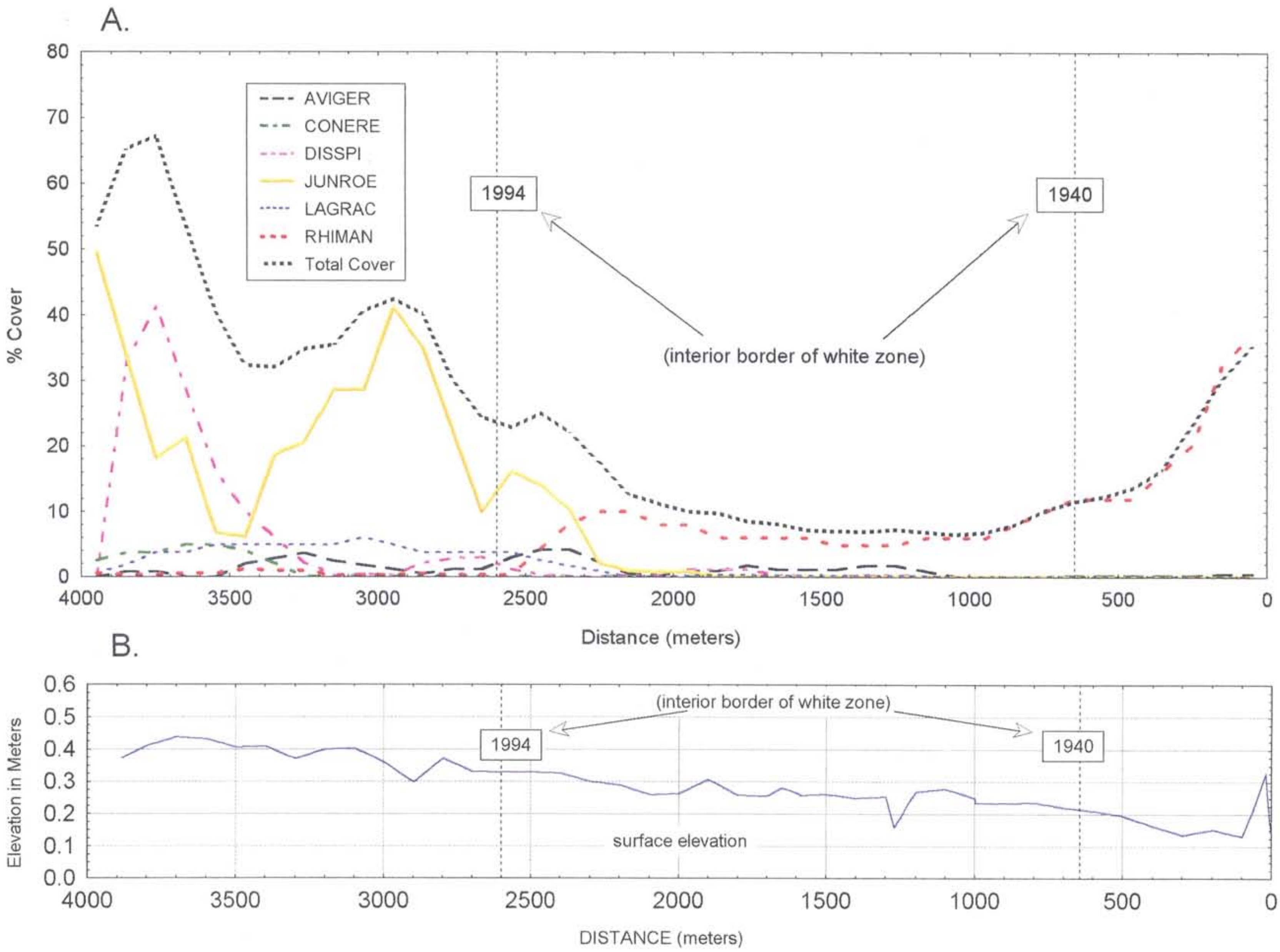


Figure 14: Scattergram, with least squares linear regression line, for four *C. jamaicense* data sets. Data are frequency of occurrence (in 1 m^2 plots) vs. Distance to Coast for sites south or southwest of C-111 Canal, as sampled in 1967 or 1995.

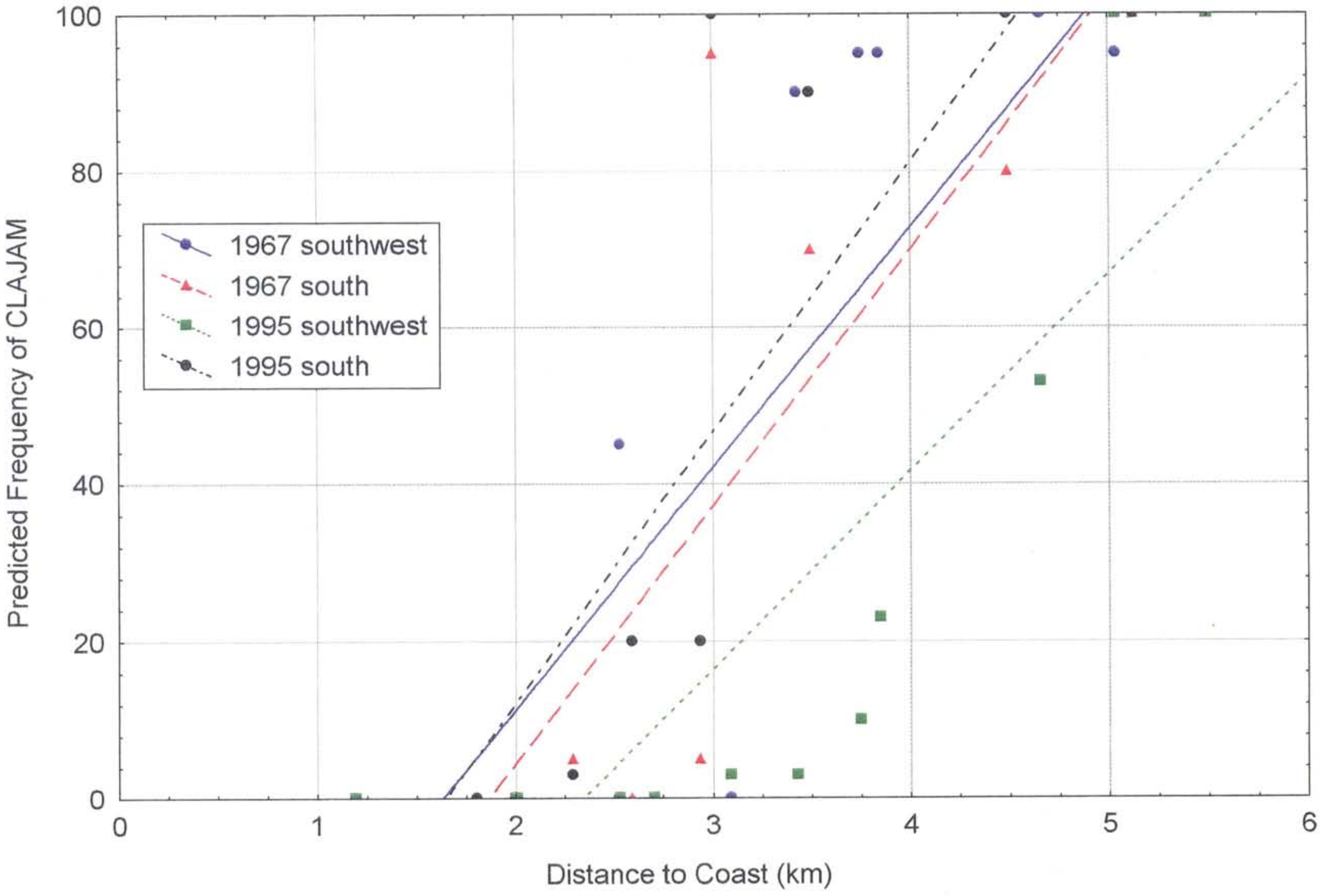


Figure 15: Scattergram, with least squares linear regression line, for four *E. cellulosa* data sets. Data are frequency of occurrence (in 1 m^2 plots) vs. Distance to Coast for sites south or southwest of C-111 Canal, as sampled in 1967 or 1995.

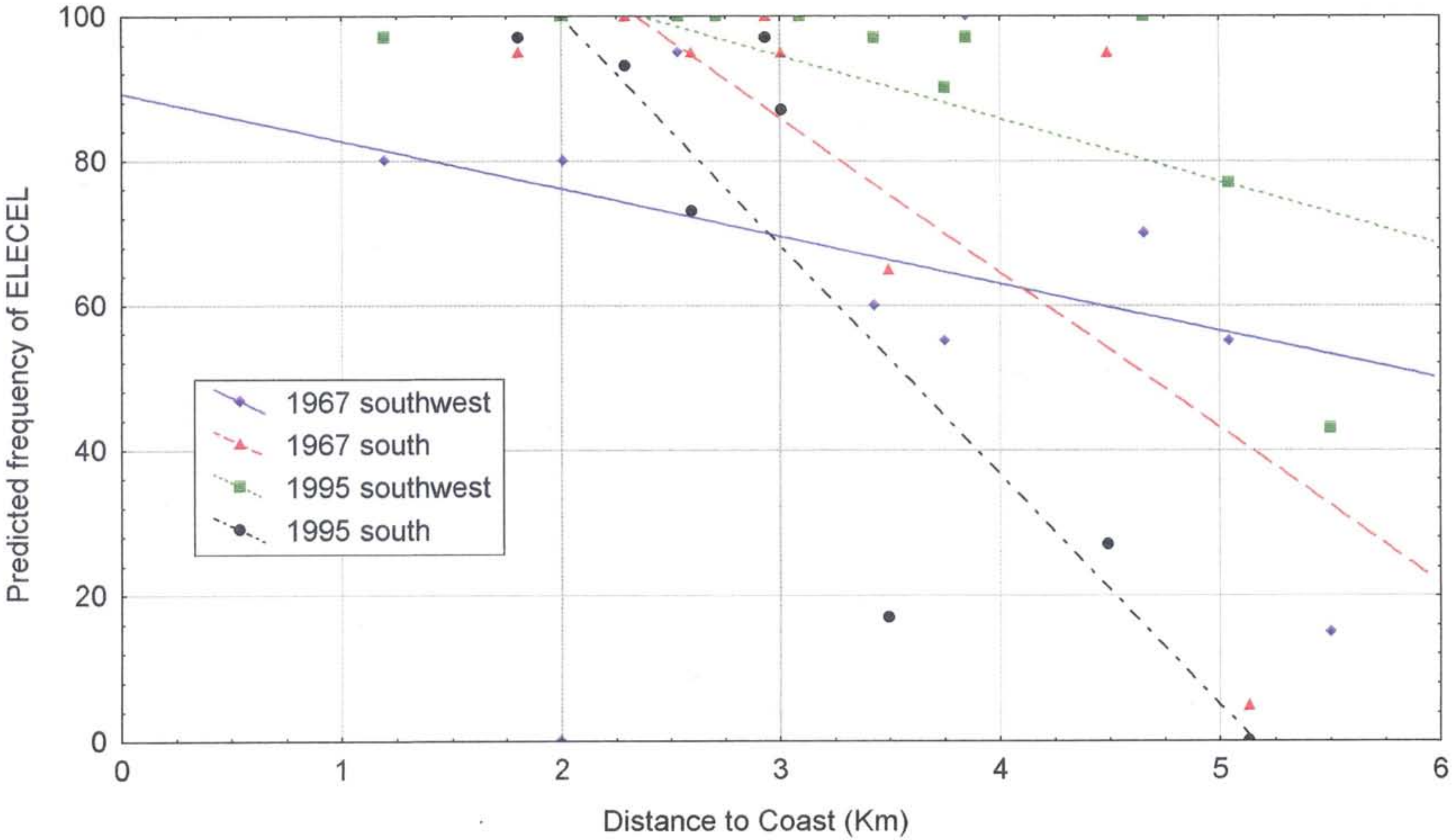
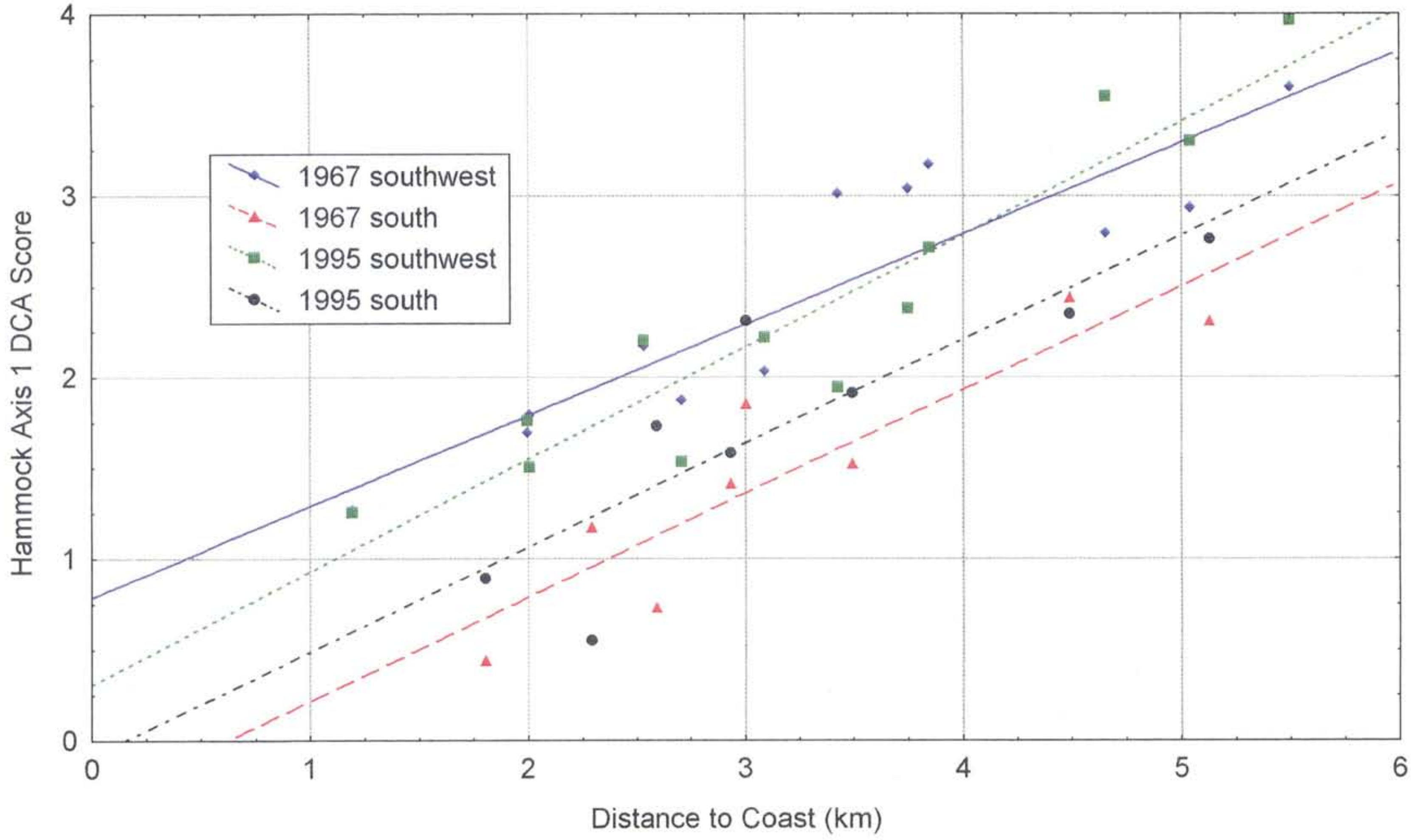


Figure 16: Scattergram, with least squares linear regression line, for four tree island data sets. Data are DCA Axis 1 scores vs. Distance to Coast for sites south or southwest of C-111 Canal, as sampled in 1967 or 1995.



