SPATIAL AND TEMPORAL VARIATION IN PLANT COMMUNITIES OF THREE TIDAL SALT MARSHES ALONG THE YORK RIVER, VIRGINIA

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Dedication

In loving memory of my parents, who showed me the beauty of the natural world.

"He who can no longer pause to wonder and stand rapt in awe is as good as dead;
his eyes are closed." - Albert Einstein

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ABSTRACT

Data on marsh vegetation in three tidal salt marshes along the salinity gradient of the York River, Virginia were collected over a five year period. All three sites are components of the Chesapeake Bay National Estuarine Research Reserve /in Virginia and range over a salinity gradient of polyhaline to mesohaline to oligohaline. Data collection was done monthly from May through September each year from 1991 to 1995. Multiple transects were established at each of the three marsh sites, with 1m x 1m plots placed every ten meters along the transects. In all plots in each transect all plants were identified to species. Estimates of percent species cover and density counts were taken at each plot.

Species frequency, dominance, importance values, similarity indices, and diversity indices were calculated from density and cover data. Analysis of the plant communities among the three sites show them to be comparable in overall diversity and indices values. Shannon Diversity indices for the sites were: Goodwin Islands, 1.4; Catlett Islands, 1.3; and Taskinas Creek, 2.9; evenness indices were 0.54, 0.61, and 1.83 respectively. Three main species were dominant at each site, *Spartina alterniflora*, *Distichlis spicata*, and *Spartina patens*. Greater diversity is evident at smaller scales of transects within the sites, and plots within the transects. Multivariate analysis was used to examine temporal variation of community composition within and among sites and along a salinity gradient. Variation over time was looked at using Principal Component Analysis for the three dominant species. Results show that one main environmental variable explains most of the variation observed. A one dimensional salinity model of the York River was used for direct gradient analysis of salinity and vegetation data, using regression. R-square values of less than 0.2 and mostly less than 0.1 indicate no correlation.

The plant communities at the sites studied show interannual variation over the five year time period, with no correlation between salinity variation and vegetation community changes over that time.

SPATIAL AND TEMPORAL VARIATION IN PLANT COMMUNITIES OF THREE TIDAL SALT MARSHES ALONG THE YORK RIVER, VIRGINIA

Introduction

Salt marshes play an important role in the ecology of coastal and estuarine systems. They function as flood control systems, sinks for sediment, and habitat for water fowl and other species. Salt marshes serve to protect water quality of adjacent water bodies and play an important role in the life cycles of many commercially important fish and shellfish (Rozas and Hackney, 1983; Turner, 1977; Valiela et al., 1977). Historically, wetlands have been filled and converted to other uses, such as agriculture or urban development, throughout the country. In some places as much as ninety percent of historical wetlands have been lost to these conversions (San Francisco Estuary Institute, 1999) Because of the importance of wetlands and the extent of loss to date, the federal government in 1993 established "a no net loss policy" for wetlands (White House, 1993). This policy of avoiding loss includes protection or enhancement of existing wetlands, as well as compensatory mitigation for loss of wetlands. To help in accomplishing the overall goal of wetland protection a clear understanding of the successional processes that occur in wetlands and the relationship of these processes are to environmental factors is requisite.

Improved scientific understanding of successional processes may not come from more information on more variables, but from a better understanding of changes in spatial, temporal, and organizational scales (Bedford and Preston, 1988). For wetlands, that change in scale can mean moving from investigating an individual marsh to a project involving multiple wetlands in a watershed or basin area, or a landscape level project over time.

Wetlands do not exist in isolation, there are inputs, flows, and outputs. Examination of the larger spatial scale connects the wetland to the factors influencing, and influenced by, the wetland. Wetlands affect flood control and water quality along a river basin; they also make cover, nesting, or feeding habitat available for species that also utilize upland habitats or are migratory (Turner and Boesch, 1988; Vernberg, 1996). Variables that in turn influence the wetland include surrounding topography, land use, climatic variations, geology, soils and disturbance, among others. Changes in any part of the continuous hydrologic system will affect the wetland community and neighboring components.

Salinity changes affecting wetlands, whether due to relative sea level rise (RSLR) occurring from local subsidence or larger scale climate change, can bring about alterations in plant communities (Perry and Hershner, 1999). RSLR is the measured rise in mean sea level at a given point (DeLaune et al., 1983; Morris et al., 1990) and can occur for several reasons: eustatic increase in oceanic water volume from climatic warming, local subsidence due to isostatic changes or local aquifer withdrawal, or lack of sediment input (Gornitz et al., 1982; Morris et al., 1990). Rise in sea level has become an important factor in wetland survival in places such as Louisiana where many acres of wetland are lost each year to inundation (DeLaune et al., 1987b & 1990). Climate change can also alter salinity; increased salinity may be due to loss of freshwater input during drought, decreased salinity may occur during years of high precipitation. Changes in salinity, either increases or decreases will alter plant community structure.

Observations of change within tidal wetland plant communities over time periods of several years may provide a model of vegetation dynamics and trends occurring in that plant community (Perry and Atkinson, 1997; Perry and Hershner, 1999). Evaluation of these trends allows us to determine if environmental variables, such as salinity, correlate to changes in the plant community (Brewer and Grace, 1990; Shaffer et al, 1992; Ter Braak, 1987). The purpose of this work is to evaluate the spatial and temporal variation of vegetation data collected in three tidal wetlands along a salinity gradient in the York River during the growing season over a five year period (1991 - 1995).

Literature Review

Succession

Succession is defined as "the sequence of communities that develops in an area from the initial stages of colonization until a stable mature climax community is achieved" (Martin et al, 1996). The term "climax community" indicates a community in which a dynamic equilibrium has been achieved between the vegetation and the environmental variables that enable this community to maintain its character (Barbour et al., 1987; Mitsch and Gosselink, 1993).

Primary succession is the establishment of plants on land that was not previously vegetated. This new land may result from landslides, volcanic activity, storm deposition, mining, ice scour, or other activities that expose new land surfaces where vegetation has not previously existed. Pioneer species colonize the site and may facilitate colonization by other species (Barbour et al., 1987).

Secondary succession is the invasion of land that has been previously vegetated, the previous vegetation having been removed by natural or human disturbance such as storm wash, logging, cultivation, or fire (Barbour et al., 1987). The exposed land surface usually has more nutrients remaining than the new land surface in primary succession; this allows secondary succession to proceed at a rate 5 to 10 times that of primary succession (Major, 1974). Secondary succession also occurs when one species outcompetes another due to changes in environmental variables, as when *Spartina alterniflora* replaces *Spartina patens* due to local subsidence (Shumway, 1991; Shumway and Bertness, 1992; Teal, 1986). The incursion of invasive species is also a form of secondary succession. The invader may rapidly occupy a vacated niche or out-compete its neighbor resulting in a gain or loss in species diversity (Mooney and Drake, 1989).

Clements (1916) is generally cited as the originator of the debate over succession, its definition and its processes. He visualized it as several discrete seral (successional) communities which undergo changes together in such a way that new species are at a competitive advantage as they supplant the previous community. This process, termed relay floristics, continues until a climax community is reached that continues indefinitely, preventing the invasion of other species.

Gleason (1926), however, concluded that changes in species abundance and presence occurred so gradually that it was not practical to divide the vegetation into discrete seral communities. He saw the vegetation community as the result of chance immigration of plants and variable environmental conditions, resulting in an individualistic rather than community successional model.

The succession discussion continued throughout the twentieth century to include initial floristic composition (chance determines which propagules are present at the onset of succession) (Egler, 1954; McCormick, 1968); the triple models of facilitation (an updated relay floristics), tolerance (a version of initial floristic composition) and inhibition (an inversion of relay floristics using allelopathy to inhibit succession) proposed by Connel and Slayter (1977); and a model based on resource use and availability as the driver of succession (Tilman, 1985). All of these were based on the Clementsian model. There were also proponents of the Gleasonian school of succession: Billings' (1949) studies in Nevada fit this model, as did studies in conifer forests (Whittaker, 1960) and arctic tundra species (Chapin, 1985).

A major factor behind succession is the effect the plants themselves have on their habitat. Plants cast shade, add litter, dampen temperature oscillations, and their root mass accumulates over time, changing the soil structure and chemistry with the increase in organic material. Wetland plants allow sediment to deposit out of the water column by creating friction (Mitsch and Gosselink, 1993). Tansley (1935) called this autogenic (biotic) succession. Some of these modifications put seedlings of other species at a disadvantage, or adversely affect established plants, thus allowing one species to outcompete another. Plants in some situations determine the direction of succession.

Abiotic factors (environmental variables not influenced by the vegetation) also affect succession; this is termed allogenic succession (Barbour et al., 1987; Mitsch and Gosselink, 1993). Changes in topography, sea level, or fluctuating meanders in a river are factors beyond the control of the plant community. But they can have profound effects on the types of vegetation able to survive in a given area. The plant community of a tidal wetland in Chesapeake Bay is generally inundated by tides twice daily; this tidal overwash may bring nutrients, deposit or remove wrack, affect where invertebrates dwell, or leave sediment behind as it ebbs (Frey and Bassan, 1985; Wiegert and Freeman, 1990). Local subsidence due to groundwater withdrawal may cause the wetland to be completely inundated continually, causing vegetation to change or die and open water spaces to increase (DeLaune et al., 1987b)

Succession in wetlands

The debate over successional models has not excluded wetlands; succession in wetlands has been attributed to both Clementsian (Gaudet, 1977) and Gleasonian models (Van der Valk, 1981). Van der Valk (1981) particularly makes the case for Gleasonian succession in wetlands with an allogenic model. He argues that the physical environment acts as a variable sieve that allows one to predict whether a species will be present or not in the wetland by its presence in the seed bank, and by environmental conditions affecting germination and growth.

Van der Valk's model does not specifically allow for autogenic mechanisms of succession. However it is usually a combination of biotic and abiotic factors that drive succession. Salt marshes maintain elevation or accrete sediment in part by retaining organic material grown in place (autogenic succession) (Hackney, 1987; Kearney and Ward, 1986; Mitsch and Gosselink, 1993). But they may also need inorganic sediments brought in by the tide to provide minerals and stabilize the soil (allogenic succession) (DeLaune et al., 1983; DeLaune et al., 1990). A combination of factors is demonstrated by how the vegetation in the salt marsh slows the rate of flow of the tide across the marsh, allowing more time for flocculation and sedimentation to occur, thus increasing the sediment deposition in the marsh (Shi et al., 1996). A particular salt marsh represents a combination of both allogenic and autogenic processes unique to the environment it exists in.

Wetlands plants often grow very dense, occupying available space and resources. Disturbances, on small or large scales, open space and free resources for expansion and recruitment of new vegetation. On the small scale (less than $1m^{2)}$ secondary succession is often determined by competition (Shumway and Bertness, 1994). Small scale vegetation patterns can be dynamic, influenced by a number of environmental factors including salinity (Mahall and Park, 1976; Snow and Vince, 1984), hydroperiod, substrate, nutrient availability, storm effects, and local subsidence, as well as anthropogenic contributions (Niering and Warren, 1980; Vince and Snow, 1984). For example, Perry (pers. com.) noted the increased growth of plants around a marker post in a tidal salt marsh. It has been observed that birds use these as perches leading him to hypothesize that the extra nutrients supplied by their feces may have lead to increased plant growth in the area around the post.

Secondary succession after disturbance on a larger scale (greater than 1m^2) is influenced by many of these same factors, but also by other factors (Bertness & Shumway 1993; Shumway & Bertness 1992). Shumway (1991) described a complex secondary succession in a hypersaline environment of bare patches in a salt marsh. While the environment was too saline for most marsh plants to germinate, glasswort (*Salicornia sp.*) thrives in hypersaline bare patches. Spikegrass (*Distichlis spicata*) moves in shortly after through asexual means and survives through rhizomal connections. The external rhizomal connections bring water to the plant from outside the hypersaline patch. The spikegrass shades the soil, reducing evaporation, which in turn reduces salinity. As the salinity decreases glasswort declines and other high-marsh plants are able to germinate in the site.

Succession is an ongoing process, continuing over time. But the results of this process at a given point in time determine the makeup or type of a given wetland community.

Wetland plant communities

The names of different wetland types (communities), ie. bog, swamp, marsh often appear with a dominant plant name, as in sphagnum bog, cypress swamp, or cordgrass marsh (Mitsch and Gosselink, 1993). This qualitative identification of dominant plant type has been supported in some cases by semi-quantitative analysis (Chabreck, 1972). But community as a concept is subject to the perspective of scale; looking at a large area may present one picture of dominant community type, while examination of many smaller areas within the larger one shows a patchwork of vegetation within this landscape.

Salt marsh community vegetation in the mid-Atlantic region has been observed to follow the pattern of low marsh at the water's edge with high marsh as you move inland (Figure 1). *Spartina alterniflora* tall form dominates the intertidal zone, with *Spartina alterniflora* short form inland slightly from the water's edge. As the elevation of the marsh increases slightly landward, the vegetation community changes to being dominated by *Spartina patens* and *Distichlis spicata.* Salicornia species often colonize bare patches in higher saline areas. *Iva frutescens*, *Borrichia frutescens* and *Juncus romerianus* can also be found in high marsh areas grading to upland (Adams, 1963; Brinson, 1993; Chalmers, 1982; Niering and Warren, 1980). Moving up river along a decreasing salinity gradient the community begins to change. The more halophytic species disappear and species that can tolerate more brackish conditions appear. The species that can survive over a broad range of salinities are retained (Odum, 1988; Perry and Atkinson, 1997).

Salinity, sea level rise, and wetlands

Historical changes over long time periods give us information on the patterns of succession for salt marshes. Sixty five thousand years ago, when sea level was much lower, the area that is now Chesapeake Bay was a river valley and what is now the York River was a feeder stream emptying into it. As sea level rose during deglaciation the river valley was drowned and a bay formed, with the former streams becoming rivers (Finkelstein and Hardaway, 1988). The areas of present marsh coverage began to form about 3,000 years ago, after sea level rise slowed enough for accretion to keep up with the rate of rise (Finkelstein and Hardaway, 1988; Niering and Warren, 1980). Vertical accretion in the saline and brackish water marshes is primarily by peat accumulation (Finkelstein and Hardaway, 1988). Current accretion rates around Chesapeake Bay vary from 1.7 to 7.4 mm/year; generally enough to keep up with a local relative sea level rise of 3.9 mm/year (Brush, 1984; Kearney and Ward, 1986; Oertel et al., 1989; Stevenson et al., 1985).

Sea level rise may change the character of a plant community as saline waters move higher on the landscape and further up tidal channels. Salinity and periods of submergence may increase if sea level rises faster than accretion, causing physical and chemical changes that adversely affect the metabolism of the vegetation (Tolley and Christian, 1999). Increases or decreases in salinity or inundation period may result from events other than sea level rise, like storm events or drought. Periods of drought or water diversions may decrease freshwater input to a tidal system, thus effectively increasing salinity to previously brackish or fresh water areas. Above average rainfall from storms or changes in land use may decrease salinity by increasing freshwater input flow (Warren and Niering, 1993). Periodicity of inundation may be changed by local topographical alteration due to storm overwash or anthropogenic disturbance.

Salt-tolerant plants (facultative halophytes) have developed methods for coping with increased salinity not found in non-salt tolerant plants (glycophytes), including preferential uptake of less toxic ions, intracellular compartmentalization of compatible and incompatible solutes, translocation of ions to shoots, and/or extrusion of ions through salt glands in the leaves (Anderson, 1974; Ewing et al., 1995; Flowers, 1985). Increases in salinity beyond a specie's normal range stress the plant, changing its metabolism and ability to photosynthesize. Non-salt tolerant species will die out and others move in according to their tolerance for salt water. Increases in periods of submergence allow less oxygen to move into the pore spaces causing chemical changes in the plant (DeLaune et al., 1987a; Portnoy and Valiela, 1997); stresses that cause plants to die and more open water space to result (Van der Valk et al., 1994; Orson et al., 1985).

Hypotheses

H_1: Vegetation community types will exhibit significant small spatial scale changes and variations correlated to relative elevation and/or salinity changes over a five year time period.

H_0: Null hypothesis: there will be no significant change in the plant community composition at any of the sites over the five year period.

Methods

Site descriptions

The sites used in this study were located along the York River, Virginia, USA (Figure 2). All are components of the Chesapeake Bay National Estuarine Research Reserve, Virginia (CBNERRVA) and represent a salinity gradient range of polyhaline (Goodwin Island) to mesohaline (Catlett Island) to oligohaline (Taskinas Creek) (Figure 2, Table 1) (Perry and Atkinson, 1997). All sites have a similar semi-diurnal tidal range of about 0.67 - 1.1 meter (CBNERRVA, 1991).

Goodwin Islands is an archipelago of marsh and forested islands located at the mouth of the York River, York County, Virginia (Figure 3). The Islands are a ridge and swale system developed from a series of beach ridges deposited during a lowering of sea level approximately 65,000 years ago. Extensive salt marshes with both low and high marsh components characterize the complex. The reserve consists of a 314 hectare research core encompassing all the Goodwin Islands and a 336 hectare buffer zone.

Table 1. Physical descriptions of CBNERRVA sites used in this study (from Perry and Atkinson, 1997).

Site	Salinity Range (ppt)	Distance upstream (km)	Total size (ha)	Marsh size (ha)
Goodwin Islands	18.0-22.0	0.0	154.5	111.7
Catlett Islands	8.0-18.0	35.2	168.4	84.2
Taskinas Creek	0.5-8.0	44.4	210.7	33.6

The core area includes 23 hectares of upland forest, 3 hectares of needle-leaved forested wetlands, 12 hectares of broad-leaved forested wetlands, 117 hectares of emergent polyhaline wetlands, 36 hectares of intertidal flats, 4 hectares of scrub-shrub wetlands, 2 hectares of palustrine open water, 123 hectares of submerged aquatic vegetation beds, and 139 hectares of non-vegetated subaqueous bottoms. The buffer zone around the islands extends seaward from the core boundary out to a depth of 2.0 meters. Circulation patterns around the islands are influenced by discharge from the York River and polyhaline conditions prevail with salinities ranging from 16-22 parts per thousand (ppt) (CBNERRVA, 1991).

Catlett Islands are located on the north shore of the York River in Gloucester County, Virginia approximately 35 kilometers from the mouth of the river (Figure 4). They are also ridge and swale topography, possibly resulting from deposition of beach sediments parallel to the shore at successively lower stands of sea level approximately

65,000 years ago. The habitat on the island varies from emergent wetlands to forested ridges, forested upland hammock, tidal flats and tidal creeks. The marsh vegetation is classified as brackish water, mixed community type and broad-leaved, deciduous forested wetlands on the ridges, with one ridge being pine-hardwood upland forest. The reserve consists of a 311 hectare research core, which covers the entire Catlett Islands and a 89 hectare buffer zone. The core includes: 84 hectares of emergent mesohaline marsh, 76 hectares of broad-leaved forested wetlands, 8 hectares of forested upland hammock, and 146 hectares of submerged bottoms. The buffer zone extends seaward to a depth of 2.0 meters and includes 89 hectares of submerged bottoms. The circulation is strongly influenced by tidal currents and discharge from tidal creeks. Salinities range from 8-18 ppt, mesohaline conditions, and vary seasonally (CBNERRVA, 1991).

