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Distribution of Foraminifera and Pollen in Coastal Depositional Environments of the Southern Delmarva Peninsula, Virginia, U.S.A.

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DISTRIBUTION OF FORAMINIFERA AND POLLEN IN COASTAL DEPOSITIONAL ENVIRONMENTS OF THE SOUTHERN DELMARVA PENINSULA, VIRGINIA, U.S.A.

by

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ABSTRACT

DISTRIBUTION OF FORAMINIFERA AND POLLEN IN COASTAL DEPOSITIONAL ENVIRONMENTS OF THE SOUTHERN DELMARVA PENINSULA, VIRGINIA, U.S.A.

Han Jun Woo
Old Dominion University, 1992
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The coastal zone of the southern Delmarva Peninsula exhibits a wide variety of barrier island system subenvironments. This study investigates whether 20 *a priori* subenvironments can be distinguished from each other on the basis of abiotic environmental variables, pollen assemblages, living foraminiferal populations, and total (living plus dead) foraminiferal assemblages.

The physical data collected from the coastal zone were subjected to canonical variate analysis which discriminated 83% of the stations in 19 groups. These groups were clustered into two internally overlapping sets which represented the inside and outside of the inlet.

Twenty-two pollen types were found in low-energy marsh and mud-flat environments. Canonical variate analysis of pollen data showed that the inner, middle, and outer parts of the lagoon were clearly discriminated suggesting that variations in modern pollen assemblages from the barrier lagoon can be used in paleogeographic interpretations under warm climatic conditions.

Sixty-eight foraminiferal species were recorded from 57 surface sediment samples. The values of species diversity (H(S)) and equitability (E) exhibit a striking contrast between the marshes and other areas. The marshes had higher values of

species diversity and equitability than the tidal flats and the channels-inlets-shoreface. Stepwise regression analyses indicate correlation of the five most frequently occurring species in living populations (> 30% of the total stations) and the seven most frequently occurring species in total assemblages (> 30% of the total stations) with combinations of one to three environmental variables at the 95% level.

Neither living nor total foraminiferal distribution data allow for recognition of the 20 *a priori* subenvironments. Ten biofacies are defined by the distribution patterns of the dominant living species (> 25% of the population); eight biofacies are defined by the distribution patterns of the dominant species (> 25% of the assemblage) in total assemblages. Canonical variate analysis were performed to test whether the 20 *a priori* subenvironments are statistically distinct. Results indicated that 11 discrete biofacies were defined by living foraminiferal populations, and different set of 11 biofacies (brackish marsh and channel, restricted tidal bay, inner muddy sand flat, middle sandy bays-washover fan, middle to outer bays-ebb deltas-shoreface, mud flats, inner protected fringe marsh, inner exposed fringe marsh, outer fringe marsh, intermediate tidal channel, and deep tidal channel) were defined by total foraminiferal assemblages.

On the basis of this study, modern physical, pollen and foraminiferal data are useful for discriminating sedimentary environments of a barrier island system, and provide a model for paleoenvironmental interpretations in late Quaternary coastal deposits. However, the total foraminiferal assemblage model must be applied with caution because the character of fossil assemblages in short cores from the outer fringe marsh and tidal flats indicates that taphonomic loss of foraminiferal tests is both considerable and variable.

DEDICATION

To my parents,

Jae Ho Woo and Kyung Ok Yu

and to the memory of my maternal grandmother,

Tae Soo Na

ACKNOWLEDGEMENTS

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Chapter 1
Introduction

The coastal zone is composed of estuarine, lagoonal and near-shore environments. These environments exhibit wide ranges of conditions because they are affected by land and sea. Lagoonal coasts are transitional zones where terrestrial and marine conditions interact to produce a variety of complex subenvironments.

James Hutton's Law of Uniformitarianism encapsulated in the phase, " the present is the key to the past, " has been a tool for geologic studies for over two centuries. The characteristics of modern environments are important to geologists because they may provide information used in reconstructing paleogeography from the geologic record. Since barrier coasts have a variety of subenvironments, it is believed that the resultant distributions of grain-size, pollen and foraminiferal assemblages may be useful tools for distinguishing among subenvironments in the coastal lagoon and recognizing these respective lithosomes in the geological record.

This study focuses on the characteristics and relationships among different depositional environments in the barrier island system through the study of pollen and foraminiferal distributions. The plan is to determine if variability in the lithologic and paleontologic characteristics of coastal depositional environments is sufficient to subdivide lithosomes for geologic recognition. Surface sampling of sediment, flora, and fauna will be used to determine their characteristics in the modern lagoon and shoreface. Cores from a barrier fringe marsh and tidal flats will be used to determine the relationship between surface characteristics and their buried lithologic records.

1.1 Statement of Problem

Identification of barrier lagoons in the geologic record is generally based on the geometric association of inlets and barrier sands, yet further differentiation of subenvironments in lagoon is rare. The modern barrier lagoons of the southern Delmarva Peninsula have a variety of different depositional environments including deep tidal channels, marshes, tidal flats, subtidal flats, bars, storm berms, exposed bays, restricted bays, and inlets. For this research, I have identified 20 different subenvironments in a coastal barrier island system (Table 1) based on a variety of physical, geological and geomorphic parameters. The main parameters used were elevation, grain-size distribution, tidal inundation, salinity and dominant flora. It is believed that differences in these parameters may control and produce distinctive foraminiferal populations and assemblages (Parker, 1952a, b; Phleger, 1952; Miller, 1953; Ronai, 1955; Kraft and Margules, 1971; Buzas and Severin, 1982).

While these parameters may also affect the local distribution of plants, climatic influences generally have more pronounced regional effects. Therefore, the aeolian transport and accumulation of pollen is not assumed to be altered by local parameters and processes. The wide-spread transport and mixing of pollen by winds is generally believed to form a uniform blanket of pollen representing climatic conditions at a specific time (Sirkin et al., 1977; Brush and DeFries, 1981; Gaudreau and Webb, 1985). However, it is not known how processes in lagoonal subenvironments may alter the accumulation of pollen into the lithofacies. Knowledge of the relationships between these parameters and the specific distributions of pollen and foraminifera may be used for identifying the record of the depositional environments that they represent.

The purpose of the research is to investigate quantitatively whether different depositional environments of the barrier island system are characterized by different pollen and foraminiferal populations and assemblages, and to determine whether these

Table 1. Four major zones, eight environments and 20 subenvironments of a barrier island system based on a variety of physical and geomorphic parameters.

FLUVIO-TRANSITION
- Brackish marsh / channel (< 10 psu salinity)

BARRIER LAGOON
- Restricted tidal bay, flat
- Exposed bay
    - inner muddy sand flat
    - middle/outer muddy sand flat
    - inner sand flat
    - middle sand flat
    - outer sand flat
    - inner mud flat
    - outer mud flat
- Marshes
    - inner lagoon, protected fringe marsh
    - inner lagoon, exposed fringe marsh
    - middle lagoon, marsh
    - outer lagoon, fringe marsh
- Tidal channel
    - channel margin
    - intermediate channel (5 - 10 m)
    - deep channel (14 m)
- Washover fan (outer lagoon)

INLET-MARINE
- Ebb delta
    - axial channel
    - inlet shoals

ISLAND-MARINE
- Shoreface
    - barrier island shoreface

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assemblages can be used as paleoenvironmental indicators in a late Quaternary, temperate coastal barrier island system.

1.2 Hypotheses

Grain-size distribution is a direct response to the sediment transport and mixing characteristics in depositional environments. It also reflects the characteristics of every environment on the dispersal pathway from the source environment to the depositional site. Thus, grain-size distribution may partially reflect sedimentary response to patterns of lagoonal fluid power in different lagoonal sedimentary environments.

Since plant communities are very sensitive to climatic change, pollen assemblages are used to determine paleoclimatic conditions. Pollen analysis is particularly useful to determine the association of sedimentary beds with interglacial or glacial climatic history. Pollen assemblages on the modern seabed should characterize the warm climatic flora of this time. However, since most pollen grains are silt-sized (0.01-0.05 mm), pollen assemblages are in part also influenced by variations in processes of sedimentation within the barrier island system. Since grain size distributions are a surrogate for variations in sedimentary processes, it will be used to determine what characteristics of a pollen assemblage are influenced by association with a different barrier island environment.

Foraminiferal populations and assemblages in the surface sediment are related to ecological processes at each environment. Species and percentages of live foraminifera at each depositional environment are therefore an indicator of present ecological conditions. Dead foraminiferal assemblages may be related to living assemblages or result from physical transport processes or other taphonomic processes at each environment.

According to these concepts, the general null and alternative hypotheses of research can be made:

H_{o1} : Pollen assemblages are uniform in surface sediments at the subenvironments of the barrier island system.

H_{A1} : Different pollen assemblages are distinguishable in surface sediments of the subenvironments of the barrier island system.

H_{o2} : Foraminiferal assemblages are not distinguishable between the subenvironments of the barrier island system.

H_{A2} : The subenvironments of the barrier island system that can be qualitatively defined by differences in water depth, hypsometry, flora and salinity may also be defined independently by foraminiferal assemblages in surface sediments.

1.3 Objectives

In order to test the above hypotheses, several objectives needed to be achieved. The main objective is to determine whether modern subenvironments within a barrier island system (that have been defined based on measurable physical parameters such as water depth, exposure, salinity, etc.) can be recognized by evaluating combinations of parameters that can only be determined from the sediment record.

Several specific objectives are used for testing the hypotheses above.

(1) Initially, it is necessary to determine whether classes of grain-size textures are associated with each of the 20 different subenvironments in the barrier island system.

(2) In order to determine whether pollen assemblages are associated with each of the four major zones of the barrier island system, it will be necessary to determine average

types and concentrations in these zones.

(3) In order to determine whether different foraminiferal assemblages are related to the different subenvironments of the barrier island system, the identity, abundance, and distribution of foraminifera must be determined.

(4) In order to test the hypotheses, canonical variate analysis of environmental, pollen and foraminiferal data will be used.

1.4 Geologic Setting

The southern Delmarva Peninsula is located on the Middle Atlantic Coast Plain in the southern portion of Maryland and southeastern Virginia (Fig. 1). The central upland area of the southern Delmarva Peninsula is a drainage divide surrounded by gently sloping lowland plains which drain toward the Chesapeake Bay and the Atlantic Ocean. The lowland plains are separated from the central upland area by scarps of former marine bay, or estuarine shorelines.

Ground water resource studies by Sinnett and Tibbitts (1968) have produced a general lithology and stratigraphy for the southern Delmarva Peninsula. They described consolidated to unconsolidated sedimentary deposits ranging from Cretaceous to Holocene age (Sinnett and Tibbitts, 1968; Mixon, 1985). A summary of the lithologic characteristics of stratigraphic units by Mixon (1985) and Colman and Mixon (1988) is presented below (Fig. 2).

A regionally extensive erosional unconformity marks the end of the Tertiary in the southern Delmarva Peninsula and Chesapeake Bay area. Initially, material eroded from headlands in Maryland and Delaware accumulated on spits causing them to prograde south during a late Pleistocene high stand. The Accomack Member of the Omar Formation was deposited as a barrier-spit system in the late Pleistocene. After

Fig. 1. Location map of the southern Delmarva Peninsula.

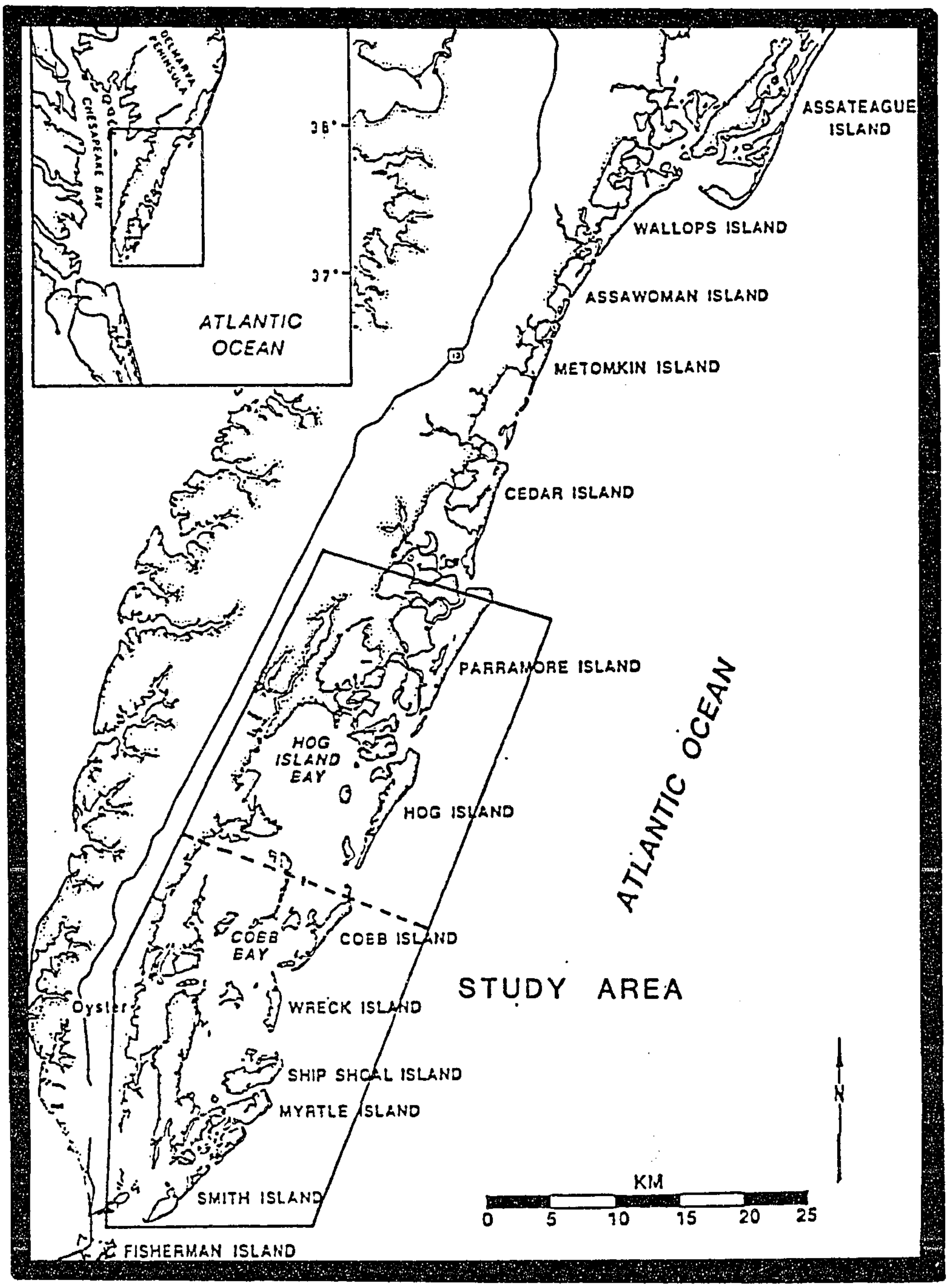

ASSATEAGUE ISLAND
WALLOPS ISLAND
ASSAWOMAN ISLAND
METOMKIN ISLAND
CEDAR ISLAND
PARRAMORE ISLAND
HOG ISLAND BAY
HOG ISLAND
ATLANTIC OCEAN
COBB BAY
COBB ISLAND
STUDY AREA
Oyster
WRECK ISLAND
SHIP SHOAL ISLAND
MYRTLE ISLAND
SMITH ISLAND
FISHERMAN ISLAND
KM
0 5 10 15 20 25
N
38°
37°
CHESAPEAKE BAY
DELMARVA PENINSULA
ATLANTIC OCEAN

Fig. 2. The lithology and stratigraphic units in the southern Delmarva Peninsula (from Mixon, 1985).

Epoch	Unit			Lithology
	Central and western parts, VA & MD		Eastern part in VA	
Late Pleistocene Post - 140,000 YBP	Kent Island Formation		Wachapreague Formation	Coarse and fine to medium quartz and chert sand (Kent Island Formation) Silty sand and clay-silt and coarse sand (Wachapreague Formation)
	Nassawadox Formation	Occochannock Member	Joynes Neck Sand	Fine to medium quartz sand (Occochannock Member) Fine to coarse quartz sand (Joynes Neck Sand)
		Butlers Bluff Member		Fine to coarse sand and gravel
		Stumptown Member		Sandy gravel, clay-silt and muddy fine sand
Pre-140,000 YBP	Omar Formation (Accomack Member)			Sand, gravel, silt, clay and peat
Middle Pliocene 3.0 - 3.4 Million YBP	Yorktown Formation	Upper shelly sand member		Fine to coarse glauconitic quartz sand with abundant large bivalves
		Tunnels Mill member		Clayey silt, silty clay, and lesser amounts of very poorly fine to coarse pebbly sand
		Lower shelly sand member		Shelly glauconitic quartz sand
Late Miocene 5.3-11.1 Million YBP	Eastover Formation	Cobham Bay Member		Greenish-gray, clayey, silty and shelly quartz sand
		Claremont Manor Member		

regression and subsequent transgression, the Nassawadox Formation was deposited on the southern part of the southern Delmarva Peninsula. The lower part of the Nassawadox Formation, the Stumptown Member filled of the Eastville paleochannel. The channel-fill units have a sequence of sandy gravel, clay-silt , and muddy fine sand. These units represented from fluvial to estuarine-marine environments. The Butlers Bluff Member of the Nassawadox Formation is composed of barrier-spit and nearshore-shelf deposits that were deposited during late stages of the transgression. The Occohannock Member was deposited in a large bay or estuary environment behind the Nassawadox barrier.

The coarsening-upward Wachapreague Formation is composed of regressive nearshore-marine deposits; the lower unit is composed of fossiliferous, muddy, fine sand and the upper unit is composed of relatively clean, gravelly sand. Pollen assemblages indicated that the Wachapregue Formation was initially deposited during warm climatic conditions which changed to cooler climatic conditions in Late Pleistocene (82,000 - 128,000 YBP) (Mixon, 1985).

Holocene deposits of barrier-lagoon systems have been studied by Newman and Rusnak (1965), Newman and Munsart (1968), Harrison (1972), Shideler et al. (1984), and Oertel et al. (1989, 1992). The lagoons of the southern Delmarva Peninsula are believed to have formed between 1,400 and 5,500 YBP (Newman and Munsart, 1968; Finkelstein, 1981, 1986). Mixon (1985) believed that the unconsolidated Holocene deposits (2,550±70 to 5,120±145 YBP) of the barrier lagoon system increase in thickness eastward from mainland side of the lagoon to 11 meters east of Wachapreague and about 15 meters near the southern end of Assateague Island. Shideler et al. (1984) determined that the maximum thickness of Holocene deposits reached 19 meters in the southern parts of the southern Delmarva Peninsula. However, Oertel et al. (1989,1992) and Foyle and Oertel (1992) suggested that a significant part of these lagoonal sediments are probably pre-Holocene lagoonal sediments that were deposited

during previous high stands.

1.4 Area of Investigation

The study area is part of the southern Delmarva Peninsula between Smith Island and Parramore Island and between the mainland and the shoreface (Fig. 1). Barrier islands and lagoons at present form the seaward fringe of the southern Delmarva Peninsula. Lagoonal environments in this region include deep tidal channels, marshes, tidal flats, oyster reefs, bars, storm berms, restricted bays, and inlets.

Lagoonal sediments consist of interfingering Quaternary and Holocene paralic and fluvial deposits (Mixon, 1985; Oertel et al., 1989). The barrier lagoons have semidiurnal tides with average tidal ranges between 0.9 m and 1.2 m. The salinities in the barrier lagoons between Smith Island and Parramore Island are relatively constant (between 28 and 32 psu). Brackish salinities (< 10 psu) are only present near the heads of small streams that drain into the lagoon.

Based on differences in sediment texture, tidal inundation and exposure, flora, wave exposure, apparent flushing, current flow and salinity, 20 different depositional subenvironments have been distinguished within the barrier island system (Table 2; Fig. 3, 4). Brackish marshes (stations 1-3) in the study area are located in the upper parts of the river where the salinity remains below 10 psu. Brackish marshes are characterized by organic-rich, silty clay sediments. The restricted bay (stations 4-6) is surrounded by marshes and connected to the bay via tidal channels. Sediments of this area compose of very fine sand and mud that are extensively bioturbated. Interfluve areas (stations 7-22) are tidal and sub-tidal flats that have muddy and sandy surfaces. Some parts of these areas are exposed at mean low water. Fringe marshes (stations 23-29, 32-37) in the study area occur along both the mainland and barrier-island sides of

Table 2. Sampling localities and station numbers of the 20 *a priori* subenvironments.

Subenvironments (Group No.)	Location	Stations	No.
Brackish marsh / channel (1)	Machipongo River	MREF 1	1
	Machipongo River	MREF 2	2
	Machipongo River	MREF 3	3
Restricted tidal bay, flat (2)	Boardenstake Bay	BSRB 1	4
	Boardenstake Bay	BSRB 2	5
	Boardenstake Bay	BSRB 3	6
Inner muddy sand flat (3)	Hog Island Bay	EB 3	7
	Hog Island Bay	EB 4	8
	Hog island Bay	FMFI 3	9
Middle/outer muddy sand flat (4)	Hog Island Bay	EB 1	10
	Hog Island Bay	EB 2	11
Inner sand flat (5)	Cobb Bay	CBSFI 1	12
	Cobb Bay	CBSFI 2	13
Middle sand flat (6)	Cobb Bay	ECSFM 1	14
	Cobb Bay	ECSFM 2	15
Outer sand flat (7)	Cobb Bay	CBSFO 1	16
	Cobb Bay	CBSFO 2	17
Inner mud flat (8)	Oyster flat*	OYMFI 1	18
	Oyster flat	OYMFI 2	19
	Oyster flat	OYMFI 3	20
Outer mud flat (9)	South Bay	WIMFO 2	21
	South Bay*	WIMFO 1	22
Inner lagoon, protected fringe marsh (10)	Phillips Creek Marsh	PCSM 1	23
	Phillips Creek Marsh	PCSM 2	24
Inner lagoon, exposed fringe marsh (11)	Fowling Point Marsh	FMFI 1	25
	Fowling Point Marsh	FMFI 2	26
	Ramshorn Marsh	RS 1	27
	Ramshorn Marsh	RS 2	28
	Ramshorn Marsh	RS 3	29
Middle lagoon,marsh (12)	Eckichy Marsh	EMCM 1	30
	Eckichy Marsh	EMCM 2	31

Continued

Subenvironments	Location	Stations	No.
Outer lagoon, fringe marsh (13)	Hog Island Marsh	HIFO 1	32
	Hog Island Marsh*	HIFO 2	33
	Smith Island Marsh	SI 1	34
	Smith Island Marsh	SI 2	35
	Wreck Island Marsh	WI 1	36
	Wreck Island Marsh	WI 2	37
Tidal channel margin (14)	Sand Shoal Channel Margin	WIMFO 3	38
	Phillips Creek Channel	PCSM 3	39
	Eckichy Channel	EMCM 3	40
	Heather Channel	HIFO 3	41
Intermediate tidal channel (15)	Sand Shoal Channel	SSTC 4	42
	Sand Shoal Channel	SSTC 3	43
Deep tidal channel (16)	Sand Shoal Channel	SSTC 2	44
	Sand Shoal Channel	SSTC 1	45
Washover fan (17)	Cobb Island	CIWF 1	46
	Cobb Island	CIWF 2	47
	Cobb Island	CIWF 3	48
Ebb delta, axial channel (18)	Sand Shoal Inlet	SSIC 5	49
	Sand Shoal Inlet	SSIC 4	50
Ebb delta, inlet shoals (19)	Sand Shoal Inlet	SSIC 3	51
	Sand Shoal Inlet	SSIC 1	52
	Sand Shoal Inlet	SSIC 2	53
	Sand Shoal Inlet	SSIC 6	54
Barrier island shoreface (20)	Cobb Island Shoreface	CISF 1	55
	Cobb Island Shoreface	CISF 2	56
	Cobb Island Shoreface	CISF 3	57

* : short core was taken.

Fig. 3. Location map of the northern part of the study area and sample stations. Numbers on the map represent stations at specific subenvironments. See table 2 for subenvironments, locations, and stations.

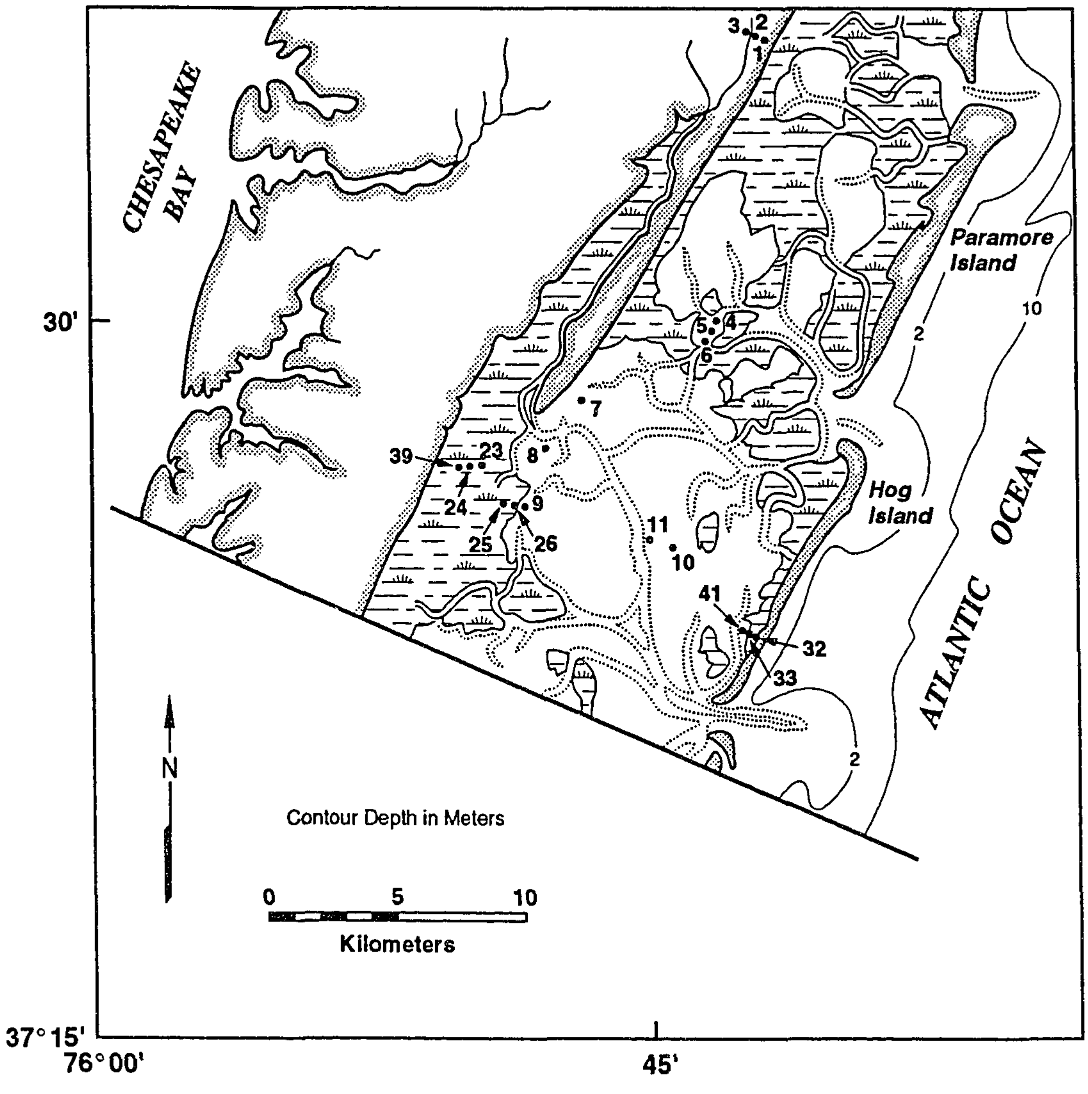
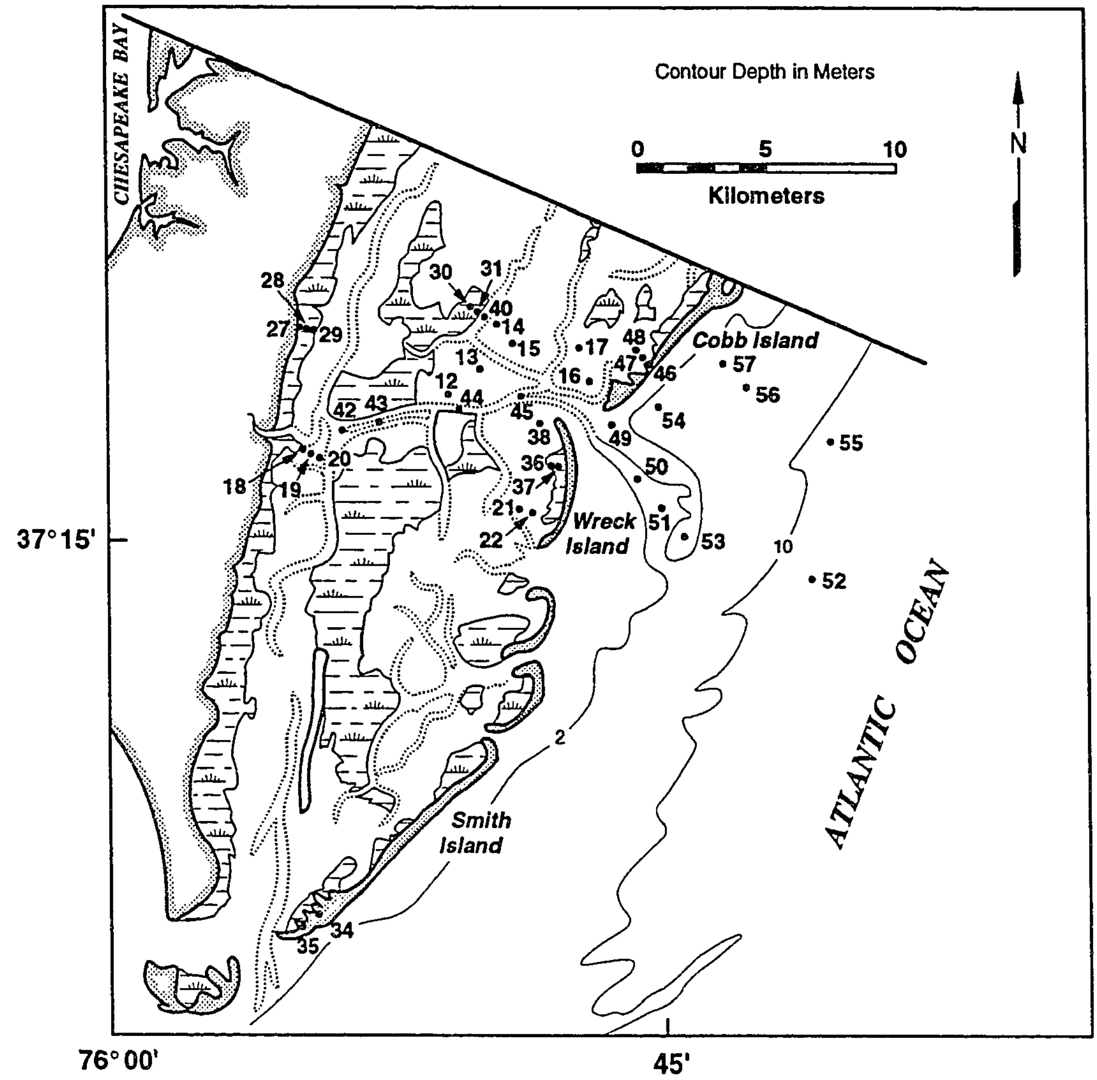

CHESAPEAKE BAY
Paramore Island
Hog Island
ATLANTIC OCEAN
30'
37° 15'
76° 00'
45'
N
Contour Depth in Meters
0 5 10
Kilometers

Fig. 4. Location map of the southern part of the study area and sample stations. Numbers on the map represent stations at specific subenvironments. See table 2 for subenvironments, locations, and stations.


CHESAPEAKE BAY
Contour Depth in Meters
0 5 10
Kilometers
N
28
27
29
30
31
40
14
15
13
12
44
42
43
17
48
47
46
16
45
Cobb Island
57
56
54
55
38
49
36
37
50
18
19
20
21
22
Wreck Island
51
53
10
52
37°15'
ATLANTIC OCEAN
2
Smith Island
34
35
76° 00'
45'

the lagoon. Marsh islands (stations 30 and 31) occur in the central parts of the lagoon. Marshes in the study area occupy about 40% of the lagoon. Marsh facies are characterized by highly-organic, muddy sediments and an abundance of organisms. Marsh plants are well developed on marsh surface. Low marsh is dominated by tall *Spartina alterniflora*. The high marsh is characterized by short *Spartina alterniflora*, *Salicornia* sp. and *Distichlis spicata*. *Juncus* sp. and *Spartina patens*. Tidal channels (stations 38-45) in the study area generally form dendritic drainage systems toward the inlets. Inlet and tidal channels are relatively deep (4-14 m) with a variety of lithologies on the floors ranging from gravels to muds. Washover fans (stations 46-48) occur on the barrier islands and consist of sand washed onto the bay side of the lagoon during storms. The ebb-tidal delta is a large sand body found adjacent to Sand Shoal inlet. Axial channels (stations 49 and 50) and inlet shoals (stations 51-54) within the ebb delta consist of moderately to poorly-sorted sands. The shoreface (stations 55-57) is sea bed of the nearshore zone between the low-water shoreline at about -15 to -20 m. Sediments of the shoreface are composed of moderately-sorted sand with little biogenic structures.

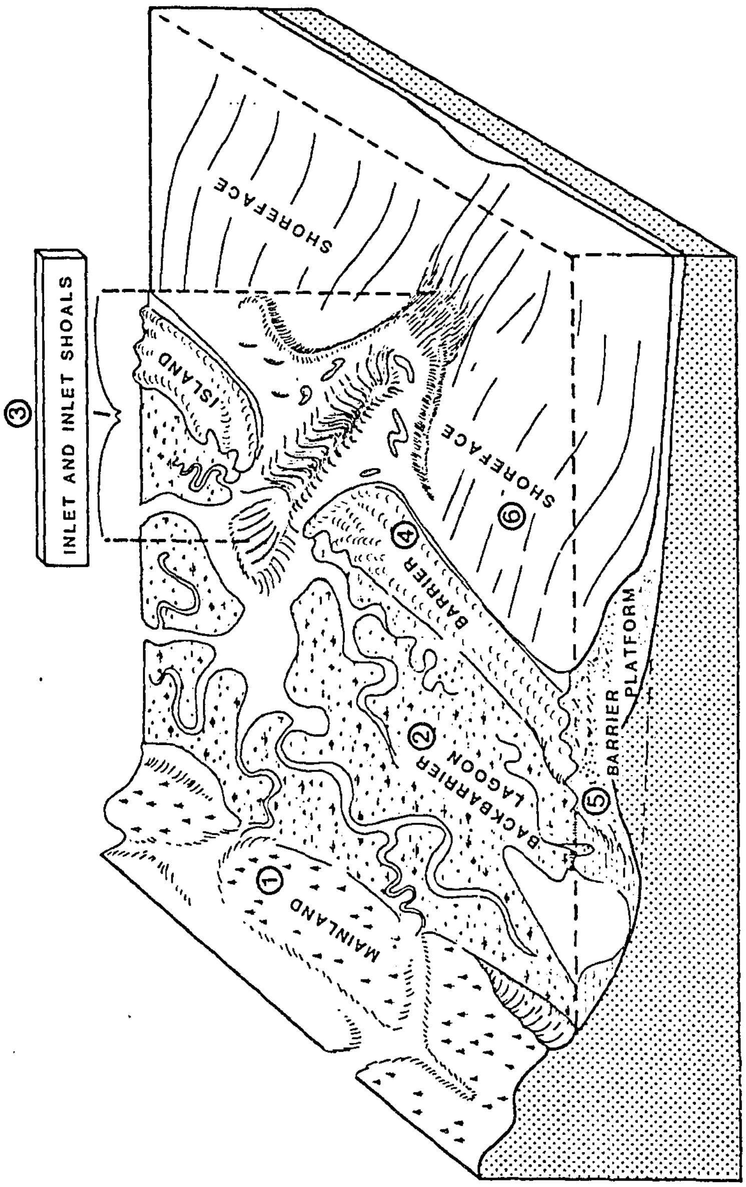
Chapter 2
Concepts and Previous Studies

2.1 Coastal Depositional Environments

A variety of coastal sedimentary environments, such as rivers, estuaries, bays, marshes, beaches, tidal flats, inlets, and shoreface, have been classified and described by Twenhofel (1950), Dunbar and Rodgers (1957), Rusnak (1960), Krumbein and Sloss (1963), Crosby (1972), Reineck and Singh (1980), Davis (1985) and Oertel (1985). Reineck and Singh (1980) classified the modern sedimentary environments and described their primary structures, textures, and depositional processes. They identified broad environments and their subenvironments, glacial, desert, lake, fluvial, deltaic, coastal sand, shelf, lagoonal, tidal flat, continental margin, and ocean basin environments, based on climate, energy of environment, availability of sediment, and type of sediment. A relatively comprehensive description of morphology, sediment distribution, and physical processes in coastal sedimentary environments is provided in Davis (1985).

The coastal environments associated with barrier islands are common features in the United States. The barrier coasts form a variety environments where physical, biological and chemical parameters interact at sedimentary environments. Oertel (1985) proposed that the barrier island system is composed of six major elements which are sedimentary environments in the system: (1) mainland; (2) backbarrier lagoon; (3) inlet and inlet deltas; (4) barrier island; (5) barrier platform; and (6) shoreface (Fig. 5). The six major environments of a barrier island system are required for the existence of the

Fig. 5. Schematic diagram of six major coastal sedimentary environments of a barrier island system (from Oertel, 1985).


③ INLET AND INLET SHOALS
ISLAND
SHOREFACE
④ BARRIER
⑥ SHOREFACE
② BACKBARRIER LAGOON
① MAINLAND
⑤ BARRIER PLATFORM

barrier islands.

The following concepts and descriptions of modern coastal depositional environments are a basis for establishing four major zones (fluvio-transition, barrier lagoon, inlet-marine, and island-marine) within barrier island system (Table 1).

Fluvio-transition

The estuarine environment is a transitional zone where freshwater flowing from the mainland mixes with saltwater from the ocean. Tides cause the mixing of river water and saltwater producing a salinity gradient from river-mouth to entrance of the river. Tide level strongly affects the changes in salinity throughout the estuary.

Sediments from weathering processes on the land are transported to the coastal areas by streams and deposited the coastal regions under the interactions of fluvial and coastal processes (Reineck and Singh, 1980). Multiple transgressive and regressive events may reason these initial deposits many times. The dominant type of substratum in the upper estuary is a soft, silty clay. The lower estuary is characterized by sandy materials. The transition between upper and lower estuarine zones is also marked by changes from tidal to brackish marsh.

Brackish marshes are only located along the uppermost reaches of protected watersheds that drain into the lagoons of the southern Delmarva Peninsula. Marshes formed on submerged upland surface like this may rapidly change to open water because of relatively high rates of sea-level rise or decreasing inorganic sediment input (Darmody and Foss, 1979; Stevenson et al., 1985). Brackish marsh is characterized by silty clay facies. In freshened areas (<5 psu salinity) the higher marsh is vegetated by the mixture of *Phragmites australis* and *Typha latifolia* (Stevenson et al., 1985) and the middle marsh is characterized by *Scirpus americana* and *Sagittaria subulata* (Ellison and Nichols, 1970). *Spartina patens*, *Distichlis spicata* and the short form of *Spartina alterniflora* are dominant in relatively low salinity area (about 5 to 10 psu) (Ellison and

Nichols, 1970; Kraft et al., 1979; Stevenson et al., 1985)

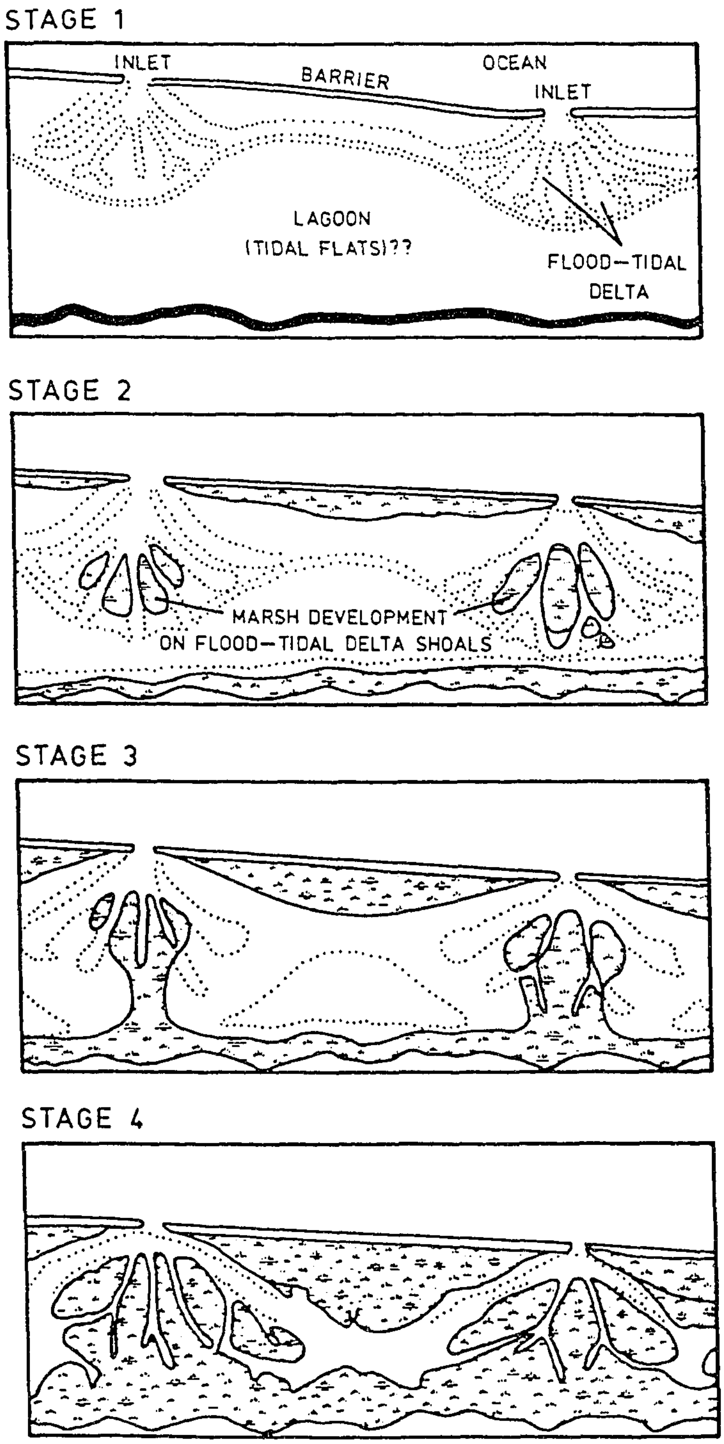
Barrier lagoon

Coastal barrier lagoons are transitional water bodies found between the mainland and the barrier islands. They communicate with upland drainage basins via rivers and estuaries and with the sea via tidal inlets. They often extend roughly parallel to the coast and are variable in size, drainage pattern and shape.

The formation of a barrier lagoon is related to the origin of barrier islands. Barrier lagoons may be cut-off sections of the sea by the emergence of offshore bars (de Beaumont, 1845) or the coastwise progradation of sand spits (Gilbert, 1885) or they may be inundated sections of land by sea level rise (McGee, 1890; Hoyt, 1967). The different modes of lagoon formation exhibit different shapes of lagoon floors. Marine embayments (de Beaumont, 1845; Gilbert, 1885) characteristically have smooth lagoon floors, whereas antecedent topography (McGee, 1890; Halsey, 1979) has a greater effect on lagoons formed by inundation. The evolution of barrier lagoons is strongly influenced by original characteristics of the lagoon floors.

Lucke (1934) illustrated a model of lagoon development which depended on lagoonal fill patterns (Fig. 6). According to his model, the initial lagoon is a moderately deep subtidal basin. Intertidal areas are formed by accumulation of sediment at flood deltas and land margins. Thereafter, marshes develop on these surfaces and drainages in intermarsh areas evolve into tidal channels. The Lucke model provides the theoretical basis that the accumulation of sediment in lagoon follows a predictable facies succession. However, the Lucke model may not be appropriate for all barrier island systems. If the drainage complexity of lagoon is inherited from a recently submerged mainland, antecedent topography may strongly affect the accumulation patterns of the lagoon (Kraft, 1971; Morton and Donaldson, 1973; Halsey, 1979; Belknap and Kraft, 1985). During transgression, topographically low

Fig. 6. Lucke model of barrier lagoon development (from Oertel et al., 1989).


STAGE 1
INLET
BARRIER
OCEAN
INLET
LAGOON
(TIDAL FLATS)??
FLOOD-TIDAL
DELTA
STAGE 2
MARSH DEVELOPMENT
ON FLOOD-TIDAL DELTA SHOALS
STAGE 3
STAGE 4

areas evolve into channels and estuaries, whereas interfluve areas often form marshes and tidal flats (Oertel et al., 1989). Sedimentation rates in these environments are important for estimating ages of initial submergence.

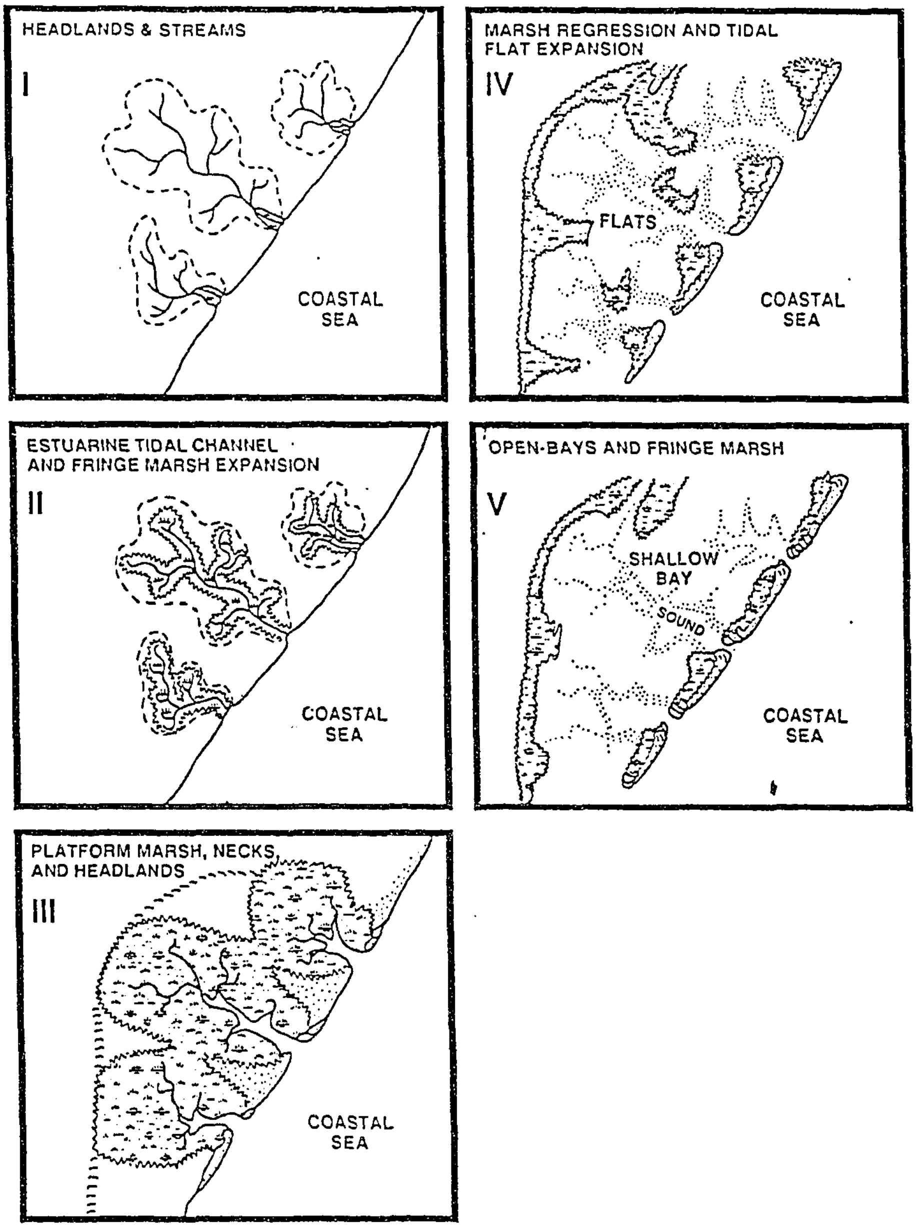
Recently, Oertel et al. (1992) presented a Landscape Topographic Model of lagoon development which is controlled by the antecedent topography of the terrestrial landscape, sea-level fluctuation and sediment input (Fig. 7). In this model, marshes form and spread on low-relief interfluve areas during initial inundation of the landscape (Fig. 7, stage I and II). Tidal channels evolve from submerged terrestrial drainages and platform intermarshes with continued sea level rise (Fig. 7, stage III). With insufficient sediment supply, tidal channels expand into sounds and subaqueous flats and isolate marsh islands (Fig. 7, stage IV). With continued sea level rise, submerged platform marshes produce subtidal flats and shallow bays (Fig. 7, stage V). The Landscape Topographic Model for lagoon evolution (Oertel et al., 1992) provides the principal theory for barrier lagoons of transgressive coasts in terms of antecedent topography, sea level rise, and sediment input.

The water in lagoons communicates with mainland watershed by rivers and streams and with the sea by inlets. The circulation of lagoon water occurs as a result of tides, river discharge and wind (Kjerfve and Magill, 1989). In open-water lagoons, the stress of wind on the lagoon surface may play a very important role in generating currents and waves which mix lagoonal water (Kjerfve and Magill, 1989).

Oertel (1985) suggested that there are two types of lagoons related to tides: open-water lagoons and expandable tidal lagoons. Water surface areas of open-water lagoons are relatively constant between the mainland and barrier islands. Expandable tidal lagoons have greater than a 15% increase in water-surface area between low and high water. The main reason for the difference is the hypsometric changes associated with the tidal range.