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 insance, Steward and Ornes' (1975) average monthly live standing crop of 1130 g/m^2 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/m^2). 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/m^2 in a scrub mangrove stand south of Turkey Point (Lugo and Snedaker 1974), and 17,932 g/m^2 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/m^2 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 m^2/m^2 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., *Borrichia 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 *Calyptranthes 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 *Annona 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 interioward 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 strorm 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.

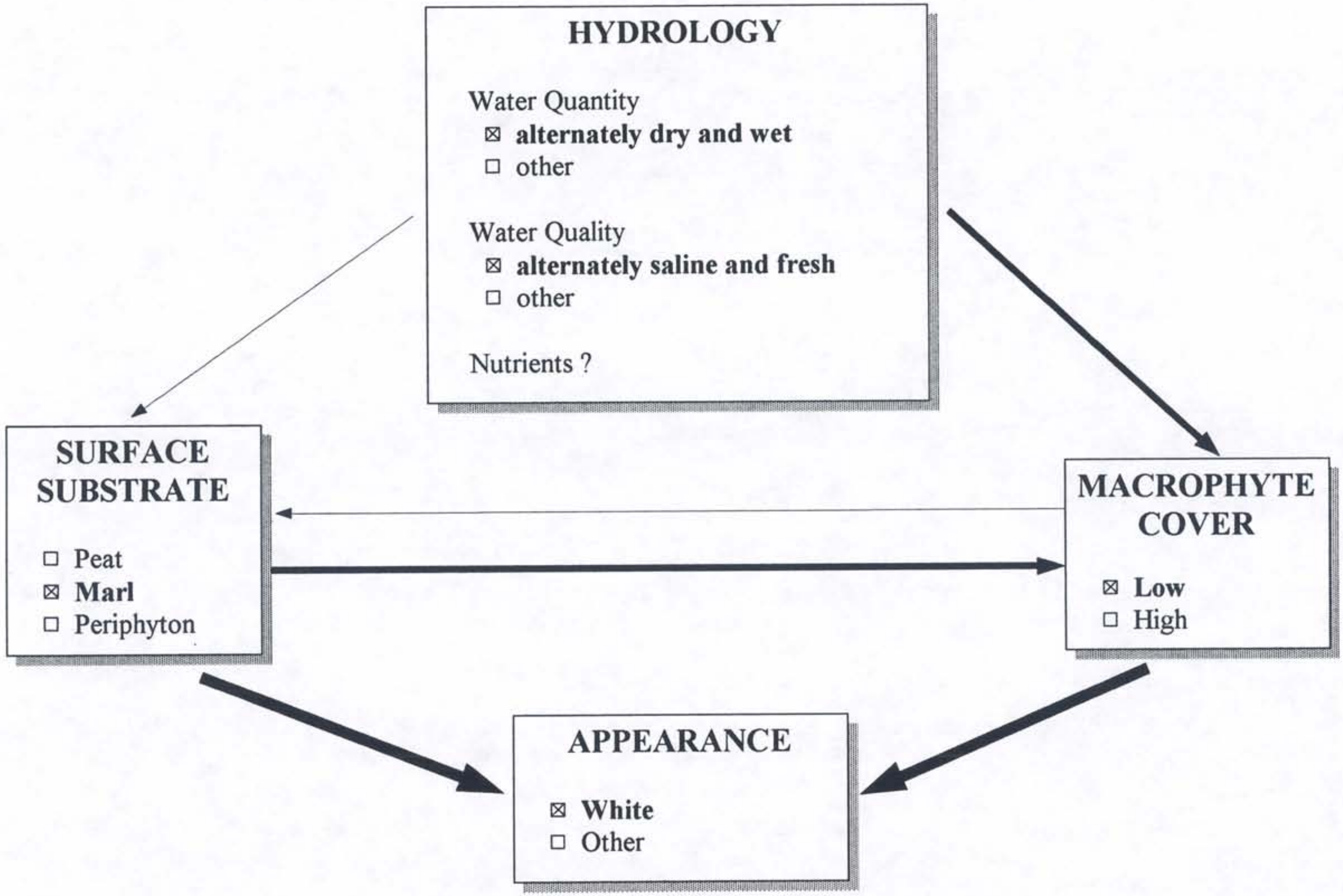


Figure 17: “White Zone” model

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 approximaely 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 3.31km 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. jamaicense* (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. jamaicense*-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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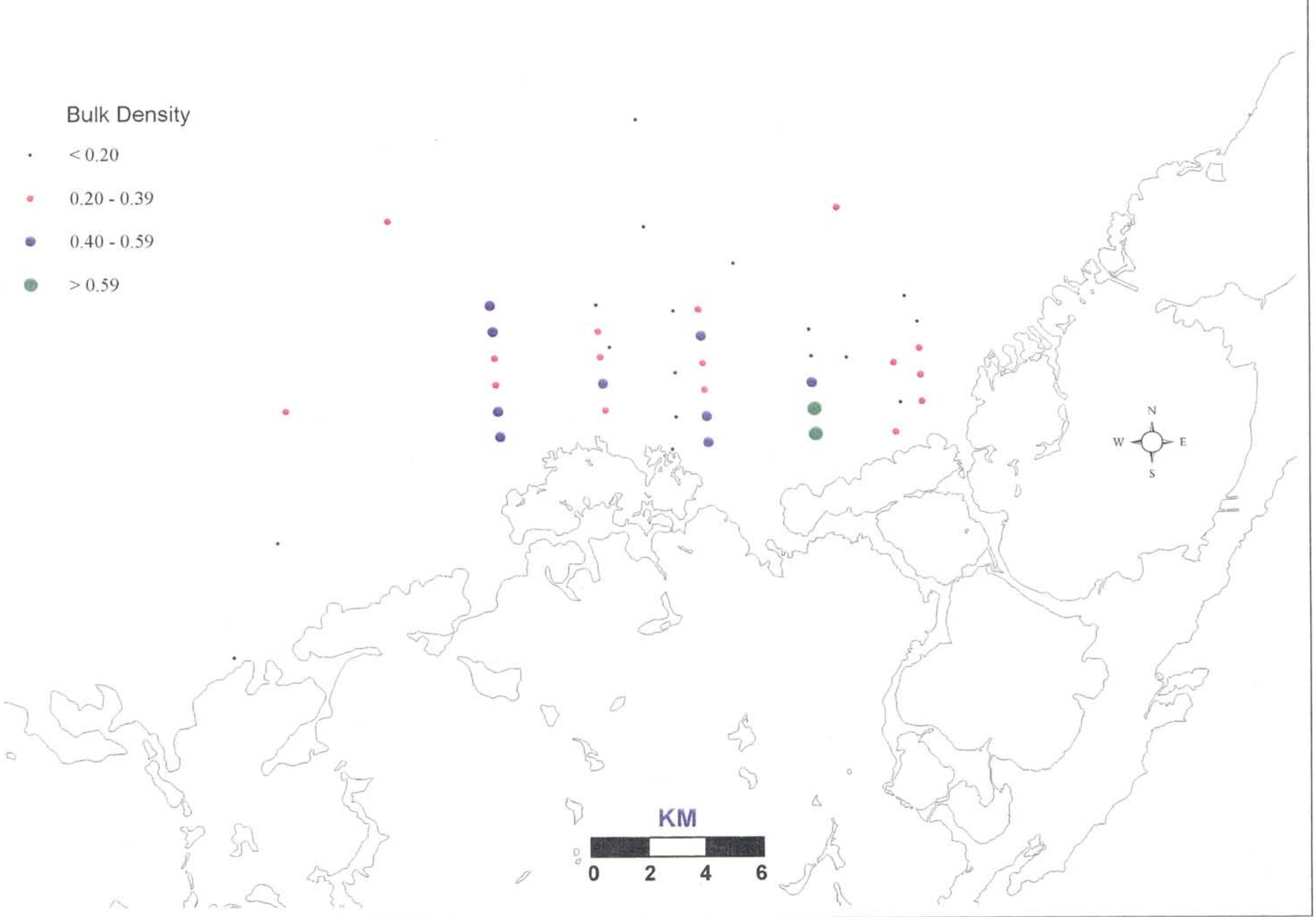
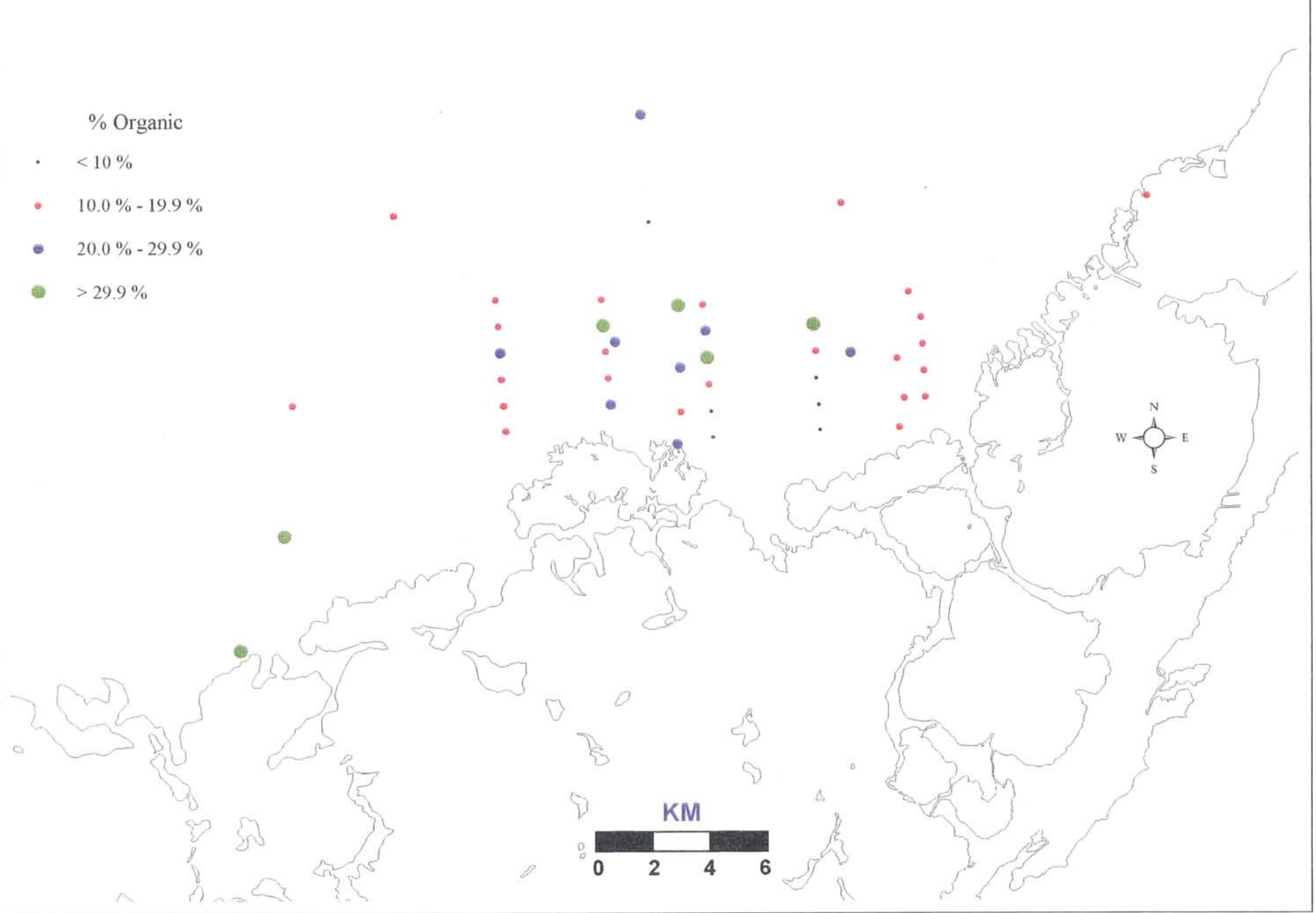
Appendix - 1

(longitude and latitude are in decimal degress)					
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			

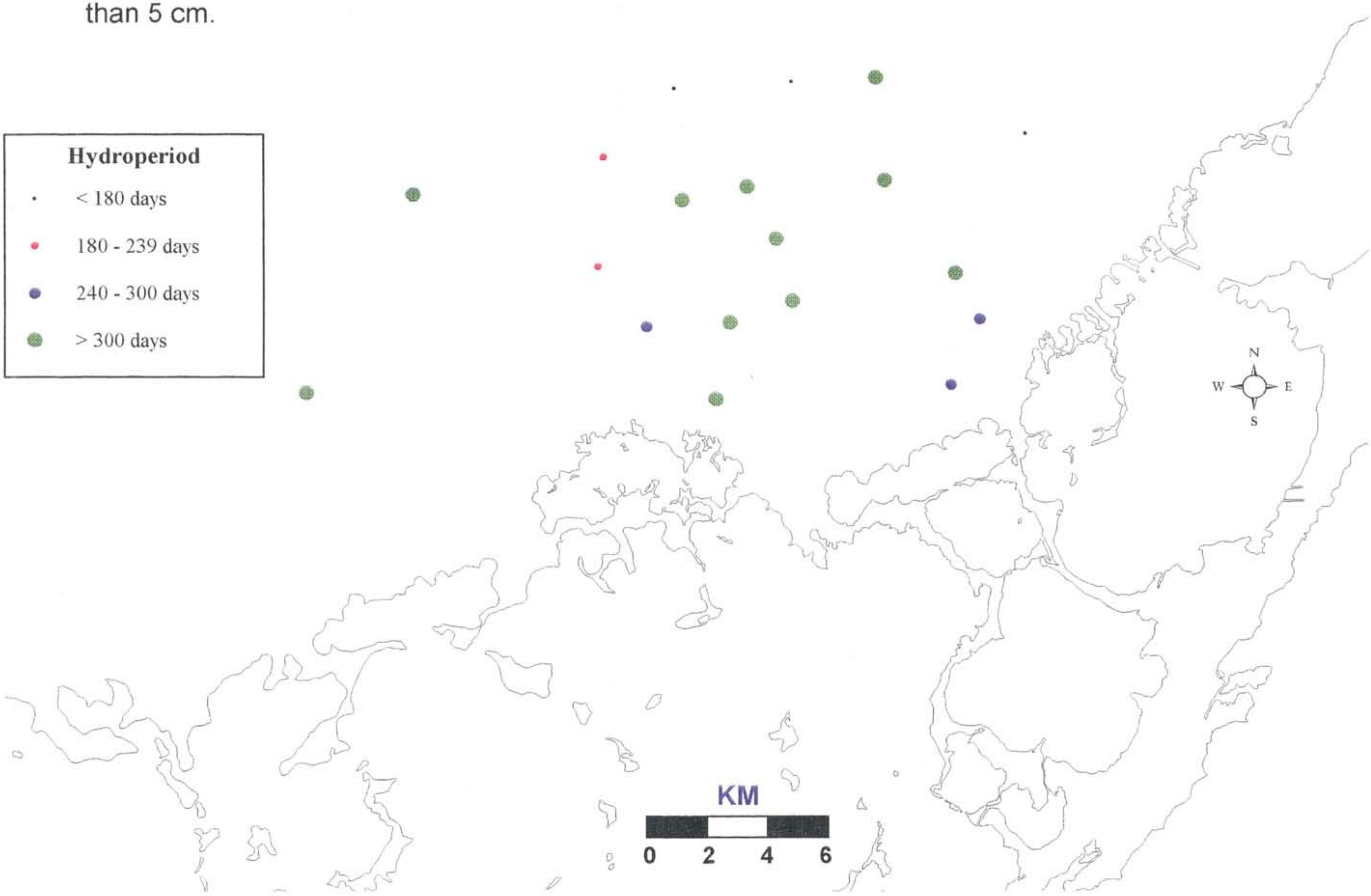
Appendix 2 : Current distribution of Bulk Density of surface soils in the SESE.