Taskinas Creek is located in James City County, Virginia on the south shore of the York River (Figure 5). It enters the York River 44 kilometers upstream from the mouth. Much of the watershed is contained within the York River State Park. Salinities within the reserve vary from 9-13 ppt at the mouth of the creek in the fall to 3-7 ppt in the spring. Taskinas Creek is tidal for most of its extent, but salinities gradually decrease to 0.5 ppt at the headwaters. The shoreline of the creek grades into steep uplands which are cut by feeder streams. The reserve consists of a 397 hectare research core within the park. The core includes 320 hectares of upland deciduous forest, 27 hectares of bottomland forest, 34 hectares of marsh, 15 hectares of intertidal flats and 0.5 hectare of creek bottom. The buffer zone contains 10 hectares of bottomland hardwood forest, 3 hectares of creek bottom, and 142 hectares of upland forests. The shoreline is characterized by fringing marshes and tidal creeks which extend into the uplands. Six types of creek marsh communities; bottomland hardwood forests; and mesic hardwood forests make up the habitats along Taskinas Creek (CBNERRVA, 1991).

Data Collection

Initial community identification was done by visual examination of aerial photographs and verified by field observation. Transects were established in the dominant plant communities at each. Each transect was randomly established perpendicular to the shoreline (Table 2). Goodwin Islands transect 1 was in high marsh in a ridge and swale area, transects 2 and 3 were placed in open marshland, and transect 4 ran from low marsh through high marsh to the edge of an upland area. Catlett Islands transect 1 ran across a swale, with each end of the transect terminating in a wetland/upland ecotone. Transects 2 and 3 on Catlett, where *Juncus roemerianus* was present, were laid across open marshland with at least one end of the transect at the water's edge. Transect 2 was bisected by a tidal creek. Taskinas Creek's three transects start with transect 1 at the mouth of the creek, on the York River, and move up the creek, with transect 3 being furthest upstream from the York River. The farther the distance the transects are up creek the more freshwater input and less tidal influence they received. Transects ended at the upland boundary of the site or at open water, crossing both low and high marsh areas. Plots were established at 10 meter intervals along each transect and marker stakes put in place. Vegetation within each plot was measured by using 1.0 m x 1.0 m PVC frames. All frames were oriented in the same direction, with a corner of the plot anchored by the marker.

All plants within each plot were identified to species level. Percent aerial cover was estimated visually for each species as a value between 1 and 100% or trace (<1%). Estimated values of cover were then transposed to mid-class ranges using a modified

Braun-Blanquet cover scale (Daubenmire 1966 & 1968) where: 0<1% = trace, 1 - 5% = 2.5%, 6 - 25% = 15.0%, 26 - 50% = 37.5%, 51 - 75% = 62.5%, 76 - 95% = 85.0%, 96 - 100% = 97.5%. Density, or stem counts, for each species were done in 1/4 meter by 1/4 meter quadrats within the 1 meter square plots, at the same point in each plot. All measurements were taken in the same place each time. Travel between plots was done outside the transect line to minimize human impact. Five years of data was collected monthly, May through September, from 1991 through 1995.

Data Analysis

Density and cover were measured and used to calculate species frequency, dominance, importance values, similarity indices, and diversity indices (Mueller-Dombois

Table 2. Number and lengths of transects per site.

Site	Transect number	Transect length (meters)
Goodwin Islands	1	200
	2	100
	3	300
	4	140
Catlett Islands	1	60
	2	130
	3	130
Taskinas Creek	1	150
	2	140
	3	80

and Ellenberg, 1974). Species diversity was calculated for each site as a whole over all five years, and for each transect for each year using the Shannon indices (Shannon and Weaver, 1949); Sorensen's similarity indices (Magurran, 1988) were calculated for each site and transect. Formulas for these calculations are given in Table 3 (Mueller-Dombois and Ellenberg, 1974; Perry and Atkinson, 1997; Perry and Hershner, 1999). Diversity indices for each site were compared using a Student T-test. SAS statistical software (SAS, 1999) was used to test the diversity indices for each transect for all years for normality and to perform a General Linear Model test followed by a Tukey test.

Principal component analysis (PCA) was used to examine temporal variation of community composition within and among sites and along a salinity gradient. PCA is an ordination technique that is used to look for latent or underlying structure in species data that may be determined by unknown variables (Ter Braak, 1995). PCA is an extension of fitting lines or planes by least squares regression. The assumption is that doing a PCA on quantitative data without an associated environmental variable detects and recovers underlying structure in the data giving an idea of whether unknown or unmeasured variables may underlying the data (Ter Braak, 1995). The quantitative density data over the five years for the three dominant species, *Spartina alterniflora*, *Distichlis spicata*, and *Spartina patens,* was used as the data sets for PCA analysis. Where the analysis resulted in more than one dominant factor (environmental variable), a factor loadings plot was generated by the SYSTAT program (Figure 17). Data sets were run for each transect at each site and for each site averaged as a whole. Data sets for selected transects (transect 2, Catlett Islands and transect 3, Taskinas Creek) were run again with the species ranking fourth in importance value to look for additional trends. These multiple PCA's were run on a SYSTAT software program (SPSS Inc., 1998).

A one dimensional salinity model of the York River was developed by the Physical Oceanography Department at Virginia Institute of Marine Science from the daily records of discharge in Hanover County, VA on the Pamunkey River and at Beaulahville, VA on the Mattaponi River. Salinity data for the model was provided by the Bay Monitoring Program from the mouth of theYork River collected and vertically averaged (http://www.vims.edu/physical/projects/yorksalt.htm). Daily averages of salinity are predicted at 102 transect locations (1991-1995) (Kuo and Sisson, 1998). Predicted salinity in the general vicinity of the sites used in this study was used for direct gradient analysis of salinity and vegetation data, using regression analysis.

Table 3. Formulas.

Indices	equation
relative frequency	= species frequency ÷ $\sum$all species frequencies × 100
relative density	= no. of individuals of a species ÷ no. of individuals of all species × 100
relative dominance	= species coverage ÷ sum of coverage for all species × 100
importance value	= relative frequency + relative dominance + relative density
Shannon diversity	$H = -\sum p_i \ln p_i$ where $p_i = n_i/N$ n_i = ith species, N = total number of species
evenness index	$E = H/\ln$ (number of species)
Sorensen's similarity index	$QS = 2c \div a+b \times 100$ a = no. of species in site A, b = no. of species in site B, c = no. of species common to both sites

Results

Species Composition

Twenty vascular plant species were identified from the three research sites (Table 4). Five species, *Aster tenuifolius, Fimbristylis spadicea, Distichlis spicata, Spartina alterniflora, and Spartina patens* were present in all three sites, but not along each transect in each site. *Suaeda linearis*, *Limonium carolinianum*, *Salicornia virginica* and *Salicornia bigelovii* were found only on Goodwin Islands (Figure 3), with *Suaeda linearis* being found only in transect 3 of Goodwin Islands; all are obligate halophytes. *Juncus roemerianus* was found only in transects 2 and 3 on the Catlett Islands (Figure 4). Taskinas Creek (Figure 5) had the largest number of species found only in transects at that site; *Hibiscus moscheutos* was found only in transect 3, *Juncus gerardii* only in transect 1, *Pluchea purpurascens* was found in transects 1 and 3, *Scirpus americanus* and *Spartina cynosuroides* appeared in transects 2 and 3 (Table 4). *Hibiscus moscheutos*, *Scirpus americanus*, and *Spartina cynosuroides* are species that prefer fresh to brackish conditions and were found in transects 2 and 3, farther up Taskinas Creek where they receive more freshwater input than transect 1 at the mouth of Taskinas Creek.

Plant Community Structure

Relative frequency, relative density, relative dominance and Importance Values (IV) of each plant species found at each site are presented in Tables 5. These trends are not statistically significant, but show yearly variations in the quantitative species data.

Table 4. Species present by transect.

	Goodwin Islands transect				Catlett Islands transect			Taskinas Creek transect		
Plant species	G 1	G 2	G 3	G 4	C1	C2	C3	T1	T2	T3
Aster tenuifolius		X	X	X	X			X	X	X
Atriplex patula					X			X		
Borrichia frutescens				X				X		
Distichlis spicata	X	X	X	X	X	X	X	X	X	X
Fimbristylis spadicea	X				X			X		
Hibiscus moscheutos										X
Iva frutescens				X				X		
Juncus gerardii								X		
Juncus roemerianus						X	X			
Kosteletzkya virginica										X
Limonium carolinianum		X	X	X						
Pluchea purpurascens								X		X
Salicornia bigelovii		X	X	X						
Salicornia virginica		X	X	X						
Scirpus americanus									X	X
Scirpus robustus				X				X	X	X
Spartina alterniflora		X	X	X	X	X	X	X	X	X
Spartina cynosuroides									X	X
Spartina patens	X		X		X	X	X	X	X	X
Suaeda linearis			X							

Table 5. Relative Frequency, Density, Dominance, and Importance Values.

	Site											
	Goodwin Islands				Catlett Islands				Taskinas Creek			
Plant species	RF	RD	DM	IV	RF	RD	DM	IV	RF	RD	DM	IV
A. tenuifolius	0.04	0.16	0.59	0.79	0.02	0.01	< 0.01	0.03	0.05	0.68	0.52	1.25
A. patula					0.02	< 0.01	< 0.01	0.02	0.02	< 0.01	< 0.01	0.02
B. frutescens	0.01	< 0.01	< 0.01	0.01					0.01	< 0.01	< 0.01	0.01
D. spicata	0.25	37.1	26.3	63.6	0.21	22.5	13.1	35.8	0.22	28.2	24.2	52.6
F. spadicea	0.01	0.10	0.03	0.14	0.02	0.10	0.01	0.13	0.01	0.10	0.01	0.12
H. moscheutos									0.01	< 0.01	0.06	0.07
I. frutescens	0.01	< 0.01	1.49	1.50					0.01	0.01	0.01	0.03
J. gerardii									0.01	1.75	0.20	1.96
J .roemerianus					0.06	9.3	5.07	14.4				
K. virginica									0.01	< 0.01	< 0.01	0.01
L. carolinianum	0.09	1.50	1.54	3.13								
P. purpurascens									0.01	0.03	0.05	0.09
S. bigelovii	0.01	1.74	1.08	2.83								
S. virginica	0.14	5.10	1.52	6.76								
S .americanus									0.05	1.44	4.64	6.13
S. robustus	0.01	31.6	0.15	0.20					0.05	0.18	3.32	3.55
S. alterniflora	0.30	31.6	42.7	75	0.50	42.2	59.1	102	0.23	3.69	22.2	26.1
S. cynosuroides									0.08	0.44	6.30	6.82
S. patens	0.13	22.6	40.6	17.8	0.17	26.0	37.5	11.4	0.23	63.6	34.8	98.6
S. linearis	0.01	< 0.01	0.02	0.01								

RF = Relative Frequency; RD = Relative Density, DM = Relative Dominance, IV = Importance Values

Catlett Islands, which has a mesohaline salinity range, had the fewest number of plant species (seven) , Goodwin Islands, with polyhaline salinity, had twelve species, and Taskinas Creek, oligohaline salinity, had the most species of plants (fifteen) within the transects. *Salicornia virginica* and other obligate halophytes were present only at the Goodwin Islands site where salinities are higher; *Juncus roemerianus* was seen only in the mesohline range transects on Catlett Islands. A few fresh to brackish water species such as *Hibiscus moscheutos*, *Scirpus americanus* and *Spartina cynosuroides* were seen only in the upper reaches of Taskinas Creek.

All three sites exhibited differences in species composition among transects within a site, to varying degrees (Table 4). Transect 1 on Goodwin Islands was almost exclusively *Distichlis spicata* and *Spartina patens*, high salt marsh vegetation. *Spartina alterniflora* was not present on transect 1, but was present on the other Goodwin Islands transects. *Iva frutescens* was found in transect 4 on Goodwin Islands and on transect 1 at Taskinas Creek at slightly higher elevations. The transects at Catlett Islands also exhibited differences in species present; transects 2 and 3 contained *Juncus roemerianus* where transect 1 did not. Taskinas Creek's transect 3, the furthest upstream from the York River, had the most species present that prefer fresh to brackish water conditions, as noted above.

Community structure varied from plot to plot along the transects. Differences in elevation and distance from the edge of the river exposed the plots to slightly different hydrological conditions; these varied conditions are reflected in the species and quantity of vegetation in the plot. This was evident in transect 2 on Catlett Islands: one plot in which *Spartina alterniflora* was the dominant species was next to a plot dominated by *Juncus roemerianus*; the next plot on the transect was dominated by *Distichlis spicata*. This pattern of varying species present along an individual transect was present at each of the three sites. Figures 7, 8, and 9 show the dominant vegetation type along the length of selected transects at each site, and the changes which occurred in some plots over the period of the study. Some plots were lost to erosion or local subsidence and became dominated partially or fully by open water.

Indices

Results of the Shannon Diversity index, calculated for each site as a whole, are presented in Table 6. Taskinas Creek indices differed from the other two sites on a site to site comparison, but a Student T-Test indicated there is no significant difference in diversity among the three sites. Shannon Evenness indices for Goodwin Islands was 0.54, Catlett Islands 0.61, and Taskinas Creek was 1.83. Sorenson's Similarity index among sites was QS = 30.76.

To look at the diversity in more depth, the Shannon Diversity indices were calculated for each transect within a site over the five years (Table 8). These indices were tested for normality (Table 7 and Figure 11) using SAS General Linear Model test followed by a Tukey-Kramer, least squares means test. Comparing diversity indices for each transect for each year shows small differences in diversity among transects within each site and differences over the five years in the same transect. The differences among sites is small, but reflects the differences in the number of species found in each transect and at each site.

Table 6. Shannon Diversity Index per site.

Shannon Diversity Index = H'

	Goodwin	Catlett	Taskinas
H'	1.375	1.274	2.94

t-test of sites	value of t	DF	critical value at ∝ = 0.05
Taskinas vs. Catlett	0.00805	1305	1.96
Catlett vs. Goodwin	0.0586	1127	1.96
Taskinas vs. Goodwin	0.00652	1776	1.96

No significant difference between sites at p= 0.05

Table 7. Normality test for Diversity Indices by transect per year.

Tests for Normality		
Tests	Statistic	p-Value
Shapiro-Wilk	W 0.96	Pr<W 0.0924
Kolmogorov-Smirnov	D 0.095	Pr>D >0.1500
Cramer-von Misese	W-Sq 0.068	Pr> W-Sq >0.250
Anderson-Darling	A-Sq 0.509	Pr> A-Sq 0.198

Community Changes Over Time

Changes in the species density of the three dominant plant species at all sites were examined over the five year period (Figure 12). When looked at by site, *Spartina alterniflora* shows a small trend toward increasing density over the five years. *Distichlis spicata* exhibits mixed trends: a small trend to increase in density at Taskinas Creek, a very small decrease in density at Catlett Islands and an increase in density on Goodwin Islands. *Spartina patens*, unlike the other two species, trends toward decreasing density at all three sites, although the decrease at Catlett and Goodwin Islands is very small. While not statistically significant, these trends reflect yearly variations in the plant community.

Table 8. Diversity Indices for each transect for each of the five.

		1991	1992	1993	1994	1995
Goodwin Islands	transect 1	0.70	0.70	0.70	0.69	0.69
	transect 2	0.39	0.42	0.33	0.90	0.83
	transect 3	0.84	0.81	0.73	0.85	0.72
	transect 4	1.09	1.03	1.01	1.01	1.11
Catlett Islands	transect 1	1.12	1.03	1.08	1.09	1.06
	transect 2	0.92	1.15	1.04	1.24	1.30
	transect 3	1.14	1.26	1.21	1.28	1.28
Taskinas Creek	transect 1	0.75	0.75	0.82	0.96	0.93
	transect 2	0.35	0.28	0.47	0.58	0.50
	transect 3	0.82	0.97	0.79	0.95	1.01

Changes in percent cover also vary by site (Figure 13). *Spartina alterniflora* at Goodwin Island varied from the lowest total percent cover per plot in 1992, to the highest percent cover in 1994. For Catlett Islands, the lowest total percent cover per plot of *Spartina alterniflora*, occurred in 1992, while the highest values were nearly equal in 1991, 1994, and 1995. Taskinas Creek had the lowest total percent cover of *Spartina alterniflora* in 1992, and nearly equal values 1991, 1994, and 1995; the highest value was in 1993. Graphs of average plant density for each transect, at each site, over time (Figures 14, 15, 16) show some individual variation. Individual transects had higher values for some species than other transects; an example is Goodwin Islands transect 1, which has no *Spartina alterniflora* (Table 4, Figure 14).

Results of the PCA (Table 9) for Goodwin Islands show three of the four transects having most of the underlying variation explained by one factor (environmental variable). Transect 1, containing only *Distichlis spicata* and *Spartina patens*, had 81% of the variation explained by 1 factor. Transect 2 was almost entirely *Spartina alterniflora* and *Distichlis spicata*, with a small amount of *Spartina patens*. The total variance is explained by 2 factors; factor 1 explaining 54.8% and factor 2 explains 34.5% for a total of 89.3%. The analysis for transect 3 gave only 1 factor that explained 60.6% of the variance. Transect 4 was primarily *Spartina alterniflora* and *Distichlis spicata* with only a small amount of *Spartina patens* in one year. The analysis gives 1 factor explaining 66.4% variance with *Spartina patens* used in the analysis and 78.9% without *Spartina patens*. Goodwin Islands data averaged for the whole site resulted in 1 factor explaining 71.4 % of the variation.

Catlett Islands, transect 1 resulted in only 1 factor explaining 46.8% of the variation. Transect 2 analysis, when run with *Spartina alterniflora*, *Distichlis spicata*, and *Spartina patens*, has 1 factor explaining 79.4 % of the variation. *Juncus roemerianus* was the species third in rank in Importance Value at this site. If *Juncus roemerianus* is added to the analysis of this transect there are 2 dominant factors explaining 60.0 and 33.9 % of the variation. Transect 3 when run with the three main species resulted in 2 factors explaining 60.6 and 35.4 % of the variation. When *Juncus roemerianus* was added the results changed to 2 factors explaining 51.8 and 37.4 % variation. Catlett Island data run for the site as a whole resulted in 2 factors explaining 51.0 and 35.7 % of the variance when run with the three main species. The results when the fourth species is added imply that *Juncus roemerianus* responds to a different environmental variable than the three main species.

Taskinas Creek, transect 1, resulted in 1 factor explaining 76.8 % of the variation. Transect 2 also had 1 factor explaining 69.8 % of the variation. Transect 3 analysis resulted in 1 factor explaining 84.6 % of the variance with the three dominant species. *Scirpus americanus* and *Spartina cynosuroides* were found in transect 2 and predominately transect 3; their importance values, ranking close together, were fourth and fifth after the three dominant species. When the analysis was run with *Spartina cynosuroides* added, there was still only 1 factor explaining 70.4 % of the. The data for these two species did not contribute to the number of factors explaining variance. The analysis of Taskinas Creek site data gives 2 factors explaining 53.8 and 41.5 % of the variation. The higher density of *Spartina patens* with a corresponding decrease in *Distichlis spicata* density on transect 2 as compared to transects 1 and 3 (Figure 16), when averaged over the site may contribute to the second factor explaining variation at the site level.