The barrier lagoons are composed of a variety different environments including

Fig. 7. Landscape topographic model of barrier lagoon development (from Oertel et al., 1992).


HEADLANDS & STREAMS
I
COASTAL
SEA
MARSH REGRESSION AND TIDAL
FLAT EXPANSION
IV
FLATS
COASTAL
SEA
ESTUARINE TIDAL CHANNEL
AND FRINGE MARSH EXPANSION
II
COASTAL
SEA
OPEN-BAYS AND FRINGE MARSH
V
SHALLOW
BAY
SOUND
COASTAL
SEA
PLATFORM MARSH, NECKS,
AND HEADLANDS
III
COASTAL
SEA

restricted bay, tidal flats, marshes, tidal channels, bars, flood deltas and inlets. In general, lagoons are low-energy environments that are composed of silt and clay with extensive bioturbation (Oertel, 1985; Howard and Frey, 1985).

Storms provide sand to lagoons through inlets and overwash. Sandy deposits are associated with inlet deltas, sand flats, point bars of tidal channels and washover deposits. During storms, washover fans are formed by water flowing inland and distributing sand on the barrier flats, marshes and into the lagoon (Leatherman, 1979). Storm overwash breaks dunes and ridges and forms washover channels. The sizes and shapes of washover fans are dependent upon the magnitude of storm, relief and width of barrier islands (Leatherman, 1979). Smaller amounts of sand may come from aeolian sources and from tidal flats and lagoonal margins (Reineck and Singh, 1980). After entering the lagoon, the sand is reworked and mixed with mud by lagoonal processes, often disguising it's source (Kraft, 1971).

Fine-grained material (silt and clay) is delivered to lagoons from the sea, through tidal channels, and from the Coastal Plain via rivers and streams. Much fine sediment accumulates on marshes between mean sea level and mean high water. Marshes are tidal environments of barrier lagoons whose deposits consist of dark-gray-colored highly organic clay and silt sediments with vegetation and an abundance of micro- and macro-organisms. Tidal flats occur at lower elevations between mean low water and a few meters below mean low water. They consist of mud mixed with fine sand and minor amounts of organic material. Generally, muddy sediments that have been deposited in low marsh areas, quiescent bays and point bars show the greatest rates of sedimentation in the lagoon (Oertel, 1985).

Inlet-marine

Barrier inlets are orifices connecting barrier lagoons with open seas. They are major pathways for exchange of water and sediment between the sea and coastal

lagoons, sounds, estuaries and rivers. Inlet form is controlled by the patterns of water and sediment exchange through the inlet (Oertel, 1982).

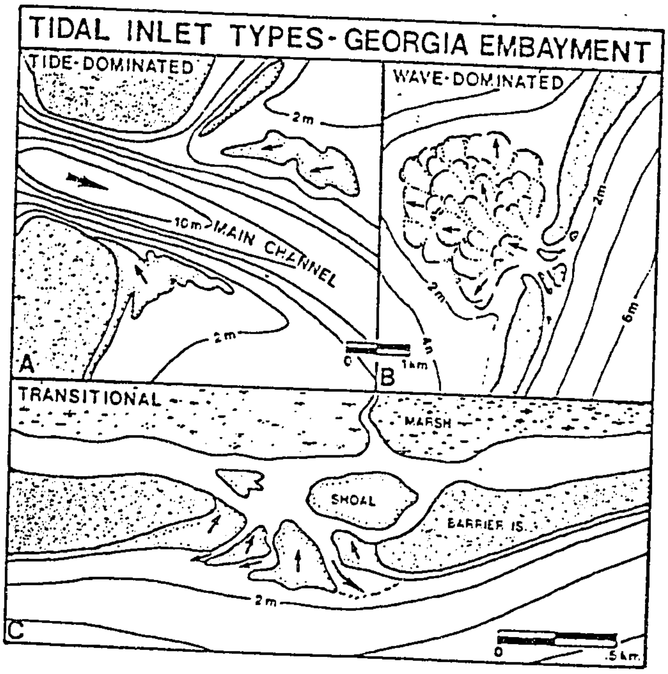
A linear relationship between stable inlet area and tidal prism has been established by O'Brien (1931, 1969) and Jarrett (1976). This relationship assumes that the accumulation and erosion of sediment in inlet area is related to magnitude of tidal prism. In addition, Escoffier (1940, 1972) suggested that inlet stability is balanced between maximum velocity of tidal current and magnitudes of littoral drift. The above relationships assume shore-normal orifices, where the maintenance of inlet area requires a dynamic equilibrium between the amount of sediment input through the inlet and erosion of material from the gorge by inlet tidal currents (Oertel, 1988).

The size and shape of the inlet are dependent upon the patterns and characteristics of water flowing through the inlet (Oertel, 1982). Two different types of barrier inlets occur along barrier coasts associated with the source of water flowing through the inlet; (1) fluvial barrier inlets and (2) tidal barrier inlets.

Fluvial inlets are developed in the wide estuary entrances where the water column is vertically and horizontally stratified because of density differences between river water and sea water (Oertel, 1982, 1985). This pattern of water flow, coupled with large sediment discharge of rivers, produces multiple distributary channels and shoaling the entrance throat areas (Van Veen, 1950; Robinson, 1960; Ludwick, 1973; Oertel, 1979).

Tidal inlets between barrier islands are generally developed and maintained by tides and waves. Morphological and sedimentological variabilities of tidal inlets result from the interaction of tidal currents, waves, sediment supply, backbarrier energy sources and open-sea energy sources (Hubbard et al., 1979; Oertel, 1985). Hubbard et al. (1979) identified three different types of inlets based on morphologic variability along the southeastern United States: (1) tide-dominated inlet, (2) wave-dominated inlet, and (3) transitional inlet (Fig. 8).

Fig. 8. Three different types of tidal inlets: (A) tide - dominated, (B) wave - dominated, and (C) transitional (from Hubbard et al., 1979).


TIDAL INLET TYPES - GEORGIA EMBAYMENT
TIDE-DOMINATED
2m
10m
MAIN CHANNEL
2m
A
0
1km
WAVE-DOMINATED
2m
2m
4m
6m
B
TRANSITIONAL
MARSH
SHOAL
BARRIER IS.
2m
C
0
.5km

Tide-dominated inlets are those that tidal currents cause significant sediment transport through the inlets. The main channel of tide-dominated inlets is deepest at inlet troughs and flanked by long, linear channel-margin bars (Oertel, 1975; Hubbard et al., 1979). Ebb-tidal deltas are well-developed seaward of most tidal inlets. The shapes and orientations of ebb deltas are controlled by interactions between coastal and inlet currents (Oertel, 1975). Oertel (1975) classified different types of ebb deltas based on configuration and related configurations to the relative magnitudes of the coastal and inlet currents (Fig. 9).

Wave-dominated inlets are regions where a large amount of sand is transported into the lagoon through the inlet throat by waves, or is bypassed around the inlet (Bruun, 1967; Hubbard et al., 1979). Generally, the flood-tidal delta is large and multi-lobate, whereas the ebb-tidal delta is proportionally small and is often segmented by numerous shallow tidal channels (Hubbard et al., 1979; Hayes, 1975). The main channel is shallow and generally flood-dominant (*e.g.*, Drum Inlet and Bogue Inlet, North Carolina) (Hubbard et al., 1979).

Transitional inlets show shoals within the inlet throat (*e.g.*, Little river inlet and Stono Inlet, South Carolina). These inlets are relatively wide and have one ebb-dominated main channel and numerous secondary channels (Hubbard et al., 1979).

Tidal deltas are large sand deposits found adjacent to the tidal inlets. They form landward of the inlet throat (flood-tidal delta) by onshore currents and seaward of the inlet throat (ebb-tidal delta) by an interaction forces of onshore, longshore and offshore currents (Hayes, 1975, 1980; Oertel, 1975; Boothroyd, 1985).

Morphologic and sedimentologic characteristics of flood-tidal deltas have been described by Hayes (1975, 1980), Hubbard et al. (1979) and Boothroyd (1985). A typical model for flood-tidal delta consists of a flood ramp, flood channels, ebb shields, ebb spits and spillover lobes (Fig. 10) (Hayes, 1975). These tidal-delta, tidal-inlet models applied to mesotidal mixed-energy conditions (Park River Estuary,

Fig. 9. Different types of ebb-tidal deltas. Arrows show the relative forces of the onshore, longshore, and offshore currents (from Oertel, 1975).

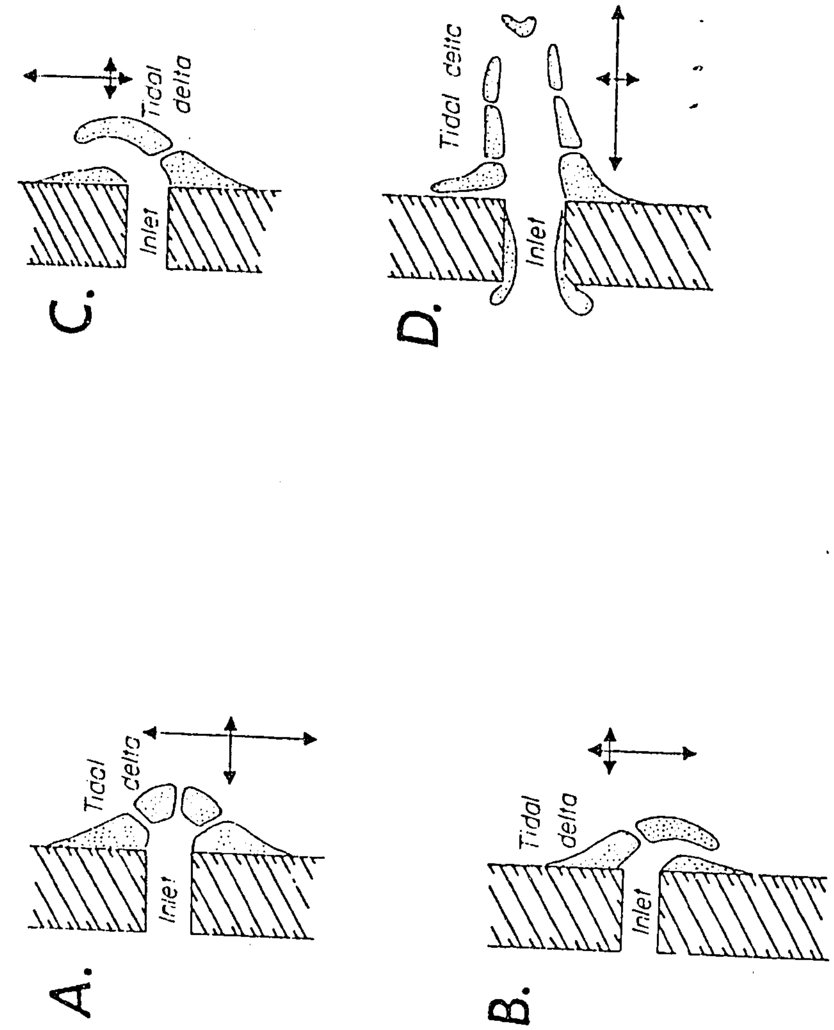
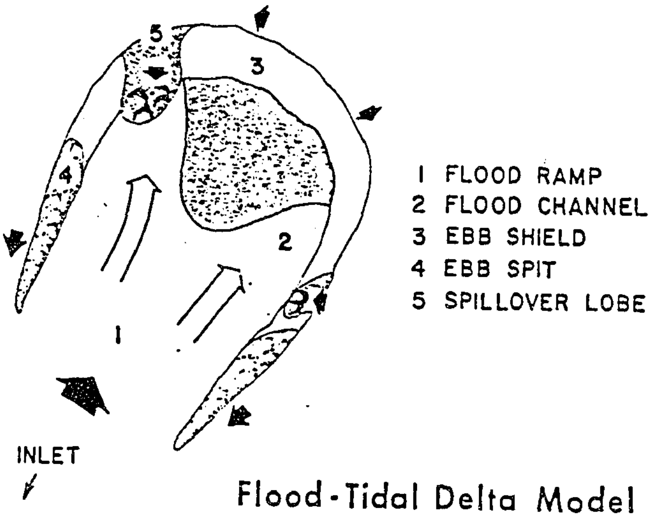

A.
Tidal delta
Inlet
B.
Tidal delta
Inlet
C.
Tidal delta
Inlet
D.
Tidal delta
Inlet

Fig. 10. Morphology of the flood-tidal delta model. Arrows illustrate dominant direction of tidal currents (from Hayes, 1975).



Flood-Tidal Delta Model

Massachusetts) (Hayes, 1975) as well as more wave-dominated microtidal inlets (Drum Inlet, North Carolina) (Hubbard et al., 1979). The bedforms of flood-tidal delta are characterized by flood-oriented sand waves on the flood ramp and megaripples on the ebb shields, ebb spits, and ebb-oriented spillover lobes (Boothroyd and Hubbard, 1974; Boothroyd, 1985).

Ebb-tidal deltas are large sand bodies seaward of the inlet throat. Hayes (1975) described a morphologic model of ebb-tidal delta consisting of a main ebb channel, channel-margin linear bars, terminal lobe, swash platforms, swash bars and marginal flood channels. Oertel (1972, 1975) used other terms to describe ebb delta features and processes along the Georgia coast (Fig. 11). The main features of ebb tidal-delta are : (1) the inlet trough located in the deepest part of the inlet channel; (2) the ramp-to-the-sound at the landward side of the inlet trough which is a wedge-shaped accumulation of sediment; (3) the ramp-to-the-sea at the seaward side of inlet trough which is a wedge-shaped accumulation of sediment; (4) segmented ramp-marginal shoals are present one or both sides of the ramp-to-the-sea that are separated from the shoreline by tidal channels; (5) attached ramp-marginal shoals are triangular sand bodies that are attached to the shoreline; (6) distal shoals are poorly developed sand bodies found at the seaward end of the ramp-to-the-sea; (7) spill-over channels are tidal channels where water drains through segmented ramp-marginal shoals; (8) a funnel channel is shallow channel found between the ramp-margin shoals and the barrier beach (Oertel, 1975).

Oertel (1975) also represented the textural and sedimentary structures of ebb tidal-delta at the Georgia coast (Fig. 12). The shoals consist of clean well-sorted sands, whereas fecal pellet flasers occur in deeper low-energy zones adjacent to shoals. Interbedded layers of mud and sand are deposited in the inlet ramps reflecting the transition between muddy lagoonal sediments and sandy inlet sediments. The inlet trough is eroded into pre-Holocene substrates by tidal currents.

Fig. 11. The terminology of the ebb delta (from Oertel, 1975).

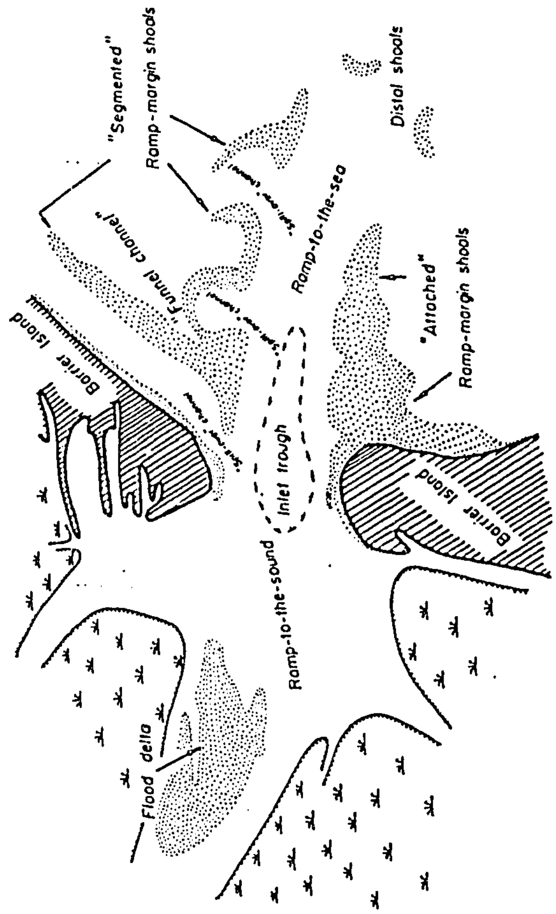
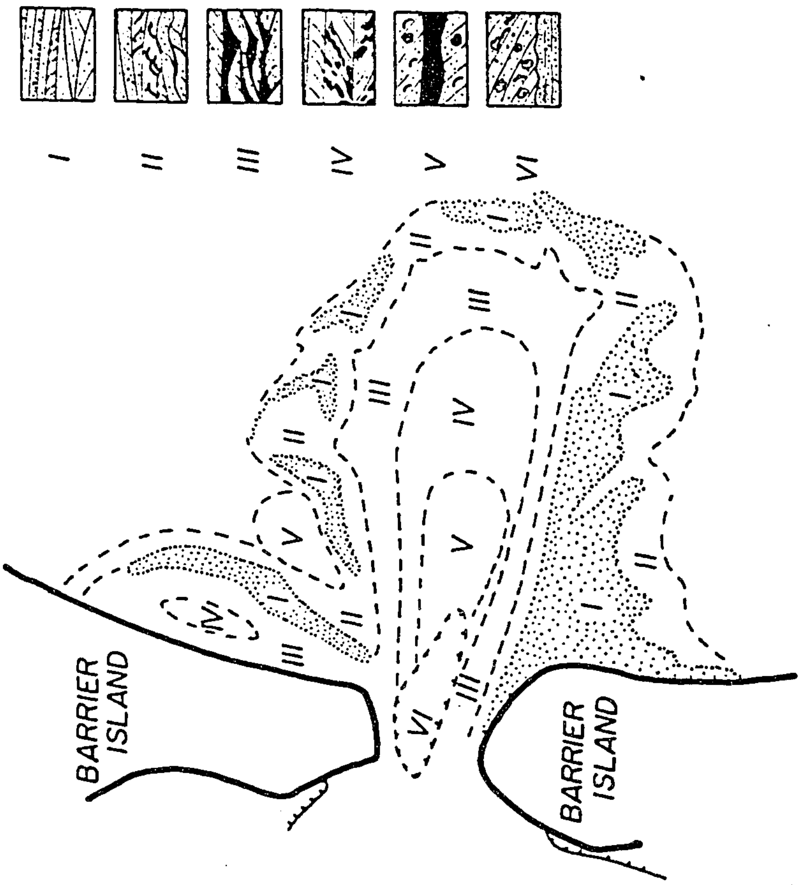

"Segmented"
Ramp-margin shoals
Distal shoals
"Funnel channel"
Ramp-to-the-sea
"Attached"
Ramp-margin shoals
Barrier Island
Barrier Island
Inlet trough
Ramp-to-the-sound
Flood delta

Fig. 12. The facies of the ebb tidal-delta. Facies I is generally composed of clean, well-sorted sands in interbedded foresets, horizontal laminal and wedge-sets. Facies II is composed of low-amplitude foresets interlaminated with fecal pellet flasers. Facies III is a wavy bedding texture composed of interbedded bidirectional foresets and lays of fine mud and fecal pellets. Facies IV is composed of bidirectional foresets of sandy material with imbricated mud pebbles along bedding planes. Facies V is composed of tabular beds of mud and megaripple foresets. Facies VI is lag material eroded from pre-Holocene substrates (from Oertel, 1975, 1985).


I
II
III
IV
V
VI
BARRIER ISLAND
BARRIER ISLAND

Island-marine

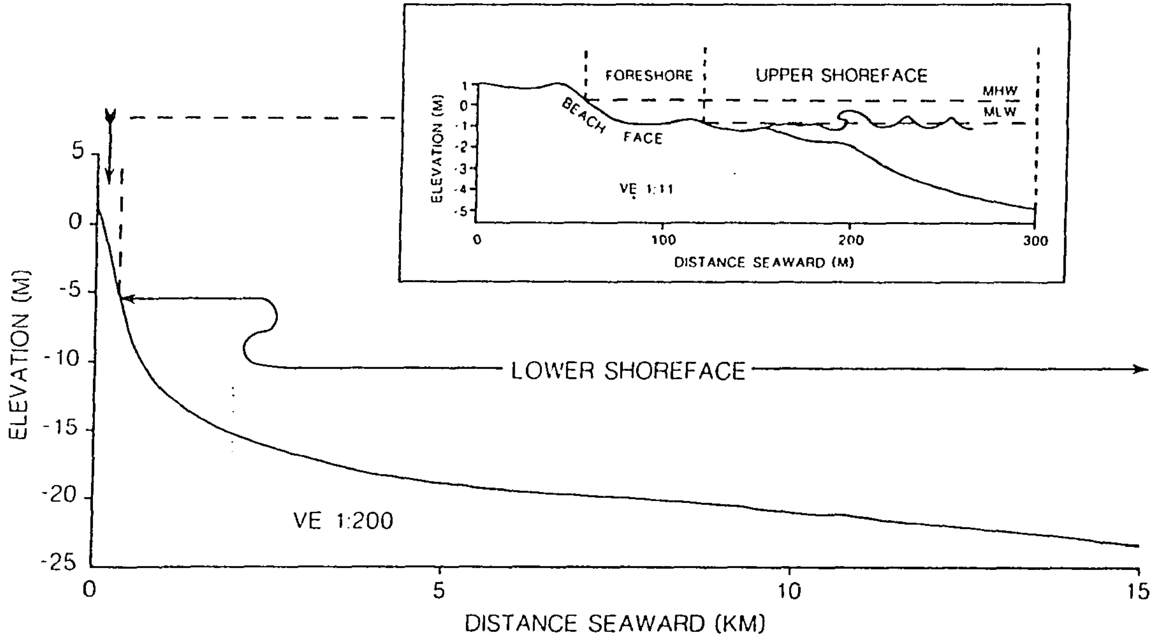
Johnson (1919) defined the shoreface as the narrow, rather steeply sloping zone seaward from the low-water shoreline and permanently covered by water over which beach sands and gravels actively oscillate with changing wave conditions. Price (1954) suggested that the shoreface could extend to maximum depth of 16.5 m. In physical terms, the shoreface is a transitional zone between shelf processes and near shore processes such as the breaking of waves (Reading, 1980).

The shoreface can be divided into two distinct zones: the upper shoreface and lower shoreface (Fig. 13). The upper shoreface is relatively steep (1:10) and is dominated by shoaling and breaking waves and to a lesser extent rip currents (Swift, 1975, 1976). The shapes of the upper shoreface profile are dependent upon the wave energy. Reflective beaches have a simple profile, whereas dissipative beaches often consist of distinct beach, inshore and nearshore profiles (Wright et al., 1979). Sand transport on the upper shoreface is dominantly controlled by waves with secondary transport by currents (Niedoroda et al., 1984). The upper shoreface is characterized by relatively well-sorted, fine-grained sediments with an absence of biologenic structures (Davis, 1983).

The lower shoreface has relatively gentle slope (1:200) extending to depths of approximately 15-20 m and is influenced by tidal currents and storm-induced flows of the shelf regime (Swift, 1975, 1976; Swift et al., 1985). Sediment on the lower shoreface is entrained by storm waves and transported by complex processes of the fluid shear stresses and bottom boundary layer currents (Niedoroda et al., 1984). The characteristics of the lower shoreface are relatively coarse-grained sediments with high energy bedforms and internal structures (Swift, 1976).

In summary, it can be said that there is significant variance in the magnitudes and occurrences of turbulent and lamina processes at subenvironments of the barrier island

Fig. 13. Cross-sectional diagram of a shoreface (from Oertel, 1985).



FORESHORE
UPPER SHOREFACE
MHW
MLW
BEACH FACE
ELEVATION (M)
VE 1:11
0
100
200
300
DISTANCE SEAWARD (M)
LOWER SHOREFACE
ELEVATION (M)
VE 1:200
0
5
10
15
DISTANCE SEAWARD (KM)

system to produce different facies patterns and different environmental conditions. It is hypothesized that processes producing these conditions will also affect variations and distributions in sediment texture, pollen, and foraminifera.

2.2 Pollen Distribution

Pollen is a microfossil transported by atmospheric or hydraulic processes and found in many sedimentary environments, including barrier lagoons. Characteristics of pollen assemblages are believed to be good indicators of the types of vegetation growing near the study area (Brush and DeFries, 1981). Pollen is primarily found in muddy areas because pollen grains are very small (0.01-0.05 mm) and have settling velocities equivalent to silt and clay. Since plants are very sensitive to climatic changes, pollen assemblages are good indicators of the climatic conditions. Pollen data also has been related to human influence upon vegetation (Iversen, 1941). Increases in agricultural activity is identified by a relative decrease in tree pollen accompanied by an increase in herbaceous pollen (Iversen, 1941; Davis, 1976; Bernabo and Webb, 1977; Gaudreau and Webb, 1985).

In general, differences in type and concentration of pollen in sediments appear to be related to a variety of different ecological and physical parameters. Ecological mechanisms primarily control the initial distribution of living plants. However, the ultimate fate of pollen grains also depends on processes of sediment transport and accumulation. These processes of pollen distribution may be used in understanding potential changes in surface sediments.

On a global scale, different floral species occur at different latitudes, because they are sensitive to temperature changes. The regional variations of pollen assemblage in the late Quaternary across the northeastern United States indicate that the vegetational

patterns changed with climatic conditions along latitudes. For example, spruce moved into the southern part of north America at 14,000 YBP, was absent in the middle Atlantic Coast at ~ 10,000 YBP and increased in the northern highlands within the past 4,000 years (Sirkin et al., 1977; Gaudreau and Webb, 1985).

Iversen (1941) suggested that certain changes in pollen assemblages were associated with activities of man. The periodic increases in the ratio of non-arboreal pollen to arboreal pollen are caused by the gradual destruction of forest and increase of agriculture. Agricultural land clearance caused increasing ragweed pollen percentage (> 5%) and decreasing hemlock pollen percentage in the last 300 years in the eastern North America (Bernabo and Webb, 1977; Gaudreau and Webb, 1985).

Table 3 shows a late Quaternary pollen geochronology suggested for the middle Atlantic Bight by Oertel et al. (1989). The modern climatic (late Holocene) conditions (300 YBP) can be recognized by sediments containing several varieties of gum and *Ambrosia* (ragweed) (> 5% of total pollen grains) associated with agricultural land clearance. *Picea* (spruce) and *Abies* (fir) indicate cooler boreal forest indicators. The cool conditions for these types of boreal forest development was last present in this part of southern Virginia about 10,000 YBP (pre-Holocene). Moderate quantities of spruce and fir (< 1-2%) may indicate early Holocene or similar climatic conditions.

Physical transport processes secondarily control the distribution of pollen. Pollen grains can be airborne and carried long distances from sources. For example, *Ephedra* and *Sarcobatus* pollen are dispersed several hundred kilometers from western North America to the Great Lakes region by wind (Maher, 1964). However, most pollen grains settle down very near the source plant (within one km) because sinking rates of pollen grains in air are relatively fast (Traverse, 1988). Niklas (1984) provided the sinking rates of pollen grains in air based on sophisticated modern techniques and yielded an average sinking rate of 2.7 cm/sec. Brush and DeFries (1981) investigated spatial distributions of pollen in surface sediments of the Potomac River, Chesapeake

Table 3. Late Quaternary vegetational changes for the middle Atlantic Bight (from Oertel et al., 1989).

TIME PERIOD [a] (Years before present)	PRINCIPAL ARBOREAL TAXA [a]	PRINCIPAL SHRUB AND HERB TAXA [a]
5,000 - PRESENT	QUERCUS, CUPRESSACEAE, LIQUIDAMBAR NYSSA, ACER, MAGNOLIA, PINUS	ERICACEAE, ILEX, AMBROSIA [b] PLANTAGO [c], RUMEX [c]
10,000 - 5,000	QUERCUS, FAGUS, CARYA, ULMUS, LIQUIDAMBAR, FRAXINUS	BETULA, ALNUS, UMBELLIFERAE, COMPOSITAE, AMBROSIA, GRAMINEAE, CYPERACEAE
21,000 - 10,000	PINUS, PICEA, ABIES, CORYLUS	BETULA, ALNUS, CYPERACEAE, GRAMINEAE, COMPOSITAE, ARTEMISIA, THALICTRUM, SPHAGNUM, LYCOPODIUM

a: Compiled from Whitehead (1972, 1981), Sirkin et al. (1977) and Kearney (Unpubl.).

b: 5-10% of total pollen grains. c: Non-native plant (300 yrs B.P. - Present).

Bay. They suggested that atmospheric or estuarine transport processes remove the patchy distribution of tree pollen along estuary.

2.3 Foraminiferal Distribution

Foraminifera are testate protozoans that live either on the sea floor or among the marine plankton. The distribution of benthic foraminifera is very wide ranging from brackish to marine environments. They are useful indicators of modern and ancient environmental conditions because the distribution of foraminifera is affected by a variety of interrelated ecological conditions.

The ecological studies of recent foraminifera have added to their value as paleoenvironmental indicators (Phleger, 1960; Murray, 1973; Boltovskoy and Wright, 1976). Culver and Banner (1978) has shown that the distribution of foraminifera can be related to grain-size distributions because both are affected by the waves, currents and tides. The distribution of foraminifera is also affected by other ecological parameters including temperature, salinity, pH, water depth and exposure (Phleger, 1960; Murray, 1973; Boltovskoy and Wright, 1976).

Although the ecology of modern foraminifera of the North American Atlantic Coast has been well studied, no previous work on foraminifera ecology has been done in the southern Delmarva Peninsula. Quantitative studies of North American foraminifera have been at continental shelves (Parker, 1948; Schnitker, 1971; Poag et al., 1980), brackish bays and lagoons (Phleger, 1952; Parker, 1952a, 1952b; Miller, 1953; Ronai, 1955; Kraft and Margules, 1971; Buzas and Severin, 1982), marshes (Parker and Athearn, 1959; Scott and Medioli, 1980a), and estuaries (Nichols and Norton, 1969; Ellison and Nichols, 1970). These studies related foraminiferal distribution to ecology and divided areas into faunal zones or biofacies.

The regional synthesis of benthic foraminiferal distribution of the continental shelf from the Gulf of Maine to Maryland was published by Parker (1948). She found four faunal zones: zone 1 = 0-15 m; zone 2 = 15-90 m; zone 3 = 90-300 m; zone 4 = 300-680 m, where distribution patterns were mainly controlled by temperature and abundance of foraminifera increased with depth. She noted that light, salinity and food supply probably also affected on faunal zonations. The foraminiferal distribution on the North Carolina continental shelf was studied by Schnitker (1971). *Elphidium clavatum* dominated all shelf samples north of Cape Hatteras. A major faunal boundary at the shelf edge (60-140 m) was produced by dominant (> 10%) *Islandiella subglobosa* and *Bulimina marginata*. He reported high foraminiferal populations on very-fine sandy bottom. Poag et al. (1980) described the modern benthic foraminiferal distribution on the New Jersey outer continental shelf. They found three generic predominance facies, *Elphidium, Cibicides* and *Saccammina*, whose generic distribution patterns were associated with the bottom topography and sediment distribution as well as the temperature, salinity and dissolved oxygen concentrations of the bottom waters.

Ecological conditions in lagoons and bays exhibit much greater variability than those of open ocean because lagoons and bays are transitional water bodies between fresh water and sea water. Parker (1952b) described three foraminiferal facies (river, bay and shallow-water, open-ocean facies) in Long Island Sound and Buzzards Bay. She suggested that temperature was a main controlling factor from bay to open-ocean facies, and salinity was a chief controlling factor from river to bay facies. Miller (1953) studied foraminiferal distribution in the brackish lagoon behind Mason Inlet, North Carolina. He found forty-two species of foraminifera ranging from brackish water to open-sea facies where the distribution was controlled by substratum conditions. The largest faunal assemblages were reported at clean, fine sandy areas. The foraminifera of brackish-water bays and lagoons of the New York Bight were investigated by Ronai

(1955). Eleven genera were dominant in the lagoonal environment: *Ammobaculites, Ammoastuta, Eggerella, Miliammina, Quinqueloculina, Triloculina, Trochammina, Nonion, Elphidium, Buccella* and *Rotalia.* He suggested that the controlling factors of faunal assemblages were salinity, organic content of sediments, currents affecting sedimentation and possibly temperature. However, Kraft and Margules (1971) recognized six foraminiferal assemblages (1-Western tidal streams and mid bay: *Ammobaculites salsus* assemblages; 2-Western bay - tidal stream mouth: *Ammobaculites salsus - Elphidium incertum* assemblage; 3-Southeast bay - near shore: *Pseudoclavulina gracilus - Ammoscalaria* sp. assemblage; 4-Central bay - lagoonal: *Ammonia beccarii - Elphidium incertum - Elphidium clavatum* assemblage; 5-Tidal delta: "Barren" assemblage; 6-Eastern peripheral (protected): *Ammonia beccarii - Ammoscalaria* sp. - *Textularia earlandi* assemblage) in Indian River Bay, DE (a coastal barrier lagoon). They found no significant correlation between the abundance of foraminifera and the distribution of sediment types. In addition, there was no significant correlation between species occurrence and physical characters of the water mass and sediment, except for an *Ammobaculites salsus* assemblage occurring in the tidal streams to the west. Buzas and Severin (1982) investigated that the distribution of living foraminiferal populations in the various areas of the Indian River, Florida. Twelve different areas were characterized by different densities of the 15 most abundant species. In addition, the results of canonical variate analysis of the 15 most abundant species indicated that the inlets and the northern end of the estuary were clearly distinguished from the other areas. They suggested that foraminiferal densities in the Indian River were controlled by predation and tidal influence.

Studies in marshes have been more numerous. Parker and Athearn (1959) examined the distribution of marsh foraminifera from nonmarine to near marine conditions in Poponesset Bay, Massachusetts and suggested that controlling factors were type of vegetation, chemical factors, pH, nutrients and food. They reported that

some agglutinated foraminifera were sensitive to salinity change but *Ammobaculites dilatatus*, *Ammotium salsum*, *Miliammina fusca* and *Protelphidium tisburyense* were distributed over a wide ranges of brackish and marine conditions. Scott and Medioli (1978, 1980a, 1986) studied the effects of elevation and salinity on marsh foraminiferal distributions. They investigated two vertical foraminiferal zones in tidal marshes of the Nova Scotia in which elevational ranges were determined for each assemblage zone. Zone I, which covered the high marsh and part of the middle marsh, was characterized by *Trochammina macrescens* and *Tiphotrocha comprimata*. Zone II, which covered most of the middle and lower marsh, was characterized by *Cribrononion umbilicatulum*, *Ammotium salsum*, *Miliammina fusca* and *Trochammina inflata*. They concluded that marsh foraminiferal assemblages could be used as paleosea level indicators on the basis of the comparison of detailed studied in California and less detailed ones from other parts of the world. However, this conclusion may require that the faunas are not affected by mixing, reworking and preservation. Jennings and Nelson (1992) investigated foraminiferal assemblage zones in Oregon tidal marshes, and found large vertical ranges on high and low marsh foraminiferal assemblage zones in this region. They concluded that marsh foraminiferal assemblages limit accurate reconstruction of former sea levels at coasts with relatively low rates of sea-level change.

Nichols and Norton (1969) described foraminiferal populations of the James River estuary and found that lower salinity (0.5-14 psu) reaches of the upper estuary were characterized by an arenaceous *Ammobaculites* fauna whereas the lower estuary (> 14 psu) was dominated by a calcareous *Elphidium* fauna. They suggested that a sharp faunal boundary was associated with salinity shift with time and changing river flow. Ellison and Nichols (1970) studied populations of benthic foraminifera in the Rappahannock River, Virginia and found that the lower part of estuary (> 15 psu) consisted mainly of *Elphidium clavatum* variants, whereas at upper reaches with lower

salinities (0.5-15 psu) the main species was *Ammobaculites crassus* and there were a few specimens of *Miliammina fusca*, *Ammoastuta salsa* and *Trochammina inflata*. They suggested that two biofaces in estuary were related to different estuarine layers which fluctuate with river inflow and estuarine mixing. They also recognized two biofaces in the marshes: abundant *Miliammina fusca* and a few *Ammonia beccarii tepida* and *Trochammina inflata* in relatively salty water, and *Ammoastuta salsa* and some *Astrammina rara* in freshened reaches.

Numerous studies on the effects of ecological factors on modern benthic foraminifera suggest that complex ecological conditions of coastal areas produce the different patterns of foraminiferal distributions. The existence of some sensitive foraminiferal species associated with salinity changes has been used for paleoenvironmental interpretations in lithofacies (Newman and Munsart, 1968; Shideler et al., 1984; Otvos, 1985). Shideler et al. (1984) interpreted four paleoenvironments (the upper estuarine, the brackish salt-marsh, a lagoon or bay and adjacent parts of lower estuaries, and the marginal marine-inlet environments) in the Holocene lithosomes in the southern Delmarva Peninsula coast based on comparisons of Holocene microfaunal assemblages with modern dominant species in salinity changes. Otvos (1985) investigated the formation and evolution of barrier islands on the northern Gulf of Mexico coast based on comparisons of foraminiferal biotopes and lithologies of various lagoonal and barrier platform facies. These interpretations in the Quaternary coastal deposits have based on direct comparison of the buried fossil assemblages with the modern assemblages. However, such interpretations must be made care, and should be considered taphonomic changes from modern to buried fossil assemblages in a certain environments.

Previous investigators have been cited for the taphonomic processes of foraminifera from the sediment, including mechanical destruction by transport and mixing (Murray, 1984), infaunal occurrence and selective preservation (Goldstein,

1988; Goldstein and Harben, 1992), predation (Buzas, 1978, 1982), predatory boring (Sliter, 1971), and dissolution of calcium carbonate (Berger, 1970; Wefer and Lutze, 1978). The documentation of taphonomic changes from surface to buried fossil assemblages in a certain environment is important for the reconstruction of paleoenvironments in the coastal areas.

Chapter 3
Methodology

3.1 Field Methods

Sediment samples were collected from the sea bed at 57 stations. Forty-six surface samples and three cores were taken between June 1989 and July 1989. Four stations (CBSFI 1,2; ECSFM 2; CBSFO 2) were sampled in a sand flat on August 16, 1990. Seven surface samples (RS 1,2,3; SI 1,2; WI 1,2) were taken in inner and outer fringe marshes between August 1991 and October 1991. Water column salinities and temperatures were measured at each environment. Most samples were collected during low water when the sea bed was exposed or less than two meters deep. In water depths greater than two meters, a box corer was used to take sediment samples. The upper one cm of sediment was scraped from about 120-160 cm^2 to produce subsamples of approximately 140 ml. Three replicate sediment samples were taken at each station to account for patchiness in horizontal distributions of foraminifera (Buzas, 1968). The surface subsample was split into two replicate samples of approximately 70 ml each. One sample was preserved in the sample bag for sedimentologic analysis. The other sample was preserved in a plastic bottle for micropaleontological analysis. The micropaleontological sample was preserved immediately in the field in a buffered formalin solution (5%, buffered with Hexamine to pH 8 or 9).

Shallow (about 1 m), three inch diameter cores were taken by hand at a barrier fringe-marsh, and two tidal flats in the inner and outer parts of the lagoon. Stratified sampling of the upper one-meter of core was used for foraminiferal and grain size

analysis. Cores approximately 50 cm in length were taken at each of the three stations to determine sedimentation rates via Pb-210 analysis.

3.2 Laboratory Methods

Core liners were split using a router. Each split was labelled, wrapped in plastic and stored in D-tubes. One split was cataloged and stored in the Marine Geology Core Repository. The other half was photographed, logged and sampled for grain-size and foraminiferal analysis.

Core logs of each core included color, sedimentary structures, organic material and contacts. Samples for grain-size and foraminiferal analysis were selected based on lithological changes in the cores.

X-ray radiographic analysis was used to determine internal sedimentary structures. Core sections (30 cm in length) were exposed on Kodak Industrex AA film in Hewlett-Packard Faxitron Series X-ray instrument. X-ray radiographs illustrated textural changes produced by physical and biological events.

3.2.1 Grain size distributions and sediment characterization

Grain-size distributions were determined using standard sieving and pipetting techniques at half and one phi intervals, respectively (Folk, 1980). Initially, the sand and mud fractions were separated by wet sieving through a 62 micron stainless-steel sieve. The distribution of the coarse fraction (0.5 - 4 phi) was determined using gravimetric analysis of fractions separated after 15 minutes of agitation in a standard sieve shaking apparatus. The distribution of the fine fraction (5 - 11 phi) was determined using standard pipetting techniques (Folk, 1980). The pipette method is based on the settling velocity of the particles and computed on the bases of Stokes' law.

Weight percents of size-class intervals were determined between 0.5 and 11 phi. A computer program calculated moment and Folk inclusive graphic statistics. Moment and graphic statistics were used to determine the mode, mean, median, sorting, skewness and kurtosis.

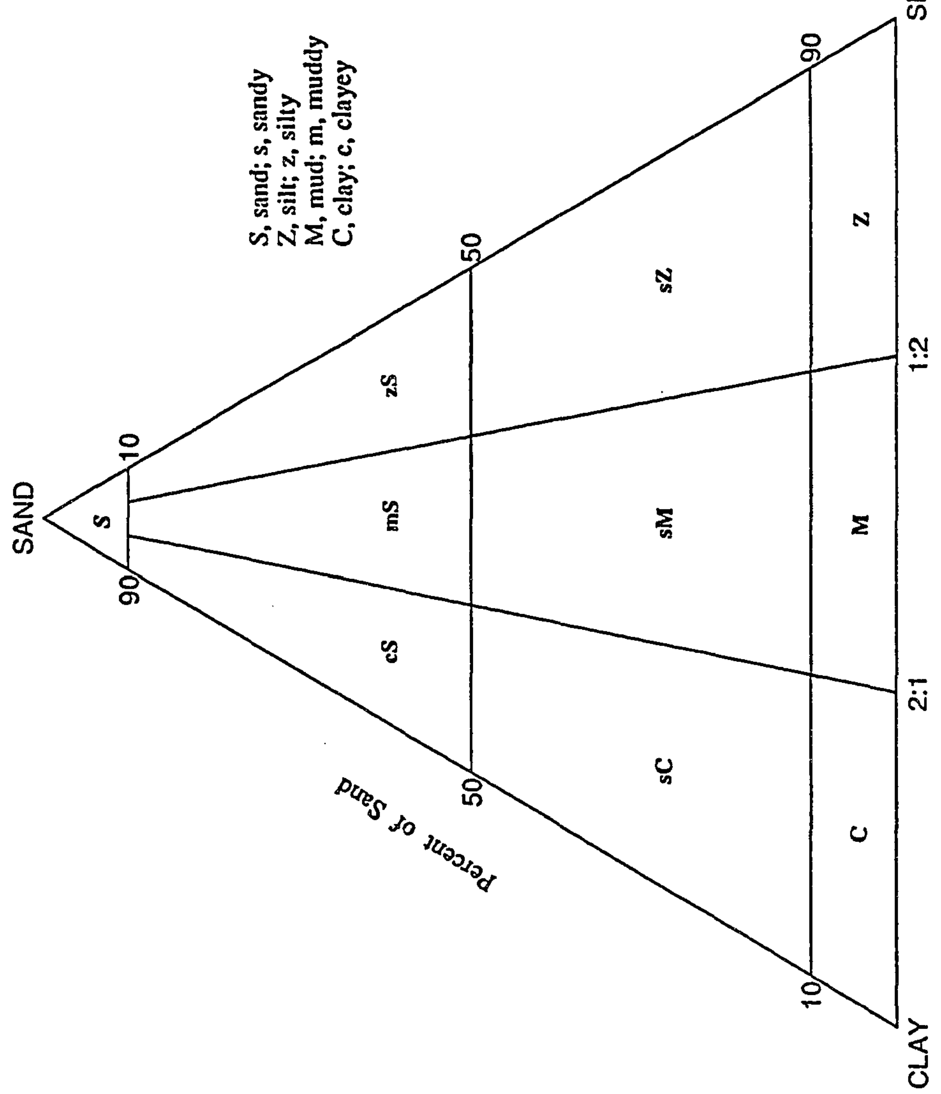
The percentages of sand, silt and clay were plotted on triangular diagrams to classify the samples into ten different textual groups depending on the relative proportion of sand, silt and clay which is first based on the percentage of sand, then based on the ratio of silt to clay (Fig. 14) (Folk, 1954,1980). Folk (1954,1980) suggested a three-fold division: (1) if the percentage of silt is more than 67%, the material is called "silt", "sandy silt" or "silty sand"; (2) if the percentage of clay is more than 67%, it is called "clay", "sandy clay" or "clayey sand"; (3) if intermediate mixtures with silt and clay are present, it is called "mud", "muddy sand" or sandy mud. Each sample was assigned a texture name based on this nomenclature and its characteristics of mean grain-size and sorting.

The bulk density (g/ml) of the surface sediment was calculated by dry weight of sediment and its wet volume. Initially, a 100 ml beaker was washed and dried. The dried beaker was weighed on the Mettle-top-loading balance. The sediment was placed into pre-weighed 100 ml beaker and filled with distilled water. It was allowed to stand for 48 hours, and then its wet volume was recorded. The sediment was dried in an oven to a constant weight at 100 degree C until all water was evaporated. The dried sediment was weighed on the Mettle-top-loading balance. The bulk density of sample was determined by dividing dried sediment weight (g) by wet volume (ml).

3.2.2 Pollen analysis

Samples for pollen analysis were taken from fine-grained (mean: 6~9 phi) surface samples. Samples of about one gram were treated with the standard KOH - acetylation procedure described by Faegri and Iversen (1975). Initially about 1 g of sample was

Fig. 14. A triangular diagram for ten different textual groups on which are plotted the percentages of sand, silt and clay (from Folk, 1954, 1980).


S, sand; s, sandy
Z, silt; z, silty
M, mud; m, muddy
C, clay; c, clayey
SAND
SILT
CLAY
10
90
50
50
90
10
1:2
2:1
S
zS
mS
cS
sZ
sM
sC
Z
M
C
Percent of Sand

placed in a 15 ml Nalgene test tube with three *Lycopodium* (36,231±5,676) tracer tablets. Then 12 ml of 10% HCl was added to the sample and heated in a water bath at 60 degree C to remove carbonates and release tracer spores. After 4 minutes, 12 ml of 5% KOH was added to the sample and heated for an additional 4 minutes. Next the sample was put in a crucible strainer in a 100 ml beaker and strained through the beaker. The organic matter was left in the strainer. The decanted sample was transferred into test tube and 12 ml of HF was added to the sample and heated in a water bath for 4 minutes to dissolve silicates. Twelve ml of glacial acetic acid was added to the sample and stirred to remove the water remaining in the sample. An acetolysis mixture (9 parts acetic anhydride to 1 part sulfuric acid) was added to sample and heated in a water bath for 2 minutes. The sample was washed in distilled water and two drops of saffranin - O stain were added. Twelve ml of tertiary butyl alcohol (TBA) were added to the sample and the suspended sample in TBA was transferred to vials. Three drops of glycerol to vial and stirred gently remaining TBA, pollen residue, and glycerol.

A 3x1 inch precleaned micro slide was labelled and two or three drops of well-mixed residue were placed on the center of the slide. A circular cover glass (18x18 mm) was placed on the residue and allowed to spread to the margins of the cover glass. Then, pollen counts were made by traversing slides from side to side at a magnification of 500X using a Zeiss microscope. Two to three hundred pollen grains (Excluding *Lycopodium* (Spike)) were identified and counted on each slide of sample.

3.2.3 Foraminiferal analysis

Core subsamples were used to examine the vertical distribution of foraminiferal species and determine changes in fossil foraminiferal assemblages within the substrates. Subsamples were taken from the cores at textually different horizons.

The core subsamples were soaked in distilled water for 48 hours and then the wet

volume of the material was recorded. The sample was wet sieved through a 63 micron sieve to remove silt and clay. The residues on the sieve were soap-floated to separate and concentrate foraminifera from quartz grains (Harris and Sweet, 1989). The residues on the sieve were transferred to an evaporating basin. Then a lather is made with Ivory soap and gently washed into the evaporating basin to form a solution 1 cm deep above residues. The soap solution was swirled in the evaporating basin and soap-coated particles rose to form a surface film. The surface film was carefully decanted onto a 63 micron sieve. This procedure was repeated five times in order to maximize retrieval of foraminifera from sample. Soap-coated particles on the sieve were washed thoroughly with enough water to remove excess soap. The sand fractions and soap-floated materials were dried in an oven at 40-60° C and weighed on a Mettle top-loading balance.

The soap-floated materials were spreaded in a thin layer on a gridded picking tray, and viewed at 42X magnification within an American Optical microscope. Specimens were picked with 00000 brush, transferred to a labelled slide and sorted into different morphologic groups. Identification of foraminifera was made through comparison with reference literature and type specimens in the National Museum of Natural History, Smithsonian Institution, Washington, D. C.

Surface samples preserved with a buffered formalin solution were washed through a 0.063 mm sieve to remove silt, clay and formalin on the same day of collection. The volume of residue was recorded. Residues were stored in plastic bottles with isopropyl alcohol (mix 1:1, water and alcohol). The residue was stained with approximately 0.1 g of rose Bengal (Walton, 1952), gently shaken, and allowed to stand overnight (6-8 hours). A second wash through a 0.063 mm sieve was used to remove excess stain. Organic materials were removed from the sample by decantation after settling. The sample was transferred to an evaporating basin, and "soap-floated" to separate and concentrate foraminifera from quartz grains. "Soap-floated" materials

were transferred to the 4 phi sieve. This technique was repeated five times and then "soap-floated" materials were washed to remove excess soap. The assumption is that all foraminifera are transferred to the 4 phi sieve from the sample by soap-floating. Sand-sized samples and soap-floated samples were dried in an oven at 40-60 degrees C and weighed. If a soap-floated sample contained more than 300 foraminifera, it was split into smaller aliquots with a microsplitter, and all specimens were picked from the aliquot. If the soap-floated sample contained a small number of foraminifera, all specimens were picked.

In order to distinguish the living and dead foraminifera, the aperture of each foraminifera was evaluated for the presence of stained protoplasm. A thin layer of the soap-floated sample was spread on a gridded petri dish covered with water. The water made the stained protoplasm visible during picking. Occasionally, the tests of dead foraminifera show a red color or small red-spots on the walls. This coloration is caused by the presence of other organic materials (e.g. bacteria, worms) in dead tests. Sufficient washing of samples may prevent from red color remaing in the tests (Boltovskoy and Wright, 1976). At least three hundred live and dead foraminifera (Dennison and Hay, 1967; Buzas, 1990) were picked using a 00000 brush. Specimens were transferred to a labelled slide, sorted into different morphologic groups, and identified using reference literature. Specimens were compared with type specimens in the National Museum of Natural History, Smithsonian Institution, Washington, D. C.