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 romoerianus*), SALVIR (*Salicornia virginiana*), BORARB (*Borrichia arborescens*), AVIGER (*Avicennia germinans*),& DISSPI (*Distichlis spicata*).

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

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 a. 1968 stations) were plotted in respect to distance from the coast. A linear regression with 95 % confidence interval has a r2 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 macrophalagonous alga grazer paucity or absence.

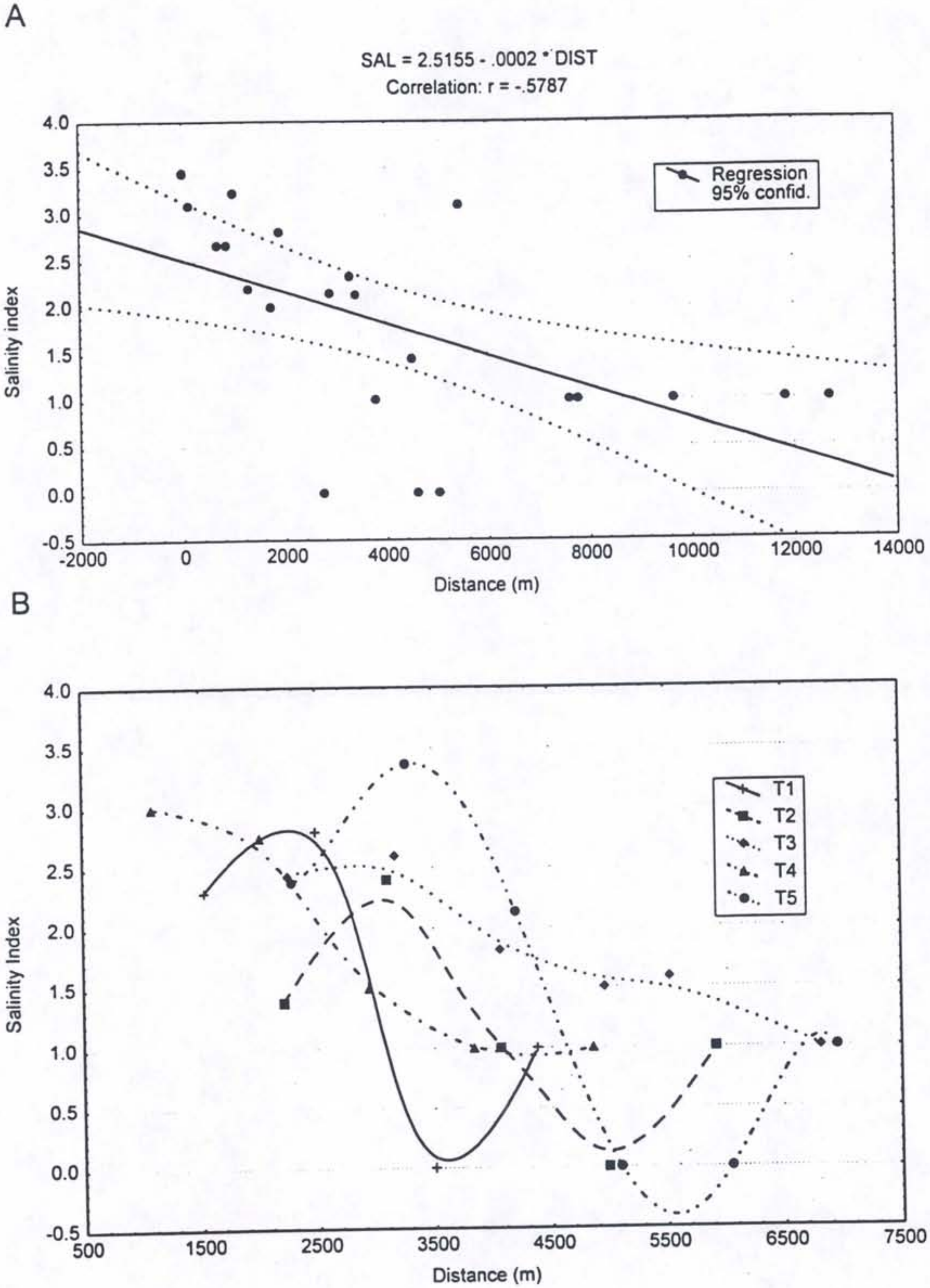

A
SAL = 2.5155 - .0002 * DIST
Correlation: r = -.5787
Regression
95% confid.
Salinity index
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-2000
0
2000
4000
6000
8000
10000
12000
14000
Distance (m)
B
Salinity Index
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
500
1500
2500
3500
4500
5500
6500
7500
Distance (m)
T1
T2
T3
T4
T5

Figure 17. Salt water encroachment rates for each transect.

a. Illustrates the change in elevation of the marine contact line with time. The change is 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.

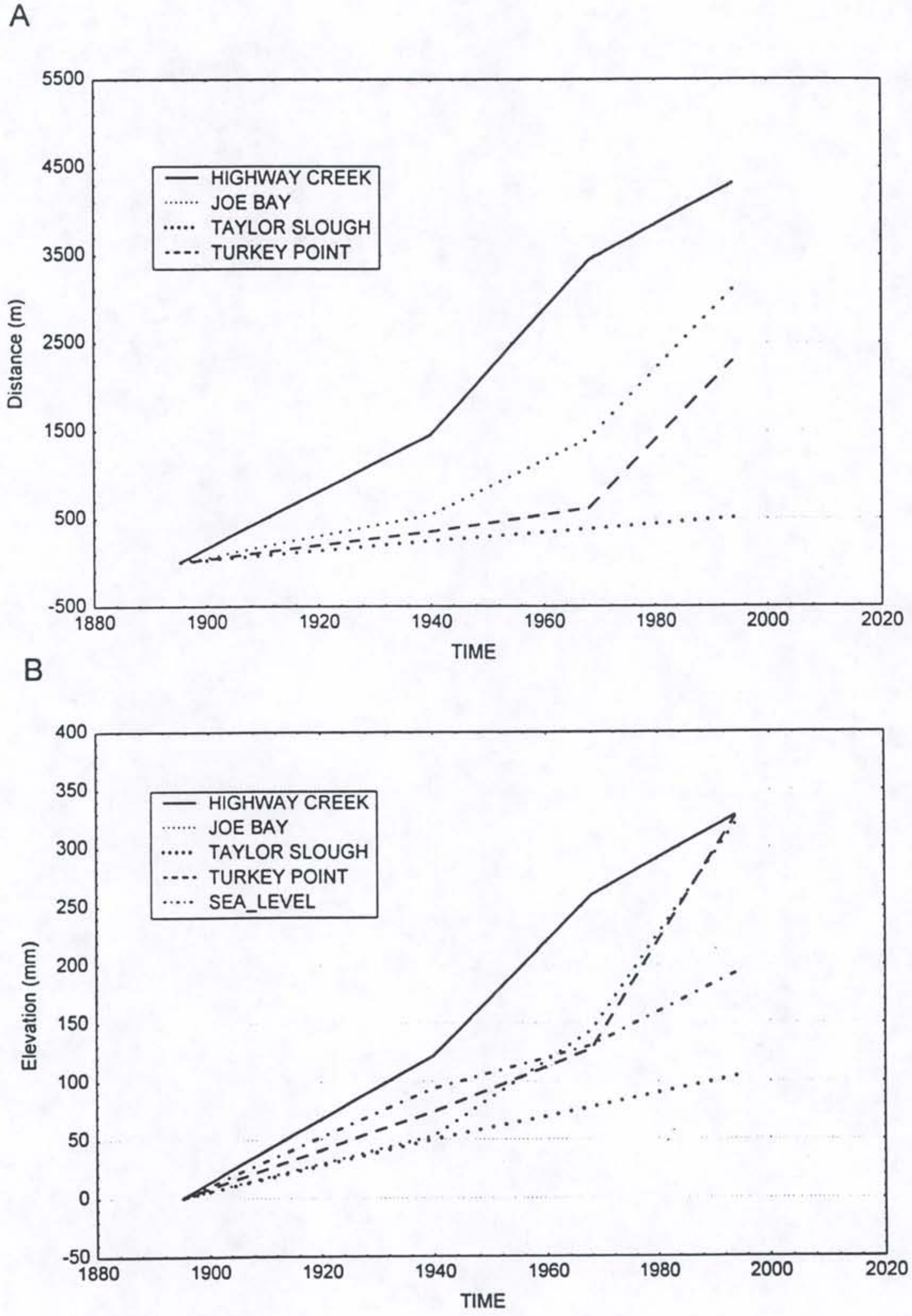

A
5500
4500
3500
2500
1500
500
-500
Distance (m)
1880
1900
1920
1940
1960
1980
2000
2020
TIME
HIGHWAY CREEK
JOE BAY
TAYLOR SLOUGH
TURKEY POINT
B
400
350
300
250
200
150
100
50
0
-50
Elevation (mm)
1880
1900
1920
1940
1960
1980
2000
2020
TIME
HIGHWAY CREEK
JOE BAY
TAYLOR SLOUGH
TURKEY POINT
SEA_LEVEL

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

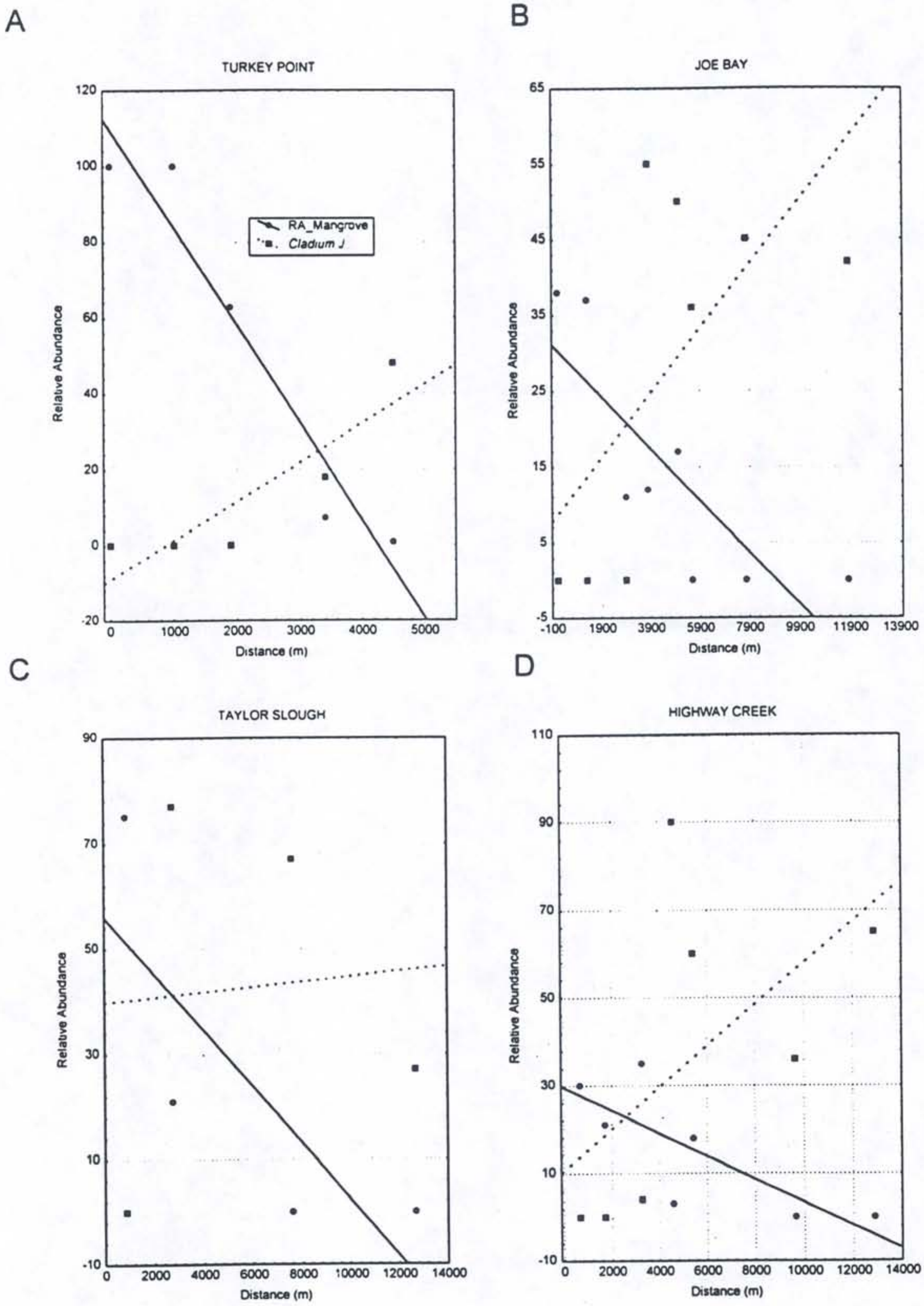

A
TURKEY POINT
Relative Abundance
Distance (m)
120
100
80
60
40
20
0
-20
0
1000
2000
3000
4000
5000
RA_Mangrove
Cladium J
B
JOE BAY
Relative Abundance
Distance (m)
65
55
45
35
25
15
5
-5
-100
1900
3900
5900
7900
9900
11900
13900
C
TAYLOR SLOUGH
Relative Abundance
Distance (m)
90
70
50
30
10
-10
0
2000
4000
6000
8000
10000
12000
14000
D
HIGHWAY CREEK
Relative Abundance
Distance (m)
110
90
70
50
30
10
-10
0
2000
4000
6000
8000
10000
12000
14000

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.