Spatial Community Changes

Spatial community changes include changes in plant community from one transect to another within a site, and from one plot to the next along one transect. Taskinas Creek included some species preferring fresh to brackish salinities *(Hibiscus moscheutos*, *Scirpus americanus*, and *Spartina cynosuroides*) in the transects furthest upstream from the York River. Goodwin Islands, transect 4 had essentially no *Spartina patens* while transect 1 had no *Spartina alterniflora.* Catlett Islands, transects 2 and 3 had *Juncus roemerianus*, but it was not present in transect 1.

Spatial changes occur on the scale of plots within the transects of each site. Some plots showed changes in dominant vegetation species by plot along the transect.

The plots at Goodwin Islands, transect 3 (Figure 7) were mostly dominated by *Spartina alterniflora*, except near the inland end of the transect, where *Distichlis spicata* was predominate. Catlett Islands, transect 2 (Figure 8) shows changes in the species dominant within a plot from *Spartina alterniflora* to *Juncus roemerianus* in the next plot to *Distichlis spicata* in the plot after that along the transect. Taskinas creek, transect 1 (Figure 9) displays variation from low marsh *Spartina alterniflora* in the plots near the water's edge to higher marsh *Spartina patens* away from the water.

Table 9. PCA Factor Loading Results.

		Factor Loadings		
Site	Transect/Site	*S. alterniflora*	*D. spicata*	*S. patens*
Goodwin Islands	transect 1		0.902	0.902
	transect 2	-0.887 (0.256)	0.914 (0.095)	0.143 (0.980)
	transect 3	0.570	0.887	-0.840
	transect 4	0.723	-0.930	0.777
	whole site	0.968	0.977	0.498
Catlett Islands	transect 1	0.724	-0.673	0.652
	transect 2	0.936	0.947	-0.780
	transect 3	0.130 (-0.987)	-0.963 (0.126)	0.935 (0.266)
	whole site	-0.564 (0.764)	0.632 0.699	0.902 -0.012
Taskinas Creek	transect 1	0.914	0.960	-0.741
	transect 2	0.942	0.950	0.549
	transect 3	-0.835	0.928	0.990
	whole site	0.868 (-0.439)	0.922 0.306	0.101 0.979

Parentheses ( ) denote second factor.

Salinity and species density

Density of the three dominant species were compared to the salinity distribution predicted by the model (Figure 18) for each site during the five year period. Figures 19, 20, and 21 show the average monthly density for each of the species plotted with the average monthly salinity. These charts show no consistent relationship of species density to changes in salinity. Regressions were run on the monthly averages of stem density against the monthly average of salinity over five years. The regression results showed that species density was not related to salinity; R squared values were extremely low (Tables 10, 11, 12 and Figures 22, 23, 24).

Table 10. Results of salinity/species regression analysis for Goodwin Islands.

Dependent Variable: *Spartina alterniflora* ;   Analysis of Variance

```
                         Sum of          Mean
Source            DF     Squares         Square    F Value    Pr > F
Model              1   1828.77231    1828.77231       2.01    0.1701
Error             23        20968     911.64859
Corrected Total   24        22797
         Root MSE              30.19352    R-Square     0.0802
         Dependent Mean       112.58280    Adj R-Sq     0.0402
         Coeff Var             26.81894
     Variable    DF      Estimate        Error    t Value    Pr > |t|
     Intercept    1    -937.56721    741.48037      -1.26      0.2187
     salin        1      50.75542     35.83574       1.42      0.1701
```

Dependent Variable: *Distichlis spicata*;   Analysis of Variance

```
                         Sum of          Mean
Source            DF     Squares         Square    F Value    Pr > F
Model              1      9.17860       9.17860       0.02    0.8859
Error             23        10025     435.87280
Corrected Total   24        10034
         Root MSE              20.87757    R-Square     0.0009
         Dependent Mean        81.75840    Adj R-Sq    -0.0425
         Coeff Var             25.53568
     Variable    DF      Estimate        Error    t Value    Pr > |t|
     Intercept    1       7.36068    512.70294       0.01      0.9887
     salin        1       3.59576     24.77893       0.15      0.8859
```

Dependent Variable: *Spartina patens* ;   Analysis of Variance

```
                         Sum of          Mean
Source            DF     Squares         Square    F Value    Pr > F
Model              1    429.18013     429.18013       0.23    0.6354
Error             23        42749    1858.65156
Corrected Total   24        43178
         Root MSE              43.11208    R-Square     0.0099
         Dependent Mean       113.22080    Adj R-Sq    -0.0331
         Coeff Var             38.07788
     Variable    DF      Estimate        Error    t Value    Pr > |t|
     Intercept    1    -395.51386   1058.72926      -0.37      0.7121
     salin        1      24.58796     51.16838       0.48      0.6354
```

Table 11. Results of salinity/species regression analysis for Catlett Islands.

Dependent Variable: *Spartina alterniflora* ;   Analysis of Variance

```
                              Sum of         Mean
Source              DF       Squares        Square   F Value    Pr > F
Model                1     128.17134     128.17134      1.31    0.2646
Error               23    2254.20501      98.00891
Corrected Total     24    2382.37634
          Root MSE             9.89995    R-Square    0.0538
          Dependent Mean      39.80680    Adj R-Sq    0.0127
          Coeff Var           24.86998
    Variable   DF      Estimate        Error   t Value   Pr > |t|
    Intercept   1     -86.26742    110.26397     -0.78     0.4420
    salin       1       6.69809      5.85718      1.14     0.2646
```

Dependent Variable: *Distichlis spicata;*   Analysis of Variance

```
                              Sum of         Mean
Source              DF       Squares        Square   F Value    Pr > F
Model                1       3.49903       3.49903      0.03    0.8605
Error               23    2548.40577     110.80025
Corrected Total     24    2551.90480
          Root MSE              10.52617    R-Square     0.0014
          Dependent Mean        31.73800    Adj R-Sq    -0.0420
          Coeff Var             33.16583
    Variable   DF      Estimate        Error   t Value   Pr > |t|
    Intercept   1      52.56873    117.23876      0.45     0.6581
    salin       1      -1.10670      6.22768     -0.18     0.8605
```

Dependent Variable: *Spartina patens* ;   Analysis of Variance

```
                              Sum of         Mean
Source              DF       Squares        Square   F Value    Pr > F
Model                1     620.56495     620.56495      3.70    0.0668
Error               23    3855.41905     167.62692
Corrected Total          24    4475.98400
          Root MSE              12.94708    R-Square     0.1386
          Dependent Mean        33.39000    Adj R-Sq     0.1012
          Coeff Var             38.77533
    Variable   DF      Estimate        Error   t Value   Pr > |t|
    Intercept   1     310.80149    144.20248      2.16     0.0418
    salin       1     -14.73837      7.65998     -1.92     0.0668
```

Table 12. Results of salinity/species regression analysis for Taskinas Creek.

Dependent Variable:*Spartina alterniflora* ; Analysis of Variance

```
                              Sum of          Mean
Source              DF       Squares        Square   F Value    Pr > F
Model                1      86.29123      86.29123      4.30    0.0505
Error               21     421.13069      20.05384
Corrected Total     22     507.42192
          Root MSE                4.47815   R-Square     0.1701
          Dependent Mean         11.74652   Adj R-Sq     0.1305
          Coeff Var              38.12321
   Variable    DF      Estimate         Error   t Value    Pr > |t|
   Intercept    1    -126.55551      66.67862     -1.90      0.0715
   salin        1       8.70110       4.19459      2.07      0.0505
```

Dependent Variable: *Distichlis spicata;* Analysis of Variance

```
                              Sum of          Mean
Source              DF       Squares        Square   F Value    Pr > F
Model                1     514.90221     514.90221      0.62    0.4403
Error               21         17479     832.33337
Corrected Total     22         17994
          Root MSE               28.85019   R-Square     0.0286
          Dependent Mean         95.04870   Adj R-Sq    -0.0176
          Coeff Var              30.35306
   Variable    DF      Estimate         Error   t Value    Pr > |t|
   Intercept    1    -242.78862     429.57251     -0.57      0.5779
   salin        1      21.25460      27.02336      0.79      0.4403
```

Dependent Variable: *Spartina patens* ; Analysis of Variance

```
                              Sum of          Mean
Source              DF       Squares        Square   F Value    Pr > F
Model                1     891.12191     891.12191      0.11    0.7409
Error               21        166750    7940.49041
Corrected Total     22        167641
          Root MSE               89.10943   R-Square     0.0053
          Dependent Mean        276.24087   Adj R-Sq    -0.0421
          Coeff Var              32.25787
   Variable    DF      Estimate         Error   t Value    Pr > |t|
   Intercept    1     720.68154    1326.81841      0.54      0.5927
   salin        1     -27.96142      83.46690     -0.34      0.7409
```

Discussion

Community Structure

The community structure of each site reflects the different environmental conditions found at the sites and among the individual transects. The species diversity and distribution represents the vegetation's response to climate, hydrology, salinity, geomorphic changes, stochastic events, and other variables existing in the surroundings, as well as biotic factors like interspecific interactions (Bertness and Ellison, 1987; Mitsch and Gosselink, 1993). The three sites have different salinity ranges along their respective reaches of the York River. Transects at Taskinas Creek, with oligohaline salinity, were placed along the reach of the creek and are influenced by different conditions in the creek watershed. The more fresh to brackish water species, such as *Hibiscus moscheutos* and *Kosteletzkya virginica*, seen only in transects in upper Taskinas Creek, reflect the difference in salinity in the upper reaches of the creek from the mouth of the creek, at the York River. Catlett Islands, with the least number of plant species, has mesohaline salinity and a more uniform influence of the York River on all transects of all the sites. Goodwin Islands environmental conditions include polyhaline salinity and more exposure to the open conditions of the Chesapeake Bay than sites further up the river.

Many environmental variables other than salinity contribute to marsh community structure. Some of the differences in species composition among transects at the

Goodwin Islands site are due to elevational variation. Transect 1 on Goodwin Islands was almost exclusively *Distichlis spicata* and *Spartina patens*, high salt marsh vegetation. *Spartina alterniflora* was not present on this transect, which had a higher bank at the water edge than the other three transects. *Spartina alterniflora* grows up to mean high water level; the bank on transect 1, during the study, was above this level, due in part, to storm overwash. Other factors not measured influence the plant community structure.

Community Changes Over Time

No significant trend in plant species density or cover data was observed over the five year period at any of the sites. Vegetation values at the three sites did not increase or decrease in a consistent manner. Lack of significant trends at the scale of transects within the site was also seen, with the exception of a steady decrease in *Spartina patens* on transect 2 at Catlett Islands (Figure 15), due in part to bank erosion and loss of plots in low marsh area.

Moving in scale to plot level shows a loss of plots to erosion over the five year time period at all sites, and a change in dominant vegetation for some individual plots (Figures 7, 8, & 9). With the transects shown in each of these figures the changes almost all reflect a decrease in the quantity of the high marsh species present, such as *Distichlis spicata*, and an increase in *Spartina alterniflora*, a low marsh species. Local changes can be influenced by inputs or variables of the same scale. In these transects the addition of nutrients from bird droppings at the plot marker posts enhanced plant growth immediately around the post, slumping along tidal channels increased the depth of inundation, favoring low marsh vegetation; erosion at the edge of a channel or the river caused some plots to be lost totally. Plots also lost vegetation at the Goodwin Islands site in those plots that became open water pans due to localized subsidence.

The results of the PCA analyses of the species data over time are consistent with the quantitative data. When the data shows the three dominant species increasing or decreasing in density concurrently, one factor explains most of the variation. If one of the species densities changes in a different direction than the others, two factors explain most of the variation. None of the analyses resulted in more than two factors explaining the majority of the variance. Eight of the ten transects from all sites had the variation in density of the three dominant species explained by one factor.

Transect 2 at Goodwin Islands, with two factors explaining most of the variance, was predominantly *Spartina alterniflora*, low marsh vegetation. This transect had a small amount of *Distichlis spicata* each year and a very small amount of *Spartina patens* only in 1994, both high marsh vegetation. The two factors explaining variance might be indicative of variables acting at the two different marsh elevations, such as inundation frequency or period. Other factors affecting the density of the different species may include physical disturbance, soil salinity, and interspecific competition (Bertness and Ellison, 1987). The other transect with two factors is transect 3 on Catlett Islands. Transects 1 and 2 had relatively equal densities of the three dominant species, while transect 3 had an order of magnitude lower *Spartina patens* density. One factor may explain the lower density. Catlett Islands, transect 1 with 1 factor explaining 46.8% of the variation may reflect the dip in *Spartina patens* density values by half in 1993, while the other 2 species did not show as much change.

Adding data for the fourth dominant species on a transect to the PCA analysis changed some results. For the factor loading plots on Catlett Islands, transect 2, when the analysis is run with *Juncus roemerianus*, *Distichlis spicata* and *Spartina patens* plot in opposite directions, *Spartina alterniflora* moves with *Distichlis spicata*, while *Juncus roemerianus* plots at another angle. This follows the data, in that *Spartina alterniflora* and *Distichlis spicata* generally increase in density over the 5 years, *Spartina patens* decreases in density, and *Juncus roemerianus* decreases in density the first four years, then doubles in density in the last year. The addition of species data did not appreciably change the analysis results for individual sites. Catlett Island data run for the site as a whole resulted in 2 factors explaining 51.0 and 35.7 % of the variance when run with only 3 species, and 2 factors explaining 50.2 and 38.3 % of the variation with the fourth species, *Juncus roemerianus.*

If the factors in the analysis results are indicative of environmental variables influencing changes in the plant community, there is one main factor for eight of ten transects and one of the three sites. Two transects and two sites have their variance explained by two main factors. These may or may not be the same factor(s). The community composition of salt marsh communities are a result of multiple factors or environmental variables, including geomorphology, sediment inputs, salinity, and nutrient availability, among others (Mitsch and Gosselink, 1993). Changes in the plant community could be expected to occur in response to changes in these environmental variables. Quantitative data, if collected for some of these variables at the same time the vegetation data is compiled, would allow a multivariate analysis to be run including that data, which would determine if those variables corresponded to changes in the plant community.

In the absence of major change in one or more environmental variables, or large scale disturbance, changes were seen only at smaller scales. The data collected for the five year period shows interannual variation; no significant trends are detectable at the scales used. Data collected over longer time periods would demonstrate different trends that may relate to longer term environmental changes, such as changes in climate and precipitation, or changes in sediment load and deposition.

Spatial Community Changes

Spatial changes are evident in the difference in dominant vegetation for the transects (Figures 14, 15, & 16) and on the scale of individual plots (Figures 7, 8, & 9). The greater density of high marsh vegetation and corresponding reduced density of low marsh vegetation in some transects is especially evident at Goodwin Islands. Transect 1 lacked *Spartina alterniflora,* low marsh vegetation, and was dominated by high marsh species *Distichlis spicata* and *Spartina patens;* transects 2 and 4 had essentially no *Spartina patens*; transect 3 contained all three species. Differences in transects elevation, low marsh to high marsh, can be due to local subsidence or accretion. Spatial differences occur at the other sites; the fresh to brackish water species in transects 2 and 3 of Taskinas Creek indicate salinity differences over the extent of the site. Other environmental variables not measured in this study would also be contributing factors.

Spatial changes are seen on the scale of plots within transects. The data for Catlett Islands, transect 2, shows a plot in which *Spartina alterniflora* is dominant next to a plot with *Juncus roemerianus*, with the next plot on the transect dominated by *Distichlis spicata*. These local changes in the plant community can be the result of differences in elevation or hydrologic conditions, or other environmental factors that may have influence along the transect. Some plots show changes in dominant vegetation species over the five year period. Other plots lost vegetation, either to erosion of the soil into the river, or to increases in open water areal coverage. Examples of changes within transects include Goodwin Islands, transect 3 which lost two and one half plots to open water from 1991 to 1995, transect 4 lost one plot to open water, another plot lost all *Distichlis spicata* from 1991 to 1995 with no significant increase of other species or open water; Catlett Islands, transect 2 lost one plot to open water and four plots lost all *Distichlis spicata* from 1991 to 1995; Taskinas Creek, transect1 had three plots gain *Spartina alterniflora* coverage and one plot was lost to erosion.

Salinity and species density

Results of regressions comparing species density and salinity for the study period indicate there was no relationship between the stem density per plot of the three dominant species (Figures 19, 20, and 21) and the York River salinity as shown in the model (Figure 18). We were unable to do a more detailed study, at a smaller spatial scale, of the salinity of the pore water in each plot. Such a closer look might show if there are localized changes in vegetation density and salinity, or other variables, within the marsh. Studies in a New England salt marsh (Bertness and Ellison, 1987) showed a decrease in substrate salinity, as measured by pore water, as the distance from the shore increased. Low marsh habitat had significantly higher salinity than high marsh habitat. These changes in salinity across the marsh are not reflected in the York River salinity model.

Community Changes and Salinity

None of the changes in vegetation measured during this time period could be attributed to, or correlated with, changes in salinity as represented by the York River Salinity Intrusion Model for the same period. Differences in species present at the three sites (Table 4) reflect the different salinity ranges of the sites. Fresh to brackish water species were present at Taskinas Creek transects but not at Goodwin Islands, where halophytes were found. The observed changes in species density per plot or on transects did not show a relationship to the salinity changes in the York River.

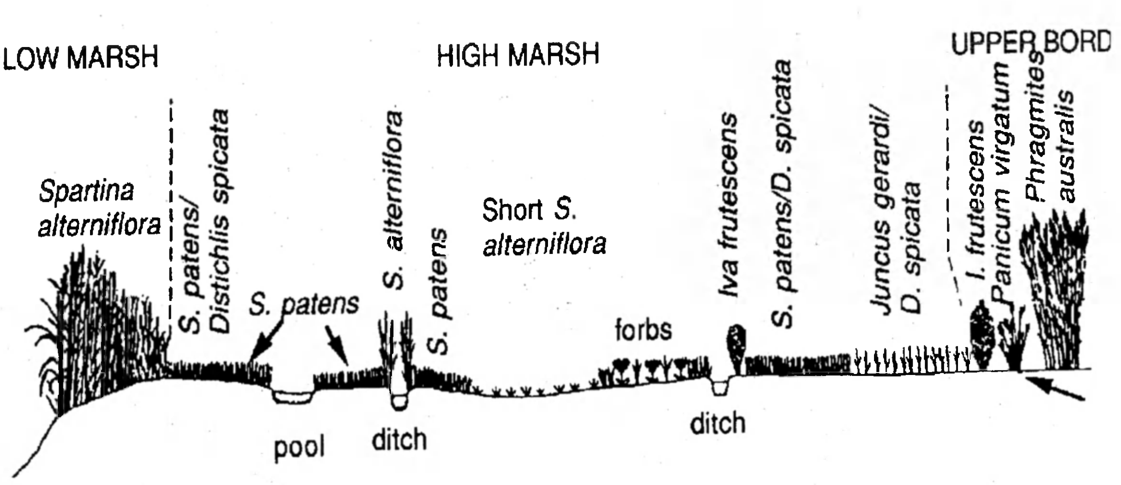
Conclusions

The data gathered over the five year period from all three sites resulted in some basic conclusions. One: comparisons of the plant communities among the three sites show them to be similar in overall diversity and evenness. The indices indicate no major differences, primarily because of the dominance of the same three plant species, *Spartina alterniflora*, *Distichlis spicata*, and *Spartina patens* at all the sites. Two: comparisons of plant communities among transects within each site shows less similarity than the whole site, more diversity is evident at the smaller scale of transects. Diversity increases again within the transect, in differences among the plots along the transect. Three: these plant communities at the sites studied show interannual variation over the five year time period they were observed. Four: there was no significant correlation between salinity variation in the York River, as represented by the model, and vegetation community changes over the five year period.