Scanning electron micrographs (SEM) of foraminifera were prepared in the following manner. Specimens were picked from a slide with a moist 00000 brush and placed on a SEM stub covered with double coated adhesive tape. In cases where a dorsal and ventral view were needed, two specimens were mounted. A stub with mounted foraminiferal specimens was coated with gold/paladium alloy on a rotary stage of a SEM Autocoating Unit E5200 at 20 mA. The coated stub was placed in a holder in the vacuum chamber of a Cambridge Stereoscan 100. Specimens were exposed at 5

KV on Polaroid Positive/Negative 55 film. After 20 seconds, the print and negative were separated from the Polaroid 55 film envelope.

3.3 Statistical-Testing Methods

3.3.1 Environmental variables and Pollen data

Canonical variate analysis

Canonical variate analysis (multiple discriminant analysis) of environmental data and modern pollen data was used to compare and discriminate among pre-defined *a priori* groups of sedimentary environments. If there were p variables and h *a priori* groups and $p > h$, then canonical variate analysis obtained the h-1 possible canonical variates that most efficiently discriminate the groups. The first canonical variate accounted for the greatest variability between the group-means, the second much less, and so on (Buzas, 1967). Since the canonical variates are statistically independent, the results of comparison can be used to distinguish between the groups. The 95% confidence intervals for each group-mean were calculated as $\pm 1.96 / \sqrt{n}$, where n was the total number of samples in each group (Seal, 1964). These intervals indicate the degree of overlap between groups.

Ten environmental variables (water depth, percentage of organic, sand, silt, clay, mean-grain size, sorting, bulk density in the surface sediment, distance from mainland and inlet) were used for canonical variate analysis. Salinity and temperature were excluded for analysis because these data only represented summer characteristics and probably do not represent long-term mean conditions.

The most-abundant pollen taxa operationally defined as any taxa with greater than 1% of the total count were used for canonical variate analysis. Relative abundance (%) of the most abundant pollen types were transformed to 2 arc $\sin\sqrt{pi}$, pi, the proportion

of the *i*th pollen taxa within the sample, for canonical variate analysis. The canonical variate analysis program in which the data was analyzed is part of the Statistical Package for the Social Sciences (SPSS) on the Old Dominion University' s IBM 3090.

3.3.2 Foraminiferal data

Approximately three hundred foraminifera were picked from each sample. Foraminifera were identified and tabulated as relative proportions and percentages of each species of live and dead foraminifera.

Living and total (living+dead) benthic foraminifera assemblages are usefulness for ecological interpretations (Murray, 1973; Buzas, 1968; Scott and Medioli, 1980b). There are different opinions as to whether living or total assemblages should be used as short- or long-term environmental indicators. Murray (1973) mentioned that the relative abundance of living and dead individuals of foraminifera within a single sample are generally different, and counts dead foraminiferal assemblages are often higher than living ones due to production and postmortem changes. He concluded that only living benthic foraminiferal population represented the environmental conditions.

However, Parker and Athearn (1959), Matera and Lee (1972) and Scott and Medioli (1980b) investigated seasonal variations in living foraminiferal populations in marsh areas. Buzas (1968) illustrated that the living benthonic population at particular time could not be used as an environmental indicator. His study showed that the low-density living populations were randomly distributed, while the most abundant species were aggregated due to asexual reproduction. Scott and Medioli (1980b) investigated living and total assemblages over a three year period in a Nova Scotia salt marsh. They found that while living populations are highly variable due to climatic or micro-environmental changes the total assemblages did not change significantly over time. These studies suggest that the total benthic foraminiferal assemblages are reliable

to interpret environmental conditions over relatively long periods of time. Therefore, living foraminiferal populations were used as short-term environmental indicators, and total foraminiferal assemblages were used for interpreting long-term environmental conditions.

A stepwise regression analysis

A stepwise regression analysis was used to predict the relationship between species densities and environmental variables. The data composed of 12 measured environmental variables and the densities of the most frequently occurring species in living and total assemblages. The most frequently occurring species determined as any species occurring in more than 30% of the total stations. Each species consisted of the number of individuals in 70 ml of sediment. The number of individuals was transformed to ln $(x+1)$ to normalize data, where x is the number of individuals in 70 ml of sediment (Buzas, 1968, 1969). The data were analyzed on Macintosh IIcx computer using the stepwise regression analysis part of a SYSTAT™ software package.

Species diversity

The number of benthic foraminiferal species varies spatially. Generally, the number of species increases with decreases in latitude and increases in depths. Buzas and Gibson (1969) reported the maximum diversity of benthonic foraminifera occurring in depths greater than 2500 meters in the Western North Atlantic. Culver and Buzas (1980) reported a large increase in the number of species from the coastal zone to open shelf environments on the North American Atlantic Coast.

The number of species (S) is the simplest measure of species diversity. However, the number of species is correlated with the number of individuals. Consequently, the number of species (S) may vary depending on sample size.

The most commonly used formula for species diversity is the Shannon-Wiener *information function* (MacArthur and MacArthur, 1961) which measures the number of species and the proportions of the each species. The equation for the *information function* H(S) is

$$H(S) = -\sum_{i=1}^{S} p_i \ln p_i$$

where S is the number of species and p_i is the proportion of the *i*th species in each sample. The *information function* H(S) is dependent on proportions of each species rather than the absolute number of individuals, so that samples do not need to have equal numbers of individuals (Sen Gupta, 1971). Providing the numbers of species are equal, low H(S) values indicate dominance by a few species with others species of low proportions (Buzas and Gibson, 1969) and high H(S) values indicate that the proportions of species is more equally distribution (Gibson and Buzas, 1973). In general, *pi* values for rare species contribute little to the value of H(S)

In order to measure distribution of species proportions within samples, Buzas and Gibson (1969) used the ratio of species equitability. The formula of equitability E is

$$E = \frac{e^{H(S)}}{S}$$

where e is the base of the natural logarithms, H(S) is the *information function*, and S is the number of species in the sample.

$e^{H(S)}$ is the number of equally distributed species and $e^{H(S)} / S$ which ranges from 0 to 1 measures the equitability of their distribution (Buzas and Gibson, 1969). If all species are equally distributed within a sample, then the ratio of species equitability will be 1.0 (Buzas and Gibson, 1969).

Canonical variate analysis

Canonical variate analysis (multiple discriminant analysis) of foraminiferal data can be used to compare or discriminate between the groups of sedimentary environments which are previously defined by some criteria (Buzas, 1967,1972). A brief conceptual and mathematical description of canonical variate analysis for faunal analysis was given by Buzas (1967), and summarized in the first paragraph of section 3.3.1 above.

The most-abundant foraminiferal species were used for canonical variate analysis. The most abundant species of foraminifera were operationally defined as those having: (1) more than 5% of the living populations excluding less than nine total number of living individuals in any station and (2) more than 2% of the total assemblages in any station. Relative abundance (%) of species were transformed to $2 \arcsin \sqrt{pi}$, where *pi* is the proportion of the *i*th foraminiferal species within the sample, because percentages are not distributed normally. The computer program for canonical variate analysis is part of the Statistical Package for the Social Sciences (SPSS) on the Old Dominion University's IBM 3090.

Chapter 4
Results

4.1 Environmental variables

Characteristics of twelve locational and environmental variables (salinity, temperature in the water column, water depth, percent of organic, sand, silt, clay, mean-grain size, sorting, bulk density in the surface sediment, distance from mainland and inlet) were evaluated during the summers of 1989, 1990 and 1991 (Table 4). The salinities in the study area are relatively constant (28-32 psu) except in the upper parts of small watersheds where brackish salinities of 9.4 psu were recorded. Summer temperatures in the water column were also relatively constant (26-30^{0} C) throughout the lagoon.

Sediment characteristics of surface sediments are illustrated by statistical parameters and sediment descriptions (Appendix A). Distribution of sediment within a coastal lagoon changes seaward from fine to coarse. The sediment patterns in the study area are as follows: (1) very poorly sorted, fine-grained organic-rich muddy sediments in marshes and the restricted tidal bay; (2) a mixture of sediments comprising fine sand and mud with small amount of organic matter in tidal flats and channels; (3) poorly to moderately sorted sandy bodies in sand flats, washover fans, ebb deltas, and the shoreface.

Canonical variate analysis of the environmental variables was used to discriminate between subenvironments within a coastal barrier system. Since environmental variables in the brackish marsh and channel were quite distinct from those of the other

Table 4. Twelve environmental variables in the study area, including salinity (Sal.), temperature (Temp.), water depth (Depth), percent of organic (Org.), sand, silt, clay, mean-grain size (Mean), sorting, distance from mainland (DFM) and inlet (DFI), and bulk density. Datum of water depth is High High Water (HHW). The mean range of tide is approximately 4 feet (1.2 m) in this area. Negative values of DFI indicate landward distance from inlet.

Sample	St. No.	Gr. No.	Sal. (psu)	Temp. (deg.)	Depth (m)	Org. (%)	Sand (%)	Silt (%)	Clay (%)	Mean (phi)	Sorting	DFM (km)	DFI (km)	Bulk density (g/ml)
MREF 1	1	1	9.44	28.98	0.3	1.3	63.01	14.41	21.84	4.4106	3.1729	0.638	-30.745	0.5429
MREF 2	2	1	9.44	28.98	0.9	2.328	41.6	21.42	38.2	6.0003	3.178	0.851	-30.479	0.5881
MREF 3	3	1	9.44	28.98	1.5	0.377	89.36	2.95	6.53	2.5251	2.124	1.064	-30.319	1.2138
BSRB 1	4	2	30.6	27.54	1.2	0.388	15.34	50.98	34.33	6.6281	2.3843	3.83	-7.34	0.4223
BSRB 2	5	2	30.6	27.54	1.2	0.365	25.21	50.68	24.11	6.0427	2.3408	3.404	-7.766	0.7122
BSRB 3	6	2	30.6	27.54	1.2	0.327	26.57	45.78	27.71	6.0436	2.5259	3.617	-7.447	0.5688
EB 3	7	3	32.2	27.8	1.1	0.361	53.76	30.49	14.78	4.2102	2.8162	1.064	-12.713	0.7921
EB 4	8	3	32.2	28.9	1.1	0.198	20.92	52.92	25.6	6.0165	2.3393	4.043	-11.862	0.88
FMFI 3	9	3	33.1	28	1.5	0.241	3.49	75.66	21.06	6.1492	1.9616	4.149	-10.638	0.6078
EB 1	10	4	32.2	26.5	1.7	0.171	52.79	29.44	17.41	4.9812	2.3837	10.851	-6.489	0.8956
EB 2	11	4	32.2	26.5	1.4	0.16	79.23	11.23	8.05	3.9555	1.8637	9.894	-7.021	0.9218
CBSFI 1	12	5	30.74	27.98	1.2	0	94.23	1.4	2.44	3.1725	1.1181	6.489	-5.585	1.2345
CBSFI 2	13	5	31.5	28.52	1.2	0.2	73.07	17.29	8.38	4.109	1.8611	7.5	-4.787	0.9668
ECSFM 1	14	6	31.5	28.52	1.3	0	94.65	2.88	1.68	3.209	0.9768	7.766	-5.106	1.4
ECSFM 2	15	6	31.5	28.52	1.3	0	97.22	0.96	1.25	2.9671	0.8737	8.298	-4.362	1.3847
CBSFO 1	16	7	30.94	28.02	1.79	0	96.33	0.72	1.71	2.5528	1.0888	11.806	-1.702	1.2566
CBSFO 2	17	7	30.94	28.02	1.79	0.155	79.42	13.18	6.41	3.7503	1.7542	11.064	-2.979	1.1208
OYMFI 1	18	8	31.62	27.12	1.13	0.205	80.24	18.14	1	3.5517	1.1746	1.277	-11.064	1.1933
OYMFI 2	19	8	31.62	27.34	1.02	0.158	45.73	39.67	14.24	4.9512	2.1347	1.596	-10.798	0.9791
OYMFI 3	20	8	31.54	27.19	0.91	0.205	44.32	43.05	11.98	4.9501	2.1479	1.915	-10.532	0.7886
WIMFO 2	21	9	31.72	29.48	1.34	0.169	79.07	12.3	7.99	4.0032	1.8637	10	-2.34	1.0745
WIMFO 1	22	9	31.72	29.48	1.32	0.113	81.65	11.57	5.88	3.6445	1.7086	10.638	-2.021	1.1784
PCSM 1	23	10	31.9	30.68	0.3	0.082	0.255	56	43.71	7.5887	1.922	1.702	-12.926	0.4379
PCSM 2	24	10	31.9	30.68	0.9	0.186	14.07	55.48	30.56	6.374	2.3835	1.489	-13.085	0.7109
FMFI 1	25	11	33.1	28	0.3	1.504	72.9	15.15	10.52	3.1729	2.6231	3.404	-11.17	0.8132
FMFI 2	26	11	33.1	28	0.9	1.638	63.42	17.07	18.13	4.0635	2.9883	3.723	-10.904	0.6836
RS 1	27	11	33	29	0	0.911	79.96	12.42	5.41	2.525	2.3278	0.004	-16.383	1.0386
RS 2	28	11	33	29	0.7	1.818	31.45	30.68	36.68	6.1233	3.3999	0.026	-16.361	0.3804
RS 3	29	11	33	29	0.9	0.332	0.31	51.86	47.87	7.7733	1.8244	0.122	-16.243	0.3973
EMCM 1	30	12	31.78	27.04	0.3	0.574	12.08	55.62	33.01	6.5929	2.3192	6.702	-6.223	0.6019
EMCM 2	31	12	31.78	27.04	0.9	0.647	9.12	60.95	30.2	6.4845	2.2791	6.915	-6.064	0.6463
HIFO 1	32	13	32.24	26.08	0.3	0.827	17.81	48.84	32.72	6.6121	2.4487	15.532	-4.043	0.6377
HIFO 2	33	13	32.24	26.08	0.9	1.047	52.74	24.57	20.74	4.6078	3.1097	15.372	-3.83	0.6748
SI 1	34	13	33	29	0.3	8.004	7.65	31.07	61.66	7.968	2.4262	5.213	-2.713	0.1433
SI 2	35	13	33	29	0.9	0.996	65.19	14.71	18.71	4.5445	2.6279	5.106	-1.862	0.5162
WI 1	36	13	33	29	0.9	0.645	66.03	20.71	11.68	4.3133	2.2716	11.223	-2.394	0.8563
WI 2	37	13	33	29	0.9	0.551	41.51	33.72	25.04	5.5316	2.7369	11.277	-2.5	0.4194
WIMFO 3	38	14	31.72	29.48	1.49	0.145	91.92	4.42	3.58	3.172	1.3699	10.266	-1.809	1.1863
PCSM 3	39	14	31.9	30.68	1.5	0.084	6.94	48.96	44.22	7.3032	2.2685	1.17	-13.245	0.5675
EMCM 3	40	14	31.78	27.04	1.5	0.157	64.68	25.08	9.65	4.2053	2.033	7.234	-5.851	0.9669
HIFO 3	41	14	32.24	26.08	1.5	0.22	72.62	13.42	11.4	4.0506	2.2852	15.106	-3.617	0.9648
SSTC 4	42	15	30.88	28.16	5.1	0.258	79.69	11.22	7.85	3.5374	2.1883	2.66	-9.468	1.1336
SSTC 3	43	15	30.8	27.85	12.8	0.523	85.02	8.27	5.38	2.9161	2.0346	4.043	-8.138	1.1589
SSTC 2	44	16	30.74	27.98	14.9	0.191	75.16	15.25	8.15	3.8407	2.0997	6.968	-5.106	1.2079
SSTC 1	45	16	30.76	27.84	14.9	0.141	78.48	19	1.9	3.5779	1.448	9.149	-2.979	1.165
CIWF 1	46	17	32	27.48	0.3	0	97.14	0.2	1.68	2.8245	0.9684	14.149	-3.777	1.6333
CIWF 2	47	17	32	27.48	0.9	0	96.4	1.54	1.27	2.7637	0.9602	13.83	-3.457	1.248
CIWF 3	48	17	32	27.48	1.5	0	93.14	3.08	3.04	2.998	1.2911	13.404	-3.511	1.1773
SSIC 5	49	18	30.55	27.16	18.1	0.231	94.01	3.19	2.34	2.3503	1.4693	13.085	0.904	1.4423
SSIC 4	50	18	30.55	27.16	7.9	0	96.77	1	1.58	2.6903	1.1821	14.574	2.766	1.5057
SSIC 3	51	19	30.55	27.16	5	0	97.54	0.47	1.17	2.979	0.8291	15.638	4.149	1.2172
SSIC 1	52	19	30.55	27.16	14.3	0	94.45	1.63	2.56	3.2731	1.1376	22.447	10.479	1.1469
SSIC 2	53	19	30.55	27.16	7.9	0	93.24	4.05	2.2	3.0451	1.1464	17.021	5.585	1.402
SSIC 6	54	19	30.55	27.16	4.55	0	98.38	0.61	0.7	2.859	0.6819	14.787	2.819	1.3755
CISF 1	55	20	30.35	28	12.9	0	95.39	2.48	1.21	3.324	1.008	21.702	9.468	1.2358
CISF 2	56	20	30.35	28	7.9	0	96.49	0.9	1.66	3.04	0.9257	18.404	6.596	1.2783
CISF 3	57	20	30.35	28	4.9	0	96.12	0.66	1.87	3.1608	0.9813	16.915	5.585	1.432

areas (*e.g.*; salinity, distance from mainland and inlet), group 1 (stations 1-3) was excluded from the analysis. Salinity and temperature were also excluded for analysis because these data only represented summer characteristics and not long-term trends or seasonal fluctuations. The other ten environmental variables were believed to be seasonally more stable. Thus, there were 54 stations (N=54), 19 groups (h=19), and 10 variables (p=10) (environmental variables).

Because h was greater than p, there were 10 possible eigenvalues, of which four were significant at the 95% level (Table 5). The right side of Table 5 indicated that non-significant lambda value was found after some of the discriminating power had been removed by the third discriminant function. Therefore, the first three discriminant functions were statistically significant.

The first three mean canonical variates for the groups are shown in Table 6. Mean canonical variate 1 accounts for 57.78% of the variability. The greatest contrast respectively is between a cluster of three groups (the axial channel (group 18), the inlet shoals (group 19) and the barrier island shoreface (group 20)) on the left side of CV1 and two groups (the inner exposed fringe marsh (group 11) and the inner muddy sand flat (group 3)) on the far right side of CV1 (Table 6, Figs. 15, 16). Although distinguishable at the 95% confidence level, other groups occurring between these clusters show a strong similarity.

The standardized canonical discriminant function coefficients representing relative importance of the variables in separating the groups are shown in Table 7. The large absolute values represent the relative contribution for separating the groups. Table 7 indicates that percentage of sand and distance from inlet are mainly responsible for this contrast. From the group means of environmental variables (Appendix B), percentage of sand are high outside of the inlet (groups 18, 19 and 20) with group averages of 95.3 - 96%, whereas it is low at the inner muddy sand flat (group 3) with a group average of 26%. The inner exposed fringe marsh (group 11) is located 14 kilometers

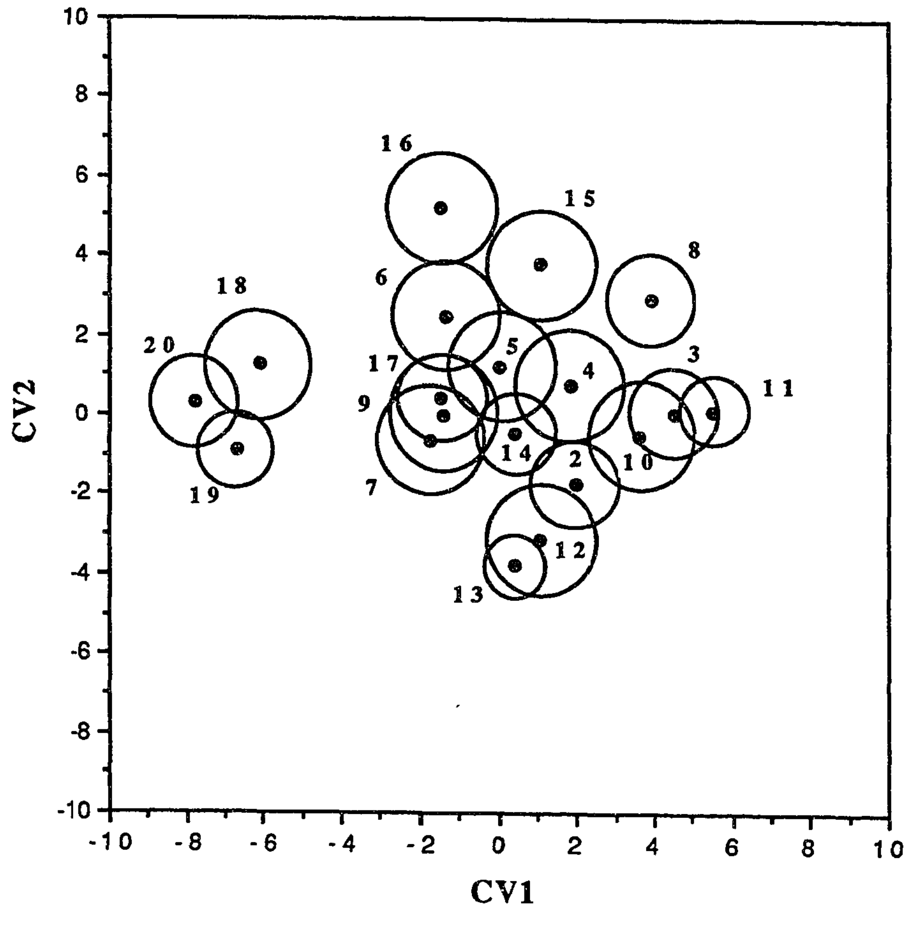
Table 5. The first four significant eigenvalues with the percentage of variability accounted for, and their cumulative percent for environmental variables.

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	:	AFTER FUNCTION	WILK' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					:	0	0.000053	383.93	162	0
1	22.02736	57.78	57.78	0.9780457	:	1	0.0012214	261.6	136	0
2	7.06952	18.54	76.32	0.9359898	:	2	0.0098564	180.17	112	0
3	4.44386	11.66	87.98	0.9034969	:	3	0.0536569	114.08	90	0.0441
4	2.17992	5.72	93.7	0.8279651	:	4	0.1706244	68.963	70	0.5126

Table 6. The first three mean canonical variates for 19 groups.

Group	CV1	CV2	CV3
2	1.98782	-1.70439	-2.60525
3	4.51081	0.08647	-2.20579
4	1.85011	0.74130	2.19929
5	0.04485	1.21788	1.28322
6	-1.31633	2.45683	1.86542
7	-1.72002	-0.61750	1.33595
8	3.91154	2.95044	-0.86494
9	-1.39270	0.02909	0.46713
10	3.59159	-0.50571	-1.20087
11	5.51475	0.15679	1.57392
12	1.09686	-3.12423	-3.12719
13	0.44910	-3.75066	0.37913
14	0.42494	-0.46117	0.71750
15	1.08532	3.81949	-0.84603
16	-1.43534	5.20096	-2.28080
17	-1.45503	0.42629	3.46374
18	-6.11928	1.24936	-1.96823
19	-6.70091	-0.87693	-0.00998
20	-7.80002	0.28704	-0.59785

Fig. 15. Plot of mean canonical variate 1 against 2 with 95% confidence circles for environmental variables. Numbers refer to *a priori* groups (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 5: the inner sand flat, 6: the middle sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: the tidal channel margin, 15: the intermediate tidal channel, 16: the deep tidal channel, 17: the washover fan, 18: the axial channel, 19: inlet shoals, 20: barrier island shoreface).



CV2
CV1
10
8
6
4
2
0
-2
-4
-6
-8
-10
-10
-8
-6
-4
-2
0
2
4
6
8
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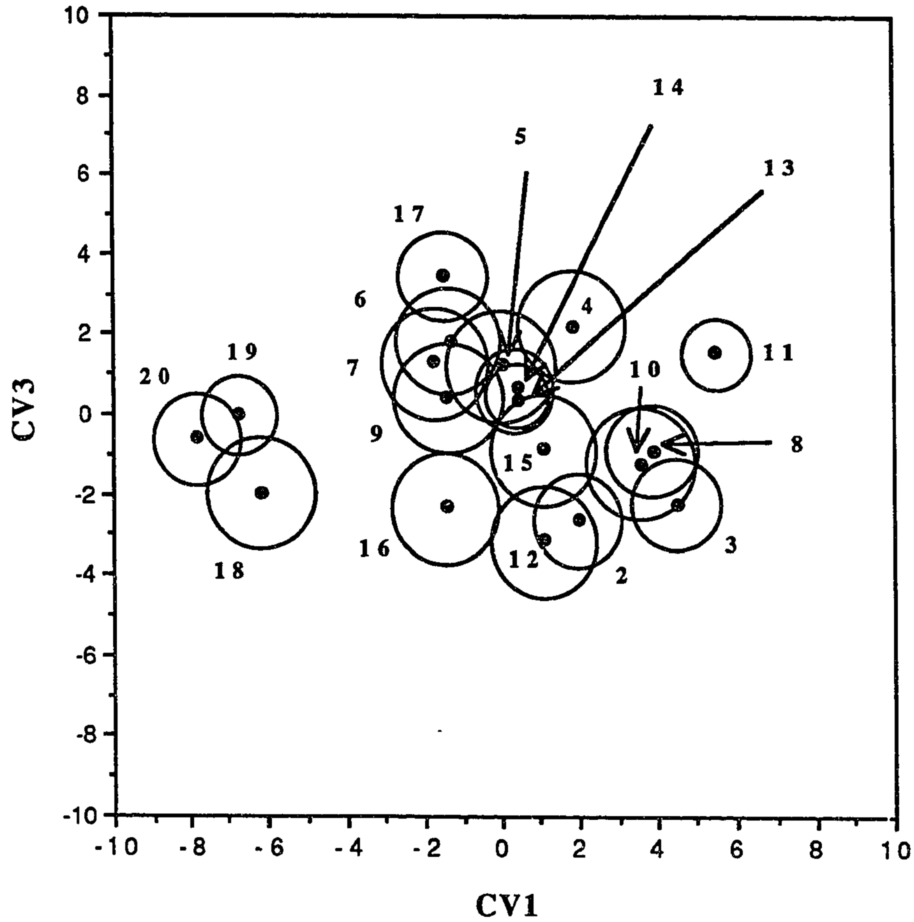
16
15
8
18
6
20
17
5
4
3
11
9
14
2
10
19
7
12
13

Fig. 16. Plot of mean canonical variate 1 against 3 with 95% confidence circles for environmental variables. Numbers refer to *a priori* groups (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 5: the inner sand flat, 6: the middle sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: the tidal channel margin, 15: the intermediate tidal channel, 16: the deep tidal channel, 17: the washover fan, 18: the axial channel, 19: inlet shoals, 20: barrier island shoreface).


CV3
CV1
10
8
6
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2
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Table 7. Standardized canonical discriminant function coefficients for environmental variables.

Variables	FUNC 1	FUNC 2	FUNC 3
Depth	-0.18277	0.84956	-0.33960
Organic (%)	0.74009	0.61503	0.18693
Sand (%)	4.25183	7.18144	1.54229
Silt (%)	2.52802	2.79782	-0.78649
Mean (phi)	0.79998	4.24842	1.18812
Sorting (phi)	0.17112	-0.05100	-0.42796
DFM (km)	0.27982	-0.09920	1.18009
DFI (km)	-1.29426	-0.95065	-1.08162
Bulk density	-0.92241	0.59856	-0.72100

from inlet but groups outside of inlet (group 18, 19 and 20) are located one to seven kilometers from inlet.

Mean canonical variate 2, accounting for 18.54% of the variability, contrasts the outer fringe marsh (group 13) and the marsh island (group 12) with intermediate and deep tidal channels (groups 15 and 16) (Table 6, Fig. 15). Percent sand and mean-grain size mainly contribute to the second canonical variate (Table 7). From the group means of environmental variables (Appendix B), intermediate and deep tidal-channels (groups 15 and 16) have high percentages of sand with group averages of 77-82%, whereas the marsh island (group 12) has low percentage sand with a group average of 10.6%. Mean grain size is finer at the marsh island (group 12) and the outer fringe marsh (group 13) with group averages of 5.6-6.5 phi (medium to fine silt). Intermediate and deep tidal-channels (groups 15 and 16) have group averages of 3.2-3.7 phi (very fine sand).

The third canonical variate, accounting for 11.66% of the variability, does not provide any contrasts among the groups that have low positive and negative values (Table 6, Fig. 16). Table 7 suggests non-significant variables in the third canonical variate.

Plots of the means for the first three canonical variates are shown in Figures 15 and 16. The plot of CV1 against CV2 shows that groups outside of the inlet (groups 18,19 and 20) are clustered and the 95% confidence circles overlap. The cluster is clearly distinct from the other groups (Fig. 15). The other groups also show considerable overlap of the 95% confidence circles except groups 16, 15 (tidal channel) and 8 (inner mud flat). Figure 15 indicates a strong similarity: (1) between the washover fan (group 17), the outer mud flat (group 9) and the outer sand flat (group 7); (2) between the marsh island (group 12) and the outer fringe marsh (group 13); (3) between the inner muddy sand flat (group 3), the inner protected fringe marsh (group 10) and the inner exposed fringe marsh (group 11). Along the third mean canonical

axis, these groups are not well discriminated from each other (Fig. 16). However, the inner exposed fringe marsh (group 11) is separated from the inner muddy sand flat (group 3) and the inner protected fringe marsh (group 10) along CV3.

The classification results in Table 8 show that 83.33% of the grouped cases correctly matched the *a priori* groups. The percent of stations matched within each group was from a low 50% correct for groups 5, 7, 10 and 14 to a high 100% correct for 11 groups (2, 3, 4, 6, 8, 9, 12, 15, 16, 17, 18). The very low 50% predicted groups 5, 7 and 10 results from only one sample misclassified among two samples for the group. The SPSS program lists the predicted group membership for each observation. Each station is assigned to the group with the highest membership probability (choice 1) and the second highest group probability (choice 2) on which the classification was based. Although nine of the 54 stations were not classified correctly by choice 1 (Table 9), seven of these were correctly predicted by choice 2. Two stations (17 and 38) were incorrectly predicted at both choices 1 and 2. Station 38, which was a member of *a priori* group 14 (tidal channel margin), was incorrectly classified as group 7 (outer sand flat; choice 1) and group 9 (outer mud flat; choice 2). This suggests that the true environmental condition of station 38 may lie between that of group 7 and group 9. In fact, station 38 is located between an outer sand flat (Cobb Bay) and an outer mud flat (South Bay).

4.2 Pollen distribution

Since most pollen grains are small in size and have low settling velocities, the eight surface samples for pollen analysis were sampled from low-energy environments. Sampling stations were at a brackish marsh, protected and exposed fringe marshes in the inner lagoon, the restricted bay, an open bay, a marsh island, and barrier fringe

Table 8. The classification results of environmental data. Number and percent of samples were correctly matched with "*a priori*" groups.

		Match with "*a priori*" groups	
Actual group	No. of samples	Number	Percent
2	3	3	100
3	3	3	100
4	2	2	100
5	2	1	50
6	2	2	100
7	2	1	50
8	3	3	100
9	2	2	100
10	2	1	50
11	5	4	80
12	2	2	100
13	6	5	83.3
14	4	2	50
15	2	2	100
16	2	2	100
17	3	3	100
18	2	2	100
19	4	3	75
20	3	2	66.7

83.33% of grouped cases were correctly classified.

Table 9. The classification information for " *a priori* " groups that matched the second choice.

Station No.	Actual group	Predicted by canonical variate analysis as:	
		Choice 1	Choice 2
12	**5**	6	**5**
17	7	9	5
24	**10**	3	**10**
29	**11**	10	**11**
36	**13**	14	**13**
38	14	7	9
39	**14**	10	**14**
52	**19**	20	**19**
57	**20**	19	**20**

marshes. Sediments in these stations consist of silt and clay with little sand. The mean-grain size of these stations is finer than six phi.

Pollen-type counts and percentages of the individual sample are presented in Table 10. Twenty-two pollen types were identified in surface sediments. The pollen of *Pinus* (pine) and *Quercus* (oak) were the dominant types in all samples. Herb pollen, Gramineae (grass), other Compositaes, *Ambrosia* (ragweed) and Chenopods, occurred in relatively low percentages with local variation in surface sediments. Low percentages of Aquatics (*Potamogeton* (pondweed) and *Typha* (cat-tail)) occurred only in the brackish marsh, the protected marsh in the inner lagoon, and the high elevation barrier fringe marsh.

The pollen concentrations per gram dry sediment were calculated by dry weight of sample, tracer (*Lycopodium* : x=12,077±1,892) and total pollen counts (Table 11). Pollen concentrations in surface samples ranged from 61,983±9,710 to 254,367±39,849 grains per gram of dry sediment. The highest pollen concentration occurred in the outer fringe marsh of Smith Island (SI 1). The tidal flat in the open bay contained the lowest pollen concentration (EB 4). Generally, high pollen concentrations occurred in inner fringe marshes where source plants grew near the sampling area.

Canonical variate analysis was used to compare modern pollen data in surface sediments from three environment groups. Three *a priori* groups were chosen on the basis of the location relative position in the lagoon: inner, middle and outer part of the lagoon (Table 12). The sixteen most abundant taxa were used for canonical variate analysis (Table 13). The most abundant taxa were defined as any taxa containing 1% or more of total counted pollen grains in any station.

There were eight stations (N=8), three groups (h=3), and 16 variables (p=16) (pollen types). In the grouping, h-1=2 eigenvalues were possible because p was greater than h. The first eigenvalue accounted for 92.70% of the variability. The

Table 10. Counts and percentages of pollen types in the surface sediment from the eight stations (MREF 2, PCSM 1, RS 3, BSRB 1, EB 4, EMCM 1, HIFO 1, SI 1).

Sample	MREF 2		PCSM 1		RS 3		BSRB 1		EB 4		EMCM 1		HIFO 1		SI 1	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
PINUS (Pine)	132	58.4	102.5	40.3	103	45.8	110	50.7	138.5	57.3	122	52.4	84	36.5	63	24.8
QUERCUS (Oak)	24	10.6	47	18.5	51	22.7	28	12.9	28	11.6	52	22.3	40	17.4	40	15.7
CARYA (Hickory)	12	5.3	6	2.4	2	0.9	8	3.7	2	0.8	2	0.9	4	1.7	17	6.7
TSUGA (Hemlock)	0	0	0	0	0	0	0	0	2	0.8	0	0	0	0	0	0
ACER (Maple)	3	1.3	8	3.1	9	4	9	4.1	4	1.7	9	3.9	2	0.9	7	2.8
FRAXINUS (Ash)	0	0	2	0.8	2	0.9	0	0	0	0	2	0.9	4	1.7	4	1.6
ULMUS (Elm)	0	0	6	2.4	4	1.8	8	3.7	4	1.7	8	3.4	6	2.6	8	3.1
LIQUIDAMBAR (Sweet Gum)	6	2.7	8	3.1	5	2.2	5	2.3	6	2.5	3	1.3	6	2.6	5	2
MORUS (Red Mulberry)	4	1.8	5	2	3	1.3	2	0.9	6	2.5	0	0	7	3	4	1.6
SALIX (Willow)	2	0.9	8	3.1	4	1.8	5	2.3	6	2.5	3	1.3	3	1.3	1	0.4
JUNIPERUS (Red Cedar)	1	0.4	1	0.4	0	0	2	0.9	1	0.4	0	0	1	0.4	1	0.4
JUGLANS (Black Walnut)	0	0	2	0.8	2	0.9	0	0	0	0	1	0.4	4	1.7	2	0.8
ALNUS (Alder)	0	0	1	0.4	0	0	0	0	0	0	0	0	0	0	0	0
MYRICA	1	0.4	9	3.5	9	4	8	3.7	7	2.9	3	1.3	11	4.8	23	9.1
SAMBUCUS (Elderberry)	0	0	0	0	0	0	0	0	1	0.4	0	0	0	0	0	0
GRAMINEAE (Grass)	5	2.2	6	2.4	5	2.2	3	1.4	5	2.1	4	1.7	8	3.5	13	5.1
Other COMPOSITAES	6	2.7	15	5.9	7	3.1	11	5.1	11	4.6	10	4.3	16	7	36	14.2
AMBROSIA (Ragweed)	15	6.6	13	5.1	12	5.3	13	6	9	3.7	9	3.9	20	8.7	22	8.7
CHENOPODS	9	4	14	5.5	7	3.1	5	2.3	11	4.6	5	2.1	12	5.2	8	3.1
POTAMOGETON (Pondweed)	2	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TYPHA (Cat-tail)	4	1.8	1	0.4	0	0	0	0	0	0	0	0	1	0.4	0	0
OSMUNDA	0	0	0	0	0	0	0	0	0	0	0	0	1	0.4	0	0
LYCOPODIUM CLAVATUM (Spike)	107		117		115		164		156		146		153		118	
Total pollen count per fraction	226	100	254.5	100.1	225	100	217	100	241.5	100	233	100	230	99.8	254	100
excluding "Spike"																
Sediment Weight (g)	0.6281		0.6845		0.5335		0.6602		0.9049		0.817		0.697		0.3066	

Table 11. The pollen concentrations per gram dry sediment of the eight stations.

Sample	Sub-environments	Pollen concentration (grain/g)
MREF 2	Brackish marsh	121,836±19,087
PCSM 1	Inner protected fringe marsh	115,135±18,037
RS 3	Inner exposed fringe marsh	132,871±20,815
BSRB 1	Restricted tidal bay	72,614±11,376
EB 4	Open bay	61,983±9,710
EMCM 1	Marsh island	70,772±11,087
HIFO 1	Outer fringe marsh	78,142±12,242
SI 1	Outer fringe marsh	254,367±39,849

Table 12. List of group and station for pollen data.

(Group 1 = inner, Group 2 = middle and Group 3 = outer parts of lagoon)

Sub-environments	Group No.	Stations	Station No.
Brackish marsh	1	MREF 2	2
Inner protected fringe marsh	1	PCSM 1	23
Inner exposed fringe marsh	1	RS 3	29
Restricted tidal bay	2	BSRB 1	4
Open bay	2	EB 4	8
Marsh island	2	EMCM 1	30
Barrier fringe marsh	3	HIFO1	32
Barrier fringe marsh	3	SI1	34

Table 13. List of the most abundant pollen taxa (those representing 1% or more of the pollen assemblage in any station).

Code No.	TAXA
V1	*Pinus* (Pine)
V2	*Quercus* (Oak)
V3	*Carya* (Hickory)
V5	*Acer* (Maple)
V6	*Fraxinus* (Ash)
V7	*Ulmus* (Elm)
V8	*Liquidambar* (Sweet Gum)
V9	*Morus* (Red Mulberry)
V10	*Salix* (Willow)
V12	*Juglans* (Black Walnut)
V14	*Myrica*
V16	Gramineae (Grass)
V17	Other Compositaes
V18	*Ambrosia* (Ragweed)
V19	Chenopods
V21	*Typha* (Cat-tail)

second eigenvalue accounted for 7.30% for a total of 100% of the variability (Table 14).

Table 15 shows canonical variate group-means for the first two canonical variates and the standardized canonical discriminant function coefficients which indicate the relative importance of the variables (pollen types) to the respective functions. In the first mean canonical variate, three groups are clearly separated from one another (Table 15, Fig. 17). *Quercus* (oak), *Fraxinus* (ash) and *Acer* (maple) are important species that influence the separation of the groups. The relative abundance (%) of *Quercus* (oak) is slightly higher at inner part of the lagoon (17%) than middle and outer parts of the lagoon (15.6-16.5%). *Fraxinus* (ash) has higher frequencies at outer part of the lagoon (1.85%) than middle and inner parts of the lagoon (0.3-0.6%), whereas *Acer* (maple) has higher frequencies at middle part of the lagoon (3.2%) than outer and inner parts of the lagoon (1.85-2.8%). In the second mean canonical variate, the three groups that have low positive and negative values are only weakly separated from one another (Table 15, Fig. 17). The largest standardized discriminant function coefficients are *Quercus* (oak) and *Fraxinus* (ash) in the second function.

Plots of the canonical group-means for three groups on the first and second canonical variate axes with 95% confidence circles are shown in Fig. 17. In the plot of the three groups, all the groups are clearly discriminated from one another along the first axis. The classification results show that 100% of the three grouped cases matched the proposed *a priori* groups.

4.3 Foraminiferal distribution

4.3.1 Abundance of foraminifera

Surface samples

Table 14. The first two eigenvalues accounted for a total of 100% of the variability for pollen assemblages.

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	:	AFTER FUNCTION	WILK' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					:	0	0.0042508	16.382	10	0.0892
1	48.11174	92.7	92.7	0.9897668	:	1	0.2087657	4.6996	4	0.3195
2	3.79006	7.3	100	0.8895135	:					

Table 15. The first two mean canonical variates (a) and standardized canonical discriminant function coefficients (b) for the five most abundant pollen types.

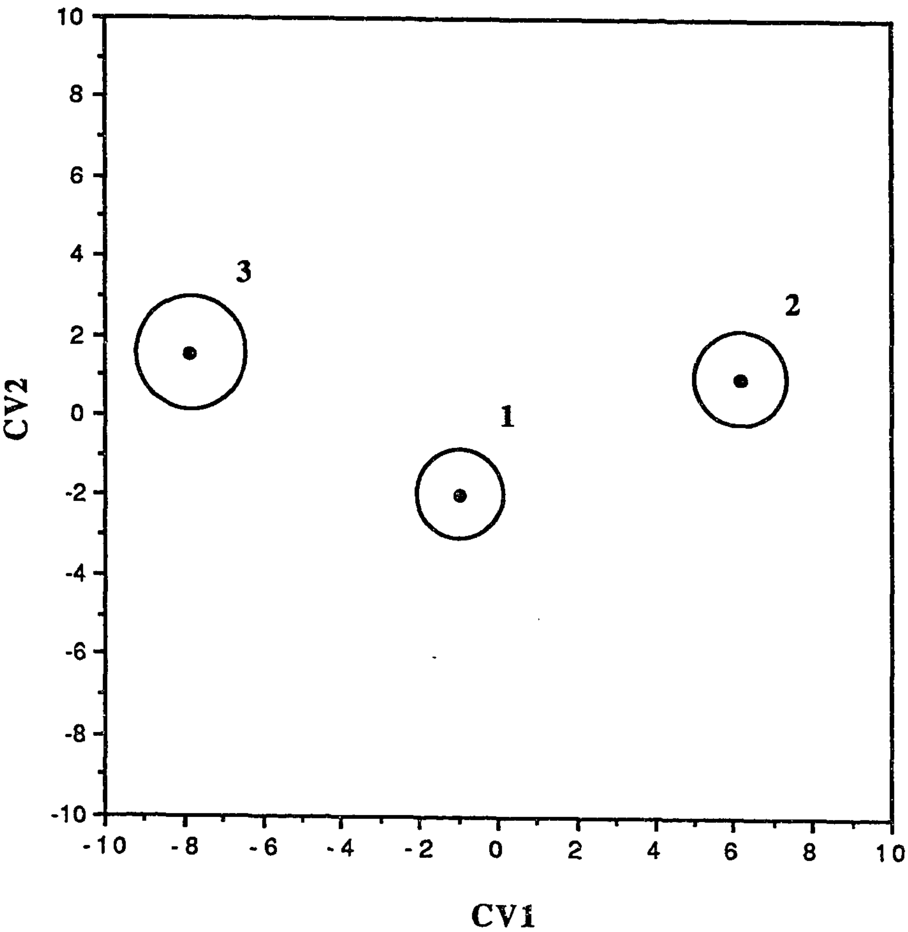
a. Canonical discriminant functions evaluated at group means (group centroids)

Group	CV1	CV2
1	-0.97829	-1.96789
2	6.19607	0.96107
3	-7.82667	1.51023

b. Standardized canonical discriminant function coefficients

Variables	FUNC 1	FUNC 2
V1 (*Pinus*)	5.90706	3.40842
V2 (*Quercus*)	-16.00345	-15.08558
V3 (*Carya*)	-4.19527	-2.92159
V5 (*Acer*)	9.09100	5.60557
V6 (*Fraxinus*)	10.85078	11.66322

Fig. 17. Plot of mean canonical variate 1 against 2 with 95% confidence circles for pollen assemblages. Numbers refer to groups 1-3 (1=inside, 2=middle and 3=outside of lagoon).



10
8
6
4
2
0
-2
-4
-6
-8
-10
CV2
3
2
1
-10
-8
-6
-4
-2
0
2
4
6
8
10
CV1

Forty-four living benthic species were identified in the study area. The number of individuals and relative abundance (%) for the living and total (living+dead) assemblages are listed in Appendices C and D. The number of living individuals per 70 ml of sediment varies from 0 to 4880 specimens over the study area. Generally, the number of living individuals was low at the ebb delta and the shoreface (stations 49-57) with an average of 18 specimens/70 ml sample, whereas generally the greatest number of living individuals occurred in restricted bays (stations 4-6) with an average of 2113 specimens/70 ml sample. The highest number of living specimens occurred in station 47 (4880 specimens/70 ml; washover fan) where *Quinqueloculina* dominated.

Sixty-eight species (66 benthic; 2 planktonic) were recorded in total assemblages of surface sediments from 57 stations. The number of total (living+dead) individuals per 70 ml of sediment varied from 2 to 7776 specimens. Generally, low specimen numbers occurred in outer tidal flats and inner fringe marshes where the mean was approximately 300 specimens/70 ml sediment. The high numbers of specimens occurred in the restricted bay and on the washover fan, with an average of about 2950 specimens/70 ml sample. For ease of discussion, relative abundance (%) of species can be qualitatively described as most abundant equals more than 50%, abundant equals 25 to 49%, common equals 5 to 24%, and rare equals less than 5% of the living population or the total assemblage in any station within the group. In the restricted bay, *Ammonia beccarii* and *Elphidium excavatum* were most abundant species in living and total assemblages. *Quinqueloculina seminula* was a most abundant species in living and total assemblages on the washover fan.

The species of the living and total assemblages of the brackish marsh and channel (stations 1-3) are quite different from those of the other areas. The samples of the brackish marsh and channel were taken near the head of the Machipongo River where the salinity was 9.4 psu. The samples from this area were rich in agglutinated taxa (98% of total assemblages). Only three living calcareous species, *Ammonia beccarii*,

Elphidium excavatum and *Haynesina germanica*, were found at station 3 in a brackish channel. *Trochammina inflata* was the abundant species with an average contribution of 17% in living populations and 37% in total assemblages. Other common species of total assemblages were *Ammoastuta inepta*, *Arenoparrella mexicana*, *Haplophragmoides bonplandi*, *Haplophragmoides wilberti*, *Jadammina macrescens*, *Trochammina "squamata"* and *Trochammina* sp. A. *Ammoastuta inepta* was only found in the brackish marsh and channel.

Core samples

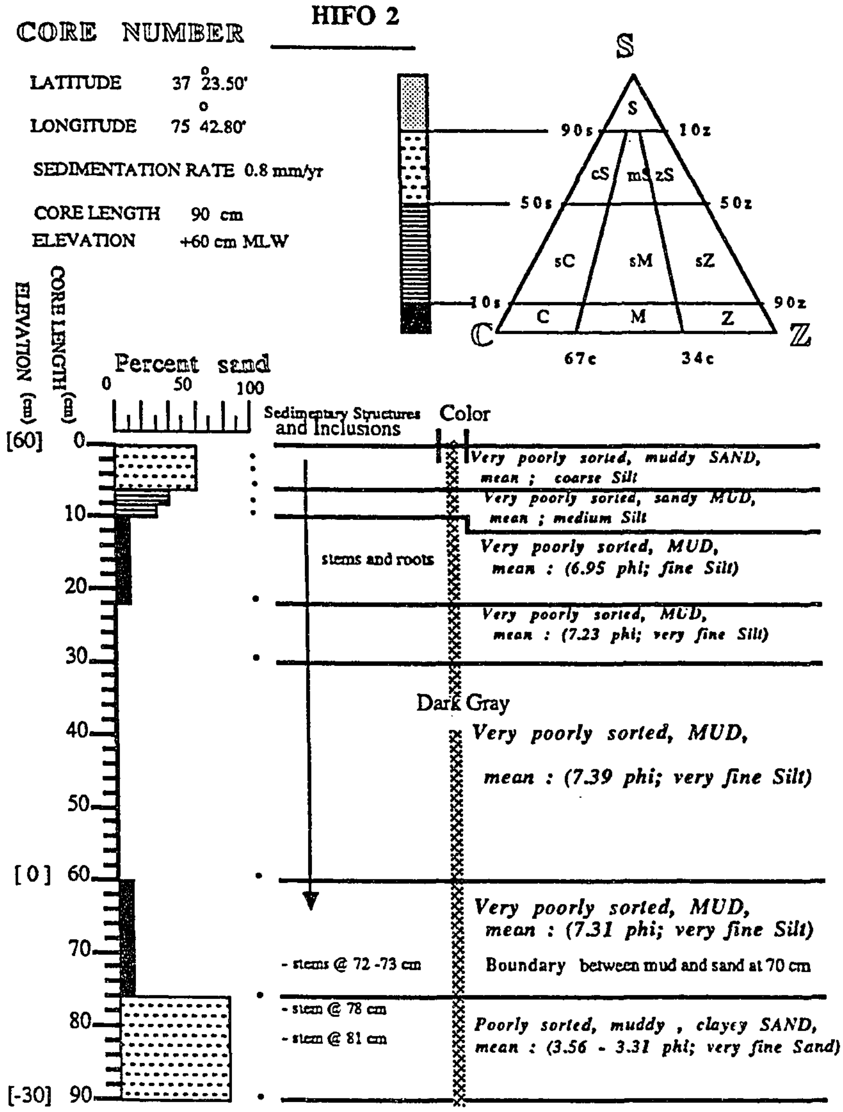
The distribution of fossil foraminifera was examined in three short cores (about 1 m) collected from a barrier fringe marsh (HIFO 2), an inner mud flat (OYMFI 1) and an outer mud flat (WIMFO 1) (Table 2). Statistical parameters of grain-size analysis were listed in Appendix E. Core logging graphs of each core show percent sand, color, structure, textual name, mean and sorting class. Table 16 shows fossil foraminiferal assemblages of three cores with core depths.