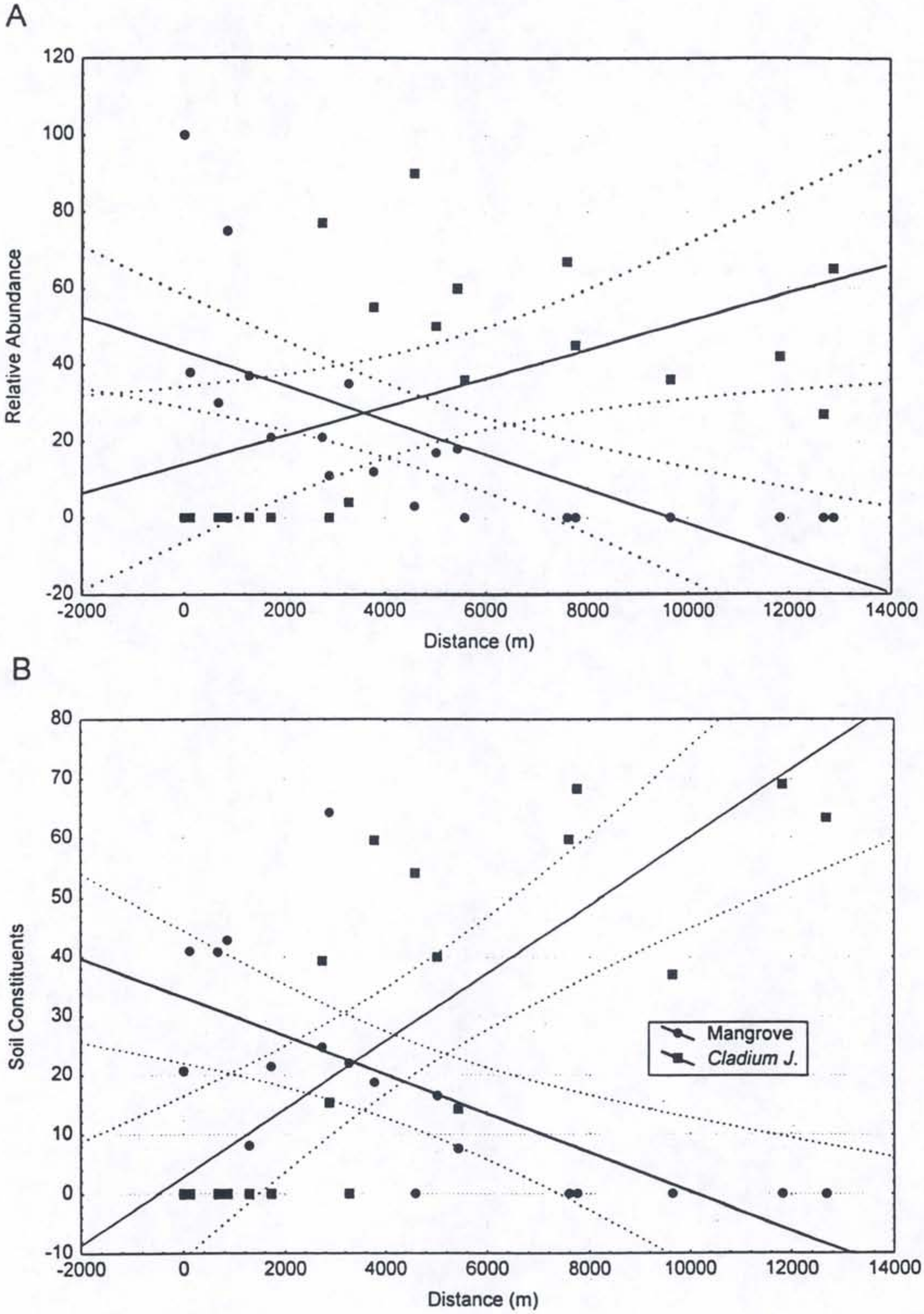

A
Relative Abundance
120
100
80
60
40
20
0
-20
-2000
0
2000
4000
6000
8000
10000
12000
14000
Distance (m)
B
Soil Constituents
80
70
60
50
40
30
20
10
0
-10
-2000
0
2000
4000
6000
8000
10000
12000
14000
Distance (m)
Mangrove
Cladium J.

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

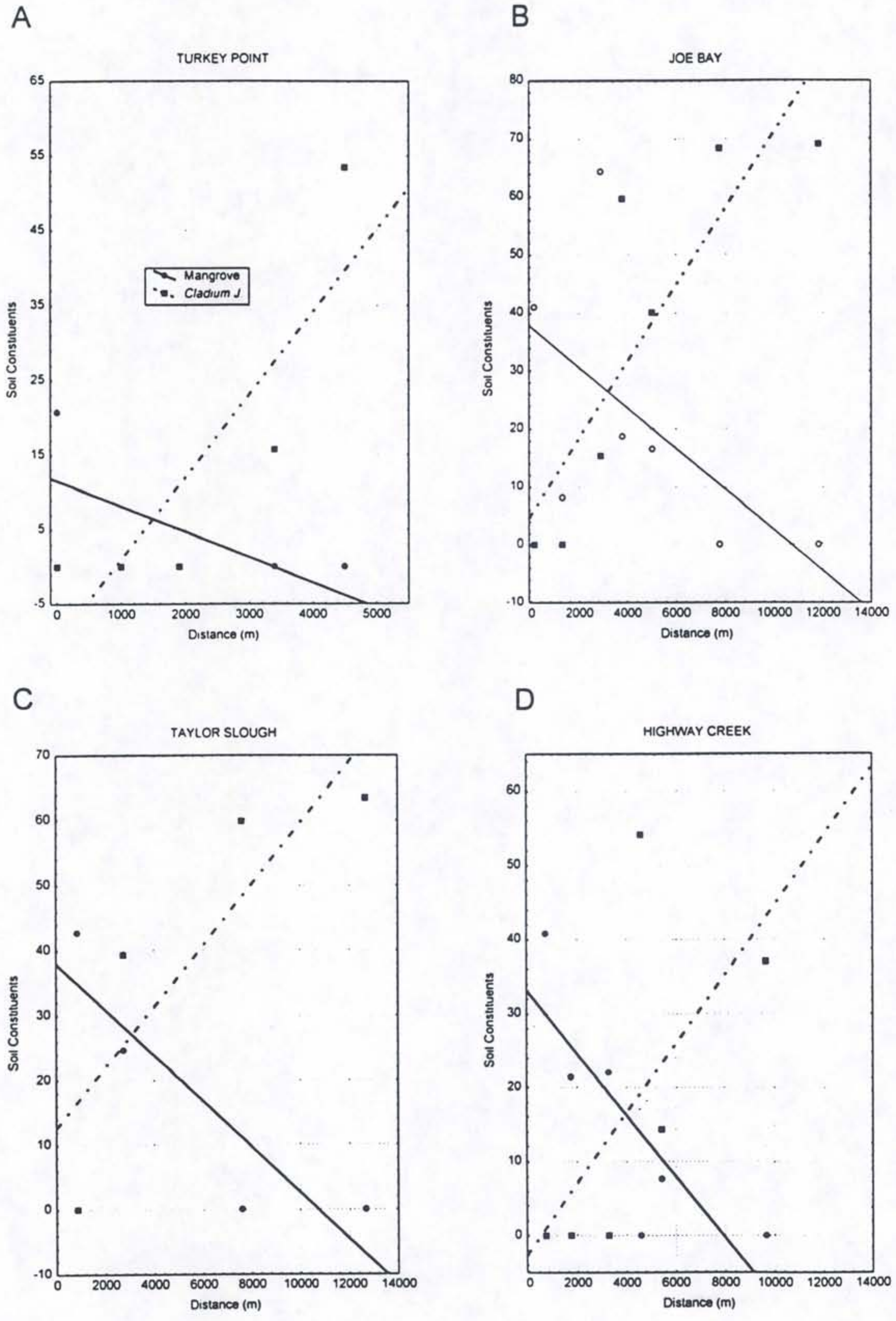
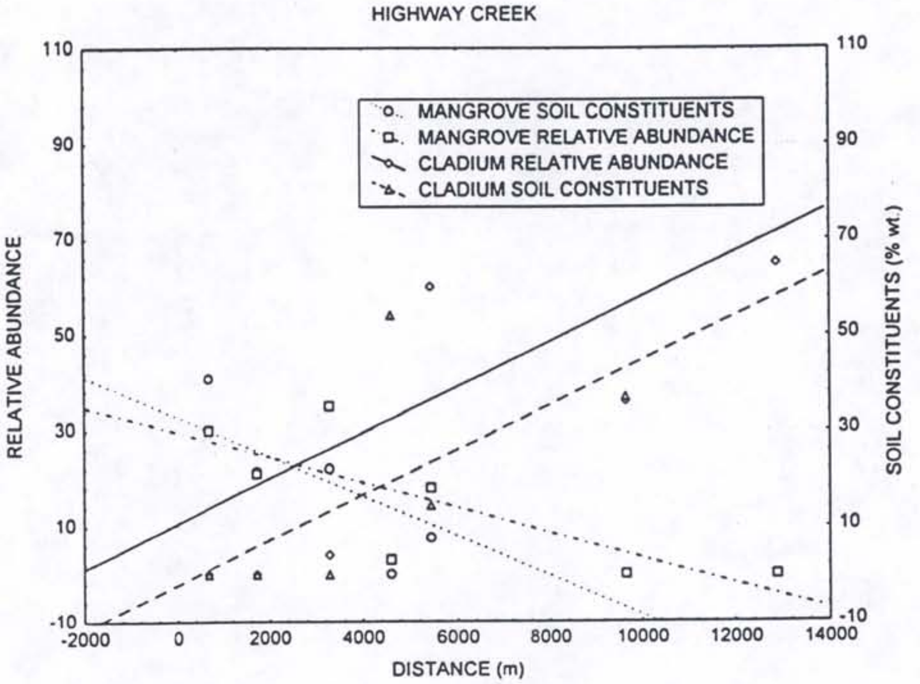

A
TURKEY POINT
Mangrove
Cladium J.
Soil Constituents
Distance (m)
65
55
45
35
25
15
5
-5
0
1000
2000
3000
4000
5000
B
JOE BAY
Soil Constituents
Distance (m)
80
70
60
50
40
30
20
10
0
-10
0
2000
4000
6000
8000
10000
12000
14000
C
TAYLOR SLOUGH
Soil Constituents
Distance (m)
70
60
50
40
30
20
10
0
-10
0
2000
4000
6000
8000
10000
12000
14000
D
HIGHWAY CREEK
Soil Constituents
Distance (m)
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
12000
14000

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


HIGHWAY CREEK
MANGROVE SOIL CONSTITUENTS
MANGROVE RELATIVE ABUNDANCE
CLADIUM RELATIVE ABUNDANCE
CLADIUM SOIL CONSTITUENTS
RELATIVE ABUNDANCE
SOIL CONSTITUENTS (% wt.)
DISTANCE (m)
110
90
70
50
30
10
-10
-2000
0
2000
4000
6000
8000
10000
12000
14000

B

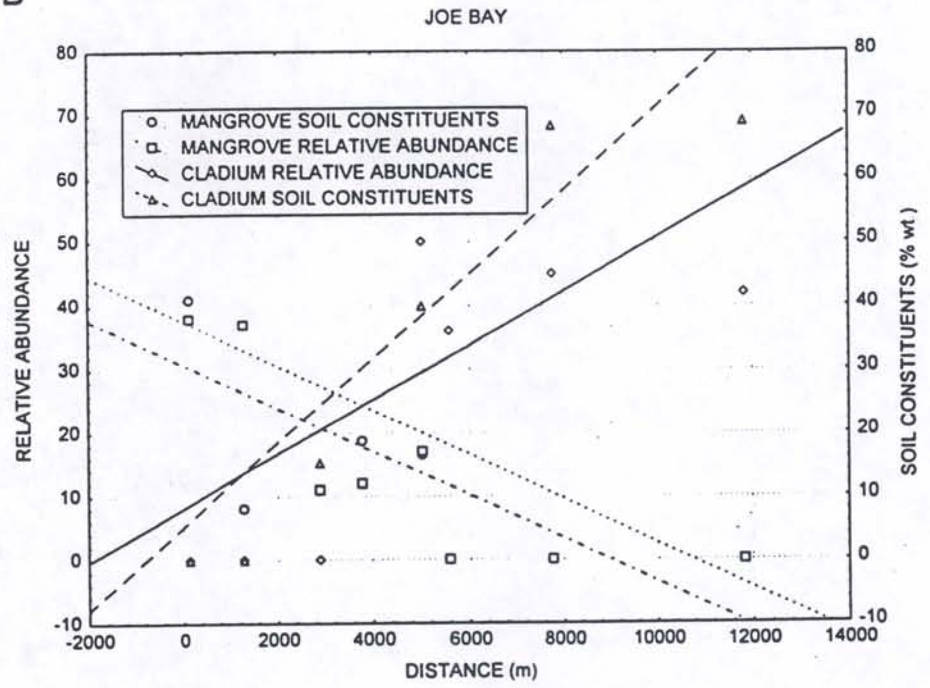

JOE BAY
MANGROVE SOIL CONSTITUENTS
MANGROVE RELATIVE ABUNDANCE
CLADIUM RELATIVE ABUNDANCE
CLADIUM SOIL CONSTITUENTS
RELATIVE ABUNDANCE
SOIL CONSTITUENTS (% wt.)
DISTANCE (m)
80
70
60
50
40
30
20
10
0
-10
-2000
0
2000
4000
6000
8000
10000
12000
14000

Figure 22. Coastal slopes for each transect.

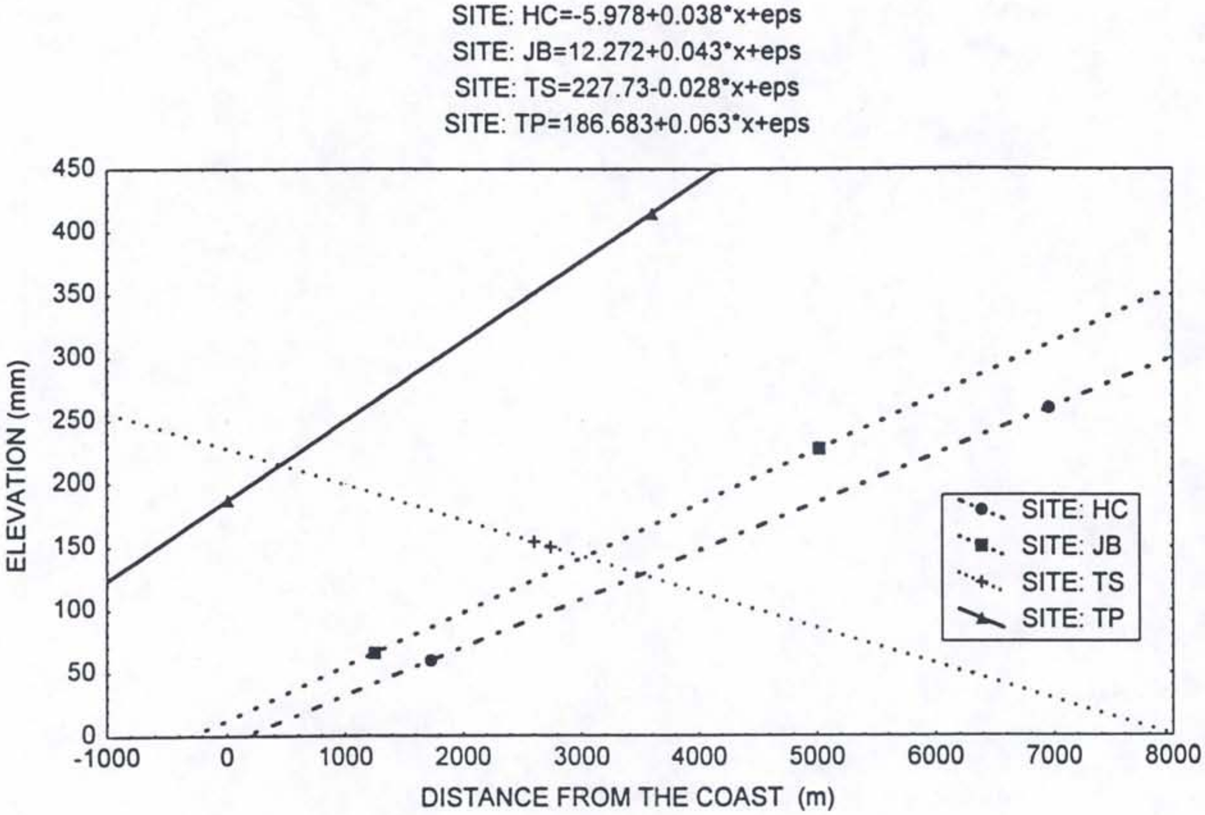

SITE: HC=-5.978+0.038*x+eps
SITE: JB=12.272+0.043*x+eps
SITE: TS=227.73-0.028*x+eps
SITE: TP=186.683+0.063*x+eps
ELEVATION (mm)
450
400
350
300
250
200
150
100
50
0
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
DISTANCE FROM THE COAST (m)
SITE: HC
SITE: JB
SITE: TS
SITE: TP