A five year time period may be too short to show significant trends in the absence of large scale changes in the surrounding watershed. Longer time periods are needed to observe the successional changes that occur. Because these sites are part of the National Estuarine Research Reserve System, the opportunity exits to continue observations of the same sites and in fact the same transects and plots.

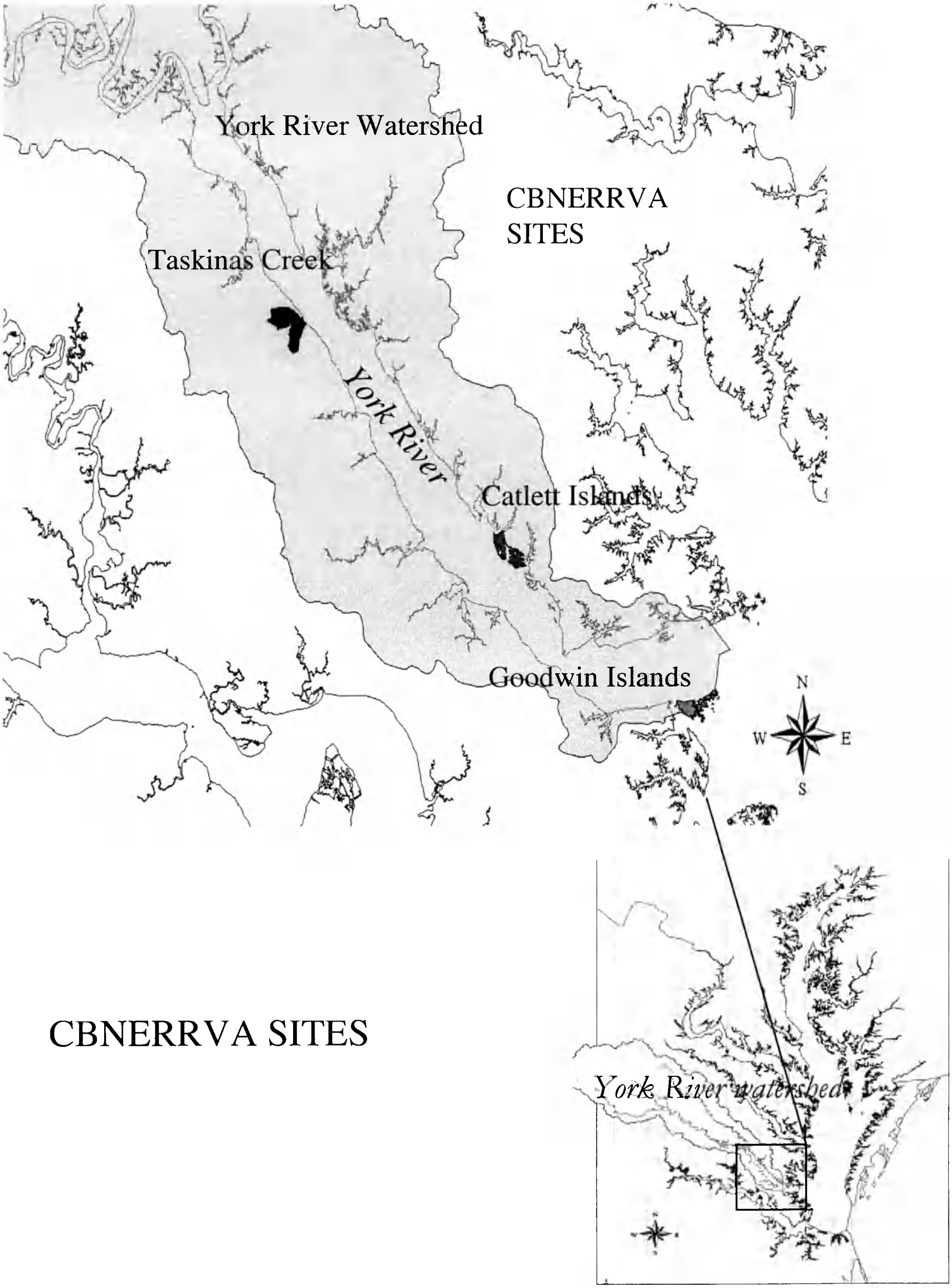
Figure 1. Zonation of salt marsh vegetation.

Salt Marsh Vegetation Zonation



After Niering and Warren, 1980.

Figure 2. CBNERRVA sites.



CBNERRVA SITES

Figure 3. Goodwin Islands.

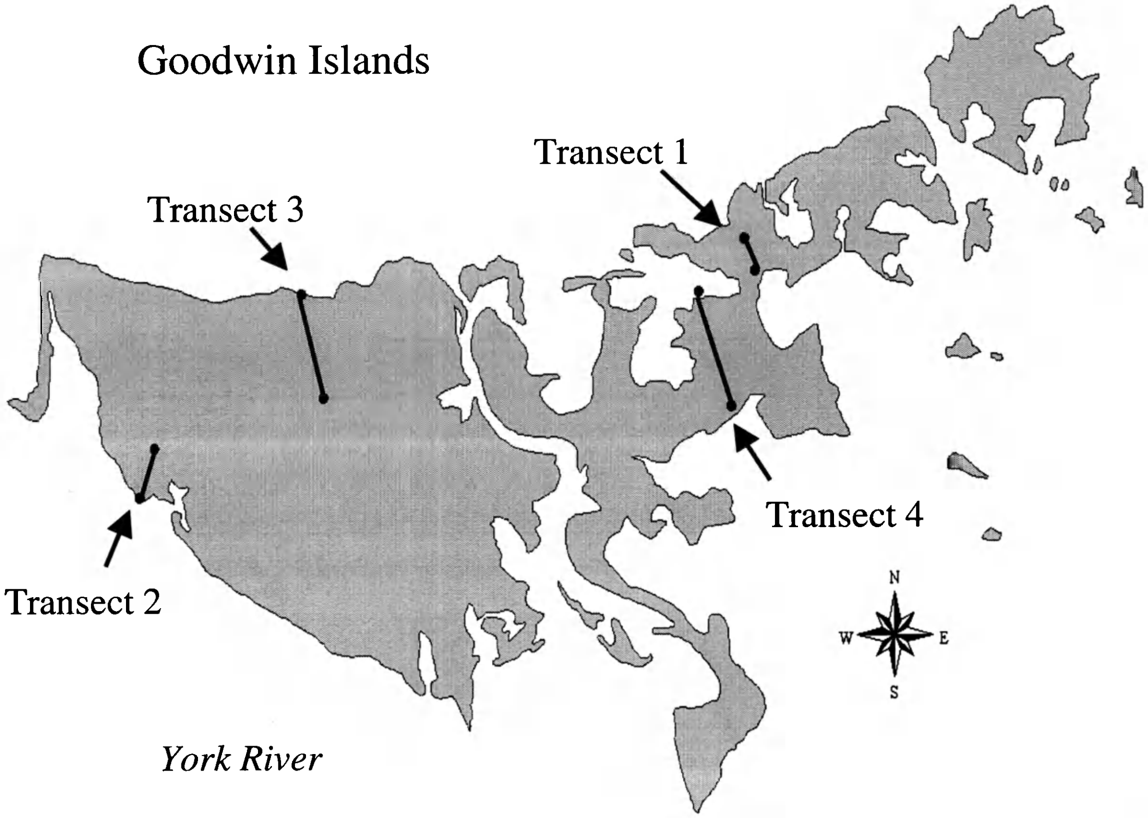

Goodwin Islands
Transect 1
Transect 3
Transect 4
Transect 2
N
W
E
S
York River

Figure 4. Catlett Islands.

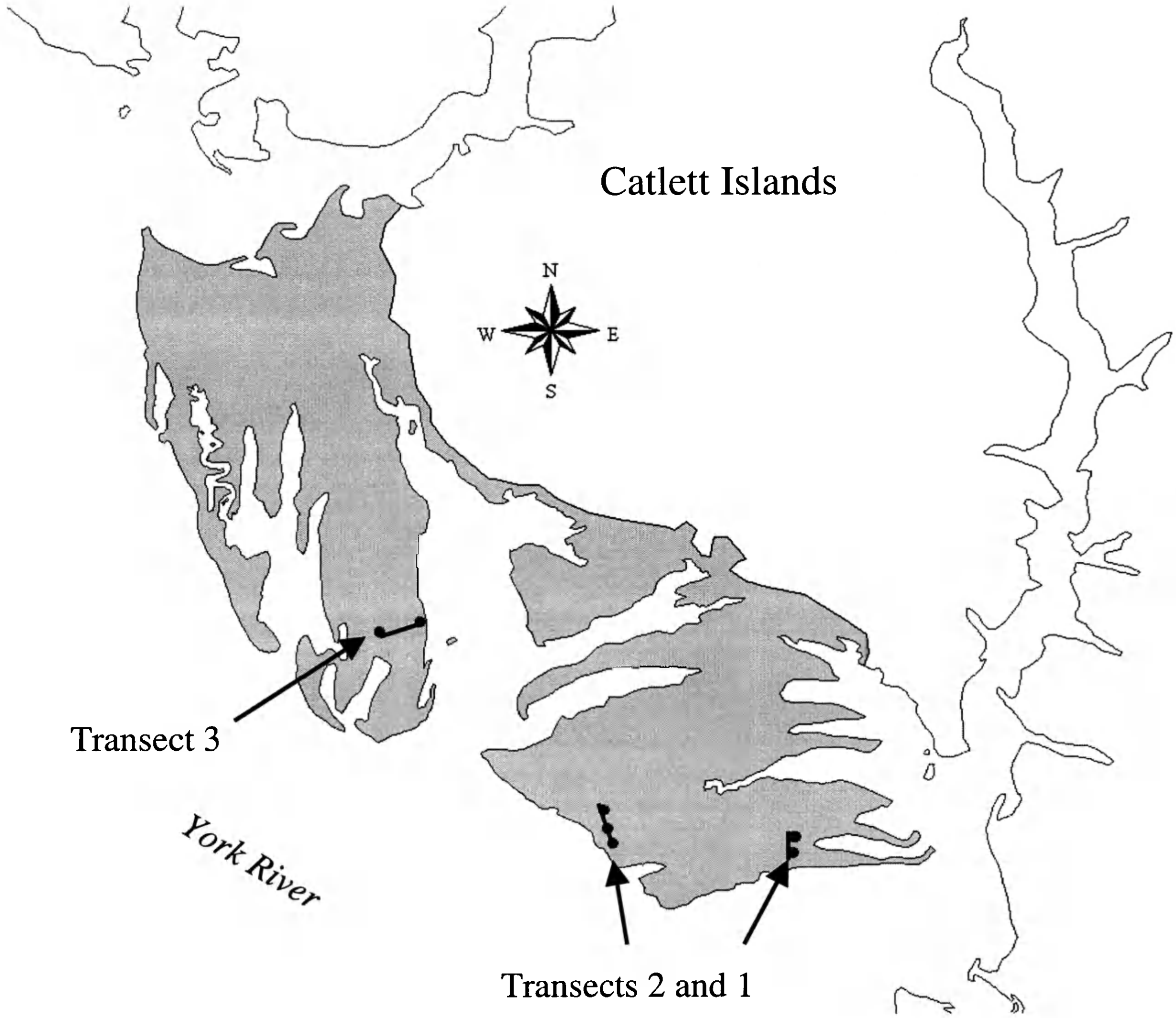

Catlett Islands
N
W
E
S
Transect 3
York River
Transects 2 and 1

Figure 5. Taskinas Creek.

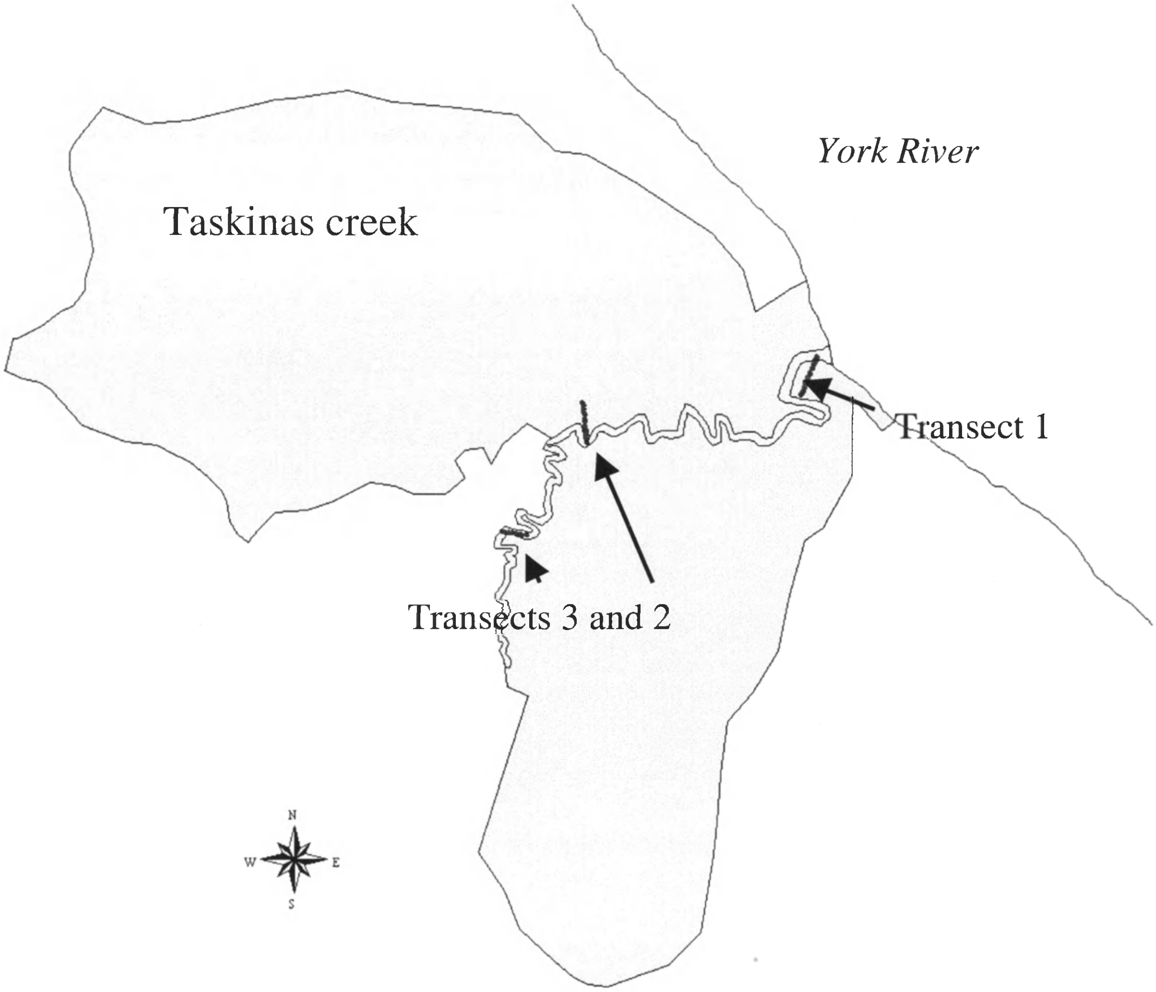

York River
Taskinas creek
Transect 1
Transects 3 and 2
N
W
E
S

Figure 6. Importance Values.

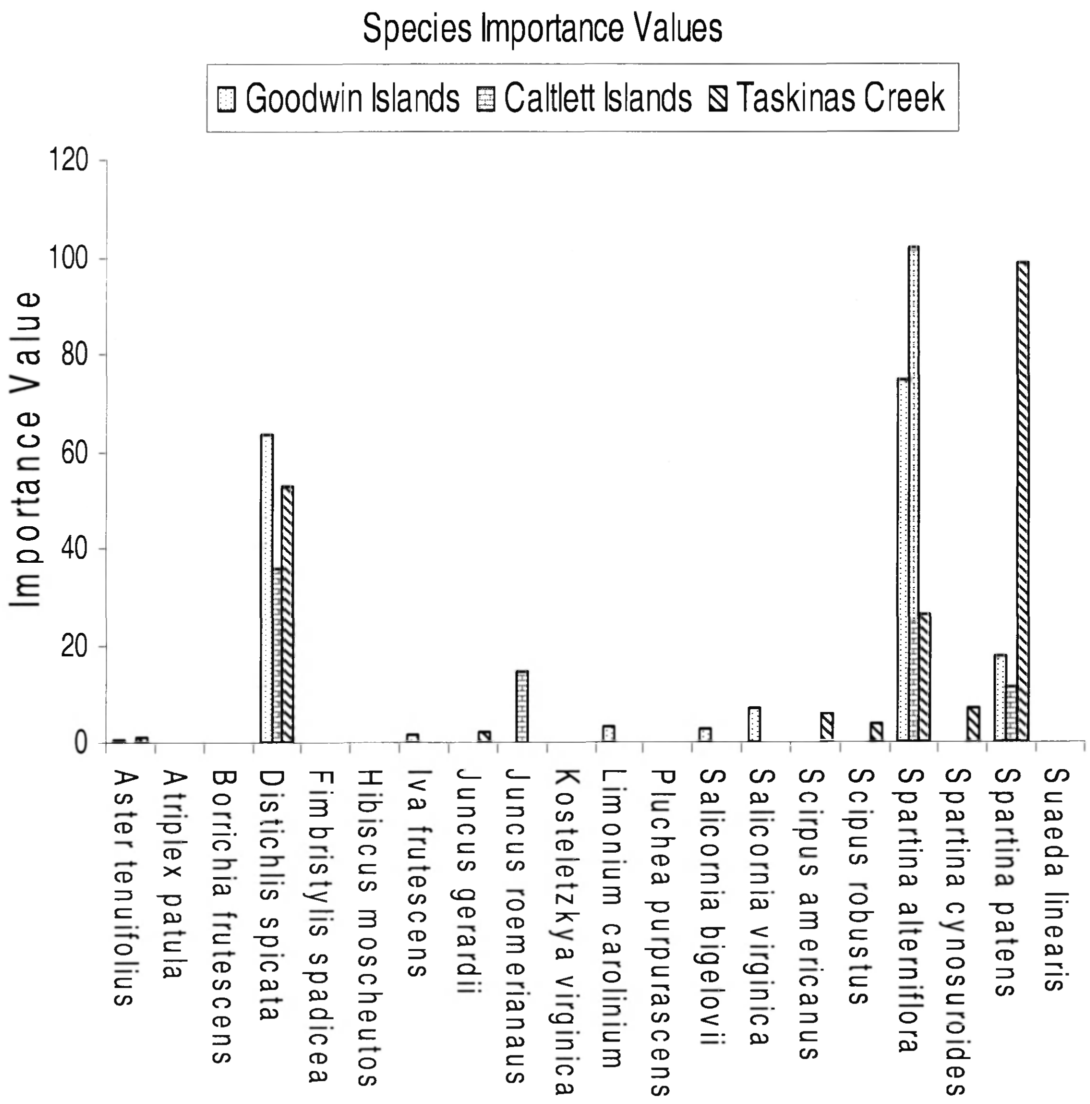
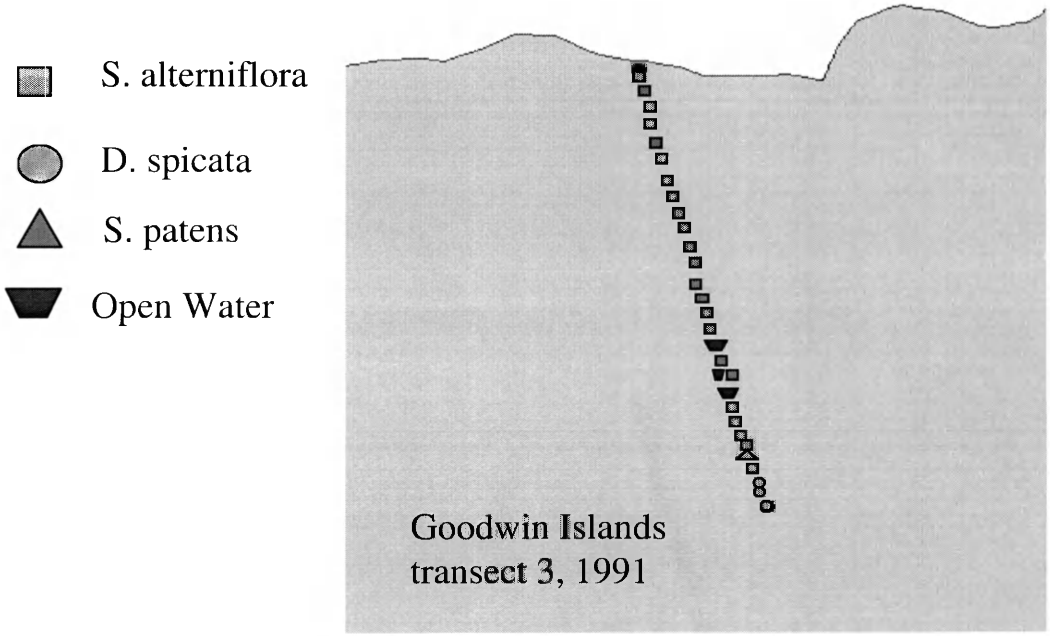