Core HIFO 2 was obtained from a fringe marsh (MSL) on the backbarrier region of Hog Island (station 33; Fig. 3). The sediment analysis of core HIFO 2 shows a fining downward sequence from muddy sand to sandy mud to mud sitting above a clayey sand (Fig. 18). The sedimentation rate at this station is 0.8 mm/yr (Appendix F). Fossil assemblages in this core contain only a sparse assemblage of agglutinated taxa (mainly *Trochammina inflata*) (Table 16). The upper 6 cm is a muddy sand that is composed of 57% sand with organic matter (stems and roots), it is very poorly sorted (2.6 phi), and has a mean size of coarse silt (about Mz=4.7 phi). Between 6 to 10 cm is a very poorly sorted (2.6 phi) sandy mud with a mean size of medium silt (about Mz=5.5 phi), and a sparse assemblage of foraminifera (9 specimens/70 ml). The mud facies (10-76 cm) is composed of more than 90% mud (silt+clay) which is very poorly sorted (about 2.1 phi) producing a mean size of very fine silt (about Mz=7.2 phi). The

Table 16. Fossil foraminiferal assemblages from three cores from a backbarrier fringe marsh (HIFO 2), a mud flat on the outer fringe of the lagoon (WIMFO 1) and a mud flat on the inner fringe of the lagoon (OYMFI 1).

Core	HIFO 2	HIFO 2	HIFO 2	HIFO 2	HIFO 2	WIMFO 1	WIMFO 1	WIMFO 1	OYMFI 1	OYMFI 1	OYMFI 1
Depth (cm)	6-8	20-22	59-61	74-76	88-90	29-31	59-61	89-91	31-33	61-63	91-93
Wet vol. of sample (ml)	60	62	61	45	40	61	55	61	60	60	60
No. of species	3	2	1	1	0	2	4	4	3	6	6
No. of individuals	8	12	2	3	0	2	6	4	13	75	12
Extrapolated Number of individuals per 70 ml	9	14	2	9	0	2	8	5	15	88	14
AMMONIA BECCARII										4	1
ARENOPARRELLA MEXICANA											
ELPHIDIUM EXCAVATUM							3		7	64	3
JADAMMINA MACRESCENS		1									
TROCHAMMINA INFLATA	6	11	2	3			1	1		2	1
TROCHAMMINA OCHRACEA						1	1	1		1	2
TROCHAMMINA "SQUAMATA"	1							1	2	1	1
TROCHAMMINA sp. A	1					1	1	1	4	3	4

Fig. 18. Graphic core log of HIFO 2, showing a fining downward sequence to a clayey sand. S, SAND; s, sandy; Z, SILT; z, silty; M, MUD; m, muddy; C, CLAY; c, clayey.


CORE NUMBER HIFO 2
LATITUDE 37° 23.50'
LONGITUDE 75° 42.80'
SEDIMENTATION RATE 0.8 mm/yr
CORE LENGTH 90 cm
ELEVATION +60 cm MLW
S
Z
C
90s
10z
50s
50z
10s
90z
67c
34c
s
cS
mS
zS
sC
sM
sZ
M
ELEVATION (cm)
CORE LENGTH (cm)
Percent sand
0 50 100
Sedimentary Structures and Inclusions
Color
[60] 0
10
20
30
40
50
[0] 60
70
80
[-30] 90
Very poorly sorted, muddy SAND, mean ; coarse Silt
Very poorly sorted, sandy MUD, mean ; medium Silt
stems and roots
Very poorly sorted, MUD, mean : (6.95 phi; fine Silt)
Very poorly sorted, MUD, mean : (7.23 phi; very fine Silt)
Dark Gray
Very poorly sorted, MUD, mean : (7.39 phi; very fine Silt)
Very poorly sorted, MUD, mean : (7.31 phi; very fine Silt)
- stems @ 72 -73 cm
Boundary between mud and sand at 70 cm
- stem @ 78 cm
- stem @ 81 cm
Poorly sorted, muddy , clayey SAND, mean : (3.56 - 3.31 phi; very fine Sand)

number of foraminiferal specimens increases at 20 cm (14 specimens/70 ml) and then decreases with depth. The characteristics of the lower muddy sand (76-90 cm) are different from upper surface sand (0-6 cm). The lower layer contains a relatively high percent sand (80-90%) with a low organic content and is poorly sorted (1.8 phi). The sand of this unit was probably provided by overwash from Hog Island during storms and then mixed with lagoonal mud. The unit contains a sparse amount of foraminifera (9 specimens/70 ml) and eventually becomes devoid of foraminifera at 90 cm.

Core WIMFO 1 was taken in a tidal flat on the outer part of the lagoon behind Wreck Island (station 22; Fig. 4). It was characterized by two main units: muddy sand and sandy mud (Fig. 19). The muddy sand (0-90 cm) is very poorly sorted (2.1-2.5 phi) with a mean size of medium to coarse silt (Mz=4.1-5.1 phi). The upper 30 cm of this unit is bedded and contains a relatively high percent of clean sand (70-80%), which was probably provided by overwash from Wreck Island. The lower part of the muddy sand unit (30-90 cm) is a homogeneous mixture of mud and only 60% sand. The lower part of the core (90-101 cm) is characterized by a sandy mud facies that is very poorly sorted (2.4 phi), and has a mean size of medium silt (Mz=5.7-5.97 phi).

Fossil assemblages in the WIMFO 1 core consist of one calcareous and four agglutinated species (Table 16). A few specimens of the agglutinated genus *Trochammina* were found at 30 and 90 cm core depths (2-5 specimens/70 ml). The middle part of this core (60 cm) contains a few specimens of the calcareous species *Elphidium excavatum* and the agglutinated genus *Trochammina* (8 specimens/70 ml). The distinct differences in lithology and the few specimens of agglutinated taxa below 90 cm in the core may indicate a significant change in the depositional environment during the filling of the lagoon.

Core OYMFI 1 was taken on the tidal flat in the inner part of the lagoon on the northernmost side of Mockhorn Bay (station 18; Fig. 4). The upper 70 cm of the core is a muddy sand (Fig. 20). The uppermost 50 cm contains a relatively high percent

Fig. 19. Graphic core log of WIMFO 1, showing a fining downward sequence. S, SAND; s, sandy; Z, SILT; z, silty; M, MUD; m, muddy; C, CLAY; c, clayey.

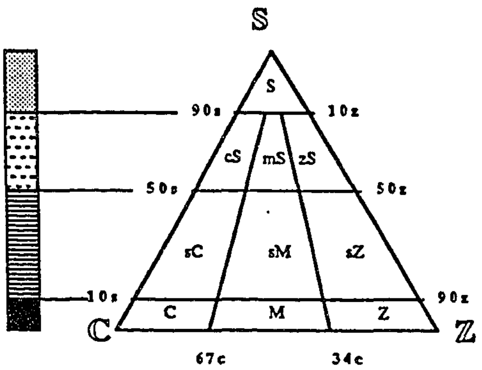
CORE NUMBER WIMFO 1

LATITUDE 37° 15.65'

LONGITUDE 75° 48.45'

CORE LENGTH 101 cm

ELEVATION 0 cm MLW



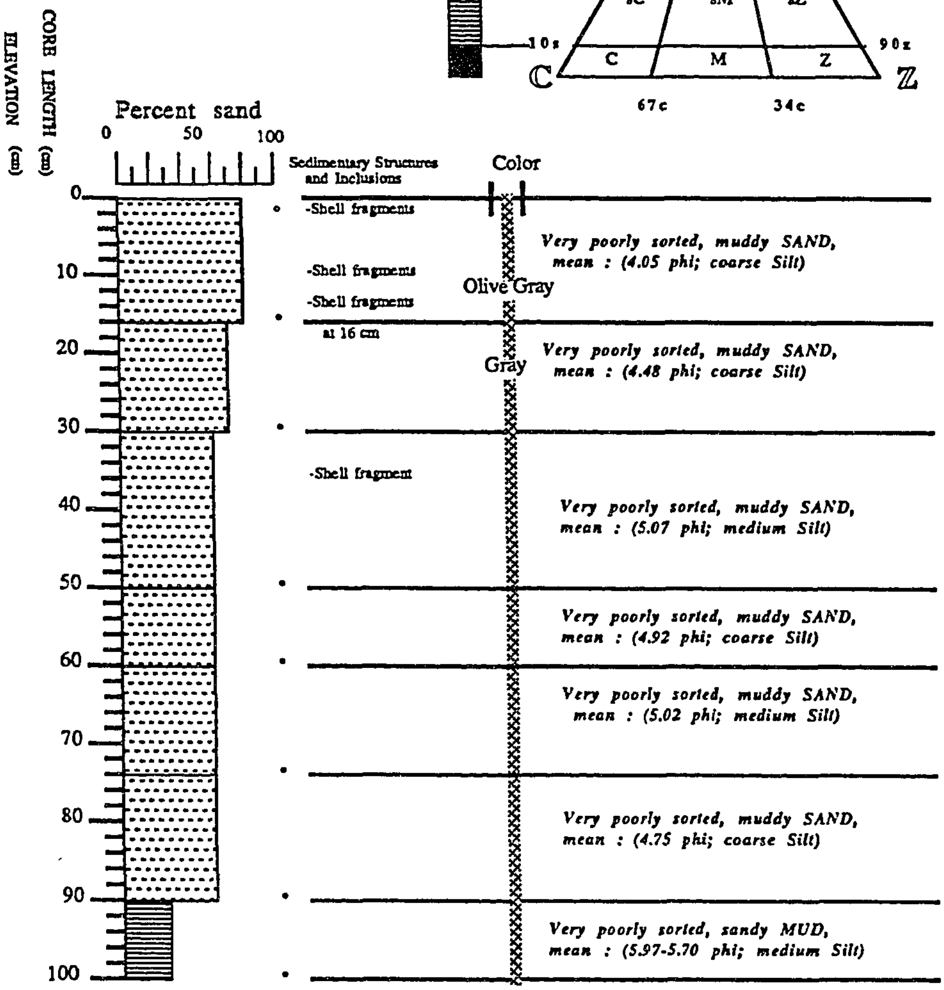
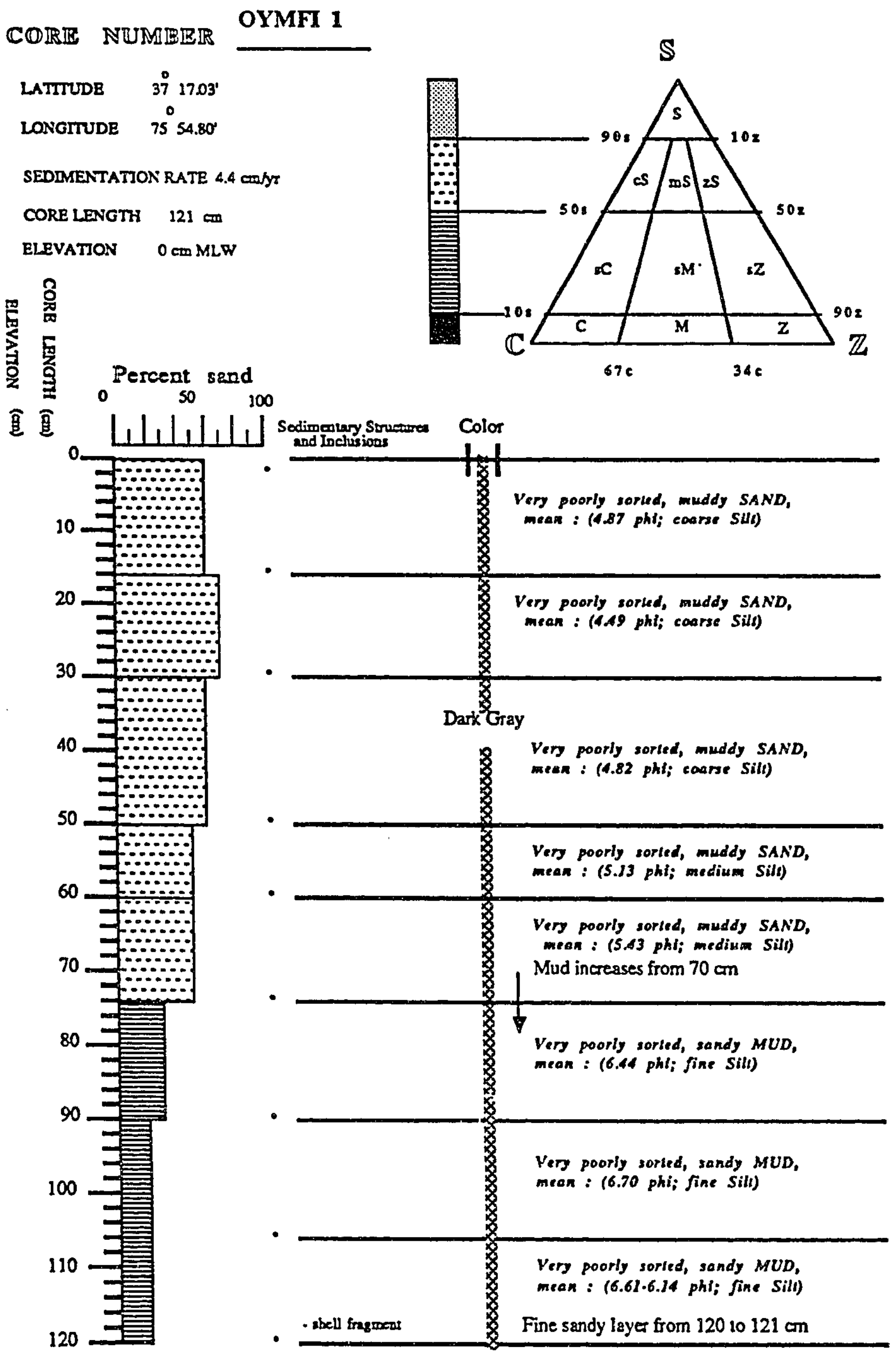


Fig. 20. Graphic core log of OYMFI 1, showing a fining downward sequence. S, SAND; s, sandy; Z, SILT; z, silty; M, MUD; m, muddy; C, CLAY; c, clayey.


CORE NUMBER OYMFI 1
LATITUDE 37° 17.03'
LONGITUDE 75° 54.80'
SEDIMENTATION RATE 4.4 cm/yr
CORE LENGTH 121 cm
ELEVATION 0 cm MLW
S
S
90s
10z
cS
mS
zS
50s
50z
sC
sM
sZ
10s
90z
C
M
Z
C
Z
67c
34c
ELEVATION (m)
CORE LENGTH (cm)
Percent sand
0 50 100
Sedimentary Structures and Inclusions
Color
0
10
20
30
40
50
60
70
80
90
100
110
120
Very poorly sorted, muddy SAND, mean : (4.87 phi; coarse Silt)
Very poorly sorted, muddy SAND, mean : (4.49 phi; coarse Silt)
Dark Gray
Very poorly sorted, muddy SAND, mean : (4.82 phi; coarse Silt)
Very poorly sorted, muddy SAND, mean : (5.13 phi; medium Silt)
Very poorly sorted, muddy SAND, mean : (5.43 phi; medium Silt)
Mud increases from 70 cm
Very poorly sorted, sandy MUD, mean : (6.44 phi; fine Silt)
Very poorly sorted, sandy MUD, mean : (6.70 phi; fine Silt)
Very poorly sorted, sandy MUD, mean : (6.61-6.14 phi; fine Silt)
- shell fragment
Fine sandy layer from 120 to 121 cm

sand (60-70%) that is very poorly sorted (2.3 phi), and has a mean size of coarse silt (about Mz=4.8 phi). Most of sand in this unit was probably transported from the mainland by run-off. Pb-210 analysis suggests a very high sedimentation rate (4.4 cm/yr) through 80 cm core depth (Appendix F). However, X-ray radiography (5-40 cm) reveals that the sediment has been mechanically and biogenically mixed by worm tubes and burrows. Thus, high concentrations of Pb-210 probably represent downward biogenic mixing rather than sedimentation. At 30 cm core depth, there are a few specimens of *Elphidium excavatum*, *Trochammina* "*squamata*" and *Trochammina* sp. A (15 specimens/70 ml) (Table 16). The base of the unit (50-74 cm) is a homogeneous sand (50%) which is very poorly sorted (2.3 phi) and has a mean size of medium silt (Mz=5.1-5.4 phi). The concentration of foraminifera at 60 cm is relatively high (88 specimens/70 ml). *Elphidium excavatum* is the most abundant species and comprises 85% of the assemblage (Table 16). Several species of *Trochammina* and the hyaline species *Ammonia beccarii* are present.

The lower part of the core (74-121 cm) is a sandy mud that is very poorly sorted (2.5 phi) and has a mean size of fine silt (about Mz=6.1-6.7 phi) with minor amounts of organic matter (Fig. 20). Some of the very fine sand in the upper unit (70-90 cm) was probably introduced by bioturbation. The composition of the fossil assemblage at 90 cm depth is the same as at the 60 cm depth, but specimen numbers are significantly lower (14 specimens/70 ml). The fine sediment with organic matter and a sparse amount of agglutinated foraminifera in this unit may indicate a buried fringe marsh.

4.3.2 Species diversity

The foraminiferal diversity was analyzed by calculating the Shannon-Weiner information function (H(S)) and equitability ($E=e^{H(S)}/S$) and counting the number of species (S) in the sample (Buzas and Gibson, 1969). Using the information function (H(S)), Gibson and Buzas (1973) demonstrated that the minimum sample size required

is approximately 100 specimens. They examined the relationships between S, H(S), E and sample size on the continental shelf off Cape Hatteras. With increasing sample size from 121 to 506, the number of species (S) almost doubled (from 21 to 41) because of the addition of rare species, whereas the information function values (H(S)) increased less than 5% (from 2.44 to 2.53). The test result indicated that the information function values, H(S), are dependent on the proportions of the common species. In living populations, many stations contained a small number of species and specimens (less than 100) so that species proportions are not reliable for the diversity analyses. Therefore, total foraminiferal assemblages were used in diversity analyses.

Table 17 lists the results of the diversity analyses (H(S), S, E, n and N), and plots of H(S), S and E against the 47 stations are shown in Fig. 21. Values of H(S) in this coastal barrier system range from 0.2119 on the shoreface (station 57) to 2.1463 in a brackish channel (station 3). Relatively low values of H(S) occur at sandy environments like the sand flat (stations 12-16), the ebb delta (stations 49-54) and on the shoreface (stations 55-57). The highest values of H(S) at the brackish marsh and channel (stations 1-3) indicate that some abundant species (*e.g., Arenoparrella mexicana, Jadammina macrescens, Trochammina inflata* and *Trochammina* sp. A) are more evenly distributed in the assemblages. However, one dominant species (*Elphidium excavatum*) contributes the low values of H(S) at the sand flat, the ebb delta and on the shoreface. Buzas and Gibson (1969) stated that the low diversities in shallow water could be influenced by the extreme stress. The low values of H(S) in these areas may be influenced by the high energy conditions caused by tides and waves.

The number of species, S, varies considerably. Fig. 22 is a plot of the number of individuals for the picked fraction in each station against the number of species. The general pattern of the number of species (S) increases as the number of individuals increases. The samples with the greatest numbers of species (S=20-23), the inner mud flat (stations 19 and 20), are also the samples with the greatest numbers of individuals

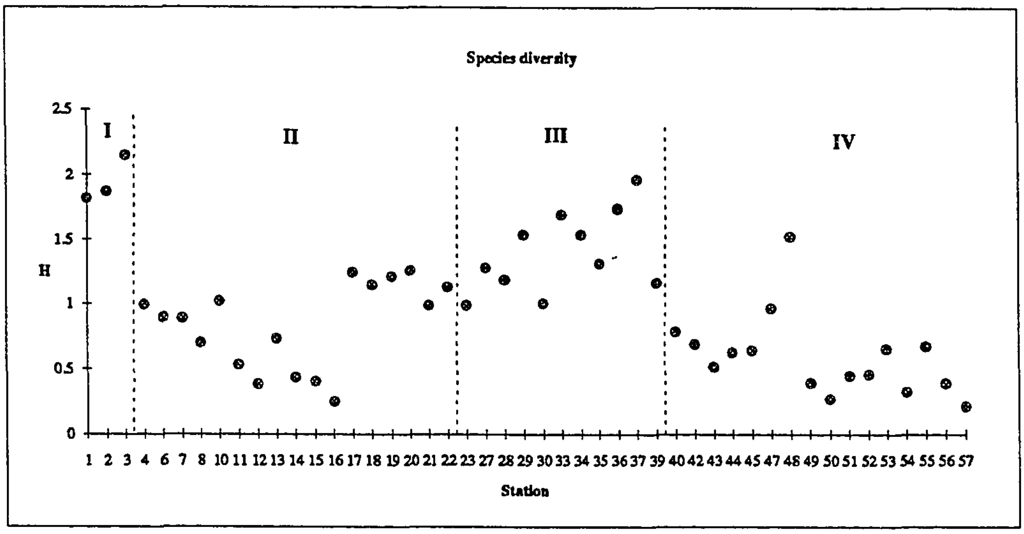
Table 17. Species diversity and equitability of total foraminifera in the study area (ST=Station No, H(S)=Species diversity, S=No. of species, E=Equitability, n=No. of individuals picked, N=No. of individuals per 70ml). Ten stations (5, 9, 24, 25, 26, 31, 32, 38, 41, 46) were excluded from the species diversity analyses statistics because they contained less than 100 specimens.

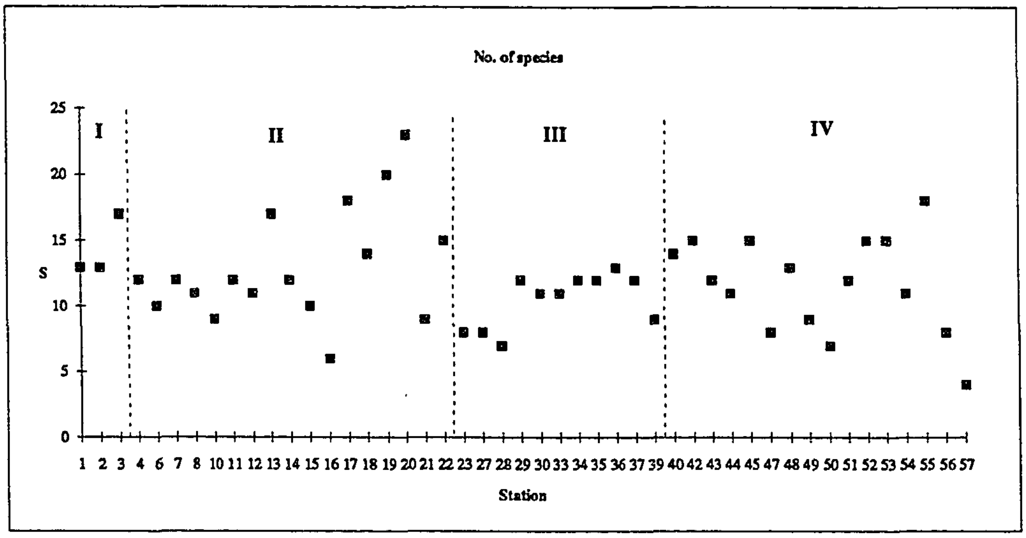
ST	Environments	H(S)	S	E	n	N
1	**Brackish marsh/**	1.8140	13	0.4719	639	2556
2	**channel**	1.8725	13	0.5004	319	2552
3		2.1463	17	0.5031	373	746
....		....	...	....	.....	....
Mean		**1.9443**	**14**	**0.4918**	**444**	**1951**
4	**Lagoonal**	0.9952	12	0.2254	447	3576
6	**tidal flats**	0.8938	10	0.2444	322	5152
7		0.8859	12	0.2021	348	5568
8		0.7006	11	0.1832	289	289
10		1.0188	9	0.3077	218	218
11		0.5284	12	0.1414	377	377
12		0.3810	11	0.1331	321	2568
13		0.7313	17	0.1222	487	1948
14		0.4338	12	0.1286	453	3624
15		0.4015	10	0.1494	334	1336
16		0.2479	6	0.2136	272	272
17		1.2449	18	0.1929	306	306
18		1.1468	14	0.2249	237	237
19		1.2138	20	0.1683	692	692
20		1.2607	23	0.1534	668	1336
21		0.9889	9	0.2987	125	125
22		1.1317	15	0.2067	352	704
....		....	...	....	.....	....
Mean		**0.8356**	**13**	**0.1939**	**368**	**1666**

Continued

ST	Environments	H(S)	S	E	n	N
23	**Lagoonal**	0.9870	8	0.3354	469	469
27	**marshes**	1.2796	8	0.4494	299	598
28		1.1850	7	0.4672	304	608
29		1.5402	12	0.3888	343	457
30		1.0041	11	0.2481	447	1788
33		1.6966	11	0.4960	277	277
34		1.5361	12	0.3872	304	304
35		1.3138	12	0.3100	290	1160
36		1.7360	13	0.4365	295	1180
37		1.9625	12	0.5931	158	158
39		1.1670	9	0.3569	344	344
....		....	...	....	.....	....
Mean		**1.4007**	**10**	**0.4062**	**321**	**668**
40	**Channels-**	0.7899	14	0.1574	338	451
42	**inlets-**	0.6917	15	0.1331	307	614
43	**shoreface**	0.5158	12	0.1396	243	243
44		0.6278	11	0.1703	310	620
45		0.6446	15	0.1270	393	786
47		0.9641	8	0.3278	486	7776
48		1.5256	13	0.3537	525	1050
49		0.3943	9	0.1648	409	409
50		0.2742	7	0.1879	439	1756
51		0.4488	12	0.1305	456	912
52		0.4603	15	0.1056	326	5216
53		0.6540	15	0.1282	378	378
54		0.3260	11	0.1259	429	1716
55		0.6743	18	0.1090	393	1572
56		0.3905	8	0.1847	291	291
57		0.2119	4	0.3090	148	148
....		....	....	....	......	....
Mean		**0.5996**	**12**	**0.1784**	**367**	**1496**

Fig. 21. Plots of the diversity analyses statistics (H(S), S, and E) of total foraminiferal assemblages at 47 stations in the coastal barrier system (H= H(S)). Ten stations (5, 9, 24, 25, 26, 31, 32, 38, 41, 46) were excluded from plots because they contained less than 100 specimens. Environment I is the brackish marsh/channel (stations 1-3). Environment II is the lagoonal tidal-flats (stations 4-22). Environment III is the lagoonal marshes (stations 23-39). Environment IV is the channels-inlets-shoreface (stations 40-57).


Species diversity
H
I
II
III
IV
0
0.5
1
1.5
2
2.5
1 2 3 4 6 7 8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 27 28 29 30 33 34 35 36 37 39 40 42 43 44 45 47 48 49 50 51 52 53 54 55 56 57
Station


No. of species
S
I
II
III
IV
0
5
10
15
20
25
1 2 3 4 6 7 8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 27 28 29 30 33 34 35 36 37 39 40 42 43 44 45 47 48 49 50 51 52 53 54 55 56 57
Station

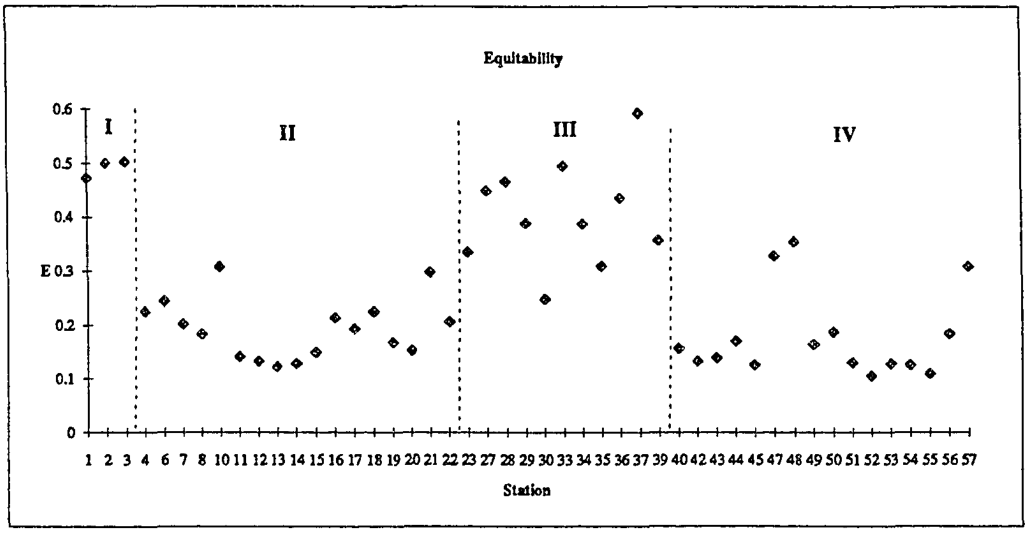
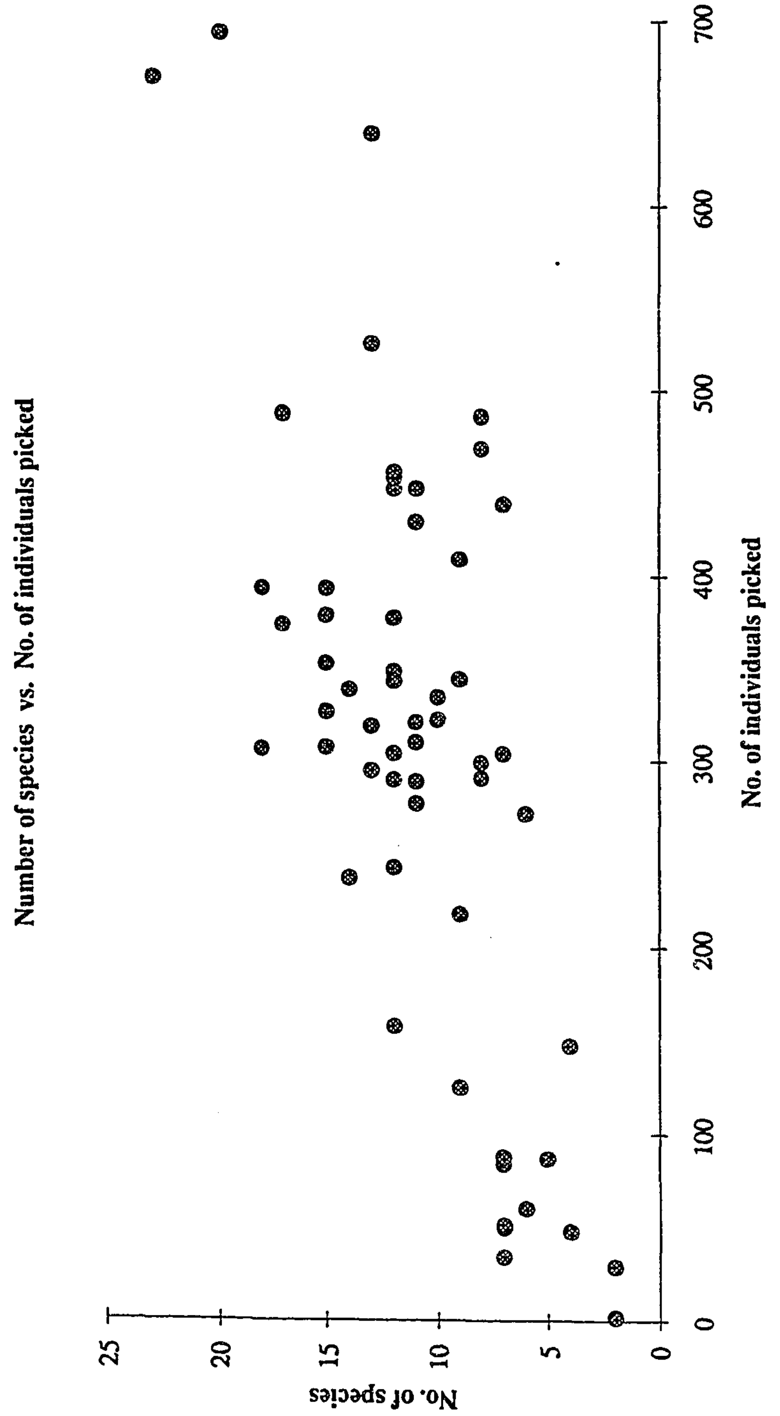

Equitability
E
I
II
III
IV
0
0.1
0.2
0.3
0.4
0.5
0.6
1 2 3 4 6 7 8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 27 28 29 30 33 34 35 36 37 39 40 42 43 44 45 47 48 49 50 51 52 53 54 55 56 57
Station

Fig. 22. Plot of number of foraminiferal species against the number of individuals for the picked fraction each station.


Number of species vs. No. of individuals picked
No. of species
No. of individuals picked
0
5
10
15
20
25
0
100
200
300
400
500
600
700

picked (n=668-692). The inner mud flat (stations 18-20) and the outer fringe marsh (stations 33-37) have relatively high numbers of species and species diversity (H(S)). This is probably caused by a mixing of faunas from the lagoon and offshore. The high energy environments, sand flats (stations 12-16), tidal channels (stations 42-45) and ebb deltas (stations 51-54), have relatively high values of the number of species (S) but low values for species diversity (H(S)). This is caused by the addition of rare offshore species.

Values of species equitability (E) in the brackish marsh and channel (stations 1-3), and fringe marshes (stations 23, 27, 28, 29, 33-37) are higher than those of the other areas. This indicates that some agglutinated species, which are rare species in the other areas, produce a more equitable distribution in the assemblages. The lower E values (0.1-0.3) from tidal flats (stations 7, 8, 10-22), the ebb delta (stations 49-54) and the shoreface (stations 55-57) are produced by relatively higher numbers of species and one dominant species (*Elphidium excavatum*).

4.4 Generalizations of the 20 *a priori* subenvironments

The following generalizations are made on the distribution patterns of environmental variables, pollen and foraminifera (described in sections 4.1, 4.2, and 4.3 above) of the 20 *a priori* subenvironments (Appendix G). For ease of discussion, relative abundance of pollen and foraminiferal species is defined in four categories as follows: most abundant equals more than 50%, abundant equals 25 to 49%, common equals 5 to 24%, and rare equals less than 5% of the living population or the total assemblage in any station within the group. Stations represented by less than nine foraminiferal individuals for the picked fraction were excluded from the review because relative abundance (%) of species in these stations was not reliable for these categories.

The values of species diversity (H(S)) of total foraminiferal assemblages are defined as low (0-0.7), medium (0.7-1.4), and high (> 1.4) within the subenvironment.

Samples of a brackish marsh and channel (group 1; stations 1-3) were taken on a marsh in the upper part of the Machipongo River where salinity was 9.4 psu. Sediments of the brackish marsh (stations 1 and 2) were composed of very poorly sorted silt, with low bulk densities and large amounts of organic matter. Sediment of the brackish channel (station 3) was a very poorly sorted clayey sand that was composed of 89% sand with small amounts of organic matter, and had a mean size of fine sand. The pollen of *Pinus* (pine) was the most abundant type and *Quercus* (oak), *Carya* (hickory) and *Ambrosia* (ragweed) were common types in brackish marsh. *Ammonia beccarii*, *Trochammina inflata* and *Trochammina* "*squamata*" were abundant foraminiferal species in living populations. *Ammoastuta inepta*, *Ammobaculites exiguus*, *Arenoparrella mexicana*, *Elphidium excavatum*, *Haplophragmoides wilberti*, *Jadammina macrescens*, *Miliammina fusca* and *Trochammina* sp. A were common species in living populations.

The total foraminiferal assemblage of brackish marsh and channel consisted of 98% agglutinated species. *Trochammina inflata* was abundant in total assemblages. *Ammoastuta inepta* was found in common concentrations in the total assemblage only in this area. Three calcareous species *Ammonia beccarii*, *Elphidium excavatum* and *Haynesina germanica* were rare in the total assemblage at the brackish channel (station 3). Other common species in total assemblages were *Arenoparrella mexicana*, *Jadammina macrescens*, *Trochammina* sp. A, *Haplophragmoides bonplandi*, *Haplophragmoides wilberti* and *Trochammina* "*squamata*". Brackish marshes and channels had high values of species diversity (H(S)).

Samples of a restricted tidal bay (group 2; stations 4-6) were taken at Boardenstake Bay. This bay was shallow (< 1 m deep at mean low water), surrounded by marshes, and connected to the open bays via tidal channels. The seabed was a very

poorly sorted sandy mud with a mean grain size of fine silt, and had minor amounts of organic matter. The pollen of *Pinus* (pine) was the most abundant type and *Quercus* (oak), other Compositaes and *Ambrosia* (ragweed) were common types. *Ammonia beccarii* and *Elphidium excavatum* were the most abundant foraminiferal species in living and total assemblages. This restricted tidal bay had medium values of species diversity (H(S)).

Samples of an inner muddy sand flat (group 3; stations 7-9) were taken at the inner part of Hog Island Bay. Sediments of this area consisted of very poorly sorted coarse to fine silt, with small quantities of organic matter. The pollen of *Pinus* (pine) was the most abundant type and *Quercus* (oak) was common in station 8. *Ambrosia* (ragweed) occurred in low concentrations (3.7%). *Elphidium excavatum* was the most abundant foraminiferal species in living populations. *Haynesina germanica*, *Elphidium poeyanum*, *Glabratella* sp. A, *Miliammina fusca* and *Rosalina floridana* were common in living populations. *Elphidium excavatum* was the most abundant species in total assemblages. *Ammonia beccarii* was abundant and *Haynesina germanica* and *Miliammina fusca* were common species in total assemblages. In general, the inner muddy sand flat had medium values of species diversity (H(S)).

Samples of a middle and outer muddy sand flat (group 4; stations 10 and 11) were taken on the outer part of Hog Island Bay. Sediments of this area were composed of poorly to very poorly sorted muddy sand with relatively small quantities of organic matter. *Elphidium excavatum* was the most abundant species and *Ammonia beccarii* was common in living and total assemblages. *Bolivina striatula*, *Elphidium gunteri* and *Glabratella* sp. A were common species in living populations. *Elphidium bartletti* and *Elphidium gunteri* were common species in total assemblages. Middle and outer muddy sand flats had medium values of species diversity (H(S)).

Samples of an inner sand flat (group 5; stations 12 and 13) were taken on the inner part of Cobb Bay. The lagoon floor in this area was a poorly sorted sand with a

very low amount of organic matter. *Elphidium excavatum* was the most abundant species and *Ammonia beccarii* was common in living and total assemblages. In general, species diversity (H(S)) at the inner sand flat was low.

Samples of a middle sand flat (group 6; stations 14 and 15) were taken on the middle part of Cobb Bay. Sediments in this area were 94-97% sand that was moderately sorted, and had a mean size of very fine to fine sand. *Elphidium excavatum* was the most abundant species in living and total assemblages. Species diversity (H(S)) was low.

Samples of an outer sand flat (group 7; stations 16 and 17) were taken at the outer part of Cobb Bay. Sediments of this area were poorly sorted sand with a mean size of very fine to fine sand, and a very low organic-matter content. *Elphidium excavatum* was most abundant in living and total assemblage. *Ammonia beccarii* and *Glabratella* sp. A were common species in living populations. *Quinqueloculina seminula* was common in total assemblages. Species diversity (H(S)) was low to medium at the outer sand flat.

Samples of an inner mud flat (group 8; stations 18-20) were taken at the inner part of the lagoon on the northernmost side of Mockhorn Bay. Sediments in this area were a sandy silt that was very poorly sorted and had a mean size of coarse silt with minor amounts of organic matter. Station 18 was located on the landward side of the tidal flat and was dominated by poorly sorted sand (80.24%), with a mean size of very fine sand. *Ammonia beccarii* was the most abundant species and *Elphidium excavatum* was an abundant species in living populations. Other common species in living populations were *Elphidium bartletti* and *Glabratella* sp. A. *Elphidium excavatum* was the most abundant species and *Ammonia beccarii* was an abundant species in total assemblages. The inner mud flat had medium values of species diversity (H(S)).

Samples of an outer mud flat (group 9; stations 21 and 22) were taken on the outer part of the lagoon behind Wreck Island. Sediments in this area were a poorly

sorted muddy sand with mean grain sizes of very fine sand near Wreck Island side and coarse silt in the central part of the lagoon. *Elphidium excavatum* was the most abundant species in living and total assemblages. *Ammonia beccarii, Quinqueloculina seminula* and *Quinqueloculina dimidiata* were common in living populations, whereas *Ammonia beccarii* and *Quingueloculina dimidiata* were common in total assemblages. The outer mud flat had medium values of species diversity (H(S)).

Samples of an inner protected fringe marsh (group 10; stations 23 and 24) were taken on salt marsh in the Phillips Creek. Significant evaporation rates in the summer produced relatively high salt concentrations (40-60 psu) in the substrate pore water. Sediments in this area were very poorly to poorly sorted mud, composed of more than 85% mud (silt+clay) with a mean size of very fine to fine silt, and minor amounts of organic matter. The pollen of *Pinus* (pine) was abundant and *Ambrosia* (ragweed), other Compositaes, Chenopods and *Quercus* (oak) were common. *Ammonia beccarii* was the most abundant foraminiferal species in living and total assemblages. *Haynesina germanica* and *Miliammina fusca* were abundant species in living populations, whereas *Haynesina germanica* and *Miliammina fusca* were abundant species in total assemblages. *Arenoparrella mexicana* was common in total assemblages. Inner protected fringe marshes had medium values of species diversity (H(S)).

Samples of an inner exposed fringe marsh (group 11) were taken at a hammock marsh on Fowling Point (stations 25 and 26) and a mainland fringe marsh in Ramshorn Bay (stations 27-29). Sediments from stations 25 and 26 were a very poorly sorted muddy sand that was composed of 63-72% sand with large amounts of organic matter. Sediments from stations 27, 28 and 29 varied from silty sand to mud. The high marsh at station 27 was composed of 80% sand with a mean size of fine sand. The middle part of the marsh (stations 28 and 29) had an increase in mud (67-99%) with a mean grain size of fine to very fine silt, and large amounts of organic matter. The pollen of

Pinus (pine) was abundant and *Quercus* (oak) and *Ambrosia* (ragweed) were common. *Ammonia beccarii* and *Miliammina fusca* were the most abundant foraminiferal species in living populations and *Jadammina macrescens* and *Trochammina inflata* were abundant. Other common species in living populations were *Ammobaculites exiguus*, *Arenoparrella mexicana*, *Elphidium excavatum* and *Miliammina earlandi*. *Miliammina fusca* was the most abundant species and *Ammonia beccarii*, *Arenoparrella mexicana* and *Trochammina inflata* were abundant species in total assemblages. Other common species in total assemblages were *Ammobaculites exiguus*, *Elphidium excavatum* and *Jadammina macrescens*. Inner exposed fringe marshes had medium values of species diversity (H(S)).

Samples of a middle lagoon marsh (group 12; stations 30 and 31) were taken in Eckichy marsh. Sediments in this area were very poorly sorted silts with a mean size of fine silt and moderate concentrations of organic matter (0.6%). The pollen of *Pinus* (pine) was the most abundant and *Quercus* (oak) was common type. *Ambrosia* (ragweed) was rare (3.9%) although still in sufficient concentrations to indicate agriculture activities. *Ammonia beccarii* was the most abundant foraminiferal species in living and total assemblages. *Elphidium excavatum* and *Haynesina germanica* were abundant in living populations, whereas *Elphidium excavatum* was abundant and *Haynesina germanica* was common in total assemblages. Middle lagoon marshes had medium values of species diversity (H(S)).

Samples of an outer fringe marsh (group 13) were taken at barrier fringe marshes of Hog Island (stations 32 and 33), Smith Island (stations 34 and 35) and Wreck Island (stations 36 and 37). Sediments in the areas were composed of very poorly sorted muddy sands to muds with mean sizes of coarse silt to very fine silt. Substrates had large amounts of organic matter (0.6-8.0%). The pollen of *Pinus* (pine) was an abundant type and *Quercus* (oak), *Ambrosia* (ragweed) and Chenopods were common in station 32. The pollen of *Pinus* (pine), *Quercus* (oak), *Carya* (hickory), *Myrica*,

Gramineae (grass), other Compositaes and *Ambrosia* (ragweed) were common types in station 34. *Ammonia beccarii* and *Trochammina inflata* were the most abundant foraminiferal species in living populations and *Ammobaculites exiguus*, *Miliammina fusca* and *Textularia earlandi* were abundant. Other common species in living populations were *Arenoparrella mexicana*, *Elphidium excavatum* and *Haynesina germanica*. *Ammobaculites exiguus*, *Ammonia beccarii* and *Trochammina inflata* were most abundant and *Miliammina fusca* and *Textularia earlandi* were abundant species in total assemblages. The other common species in total assemblages were *Arenoparrella mexicana*, *Elphidium excavatum*, *Haynesina germanica* and *Tiphotrocha comprimata*. Species diversity (H(S)) was high at outer fringe marshes.

Samples of tidal channel margins (group 14) were taken in small tidal channel (stations 39, 40 and 41) and one large tidal channel (station 38). Station 39, which is located in small tidal channel near the marsh of the Phillips Creek. The floor of the channel was a very poorly sorted mud with a mean size of very fine silt and had minor amounts of organic matter. Stations 40 and 41 were located in Eckichy channel and Heather channel, and samples were very poorly sorted sand composed of 65-75% sand with small amounts of organic matter. Station 38 located in Sand Shoal channel, and samples contained very poorly sorted sediments that was 92% sand with minor amounts of organic matter. *Ammonia beccarii* was the most abundant foraminiferal species in living populations and *Elphidium excavatum* and *Haynesina germanica* were abundant. Other common species in living populations were *Ammobaculites exiguus*, *Elphidium poeyanum* and *Miliammina fusca*. *Ammonia beccarii* and *Elphidium excavatum* were most abundant and *Haynesina germanica* was abundant species in total assemblages. *Ammobaculites exiguus*, *Buccella frigida* and *Miliammina fusca* were common in total assemblages. Tidal channel margins had medium values of species diversity (H(S)).

Samples of an intermediate tidal channel (group 15; stations 42 and 43) were

taken on the inner part of the lagoon in Sand Shoal channel. Sediments in this area were very poorly sorted muddy sands composed of 80-85% sand with a mean size of very fine to fine sand. *Elphidium excavatum* was the most abundant foraminiferal species in living and total assemblages. *Ammonia beccarii*, *Elphidium poeyanum*, *Glabratella* sp. A, *Haynesina germanica* and *Trochammina ochracea* were common in living populations. Species diversity (H(S)) in intermediate tidal channels was low.

Samples of a deep tidal channel (group 16; stations 44 and 45) were taken on the outer part of the lagoon in Sand Shoal channel. Sediments in this area were very poorly to poorly sorted, and contained 75-78% sand with a mean size of very fine sand. Minor amounts of organic matter were present. *Elphidium excavatum* was the most abundant foraminiferal species in living and total assemblages. Other common species in living populations were *Glabratella* sp. A, *Haynesina germanica* and *Nonionella atlantica*. *Ammonia beccarii* was common in total assemblages. Species diversity (H(S)) was low in deep tidal channels.

Samples of a washover fan (group 17; stations 46-48) were taken on the backbarrier of Cobb Island. Sediments in this area were 93-97% sand and moderately to poorly sorted with a mean size of fine sand. *Quinqueloculina seminula* was the most abundant foraminiferal species in living and total assemblages. *Ammonia beccarii* and *Elphidium excavatum* were abundant species in living populations. *Quinqueloculina dimidiata* was common in living populations. *Elphidium excavatum* was the most abundant species in total assemblages and *Ammonia beccarii* was abundant. *Quinqueloculina dimidiata* was common in total assemblages. Medium values of species diversity (H(S)) occurred at the washover fan.

Samples of an axial channel (group 18; stations 49 and 50) were taken in the ebb delta on the outside of Sand Shoal Inlet. Sediments in this area were 94-97% sand and were poorly sorted with a mean size of fine sand. *Elphidium excavatum* was the most abundant foraminiferal species in total assemblages. Other species occurred in rare

quantities. Species diversity (H(S)) was low at the axial channel.

Samples of inlet shoals (group 19; stations 51-54) were taken in the ebb delta on the outside of Sand Shoal Inlet. Sediments were moderately to poorly sorted containing 93-98% sand with a mean size of fine to very fine sand. *Elphidium mexicanum* was the most abundant foraminiferal species in living populations and *Ammonia beccarii* and *Elphidium excavatum* were common. *Elphidium excavatum* was the most abundant species in total assemblages and other species occurred in rare quantities. Species diversity (H(S)) was low.

Samples of the shoreface (group 20; stations 55-57) were taken seaward of Cobb Island in water depths from 4 to 12 m. Sediments were moderately to poorly sorted sand with a mean size of very fine sand. *Elphidium excavatum* and *Elphidium mexicanum* were abundant foraminiferal species in living populations. *Elphidium excavatum* was the most abundant species in total assemblages. Other species occurred in rare quantities. Species diversity (H(S)) was low.

4.5 Stepwise regression analysis of the dominant foraminiferal species

Although numerous studies have been cited for environmental factors correlated with distributions of foraminifers, it is very difficult to predict the environmental factors that control distributions of abundant species in the study area because of differences in sampling methods and environmental variables. Stepwise regression analysis can be used to show the relationships between species densities and known environmental variables. The data consisted of 12 environmental variables (Table 4) and the densities of the abundant species in living and total assemblages. Since environmental variables and compositions of species in the brackish marsh and channel (stations 1-3) were quite

different from those of the other areas, the relationships were obvious and that data was excluded from this analysis.

The results of stepwise regression analysis of the relationship between the environmental variables and the densities of five living species are presented in Appendix H. The five most frequently occurring species of living populations (those which occurred more than 30% of the total stations) were *Ammobaculites exiguus*, *Ammonia beccarii*, *Elphidium excavatum*, *Haynesina germanica* and *Miliammina fusca*. Table 18 shows the relationship between the significant environmental variables and densities of the five living species at the 95% level ($P < 0.05$). Two species, *Elphidium excavatum* and *Haynesina germanica*, correlate with a specific environmental variable. Apparently, the percentage of organic matter in the sediment has a significant relationship with *Elphidium excavatum*, whereas mean-grain size has a significant relationship with *Haynesina germanica*. Living *Elphidium excavatum* generally occurred in high densities (184-1168 specimens/70 ml) at tidal flats consisting of fine sandy sediment with low percentages of organic matter (about 0.1-0.5%). This species occurred in low densities at marshes characterized by mud with a high percentage of organic matter (more than 1%). Living *Haynesina germanica* occurred in maximum densities (112 specimens/70 ml) at the inner protected fringe marsh (station 23) where the mean-grain size was very fine silt (Mz=7.6 phi). However, this species was generally found in its high densities (24-39 specimens/70 ml) at tidal flats and tidal channel margins where the mean-grain size was coarse silt (Mz=4.0-4.9 phi) (stations 7, 20, 39 and 41).