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

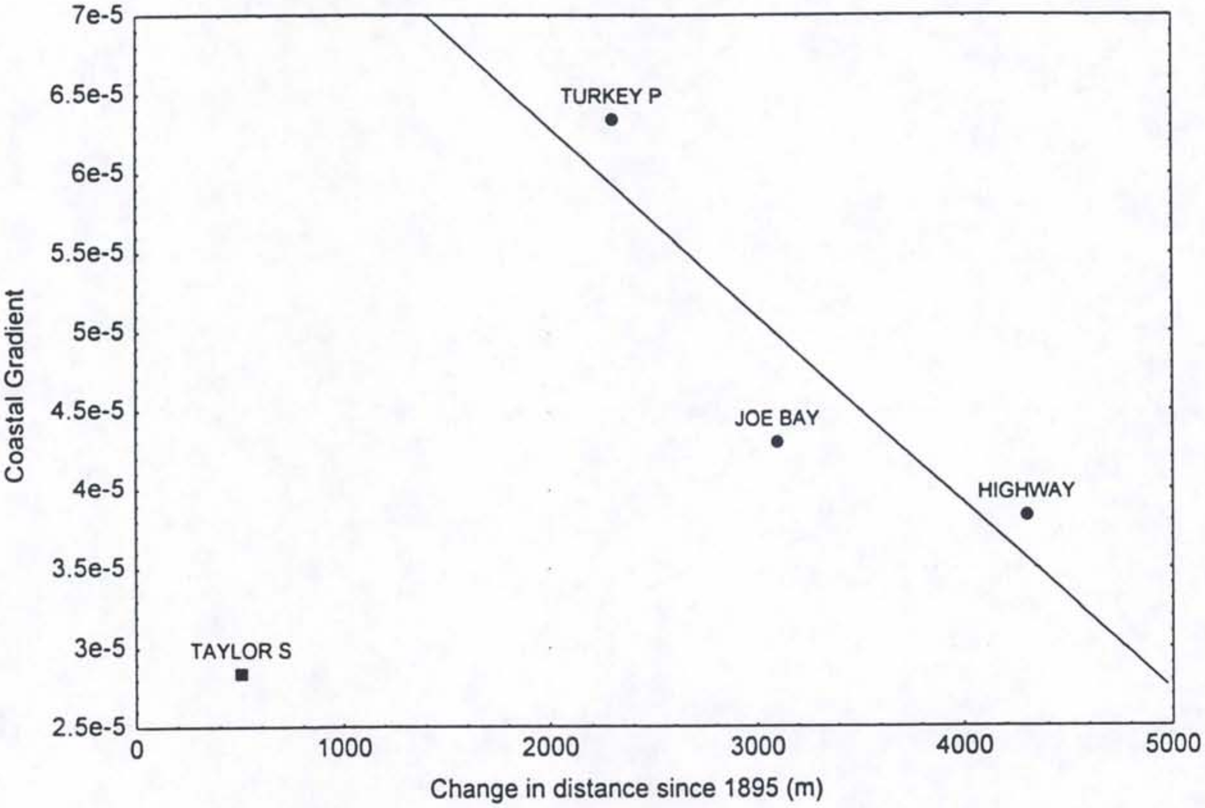

TURKEY P
JOE BAY
HIGHWAY
TAYLOR S
Coastal Gradient
7e-5
6.5e-5
6e-5
5.5e-5
5e-5
4.5e-5
4e-5
3.5e-5
3e-5
2.5e-5
0
1000
2000
3000
4000
5000
Change in distance since 1895 (m)

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).

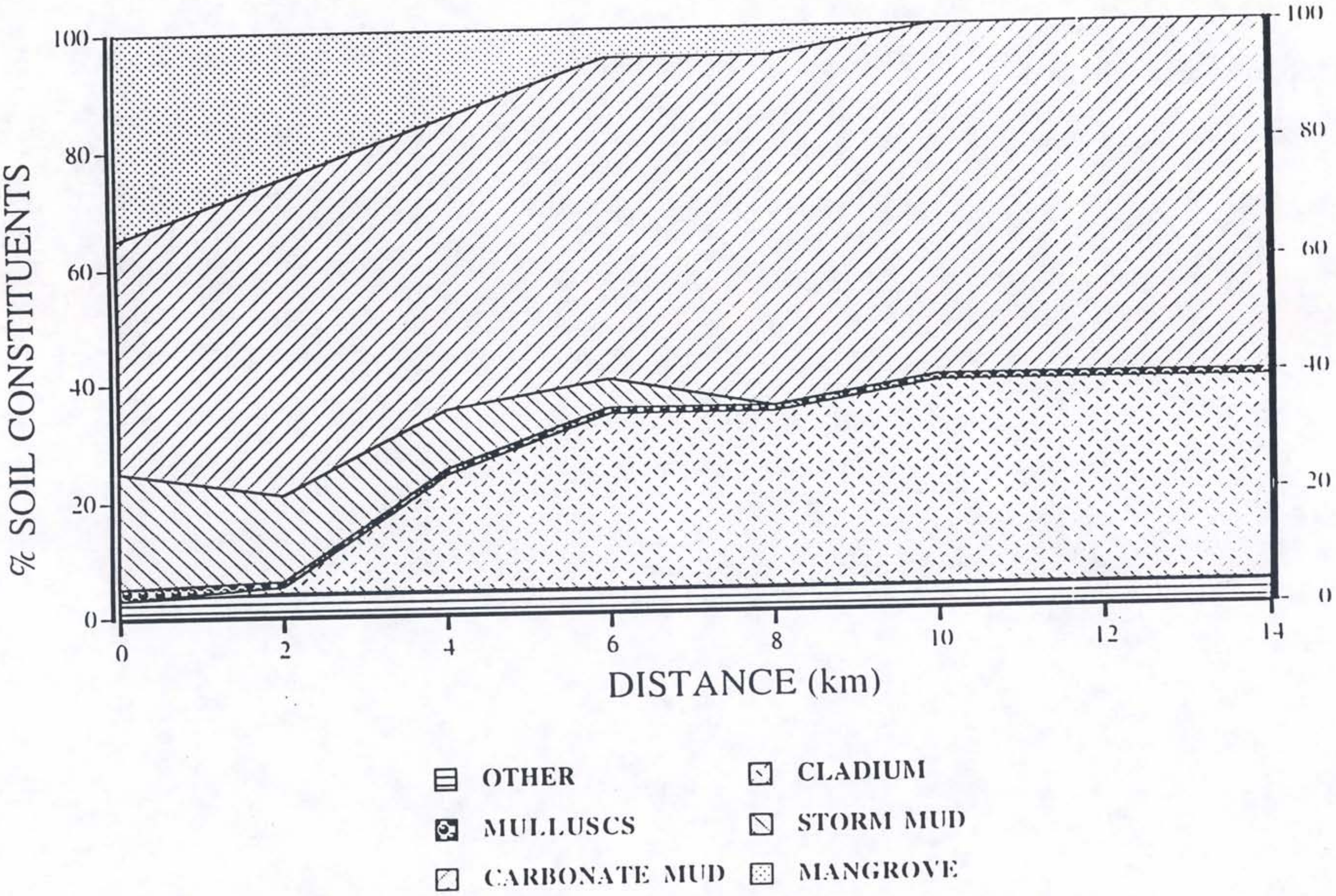

% SOIL CONSTITUENTS
100
80
60
40
20
0
0
2
4
6
8
10
12
14
DISTANCE (km)
100
80
60
40
20
0
▤ OTHER
▨ MULLUSCS
▨ CARBONATE MUD
▨ CLADIUM
▧ STORM MUD
▨ MANGROVE

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 areindicated by arrows numbered arrows (1 through 8)

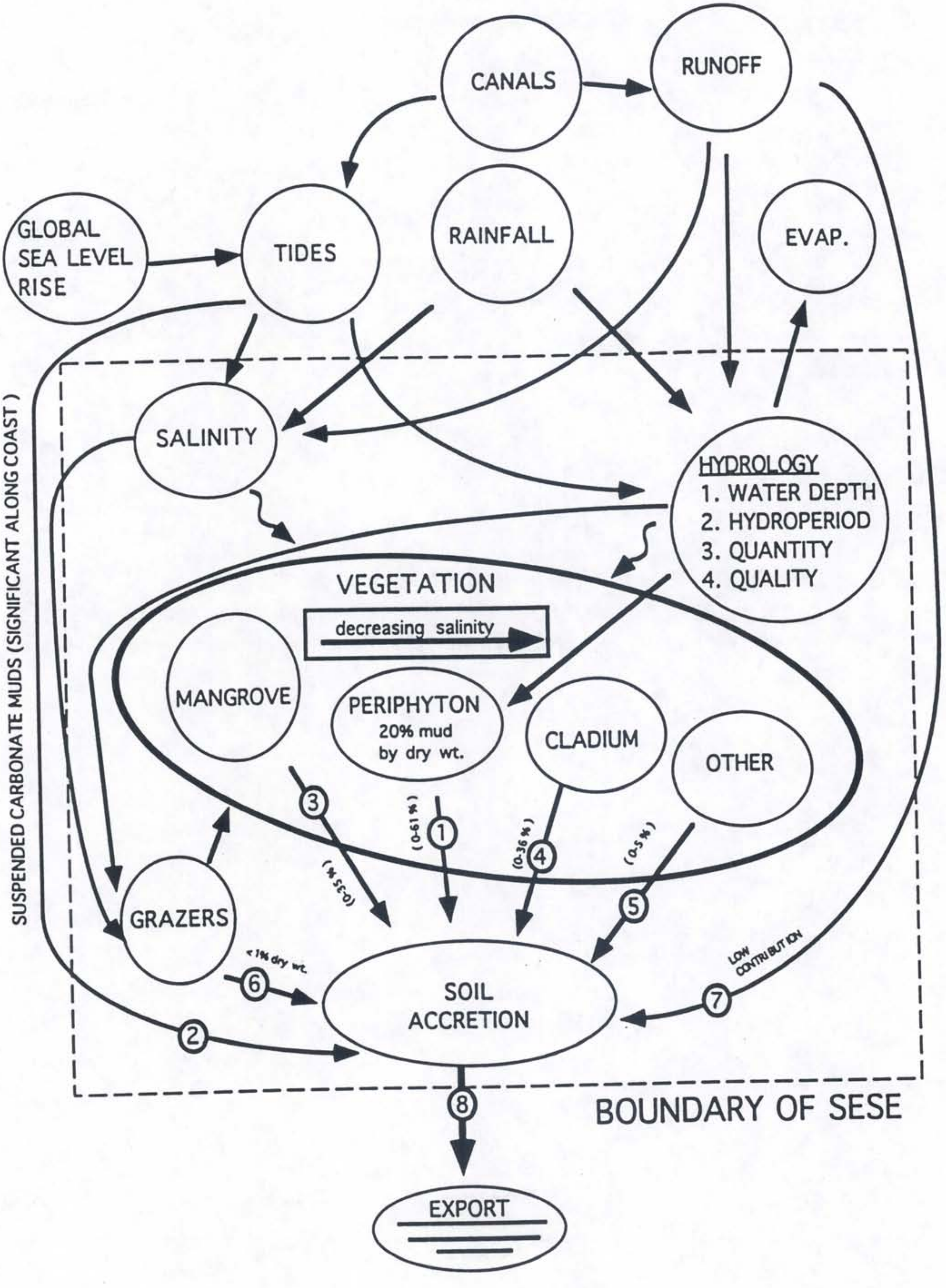
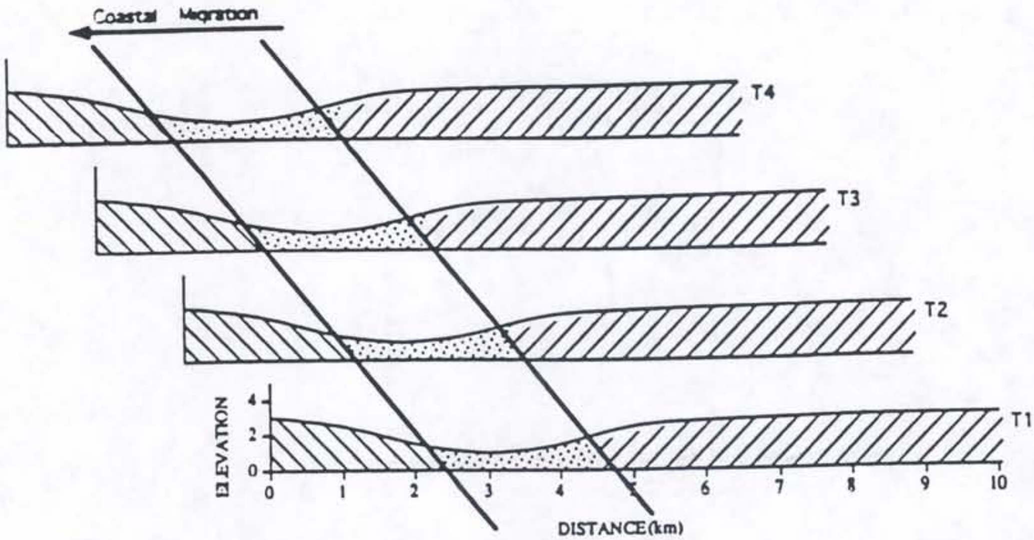
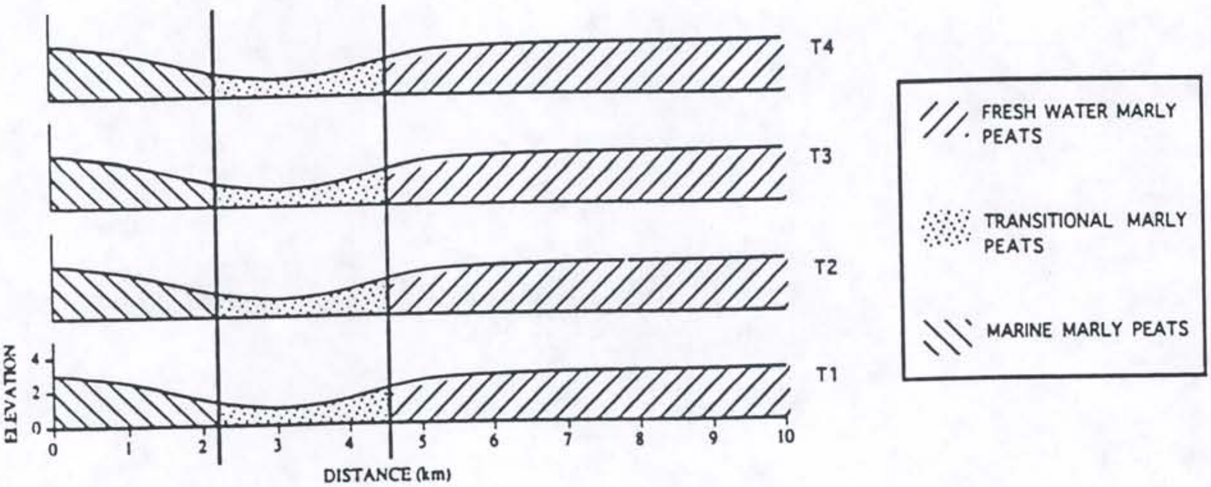

CANALS
RUNOFF
GLOBAL SEA LEVEL RISE
TIDES
RAINFALL
EVAP.
SALINITY
HYDROLOGY
1. WATER DEPTH
2. HYDROPERIOD
3. QUANTITY
4. QUALITY
VEGETATION
decreasing salinity
MANGROVE
PERIPHYTON
20% mud by dry wt.
CLADIUM
OTHER
(0-35%)
③
(0-61%)
①
(0-36%)
④
(0-5%)
⑤
GRAZERS
<1% dry wt.
⑥
SUSPENDED CARBONATE MUDS (SIGNIFICANT ALONG COAST)
②
SOIL ACCRETION
LOW CONTRIBUTION
⑦
⑧
BOUNDARY OF SESE
EXPORT

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 productity 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.