Species Importance Values
Goodwin Islands
Caltlett Islands
Taskinas Creek
Importance Value
120
100
80
60
40
20
0
Aster tenuifolius
Atriplex patula
Borrichia frutescens
Distichlis spicata
Fimbristylis spadicea
Hibiscus moscheutos
Iva frutescens
Juncus gerardii
Juncus roemerianaus
Kosteletzkya virginica
Limonium carolinium
Pluchea purpurascens
Salicornia bigelovii
Salicornia virginica
Scirpus americanus
Scipus robustus
Spartina alterniflora
Spartina cynosuroides
Spartina patens
Suaeda linearis

Figure 7. Vegetation change by plot in transect 3,
Goodwin Islands from 1991 to 1995.

Change by plot in transect 3, Goodwin Islands



Dominant species by plot

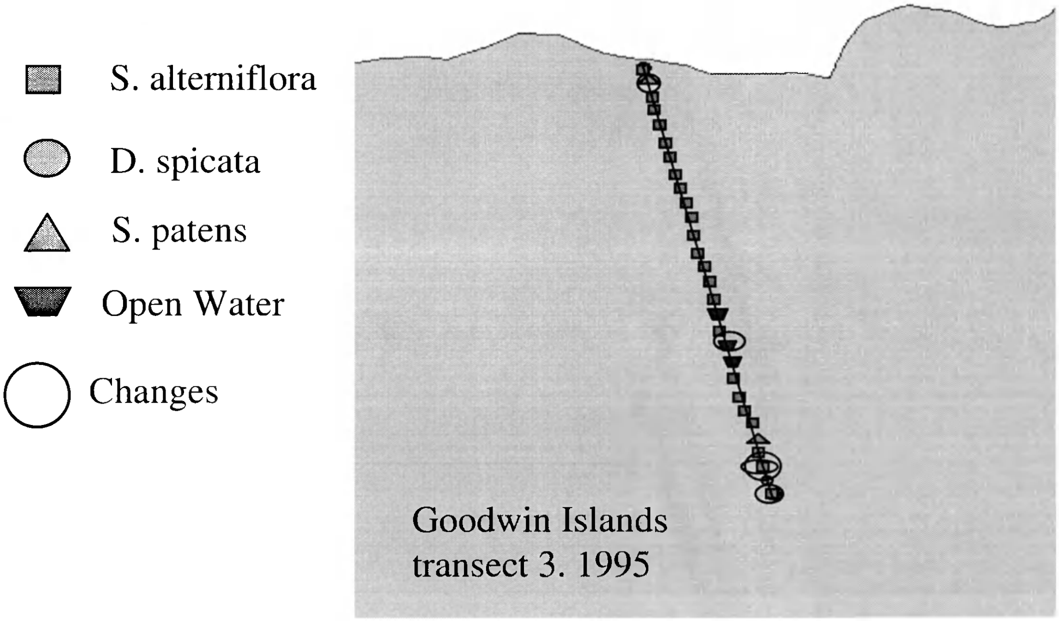
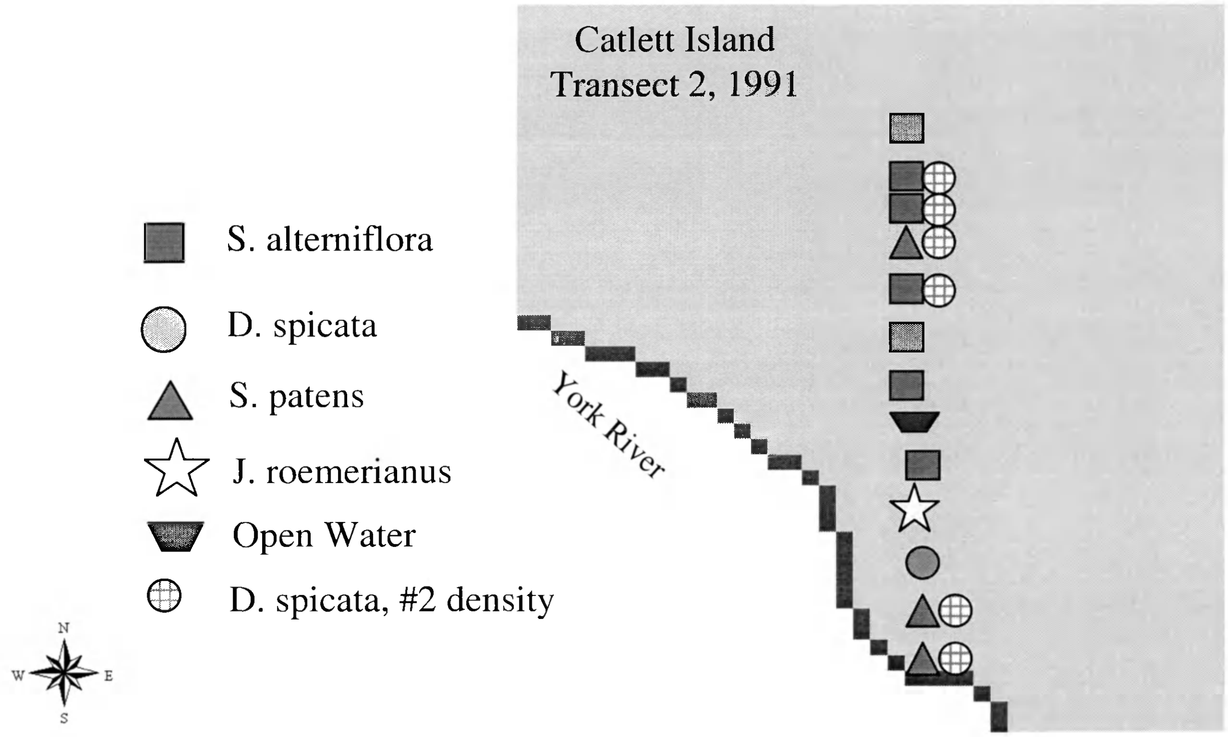


Figure 8. Vegetation change by plot in transect 2, Catlett Islands from 1991 to 1995.

Change by plot in transect 2, Catlett Islands



Dominant species by plot

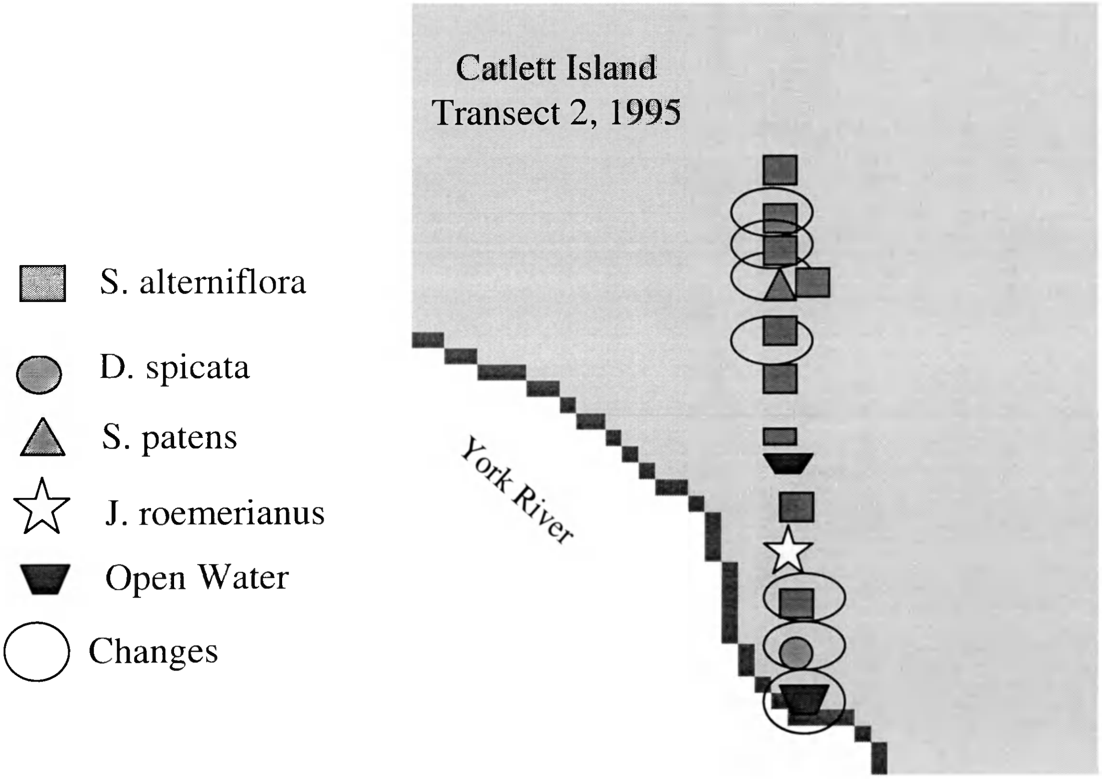
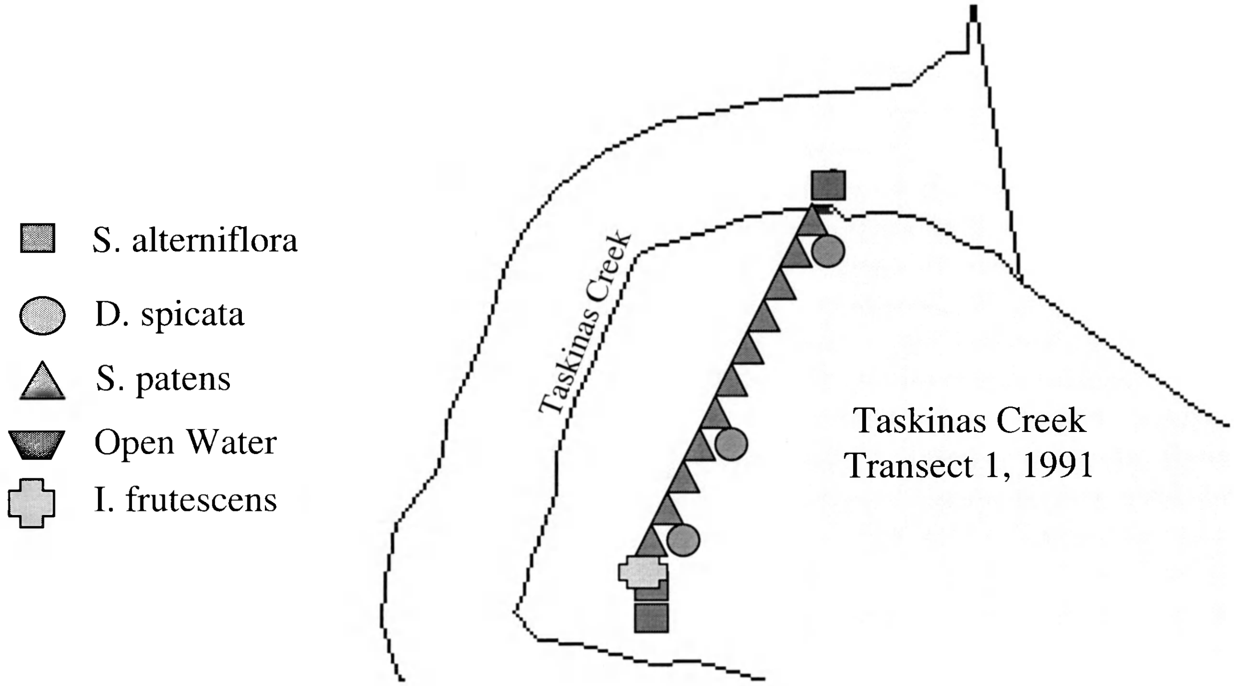


Figure 9. Vegetation change by plot in transect 1, Taskinas Creek from 1991 to 1995

Change by plot in transect 1, Taskinas Creek



Dominant species by plot

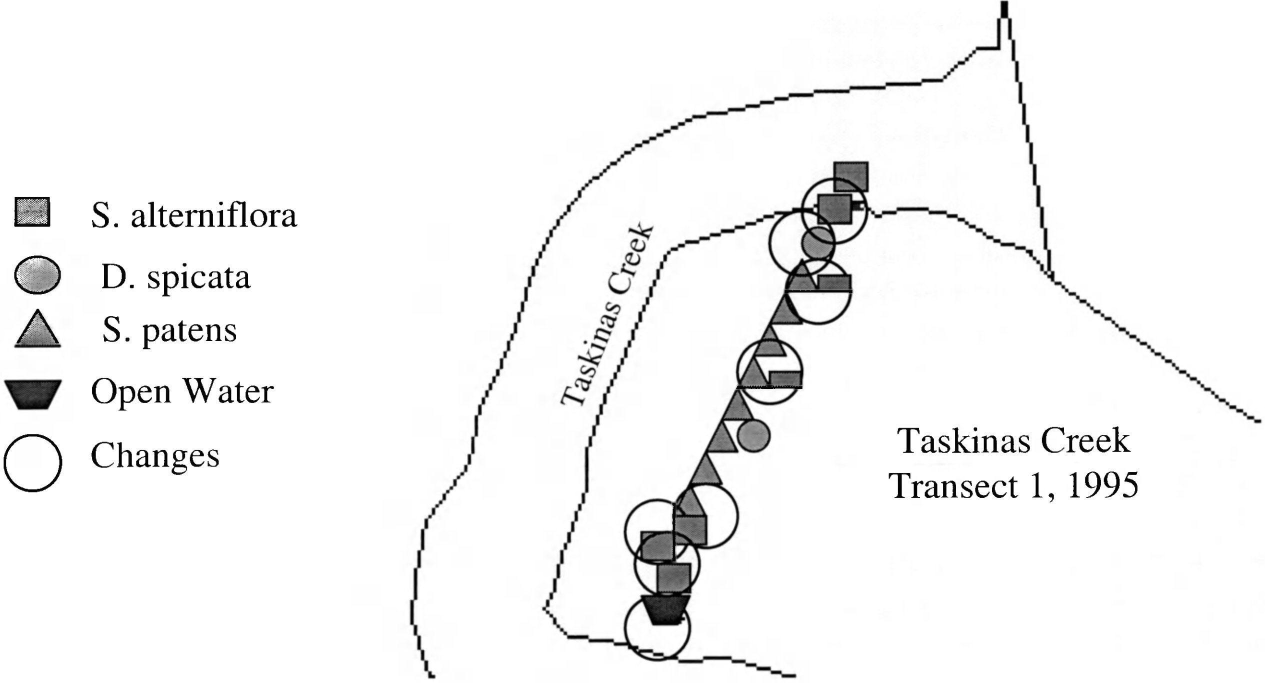


Figure 10. Diversity Indices for each site and transect,
1991 to 1995.

Diversity Indices for each site and transect

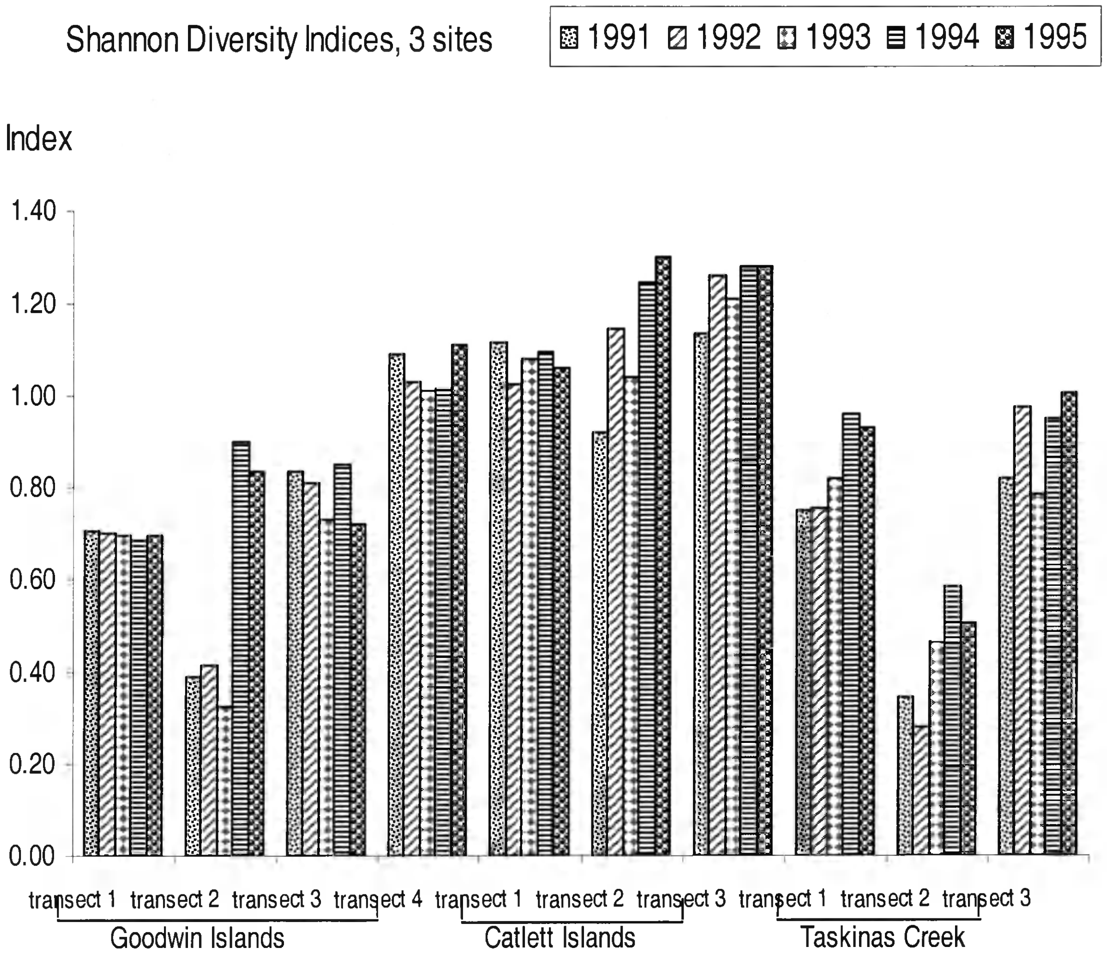


Figure 11. Normal probability plot.