Three other species, *Ammobaculites exiguus*, *Ammonia beccarii* and *Miliammina fusca*, had strong relationships with the set of two to three environmental variables (Table 18). Bulk density of the sediment appears to be a significant environmental variable associated with all three species. Bulk density and percent sand show a strong relationship with *Ammobaculites exiguus*. Living *Ammobaculites exiguus* had

Table 18. The results of stepwise regression analysis showing the relationship between the significant environmental variables and densities of five most frequently occurring living species at the 95% level (probabilities of F-ratio (P) < 0.05).

Species	Variables	F-ratio	P
Ammobaculites exiguus	Bulk density	17.959	0.000
	Sand (%)	4.378	0.041
Ammonia beccarii	Bulk density	37.748	0.000
	Water depth	18.996	0.000
	Salinity	4.517	0.038
Elphidium excavatum	Organic (%)	4.060	0.049
Haynesina germanica	Mean-grain size	10.593	0.002
Miliammina fusca	Salinity	30.309	0.000
	Bulk density	23.427	0.000
	Silt (%) *	3.869	0.055

* Probability is very close at the 95% level.

maximum density (288 specimens/70 ml) at the outer fringe marsh (station 35) which was characterized by low bulk density (0.52 g/ml) and relatively high percentage of sand (65.19%). Water depth, bulk density and salinity show a strong relationship with *Ammonia beccarii*. Living *Ammonia beccarii* occurred in high densities (1424-2368 specimens/70 ml) at the restricted tidal bay (stations 4 and 6) which was 30 cm below mean sea level and was characterized by low bulk densities (0.4-0.6 g/ml) and normal lagoon salinities (30.6 psu). Bulk density and salinity show a strong relationship with *Miliammina fusca*. As the probability value of percent silt (P=0.055) for *Miliammina fusca* is very close at the 95% level, the percent silt, bulk density and salinity may also affect density of *Miliammina fusca*. Inner and outer fringe marshes (stations 28, 33 and 35) had high densities of living *Miliammina fusca* (69-144 specimens/70 ml). These stations were characterized by normal marine and lagoon salinities (32.24-33 psu) and low bulk densities (0.38-0.67 g/ml).

The results of stepwise regression analysis of the relationship between the densities of the seven most frequently occurring species of total assemblages and the environmental variables at the 95% level are presented in Appendix I. Only three species, *Ammobaculites exiguus*, *Elphidium excavatum* and *Miliammina fusca*, of total assemblages show similarities with living populations described above. The seven most frequently occurring species (those which occurred more than 30% of the total stations) were *Ammobaculites exiguus*, *Ammonia beccarii*, *Elphidium excavatum*, *Haynesina germanica*, *Miliammina fusca*, *Trochammina inflata* and *Trochammina* sp. A. The significant environmental variables related to abundant species at the 95% level are listed in Table 19. Individual environmental variables appear to have had significant influences on the abundance of *Ammonia beccarii* and *Haynesina germanica*. Mean-grain size of sediment is important for *Ammonia beccarii* and percent silt is important for *Haynesina germanica*. *Ammonia beccarii* had high densities (996-3168 specimens/70 ml) in fine silt sediments at the restricted bay and the marsh island

Table 19. The significant environmental variables to densities of seven most frequently occurring species in total assemblages at the 95% level (probabilities of F-ratio (P) < 0.05).

Species	Variables	F-ratio	P
Ammobaculites exiguus	Bulk density	22.307	0.000
	Sand (%)	7.099	0.010
Ammonia beccarii	Mean-grain size	11.972	0.001
Elphidium excavatum	Salinity	48.416	0.000
	Organic (%)	16.905	0.000
Haynesina germanica	Silt (%)	4.928	0.031
Miliammina fusca	Salinity	39.598	0.000
	Bulk density	26.877	0.000
	Silt (%)	4.173	0.046
Trochammina inflata	Salinity	22.226	0.000
	Organic (%)	20.299	0.000
	Temperature	7.405	0.009
Trochammina sp. A	DFM *	15.452	0.000
	Sorting	6.708	0.012

* Distance from mainland.

(stations 4, 6, 30). *Haynesina germanica* occurred in high densities (171-176 specimens/70 ml) in silty sediments at an inner muddy sand flat (station 7) and an inner protected fringe marsh (station 23).

Combinations of environmental variables were significant for other species at the 95% level. The density of *Ammobaculites exiguus* were associated with bulk density and percent sand. The maximum density (612 specimens/70 ml) of *Ammobaculites exiguus* was at the outer fringe marsh (station 35) in high percentage of sand (65.19%) with low bulk density (0.52 g/ml). *Elphidium excavatum* had a strong relationship with salinity and percent organic. *Elphidium excavatum* had high densities (3328-4800 specimens/70 ml) at the inner muddy sand flat (station 7), the middle sand flat (station 14) and inlet shoals (station 52) which were sandy with very-low percentages of organic matter (0-0.361%) and normal marine and lagoon salinities (30.55-32.2 psu). *Miliammina fusca* were associated with salinity, bulk density and percent silt. Two stations (28 and 35) from inner and outer fringe marshes, which had low percentages of silt (14.7-30.7%), low bulk densities (0.38-0.52 g/ml) and normal marine salinity (33 psu), had high densities of *Miliammina fusca* (292-336 specimens/70 ml). *Trochammina inflata* had a strong relationship with salinity, percent organic and temperature. *Trochammina inflata* had high densities (165-236 specimens/70 ml) at the high elevation inner and outer fringe marshes (stations 27, 34 and 36) which were characterized by normal marine salinities (33 psu) and high percentages of organic matter in sediments (0.645-8.0%). *Trochammina* sp. A had a strong relationship with distance from mainland and grain-size sorting. *Trochammina* sp. A occurred in high densities (16-32 specimens/70 ml) at the restricted tidal bay (station 6) and the inner muddy sand flat (station 7) which were located on the inner part of the lagoon (1-3.6 km from mainland) and had very poorly sorted silt (sorting= 2.5-2.8 phi).

4.6 Canonical variate analysis of the most abundant foraminifera

Canonical variate analysis was used to compare the most abundant foraminiferal species with *a priori* groups of subenvironments. Living and total assemblages were used for statistical testing methods. Group 1 (brackish marsh and channel) was excluded from statistical procedures because it is clearly distinguished from the other groups by its faunal composition.

Living populations

The 20 most abundant species (those representing more than 5% of the living population in any station) were used for canonical variate analysis (Table 20). Thirty-six stations, those which had nine or more living individuals for the picked fraction in station were classified into 13 *a priori* groups (Table 21). The analysis contained 36 stations (N=36), 13 groups (h=13), and 20 species (p=20). There were 12 (h-1=12) possible canonical variates because p was greater than h.

The results of analysis show 12 possible eigenvalues, the percentage of variability accounted for, and their cumulative percentage. The first four eigenvalues among them are significant at the 95% level (Table 22). However, only the first two, accounting for 86.75% of the variability, are statistically useful. After some of discriminating power was removed by the second function, a non-significant lambda value was found, indicating that only the first two discriminant functions were statistically significant and useful to discriminate between the groups (the right side of Table 22).

Table 23 shows the mean canonical variates for the first two functions evaluated at group means. The magnitudes of the standardized canonical discriminant function coefficients are shown in Table 24. These coefficients represent the relative importance of variables (species) in separating the groups. Mean canonical variate 1, accounting

Table 20. List of the 20 most abundant living foraminiferal species (those representing 5% or more of the living population in any station).

Code No.	Species
V2	AMMOBACULITES EXIGUUS
V3	AMMONIA BECCARII
V5	ARENOPARRELLA MEXICANA
V6	BOLIVINA STRIATULA
V17	ELPHIDIUM BARTLETTI
V19	ELPHIDIUM EXCAVATUM
V22	ELPHIDIUM GUNTERI
V26	ELPHIDIUM POEYANUM
V32	GLABRATELLA sp. A
V34	GLABRATELLINA sp. A
V39	HAYNESINA GERMANICA
V41	JADAMMINA MACRESCENS
V43	MILIAMMINA EARLANDI
V44	MILIAMMINA FUSCA
V48	NONIONELLA ATLANTICA
V49	QUINQUELOCULINA DIMIDIATA
V52	QUINQUELOCULINA SEMINULA
V57	ROSALINA FLORIDANA
V58	TEXTULARIA EARLANDI
V61	TROCHAMMINA INFLATA

Table 21. List of 13 groups and 36 station code numbers for foraminiferal population those which had nine or more of the number of living individuals for fraction picked in the station.

Sub-environments	Group No.	Stations	Station No.
Restricted tidal bay, flat	2	BSRB 1	4
	2	BSRB 2	5
	2	BSRB 3	6
Inner muddy sand flat	3	EB 3	7
	3	EB 4	8
	3	FMFI 3	9
Middle/outer muddy sand flat	4	EB 1	10
	4	EB 2	11
Outer sand flat	7	CBSFO 1	16
	7	CBSFO 2	17
Inner mud flat	8	OYMFI 1	18
	8	OYMFI 2	19
	8	OYMFI 3	20
Outer mud flat	9	WIMFO 2	21
	9	WIMFO 1	22
Inner lagoon, protected fringe marsh	10	PCSM 1	23
	10	PCSM 2	24
Inner lagoon, exposed fringe marsh	11	FMFI 1	25
	11	RS 1	27
	11	RS 2	28
	11	RS 3	29
Middle lagoon, marsh	12	EMCM 1	30
	12	EMCM 2	31

Continued

Sub-environments	Group No.	Stations	Station No.
Outer lagoon, fringe marsh	13	HIFO 1	32
	13	HIFO 2	33
	13	SI 1	34
	13	SI 2	35
	13	WI 1	36
	13	WI 2	37
Tidal channel margin	14	PCSM 3	39
	14	EMCM 3	40
	14	HIFO 3	41
Deep tidal channel	16	SSTC 2	44
	16	SSTC 1	45
Washover fan	17	CIWF 2	47
	17	CIWF 3	48

Table 22. The first four significant eigenvalues with the percentage of variability accounted for, and their cumulative percent for living foraminiferal populations.

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	:	AFTER FUNCTION	WILK' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					:	0	0	326.26	228	0
1	92.27955	60.94	60.94	0.9946253	:	1	0.0000033	240.09	198	0.022
2	39.08792	25.81	86.75	0.9874486	:	2	0.0001304	169.96	170	0.4865
3	6.66638	4.4	91.15	0.9325022	:	3	0.0009995	131.26	144	0.7687
4	4.52402	2.99	94.14	0.904971	:	4	0.0055215	98.783	120	0.9216

Table 23. Mean discriminant scores for living foraminiferal populations on the first two functions.

Group	CV1	CV2
2	-3.29846	2.03530
3	1.01878	0.09689
4	-23.13392	2.92942
7	2.68994	11.04286
8	-0.72346	-2.10412
9	12.25605	12.62808
10	0.15604	-3.33939
11	6.29292	-3.03736
12	-5.04319	-1.53647
13	1.56786	-5.19079
14	3.07650	-3.44172
16	-12.51463	3.81906
17	8.19026	1.22399

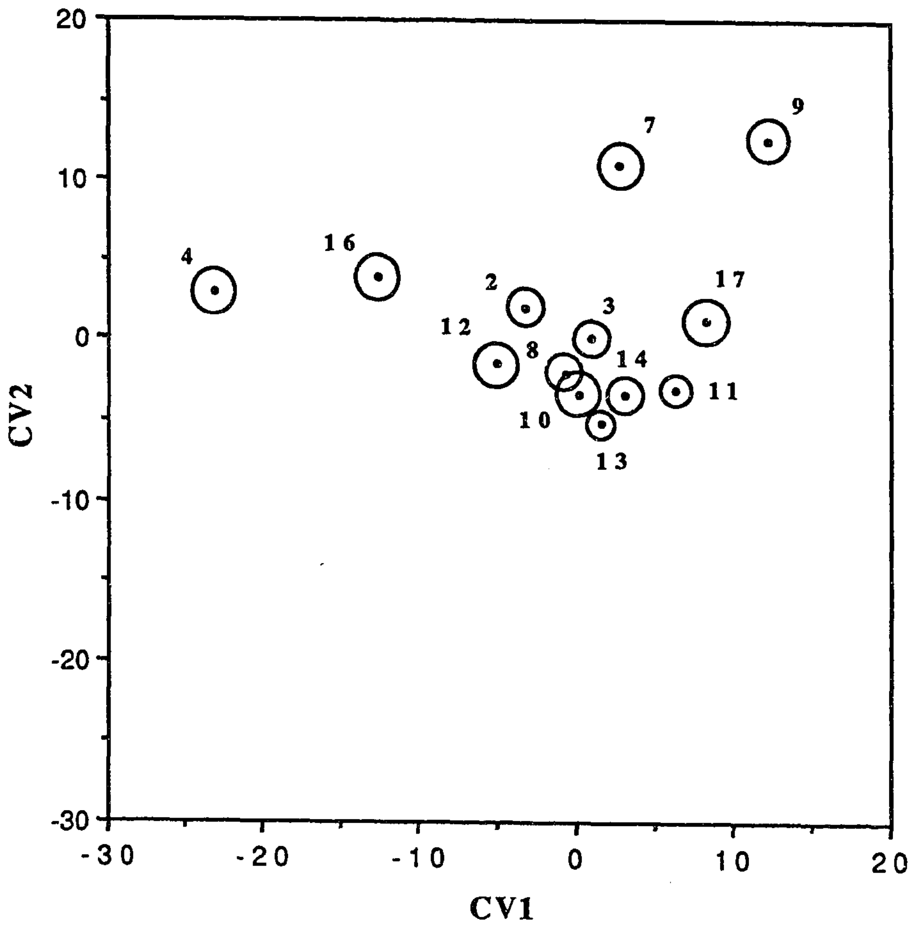
Table 24. Standardized canonical discriminant function coefficients and living foraminiferal species responsible for discrimination, showing large absolute values represent the relative contribution for separating the groups.

Variables	FUNC 1	FUNC 2
V2	3.46490	-0.31328
V3	3.71286	0.00640
V5	11.86751	2.89181
V6	-1.51092	-0.42624
V17	1.41108	-0.07037
V19	4.32673	2.34188
V22	-4.68950	-0.46791
V26	1.82652	-0.95396
V32	-3.10481	-0.57231
V34	1.15892	3.01965
V39	3.90521	0.12850
V41	-22.92558	-6.94358
V43	18.46771	5.08710
V44	7.18249	0.79804
V48	-1.70340	-0.27780
V49	4.68009	2.48447
V52	-0.58223	-1.54612
V57	1.14373	0.42565
V58	4.05060	-0.48819

for 60.94% of the variability, strongly discriminates the middle and outer muddy sand flat (group 4) and the deep tidal channel (group 16) from the outer mud flat (group 9), the washover fan (group 17) and the inner exposed fringe marsh (group 11) (Table 23, Fig. 23). Along canonical discriminant function 1, *Jadammina macrescens* (V41), *Miliammina earlandi* (V43), *Arenoparrella mexicana* (V5), *Miliammina fusca* (V44), *Elphidium excavatum* (V19), *Elphidium gunteri* (V22), *Quinqueloculina dimidiata* (V49) and *Textularia earlandi* (V58) are important species for this contrast (Table 24). From the group means of the 20 most abundant living species (Appendix J), the middle and outer muddy sand flat (group 4), the deep tidal channel (group 16), the outer mud flat (group 9) and the washover fan (group 17) did not contain *Jadammina macrescens*, *Miliammina earlandi* and *Arenoparrella mexicana*, whereas the inner exposed fringe marsh (group 11) had maximum frequencies for *Jadammina macrescens* (37.8%), *Miliammina earlandi* (8.1%) and *Arenoparrella mexicana* (16.2%) at station 27 and for *Miliammina fusca* (100%) at station 25. The middle and outer muddy sand flat (group 4) had high frequencies for *Elphidium excavatum* (72-89%), whereas it occurred in low frequencies (2-2.4%) at the inner exposed fringe marsh (group 11). *Elphidium gunteri* occurred in its high frequencies (0-5.6%) at the middle and outer muddy sand flat (group 4), but it did not occur at the deep tidal channel (group 16) and the washover fan (group 17). *Quinqueloculina dimidiata* was found in large populations (2-18.7%) at the washover fan (group 17), whereas it did not occur at the middle and outer muddy sand flat (group 4) and the deep tidal channel (group 16). The middle and outer muddy sand flat (group 4), the inner exposed fringe marsh (group 11), the deep tidal channel (group 16) and the washover fan (group 17) did not contain *Textularia earlandi*, whereas the outer mud flat (group 9) had its high frequencies for *Textularia earlandi* (0-1.8%).

Mean canonical variate 2 accounts for 25.81% of the variability, producing a total of 86.75% of the variability. Mean canonical variate 2 discriminates the outer mud flat (group 9) and the outer sand flat (group 7) from the outer fringe marsh (group 13)

Fig. 23. Plot of mean canonical variate 1 against 2 with 95% confidence circles for living foraminiferal populations. Numbers refer to *a priori* groups of subenvironments (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: thetidal channel margin, 16: the deep tidal channel, 17: the washover fan). Plots shows change along CV1 axis which separates the middle/outer muddy sand flat (group 4) and the deep tidal channel (group 16) from the outer mud flat (group 9), the washover fan (group 17) and the inner exposed fringe marsh (group 11), and change along CV2 axis which allows the outer mud flat (group 9) and the outer sand flat (group 7) to be distinguished from the outer fringe marsh (group 13).


20
10
0
-10
-20
-30
-30
-20
-10
0
10
20
CV1
CV2
4
16
2
12
8
3
14
10
13
7
9
17
11

(Table 23, Fig. 23). *Jadammina macrescens* (V41) and *Miliammina earlandi* (V43) are important species in the second discriminant function (Table 24). From the group means (Appendix J), the outer mud flat (group 9) and the outer sand flat (group 7) did not contain *Jadammina macrescens* and *Miliammina earlandi*, whereas the outer fringe marsh (group 13) had low frequencies for *Jadammina macrescens* (0.6-1.1%).

Fig. 23 is a plot of mean canonical variate 1 against mean canonical variate 2 with 95% confidence circles. Four groups, the middle and outer muddy sand flat (group 4), the deep tidal channel (group 16), the outer sand flat (group 7) and the outer mud flat (group 9), are clearly distinguished from the other groups and from one another. A set of groups, which consists of marshes and near marsh areas, exhibits less discrimination. The restricted bay (group 2), the marsh island (group 12) and the inner muddy sand flat (group 3) are contrasted with the washover fan (group 17) and the inner fringe marsh (group 11) along the first mean canonical variate. The rest of the set (groups 8, 10, 13 and 14) is less clearly distinguished from one another. There is considerable overlap between the inner mud flat (group 8) and the inner protected fringe marsh (group 10).

The classification results of analyses show that 97.22% of the grouped cases correctly matched with the *a priori* groups. While group 13 (outer fringe marsh) was 83.3% correctly predicted, the other 12 groups were 100% correctly predicted. Station 28 (*a priori* group 13) was the only station incorrectly classified, it was placed in the tidal channel margin (group 14) instead of the outer fringe marsh (group 13).

Total assemblages

The 29 most abundant species (those representing more than 2% of the total assemblage at any station) were used for canonical variate analysis (Table 25). Fifty-four stations were divided into the previously defined 19 *a priori* groups (Table 26). There were 54 stations (N=54), 19 groups (h=19), and 29 species (p=29). Eighteen (h-

Table 25. List of the 29 most abundant foraminiferal species (those representing 2% or more of the total assemblage in any station).

Code No.	Species
V2	AMMOBACULITES EXIGUUS
V3	AMMONIA BECCARII
V5	ARENOPARRELLA MEXICANA
V9	BUCCELLA FRIGIDA
V17	ELPHIDIUM BARTLETTI
V19	ELPHIDIUM EXCAVATUM
V22	ELPHIDIUM GUNTERI
V25	ELPHIDIUM MEXICANUM
V26	ELPHIDIUM POEYANUM
V32	GLABRATELLA sp. A
V34	GLABRATELLINA sp. A
V37	HAPLOPHRAGMOIDES BONPLANDI
V38	HAPLOPHRAGMOIDES WILBERTI
V39	HAYNESINA GERMANICA
V40	HELENIA ANDERSENI
V41	JADAMMINA MACRESCENS
V43	MILIAMMINA EARLANDI
V44	MILIAMMINA FUSCA
V49	QUINQUELOCULINA DIMIDIATA
V52	QUINQUELOCULINA SEMINULA
V54	QUINQUELOCULINA SEMINULA var. JUGOSA
V57	ROSALINA FLORIDANA
V58	TEXTULARIA EARLANDI
V59	TIPHOTROCHA COMPRIMATA
V60	TROCHAMMINA ADVENA
V61	TROCHAMMINA INFLATA
V64	TROCHAMMINA OCHRACEA
V65	TROCHAMMINA " SQUAMATA "
V66	TROCHAMMINA sp. A

Table 26. List of 19 groups and 54 station code numbers for total foraminiferal assemblage.

Sub-environments	Group No.	Stations	Station No.
Restricted tidal bay, flat	2	BSRB 1	4
	2	BSRB 2	5
	2	BSRB 3	6
Inner muddy sand flat	3	EB 3	7
	3	EB 4	8
	3	FMFI 3	9
Middle/outer muddy sand flat	4	EB 1	10
	4	EB 2	11
Inner sand flat	5	CBSFI 1	12
	5	CBSFI 2	13
Middle sand flat	6	ECSFM 1	14
	6	ECSFM 2	15
Outer sand flat	7	CBSFO 1	16
	7	CBSFO 2	17
Inner mud flat	8	OYMFI 1	18
	8	OYMFI 2	19
	8	OYMFI 3	20
Outer mud flat	9	WIMFO 2	21
	9	WIMFO 1	22
Inner lagoon, protected fringe marsh	10	PCSM 1	23
	10	PCSM 2	24
Inner lagoon, exposed fringe marsh	11	FMFI 1	25
	11	FMFI 2	26
	11	RS 1	27
	11	RS 2	28
	11	RS 3	29
Middle lagoon, marsh	12	EMCM 1	30
	12	EMCM 2	31

Continued

Sub-environments	Group No.	Stations	Station No.
Outer lagoon, fringe marsh	13	HIFO 1	32
	13	HIFO 2	33
	13	SI 1	34
	13	SI 2	35
	13	WI 1	36
	13	WI 2	37
Tidal channel margin	14	WIMFO 3	38
	14	PCSM 3	39
	14	EMCM 3	40
	14	HIFO 3	41
Intermediate tidal channel	15	SSTC 4	42
	15	SSTC 3	43
Deep tidal channel	16	SSTC 2	44
	16	SSTC 1	45
Washover fan	17	CIWF 1	46
	17	CIWF 2	47
	17	CIWF 3	48
Ebb delta, axial channel	18	SSIC 5	49
	18	SSIC 4	50
Ebb delta, inlet shoals	19	SSIC 3	51
	19	SSIC 1	52
	19	SSIC 2	53
	19	SSIC 6	54
Barrier island shoreface	20	CISF 1	55
	20	CISF 2	56
	20	CISF 3	57

1=18) canonical variates were possible because *p* was greater than *h*.

Results of the canonical variate analyses produced 18 eigenvalues, the percentage of variability accounted for, and their cumulative percentage. The first five eigenvalues were significant at the 95% level (Table 27). However, only the first two discriminant functions were statistically significant because non-significant lambda values occurred after some discriminating power was removed by the second discriminant function (the right side of Table 27).

The first two mean canonical variates are shown in Table 28. Table 29 shows the standardized canonical discriminant function coefficients which represent the relative contributions of the species to the respective discriminant functions for grouping. The first mean canonical variate, explaining 64.21% of the variability, differentiates outer and inner fringe marshes (groups 13, 10 and 11), intermediate and deep tidal channels (groups 15, 16) and the restricted tidal bay (group 2) from the other areas (Table 28, Fig. 24). The canonical discriminant function coefficients (Table 29) indicate that *Elphidium excavatum* (V19), *Haplophragmoides bonplandi* (V37), *Miliammina earlandi* (V43), *Textularia earlandi* (V58), *Miliammina fusca* (V44), *Jadammina macrescens* (V41) and *Ammonia beccarii* (V3) which have large positive and negative values are mainly responsible for the contrast.

Group means of the 29 most abundant species of total foraminiferal assemblages are shown in Appendix K. For ease of discussion, the important species described above by canonical variate analysis can be described in terms of their previously described relative abundance (%) where most abundant equals more than 50%, abundant equals 25 to 49%, common equals 5 to 24% and rare equals less than 5% of total assemblages in any station within the group. *Ammonia beccarii* and *Elphidium excavatum* were most abundant and *Jadammina macrescens* and *Miliammina fusca* were rare species at the restricted tidal bay (group 2). *Ammonia beccarii* was the most abundant species and *Miliammina fusca* was an abundant species at the inner protected

Table 27. The first five significant eigenvalues with the percentage of variability accounted for, and their cumulative percent for total foraminiferal assemblages.

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	:	AFTER FUNCTION	WILK' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					:	0	0	666.28	522	0
1	135.04399	64.21	64.21	0.9963179	:	1	0	523.81	476	0.064
2	32.70985	15.55	79.77	0.9850559	:	2	0.0000005	421.79	432	0.6283
3	14.48314	6.89	86.65	0.9671678	:	3	0.0000075	342.34	390	0.9606
4	9.31378	4.43	91.08	0.9502854	:	4	0.000077	274.67	350	0.9989
5	5.03993	2.4	93.48	0.9134743	:	5	0.0004653	222.51	312	1

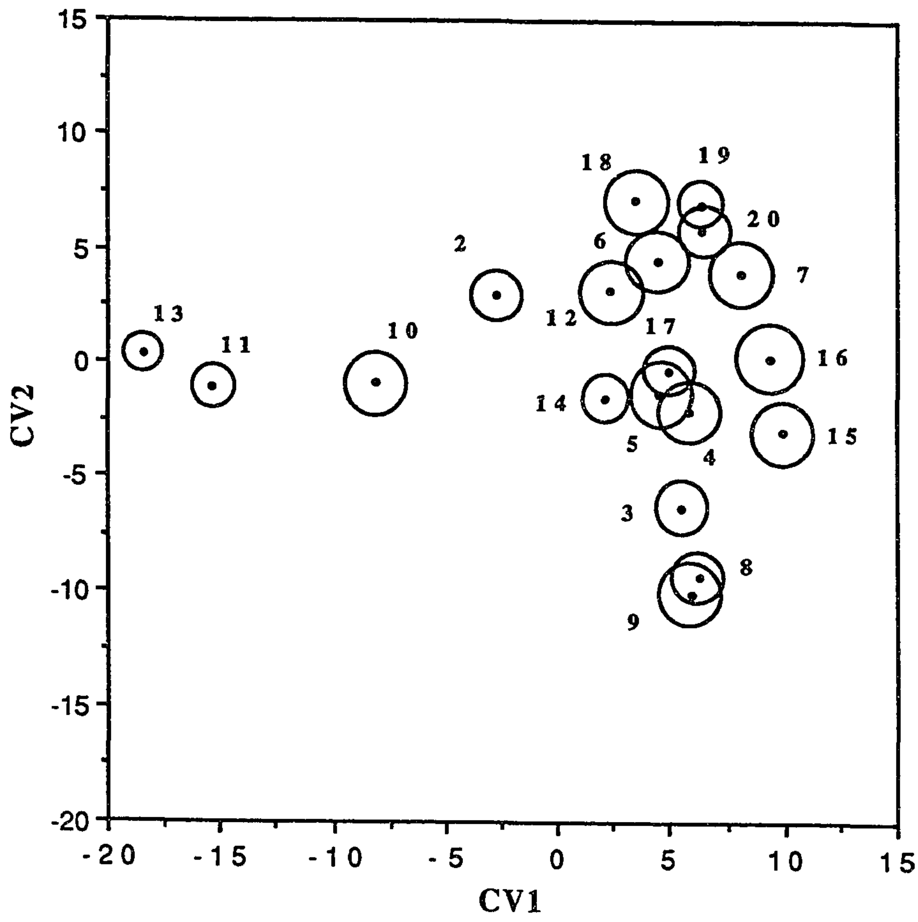
Table 28. Scores of the first two mean canonical variates for total foraminiferal assemblages.

Group	CV1	CV2
2	-2.73100	2.91839
3	5.48145	-6.26255
4	5.89912	-2.08920
5	4.54222	-1.30466
6	4.50611	4.52359
7	8.14253	3.99528
8	6.30245	-9.26964
9	5.91976	-10.04043
10	-8.11766	-0.89312
11	-15.41096	-1.09733
12	2.39951	3.16803
13	-18.40752	0.27893
14	2.08018	-1.57036
15	9.94661	-3.05128
16	9.32434	0.19946
17	4.96626	-0.29826
18	3.49276	7.12517
19	6.42514	6.98744
20	6.43685	5.87174

Table 29. Standardized canonical discriminant function coefficients and the most abundant species (variables) of total foraminiferal assemblages responsible for discrimination.

Variables	FUNC 1	FUNC 2
V2	1.41459	2.14326
V3	4.10927	2.79631
V5	2.00493	3.69203
V9	0.61887	0.77541
V17	-0.28494	1.77429
V19	10.15606	3.91427
V22	1.77749	-1.68647
V25	0.77866	1.89591
V26	-1.29803	-2.07210
V32	0.82022	-0.65054
V34	0.64995	2.38367
V37	-8.37360	18.55147
V38	-0.20683	0.13742
V39	2.86246	1.78211
V40	-2.25875	-0.31085
V41	4.79679	-2.71302
V43	7.18777	-16.1255
V44	5.11191	1.77553
V49	2.12387	0.07382
V52	2.27660	-2.33694
V54	2.26320	4.70643
V57	-0.14736	0.24829
V58	5.82674	-13.0096
V59	2.05500	-3.03448
V60	-2.68754	-0.11449
V61	-2.41472	5.76126
V64	0.33982	-0.73218
V65	0.17707	1.87603
V66	1.83726	-2.10348

Fig. 24. Mean canonical variate 1 against 2 with 95% confidence circles for total foraminiferal assemblages. Numbers refer to *a priori* groups of subenvironments (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 5: the inner sand flat, 6: the middle sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: the tidal channel margin, 15: the intermediate tidal channel, 16: the deep tidal channel, 17: the washover fan, 18: the axial channel, 19: inlet shoals, 20: barrier island shoreface). Plot shows change along CV1 axis which distinguishes outer and inner fringe marshes (groups 13, 10 and 11) from intermediate and deep tidal channels (groups 15 and 16), and change along CV2 axis which allows the axial channel (group 18) to be distinguished from inner and outer mud flats (groups 8 and 9).



15
10
5
0
-5
-10
-15
-20
CV2
-20
-15
-10
-5
0
5
10
15
CV1
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fringe marsh (group 10). Other rare species in this area were *Elphidium excavatum* and *Jadammina macrescens*. At the inner exposed fringe marsh (group 11), *Miliammina fusca* was most abundant, *Ammonia beccarii* was abundant and *Elphidium excavatum* was common. Other rare species in this area were *Haplophragmoides bonplandi*, *Jadammina macrescens*, *Miliammina earlandi* and *Textularia earlandi*. At the outer fringe marsh (group 13), *Ammonia beccarii* was most abundant, *Textularia earlandi* and *Miliammina fusca* were abundant and *Elphidium excavatum* was common. Other rare species in this area were *Haplophragmoides bonplandi* and *Jadammina macrescens*. *Elphidium excavatum* was most abundant and *Ammonia beccarii* was rare to common at intermediate and deep tidal channels.

The second mean canonical variate, accounting for 15.55% of the variability, discriminates inner and outer mud flats (groups 8 and 9) from the axial channel (group 18) (Table 28, Fig. 24). Table 29 indicates that *Haplophragmoides bonplandi* (V37), *Miliammina earlandi* (V43) and *Textularia earlandi* (V58) contribute to the second canonical variate. From the mean groups (Appendix K), inner and outer mud flats (groups 8 and 9) and the axial channel (group 18) did not contain *Haplophragmoides bonplandi* and *Miliammina earlandi*. *Textularia earlandi* occurred in low frequencies (0.2-0.8%) at inner and outer mud flats (groups 8 and 9).

Fig. 24 plots mean canonical variate 1 against mean canonical variate 2 with 95% confidence circles. The outer fringe marsh (group 13), inner exposed and protected fringe marshes (groups 10 and 11) and the restricted tidal bay (group 2) are clearly discriminated from the remaining groups and from one another. The remaining groups are less distinguished but sandy areas (ebb deltas and the shoreface (groups 18, 19 and 20)) are clearly distinct from muddy areas (inner and outer mud flats (group 8 and 9)) along the second mean canonical variate. There is considerable overlap between inlet shoals (group 19) and the shoreface (group 20), between the washover fan (group 17), the inner sand flat (group 5) and the middle and outer muddy sand flat (group 4), and

between the inner mud flat (group 8) and the outer mud flat (group 9) along the first two canonical axes (Fig. 24).

The classification of results show that 98.15% of grouped cases were correctly classified with *a priori* groups. Station 54, which was placed in group 6 (middle sand flat) instead of *a priori* group 19 (inlet shoals), was the only station to be incorrectly classified.

Chapter 5
Discussion

5.1 Environmental variables

Canonical variate analysis of measurements of environmental variables (Table 4) illustrated that the 19 *a priori* groups of subenvironments were not significantly distinct from one another. The 19 *a priori* groups were separated into two internally overlapping sets. The first set of groups is outside of the inlet: the axial channel (group 18), inlet shoals (group 19), and the barrier island shoreface (group 20). The second set contained the remaining lagoonal groups. The lagoonal groups were not well discriminated at the 95% confidence level with the exception of the inner mud flat (group 8) (mean CV1 vs. CV2; Fig. 15) and the inner exposed fringe marsh (group 11) (mean CV1 vs. CV3; Fig. 16).

Although percentage of sand and distance from inlet were the most important contributing variables along mean canonical variate 1, they only affected the discrimination of environments inside and outside of the inlet. The other variables had a weak affect upon the separation of the groups. The percentages of sand outside of the inlet (groups 18, 19 and 20) (> 93%) are generally higher than inside of the inlet (lagoonal environments) in which the percentages of sand ranged from 0.31% at an inner exposed fringe marsh to 97.22% at a mid-lagoon sand flat. Previous investigators have found similar textural trends between lagoons and offshore environments. Oertel (1985) and Howard and Frey (1985) also noted that fine sediments of the barrier lagoons were extensively bioturbated. The sand, which is

provided by inlets and overwash, is deposited in sand flats, point bars of tidal channels and washover fans (Leatherman, 1979; Oertel, 1985). However, sediments of ebb deltas and the shoreface consisted of sand with few biogenic structures. The shoals in ebb deltas were composed of clean well-sorted sand (Oertel, 1975). The upper shoreface was characterized by relatively well-sorted, fine-grained sediments absent of biogenic structures. This complements earlier findings of Davis (1983) for the upper shoreface. Coarse-grained sediments with high-energy bedforms and internal structures were at the lower shoreface (see Swift, 1976).

Consequently, sediment characteristics appeared to have limited use for discriminating subenvironments in the barrier island system. The considerable overlap between lagoonal subenvironments at the 95% confidence level suggests that sedimentary processes overlap between adjacent subenvironments and sediment characteristics shift over time. The classification results from analyses showed that only 83% of the 19 grouped cases were correctly predicted. In order to predict to more than 90% of the grouped cases, other sets of variables (biological and/or geochemical variables) would be useful. To identify subenvironments in the rock record, statistical analysis of microfossil assemblages are evaluated below.

5.2 Pollen analysis

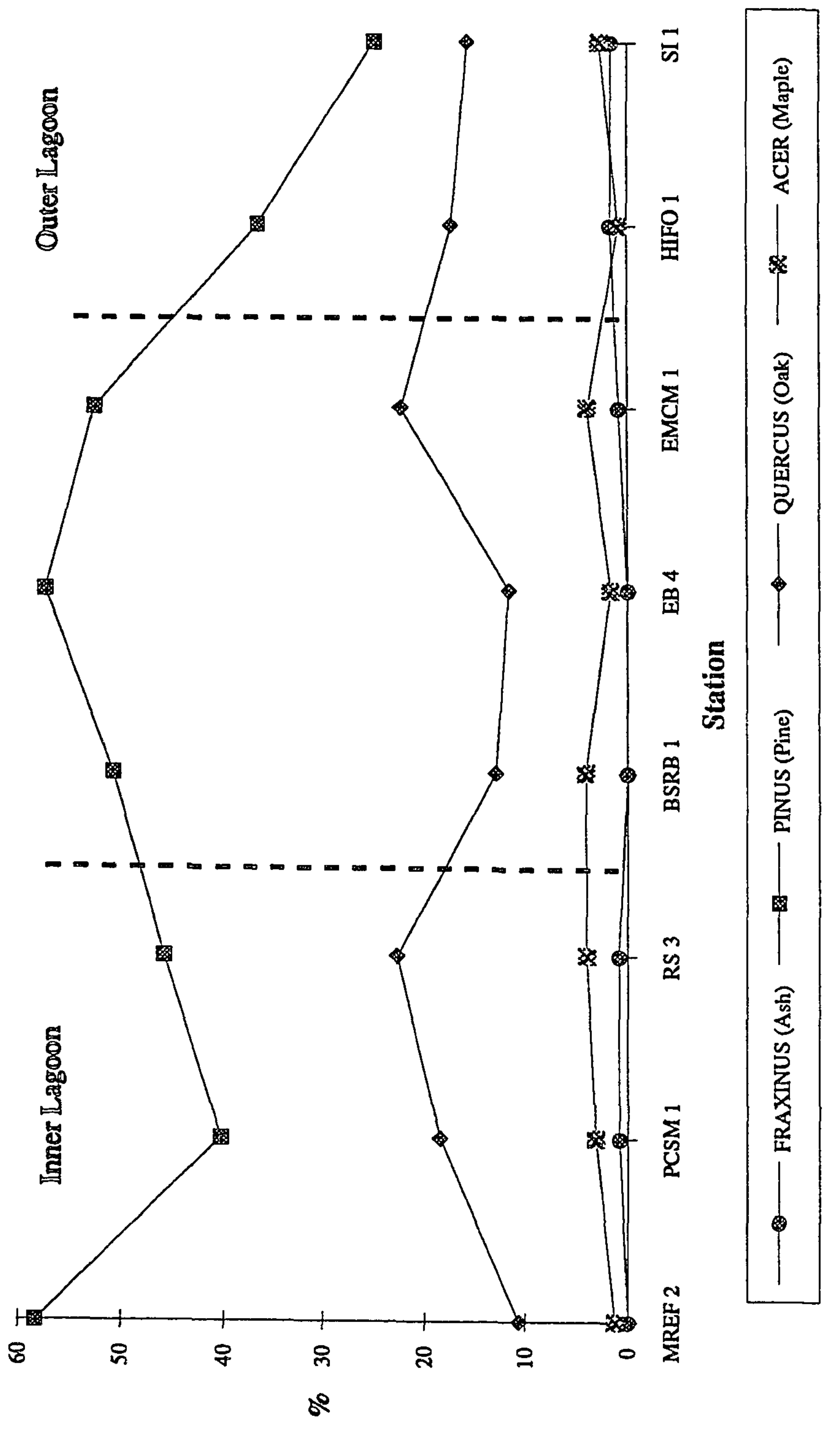
Since most pollen grains are preferentially deposited in low-energy marsh and mud-flat environments (weak tidal currents), only eight stations were sampled in the study area. The eight stations were divided into three local groups on the basis of distance from mainland: inner, middle and outer parts of the lagoon. The analysis of pollen data illustrated that all the groups are distinct from one another along two canonical axes. Variations in *Quercus* (oak), *Fraxinus* (ash) and *Acer* (maple) were

principal factors causing the separation into the groups. However, the most dominant taxa, *Pinus* (pine), was of little importance in the distinction because it was abundant everywhere.

Although dispersion of pollen grains is related to atmospheric processes and/or settling characteristics of pollen types, numerous studies suggested that most pollen grains settle down near the source plants (Brush and DeFries, 1981; Niklas, 1984; Traverse, 1988). The variations of pollen assemblages in surface sediments appear to be primarily the results of local variations in source plants. In this study, relatively high concentrations of pollen grains occurred on the inner side of the lagoon where source plants grow near the sampling area. The trend of decreasing concentration of pollen grains seaward is shown in Table 11, which represents pollen concentration per gram and distance from mainland of each sample.

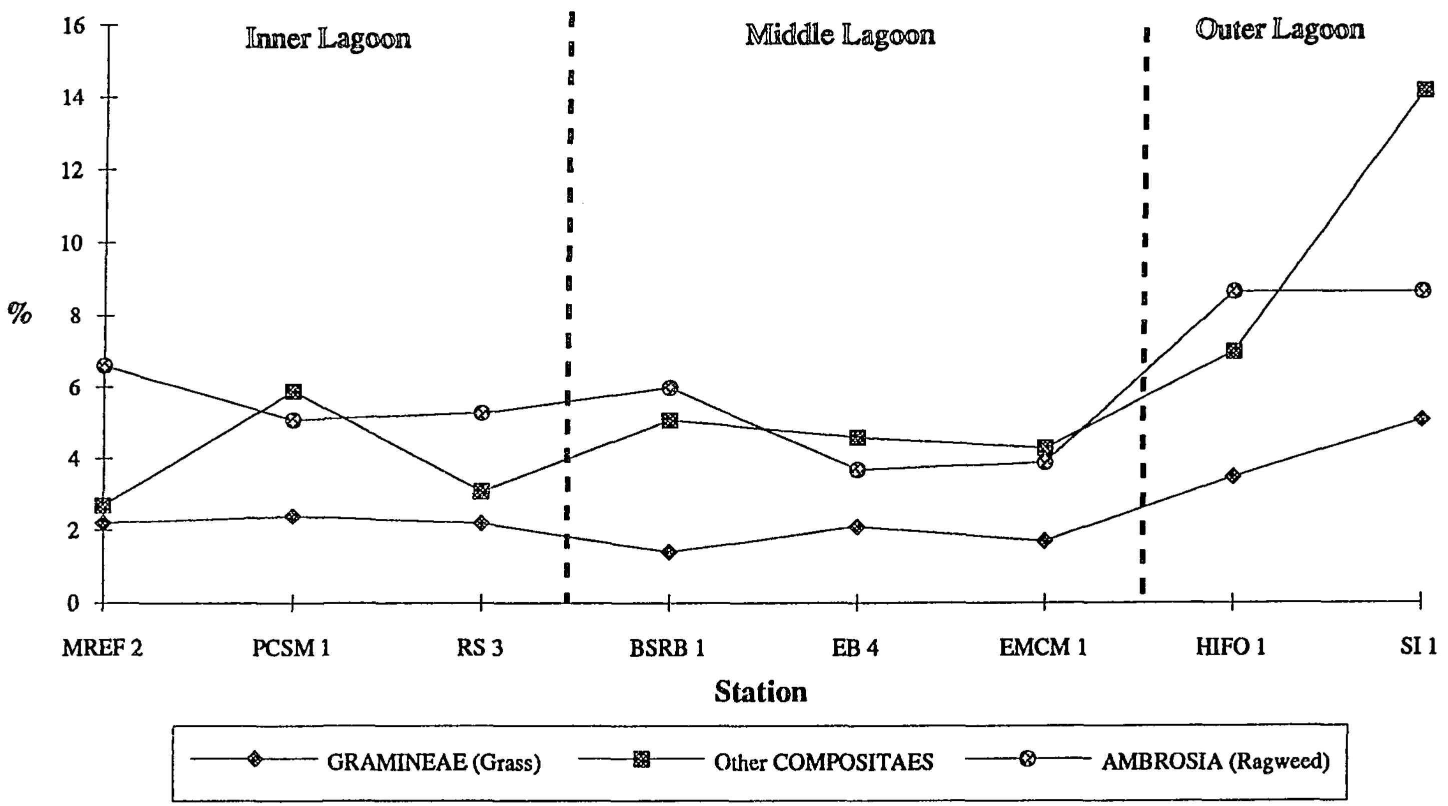
The relative abundance (%) of tree pollen grains changed with distance from mainland. Figures 25 and 26 show the percentages of pollen types at the individual sampling stations within the three groups. *Pinus* (pine), which is wind-pollinated taxa, produced large amounts of pollen and tended to be dominant in the barrier lagoon (Fig. 25). The percentages of *Pinus* (pine) pollen increased slightly from the mainland fringe marsh to the middle of the lagoon, but decreased at the barrier fringe marsh. The percentages of *Quercus* (oak) pollen decreased between the mainland and a marsh in the middle of the lagoon, but were relatively high at the inner and outer parts of the lagoon. The percentages of *Fraxinus* (ash) pollen increased from the middle to the outer part of the lagoon, but were similar at the inner and middle parts of the lagoon. The percentages of *Acer* (maple) pollen increased from the mainland to the middle part of the lagoon, but decreased at the outer part of the lagoon. Generally, the percentage of tree pollen (pine, oak, ash and maple) was relatively high between the mainland tidal stream (MREF 2) and the middle part of the lagoon. The decreasing percentages of tree pollen in the outer part of the lagoon could result from sparse tree populations on the

Fig. 25. Plots of percentages of tree pollen against individual sampling stations with three localities of the lagoon.



Inner Lagoon
Middle Lagoon
Outer Lagoon
%
60
50
40
30
20
10
0
MREF 2
PCSM 1
RS 3
BSRB 1
EB 4
EMCM 1
HIFO 1
SI 1
Station
FRAXINUS (Ash)
PINUS (Pine)
QUERCUS (Oak)
ACER (Maple)

Fig. 26. Plots of percentages of herb pollen against individual sampling stations with three localities of the lagoon.



Inner Lagoon
Middle Lagoon
Outer Lagoon
%
16
14
12
10
8
6
4
2
0
MREF 2
PCSM 1
RS 3
BSRB 1
EB 4
EMCM 1
HIFO 1
SI 1
Station
GRAMINEAE (Grass)
Other COMPOSITAES
AMBROSIA (Ragweed)

barrier islands. This suggested that the tree pollen were deposited primarily near the source plants and were not transported far from their source plants by atmospheric and hydraulic transport processes in the barrier lagoon.

The spatial variations of herb pollen, Gramineae (grass), other Compositaes and *Ambrosia* (ragweed), show local variations between three groups (Fig. 26). Relatively high percentages of herb pollen at barrier fringe marshes could result from little tree population and grass cover in the barrier islands. For example, *Ambrosia* (ragweed) pollen on the mainland side of the lagoon was 5-7% of the total counted pollen, whereas it decreased to about 4% in the middle of the lagoon and then increased at the outer side of the lagoon to about 9%. The pollen of *Ambrosia* (ragweed) which was greater than 5% of total pollen count indicated agricultural land clearance by Europeans in the last 300 years (Bernabo and Webb, 1977; Gaudreau and Webb, 1985; Oertel et al., 1989). The percentages of *Ambrosia* (ragweed) pollen in inner and outer parts of the lagoon (5-9% of total pollen grains) are in good agreement with modern climatic conditions, but slightly lower percentages in the middle part of the lagoon (4% of total pollen grains) may represent the effects of increased distance from barrier island and mainland sources. Therefore, a range of *Ambrosia* (ragweed) pollen of four to nine percent is useful for distinguishing between the inner, middle and outer parts of lagoonal sediments in the last 300 years (post-European settlement).

On the basis of this study, pollen grains are not transported a long distance from their sources and represent their relative abundances under present local vegetation at the margins of the barrier lagoon. Although some pollen (*Ephedra* and *Sarcobatus*) are dispersed several hundred kilometers from the source plants by wind (Maher, 1964), most pollen grains are not transported a long distance by atmospheric or hydraulic transport processes and are primarily deposited near the source plants (Brush and DeFries ,1981; Niklas, 1984; Traverse,1988).

From the coastal palynological viewpoint, it is encouraging that modern pollen

spectra in the barrier lagoon are characterized by local variations with distance from the mainland and the barrier island. The differences in pollen assemblages at three areas in the lagoon closely reflect the distribution of local vegetation.

While canonical variate analysis of pollen assemblages is very powerful to discriminate the inner, middle, and outer parts of the lagoon, characteristics of abundance and pollen type are also useful. Fig 27 shows that high pollen concentrations occurred in the inner part of the lagoon (environmental numbers 1-3) and the outer fringe marsh (environmental number 8) where source plants grow near the sampling area. The ratio of arboreal to non-arboreal pollen indicated the percentages of tree pollen increased from the inner to middle parts of the lagoon, but significantly decreased at the outer part of the lagoon. The percentages of *Ambrosia* (ragweed) pollen decreased from the inner (5.7%) to middle (4.5%) parts of the lagoon, but increased at the outer part of the lagoon (8.7%). The results of this study suggest that the relative compositions of fossil pollen spectra can be used in reconstructing paleogeography in the barrier lagoon.

5.3 Patterns of foraminiferal distributions

Sixty-eight species of foraminifera were found in surface sediments from the 57 stations. Two species, *Elphidium excavatum* and *Ammonia beccarii*, are widely distributed in living and total assemblages over the study area. Other species are scattered and occur in various densities in different subenvironments of the barrier island system.