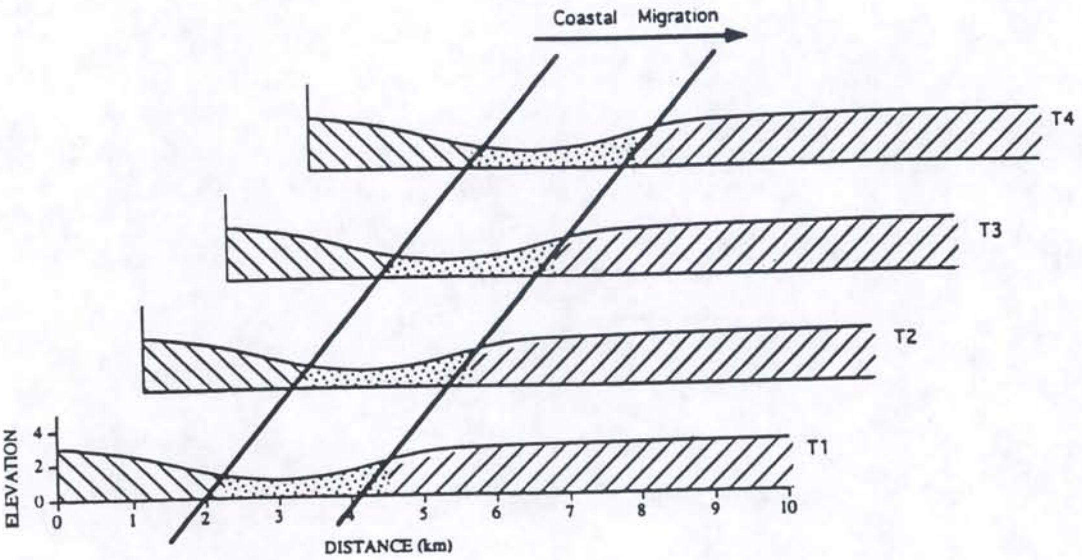


A. Progradation: regressive sequence

Stable Coastline - Lake Development



B. Equilibrium



C. Transgress sequence

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.

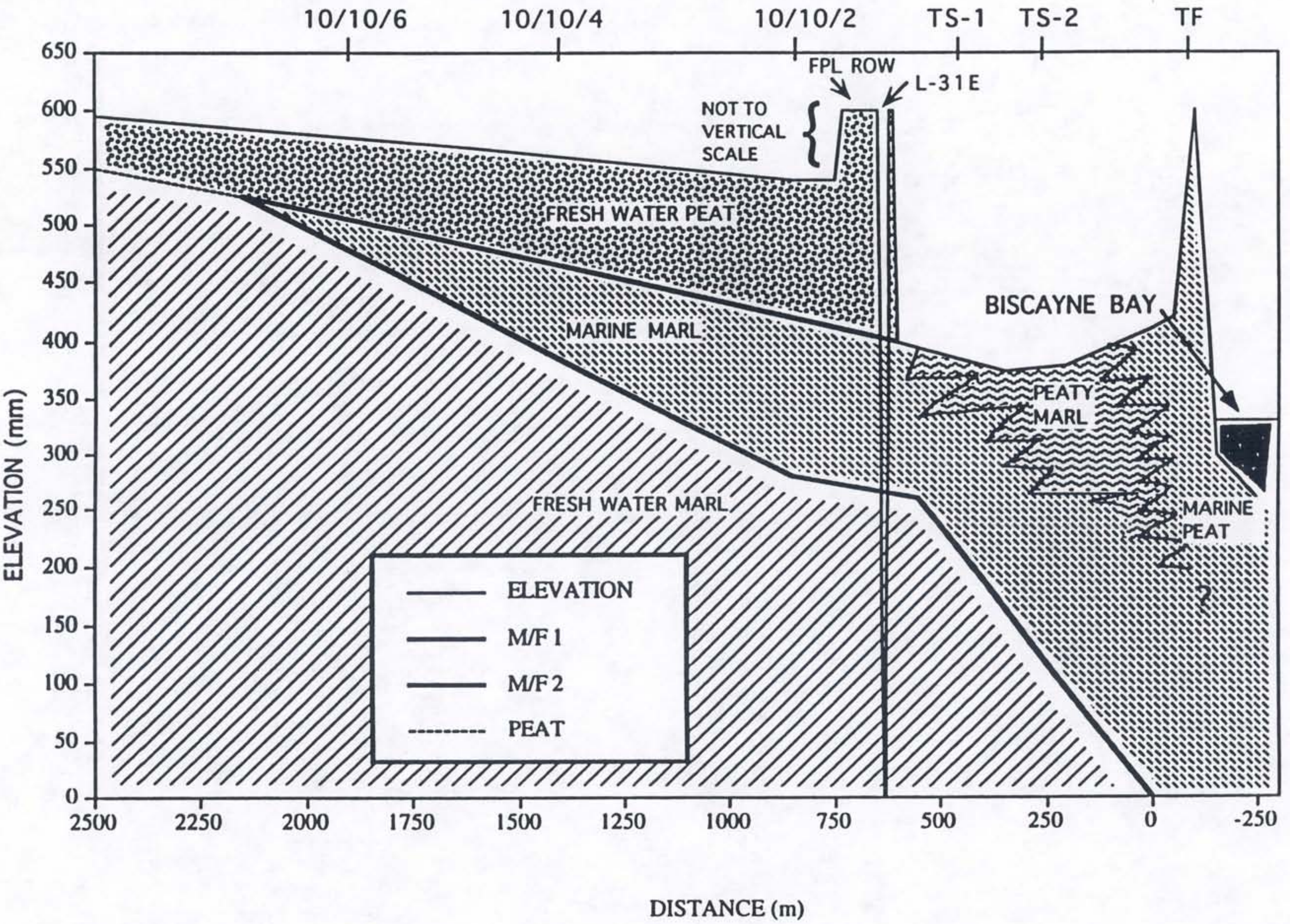

10/10/6
10/10/4
10/10/2
TS-1
TS-2
TF
FPL ROW
L-31E
NOT TO VERTICAL SCALE
FRESH WATER PEAT
MARINE MARL
FRESH WATER MARL
BISCAYNE BAY
PEATY MARL
MARINE PEAT
?
ELEVATION
M/F 1
M/F 2
PEAT
ELEVATION (mm)
650
600
550
500
450
400
350
300
250
200
150
100
50
0
DISTANCE (m)
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
-250

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

											peri	dominant plant species				
				elev.	dtb		bulk	%			BIO					tot
NAME	ABRV	LONG	LAT	(mm)	(cm)	dist (m)	den	org	S.I.	#1moll	(g/m2)	#1plant	#2plant	#3plant	#4plant	mang
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	utrfol12	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	utrfol1		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
I-1-2	na	80.4489	25 2794	nd	134	4385	0.16	11.3	1	physa	nd	clajam43	elecel26	rhiman22	utrpup7	22

											peri	dominant plant species				
NAME	ABRV	LONG	LAT	elev. (mm)	dtb (cm)	dist (m)	bulk den	% org	S.I.	#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	utrfol3	48
t-1-4	na	80.4478	25.2628	nd	141	2490	0.264	15.7	2.8	crenfla	nd	elecel61	rhiman13	fimcas5	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	utrfol7	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	utrfol30	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	utrfol7	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	*Biomphalaria havanensis*	1
2	*Cylindrella* spp.	1
3	*Laevapex peninsulae*	1
4	*Physella cubensis*	1
5	*Planorbella scalaris*	1
6	*Polygyra* spp.	1
7	*Pomacea paludosa*	1
8	*Littoridinops monoroensis*	1.5
9	*Pyrogophorus platyrachus*	2.5
10	*Cerithidea beattyi*	3
11	*Batillaria minima*	4
12	*Brachidontes exustus*	4
13	*Cyrenoida floridana*	4
14	*Littorina angulifera*	4
15	*Melampus coffeus*	4
16	*Terebra dislocata*	4.5
17	*Turbonilla* spp.	4.5
18	*Alvania* spp.	5
19	*Anomalocardia auberiana*	5
20	*Bulla striata*	5
21	*Caecum pulchellum*	5
22	*Carditas* spp.	5
23	*Chione cancellata*	5
24	*Chione latilirata*	5
25	*Corbula contracta*	5
26	*Lima pellucida*	5
27	*Marginella spp.*	5
28	*Meioceras nitidum*	5
29	*Retusa sulcata*	5
30	*Rissoina catesbyana*	5
31	*Strigilla carnaria*	5
32	*Tricolia bella*	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
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
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
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
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
43.9-44.9	44	.00	.00	.00	1.69	.00	.00	.00	.00	.00	.00	1.00	.00		.00	.00	.00	.00							.00
45.0-46.0	45			.00	.00		.00	.00	.00	.00	.00	.00	.00		.00	.00	.00	.00							

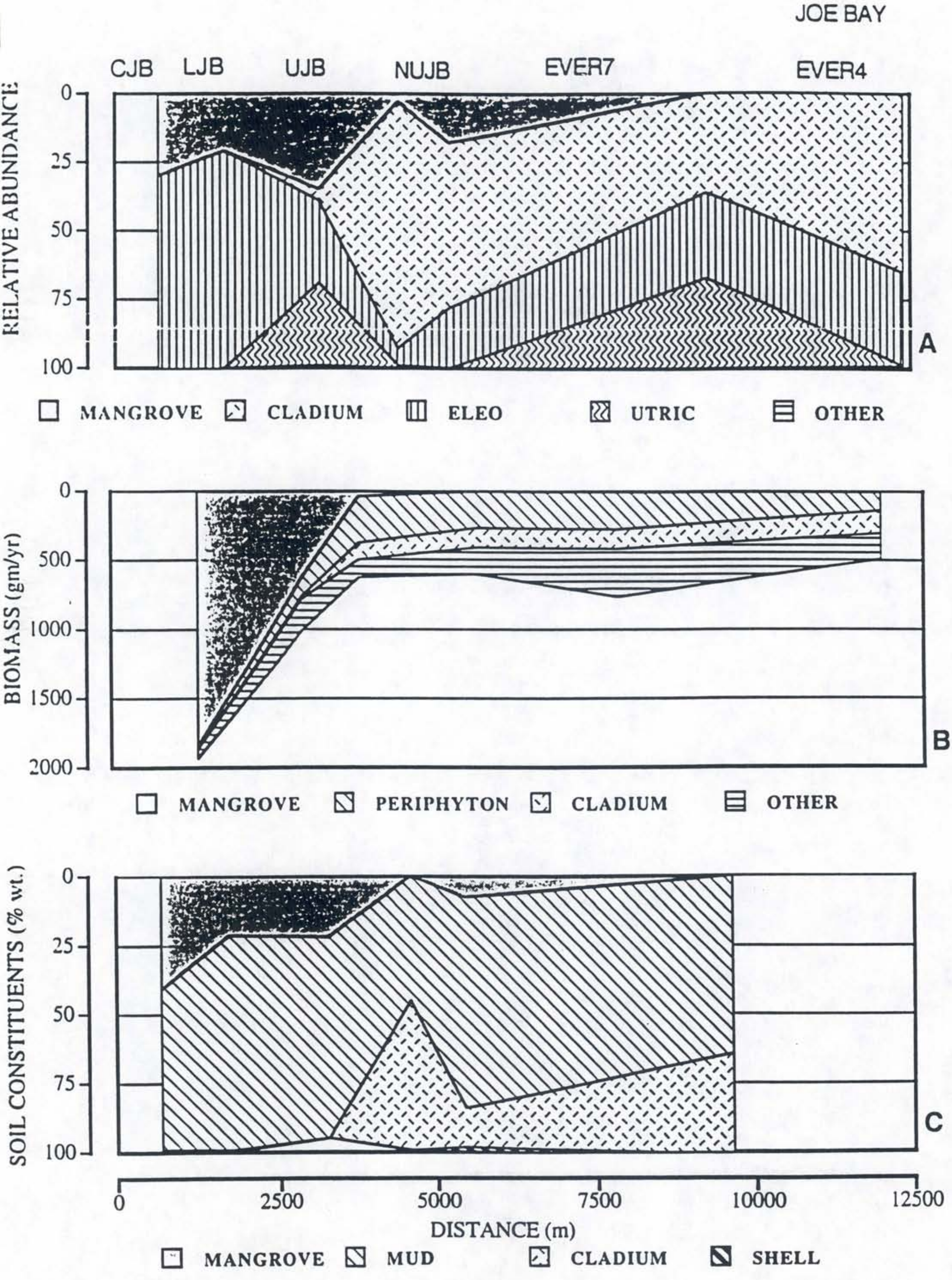

JOE BAY
CJB
LJB
UJB
NUJB
EVER7
EVER4
RELATIVE ABUNDANCE
0
25
50
75
100
A
MANGROVE
CLADIUM
ELEO
UTRIC
OTHER
BIOMASS (gm/yr)
0
500
1000
1500
2000
B
MANGROVE
PERIPHYTON
CLADIUM
OTHER
SOIL CONSTITUENTS (% wt.)
0
25
50
75
100
C
0
2500
5000
7500
10000
12500
DISTANCE (m)
MANGROVE
MUD
CLADIUM
SHELL

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. EP1r 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.

HIGHWAY CREEK

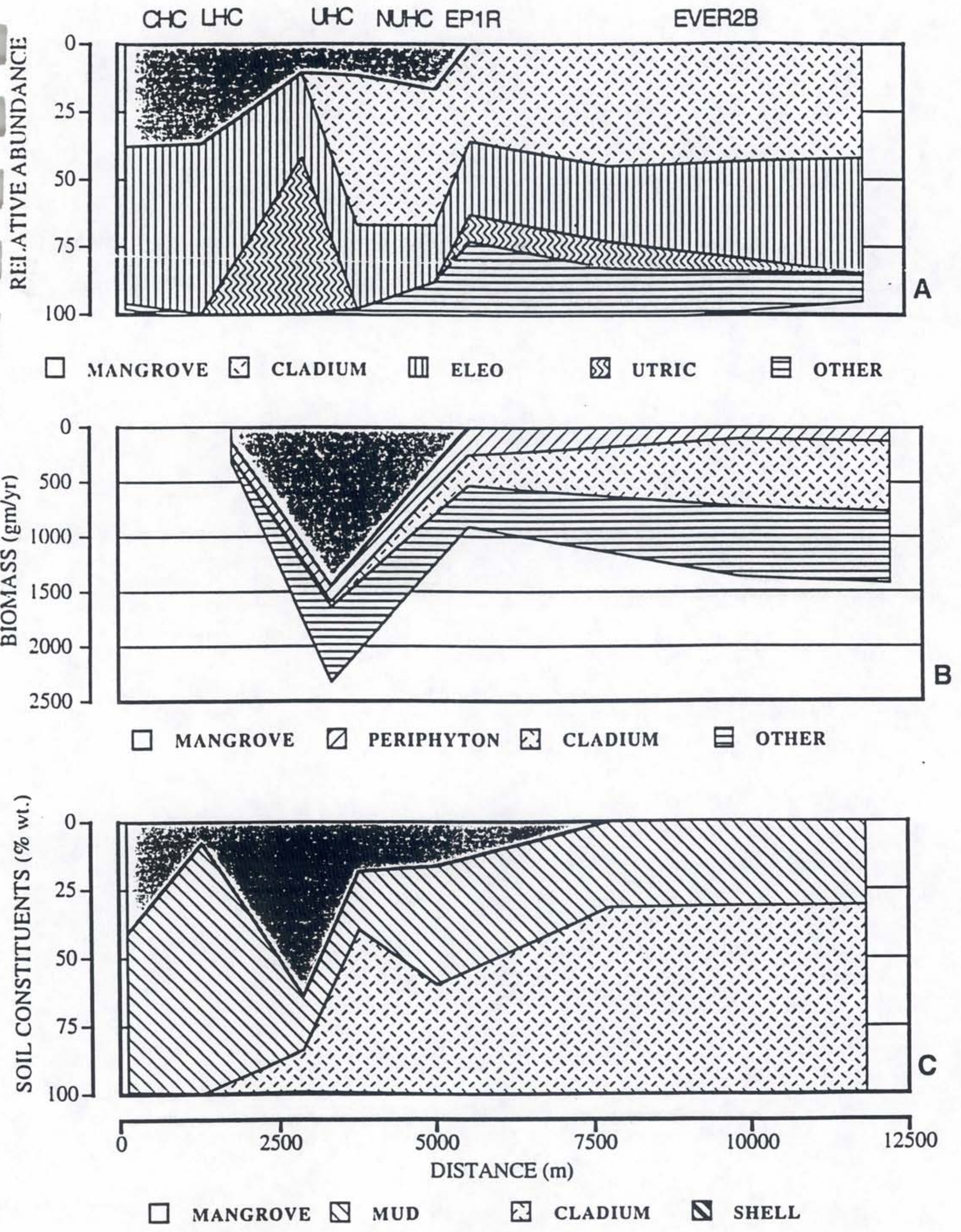


Figure 8. Vegetation and soil parameters plotted with distance from the coast along the Turkey Point Transect. Station locations along the transect are noted at the top: TPC = Turkey Point coastal. TP-EST = Turkey Point extreme east. TP-E = Turkey Point central. TP-INT = Turkey Point interior. and TPW = 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.