Normal Probablility Plot

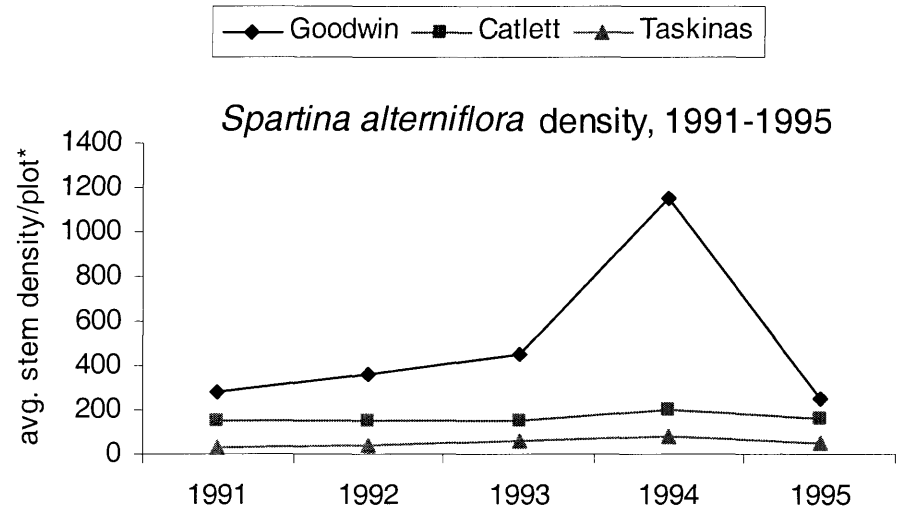
```
              The UNIVARIATE Procedure
                Normal Probability Plot


1.325+                                ++   *
     |                              **
     |                            **+
     |                           *+
     |                          **
     |                        **+
     |                      **+*
0.975+                        **++
     |                    **+
     |                   *+
     |                  ***
     |                 **+
     |               ***+
     |              *++
0.625+                ++
     |            ++*
     |           + *
     |          ++ *
     |         ++ *
     |        ++ **
     |       ++ *
0.275+  +*
      +----+----+----+----+----+----+----+----+----+----+
         -2        -1        0        +1        +2
```

* = actual diversity data values;

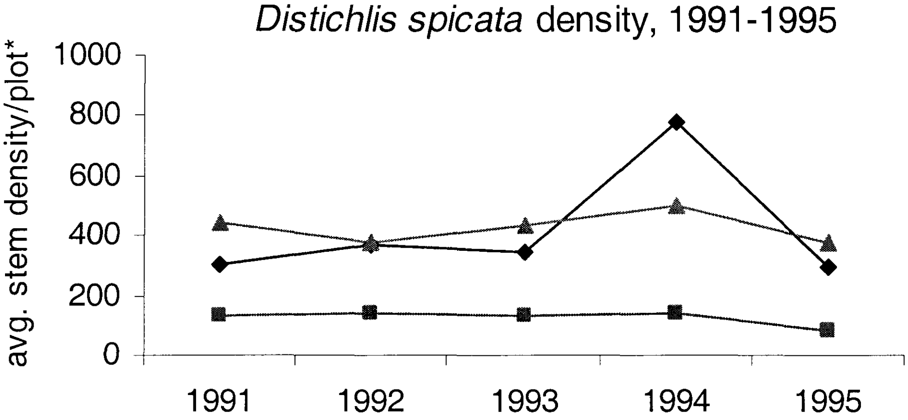
\+ = reference values based on sample mean and standard deviation

Figure 12. Average stem density of species over five years.

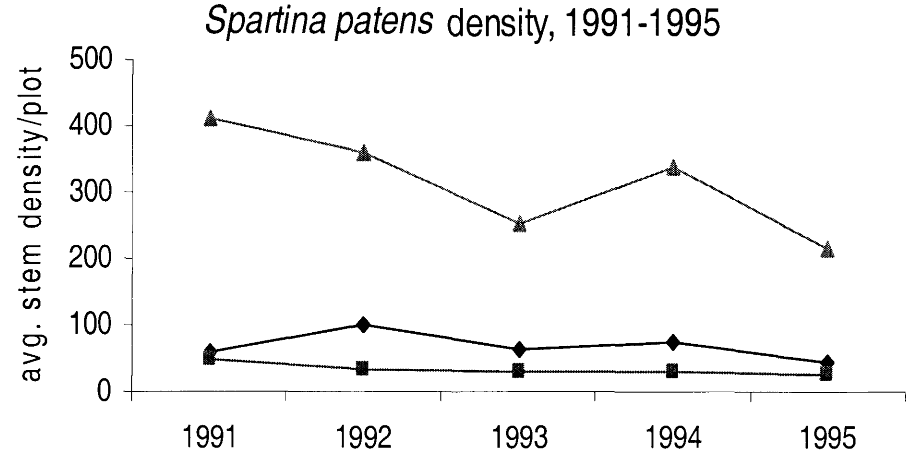
Average stem density



Spartina alterniflora density, 1991-1995



Distichlis spicata density, 1991-1995

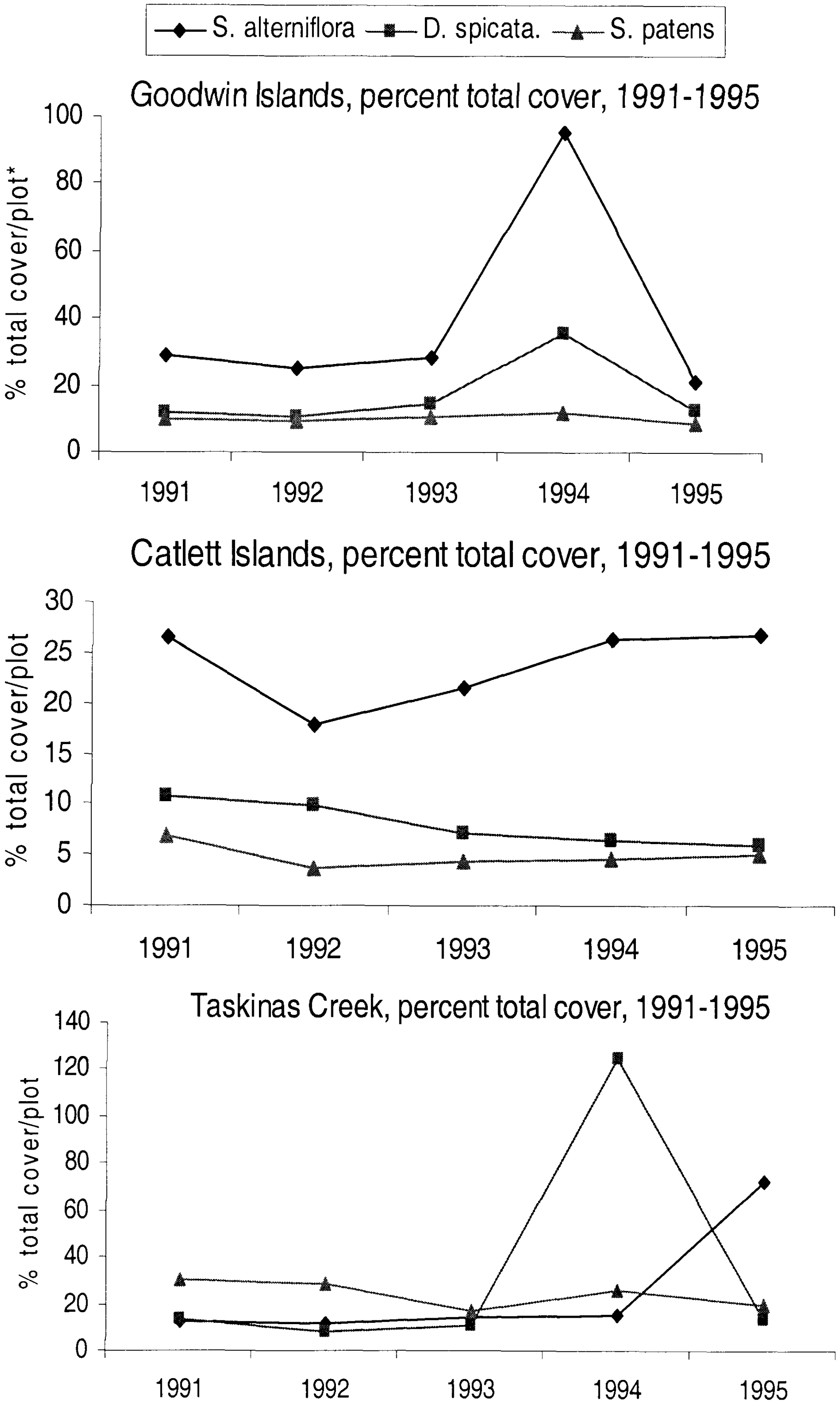


Spartina patens density, 1991-1995

*Plot equal ¼m x ¼m quadrat

Figure 13. Total percent cover of three dominant species, by site, 1991 to 1995.

Total percent cover


Goodwin Islands, percent total cover, 1991-1995

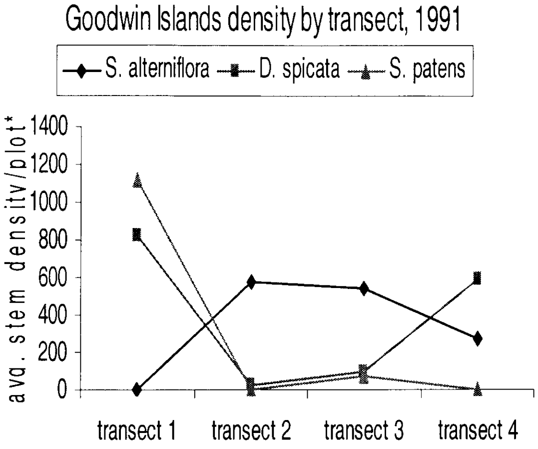
Catlett Islands, percent total cover, 1991-1995

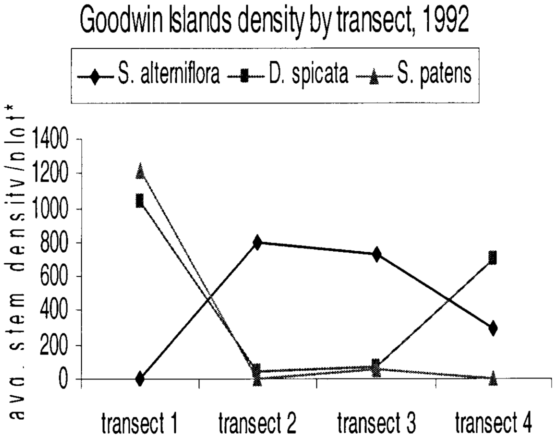
Taskinas Creek, percent total cover, 1991-1995

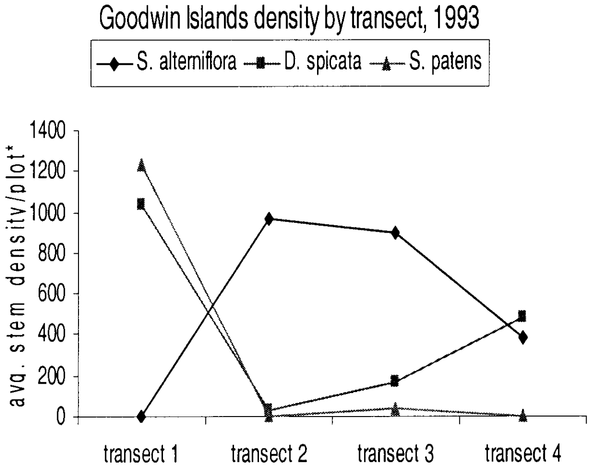
*Plot equals 1m x 1m

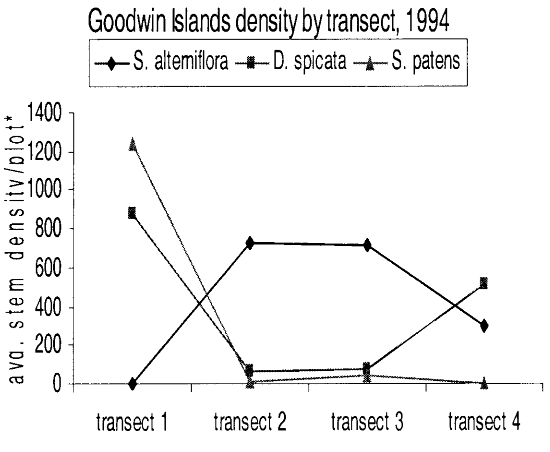
Figure 14. Average stem density per plot by transect,
Goodwin Islands, 1991 to 1995.

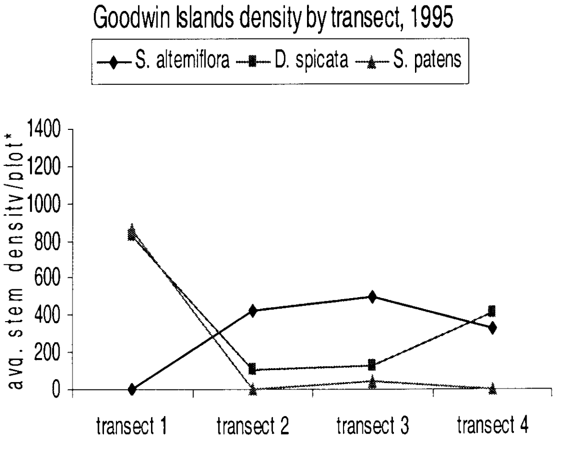
Average stem density by transect, Goodwin Islands







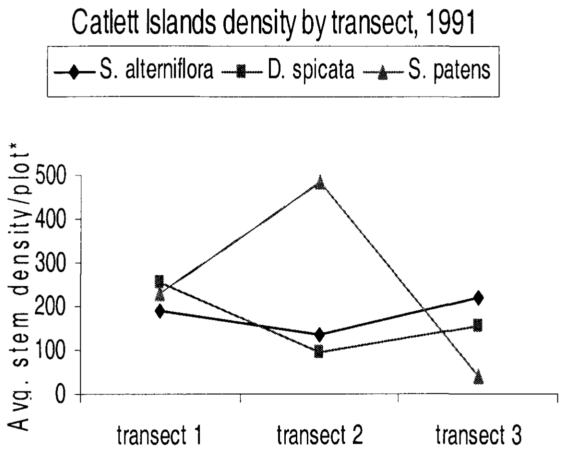


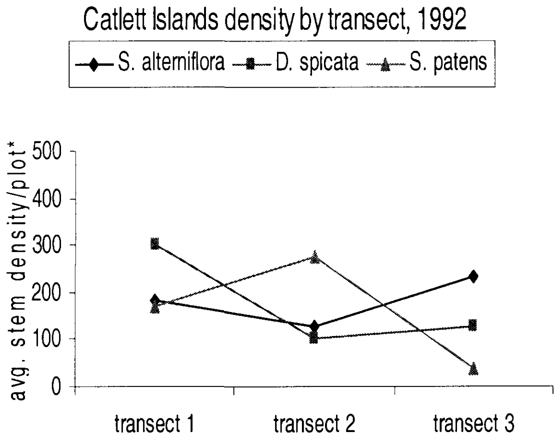


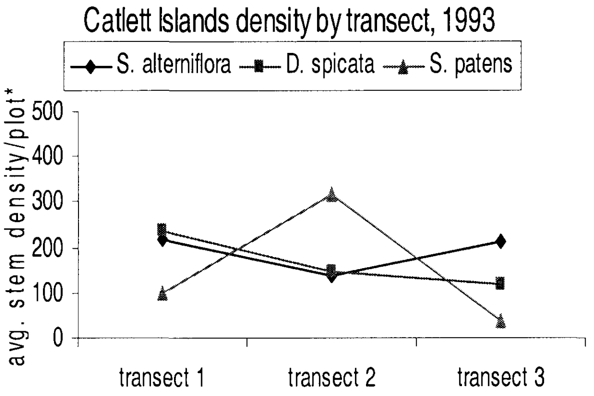
*Plot equal ¼m x ¼m quadrat

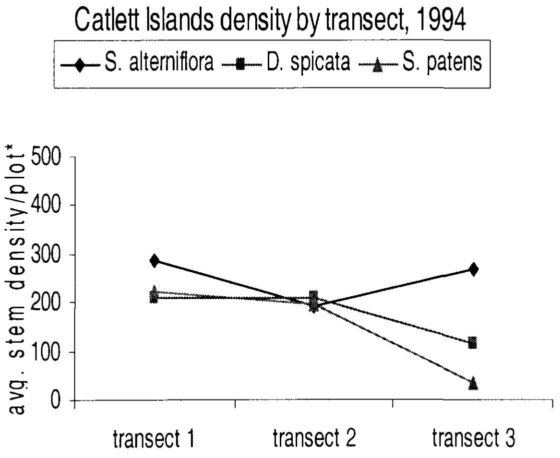
Figure 15. Average stem density per plot by transect, Catlett Islands, 1991 to 1995.