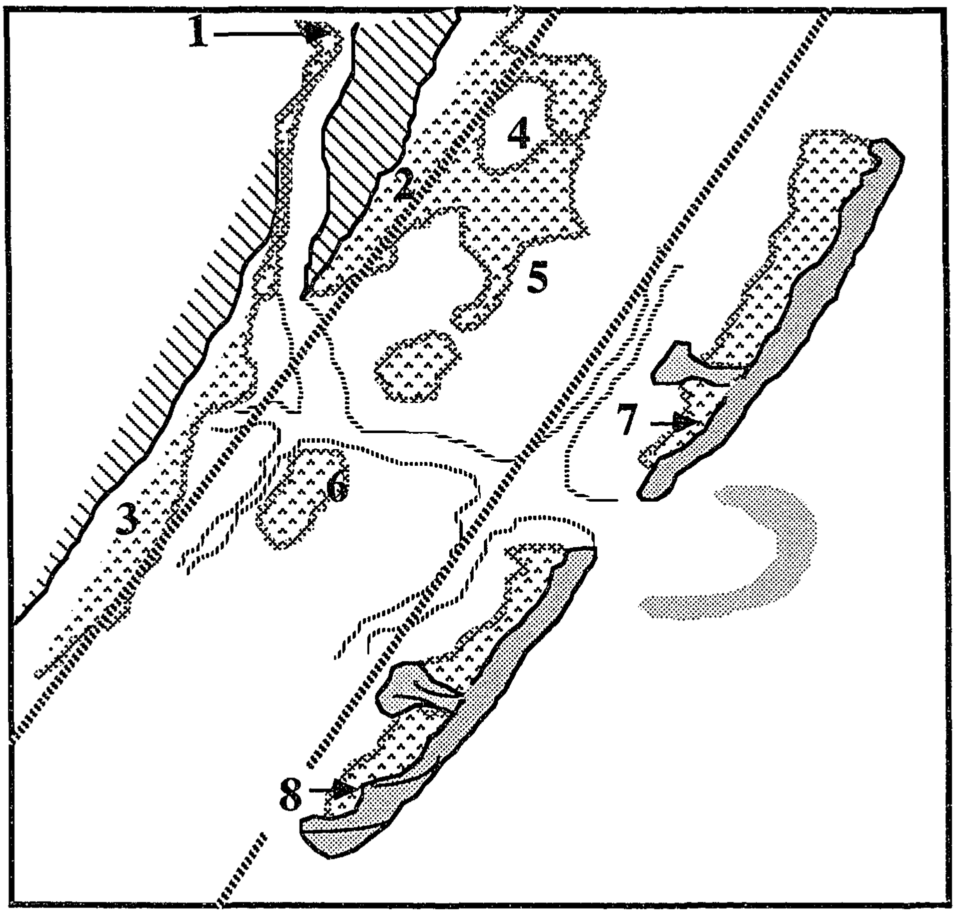
5.3.1 Relationships between surface foraminiferal assemblages and fossil foraminiferal assemblages

Fig. 27. a. The pollen concentration per gram dry sediment, the ratio of arboreal to non-arboreal pollen, and percentage of Ambrosia (ragweed) pollen of the eight environments. b. A schematic diagram of an idealized barrier island system illustrating the distribution of pollen assemblages in inner (No. 1-3), middle (No. 4-6), and outer (No. 7-8) parts of the lagoon. Numbers on the map represent environments.

a

No	Subenvironment	Pollen concentration (grains/g)	Ratio of arboreal to non-arboreal	*Ambrosia* pollen (%)
1	Brackish marsh	121,836±19,087	4.5 : 1	6.6
2	Inner protected fringe marsh	115,135±18,037	4.2 : 1	5.1
3	Inner exposed fringe marsh	132,871±20,815	6.3 : 1	5.3
4	Restricted tidal bay	72,614±11,376	5.8 : 1	6.0
5	Open bay	61,983±9,710	5.7 : 1	3.7
6	Marsh island	70,772±11,087	7.3 : 1	3.9
7	Outer fringe marsh	78,142±12,242	3.0 : 1	8.7
8	Outer fringe marsh	254,367±39,849	2.2 : 1	8.7

b



The distribution of buried fossil assemblages of three short cores were used to document taphonomic changes from living, to total (living+dead), to buried fossil assemblages. Fossil assemblages of a barrier fringe marsh core (HIFO 2) contained only agglutinated taxa (*Jadammina macrescens*, *Trochammina inflata*, *Trochammina "squamata"* and *Trochammina* sp. A) and had fewer specimens and species (Table 16) than the total assemblage in the surface sediment (Appendix C). In the surface sediment (station 33), four abundant species, *Ammonia beccarii*, *Elphidium excavatum*, *Haynesina germanica* and *Miliammina fusca*, constituted 87% of total specimens (Appendix D). Most of the specimens were alive (259 specimens/70 ml) and few were dead (18 specimens/70 ml). Five other species were found only in living populations (31 specimens/70 ml) and one species, *Trochammina inflata*, was found only dead (6 specimens/70 ml). The living population was significantly larger than the dead assemblage and composed most of the total assemblage.

Thus, the faunas at the barrier fringe marsh (station 33), which had an abundance of calcareous (*Ammonia beccarii*, *Elphidium excavatum*, *Haynesina germanica*) and agglutinated species (*Miliammina fusca*) in the surface sediment , were replaced by rare agglutinated species (mainly *Trochammina inflata*) within the substrates. The fossilization potential of the total assemblage was low and appeared to be great for only *Trochammina inflata*. These changes suggest significant taphonomic loss in the transition from living to fossil assemblages. Previous investigators reported on foraminiferal taphonomy in salt marshes (Parker and Athearn, 1959; Goldstein, 1988; Goldstein and Harben, 1992). Parker and Athearn (1959) noted that acidity (low pH) in the marsh environment resulted in rapid destruction of calcareous tests. The acidity of the marsh environment may explain the absence of fossil calcareous tests in the lithosome. Goldstein (1988) and Goldstein and Harben (1992) noted that the buried fossil assemblages in salt marshes of the Georgia coast do not exactly reflect surface assemblages. They suggested that the occurrence of infaunal foraminifera (*e.g.*,

Arenoparrella mexicana, Trochammina inflata) and processes of selective preservation modified the species composition of the buried fossil assemblages.

The total assemblage of the outer tidal flat surface sample (WIMFO 1) yielded 15 species (704 specimens/70 ml). *Elphidium excavatum*, constituted 71% of the total specimens (502 specimens/70 ml) (Appendix C). Six of 15 species were living (22 specimens/70 ml) and four were dead (18 specimens/70 ml). Two agglutinated species, *Trochammina inflata* and *Trochammina "squamata"*, were only in the dead assemblage which constituted less than 1% of the total specimens. The living population thus vastly outnumbered the dead assemblage. There was significant taphonomic loss in the transition from living to dead assemblages. Fewer specimens (2-8 specimens/70 ml) and species (2-4 species) were in the fossil assemblages (Table 16) than in the surface living population (station 22). Although the dominant calcareous species, *Elphidium excavatum*, in the surface assemblage was found in the core to depths of 60 cm, many specimens of this species were obviously lost. The fossilization potential is hence very poor for the calcareous forms. However, agglutinated genus *Trochammina* is well preserved in this area.

In the inner tidal flat surface sediment (OYMFI 1), two dominant calcareous species, *Ammonia beccarii* and *Elphidium excavatum*, comprised 86% of the specimens (204 specimens/70 ml) in the total assemblage (Appendix C). Seven other species were dead (11 specimens/70 ml) and two were only living (4 specimens/70 ml). The dead assemblage outnumbered the living population and contained more species than the living population. The increase in number of species from living to dead assemblages may reflect: (1) rapid production and preservation of tests and (2) post-mortem transport of dead tests into the area by currents. Fossil assemblage of core OYMFI 1 contained two calcareous species, *Ammonia beccarii* and *Elphidium excavatum*, and four agglutinated trochamminid species (Table 16). The most abundant surface species, *Ammonia beccarii* and *Elphidium excavatum*, were preserved in the core, but specimen

numbers were significantly decreased (5-79 specimens/70 ml). The agglutinated trochamminid species were well preserved in this core (7-9 specimens/70 ml). Thus, inner and outer mud flats both had reductions in calcareous specimens between total assemblages and buried fossil assemblages and increases in percentages of agglutinated species. The rapid destruction of calcareous tests result in the living population outnumbering the dead assemblage at the outer tidal flat. However, in the inner tidal flat the dead assemblage was larger than the outer tidal flat and may indicate an accumulation of tests caused by better preservation potential.

The decrease in calcareous tests in the tidal flat lithosome may be a result of the taphonomic processes within the bioturbated mixing zone. An X-ray radiograph of core OYMFI 1 illustrates a high degree of mixing and bioturbation in the upper 40 cm of the core. Taphonomic loss of foraminiferal tests within the substrates is possibly affected by mechanical destruction by transport and mixing (Murray, 1984), predation (Buzas, 1978, 1982), predatory boring (Sliter, 1971), infaunal occurrence and selective preservation (Goldstein, 1988; Goldstein and Harben, 1992) and dissolution of calcium carbonate (Berger, 1970; Wefer and Lutze, 1978). Since the sediments in tidal flats consist of muds and fine sands that are extensively bioturbated, mechanical destruction by mixing and predation may be more important than chemical weathering. In sand-rich (50-70%) tidal flats with small amounts of organic matter, calcium carbonate dissolution is probably a minor process.

While the calcareous tests were not preserved in the outer fringe marsh, the dominant calcareous species, *Elphidium excavatum* and *Ammonia beccarii*, in surface sediments were partially preserved in tidal flats. The acidity of the organic-rich marsh environment may cause the absence of calcareous specimens in the substrates, while the degree of preservation of calcareous species in tidal flats may be a measure of sediment mixing.

5.3.2 Relationships between species diversity and environments

The values of species diversity (H(S)) and equitability (E) had wide ranges within the barrier island system (Table 17). Plots of values diversity analyses (H(S), S, and E) against 47 stations for total assemblages show that four environments can be distinguished: (1) the brackish marsh and channel (stations 1-3), the mean value for H(S) equals 1.94 and E equals 0.49; (2) the lagoonal tidal-flats (stations 4-22), the mean value for H(S) equals 0.84 and E equals 0.19; (3) the lagoonal marshes (stations 23-39), the mean value for H(S) equals 1.40 and E equals 0.41; (4) the channels-inlets-shoreface (stations 40-57), the mean value for H(S) equals 0.60 and E equals 0.18 (Fig. 21). Generally, the values of species diversity (H(S)) and equitability (E) exhibit a striking contrast between the marshes and other areas (lagoonal tidal-flats and channels-inlets-shoreface). The higher values for species diversity (H(S)) in the marshes is the result of the higher equitability (E) of the arenaceous species in these areas. The strong dominance of *Elphidium excavatum* in the tidal flats, channels, inlets, and shoreface results in lower values of equitability (E) and consequently of species diversity (H(S)) in these areas. The mean values of number of species in four environments are relatively constant (10-14) (Table 17).

Gibson and Buzas(1973) reported values of species diversity (H(S)) and equitability (E) in the Cape Cod to Maryland area between water depths of zero and 100 meters. Their species diversity (H(S)) values averaged 1.79 and ranged from 0.78 to 2.63, equitability (E) values averaged 0.43 and ranged from 0.22 to 0.77, and number of species (S) averaged 16.6 and ranged from 6 to 42. The peak in species diversity (H(S)) (1.9-2.3) and equitability (E) (0.61-0.77) occurred at depths of 35 to 45 meters.

Plots of diversity analyses (H(S), S, E and N) of total assemblages against environmental variables (water depth, bulk density, percentage of sand, mean-grain size, grain size sorting, distance from mainland and inlet) in the barrier island system are in Appendix L. While the values of species diversity (H(S)) and equitability (E)

change with water depth (High High Water datum) and distance from inlet, these values do not show significant change with bulk density, percentage of sand, mean-grain size, grain size sorting, or distance from mainland.

The values of species diversity (H(S)) show wide ranges between water depths of zero and 1.8 meters (marshes, tidal flats and tidal channel margins), but are relatively constant in water depths of 4.5 to 18 meters (tidal channels, inlets and shoreface). Generally, the values of species diversity (H(S)) in water depths of zero to 0.9 meter (0.98-1.96) are higher than in water depths of 1.0 to 18 meters. The pattern of equitability (E) is similar to those of species diversity (H(S)) with water depth.

The values of species diversity (H(S)) change with distance from inlet. Inside of the inlet, species diversity (H(S)) decreases from the brackish marsh and channel (30.7 km from the inlet) to the middle part of the lagoon (5 km from the inlet), and have wide ranges near the inlet (< 5 km from the inlet). Outside of the inlet (10 km from the inlet; axial channels, inlet shoals, and shoreface), species diversity (H(S)) is relatively low and constant. The pattern of equitability (E) is similar to that of species diversity (H(S)) with distance from the inlet.

5.3.3 Relationships between dominant species of living and total foraminiferal assemblages and subenvironments

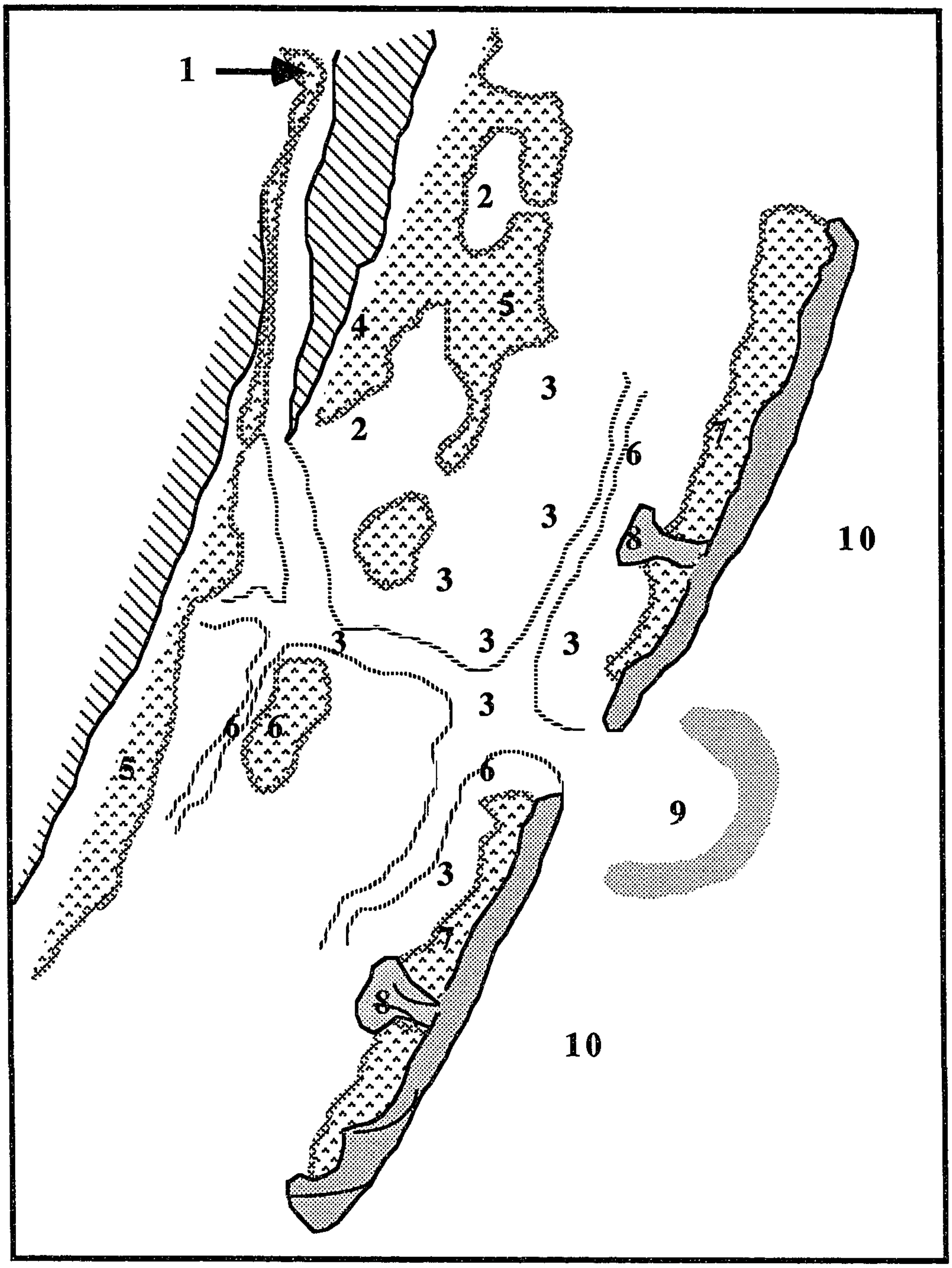
<u>Living populations</u>

The distribution of dominant living foraminiferal species (>25% of the living population in any station within the *a priori* group) in the 20 *a priori* subenvironments of the barrier island system (Appendix G) may be summarized into groups that define ten distinct biofacies: (1) brackish marsh and channel, (2) marsh-protected tidal flats, (3) open tidal bay-tidal channel, (4) inner protected fringe marsh, (5) inner exposed fringe marsh, (6) middle lagoon marsh-tidal channel margin, (7) outer fringe marsh, (8) washover fan, (9) ebb delta, and (10) shoreface (Table 30). Fig 28 shows a schematic

Table 30. Ten biofacies for living foraminiferal populations in the 20 *a priori* subenvironments of the barrier island system. The foraminiferal populations were dominant species those which represent more than 25% of the living population in any station within the *a priori* subenvironment.

No.	Biofacies	*a priori* subenvironments (Group No.)	Population
1	Brackish marsh/channel	Brackish marsh/channel (1)	*Ammonia beccarii* *Trochammina inflata* *Trochammina "squamata"*
2	Marsh-protected tidal flat	Restricted tidal bay (2) Inner mud flat (8)	*Ammonia beccarii* *Elphidium excavatum*
3	Open tidal bay-tidal channel	Inner muddy sand flat (3) Middle/outer muddy sand flat (4) Inner, middle and outer sand flats (5, 6 and 7) Outer mud flat (9) Intermediate and deep tidal channels (15 and 16)	*Elphidium excavatum*
4	Inner protected fringe marsh	Inner protected fringe marsh (10)	*Ammonia beccarii* *Haynesina germanica* *Miliammina fusca*
5	Inner exposed fringe marsh	Inner exposed fringe marsh (11)	*Ammonia beccarii* *Miliammina fusca* *Jadammina macrescens* *Trochammina inflata*
6	Middle lagoon marsh - tidal channel margin	Middle lagoon marsh (12) Tidal channel margin (14)	*Ammonia beccarii* *Elphidium excavatum* *Haynesina germanica*
7	Outer fringe marsh	Outer fringe marsh (13)	*Ammonia beccarii* *Trochammina inflata* *Ammobaculites exiguus* *Miliammina fusca* *Textularia earlandi*
8	Washover fan	Washover fan (17)	*Quinqueloculina seminula* *Ammonia beccarii* *Elphidium excavatum*
9	Ebb delta	Inlet shoals (19)	*Elphidium mexicanum*
10	Shoreface	Shoreface (20)	*Elphidium excavatum* *Elphidium mexicanum*

Fig. 28. A schematic diagram of an idealized barrier island system illustrating the distribution of ten biofacies of living populations. Numbers refer to biofacies: (1) brackish marsh/channel: *Ammonia beccarii* - *Trochammina inflata* - *Trochammina "squamata"* population, (2) marsh protected tidal flats: *Ammonia beccarii* - *Elphidium excavatum* population, (3) open tidal bay - tidal channel: *Elphidium excavatum* population, (4) inner protected fringe marsh: *Ammonia beccarii* - *Haynesina germanica* - *Miliammina fusca* population, (5) inner exposed fringe marsh: *Ammonia beccarii* - *Miliammina fusca* - *Jadammina macrescens* - *Trochammina inflata* population, (6) middle lagoon marsh - tidal channel margin: *Ammonia beccarii* - *Elphidium excavatum* - *Haynesina germanica* population, (7) outer fringe marsh: *Ammonia beccarii* - *Trochammina inflata* - *Ammobaculites exiguus* - *Miliammina fusca* - *Textularia earlandi* population, (8) washover fan: *Quinqueloculina seminula* - *Ammonia beccarii* - *Elphidium excavatum* population, (9) ebb delta: *Elphidium mexicanum* population, and (10) shoreface: *Elphidium excavatum* - *Elphidium mexicanum* population.



1
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diagram of an idealized barrier island system illustrating the distribution of ten biofacies of living populations.

The brackish marsh and channel (biofacies 1) is a marsh and small tidal channel in the upper part of a watershed that drains into a barrier lagoon. The salinity (9.4 psu) is transitional between the near marine conditions of the barrier lagoon (about 30 psu) and the fresh conditions of terrestrial creeks. The fauna is characterized by calcareous *Ammonia beccarii* and agglutinated *Trochammina inflata* and *Trochammina "squamata"*. The brackish marsh fauna consisted of 100% agglutinated specimens, whereas calcareous *Ammonia beccarii* occurred abundantly with agglutinated species at the brackish channel. The low salinity condition in these areas probably restricts calcareous species because of the decreased availability of calcium carbonate ($CaCO_3$) (Hada, 1957). Although some calcareous species (*Ammonia beccarii* and *Elphidium excavatum*) were found in the brackish channel, the biofacies was characterized by agglutinated species (mainly *Trochammina*). This biofacies is quite distinct from the other biofacies within the lagoon proper.

The three biofacies (marsh-protected tidal flats (biofacies 2), open tidal bay-tidal channel (biofacies 3), and middle lagoon marsh-tidal channel margin (biofacies 6)) were closely related. These biofacies were open-lagoon subenvironments (tidal flats, tidal channels and middle lagoon marsh) where *Ammonia beccarii* and *Elphidium excavatum* were more abundant than elsewhere. *Haynesina germanica* also was dominant in the middle lagoon marsh-tidal channel margin (biofacies 6). This species also occurred commonly in marsh-protected tidal flats (biofacies 2) and open tidal bay-tidal channel (biofacies 3). The open tidal bay-tidal channel (biofacies 3) was characterized by one dominant species, *Elphidium excavatum,* and some common calcareous species (*e.g.*, *Ammonia beccarii*, *Haynesina germanica*) (Appendix G). The density of *Elphidium excavatum* in this biofacies was higher than in marsh-protected tidal flats (biofacies 2) and the middle lagoon marsh-tidal channel margin (biofacies 6). The result of stepwise

regression analysis indicated that the density of *Elphidium excavatum* correlated with organic content of sediments (Table 18). Living *Elphidium excavatum* generally occurred in high quantities of fine sand with low percentage of organic matter. The sedimentary characteristics of the open tidal bay-tidal channel (biofacies 3) were sandy substrates (generally more than 70% sand) with very low amounts of organic matter (<0.3%). The boundaries between the three biofacies (2,3 and 6) were not sharp because of the relatively intimate association of the open lagoonal environments. Therefore, the three biofacies (2,3 and 6) may be indistinctly differentiated.

The inner protected fringe marsh (biofacies 4) was characterized by *Ammonia beccarii*, *Haynesina germanica* and *Miliammina fusca*. The fauna of this biofacies included rare species *Elphidium excavatum*, *Quinqueloculina seminula* and *Quinqueloculina dimidiata* (Appendix G). This area was characterized by high salt concentrations (40 - 60 psu) in the substrate pore water. This was apparently caused by significant evaporation rates in the summer. Previous investigators have reported that some species (*e.g.*, *Ammonia beccarii*, *Elphidium excavatum*, *Quinqueloculina seminula* and *Miliammina fusca*) were found alive in hypersaline (>40 psu) lagoons (Said, 1950; Murray, 1968, 1973). This fauna was quite different from those of the other marshes and lagoonal environments.

Fringe marshes were characterized by calcareous *Ammonia beccarii* and several agglutinated species (biofacies 5, inner fringe marsh and biofacies 7, outer fringe marsh). The distribution of dominant foraminiferal species (>25% of living population) of the two biofacies is shown in Table 30, and the relative abundance of marsh species in each biofacies is summarized in Appendix G. Many agglutinated species were dominantly distributed in fringe marshes. *Miliammina fusca* and *Trochammina inflata* were dominant species in both biofacies. While *Jadammina macrescens* was dominant with the two above species at the inner fringe marsh, *Ammobaculites exiguus* and *Textularia earlandi* were dominant with the two above species at the outer fringe marsh.

It is apparent that there were obvious similarities between the inner and outer fringe marsh biofacies. The two biofacies are separated on relative abundance (%) of species.

The washover fan (biofacies 8) was characterized by *Quinqueloculina seminula*, *Ammonia beccarii* and *Elphidium excavatum*. This biofacies occurred on the backbarrier of Cobb Island and consisted of 93-97% sand. The density of living *Quinqueloculina seminula* in this area was higher than elsewhere. The protected sandy substrates (93 - 97% sand) and normal marine salinity (32 psu) probably produced a peak density of living *Quinqueloculina seminula*. This biofacies can be distinguished from the other biofacies based on the abundance of *Quinqueloculina seminula*.

The ebb delta (biofacies 9) had only a few living foraminifers (4 - 16 specimens/ 70 ml). This biofacies was characterized by *Elphidium mexicanum*. *Ammonia beccarii* and *Elphidium excavatum* were common species in this biofacies (Appendix G). This area is composed of moderately to poorly sorted sand (93-98%). The high tidal influence and the coarse substrate in this area is probably responsible for the sparsity of living foraminiferal specimens.

The shoreface (biofacies 10) was characterized by *Elphidium excavatum* and *Elphidium mexicanum*. This area had a high percentage of sand with only a few living foraminifers (104 specimens/ 70 ml near the beach and 2 - 3 specimens/ 70 ml in the outer part of the shoreface). This biofacies is similar to the ebb delta (biofacies 9) but living *Ammonia beccarii* was absent. The faunas consisted mainly of members of the genus *Elphidium*.

Total assemblages

Eight biofacies for total foraminiferal assemblages (Table 31) were recognized by the distribution of dominant species (>25% of the total assemblage in any station within the *a priori* group) in the 20 *a priori* subenvironments of the barrier island system (Appendix G). The eight biofacies were: (biofacies A) brackish marsh and channel,

Table 31. Eight biofacies for total foraminiferal assemblages in the 20 *a priori* subenvironments of the barrier island system. The foraminiferal assemblages were dominant species those which represent more than 25% of the total assemblage in any station within the *a priori* subenvironment.

Code	Biofacies	*a priori* subenvironments (Group No.)	Assemblage
A	Brackish marsh/channel	Brackish marsh/channel (1)	*Trochammina inflata*
B	Inner bays-central marsh	Restricted tidal bay (2) Inner mud flat (8) Inner muddy sand flat (3) Middle lagoon marsh (12)	*Ammonia beccarii* *Elphidium excavatum*
C	Outer bays-offshore	Middle/outer muddy sand flat (4) Inner, middle and outer sand flats (5, 6 and 7) Outer mud flat (9) Intermediate and deep tidal channels (15 and 16) Axial channel (18) Inlet shoals (19) Shoreface (20)	*Elphidium excavatum*
D	Inner protected fringe marsh	Inner protected fringe marsh (10)	*Ammonia beccarii* *Haynesina germanica* *Miliammina fusca*
E	Inner exposed fringe marsh	Inner exposed fringe marsh (11)	*Ammonia beccarii* *Miliammina fusca* *Arenoparrella mexicana* *Trochammina inflata*
F	Outer fringe marsh	Outer fringe marsh (13)	*Ammonia beccarii* *Trochammina inflata* *Ammobaculites exiguus* *Miliammina fusca* *Textularia earlandi*
G	Tidal channel margin	Tidal channel margin (14)	*Ammonia beccarii* *Elphidium excavatum* *Haynesina germanica*
H	Washover fan	Washover fan (17)	*Quinqueloculina seminula* *Ammonia beccarii* *Elphidium excavatum*

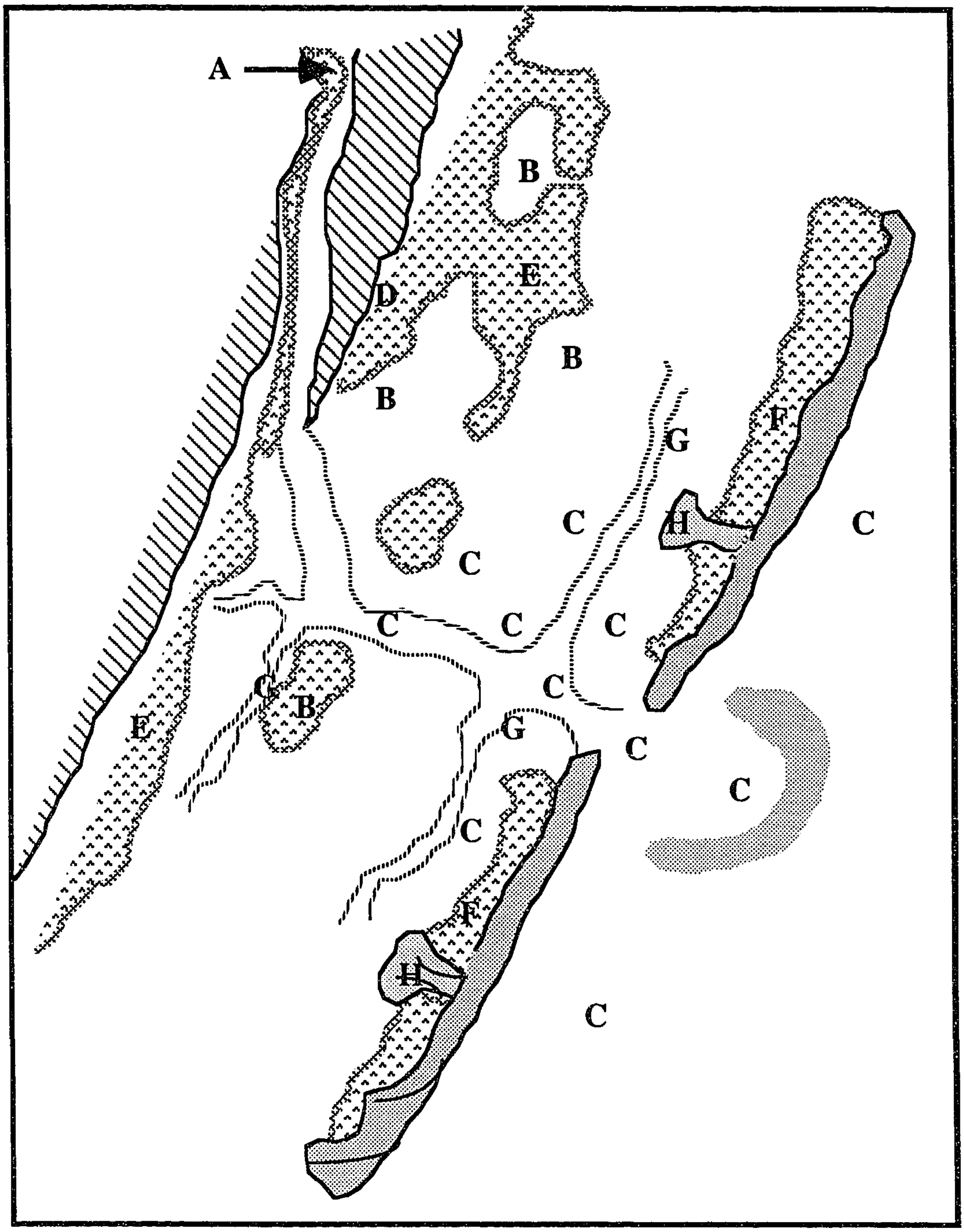
(biofacies B) inner flats-central marsh, (biofacies C) outer bays-offshore, (biofacies D) inner protected fringe marsh, (biofacies E) inner exposed fringe marsh, (biofacies F) outer fringe marsh, (biofacies G) tidal channel margin, and (biofacies H) washover fan (Table 31). Fig 29 shows an idealized schematic diagram of a barrier island system illustrating the distribution of eight biofacies of total assemblages.

The brackish marsh and channel (biofacies A) was dominantly composed of *Trochammina inflata*. The fauna consisted of 98% agglutinated species. The low salinity (9.4 psu) and acidity (low pH) in this area restricted living calcareous species and destroyed any tests soon after death. This biofacies was quite distinct from the other biofacies because the brackish marsh and channel fauna was almost totally arenaceous.

The inner bays-central marsh (biofacies B) was composed of the restricted tidal bay, inner muddy sand and mud flats, and the middle lagoon marsh. The fauna was characterized by *Ammonia beccarii* and *Elphidium excavatum*. Marshes and the diminished tidal influence from the inlet are important factors producing distributions of total assemblages that are different from the other biofacies. The marshes baffle current flow and restrict the addition of the dead offshore species (*e.g.*, *Elphidium excavatum*) along a wide front. The relative amount of *Ammonia beccarii* in the total assemblage of the biofacies was higher than the other biofacies. The result of stepwise regression analysis indicated that the density of *Ammonia beccarii* was associated with the mean grain size of sediment. *Ammonia beccarii* in this biofacies had high densities (996-3168 specimens/ 70 ml) in the fine silt sediments of restricted tidal bays and the middle-lagoon marshes.

The outer bays-offshore (biofacies C) was characterized by *Elphidium excavatum*. This biofacies consisted of middle and outer muddy-sand flats, inner, middle and outer sand flats, outer mud flats, intermediate and deep-tidal channels, ebb deltas (axial channel and inlet shoals), and the shoreface. *Ammonia beccarii*

Fig. 29. A schematic diagram of an idealized barrier island system illustrating the distribution of eight biofacies of total assemblages. Alphabets refer to biofacies: (A) brackish marsh/channel: *Trochammina inflata* assemblage, (B) inner bays - central marsh: *Ammonia beccarii* - *Elphidium excavatum* assemblage, (C) outer bays - offshore: *Elphidium excavatum* assemblage, (D) inner protected fringe marsh: *Ammonia beccarii* - *Haynesina germanica* - *Miliammina fusca* assemblage, (E) inner exposed fringe marsh: *Ammonia beccarii* - *Miliammina fusca* - *Arenoparrella mexicana* - *Trochammina inflata* assemblage, (F) outer fringe marsh: *Ammonia beccarii* - *Trochammina inflata* - *Ammobaculites exiguus* - *Miliammina fusca* - *Textularia earlandi* assemblage, (G) tidal channel margin: *Ammonia beccarii* - *Elphidium excavatum* - *Haynesina germanica* assemblage, and (H) washover fan: *Quinqueloculina seminula* - *Ammonia beccarii* - *Elphidium excavatum* assemblage.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concentrations decreased from common to rare from the middle to outer part of the lagoon. The subenvironments of this biofacies were all strongly influenced by the tidal inlet which exchanged water and sediment between the outer bays of the lagoon and the sea. The abundance of *Elphidium excavatum* in the outer bay in the lagoon may be affected by the addition of dead *Elphidium excavatum* tests from offshore. A stepwise regression analysis indicated that salinity and percent organic showed a strong relationship with *Elphidium excavatum*. *Elphidium excavatum* occurred in high densities (3328 - 4800 specimens/ 70 ml) at the middle sand flat and inlet shoals which were sandy with no organic matter and had normal marine and lagoon salinities (31 psu).

The inner protected fringe marsh (biofacies D) was characterized by *Ammonia beccarii*, *Haynesina germanica* and *Miliammina fusca*. This area had high salt concentrations (40 - 60 psu) in the pore water substrate in the summer. The fauna mainly consisted of species tolerant of wide ranges in salinity (e.g., *Ammonia beccarii*, *Miliammina fusca*). Since these areas were protected from the open sections of the lagoon, the fauna did not mix efficiently with open-bay species. *Elphidium excavatum*,which was a dominant species in open bays and outside of the inlet, occurred in rare concentrations in this biofacies.

The dominant fauna of the inner exposed fringe marsh (biofacies E) along the mainland consisted of *Miliammina fusca*, *Ammonia beccarii*, *Arenoparrella mexicana* and *Trochammina inflata*. The relative abundance of *Miliammina fusca* was higher than *Ammonia beccarii*, *Arenoparrella mexicana* and *Trochammina inflata*.

The outer fringe marsh (biofacies F) along the barrier islands was characterized by *Ammobaculites exiguus*, *Ammonia beccarii*, *Trochammina inflata*, *Miliammina fusca* and *Textularia earlandi*. *Arenoparrella mexicana* also occurred commonly in this biofacies (Appendix G). *Textularia earlandi*, which was abundantly distributed in the outer fringe marsh, occurred in rare quantities at the inner fringe marsh. The faunal

compositions between two biofacies were similar, but had different frequencies (%).

The tidal channel margin (biofacies G) was characterized by *Ammonia beccarii*, *Elphidium excavatum* and *Haynesina germanica*. *Ammobaculites exiguus*, *Buccella frigida* and *Miliammina fusca* were common species in this biofacies. *Ammonia beccarii* and *Elphidium excavatum* were dominant at open bays and *Ammobaculites exiguus* and *Miliammina fusca* were dominant at fringe marshes. These areas were located in tidal channels near the marshes, and therefore, the tidal channel margin (biofacies G) was very similar with the inner bays-central marshes of biofacies B.

The washover fan (biofacies H) was characterized by *Quinqueloculina seminula*, *Elphidium excavatum* and *Ammonia beccarii*. Large concentrations of *Quinqueloculina seminula* were deposited and accumulated as living specimens died. However, *Elphidium excavatum* concentrations were probably supplemented by dead forms coming with intermittent overwashes. This biofacies was primarily established by the dominance of *Quinqueloculina seminula* and was readily distinguished from the other biofacies.

Comparison with other regions

Ammobaculites exiguus which was dominant in the outer lagoonal fringe marsh has different distribution patterns in other regions. *Ammobaculites* fauna was dominant at (1) the upper reaches (0.5 - 15 psu) of the Rappahannock and James River, Virginia (Nichols and Ellison, 1967; Nichols and Norton, 1969; Ellison and Nichols, 1970), (2) the Rhode River, Maryland (Buzas, 1974) and (3) in the tidal streams and the mid-bay of the Indian River Bay lagoon, Delaware (Kraft and Margules, 1971). While the living *Ammobaculites* fauna occurred dominantly in low salinity conditions (0.5-15 psu) in other Virginia and Maryland estuaries, and Delaware lagoons, this fauna was dominant in living and total assemblages in normal marine salinity conditions (33 psu) at the outer fringe marsh. Thus, as suggested by the stepwise regression analysis,

Ammobaculites fauna may be affected by high percentage of sand and low bulk density rather than salinity.

The faunas of the living and total assemblages at the outer fringe marsh (biofacies 7 and biofacies F, respectively), which was characterized by *Ammonia beccarii*, *Trochammina inflata*, *Ammobaculites exiguus*, *Miliammina fusca* and *Textularia earlandi*, were similar to those found in the eastern periphery (protected backbarrier fringe) (*Ammonia beccarii* - *Ammoscalaria* sp. - *Textularia earlandi* assemblage) of the Indian River Bay lagoon, Delaware (Kraft and Margules, 1971). In this study area, *Trochammina inflata* was a dominant species in the outer fringe marsh of the lagoon, but it was absent along the outer periphery of the Indian River Bay lagoon. However, *Ammobaculites exiguus* and *Miliammina fusca* occurred in common to rare concentrations along the outer periphery of the Indian River Bay lagoon.

A variety of faunas are reported in open lagoons and bays. Phleger and Walton (1950) found that Barnstable Harbor, Massachusetts was characterized by an abundance of *Trochammina inflata* and the adjacent nearshore of Cape Cod bay was characterized by *Proteonina atlantica* and *Eggerella advena*. Miller (1953) found forty-two species in a brackish lagoon at Mason Inlet, North Carolina. *Quinqueloculina seminulum* var. *jugosa*, *Elphidium* aff. *incertum* var. *mexicanum*, "*Rotalia*" cf. *beccarii* and *Globigerinoides* cf. *ruber* were common to abundant in this area. Ronai (1955) investigated the foraminifera of brackish-water bays and lagoons of the New York Bight. Eleven genera were dominant in the lagoonal environment: *Ammobaculites*, *Ammoastuta*, *Eggerella*, *Miliammina*, *Quinqueloculina*, *Triloculina*, *Trochammina*, *Nonion*, *Elphidium*, *Buccella* and *Rotalia*.

The faunas of dominant living species in three biofacies (marsh-protected tidal flats (biofacies 2), open tidal bay-tidal channel (biofacies 3), and middle lagoon marsh-tidal channel margin (biofacies 6)) (Table 30) were similar to those found in the central bay-lagoon: *Elphidium incertum* - *Ammonia beccarii* population at the Indian River Bay

lagoon, Delaware (Kraft and Margules, 1971). However, the distribution of common to rare living species was different. The common species (*e.g.*, *Textularia earlandi*, *Trochammina squamata*, *Ammobaculites salsus* and *Elphidium subarcticum*) in the central bay-lagoon at the Indian River Bay lagoon occurred in rare quantities or were absent in biofacies 2, 3 and 6. The different distributions may be related to the differences in fluvial and tidal processes at the two lagoons. The bays in the study area are more exposed and have fewer tidal streams than those in the Indian River Bay lagoon, Delaware. The Indian River Bay lagoon is not as stress by salinity and tidal currents as the Virginia lagoon. The distribution of the dominant species of total assemblages in the inner bays and central marshes (biofacies B) were similar to those found in the central bay-lagoonal assemblage (*Ammonia beccarii* - *Elphidium incertum* - *Elphidium clavatum*) at the Indian River Bay lagoon, Delaware (Kraft and Margules, 1971).

The two regions (the Delaware and Virginia lagoons) had similar lithofacies (silty substrates) and stations were located in the inner to middle parts of the lagoons. The dominance of *Ammonia beccarii* and *Elphidium excavatum* (=*Elphidium clavatum* and *Elphidium incertum* of Kraft and Margules (1971) based on Culver and Buzas (1980)) in both regions probably resulted from the addition of dead forms from adjacent environments and offshore by tidal currents.

Elphidium excavatum which was dominant in the living and total assemblages outside of the inlet (ebb delta and shoreface) was dominant in the inner shelf of other regions. Ellison and Nichols (1976) found *Elphidium clavatum* (=*Elphidium excavatum* based on Culver and Buzas (1980)) was predominant in the inner shelf (out to 45 m depth) off the Chesapeake Bay, Virginia. Schnitker (1971) found *Elphidium clavatum* (=*Elphidium excavatum* based on Culver and Buzas (1980)) was dominant in all samples (19-60 m depth) north of the Cape Hatteras, North Carolina continental shelf.

Paleoenvironmental implications

The distribution of foraminifera in late Quaternary coastal sediments is not believed to be significantly different than the modern species in these areas (Bandy, 1956). Thus, since the modern foraminiferal assemblages are closely related to fossil assemblages found in late Quaternary deposits, they should be useful for paleoenvironmental interpretations. The dominant foraminiferal species of living and total assemblages of the 20 *a priori* subenvironments have ten well-defined populations and eight assemblages (Table 30 and 31) and also could be useful in paleoenvironmental interpretations in coastal deposits. The apparent key species with limited biofacies range in the present-day assemblages may facilitate paleoenvironmental interpretations. For example, *Trochammina inflata* and *Miliammina fusca* are key species used in marshes and *Quinqueloculina seminula* is a key species in the washover fan biofacies.

Previous studies of paleoenvironmental interpretations in the Quaternary coastal deposits have depended on direct comparison of the buried fossil assemblages with the most similar modern surface assemblages (Newman and Munsart, 1968; Shideler et al., 1984). However, interpretations solely on biofacies must be made with care, and it is necessary to analyze the combinations of sedimentary characteristics with faunal features. The buried fossil assemblages usually contained fewer specimens and species than total (living+dead) assemblages. The significant decrease of tests (usually calcareous) in the sediment could be a result of the taphonomic processes between living to total to fossil assemblages. The distribution of fossil assemblages in the outer fringe marsh and tidal flats indicated that fossilization potential was low in the lithosomes due to taphonomic loss within the substrates. Dominant surface calcareous and agglutinated species (e.g., *Ammonia beccarii, Miliammina fusca*) did not preserve well and were replaced by only a few agglutinated species (mainly *Trochammina*

inflata) in the outer fringe marsh (Table 16). At tidal flats, the dominant surface calcareous species, *Elphidium excavatum* and *Ammonia beccarii*, were preserved in low specimen numbers with agglutinated trochamminid species. Therefore, the documentation of taphonomic changes from living to total to fossil assemblages in a certain environment is important for the reconstruction of paleoenvironments in the coastal areas. Paleoenvironmental interpretation is greatly enhanced by combining microfaunal assemblages with other faunal and sedimentary characteristics. For example, while biofacies B (inner bays-central marsh) and biofacies C (outer bays-offshore) have similar faunal compositions, they are readily distinguished by the sand content of sediments. The sand content of sediments in the outer bays-offshore (biofacies C) (generally more than 70% sand) were higher than those in the inner bays-central marsh (biofacies B) (generally less than 50% sand).

5.3.4 Relationships between environmental variables and densities of foraminiferal species

The densities of the most frequently occurring species in living and total assemblages are controlled by a variety of environmental factors (Tables 18 and 19). The environmental variables evaluated during this study were primarily measured during the summer and consisted of salinity, temperature, water depth and sediment characters (Table 4). Some variables were relatively constant (*e.g.*, water depth, sediment characters, and distance from mainland and inlet) while others change seasonally (*e.g.*, salinity and temperature).

Previous investigators have suggested that some environmental variables used in this study may affect distributions of living populations, while others have impacts on distributions of total (living+dead) assemblages. Numerous studies have cited correlations between densities of living species and nutrients (Said, 1950,1951; Phleger, 1960), and amount and type of food (Bradshaw, 1955; Lee et al., 1966;

Buzas, 1969). Seasonal variations of biological factors (*e.g.*, nutrients, chlorophyll) are probably more realistic data for affecting the distributions of living foraminifers (Lee et al., 1966; Buzas, 1969). However, long-term ecological parameters (physical parameters) may impact densities of species of total assemblages. Parker and Athearn (1959), Matera and Lee (1972) and Scott and Medioli (1980b) found that while living foraminiferal populations show seasonal changes due generally to climatic or micro-environmental changes, the total foraminiferal assemblage varies little seasonally. They suggested that total foraminiferal assemblages are more useful indicators of long-term environmental conditions than living populations. Most of the environmental variables used in this study for stepwise regression analysis consisted of "long-term" physical parameters rather than "short-term" biological and geochemical parameters and are considered more useful for long-term ecological conditions. Therefore, the results of stepwise regression analysis between environmental variables and densities of abundant species of total assemblages are more meaningful than those of living species.

5.3.5 Relationships between patterns of foraminiferal variance and sedimentary environments

Canonical variate analysis of living populations illustrated that the outer tidal flats (groups 4, 7 and 9) and the deep tidal channels (16) were clearly distinct from the other groups and from one another in a plot of the first two canonical axes (Fig. 23). The groups (4, 7, 9 and 16) strongly influenced by inlet tides were dominated by *Elphidium excavatum*. The remaining groups were less clearly distinguished from one another. Among the remaining groups, the restricted bay (2), the marsh island (12), the inner muddy sand flat (group 3), the washover fan (17) and the inner exposed fringe marsh (11) were well-separated from one another. The 95% confidence circles of the other groups (8, 10, 13 and 14) were close together. Important species in living populations for separating the groups were *Jadammina macrescens*, *Miliammina earlandi*,

Arenoparrella mexicana, Miliammina fusca, Elphidium excavatum, Elphidium gunteri, Quinqueloculina dimidiata and *Textularia earlandi.*

Table 32 shows 11 biofacies for living populations illustrating the within-group range of relative abundance of species important for discrimination in the canonical variate analysis. Nine (groups 2, 3, 4, 7, 9, 11, 12, 16 and 17) of 13 *a priori* subenvironments were clearly distinguishable by canonical variate analysis at 95% confidence level (Fig. 23) and would have their own biofacies (Table 32). Four subenvironments (groups 8, 10, 13 and 14) were close together at 95% confidence level (Fig. 23) and could be combined into a single biofacies (biofacies L6) (Table 32). Although the brackish marsh and channel (biofacies L1) was not defined by canonical variate analysis, this biofacies was clearly separated from the other biofacies by its faunal composition. The inner exposed fringe marsh (biofacies L8) had maximum frequencies for *Jadammina macrescens* (37.8%), *Miliammina earlandi* (8.1%) and *Miliammina fusca* (100%). *Arenoparrella mexicana* occurred in high frequencies (3.9-17.1%) at the brackish marsh and channel (biofacies L1). The middle and outer muddy sand flat (biofacies L4) had high frequencies for *Elphidium excavatum* (72.2-88.9%) and *Elphidium gunteri* (0-5.6%). *Quinqueloculina dimidiata* appeared in high frequencies (2-18.7%) at the washover fan (biofacies L11). The brackish marsh and channel (biofacies L1) had high frequency for *Textularia earlandi* (2.4%).

The results of the canonical variate analysis for living populations indicated that the strong tidal-influence groups (the middle and outer muddy sand flat (4), the outer sand flat (7), the outer mud flat (9) and the deep tidal channel (16)) were clearly distinct from the other groups. A similar pattern of inlet influence was reported by Buzas and Severin (1982) in the Indian River, Florida. They noted that the inlets and the northern end of the estuary (away from the inlet at Haulover) were clearly discriminated from the other areas. The inlets were high-tidal influence areas, whereas the northern end of the estuary (Haulover) had almost no tidal influence.

Table 32. Eleven biofacies for living populations illustrating the within-group range of relative abundance of species important for discrimination in the canonical variate analysis. The brackish marsh and channel (biofacies L1) was not defined by canonical variate analysis because it was clearly separated from the other biofacies by its faunal composition.