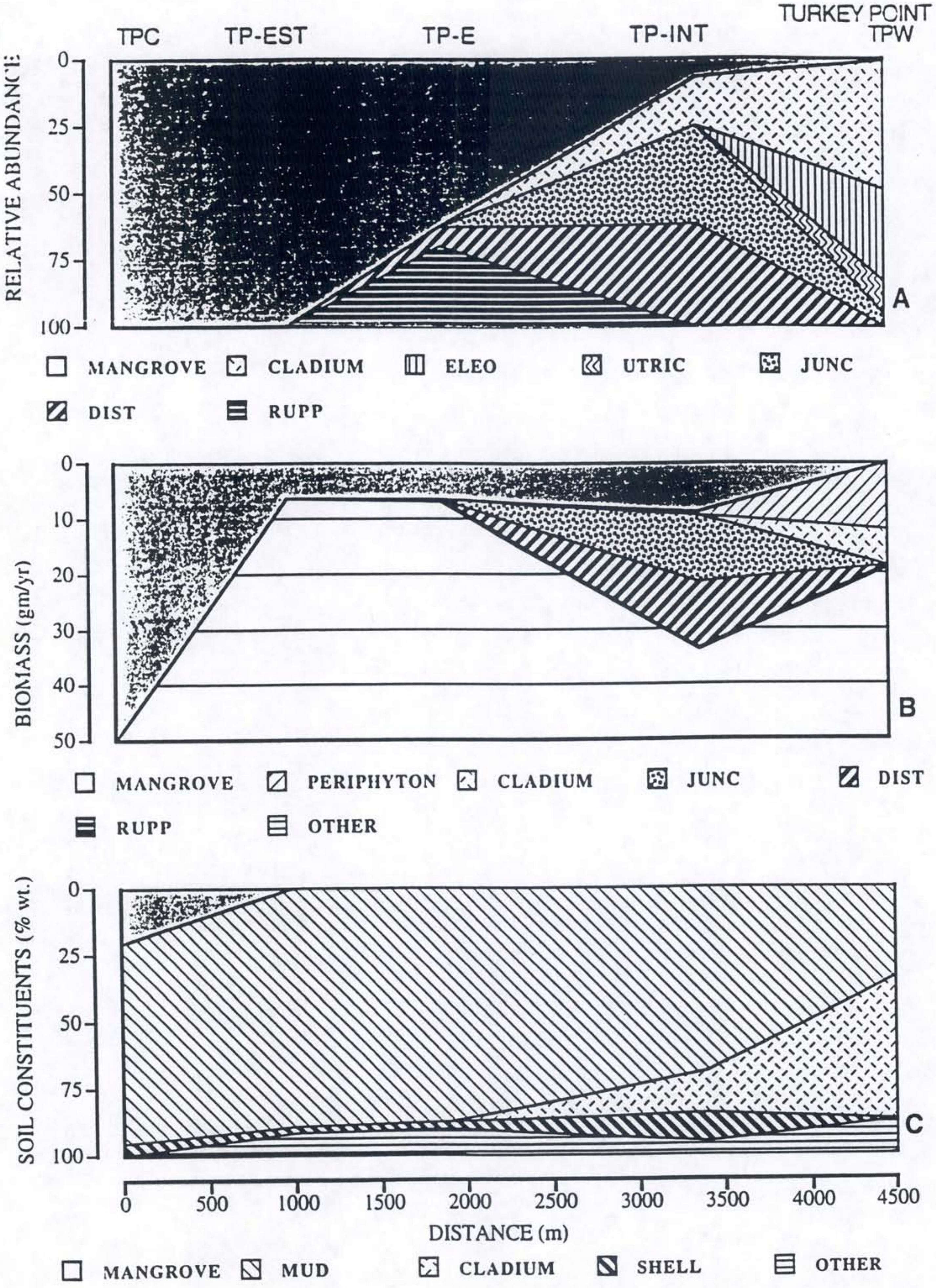

TURKEY POINT
TPC
TP-EST
TP-E
TP-INT
TPW
RELATIVE ABUNDANCE
0
25
50
75
100
A
MANGROVE
CLADIUM
ELEO
UTRIC
JUNC
DIST
RUPP
BIOMASS (gm/yr)
0
10
20
30
40
50
B
MANGROVE
PERIPHYTON
CLADIUM
JUNC
DIST
RUPP
OTHER
SOIL CONSTITUENTS (% wt.)
0
25
50
75
100
C
0
500
1000
1500
2000
2500
3000
3500
4000
4500
DISTANCE (m)
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.

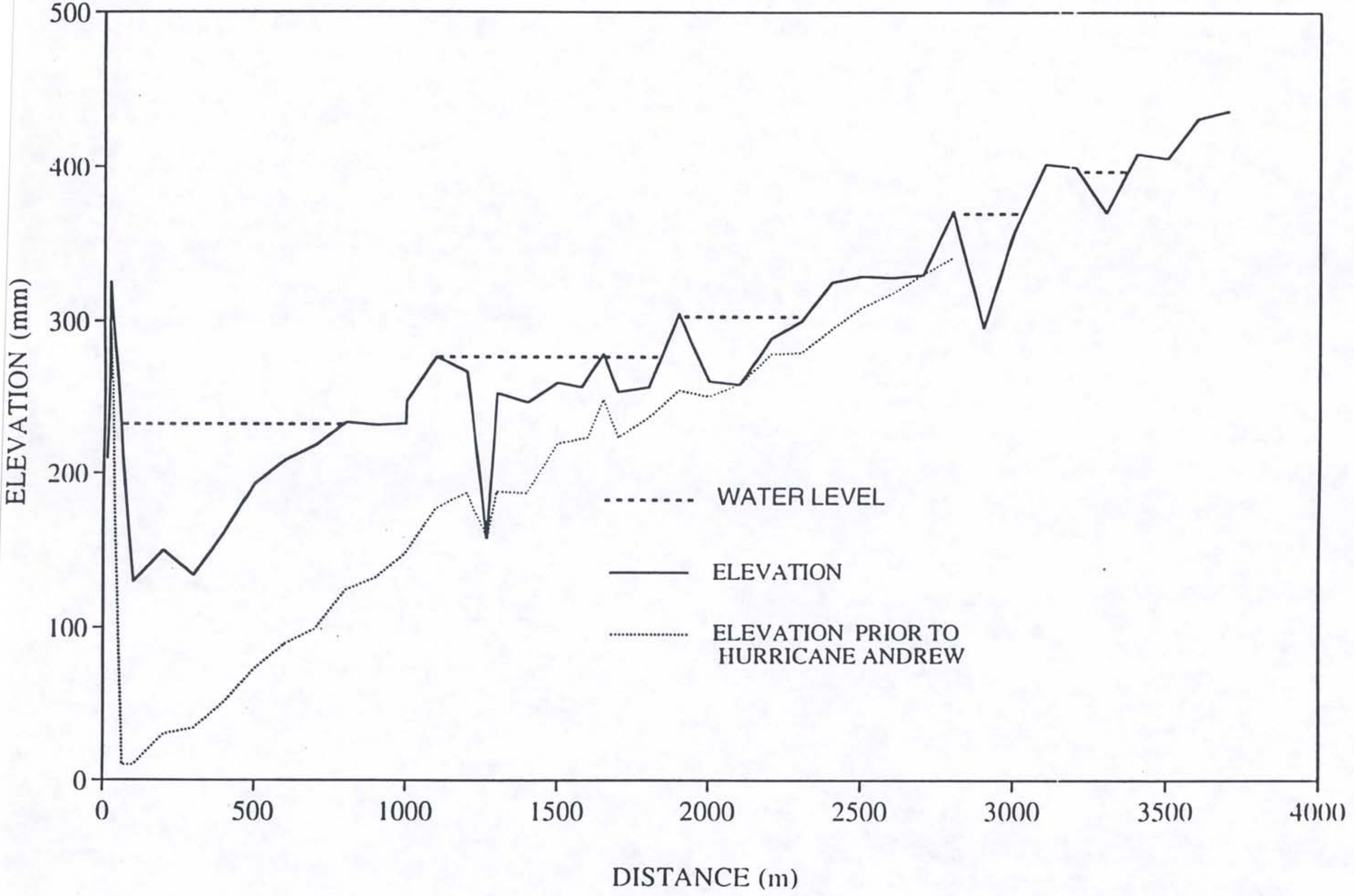

ELEVATION (mm)
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (m)
WATER LEVEL
ELEVATION
ELEVATION PRIOR TO HURRICANE ANDREW

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.

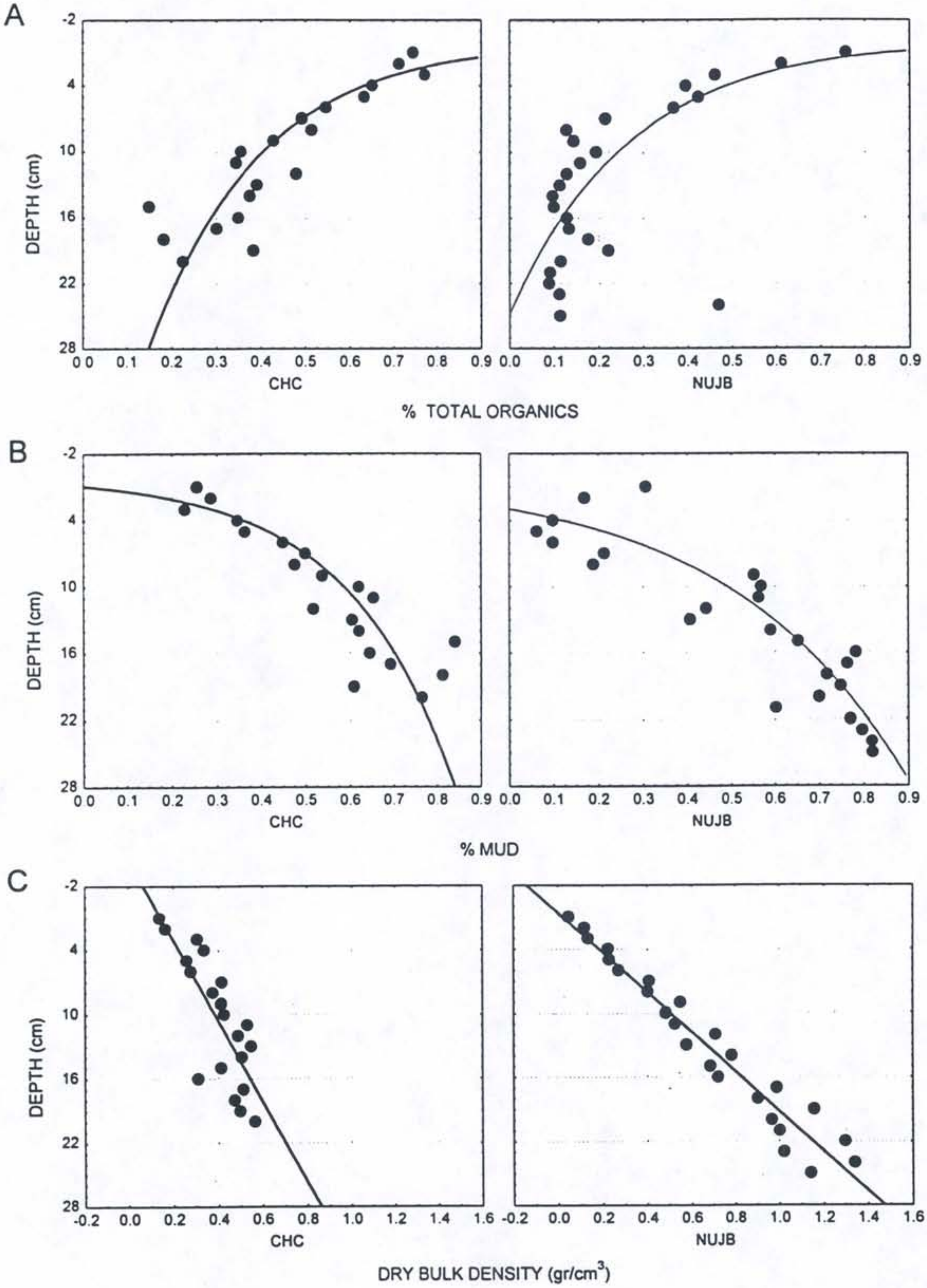

A
DEPTH (cm)
-2
4
10
16
22
28
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
CHC
NUJB
% TOTAL ORGANICS
B
DEPTH (cm)
CHC
NUJB
% MUD
C
DEPTH (cm)
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
CHC
NUJB
DRY BULK DENSITY (gr/cm³)

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).