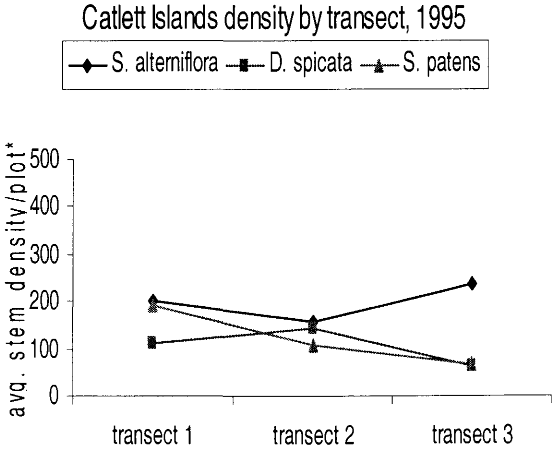
Average stem density per plot by transect, Catlett Islands







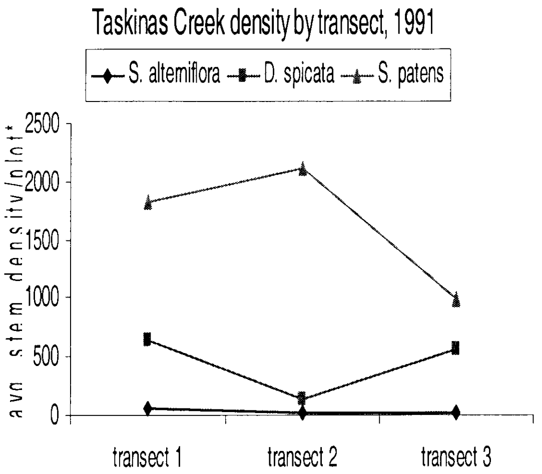


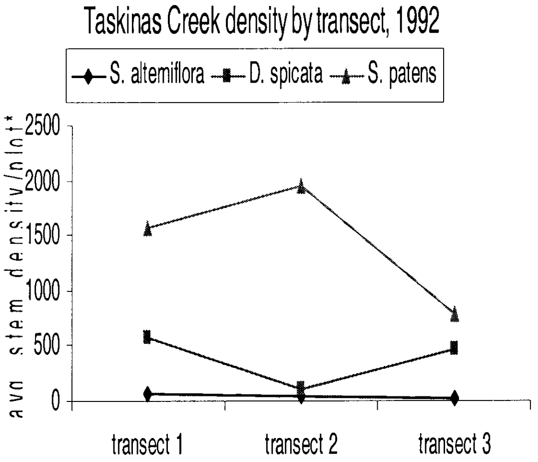


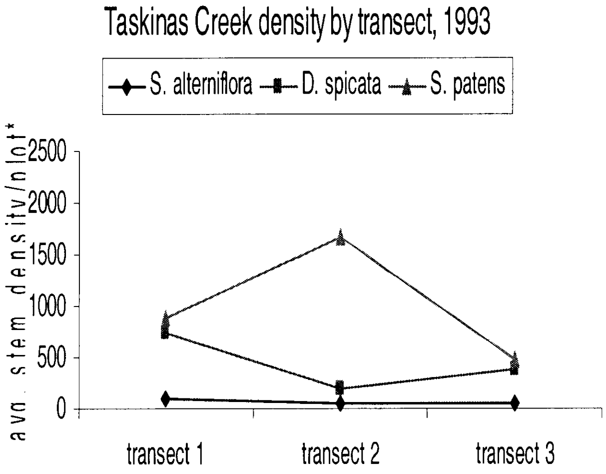
*Plot equal ¼m x ¼m quadrat

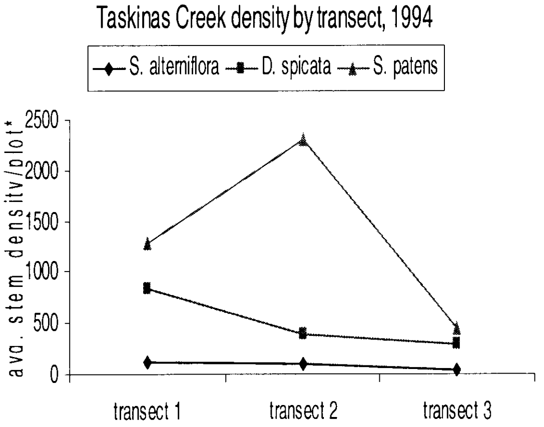
Figure 16. Average stem density per plot by transect,
Taskinas Creek, 1991 to 1995.

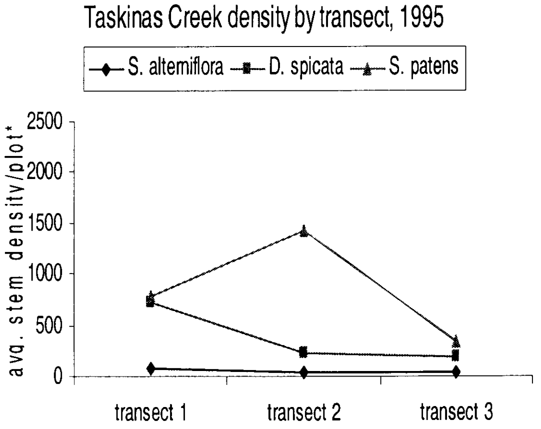
Average stem density by transect, Taskinas Creek









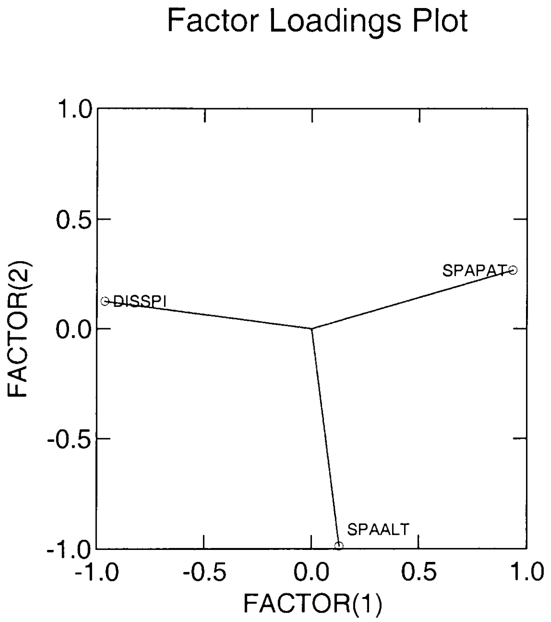


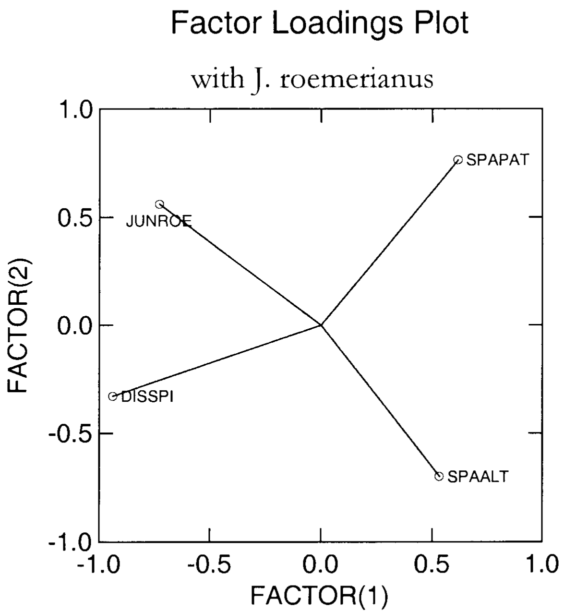
*Plot equal ¼m x ¼m quadrat

Figure 17. PCA factor loading plots.

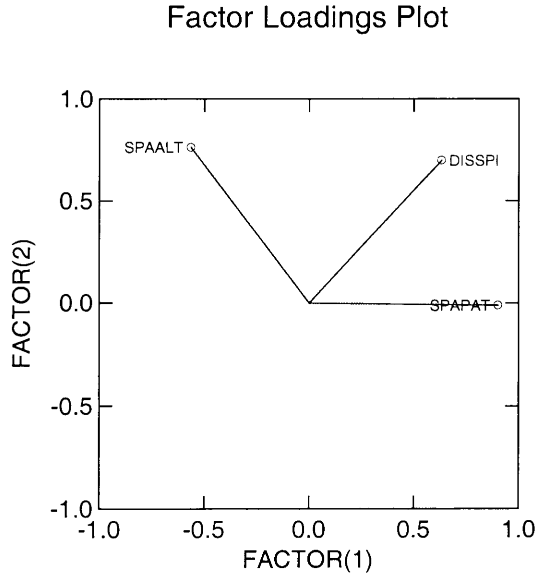
PCA factor loading plots for Catlett Islands

Catlett Islands, transect 3





Catlett Islands, whole site



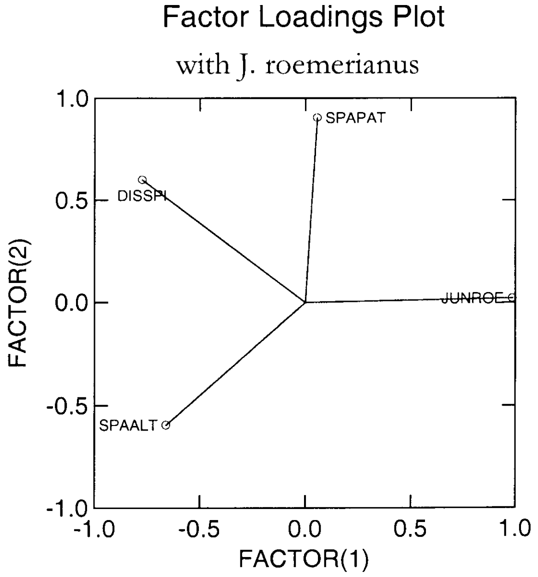
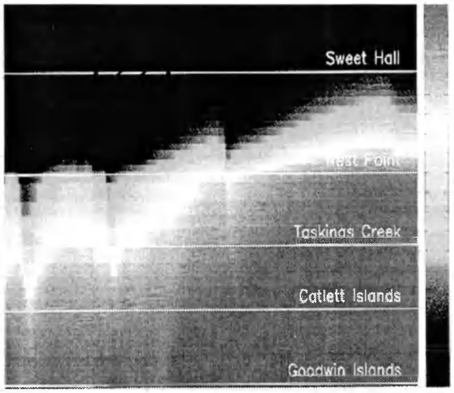
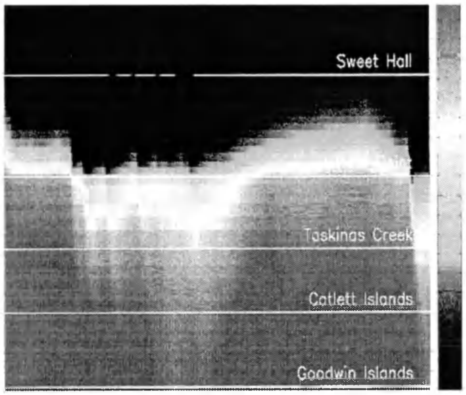
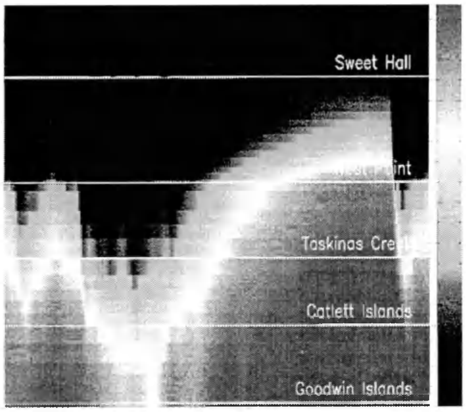


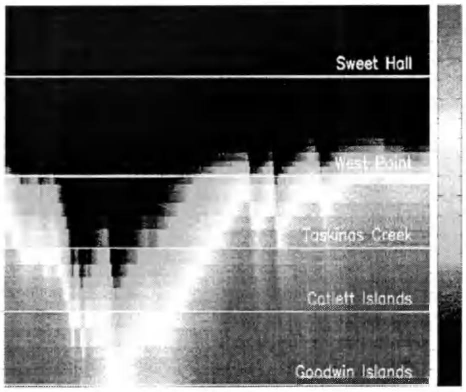
Figure 18. Model of York River salinity, 1991 to 1995.

Salinity in the York River, 1991-1995









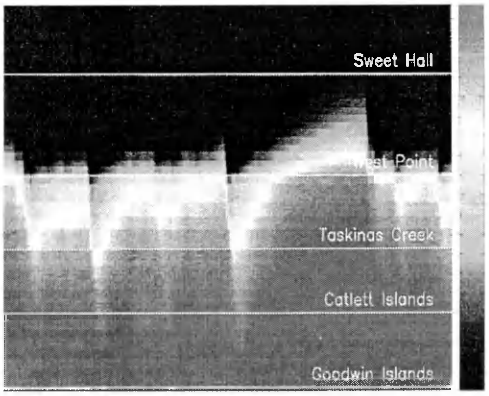


Figure 19. Goodwin Islands salinity and species density, 1991 to 1995.

Goodwin Island salinity and species density, 1991-1995

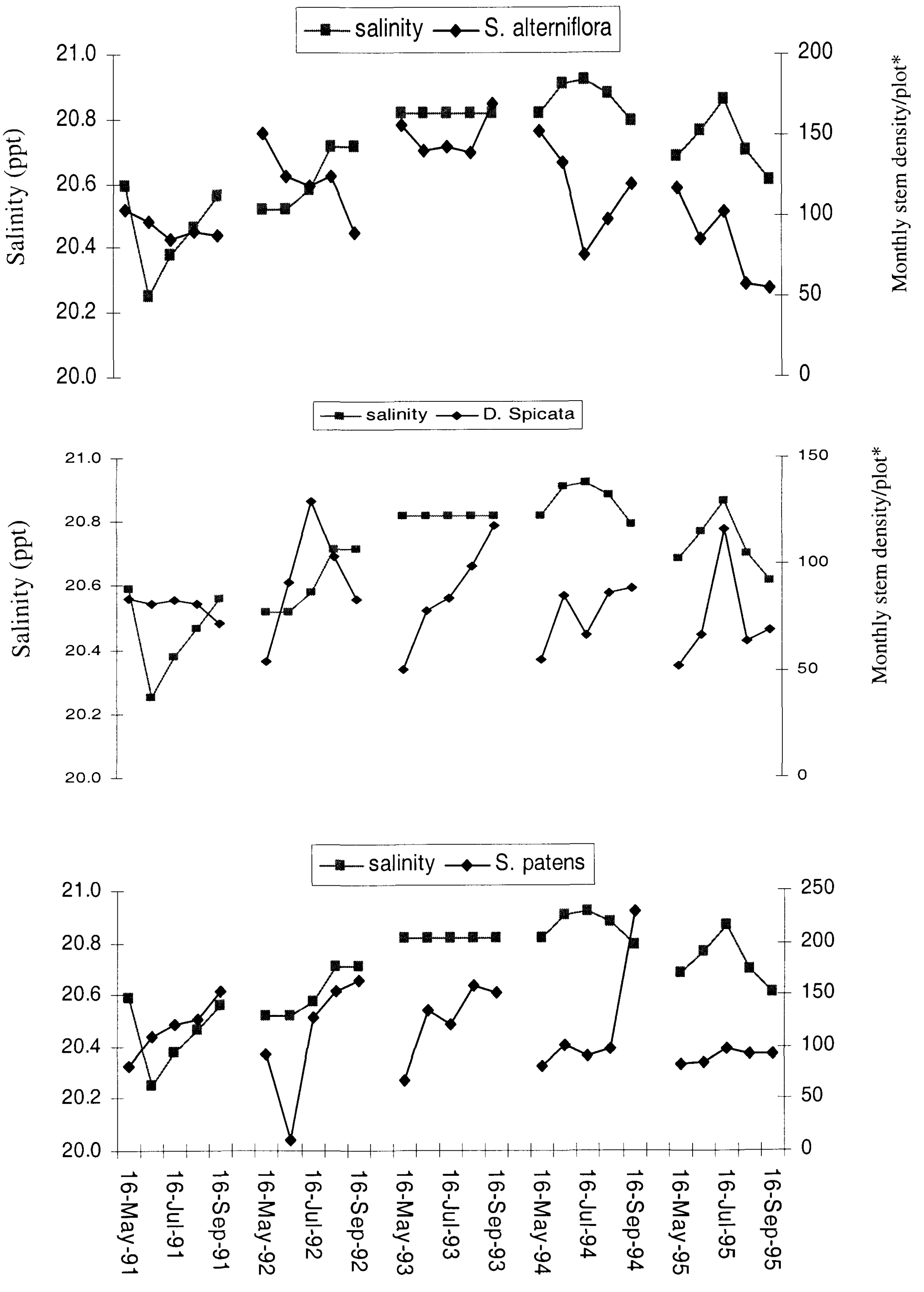


Figure 20. Catlett Islands salinity and species density, 1991 to 1995.

Catlett Island salinity and species density, 1991-1995

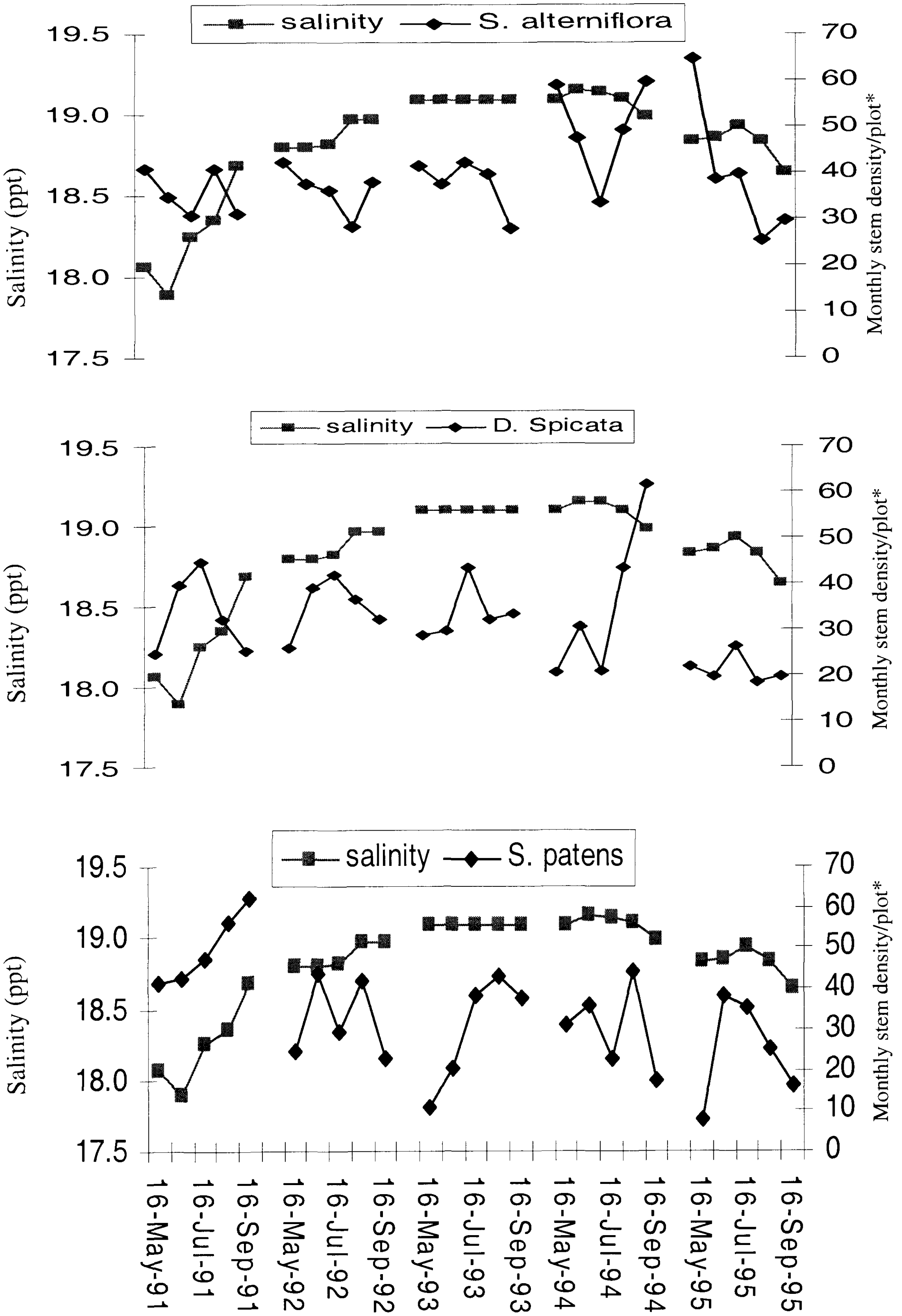


Figure 21. Taskinas Creek salinity and species density, 1991 to 1995.