Code	Biofacies	*a priori* subenvironments (Group No.)	Relative abundance of important species for discrimination using canonical variate analysis
L1	Brackish marsh/channel	Brackish marsh/channel (1)	*Arenoparrella mexicana* (3.9-17.1%) *Elphidium excavatum* (0-17.3%) *Miliammina fusca* (0-15.4%) *Jadammina macrescens* (0-9.8%) *Textularia earlandi* (0-2.4%)
L2	Restricted tidal bay	Restricted tidal bay (2)	*Elphidium excavatum* (31.6-53.5%) *Miliammina fusca* (0-0.3%) *Elphidium gunteri* (0-0.3%)
L3	Inner muddy sand flat	Inner muddy sand flat (3)	*Elphidium excavatum* (20-63.3%) *Miliammina fusca* (0-24%)
L4	Middle/outer muddy sand flat	Middle/outer muddy sand flat (4)	*Elphidium excavatum* (72.2-88.9%) *Elphidium gunteri* (0-5.6%)
L5	Outer sand flat	Outer sand flat (7)	*Elphidium excavatum* (54.3-100%) *Textularia earlandi* (0-1.1%)
L6	Marshes-flats near marsh	Inner mud flat (8) Inner protected fringe marsh (10) Outer fringe marsh (13) Tidal channel margin (14)	*Elphidium excavatum* (0-45.8%) *Textularia earlandi* (0-40.4%) *Miliammina fusca* (0-26.6%) *Arenoparrella mexicana* (0-6.2%) *Elphidium gunteri* (0-2.8%) *Jadammina macrescens* (0-1.1%) *Quinqueloculina dimidiata* (0-0.3%)
L7	Outer mud flat	Outer mud flat (9)	*Elphidium excavatum* (61.4-68.8%) *Quinqueloculina dimidiata* (1.8-7.9%) *Textularia earlandi* (0-1.8%) *Elphidium gunteri* (0-0.5%)
L8	Inner exposed fringe marsh	Inner exposed fringe marsh (11)	*Miliammina fusca* (2.7-100%) *Jadammina macrescens* (0-37.8%) *Elphidium excavatum* (2.4-24%) *Arenoparrella mexicana* (0-16.2%) *Miliammina earlandi* (0-8.1%) *Quinqueloculina dimidiata* (0-1.2%) *Elphidium gunteri* (0-0.6%)
L9	Middle lagoon marsh	Middle lagoon marsh (12)	*Elphidium excavatum* (26.7-35.3%) *Elphidium gunteri* (0-0.8%) *Miliammina fusca* (0-0.3%)
L10	Deep tidal channel	Deep tidal channel (16)	*Elphidium excavatum* (77.8%)
L11	Washover fan	Washover fan (17)	*Elphidium excavatum* (2-30.2%) *Quinqueloculina dimidiata* (2-18.7%) *Miliammina fusca* (0-1.6%)

Canonical variate analysis of the total foraminiferal assemblages clearly separated inner and outer fringe marshes (groups 10, 11 and 13) and restricted tidal bays (2) from the remaining groups and from one another along mean canonical variate axis 1 (Fig. 24). *Ammonia beccarii*, *Elphidium excavatum*, *Haplophragmoides bonplandi*, *Jadammina macrescens*, *Miliammina earlandi*, *Miliammina fusca* and *Textularia earlandi* are important species for the contrast. The remaining groups were less clearly discriminated, but can be placed into three clusters along mean canonical variate 2. The clusters were closely related to sediment types: sand (groups 6, 7, 12, 18, 19 and 20), muddy sand (groups 4, 5, 14, 15, 16 and 17) and mud (groups 3, 8 and 9) units. *Haplophragmoides bonplandi*, *Miliammina earlandi* and *Textularia earlandi* were the most important species for the separation of three clusters along the second canonical variate. *Haplophragmoides bonplandi* occurred in rare concentrations at high elevation inner and outer fringe marshes (groups 11 and 13). *Miliammina earlandi* was only found in rare concentrations at the high-elevation inner fringe marsh (group 11). *Textularia earlandi* occurred in rare concentrations at sand and mud flats, and was found in abundance at the high-elevation outer fringe marsh (group 13).

Table 33 shows 11 biofacies for total assemblages illustrating the within-group range of relative abundance of species important for discrimination in the canonical variate analysis. Seven (groups 2, 3, 10, 11, 13, 15 and 16) of 19 *a priori* groups were clearly distinguishable by canonical variate analysis at 95% confidence level (Fig. 24). Those groups had their own biofacies (Table 33). The remaining groups were placed into three sets (Fig. 24) which had their own biofacies: middle sandy bays-washover fan (biofacies T4; groups 4, 5, 14 and 17), middle to outer bays-ebb deltas-shoreface (biofacies T5; groups 6, 7, 12, 18, 19 and 20), and mud flats (biofacies T6; groups 8 and 9) (Table 33). The brackish marsh and channel (biofacies T1) was not defined by canonical variate analysis because it was clearly distinct from the other biofacies by its faunal composition. *Ammonia beccarii* had maximum frequency (81%) at the outer

Table 33. Eleven biofacies for total assemblages illustrating the within-group range of relative abundance of species important for discrimination in the canonical variate analysis. The brackish marsh and channel (biofacies T1) was not defined by canonical variate analysis because it was clearly separated from the other biofacies by its faunal composition.

Code	Biofacies	*a priori* subenvironments (Group No.)	Relative abundance of important species for discrimination using canonical variate analysis
T1	Brackish marsh/channel	Brackish marsh/channel (1)	*Jadammina macrescens* (3.2-11.4%) *Haplophrag. bonplandi* (1.9-6.3%) *Ammonia beccarii* (0-4.8%) *Elphidium excavatum* (0-2.4%) *Miliammina fusca* (0-2.2%) *Textularia earlandi* (0-0.2%)
T2	Restricted tidal bay	Restricted tidal bay (2)	*Ammonia beccarii* (38.3-61.5%) *Elphidium excavatum* (33.9-55%) *Jadammina macrescens* (0-0.3%) *Miliammina fusca* (0-0.2%)
T3	Inner muddy sand flat	Inner muddy sand flat (3)	*Elphidium excavatum* (26.5-84.8%) *Ammonia beccarii* (6.7-56%) *Miliammina fusca* (0-20.6%)
T4	Middle sandy bays-washover fan	Middle/outer muddy sand flat (4) Inner sand flat (5) Tidal channel margin (14) Washover fan (17)	*Elphidium excavatum* (1.7-96.6%) *Ammonia beccarii* (2.9-58.7%) *Miliammina fusca* (0-18.2%) *Textularia earlandi* (0-0.2%)
T5	Middle to outer bays-ebb deltas-shoreface	Middle sand flat (6) Outer sand flat (7) Middle lagoon marsh (12) axial channel (18) inlet shoals (19) shoreface (20)	*Elphidium excavatum* (37.6-96%) *Ammonia beccarii* (0.9-55.7%) *Textularia earlandi* (0-0.3%) *Jadammina macrescens* (0-0.2%) *Miliammina fusca* (0-0.2%)
T6	Mud flats	Inner mud flat (8) Outer mud flat (9)	*Elphidium excavatum* (52.2-71.3%) *Ammonia beccarii* (12.5-37.7%) *Miliammina fusca* (0-0.9%) *Textularia earlandi* (0-0.8%) *Jadammina macrescens* (0-0.4%)
T7	Inner protected fringe marsh	Inner protected fringe marsh (10)	*Ammonia beccarii* (38-55.9%) *Miliammina fusca* (0-44%) *Elphidium excavatum* (2-4.1%) *Jadammina macrescens* (0-1.7%)

Continued

Code	Biofacies	*a priori* subenvironments (Group No.)	Relative abundance of important species for discrimination using canonical variate analysis
T8	Inner exposed fringe marsh	Inner exposed fringe marsh (11)	*Miliammina fusca* (1-70.2%) *Ammonia beccarii* (0.3-49.9%) *Elphidium excavatum* (0-22.7%) *Jadammina macrescens* (0-17.4%) *Miliammina earlandi* (0-2.3%) *Haplophrag. bonplandi* (0-0.7%) *Textularia earlandi* (0-0.3%)
T9	Outer fringe marsh	Outer fringe marsh (13)	*Ammonia beccarii* (9.8-81.3%) *Textularia earlandi* (0-38%) *Miliammina fusca* (6.3-25.3%) *Elphidium excavatum* (0-7.6%) *Jadammina macrescens* (0-4.6%) *Haplophrag. bonplandi* (0-0.3%)
T10	Intermediate tidal channel	Intermediate tidal channel (15)	*Elphidium excavatum* (86.7-89.7%) *Ammonia beccarii* (4.2-4.9%) *Jadammina macrescens* (0-0.3%)
T11	Deep tidal channel	Deep tidal channel (16)	*Elphidium excavatum* (86.8-87%) *Ammonia beccarii* (5.8-6.4%)

fringe marsh (biofacies T9). Intermediate and deep tidal channels (biofacies T10 and biofacies T11) had relatively high frequencies for *Elphidium excavatum* (86.7-89.7%). *Haplophragmoides bonplandi* occurred in high frequencies (1.9-6.3%) at the brackish marsh and channel (biofacies T1). The inner exposed fringe marsh (biofacies T8) had high frequencies for *Jadammina macrescens* (0-17.4%), *Miliammina earlandi* (0-2.3%) and *Miliammina fusca* (1.0-70.2%). *Textularia earlandi* appeared in high frequencies (0-38%) at the outer fringe marsh (biofacies T9).

Fig. 23 and Fig. 24 illustrate that groups 4, 7, 9 and 16 have distinct living populations while they cluster with other groups based on total assemblages. However, fringe marshes (groups 10, 11 and 13) and the restricted tidal bay (group 2), which were weakly discriminated in living populations, were clearly separated from the other groups and from one another in total assemblages. These results indicated that the distribution patterns of living populations in the different subenvironments of the barrier island system are clearly different from those of total assemblages. The different distribution patterns are a result of post-mortem processes of dead assemblages such as transport, mixing, and test destruction by biological, physical or chemical means (Berger, 1970; Sliter, 1971; Murray, 1973, 1982, 1984; Wefer and Lutze, 1978; Buzas, 1978, 1982).

Chapter 6
Summary and Conclusions

Lagoonal coasts of the southern Delmarva Peninsula can be divided into 20 different subenvironments based on a variety of physical, geological and geomorphic parameters. These areas exhibit wide ranges of environmental conditions that produce different lithofacies patterns that can affect the distribution of pollen and foraminifera. This study has investigated quantitatively the relationships between the different depositional environments of the barrier island system and the distribution of pollen and foraminifera.

The brackish environment (brackish marsh and channel) was quite different from all other areas based on environmental variables, pollen and living and total (living+dead) foraminiferal assemblages. The salinity of the brackish marsh and channel remained below 10 psu. The brackish marsh was characterized by organic-rich, silty clay sediments vegetated by *Spartina patens*, *Distichlis spicata* and the short form of *Spartina alterniflora*. The pollen concentration in the brackish marsh was higher than the other areas. The arboreal to herb pollen ratio was higher than those of the lagoonal environments. The total foraminiferal assemblage in this area consisted mostly of agglutinated species (98%). Thus, the combination of sediment texture, arboreal to herb pollen ratio, marsh phytoliths and agglutinated foraminifera may be used to distinguish brackish environments from other lagoonal environments. The combination also would be useful in determining brackish conditions of early Holocene or late Pleistocene lithosomes.

Ten variables that described the environmental setting of a barrier island system

were subjected to canonical variate analyses to test whether there was sufficient discriminating power in the variance to recognize 19 *a priori* groups. The analysis illustrated that 83% of 54 samples could correctly be matched with 19 *a priori* groups of depositional environments in the barrier island system. The 19 groups formed two separate internally overlapping sets. One set (16 groups) was located inside of the inlet (lagoon), and the other set (3 groups) was located outside of the inlet. The percentage of sand and distance from inlet were the most important contributing variables by which these two sets were differentiated. Others (water depth, percentage of organic, silt, clay, mean-grain size, sorting, distance from inlet and bulk density) had very weak affects upon the separation of the groups.

Twenty-two pollen types were found in surface sediments of the barrier lagoon. The pollen of *Pinus* (pine) and *Quercus* (oak) were the dominant types over the study area. Generally, the tree pollen showed high percentages between the mainland tidal stream and the middle part of the lagoon and low percentages at the outer part of the lagoon. Herb pollen, Gramineae (grass), other Compositaes and *Ambrosia* (ragweed), occurred in relatively low percentages with local variation at inner, middle and outer parts of the lagoon. The percentages of *Ambrosia* (ragweed) pollen (4-9% of total pollen grains) in lagoonal surface sediments illustrates a natural range during modern climatic conditions. The variations of pollen assemblages in lagoonal sediments reflect types of local vegetation and distance from their source plants.

The pollen assemblages in low-energy marsh and mud-flat environments were subjected to canonical variate analysis to compare between three areas in the lagoon: inner, middle and outer parts of lagoon. The analysis of pollen data showed that the three areas are clearly discriminated from one another. These results indicate that modern pollen assemblages in the barrier lagoon are characterized by local variations with distance from mainland and should be useful for reconstructing barrier lagoon under warm climatic conditions. The variations in pollen concentrations, arboreal to

non-arboreal pollen ratios and percentages of *Ambrosia* (ragweed) pollen also can be used to distinguish between inner, middle and outer parts of the barrier lagoon.

Sixty-eight species of foraminifera were recorded in surface sediments from the 57 stations. Of these, 44 were found living in the study area. *Elphidium excavatum* and *Ammonia beccarii* were widely distributed in living and total assemblages over the study area. While *Ammonia beccarii* occurred in abundance within the lagoon, *Elphidium excavatum* occurred in abundance in living and total assemblages in the outer part of the lagoon, inlet and shoreface. Five agglutinated species, *Miliammina fusca*, *Ammobaculites exiguus*, *Trochammina inflata*, *Trochammina* sp. A (= *Trochammina squamata* of authors, not *Trochammina squamata* Parker and Jones, 1865) and *Arenoparrella mexicana*, in living and total assemblages were restricted to the marsh areas. *Quinqueloculina* in living and total assemblages was distributed in normal marine to hypersaline protected areas at the outer part of the lagoon and inlets. This genus was found in particularly high numbers in living and total assemblages at the washover fan.

The fossil assemblages in short cores (about one meter) of the outer fringe marsh and tidal flats had fewer specimens and species than total assemblages in surface sediments. This indicated that the fossilization potential is generally low, but appears to be great for only agglutinated trochamminid species. While the calcareous tests were not preserved at all in the outer fringe marsh subsurface, the dominant calcareous species (*Elphidium excavatum* and *Ammonia beccarii*) living in surface sediments in tidal flats were only preserved in low concentrations in the subsurface. A significant taphonomic loss was due probably to mechanical destruction, predation, and calcium carbonate dissolution in subsurface sediments.

The values of species diversity (H(S)) and equitability (E) showed wide ranges within the barrier island system. The values of species diversity (H(S)) and equitability (E) exhibit a striking contrast between the marshes and other areas (lagoonal tidal-flats

and channels-inlets-shoreface). Four environments can be distinguished: (environment 1) the brackish marsh and channel (stations 1-3), the mean value for H(S) equals 1.94 and E equals 0.49; (environment 2) the lagoonal tidal flats (stations 4-22), the mean value for H(S) equals 0.84 and E equals 0.19; (environment 3) the lagoonal marshes (stations 23-39), the mean value for H(S) equals 1.40 and E equals 0.41; (environment 4) the channels-inlets-shoreface (stations 40-57), the mean value for H(S) equals 0.60 and E equals 0.18. The higher values for species diversity (H(S)) in the marshes are the result of higher equitability (E) of the arenaceous species in these areas. The dominance of *Elphidium excavatum* in the tidal flats, channels, inlets, and shoreface results in lower values of equitability (E) and consequently lower diversity (H(S)) in these areas.

A weak trend is exhibited in the relationships between species diversity (H(S)) and two environmental variables (water depth and distance from inlet). The values of species diversity (H(S)) (0.98-1.96) in water depths (High High Water datum) of zero to 0.9 meters were generally higher than in water depths of 1.0 to 18 meters. The values of species diversity (H(S)) decreased from the inner to middle part of the lagoon, and were relatively constant with low values of species diversity (H(S)) in the outside of the inlet. However, species diversity (H(S)) had wide ranges near the inlet (< 5 km from the inlet). The pattern of equitability (E) was similar to those of species diversity (H(S)) with water depth and distance from inlet. The low values of species diversity (H(S)) and equitability (E) in the tidal channels, inlets, and shoreface are probably influenced by the high tidal stress in these areas.

Ten biofacies for living foraminiferal populations were established on the basis of distribution of dominant living species (those representing more than 25% of the living population in any station within the *a priori* group) in the 20 *a priori* subenvironments of the barrier island system (Table 30, Fig. 28). The most dominant species, *Ammonia beccarii*, was widely distributed in the lagoonal environments, but the relative

abundance of this species decreased in the outer part of the lagoon (sandy and high tidal energy environments) and eventually disappeared in the shoreface. *Elphidium excavatum* was dominant in the outer part of the lagoon and the outside of the inlet and decreased in importance toward the inner part of the lagoon. Generally, the faunas of normal salinity marshes were characterized by calcareous *Ammonia beccarii* and various types of agglutinated species (e.g., *Trochammina inflata*, *Miliammina fusca*, *Ammobaculites exiguus*). *Quinqueloculina seminula* was restricted to the washover fan facies.

The faunal boundary between three biofacies (the marsh-protected tidal flat (biofacies 2), the open tidal bay-tidal channel (biofacies 3), and the middle lagoon marsh-tidal channel margin (biofacies 6)) of living populations were not sharp because of the relatively intimate association of the open-lagoonal environments. The faunas of these areas were similar and these biofacies are weakly differentiated. The ebb delta (biofacies 9) and shoreface (biofacies 10) were composed of few living foraminiferal species and specimens. The high wave turbulence and tidal currents that sweep these areas may rework and winnow foraminifera from the sediments. Live *Elphidium excavatum* and *Elphidium mexicanum* were dominant in these areas, but living *Ammonia beccarii* were absent.

Eight biofacies of the total foraminiferal assemblages were established on the basis of the dominant species (those representing more than 25% of the total (living+dead) assemblage in any station within the *a priori* group) in the 20 *a priori* subenvironments recognized in the barrier island system (Table 31, Fig. 29). The distribution of total assemblages was similar to the distribution of living populations but the areal distribution and relative abundance of species were not entirely similar. The postdepositional alteration (*e.g.*, transportation and destruction) of the dominant species caused the different areal distribution between living and total assemblages and the reduction in the number of biofacies from ten in living populations to eight in total

assemblages.

At the brackish marsh and channel, the dominant calcareous *Ammonia beccarii* and agglutinated *Trochammina inflata* and *Trochammina "squamata"* in the living population were replaced by the single dominant agglutinated *Trochammina inflata* in the total assemblage. The low salinity (9.4 psu) and acidity (low pH) in the brackish marsh/channel resulted in the destruction of calcareous tests soon after death. The outer bays-offshore areas (biofacies C) consisted of high-tidal influence subenvironments characterized by *Elphidium excavatum* (Table 31, Fig. 29). The abundance of *Elphidium excavatum* in total assemblages in the outer bay (mud, muddy sand and sand flats, and tidal channels) was possibly enhanced by the addition of dead *Elphidium excavatum* flooding through the inlet from offshore.

The dominant species of the eight assemblages in the barrier island system are potentially useful in paleoenvironmental interpretations in late Quaternary coastal deposits. The apparent key species with limited facies range in the present-day assemblages should facilitate facies definition. However, such interpretations must be made with care and it is necessary to analyze the combinations of sedimentary characteristics with faunal features. The taphonomic processes from living to total to fossil assemblages result in the reduction of the tests in the substrates.

A stepwise regression analysis of the densities of the most frequently occurring species in living and total assemblages indicated that variables that were used to describe the environmental setting of the barrier island system were significant at the 95% level for most species (Tables 18 and 19). The environmental variables that were chosen reflected long-term average characteristics (10^0-10^2 years) of the barrier island system and were relatively constant temporally. Numerous studies (Parker and Athearn, 1959; Buzas, 1968; Matera and Lee, 1972; Scott and Medioli, 1980b) suggested that while living foraminiferal populations reflect short-term environmental characteristics, total foraminiferal assemblages are useful indicators for the

interpretation of long-term environmental conditions. Long-term ecological parameters (physical factors) should impact species density of the total assemblage. Therefore, the results of analysis on total assemblages are more meaningful than analysis of only living populations. Biotic environmental factors such as nutrients and predation are only useful for the correlations between densities of living species and environmental conditions.

The results of canonical variate analysis performed on the 20 most abundant living foraminiferal species showed that outer tidal flats (groups 4, 7 and 9) and the deep tidal channel (group 16) were clearly discriminated from the other groups and from one another (Fig. 23). The separation of species within these groups is related to the degree of tidal current influence. The results of canonical variate analysis performed on the 29 most abundant species of the total assemblages revealed that inner and outer fringe marshes (groups 10,11 and 13) and the restricted bay (group 2) were quite distinct from the other groups and from one another (Fig. 24). Fig. 23 and Fig. 24 illustrates that the distribution patterns in the barrier island system were different between living and total assemblages. The changes in distribution patterns are probably related to post-mortem processes acting upon the dead-assemblage part of the total assemblage. The classification results of two analyses indicated that approximately 98% of *a priori* grouped cases were correctly matched. Consequently, foraminiferal populations and assemblages in surface sediments from 20 different depositional environments exhibit distribution patterns useful for distinguishing among subenvironments of the barrier island system.

On the basis of this study, modern physical characteristics, pollen and foraminiferal data are useful for discriminating sedimentary environments of a barrier island system, and provide a model for paleoenvironmental interpretations in late Quaternary coastal deposits. In general, the brackish tidal creeks that drain into the lagoon may be identified in the sedimentary record by very poorly sorted silt with large

amounts of organic matter, high pollen concentrations, 7% *Ambrosia* (ragweed) pollen, high values of foraminiferal species diversity ($H(S)>1.4$), and almost totally arenaceous foraminiferal species. The inner shallow parts of the lagoon may be identified in the sedimentary record by very poorly sorted silt with moderate to minor amounts of organic matter, bioturbation, low pollen concentrations, 4% *Ambrosia* (ragweed) pollen, medium values of species diversity ($0.7<H(S)<1.4$), and *Ammonia beccarii* and *Elphidium excavatum*. The channels and deep parts of the lagoon may be identified in the sedimentary record by very poorly sorted sand with minor amounts of organic matter, mollusc shell fragments, low species diversity ($H(S)<0.7$), and *Elphidium excavatum*. The outer shallow parts of the lagoon may be identified in the sedimentary record by very poorly to poorly sorted sand (>70% sand) with minor amounts of organic matter, bioturbation, small mollusc shell fragments, low to medium values of species diversity ($0<H(S)<1.4$), and *Elphidium excavatum*. The inner fringe marshes may be identified in the sedimentary record by very poorly sorted mud with large amounts of organic matter (stems and roots), bioturbation and shells of the gastropod *Neritina*, high pollen concentrations, 5% *Ambrosia* (ragweed) pollen, medium values of species diversity ($0.7<H(S)<1.4$), and calcareous *Ammonia beccarii* and agglutinated *Miliammina fusca*, *Arenoparrella mexicana* and *Trochammina inflata*. The outer fringe marshes may be identified in the sedimentary record by very poorly sorted mud with large amounts of organic matter (stems and roots), bioturbation and shells of the gastropod *Neritina*, low pollen concentrations, decreasing tree pollen and increasing herb pollen, 9% *Ambrosia* (ragweed) pollen, high species diversity ($H(S)>1.4$), calcareous *Ammonia beccarii* and agglutinated *Ammobaculites exiguus*, *Trochammina inflata*, *Miliammina fusca* and *Textularia earlandi*. The inlets and shoreface may be identified in the sedimentary record by poorly to moderately sorted sand, an absence of biogenic structures, echinoid fragments, low species diversity ($H(S)<0.7$) and *Elphidium excavatum*.

Systematics

Sixty-eight species were recorded in this study. Thirty-one of those species were used in the canonical variate analysis and are described below and illustrated in Plates 1-3. The taxa are organized in accordance with the classification in Loeblich and Tappan (1988). Within a genus, species are arranged alphabetically. The material of this study was compared with type, figured, and unfigured specimens lodged in the National Museum of National History, Smithsonian Institution, Washington, D.C. The spatial distribution of each species in the total assemblage of the present study is described in the occurrence section. The recorded distribution of each species on the eastern North America continental shelf (based on Culver and Buzas, 1980) is also included in this section. For ease discussion, relative abundance of foraminiferal species is defined in four categories as follows: most abundant equals more than 50%, abundant equals 25 to 49%, common equals 5 to 24%, and rare equals less than 5% of the total assemblage in the station.

Order FORAMINIFERIDA Eichwald, 1830

Suborder TEXTULARIINA Delage and Herouard, 1896

Superfamily RZEHAKINACEA Cushman, 1933

Family RZEHAKINIDAE Cushman, 1933

Genus *Miliammina* Heron-Allen and Earland, 1930

Miliammina earlandi Loeblich and Tappan

Plate 1, Figure 1

Miliammina earlandi LOEBLICH and TAPPAN, 1955, p. 12, pl. 1, figs. 15, 16. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, fig. 3. -KRAFT and MARGULES, 1971, p. 252, fig. 17.

Description. Wall finely arenaceous, composed of fine sand grains, smooth surfaced; test ovate, quinqueloculine, rounded on the periphery; chambers distinct, rounded; sutures distinct, slightly depressed; aperture rounded, terminal.

Remarks. Specimens of *M. earlandi* matched the holotype and several hypotypes observed USNM collections.

Occurrence. M. earlandi occurred in low frequency (2% of the total assemblage) in the high elevation of the inner exposed fringe marsh (station 27). This species was reported on shoals of the upper estuary in the James River (Nichols and Norton, 1969), and in tributary creeks and marshes in the Rappahannock estuary of Chesapeake Bay (Ellison and Nichols, 1970). It has also been reported as rare in western tidal streams and mid-bay facies of the Indian River Bay, Delaware (Kraft and Margules, 1971).

Miliammina fusca (Brady)

Plate 1, Figure 2

Quinqueloculina fusca BRADY, 1870, p. 286, pl. 11, figs. 2,3.

Miliammina fusca (Brady). -PARKER, 1952a, p. 404, pl. 3, figs. 15,16. -PARKER, 1952b, p. 452, pl. 2, figs. 6a,b. -MILLER, 1953, p. 51, pl. 7, fig. 10. -RONAI, 1955, p. 143, pl. 20, fig. 7. -PARKER and ATHEARN, 1959, p. 340, pl. 50, figs. 11,12. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, fig. 4. -KRAFT and MARGULES, 1971, p. 252, fig. 17. -SCOTT and MEDIOLI, 1980a, p. 40, pl. 2, figs. 1-3.

Description. Wall coarsely arenaceous, composed of fine to medium sand grains, brown color; test elongate to elliptical with rounded periphery, quinqueloculine; chambers distinct, rounded; sutures distinct, depressed; aperture rounded, terminal.

Remarks. Specimens of *M. fusca* matched hypotypes of Parker and Athearn (1959) and Scott and Medioli (1980a).

Occurrence. M. fusca was common in marsh environments. Relatively high frequencies (up to 70% of the total assemblage) of this species characterized the inner and outer fringe marshes and low frequencies (<2% of the total assemblage) characterized the tidal bay. *M. fusca* was not found in high-energy environments (the sand flat, the tidal channel, the ebb delta and the shoreface). Previous records of this species were from brackish water (low salinity, 1-10 psu) (Parker and Athearn, 1959; Ellison and Nichols, 1970) to nearshore water (high salinity, 32 psu) (Parker, 1952a; Miller, 1953). Parker (1952a) found *M. fusca* only at nearshore stations in the Portsmouth area, New Hampshire. Miller (1953) reported it as moderately common in an offshore bar of Mason inlet, North Carolina. Very high frequencies of this species were observed in marsh environments from almost non-marine to near marine of Poponesset Bay, Massachusetts (Parker and Athearn, 1959). It has also been reported in lesser abundance throughout the Rappahannock estuary, Chesapeake Bay (Ellison and Nichols, 1970).

Superfamily LITUOLACEA de Blainville, 1827

Family HAPLOPHRAGMOIDIDAE Maync, 1952

Genus *Haplophragmoides* Cushman, 1910

Haplophragmoides bonplandi Todd and Bronnimann

Plates 1, Figure 3

Haplophragmoides bonplandi TODD and BRONNIMANN, 1957, p. 23, pl. 2, fig. 2. -SCOTT and MEDIOLI, 1980a, p. 40, pl. 2, figs. 4,5. -TODD and LOW, 1981, p. 16.

Descripton. Wall coarsely arenaceous, composed of fine to medium sand grains; test planispiral, periphery rounded, umbilicus deep; 6 to 7 chambers, inflated; sutures

distinct, straight to radial; aperture a low arched opening at the base of the final chamber.

Remarks. Specimens of this species compared well with the holotype and also the hypotype of Scott and Medioli (1980a).

Occurrence. Dead tests of this species were rare to common in the brackish marsh/channel (stations 1-3) (<6% of the total assemblage) and high elevation inner and outer fringe marshes (stations 27 and 36). *H. bonplandi* was recorded in high marsh areas in Nova Scotia where there were more brackish conditions (Scott and Medioli, 1980a).

Haplophragmoides wilberti Andersen

Plate 1, Figure 4

Haplophragmoides wilberti ANDERSEN, 1952b, p. 21, pl. 4, fig. 7. -TODD and LOW, 1961, p. 13, pl. 1, fig. 5. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, fig. 7. -HAMAN, 1983, p. 72, pl. 3. figs. 14, 15.

Description. Wall finely arenaceous; test planispiral, involute, depressed umbilicus, eight chambers in last whorl; seven to eight chambers, increasing gradually in size as added; sutures distinct, straight to gently curved; aperture a low arch-shaped opening at the base of the final chamber.

Remarks. Specimens of this species compared well with the plesiotype of Todd and Low (1961)

Occurrence. Rare to common specimens of this species were recorded in the brackish marsh/channel (stations 1-3) and the outer fringe marsh (station 37) (<7% of the total assemblage). *H. wilberti* was described from brackish water environments, a marsh sample from Barataria Bay, and a bottom sample from Dog Lake, Louisiana by Andersen (1952b). This species appeared in low abundance throughout the Rappahannock River, Virginia (Ellison and Nichols, 1970). Haman (1983) reported it

as the most abundant form in channel and levee subenvironments of the Balize Delta, Louisiana.

Family LITUOLIDAE de Blainville, 1827

Subfamily AMMOMARGINULININAE Podobina, 1978

Genus *Ammobaculites* Cushman, 1910

Ammobaculites exiguus Cushman and Bronnimann

Plate 1, Figure 5

Ammobaculites exiguus CUSHMAN and BRONNIMANN, 1948, p. 38, pl. 7, figs. 7,8. -PARKER, 1952b, p. 443, pl. 1, figs. 16,17. -RONAI, 1955, p. 142, pl. 20, fig. 3. -ELLISON and NICHOLS, 1970, p. 15, pl. 2, fig. 6. -HAMAN, 1983, p. 72, pl. 5, figs. 1-4.

Ammobaculites dilatatus CUSHMAN and BRONNIMANN, 1948, p. 39, pl. 7, figs. 10,11. -PARKER, 1952b, p. 443, pl. 1, fig. 23. -RONAI, 1955, p. 142, pl. 20, fig. 2. -PARKER and ATHEARN, 1959, p. 340, pl. 50, figs. 4,5. -ELLISON and NICHOLS, 1970, p. 15, pl. 2, fig. 5, -SCOTT and MEDIOLI, 1980a, p. 35, pl. 1, figs. 9,10

Description. Wall coarsely arenaceous, composed of medium to fine sand grains and heavy minerals; test elongate, periphery rounded, umbilicus not deeply depressed; initial chambers planiserial and later chambers uniserial, chambers distinct; sutures indistinct; aperture round, terminal.

Remarks. The upper uncoiled portions of the specimens in this study were broken off. The specimens of this study were very similar to the paratype (Cushman Collection # 56770) and Parker and Athearn's (1959) hypotype of *Ammobaculites dilatatus*. The sutures were horizontal and indistinct and the specimens also resembled several hypotypes of *Ammobaculites exiguus*. Culver and Buzas (1980) suggested that *A. exiguus* and *A. dilatatus* are conspecific.

Occurrence. A. exiguus was widely distributed in the lagoon. It was most abundant in the fringe marsh of Smith Island (station 35) (53% of the total assemblage) and not observed in the tidal channel, the ebb delta and the shoreface. *A. exiguus* was recorded rarely in brackish-water bays and lagoons of the New York Bight (Ronai, 1955), in the Rappahannock River, Virginia (Ellison and Nichols, 1970), and most commonly in the marsh environments of Poponesset Bay, Massachusetts (Parker and Athearn, 1959).

Superfamily TROCHAMMINACEA Schwager, 1877

Famaily TROCHAMMINIDAE Schwager, 1877

Subfamily TROCHAMMININAE Schwager, 1877

Genus *Trochammina* Parker and Jones, 1859

Trochammina advena Cushman

Plate 1, Figures 6, 7

Trochammina advena CUSHMAN, 1922a, p. 20, pl. 1, figs. 2-4. -PARKER, 1952a, p. 407, pl. 4, figs. 3a, b. -SCHNITKER, 1971, p. 212, pl. 1, fig. 16.

Description. Wall arenaceous, composed of fine to medium sand grains, smooth surfaced; test trochoid, the dorsal side more flattened than the ventral side, 4.5 whorls, umbilicus deep; chambers distinct, inflated; sutures distinct, depressed; aperture rounded at the inside of the final chamber.

Remarks. Specimens of this species compared well with the holotype (Cushman, 1922) and the hypotype of Parker (1952a).

Occurrence. T. advena was collected in low frequencies (<3% of the total assemblage) at the brackish marsh/channel (stations 1-3) and at mean sea level at fringe marshes (stations 29, 35 and 37). Parker (1952a) reported it as rare off Portsmouth, New Hampshire. It was also reported as rare at depths of 12-155 m south of Cape Hatteras, North Carolina (Schnitker, 1971).

Trochammina inflata (Montagu)

Plate 1, Figures 8, 9

Nautilus inflatus MONTAGU, 1808, p. 81, pl. 18, fig. 3

Rotalina inflata (Montagu). -WILLIAMSON, 1858, p. 50, pl. 4, figs. 93,94.

Trochammina inflata (Montagu). -PARKER and JONES, 1859, p. 347. -PARKER, 1952a, p. 407, pl. 4, figs. 6,10. -PARKER, 1952b, p. 459, pl. 3, figs 1a,b. -RONAI, 1955, p. 144, pl. 20, fig. 11. -PARKER and ATHEARN, 1959, p. 341, pl. 50, figs, 18-20. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, figs. 8,9. -SCOTT and MEDIOLI, 1980a, p.44, pl. 3, figs 12-14, pl. 4, figs. 1-3.

Description. Wall finely arenaceous, composed of fine sand grains, smooth surfaced; test trochoid, periphery rounded, umbilicus deeply depressed and open; six chambers, distinct, much more inflated in the last chamber, all chambers visible dorsally, only those of the last-formed coil visible ventrally, increasing in size gradually; sutures distinct, impressed, nearly straight; aperture small, an arched slit formed at the base of the last chamber on the ventral side.

Remarks. Specimens of this species matched hypotypes of Parker (1952a), Parker and Athearn (1959) and Scott and Medioli (1980a).

Occurrence. T. inflata was abundant in marsh environments. Specimens were found in high frequencies (up to 43% of the total assemblage) in the brackish marsh/channel and inner and outer fringe marshes and in low frequencies (<2% of the total assemblage) in the restricted bay and the mud flat. *T. inflata* was not recorded in high-energy environments (sand substrates). *T. inflata* has been commonly recorded in shallow water and marsh environments. It appeared in low numbers in shallow water bays and lagoons (Parker, 1952a, 1952b; Ronai, 1955), and estuaries (Ellison and Nichols, 1970). High abundances of this species have been reported at high marshes in the normal marine conditions in Poponesset Bay, Massachusetts (Parker and Athearn,

1959) and Nova Scotia (Scott and Medioli, 1980a).

Trochammina ochracea (Williamson)

Plate 1, Figures 10, 11

Rotalina ochracea WILLIAMSON, 1858, p. 55, pl. 4, fig. 112, pl. 5, fig. 113.

Trochammina ochracea (Williamson). -CUSHMAN, 1920, p. 75, pl. 15, fig. 3. -TODD and LOW, 1961, p. 16, pl. 1, fig. 18. -HEDLEY et al., 1964, p. 418, fig. 2. -SCOTT and MEDIOLI, 1980a, p. 45, pl. 4, figs. 4,5. -BUZAS and SEVERIN, 1982, p. 23, pl. 1, figs. 10,11.

Description. Wall arenaceous, smooth surfaced; test trochoid, flattened concavo-convex, slightly depressed umbilicus; chambers convolution, the last convolution of each chamber extend to the umbilicus; sutures distinct, arcuate.

Remarks. Specimens of this species resembled hypotypes of Scott and Medioli (1980a) and Buzas and Severin (1982).

Occurrence. Low numbers (<20 specimens/70 ml of sediment) of *T. ochracea* were scattered in the bay, the tidal channel and the ebb delta. It was found rarely in marsh environments. Most specimens were found in sandy substrates. Scott and Medioli (1980a) recorded it as rare on marshes around Nova Scotia. Buzas and Severin (1982) also reported it as rare in the southern part of the Indian River, Florida.

Trochammina "squamata"

Plate 1, Figures 12, 13

Trochammina squamata PHLEGER and WALTON, 1950, p. 281, pl. 2, figs. 12, 13. -PARKER, 1952b, p. 460, pl. 3, figs. 4a, b. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, figs. 12, 13. -SCOTT and MEDIOLI, 1980a, p. 45, pl. 4, figs. 6, 7 (not *T. squamata* Jones and Parker, 1860).

Description. Wall arenaceous, composed of fine to medium sand grains; test

trochoid, concavo-convex, circular, excavated umbilicus; more than 7 chambers on the ventral side, all chambers visible on the dorsal side, only those of the last-formed whorl visible on the ventral side; sutures distinct, curved; extra-umbilical aperture.

Remarks. Although specimens of *T.* "*squamata*" of this study were very similar to the Phleger and Walton's (1950) hypotype of *Trochammina squamata*, it was different from *T. squamata* Jones and Parker (1860). *Trochammina squamata* Jones and Parker (1860) was described as "only the four chambers of the last whorl visible on umbilical side, final chamber occupying about a quarter to a half of the umbilical side". In addition, Hedley et al. (1964) compared specimens of *T. squamata* Jones and Parker (1860) to *T. squamata* Parker and Jones (1865) and suggested that they are different. The test of *T. squamata* Parker and Jones (1865) is much flatter, circular and more chambers. The specimens in this study do not resemble the description of *T. squamata* Jones and Parker (1860). However, many authors have called specimens identical to those in this study *Trochammina squamata.* Therefore, this species is referred to here as *Trochammina "squamata"*.

Occurrence. T. "*squamata*" was widely distributed in the lagoon. It was found in low frequencies (<6% of the total assemblage) in the lagoonal environments. This species was not observed outside of the inlet.

Trochammina sp. A

Plate 1, Figures 14, 15

Description. Wall arenaceous, composed of fine to medium sand grains, smooth surfaced; test trochoid, concavo-convex, periphery rounded, depressed umbilicus; chambers distinct, inflated; sutures distinct, curved, depressed on the umbilical side; extra umbilical aperture.

Remarks. Specimens of *Trochammina* sp. A were very similar to previous species. However, specimens of this species were different from the type of specimens

of *T. "squamata"* . The test of *T. "squamata"* is much circular.

Occurrence. Trochammina sp. A appeared in low frequencies (<2% of the total assemblage) throughout the lagoon. Specimens of this species were recorded in high frequencies (7-19% of the total assemblage) at the brackish marsh/channel (stations 1-3). *Trochammina* sp. A was not found outside of the inlet.

Subfamily ROTALIAMMININAE Saidova, 1981

Genus *Tiphotrocha* Saunders, 1957

Tiphotrocha comprimata (Cushman and Bronnimann)

Plate 1, Figures 16, 17

Trochammina comprimata CUSHMAN and BRONNIMANN, 1948, p. 41, pl. 8, figs. 1-3.

Tiphotrocha comprimata (Cushman and Bronnimann). -SAUNDERS, 1957a, p. 11. -PARKER and ATHEARN, 1959, p. 341, pl. 50, figs. 14-17. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, figs. 14, 15. -SCOTT and MEDIOLI, 1980a, p. 44, pl. 5, figs. 1-3.

Description. Wall finely arenaceous, composed of fine sand grains, smooth surfaced; test trochospiral, compressed, with an irregular lobate periphery, slightly convex on the dorsal side, concave on the ventral side, slightly deepered umbilicus; chambers distinct, all chambers visible on the dorsal side, only those of last formed whorl visible on the ventral side, early whorls regularly increasing in size, those of the last whorl irregular in shape and inflated. The last chamber is roughly T-shaped in ventral view; sutures distinct, curved; apertures situated at the umbilical lobes of the last chamber.

Remarks. Specimens of this species compared well with hypotypes of Parker and Athearn (1959) and Scott and Medioli (1980a).

Occurrence. T. comprimata was found in low frequencies (<6% of the total

assemblage) in the brackish marsh/channel, the restricted bay, the open bay and fringe marshes. It was not observed in high-energy environments. *T. comprimata* is recorded as most abundant at brackish marshes of Poponesset Bay, Massachusetts (Parker and Athearn, 1959) and the Rappahannock River, Virginia (Ellison and Nichols, 1970). Scott and Medioli (1980a) also recorded large populations at marsh areas of Nova Scotia.

Subfamily JADAMMININAE Saidova, 1981

Genus *Jadammina* Bartenstein and Brand, 1938

Jadammina macrescens (Brady)

Plate 2, Figures 1, 2

Trochammina inflata (Montagu) var. *macrescens* BRADY, 1870, p. 290, pl. 11, figs. 5a-c.

Trochammina macrescens (Brady). -PARKER, 1952a, p. 408, pl. 4, figs. 8a, b. -PARKER, 1952b, p. 460, pl. 3, figs. 3a, b. -RONAI, 1955 , p. 144, pl. 20. fig. 12. -PARKER and ATHEARN, 1959, p. 341, pl. 50, figs. 23-25. -ELLISON and NICHOLS, 1970, p. 16, pl. 1, figs. 10, 11. -SCOTT and MEDIOLI, 1980a, p. 44, pl. 3, figs. 1-8.

Jadammina macrescens (Brady). -MURRAY, 1971, p. 41, pl. 13, figs. 1-5.-MURRAY, 1979, p. 28, figs. 6k-m.

Description. Wall finely arenaceous, composed of fine sand grains with organic cement, smooth surfaced; test trochoid, periphery rounded, slightly depressed umbilicus, brown color; chambers distinct, increasing in size as added, all chambers visible dorsally, only those of last-formed whorl visible ventrally, inflated; sutures distinct, slightly depressed, curved; a low arched slit aperture formed at the base of the last chamber on the ventral side.

Remarks. Specimens of *J. macrescens* were very similar to the Parker's (1952a,

b), Parker and Athearn's (1959) and Scott and Medioli's (1980a) hypotypes of *Trochammina macrescens.*

Occurrence. J. macrescens occurred in common (10-17% of the total assemblage) at the brackish marsh and at high elevation at fringe marshes. It was rarely found at the restricted bay, the mud flat and low marsh areas (<2% of the total assemblage). It has been reported as *Trochammina macrescens* in brackish marshes, bays, and estuaries (Parker, 1952 a,b; Ronai, 1955; Parker and Athearn, 1959; Ellison and Nichols, 1970; Scott and Medioli, 1980a).

Subfamily ARENOPARRELLINAE Saidova, 1981

Genus *Arenoparrella* Andersen, 1951

Arenoparrella mexicana (Kornfeld)

Plate 2, Figures 3, 4

Trochammina inflata (Montagu) var. *mexicana* KORNFELD, 1931, p. 86, pl. 13, fig. 5.

Arenoparrella mexicana (Kornfeld). -ANDERSON, 1951, p. 31, fig. 1. -PARKER and ATHEARN, 1959, p. 340, pl. 50. figs. 8-10. -ELLISON and NICHOLS, 1970, p. 15, pl. 2, figs. 1,2. -KRAFT and MARGULES, 1971, p. 251, fig. 17. -SCOTT and MEDIOLI, 1980a, p. 35, pl. 4, figs. 8-11.

Description. Wall finely arenaceous, composed of fine sand grains, smooth surfaced; test trochoid, moderately convex on the dorsal side, slightly depressed, closed umbilicus; six chambers in the last-formed coil, slightly inflated on dorsal side, all chambers visible on the dorsal side, only those of the last-formed coil visible on the ventral side, increasing regularly in size as added; sutures distinct, slightly depressed, slightly curved; aperture a curved slit at the final chamber on the ventral side.

Remarks. Specimens of this species compared well with hypotypes of Parker and Athearn (1959) and Scott and Medioli (1980a).

Occurrence. A. mexicana occurred in rare to abundant at brackish and fringe marshes. The large assemblage (15-40% of the total assemblage) was found at the brackish marsh (stations 1,2) and high elevation of the inner exposed fringe marsh (station 27). This species also was recorded in low frequencies (3% of the total assemblage) at tidal flats near the marshes. Parker and Athearn (1959) reported it as most common in less marine marsh environments of Poponesset bay, Massachusetts. Ellison and Nichols (1970) reported it in tributary creeks and marshes in the Rappahannock River, Virginia. *A. mexicana* was the first reported in marsh areas around Nova Scotia by Scott and Medioli (1980a).

Superfamily TEXTULARIACEA Ehrenberg, 1838

Family TEXTULARIIDAE Ehrenberg, 1838

Subfamily TEXTULARINAE Ehrenberg, 1838

Genus *Textularia* Defrance, 1824

Textularia earlandi Parker

Plate 2, Figure 5

Textularia earlandi PARKER, 1952b, p. 458 (footnote). -PARKER and ATHEARN, 1959, p. 340, pl. 50, fig. 7. -KRAFT and MARGULES, 1971, p. 252, fig. 17.

Description. Wall coarsely arenaceous, composed of medium sized sand grains; test elongate, slightly curved; chambers distinct, biserial, regularly increasing in size; sutures distinct, depressed; aperture a curved slit at the base of the final chamber.

Remarks. Specimens of this species resembled the hypotype of Parker and Athearn (1959). The new name *Textularia earlandi* was proposed for *Textularia tenuissima* Earland by Parker (1952b).

Occurrence. T. earlandi was scatterly distributed in the lagoon. It was found in high frequency (38% of the total assemblage) at the outer fringe marsh (station 36). This species also occurred in very low frequencies (<1% of the total assemblage) in the

brackish marsh, sand and mud flats, and fringe marshes. Parker and Athearn (1959) recorded it at marsh environments in the near marine conditions in Poponesset Bay, Massachusetts. Kraft and Margules (1971) also recorded it in bays of the Indian River Bay, Delaware.

Suborder MILIOLINA Delage and Herouard, 1896

Superfamily MILIOLACEA Ehrenberg, 1839

Family HAUERINIDAE Schwager, 1876

Subfamily HAUERININAE Schwager, 1876

Genus *Quinqueloculina* d'Orbigny, 1826

Quinqueloculina dimidiata Terquem

Plate 2, Figure 6

Quinqueloculina dimidiata TERQUEM, 1876, pl. 11, figs. 5a-c. -MURRAY, 1968. p. 94, pl. 1, fig. 2.

Quinqueloculina lata TODD and LOW, 1961, p. 15, pl. 1, figs. 10-13, 15. -TODD and LOW, 1981, p. 22 (not *Q. lata* Terquem, 1876).

Description. Wall calcareous, imperforate, smooth surfaced; test ovate, periphery rounded, quinqueloculine; chambers distinct, rounded; sutures distinct, slightly depressed; aperture rounded, terminal, with bifid tooth.

Remarks. Specimens of *Q. dimidiata* compared well with hypotype (USNM #624933). Todd and Low (1961, 1981) misidentified it as *Quinqueloculina lata. Q. lata* has parallel sides of test and a simple tooth.

Occurrence. Q. dimidiata was found in the more marine conditions (30-32 psu salinity). Large populations (18%) and assemblages (24%) were recorded in stations 47 and 48 from the washover fan. It appeared in low frequencies (<5% of the total assemblage) at the outer tidal flat (sand and mud), the fringe marsh, the ebb delta, and the shoreface.

Quinqueloculina seminula (Linne)

Plate 2, Figure 7

Serpula seminulum LINNE, 1758, p. 786, pl. 2, figs. 1a-c.

Quinqueloculina seminula (Linne). -PARKER, 1952a, p. 406, pl. 3, figs. 21a,b, 22a,b, pl. 4, figs. 1,2. -PARKER, 1952b, p. 456, pl. 2, figs. 7a,b. -SCHNITKER, 1971, p. 208, pl. 3, figs. 1a-c. -BUZAS and SEVERIN, 1982, p.26, pl. 3, figs. 7,8.

Description. Wall calcareous, imperforate; test ellipsoidal, quinqueloculine, periphery rounded; chambers distinct, inflated, arcuate; sutures distinct, depressed; aperture large, terminal, elliptical, with a simple tooth.

Remarks. Specimens of this species matched hypotypes of Parker (1952a, b) and Buzas and Severin (1982).

Occurrence. *Q. seminula* was widely distributed in the study area. It was found in high frequencies (41-67% of the total assemblage) at stations 47 and 48 from the washover fan. This species was also found in low frequencies (<5% of the total assemblage) outside of the lagoon, the ebb delta and the shoreface. Parker (1952b) reported it as abundant in sandy areas at depths of less than 90 meters in Buzzards Bay, Massachusetts. Schnitker (1971) recorded it with a patchy distribution at depths between 20 and 60 meters in Raleigh Bay and south of Cape Lookout on the central shelf, North Carolina. It was also reported in large numbers throughout the Indian River by Buzas and Severin (1982).

Quinqueloculina seminula (Linne) *jugosa* Cushman

Plate 2, figure 8

Quinqueloculina seminula (Linne) var. *jugosa* CUSHMAN, 1944, p. 13, pl.2, fig. 15. -PARKER, 1948, p. 239, pl. 1, fig. 5. -PARKER, 1952b, p. 456, pl. 2, figs. 8a, b.

Description. Wall calcareous, imperforate; test ovate, quinqueloculine, rounded on the periphery; chambers distinct, arcuate with oblique costae; sutures distinct, slightly depressed; aperture large, terminal, a simple tooth.

Remarks. Specimens of this subspecies compared well with the holotype and also with the hypotype of Parker (1952b).

Occurrence. *Q. seminiula jugosa* was found in low frequencies (0.4-3.9% of the total assemblage) in stations 47 and 48 from the washover fan. It was present at depths of less than 90 m on the adjacent continental shelf (Parker, 1948, 1952b). Parker (1948) recorded it as percentage rating in the Maryland traverse, but as rare in the New Jersey and Block Island traverses. It was also reported as rare but widely distributed on sandy or stony bottoms in Buzzards Bay, Massachusetts (Parker, 1952b).

Suborder ROTALIINA Delage and Herouard, 1896

Superfamily BOLIVINACEA Glaessner, 1937

Family BOLIVINIDAE Glaessner, 1937

Genus *Bolivina* d'Orbigny, 1839

Bolivina striatula Cushman

Plate 2, Figure 9

Bolivina striatula CUSHMAN, 1922b, p. 27, pl. 3, fig. 10. -BUZAS et al., 1977, p. 75, pl. 2, figs. 5-10. -BUZAS and SEVERIN, 1982, p. 32, pl. 5, fig. 8.