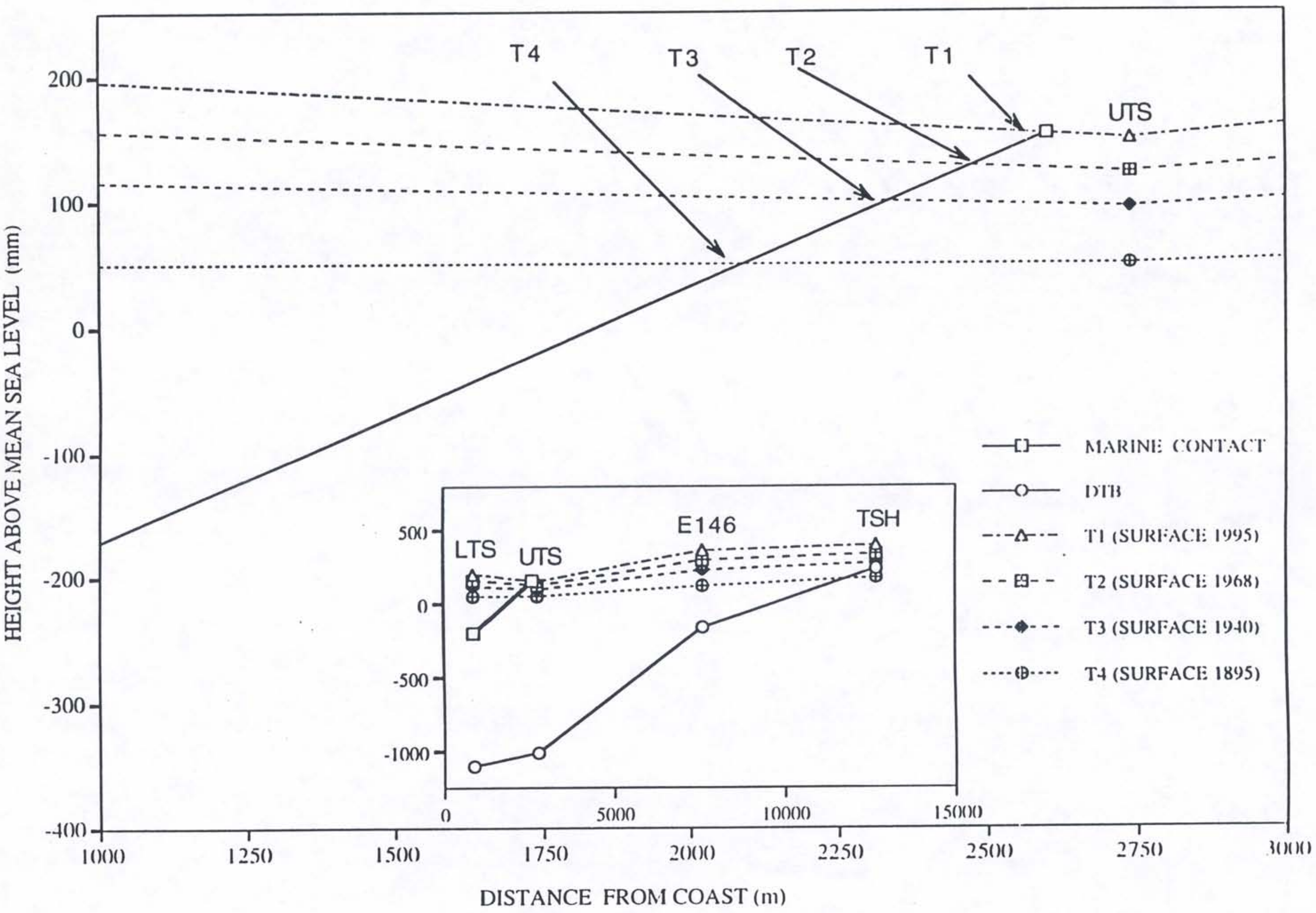

T4
T3
T2
T1
UTS
200
100
0
-100
-200
-300
-400
HEIGHT ABOVE MEAN SEA LEVEL (mm)
1000
1250
1500
1750
2000
2250
2500
2750
3000
DISTANCE FROM COAST (m)
MARINE CONTACT
DTB
T1 (SURFACE 1995)
T2 (SURFACE 1968)
T3 (SURFACE 1940)
T4 (SURFACE 1895)
LTS
UTS
E146
TSH
500
0
-500
-1000
0
5000
10000
15000

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).

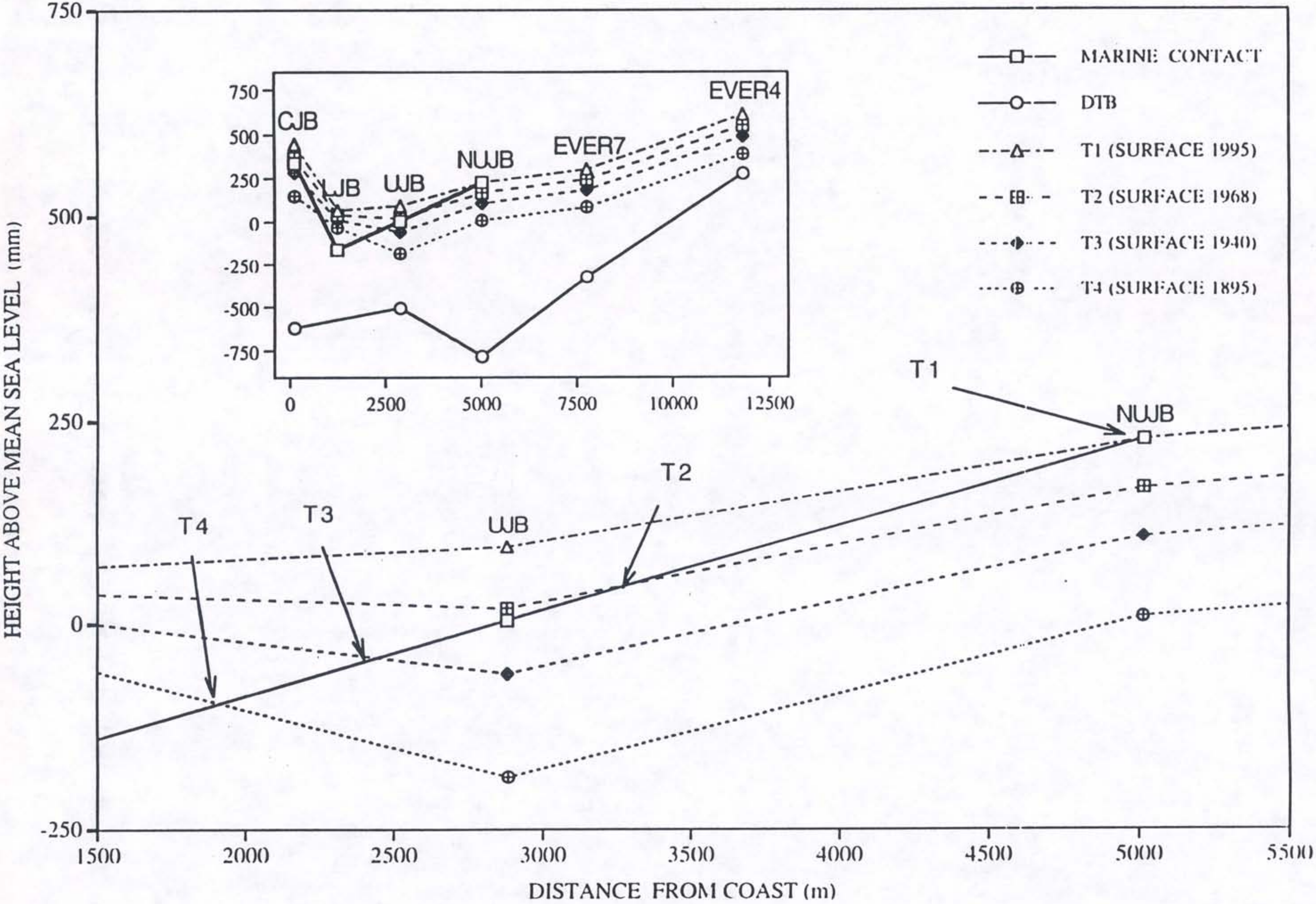

MARINE CONTACT
DTB
T1 (SURFACE 1995)
T2 (SURFACE 1968)
T3 (SURFACE 1940)
T4 (SURFACE 1895)
CJB
LJB
UJB
NUJB
EVER7
EVER4
750
500
250
0
-250
-500
-750
0
2500
5000
7500
10000
12500
T1
T2
T3
T4
UJB
NUJB
HEIGHT ABOVE MEAN SEA LEVEL (mm)
750
500
250
0
-250
1500
2000
2500
3000
3500
4000
4500
5000
5500
DISTANCE FROM COAST (m)

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).

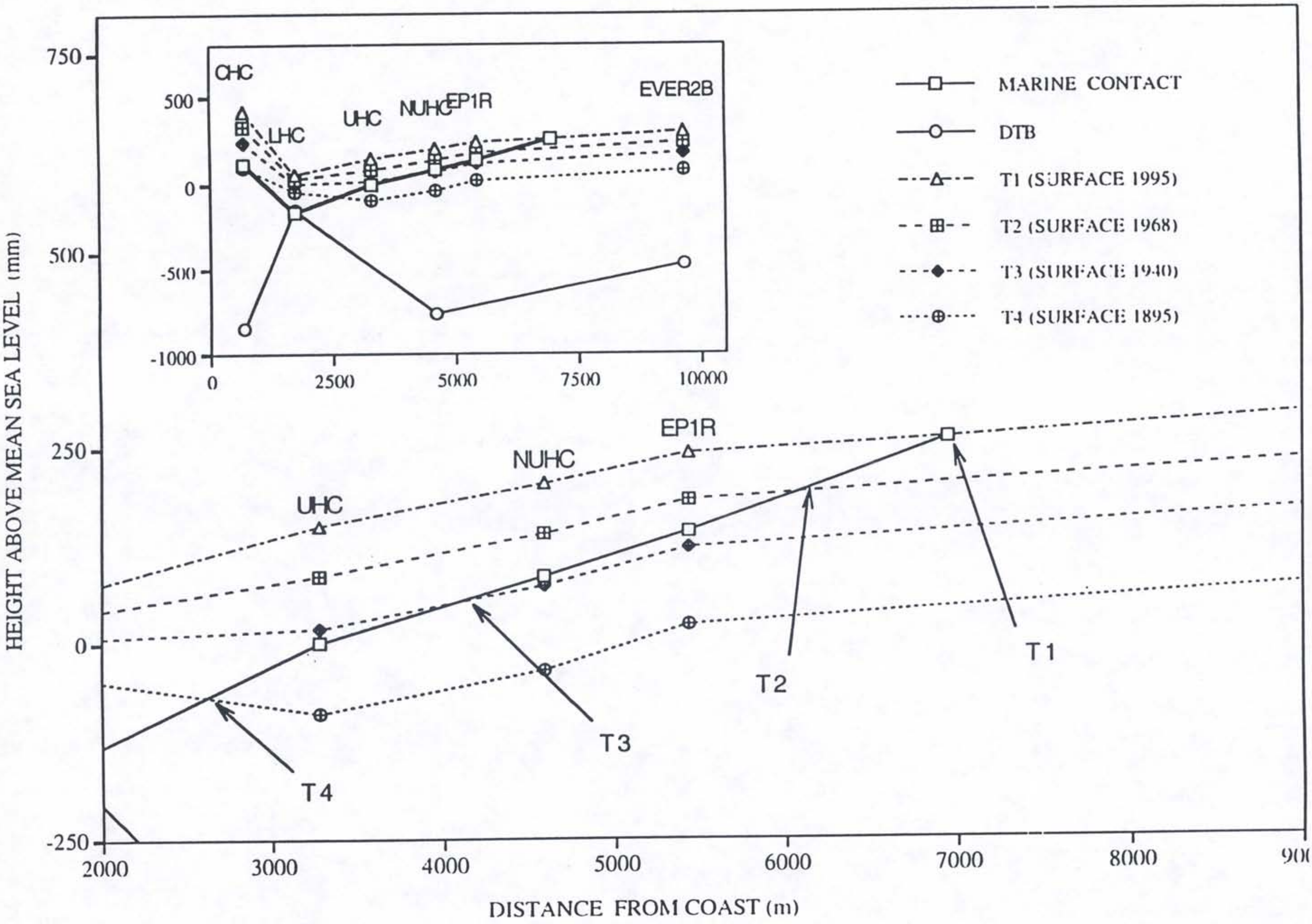
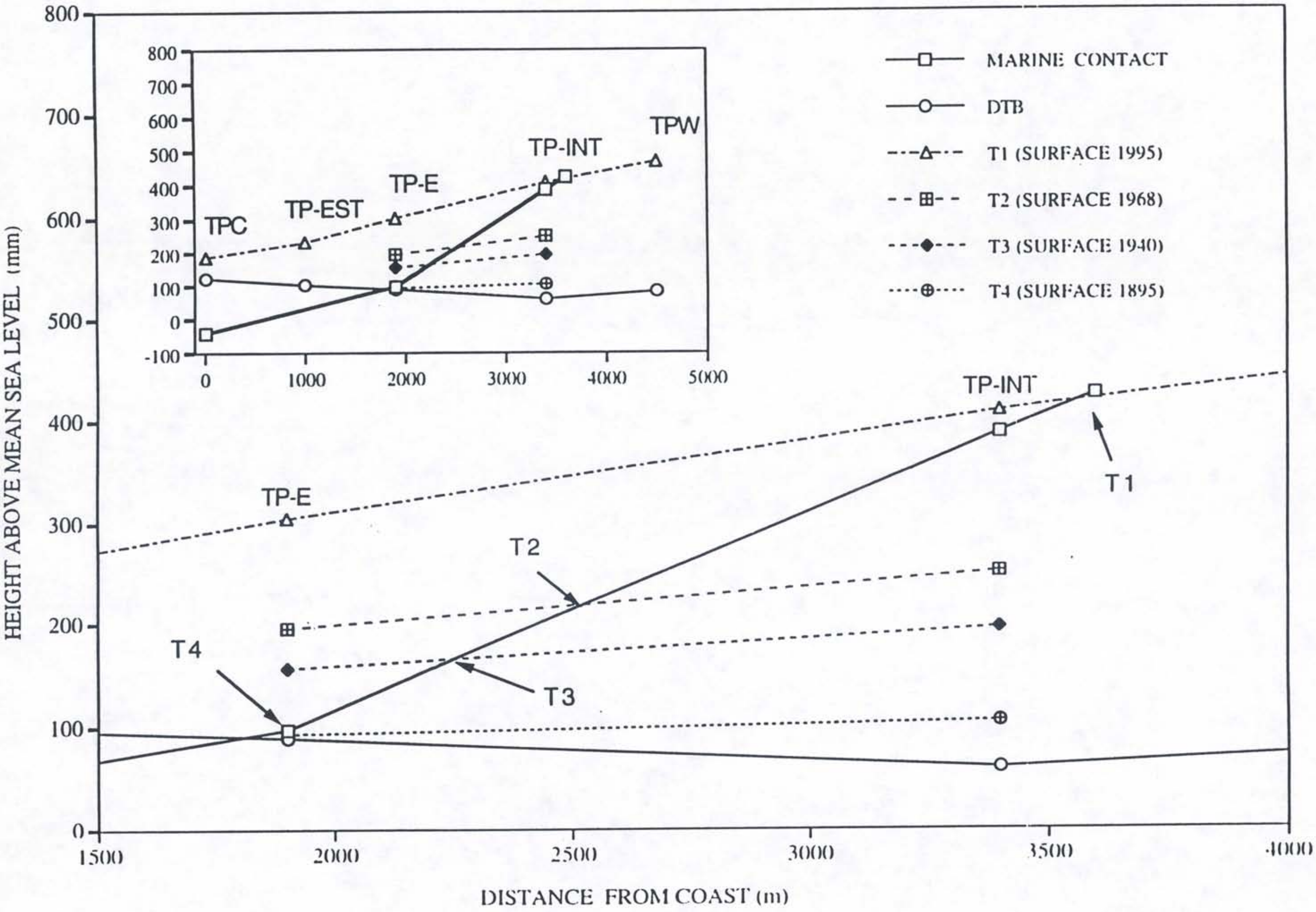

CHC
LHC
UHC
NUHC
EP1R
EVER2B
500
0
-500
-1000
0
2500
5000
7500
10000
MARINE CONTACT
DTB
T1 (SURFACE 1995)
T2 (SURFACE 1968)
T3 (SURFACE 1940)
T4 (SURFACE 1895)
UHC
NUHC
EP1R
T1
T2
T3
T4
750
500
250
0
-250
2000
3000
4000
5000
6000
7000
8000
9000
HEIGHT ABOVE MEAN SEA LEVEL (mm)
DISTANCE FROM COAST (m)

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).


800
700
600
500
400
300
200
100
0
HEIGHT ABOVE MEAN SEA LEVEL (mm)
1500
2000
2500
3000
3500
4000
DISTANCE FROM COAST (m)
MARINE CONTACT
DTB
T1 (SURFACE 1995)
T2 (SURFACE 1968)
T3 (SURFACE 1940)
T4 (SURFACE 1895)
TP-E
TP-INT
T1
T2
T3
T4
TPC
TP-EST
TP-E
TP-INT
TPW
800
700
600
500
400
300
200
100
0
-100
0
1000
2000
3000
4000
5000