Taskinas Creek salinity and species density, 1991-1995

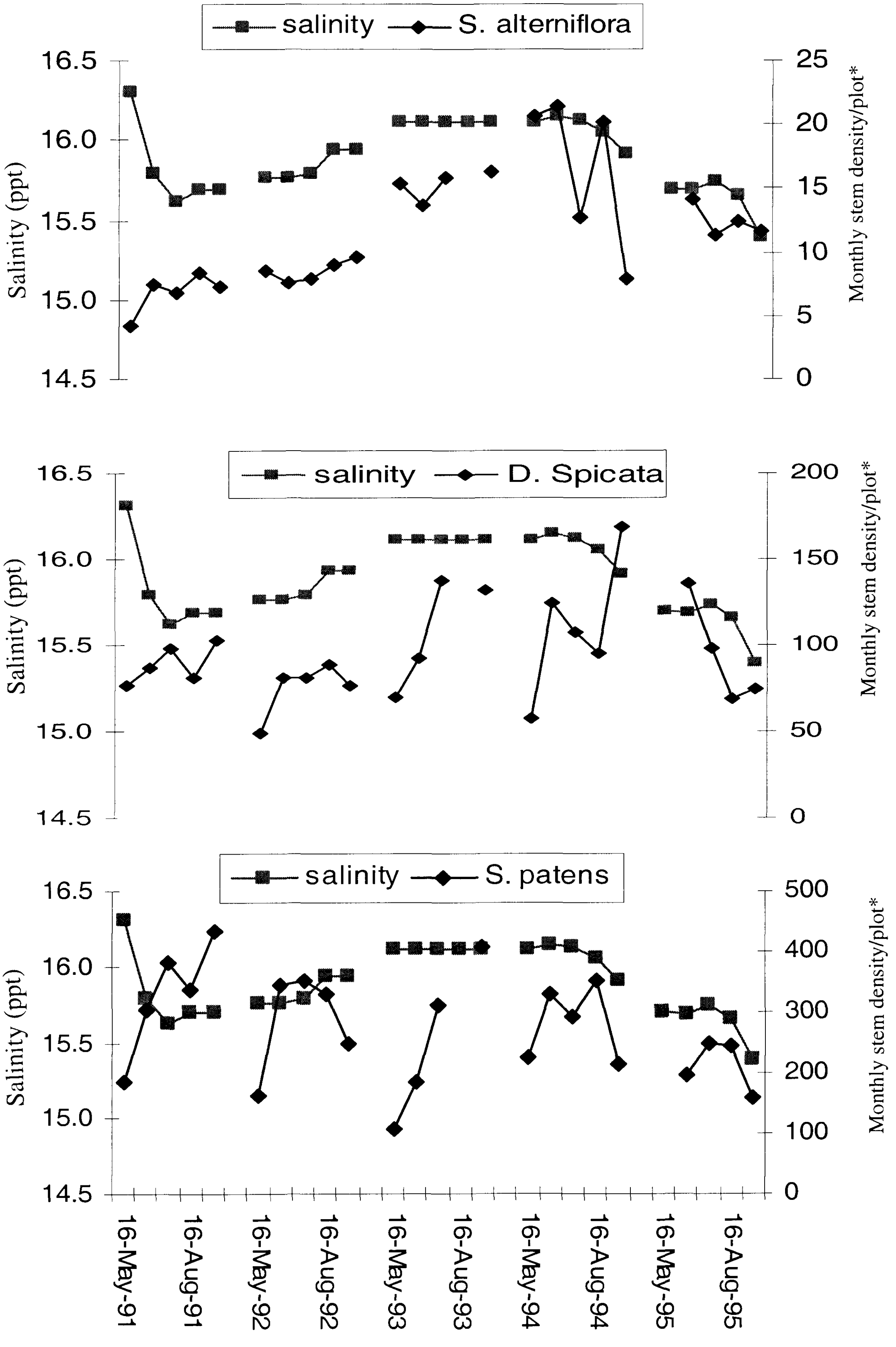
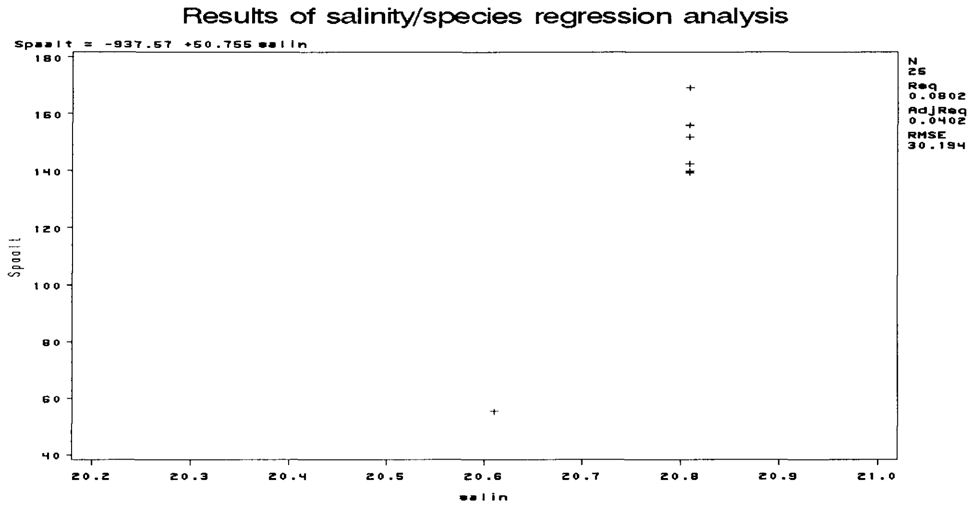
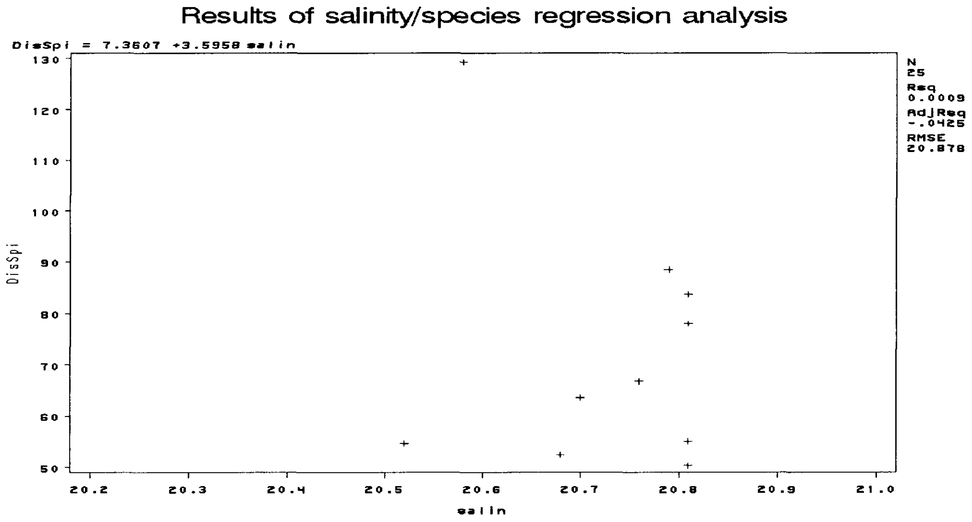


Figure 22. Regression plot of salinity and species density for Goodwin Islands

Regression plot of salinity and species density for Goodwin Islands





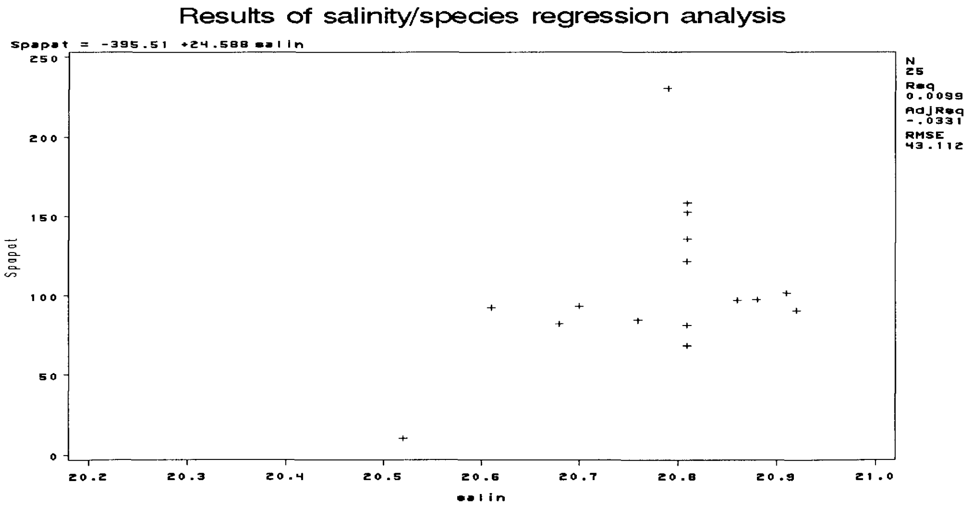
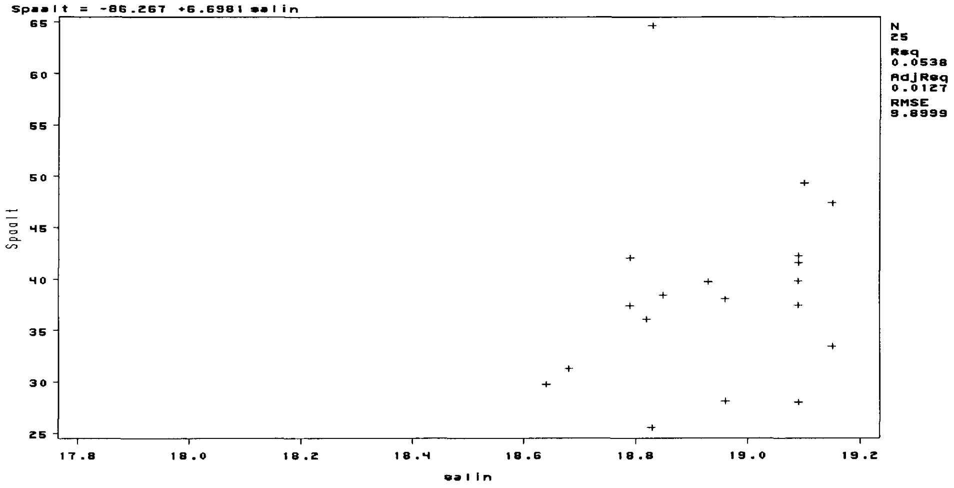


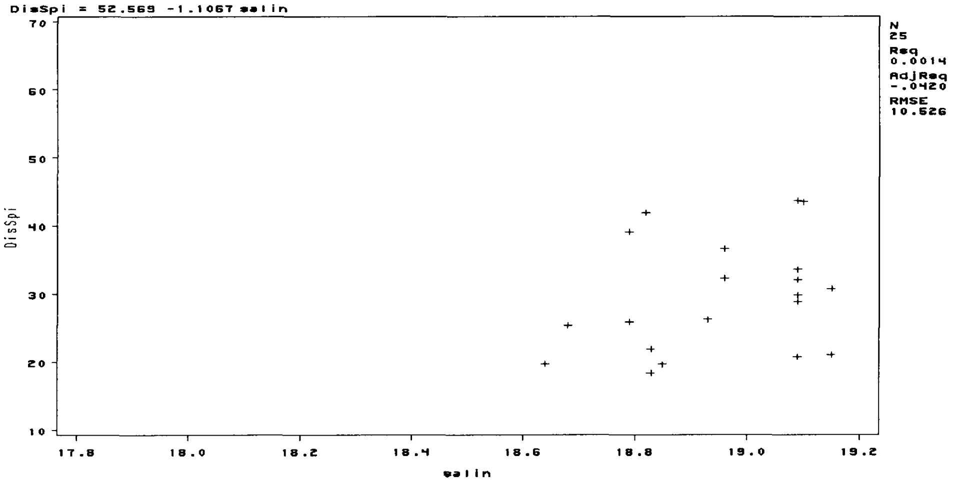
Figure 23. Regression plot of salinity and species density for Catlett Islands.

Regression plot of salinity and species density for Catlett Islands

Results of salinity/species regression analysis



Results of salinity/species regression analysis



Results of salinity/species regression analysis

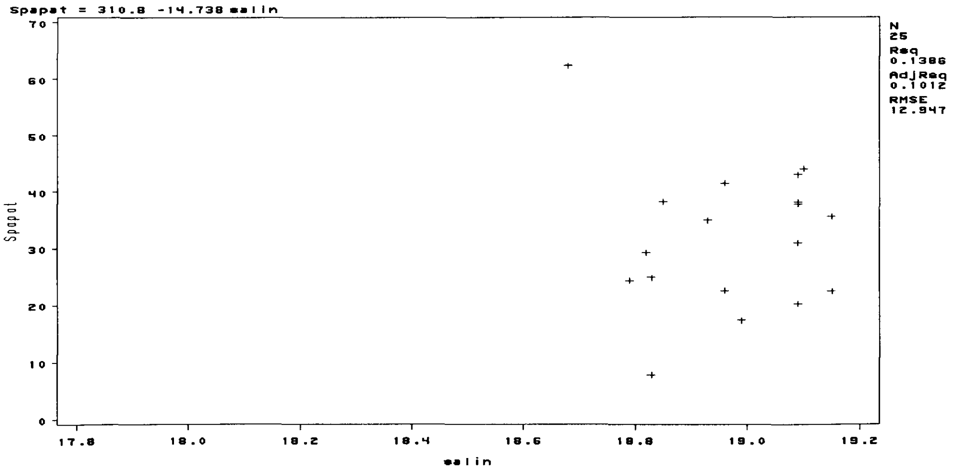
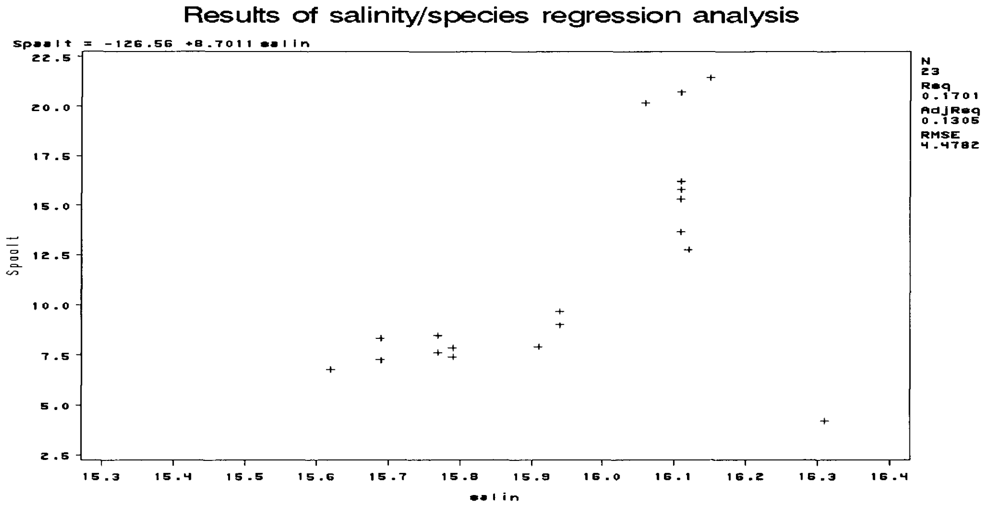
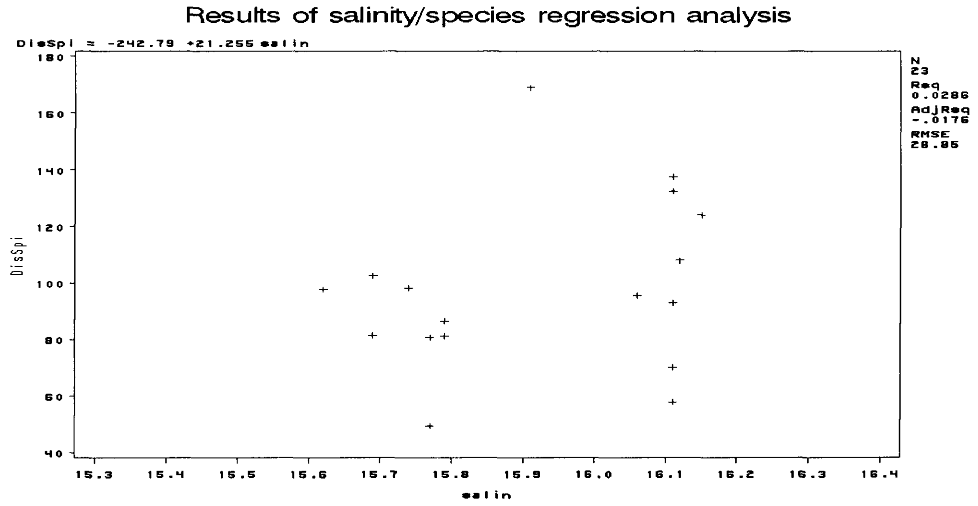
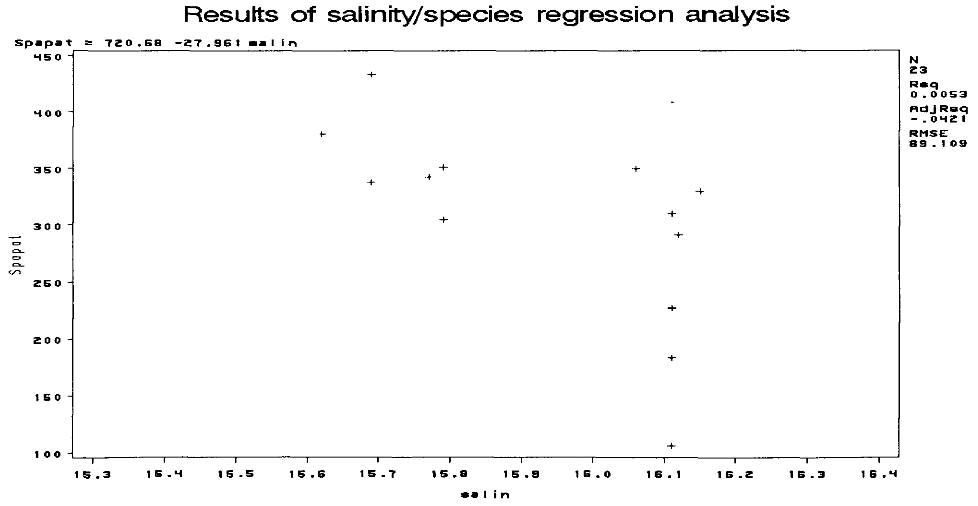


Figure 24. Regression plot of salinity and species density for Taskinas Creek.

Regression plot of salinity and species density for Taskinas Creek


Results of salinity/species regression analysis


Results of salinity/species regression analysis


Results of salinity/species regression analysis

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