Description. Wall calcareous, perforate, initial one-half to two-thirds of test with striations; test elongate, nearly parallel sides, compressed, rounded on the periphery; biserial chambers, slightly inflated; sutures distinct, slightly curved, depressed; a slitlike aperture at the lower one-half of the last chamber.

Remarks. Specimens of this species compared well with Cushman's (1922b) holotype and Buzas and Severin's (1982) hypotype (USNM # 310194).

Occurrence. One living specimen of *B. striatula* was found at station 11 from the

middle/outer muddy sand flat. Buzas and Severin (1982) reported it as common throughout the Indian River, Florida.

Superfamily DISCORBACEA Ehremberg, 1838

Family HELENINIDAE Loeblich and Tappan, 1988

Genus *Helenina* Saunders, 1961

Helenina anderseni (Warren)

Plate 2, Figures 10, 11

Pseudoeponides anderseni WARREN, 1957, p. 39, pl. 4, figs. 12-15. -PARKER and ATHEARN, 1959, p. 341, pl. 50, figs. 28-31.

Helenina anderseni (Warren). -SAUNDERS, 1957b, p. 374, figs. 1,2. -TODD and LOW, 1961, p. 18, text fig. 2-2. -SCOTT and MEDIOLI, 1980a, p. 40, pl. 5, figs. 10,11.

Description. Wall calcareous, finely perforate; test trochoid, biconvex, almost flat on the dorsal side, slightly depressed umbilical area which is closed; six to seven chambers in the last whorl, distinct, all chambers visible dorsally, only those of last-formed whorl visible ventrally, prolongation of the last chamber which forms a lobe over the umbilical area; sutures distinct, curved and deeply incised on both sides; primary aperture single or two openings at the base of the final chamber, supplementary apertures are present in deeply incised sutures on both sides.

Remarks. Specimens of this species compared well with hypotypes of Saunders (1957b) and Todd and Low (1961).

Occurrence. Seven living specimens of *H. anderseni* were found at the outer fringe marsh of Hog Island (station 33). *H. anderseni* was reported (as *Pseudoeponides anderseni*) in low frequencies at marshes in the near-marine conditions of Poponesset Bay, Massachusetts (Parker and Athearn, 1959). Scott and Medioli (1980a) reported it for the first time in marshes of Nova Scotia.

Family ROSALINIDAE Reiss, 1963

Genus *Rosalina* d'Orbigny, 1826

Rosalina floridana (Cushman)

Plate 2, Figures 12, 13

Discorbis floridana CUSHMAN, 1922b, p.39, pl. 5, figs. 11, 12. -PARKER, 1948, p. 238, pl. 5, figs. 23a, b.

Rosalina floridana (Cushman). -PARKER, 1954, p. 524, 525, pl. 8, figs. 19, 20. -SCHNITKER, 1971, p. 210, pl. 5, figs. 19a-c. -BUZAS et al., 1977, p. 86, pl. 4, figs. 7-9.

Description. Wall calcareous, moderately perforate on the spiral side, perforate to imperforate on the umbilical side; test trochoid, rounded periphery, slightly depressed umbilicus; chambers distinct, inflated, rapidly increasing in size as added; sutures distinct, deeply depressed on the umbilical side, nearly straight on both sides; extraumbilical arched aperture at the base of the final chamber.

Remarks. Specimens of this species compared well with the holotype and hypotypes of Parker (1954) and Buzas et al. (1977).

Occurrence. R. floridana had a wide distribution in mud, mixed and sand flats, the outer fringe marsh, the tidal channel, the ebb delta, and the shoreface but was usually recorded as rare (< 2.5% of the total assemblage). *R. floridana* was recorded as rare in the Maryland traverse (Parker, 1948) and the North Carolina continental shelf (Schnitker, 1971).

Superfamily GLABRATELLACEA Loeblich and Tappan, 1964

Family GLABRATELLIDAE Loeblich and Tappan, 1964

Genus *Glabratella* Dorreen, 1948

Glabratella sp. A

Plate 2, Figures 14, 15, 16

Description. Wall calcareous, finely perforate but imperforate on umbilical side; test trochoid, periphery rounded, lobate, deep umbilicus filled with granular material; chambers distinct, regularly increasing in size as added, all chambers visible dorsally, only those of the last-formed coil visible ventrally; sutures distinct, nearly straight, slightly depressed on the dorsal side, depressed on the ventral side; aperture arched at the base of the last chamber filled with granular material.

Remarks. Specimens of this species did not match any type of *Glabratella* in the USNM collections.

Occurrence. Glabratella sp. A was rare (< 3.8% of the total assemblage) but widely distributed in the study area. It was found rarely in marsh areas.

Genus *Glabratellina* Seiglie and Bermudez, 1965

Glabratellina sp. A

Plate 3, Figures 1, 2

Description. Wall calcareous, perforate on the dorsal side, imperforate on the umbilical side; highly trochospiral test, rounded on the periphery, lobate, deep and open umbilicus filled with granular material; chambers distinct, globose, arranged in three coils, with four to five chambers in each coil, gradually increasing in size as added; sutures distinct, curved on the dorsal side, radial on umbilical side; aperture an arched opening at the base of the last chamber on umbilical side.

Remarks. Specimens of this species were similar to the hypotype of *Glabratellina sagrai* (Buzas et al., 1977), but it had a much deeper umbilicus and fewer chambers (4.5-5) than *G. sagrai.*

Occurrence. Glabratellina sp. A was found in low frequencies (<2% of the total assemblage) in the restricted bay, the sand flat, the outer mud flat, and the outer fringe marsh.

Superfamily NONIONACEA Schultze, 1854

Family NONIONIDAE Schultze, 1854

Subfamily NONIONINAE Schultze, 1854

Genus *Haynesina* Banner and Culver, 1978

Haynesina germanica (Ehrenberg)

Plate 3, Figure 3

Nonionina germanica EHRENBERG, 1840, p. 23. -EHRENBERG, 1841, pl. 2, figs. 1a-g.

Nonion germanicum (Ehrenberg). -CUSHMAN, 1930, p. 8, pl. 3, figs. 5a, b.

Nonion tisburyensis BUTCHER, 1948, p. 21,22, figs. 1-3.

Protelphidium tisburyensis (Butcher). -PARKER and ATHEARN, 1959, p. 333-343, pl. 50, figs. 26,32.

Protelphidium anglicum MURRAY, 1965, p. 149, 150, pl. 26, figs. 1-6.

Haynesina germanica (Ehrenberg). -BANNER and CULVER, 1978, p. 191-195, pl. 4, figs. 1-6, pl. 5, figs. 1-8, pl. 6, figs. 1-7, pl. 7, figs. 1-6, pl. 8, figs. 1-10, pl. 9, figs. 1-11, 15, 18. -BUZAS and SEVERIN, 1982, p. 38, 39, pl. 8, figs. 10. -BUZAS et al., 1985, p. 1089, figs. 8.4, 8.5.

Description. Wall calcareous, perforate; test planispiral, involute, slightly inflated, rounded periphery, depressed umbilicus, small granules along sutures and in umbilical area; chambers distinct, eight to nine chambers, regularly increasing in size as added; sutures distinct, curved, slightly depressed to deeply depressed towards the umbilicus; aperture a low arch with obscuring granules at the base of the last chamber.

Remarks. Specimens of *H. germanica* did not exactly match the hypotype of Buzas and Severin (1982). Specimens of this study tended to have less granular material in the umbilical area than those figured Banner and Culver (1978). However, most specimens compared well with the hypotype of Cushman (1930).

Occurrence. H. germanica was widely distributed in the study area. It was common to abundant (15-37% of the total assemblage) in stations 23, 31, 33, 39 and 41 from the inner protected fringe marsh, the middle lagoon marsh, the outer fringe marsh, and the tidal channel margin, but rare to common (0.3-8% of the total assemblage) in the other areas. Only dead tests were recorded in the middle/outer muddy sand flat, the washover fan, and the ebb delta. One living specimen was found in the brackish channel. Buzas and Serverin (1982) found it in low abundance in the northern half of the Indian River, Florida.

Genus *Nonionella* Cushman, 1926

Nonionella atlantica Cushman

Plate 3, Figures 4, 5

Nonionella atlantica CUSHMAN, 1947, p. 90, pl. 20, figs. 4, 5. -PARKER, 1952b, p. 453, pl. 3, figs. 15a, b. -BUZAS and SEVERIN, 1982, p. 41, pl. 10, figs. 10- 12.

Description. Wall calcareous, smooth surfaced except the lobe on the ventral side which is covered by papillae; test trochoid, asymmetrical, compressed, rounded on the periphery, depressed umbilicus; chambers distinct, slightly inflated, gradually increasing in size as added; sutures distinct, slightly curved, slightly depressed to depressed near umbilical area on the ventral side, small granules along sutures; aperture a low arch at the base of the last-formed chamber.

Remarks. Specimens of this species compared well with the holotype of Cushman (1947) and hypotypes of Parker (1952b) and Buzas and Severin (1982).

Occurrence. N. atlantica was found in very low frequencies (0.2-0.3% of the total assemblage) at the sand flat, the tidal channel, the ebb delta and the shoreface. Dead tests were only found in these areas except at station 45 (deep tidal channel) which occurred living and dead tests. *N. atlantica* was reported as rare off Buzzards Bay,

Massachusetts by Parker (1952b). Buzas and Severin (1982) also found a few specimens throughout the Indian River, Florida.

Superfamily CHILOSTOMELLACEA Brady, 1881

Family TRICHOHYALIDAE Saidova, 1981

Genus *Buccella* Andersen, 1952

Buccella frigida (Cushman)

Plate 3, Figures 6, 7

Pulvinulina frigida CUSHMAN, 1922c, p. 12.

Eponides frigida (Cushman). -CUSHMAN, 1931, p. 45.

Eponides frigidus (Cushman). -CUSHMAN, 1941, p.37, pl. 9, figs. 16, 17. -PARKER, 1952a, p. 419, pl. 6, figs. 12a, b. -PARKER 1952b, p.449, pl. 5, figs. 2a, b.

Buccella frigida (Cushman). -ANDERSEN, 1952a, p.144, 145, figs. 4a-c, 5, 6a-c. -RONAI, 1955, p. 148, pl. 21, fig. 16. -TODD and LOW, 1961, p. 18, pl. 1, figs. 24, 25. -MILLER et al., 1982, p. 2364, pl. 2, figs. 9, 10.

Description. Wall calcareous, smooth surfaced on the dorsal side, smooth surfaced and very finely perforate on the ventral side; test trochoid, biconvex or planoconvex, periphery broadly rounded, umbilicus filled with pustules; chambers distinct, slightly inflated, six chambers in the last-formed whorl; sutures distinct, slightly depressed, curved, filled with pustules on the ventral side; aperture is obscured by pustules.

Remarks. Specimens of *B. frigida* compared well with the cotype of Cushman and the hypotype of Todd and Low (1961).

Occurrence. B. frigida was generally rare (<3% of the total assemblage). It was only recorded as dead tests throughout outer part of the lagoon and outside of the inlet. This species occurred at tidal flats, the tidal channel, the ebb delta, and the shoreface.

Relatively high frequency (8.1% of the total assemblage) was recorded in the tidal channel margin near the inlet (station 38). *B. frigida* was reported (as *Eponides frigidus*) as common in Buzzards Bay, Massachusetts by Parker (1952b). *Buccella frigida* (Cushman) was described from the mudlumps off the Passes of the Mississippi River by Andersen (1952). This species was recorded (at frequencies of 0-20%) from brackish-water bays and lagoons of the New York Bight by Ronai (1955).

Superfamily ROTALIACEA Ehrenberg, 1839

Family ROTALIIDAE Ehrenberg, 1839

Subfamily AMMONIINAE Saidova, 1981

Genus *Ammonia* Brunnich, 1772

Ammonia beccarii (Linne)

Plate 3, Figures 8, 9

Nautilus beccarii LINNE, 1758, p. 710.

Ammonia beccarii (Linne). -BRUNNICH, 1772, p. 232. -BUZAS, 1965, p. 62, pl. 4, fig. 1. -KRAFT and MARGULES, 1971, p. 251, fig. 17. -SCHNITKER, 1971. p. 193, pl. 7, fig. 1a-c. -SCOTT and MEDIOLI, 1980a, p. 35, pl. 5, figs. 8, 9. -BUZAS and SEVERIN, 1982, p. 36, pl. 7, figs. 9, 10.

Rotalia beccarii (Linne) variants. -PARKER, 1952b, p. 457, pl. 5, figs. 5a, b, 7a, b, 8a, b.

Rotalia beccarii (Linne) var. *tepida*. -RONAI, 1955, p. 148, pl. 21, fig. 17. -ELLISON and NICHOLS, 1970, p. 15. pl. 2, figs. 11, 12.

Description. Wall calcareous, perforate; test trochoid, biconvex, rounded on the periphery, deeply depressed umbilicus, umbilical plug present or absent; chambers distinct, eight in the final whorl, inflated, all chambers visible dorsally, only those of last-formed whorl visible ventrally; sutures distinct, depressed to deeply incised near umbilicus on the ventral side, pustules along sutures and in the umbilical area on the

ventral side; aperture a low arch at the base of the last chamber.

Remarks. Specimens of *A. beccarii* compared well with several hypotypes of *Rotalia beccarii* and *Ammonia beccarii* observed USNM collections.

Occurrence. A. beccarii was widely distributed in the study area but was the most abundant species in the lagoon. It was not recorded in stations 1,2, and 26 from the brackish marsh and the erosional area of the inner fringe marsh. It reached highest its frequency (81% of the total assemblage) in the fringe marsh of Hog Island (station 32). This species was found in relatively low frequencies (<6% of the total assemblage) in the tidal channel, the ebb delta, and the shoreface. Parker (1952b) reported *A. beccarii* (as *Rotalia beccarii* (Linne) variants) abundantly (33% of the total assemblage) in Buzzards Bay, Massachusetts. Ronai (1955) recorded it (as *Rotalia beccarii* (Linne) var. *tepida*) in all localities in the brackish waters of the New York Bight. Schnitker (1971) found it in low frequencies (<5% of the total assemblage) in the shallow waters (<60 m depth) of the North Carolina continental shelf north of Cape Hatteras. It was also reported in great abundance in the Indian River Bay, Delaware (Kraft and Margules, 1971) and the Indian River, Florida (Buzas and Severin, 1982).

Family ELPHIDIIDAE Galloway, 1933

Subfamily ELPHIDIINAE Galloway, 1933

Genus *Elphidium* de Montfort, 1808

Elphidium bartletti Cushman

Plate 3, Figure 10

Elphidium bartletti CUSHMAN, 1933, p. 4, pl. 1, figs. 9a, b. -RONAI, 1955, p. 145-146, pl. 21, fig. 6. -SEN GUPTA, 1971, p. 89, pl. 2, figs. 26, 27. -BUZAS et al., 1985, p. 1082, figs. 6.3, 6.6.

Description. Wall calcareous, smooth surfaced, very finely perforate; test planispiral, rounded periphery, slightly depressed umbilicus; chambers distinct,

numerous, slightly inflated; sutures distinct, depressed, curved; aperture consisting of numerous small openings at the base of the final chamber.

Remarks. Specimens of *E. bartletti* compared well with the holotype of Cushman (1933) and several paratypes observed USNM collections. Buzas et al. (1985) stated that *E. bartletti* can be distinguished from *E. subarcticum* and *E. frigidum* by its thickness, fewer opaque bands along the sutures, and lack of grooves on the final chamber.

Occurrence. E. bartletti was widely distributed in bays and outside of inlet but was recorded as rare (<3% of the total assemblage) except station 10 (6% of the total assemblage) from the middle/outer muddy sand flat. It was little found in marsh areas. Ronai (1955) found it in low numbers (<5 specimens) in harbors and bays of the New York Bight. Sen Gupta (1971) also found it in low frequencies (<2% of the total assemblage) in the Tail of the Grand Banks of Newfoundland.

Elphidium excavatum (Terquem)

Plate 3, Figures 11, 12

Polystomella excavata TERQUEM, 1875, p. 20, pl. 2, figs. 2a-b.

Elphidium excavatum (Terquem). -PARKER, 1952a, p. 412, pl. 5, fig. 8 - PARKER, 1952b, p. 448, pl. 3, fig. 13. -RONAI, 1955, p. 147, pl. 21, fig. 11. -BUZAS and SEVERIN, 1982, p. 37, pl. 8, fig. 2. -BUZAS et al., 1985, p. 1083, 1084, figs. 6.7-6.10, 7.1, 7.2.

Elphidium clavatum Cushman. -RONAI, 1955, p. 146, pl. 21, fig. 7. -ELLISON and NICHOLS, 1970, p. 16, pl. 2, figs. 7, 8. -KRAFT and MARGULES, 1971, p. 251, fig. 17. -SEN GUPTA, 1971, p. 89, pl. 2, figs. 28, 29. -SCHNITKER, 1971, p. 198, pl. 7, fig. 5.

Description. Wall calcareous, perforate, white or brown in color; test planispiral, involute, rounded periphery, elevated umbilical boss or bosses; chambers distinct, eight

to eleven in final whorl; sutures distinct, curved, regular sutural bridges on each suture; aperture consisting of small openings at the base of the last chamber.

Remarks. Specimens of *E. excavatum* matched several hypotypes observed in USNM collections. Buzas et al. (1985) suggested that *E. clavatum* and *E. excavatum* are conspecific.

Occurrence. E. excavatum was widely distributed over the study area. It was not found at the brackish marsh (stations 1-2; <9 psu salinity) and the high elevation (mean high water to high high water) of the inner fringe marsh (stations 25, 27). Frequencies in the outer part of lagoon and inlet were often 80-95% with a maximum of 96% from the washover fan (station 46) and the shoreface (station 57). Frequencies were less than 7% at inner and outer fringe marshes. *E. excavatum* is widespread in shallow waters around the northeastern United States. It was reported in abundance (as *E. clavatum*) in brackish water bays and lagoons (Ronai, 1955; Kraft and Margules, 1971), estuaries (Ellison and Nichols, 1970) and near shores (< 19 meter depth) of continental shelf (Sen Gupta, 1971; Schnitker, 1971). *E. excavatum* was recorded as rare north of Cape Cod, in the Long Island Sound, Buzzards Bay area (Parker, 1952b), the New York Bight (Ronai, 1955), and the Indian River, Florida (Buzas and Severin, 1982).

Elphidium gunteri Cole

Plate 3, Figure 13

Elphidium gunteri COLE, 1931, p. 34, pl. 4, figs. 9, 10. -PARKER and ATHEARN, 1959, p. 342, pl. 50, fig. 36. -BUZAS and SEVERIN, 1982, p. 37, pl. 8, fig. 4. -BUZAS et al., 1985, p. 1084, figs. 7.4, 7.5.

Description. Wall calcareous, coarsely perforate; test planispiral, involute, broadly rounded periphery, umbilical area elevated, numerous irregular-shaped large umbilical bosses; chambers distinct, numerous (eight to eleven); sutures distinct, not

depressed, many regular sutural bridges; aperture consisting of numerous rounded openings at the base of the final chamber.

Remarks. Specimens of *E. gunteri* compared well with hypotypes of Parker and Athearn (1959) and Buzas and Severin (1982).

Occurrence. E. gunteri had a scattered distribution in low frequencies (<3% of the total assemblage) in the study area except station 10 (middle/outer muddy sand flat; 7.3% of the total assemblage). Parker and Athearn (1959) reported it in low frequencies (<2% of the total assemblage) in marshes from Poponesset Bay, Massachusetts. Buzas and Severin (1982) reported it high numbers of specimens (up to 53-84/20 ml of sediment) in the narrow, island-filled portion of the Indian River, Florida.

Elphidium mexicanum Kornfeld

Plate 3, Figure 14

Elphidium incertum var. *mexicanum* KORNFELD, 1931, p. 89, pl. 16, fig. 1.
Elphidium mexicanum Kornfeld. -BUZAS and SEVERIN, 1982, p. 37, pl. 8, fig. 6. -BUZAS et al., 1985, p. 1087, figs. 7.9, 7.10.

Description. Wall calcareous, smooth surfaced, very fine perforate, milky color; test planispiral, involute, narrowly rounded periphery, slightly raised single umbilical boss; chambers distinct, numerous (ten to twelve); sutures distinct, curved, depressed, short sutural bridges; aperture consisting of a row of small openings at the base of the last chamber.

Remarks. Specimens of *E. mexicanum* compared well with several hypotypes observed USNM collections. Kornfeld (1931) stated that this species may have a single or multiple umbilical bosses. Specimens in this study had a large central boss.

Occurrence. E. mexicanum was recorded mostly in low frequencies (<3% of the total assemblage) at tidal flats, the ebb delta and the shoreface. It was found in high

frequencies of living populations (35-67%) at inlet shoals and the shoreface. Buzas and Severin (1982) found it throughout the Indian River, Florida with high numbers of specimens (53-74 specimens/20 ml of sediment) at stations from St. Lucie Transect.

Elphidium poeyanum (d'Orbigny)

Plate 3, Figure 15

Polystomella poeyana D'ORBIGNY, 1839, p. 55, pl. 6, figs. 25, 26.

Elphidium poeyanum (d'Orbigny). -CUSHMAN, 1930, p. 25, pl. 10, figs. 4, 5. -PARKER, 1954, p. 509, pl. 6, fig. 17. -PHLEGER, 1954, p. 639, pl. 2, figs. 8, 9. -TODD and LOW, 1961, p. 20, pl. 2, fig. 7. -KRAFT and MARGULES, 1971, p.251.

Description. Wall calcareous, perforate; test planispiral, involute, broadly rounded periphery, flush umbilicus; chambers distinct, eight to nine chambers; sutures distinct, slightly curved, slightly depressed, small sutural bridges on the sutures; aperture consisting of openings at the base of the final chamber.

Remarks. Specimens of *E. poeyanum* compared well with the hypotype of Todd and Low (1961).

Occurrence. E. poeyanum was widely distributed in the lagoon but was rare (<2% of the total assemblage). It was rarely found in marsh areas. Parker (1954) found it in low frequencies (< 2% of the total assemblage) at depths shoaler than 145 m in the northeastern Gulf of Mexico. Todd and Low (1961) recorded *E. poeyanum* as rare at all parts of Martha's Vineyard Island, Massachusetts except the ocean side. Kraft and Margules (1971) recorded *E. poeyanum* at less than 1% of the living and total assemblages in all stations from Indian River Bay, Delaware.

PLATE 1

(bar = 100 μm)

Figures

1	*Miliammina earlandi* Loeblich and Tappan
	1 side view, specimens from station 27
2	*Miliammina fusca* (Brady)
	2 side view, specimen from station 33
3	*Haplophragmoides bonplandi* Todd and Bronnimann
	3 side view, specimen from station 1
4	*Haplophragmoides wilberti* Andersen
	4 side view, specimen from station 1
5	*Ammobaculites exiguus* Cushman and Bronnimann
	5 side view, specimen from station 33
6, 7	*Trochammina adevena* Cushman
	6 dorsal view, specimen from station 1
	7 ventral view, specimen from station 1

PLATE 1 (continued)

8, 9 *Trochammina inflata* (Montagu)

8 dorsal view, specimen from station 1

9 ventral view, specimen from station 1

10, 11 *Trochammina ochracea* (Williamson)

10 dorsal view, specimen from station 18

11 ventral view, specimen from station 18

12, 13 *Trochammina "squamata"*

12 dorsal view, specimen from station 1

13 ventral view, specimen from station 1

14, 15 *Trochammina* sp. A

14 dorsal view, specimen from station 1

15 ventral view, specimen from station 1

16, 17 *Tiphotrocha comprimata* (Cushman and Bronnimann)

16 dorsal view, specimen from station 3

17 ventral view, specimen from station 3

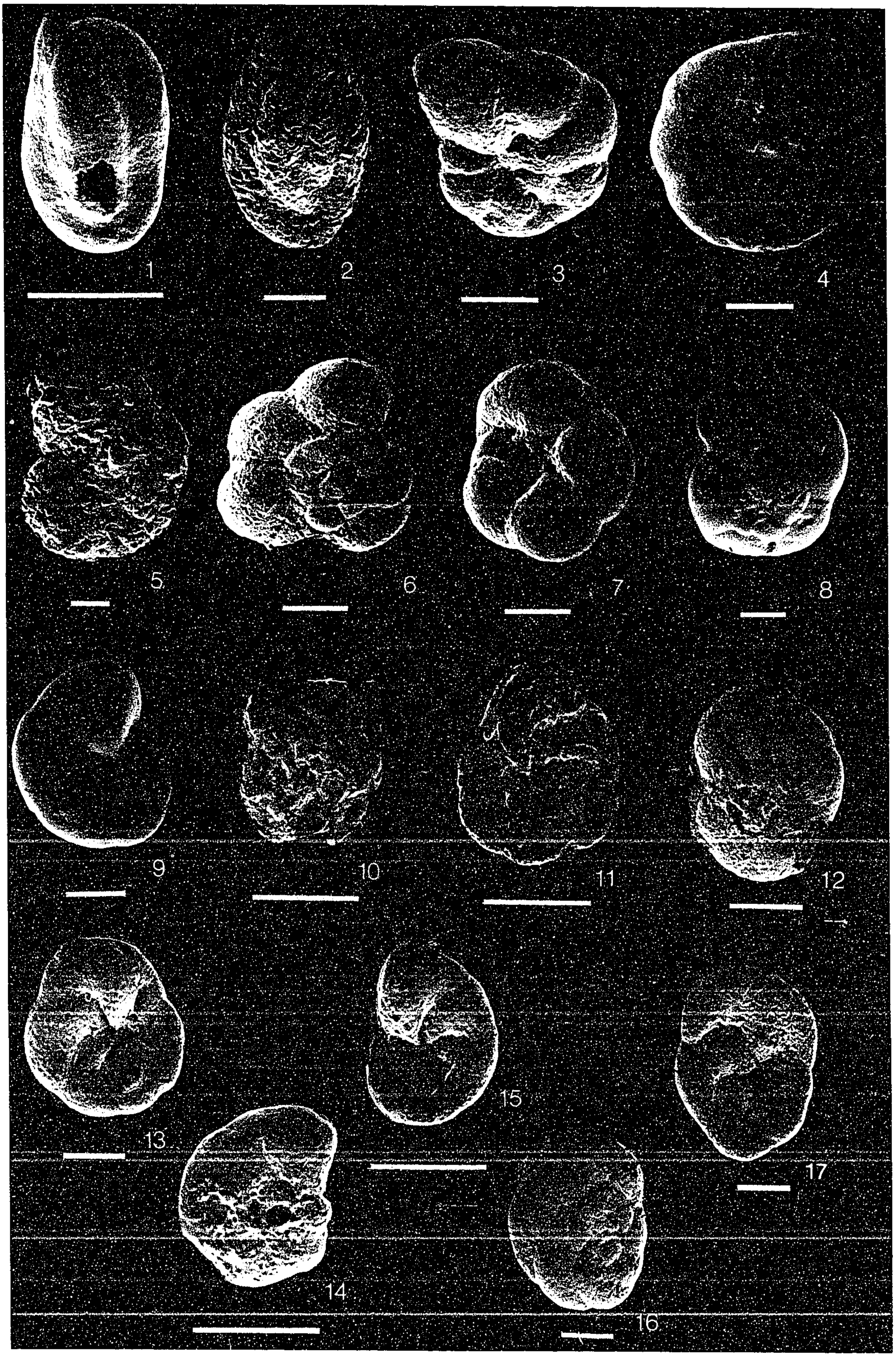
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PLATE 2

(bar = 100 µm)

Figures

1, 2	*Jadammina macrescens* (Brady)
	1 dorsal view, specimens from station 1
	2 ventral view, specimen from station 1
3, 4	*Arenoparrella mexicana* (Kornfeld)
	3 dorsal view, specimen from station 1
	4 ventral view, specimen from station 1
5	*Textularia earlandi* Parker
	5 side view, specimen from station 20
6	*Quinqueloculina dimidiata* Terquem
	6 side view, specimen from station 47
7	*Quinqueloculina seminula* (Linne)
	7 side view, specimen from station 15
8	*Quinqueloculina seminula* (Linne) *jugosa* Cushman
	8 side view, specimen from station 47

PLATE 2 (continued)

9 *Bolivina striatula* Cushman

9 side view, specimen from station 11

10, 11 *Helenina anderseni* (Warren)

10 dorsal view, specimen from station 33

11 ventral view, specimen from station 33

12, 13 *Rosalina floridana* (Cushman)

12 dorsal view, specimen from station 52

13 ventral view, specimen from station 52

14, 15, 16 *Glabratella* sp. A

14 dorsal view, specimen from station 19

15 side view, specimen from station 19

16 ventral view, specimen from station 19

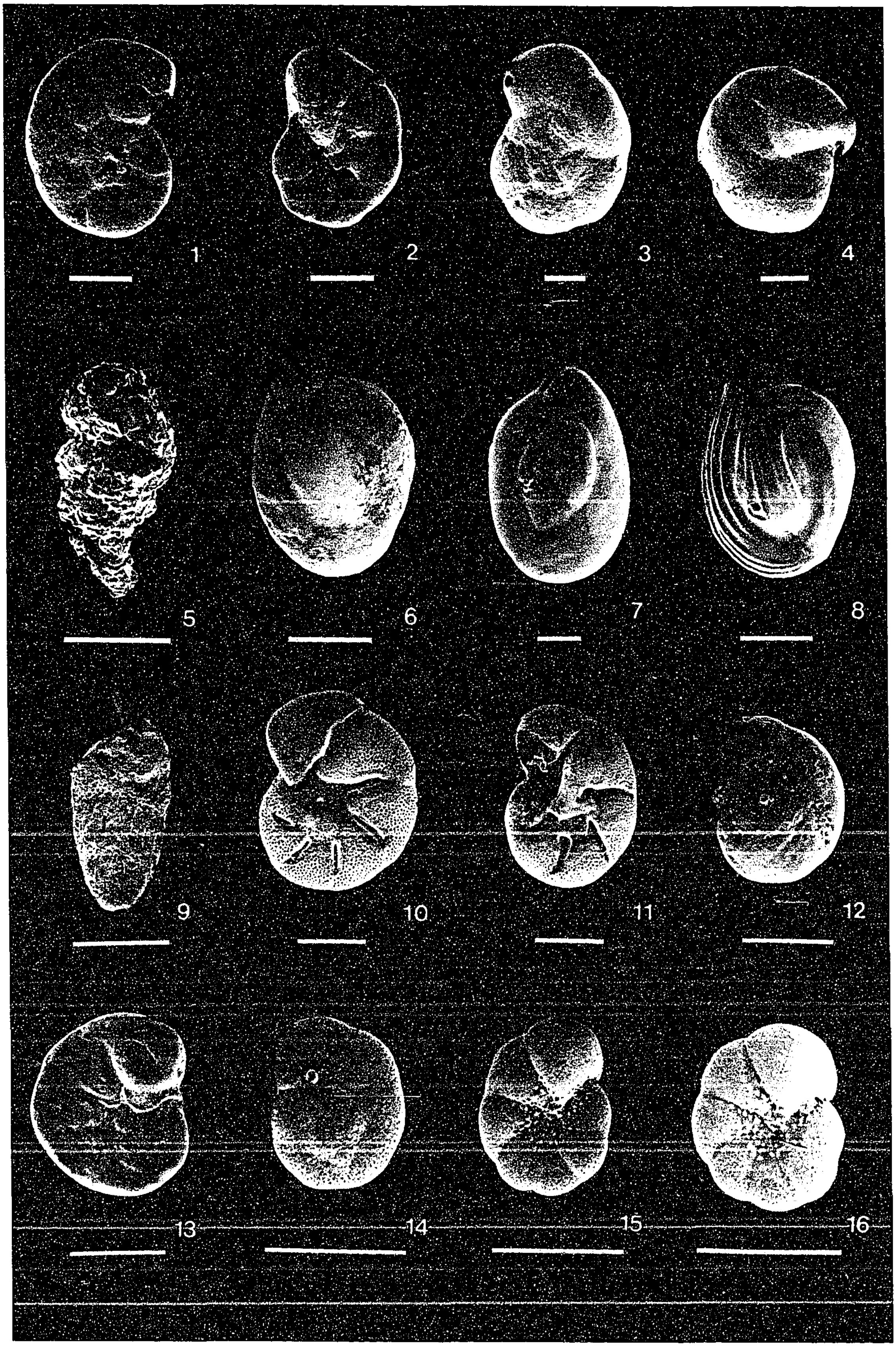
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PLATE 3

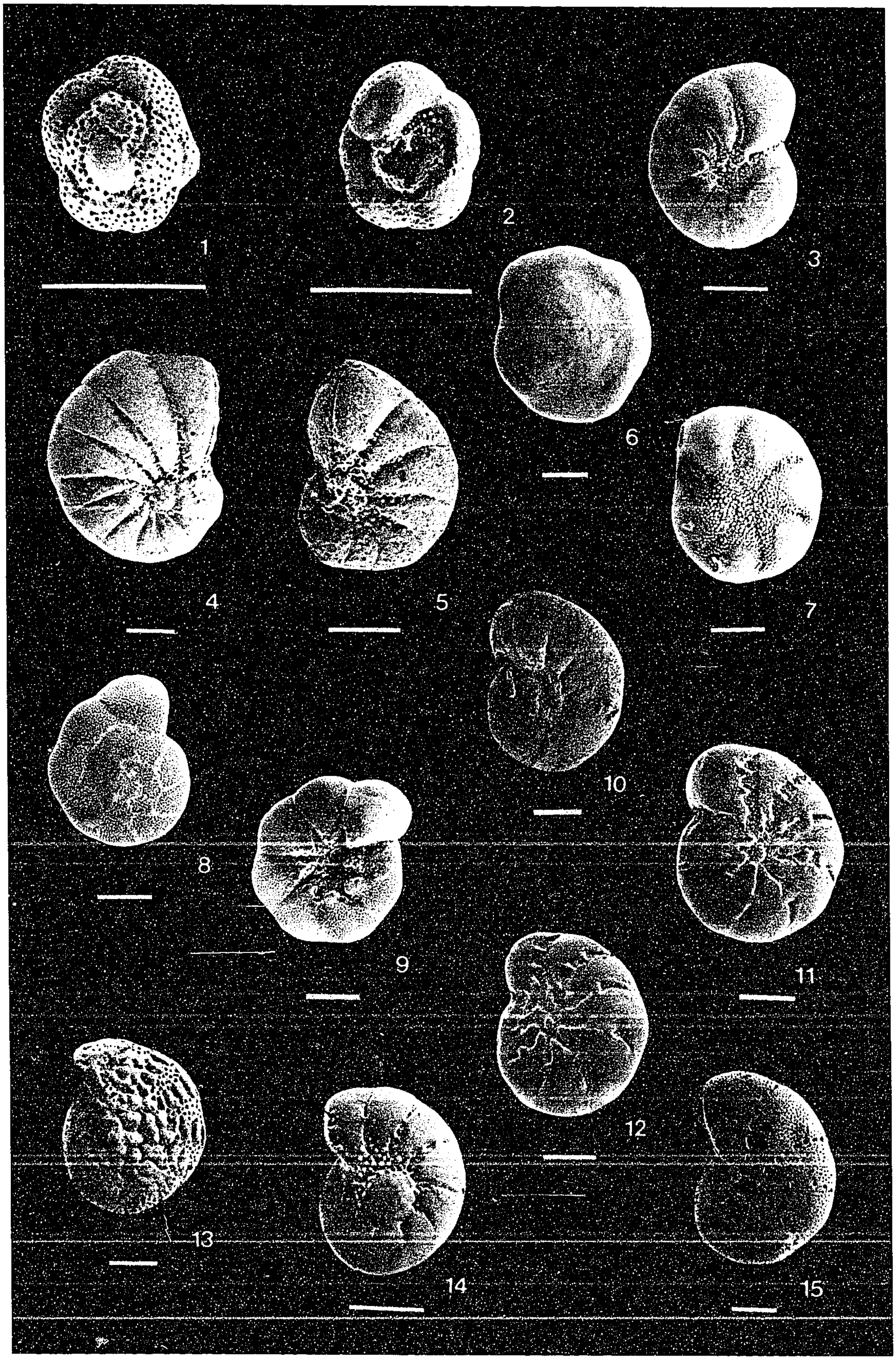
(bar = 100 μm)

Figures

1, 2	*Glabratellina* sp. A
	1 dorsal view, specimens from station 17
	2 ventral view, specimen from station 17
3	*Haynesina germanica* (Ehrenberg)
	3 side view, specimen from station 33
4, 5	*Nonionella atlantica* Cushman
	4 dorsal view, specimen from station 15
	5 ventral view, specimen from station 14
6, 7	*Buccella frigida* (Cushman)
	6 dorsal view, specimen from station 7
	7 ventral view, specimen from station 7
8, 9	*Ammonia beccarii* (Linne)
	8 dorsal view, specimen from station 33
	9 ventral view, specimen from station 33

PLATE 3 (continued)

10	*Elphidium bartletti* Cushman	
	10 side view, specimen from station 10	
11, 12	*Elphidium excavatum* (Terquem)	
	11 side view, specimen from station 10	
	12 side view, specimen from station 10	
13	*Elphidium gunteri* Cole	
	13 side view, specimen from station 33	
14	*Elphidium mexicanum* Kornfeld	
	14 side view, specimen from station 52	
15	*Elphidium poeyanum* (d'Orbigny)	
	15 side view, specimen from station 22	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Appendix A. Statistical parameters and sediment descriptions in the surface sediments at 20 different subenvironments.

Subenvironments	Sample	St. No.	Org. (%)	Sand (%)	Silt (%)	Clay (%)	Textural name	Bulk density (g/ml)	Mean (phi)	Mean class	Sorting (phi)	Sorting class
Brackish marsh / channel	**MREF 1**	**1**	1.3	63.01	14.41	21.84	muddy sand	0.5429	4.4106	Coarse silt	3.1729	Very poorly sorted
	MREF 2	**2**	2.328	41.6	21.42	38.2	sandy mud	0.5881	6.0003	Fine silt	3.178	Very poorly sorted
	MREF 3	**3**	0.377	89.36	2.95	6.53	clayey sand	1.2138	2.5251	Fine sand	2.124	Very poorly sorted
Restricted tidal bay	**BSRB 1**	**4**	0.388	15.34	50.98	34.33	sandy mud	0.4223	6.6281	Fine silt	2.3843	Very poorly sorted
	BSRB 2	**5**	0.365	25.21	50.68	24.11	sandy silt	0.7122	6.0427	Fine silt	2.3408	Very poorly sorted
	BSRB 3	**6**	0.327	26.57	45.78	27.71	sandy mud	0.5688	6.0436	Fine silt	2.5259	Very poorly sorted
Inner muddy sand flat	**EB 3**	**7**	0.361	53.76	30.49	14.78	silty sand	0.7921	4.2102	Coarse silt	2.8162	Very poorly sorted
	EB 4	**8**	0.198	20.92	52.92	25.6	sandy silt	0.88	6.0165	Fine silt	2.3393	Very poorly sorted
	FMFI 3	**9**	0.241	3.49	75.66	21.06	silt	0.6078	6.1492	Fine silt	1.9616	Poorly sorted
Middle/outer	***EB 1***	***10***	0.171	52.79	29.44	17.41	*muddy sand*	0.8956	4.9812	Coarse silt	2.3837	Very poorly sorted
muddy sand flat	**EB 2**	**11**	0.16	79.23	11.23	8.05	muddy sand	0.9218	3.9555	Very fine sand	1.8637	Poorly sorted
Inner sand flat	**CBSFI 1**	**12**	0	94.23	1.4	2.44	sand	1.2345	3.1725	Very fine sand	1.1181	Poorly sorted
	CBSFI 2	**13**	0.2	73.07	17.29	8.38	silty sand	0.9668	4.109	Coarse silt	1.8611	Poorly sorted
Middle sand flat	**ECSFM 1**	**14**	0	94.65	2.88	1.68	sand	1.4	3.209	Very fine sand	0.9768	Moderately sorted
	ECSFM 2	**15**	0	97.22	0.96	1.25	sand	1.3847	2.9671	Fine sand	0.8737	Moderately sorted
Outer sand flat	**CBSFO 1**	**16**	0	96.33	0.72	1.71	sand	1.2566	2.5528	Fine sand	1.0888	Poorly sorted
	CBSFO 2	**17**	0.155	79.42	13.18	6.41	silty sand	1.1208	3.7503	Very fine sand	1.7542	Poorly sorted
Inner mud flat	**OYMFI 1**	**18**	0.205	80.24	18.14	1	silty sand	1.1933	3.5517	Very fine sand	1.1746	Poorly sorted
	OYMFI 2	**19**	0.158	45.73	39.67	14.24	sandy silt	0.9791	4.9512	Coarse silt	2.1347	Very poorly sorted
	OYMFI 3	**20**	0.205	44.32	43.05	11.98	sandy silt	0.7886	4.9501	Coarse silt	2.1479	Very poorly sorted
Outer mud flat	**WIMFO 2**	**21**	0.169	79.07	12.3	7.99	muddy sand	1.0745	4.0032	Coarse silt	1.8637	Poorly sorted
	WIMFO 1	**22**	0.113	81.65	11.57	5.88	muddy sand	1.1784	3.6445	Very fine sand	1.7086	Poorly sorted
Inner protected fringe marsh	**PCSM 1**	**23**	0.082	0.255	56	43.71	mud	0.4379	7.5887	Very fine silt	1.922	Poorly sorted
	PCSM 2	**24**	0.186	14.07	55.48	30.56	sandy mud	0.7109	6.374	Fine silt	2.3835	Very poorly sorted
Inner exposed fringe marsh	**FMFI 1**	**25**	1.504	72.9	15.15	10.52	muddy sand	0.8132	3.1729	Very fine sand	2.6231	Very poorly sorted
	FMFI 2	**26**	1.638	63.42	17.07	18.13	muddy sand	0.6836	4.0635	Coarse silt	2.9883	Very poorly sorted
	RS 1	**27**	0.911	79.96	12.42	5.41	silty sand	1.0386	2.525	Fine sand	2.3278	Very poorly sorted
	RS 2	**28**	1.818	31.45	30.68	36.68	sandy mud	0.3804	6.1233	Fine silt	3.3999	Very poorly sorted
	RS 3	**29**	0.332	0.31	51.86	47.87	mud	0.3973	7.7733	Very fine silt	1.8244	Poorly sorted
Middle marsh island	**EMCM 1**	**30**	0.574	12.08	55.62	33.01	sandy mud	0.6019	6.5929	Fine silt	2.3192	Very poorly sorted
	EMCM 2	**31**	0.647	9.12	60.95	30.2	silt	0.6463	6.4845	Fine silt	2.2791	Very poorly sorted

Continued												
Subenvironments	**Sample**	**St. No.**	**Org. (%)**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural name**	**Bulk density (g/ml)**	**Mean (phi)**	**Mean class**	**Sorting (phi)**	**Sorting class**
Outer fringe marsh	**HIFO 1**	**32**	0.827	17.81	48.84	32.72	sandy mud	0.6377	6.6121	Fine silt	2.4487	Very poorly sorted
	HIFO 2	**33**	1.047	52.74	24.57	20.74	muddy sand	0.6748	4.6078	Coarse silt	3.1097	Very poorly sorted
	SI 1	**34**	8.004	7.65	31.07	61.66	mud	0.1433	7.968	Very fine silt	2.4262	Very poorly sorted
	SI 2	**35**	0.996	65.19	14.71	18.71	muddy sand	0.5162	4.5445	Coarse silt	2.6279	Very poorly sorted
	WI 1	**36**	0.645	66.03	20.71	11.68	muddy sand	0.8563	4.3133	Coarse silt	2.2716	Very poorly sorted
	WI 2	**37**	0.551	41.51	33.72	25.04	sandy mud	0.4194	5.5316	Medium silt	2.7369	Very poorly sorted
Tidal channel margin	**WIMFO 3**	**38**	0.145	91.92	4.42	3.58	sand	1.1863	3.172	Very fine sand	1.3699	Poorly sorted
	PCSM 3	**39**	0.084	6.94	48.96	44.22	mud	0.5675	7.3032	Very fine silt	2.2685	Very poorly sorted
	EMCM 3	**40**	0.157	64.68	25.08	9.65	silty sand	0.9669	4.2053	Coarse silt	2.033	Very poorly sorted
	HIFO 3	**41**	0.22	72.62	13.42	11.4	muddy sand	0.9648	4.0506	Coarse silt	2.2852	Very poorly sorted
Intermediate tidal channel	**SSTC 4**	**42**	0.258	79.69	11.22	7.85	muddy sand	1.1336	3.5374	Very fine sand	2.1883	Very poorly sorted
	SSTC 3	**43**	0.523	85.02	8.27	5.38	muddy sand	1.1589	2.9161	Fine sand	2.0346	Very poorly sorted
Deep tidal channel	**SSTC 2**	**44**	0.191	75.16	15.25	8.15	muddy sand	1.2079	3.8407	Very fine sand	2.0997	Very poorly sorted
	SSTC 1	**45**	0.141	78.48	19	1.9	silty sand	1.165	3.5779	Very fine sand	1.448	Poorly sorted
Washover fan	**CIWF 1**	**46**	0	97.14	0.2	1.68	sand	1.6333	2.8245	Fine sand	0.9684	Moderately sorted
	CIWF 2	**47**	0	96.4	1.54	1.27	sand	1.248	2.7637	Fine sand	0.9602	Moderately sorted
	CIWF 3	**48**	0	93.14	3.08	3.04	sand	1.1773	2.998	Fine sand	1.2911	Poorly sorted
Ebb delta, axial channel	**SSIC 5**	**49**	0.231	94.01	3.19	2.34	sand	1.4423	2.3503	Fine sand	1.4693	Poorly sorted
	SSIC 4	**50**	0	96.77	1	1.58	sand	1.5057	2.6903	Fine sand	1.1821	Poorly sorted
Ebb delta, inlet shoals	**SSIC 3**	**51**	0	97.54	0.47	1.17	sand	1.2172	2.979	Fine sand	0.8291	Moderately sorted
	SSIC 1	**52**	0	94.45	1.63	2.56	sand	1.1469	3.2731	Very fine sand	1.1376	Poorly sorted
	SSIC 2	**53**	0	93.24	4.05	2.2	sand	1.402	3.0451	Very fine sand	1.1464	Poorly sorted
	SSIC 6	**54**	0	98.38	0.61	0.7	sand	1.3755	2.859	Fine sand	0.6819	Moderately well sorted
Barrier island shoreface	**CISF 1**	**55**	0	95.39	2.48	1.21	sand	1.2358	3.324	Very fine sand	1.008	Poorly sorted
	CISF 2	**56**	0	96.49	0.9	1.66	sand	1.2783	3.04	Very fine sand	0.9257	Moderately sorted
	CISF 3	**57**	0	96.12	0.66	1.87	sand	1.432	3.1608	Very fine sand	0.9813	Moderately sorted

Subenvironments	Sample	St. No.	Sediment descriptions
Brackish marsh / channel	MREF 1	1	subrounded and rounded quartz grains, organic materials, some heavy minerals, no ostracods
	MREF 2	2	subangular and subrounded quartz grains, organic materials, no ostracods
	MREF 3	3	subrounded quartz grains, small amount of organic materials, ostracods
Restricted tidal bay	BSRB 1	4	subangular and subrounded quartz grains, worms, mica, organic materials, ostracods
	BSRB 2	5	subrounded quartz grains, worms, mica, organic materials, few ostracods
	BSRB 3	6	subrounded quartz grains, worms, mica, organic materials, ostracods
Inner muddy sand flat	EB 3	7	subangular quartz grains, mica, organic materials, oyster shell fragments, few ostracods, worms, some heavy minerals
	EB 4	8	subangular quartz grains, mica, small amount of organic materials, few ostracods, worms, some heavy minerals
	FMFI 3	9	subrounded and rounded quartz grains, Gastropoda, organic materials, shell fragments, some heavy minerals, no ostracods
Middle/outer muddy sand flat	EB 1	10	subangular quartz grains, mica, small amount of organic materials, few ostracods, worms
	EB 2	11	subangular quartz grains, mica, small amount of organic materials, few ostracods, worms
Inner sand flat	CBSFI 1	12	subangular quartz grains, very small amount of organic materials, small shell fragments, worms, few ostracods
	CBSFI 2	13	subangular quartz grains, small amount of organic materials, shell fragments, worms, ostracods, echinoid spines
Middle sand flat	ECSFM 1	14	subrounded quartz grains, mica, worms, very small amount of organic materials, shell fragments, ostracods, echinoid spines
	ECSFM 2	15	subrounded quartz grains, few worms, no organic material, small shell fragments, few ostracods, echinoid spines
Outer sand flat	CBSFO 1	16	subangular and subrounded quartz grains, worms, few mica, no organic material, shell fragments, few ostracods, echinoid spines
	CBSFO 2	17	subangular and subrounded quartz grains, mica, worms, small amount of organic materials, shell fragments, ostracods
Inner mud flat	OYMFI 1	18	subangular and subrounded quartz grains, small amount of organic materials, mica, ostracods
	OYMFI 2	19	subangular and subrounded quartz grains, small amount of organic materials, mica, worms, ostracods
	OYMFI 3	20	subangular and subrounded quartz grains, small amount of organic materials, mica, worms, ostracods
Outer mud flat	WIMFO 2	21	subangular quartz grains, small amount of organic materials, shell fragments, ostracods, worms, small clams
	WIMFO 1	22	subangular quartz grains, small amount of organic materials, shell fragments, worms, ostracods
Inner protected fringe marsh	PCSM 1	23	angular and subangular quartz grains, organic materials, few mica, small crab legs, Gastropoda, ostracods
	PCSM 2	24	subangular quartz grains, organic materials, few mica, ostracods
Inner exposed fringe marsh	FMFI 1	25	subrounded quartz grains, organic materials, few mica, Salicornia, no ostracods
	FMFI 2	26	subrounded and rounded quartz grains, heavy minerals, worms, organic materials, shell fragments, no ostracods
	RS 1	27	coarse sand, large amount of organic materials (stems & roots), Gastropoda
	RS 2	28	coarse sand, large amount of organic materials
	RS 3	29	little subangular quartz grains, large amount of organic materials, worms, ostracods, fecal pellets, Gastropoda
Middle marsh island	EMCM 1	30	subangular and subrounded quartz grains, organic materials, Gastropoda, mica, worms, ostracods
	EMCM 2	31	subangular and subrounded quartz grains, organic materials, shell fragments, mica, few ostracods
Outer fringe marsh	HIFO 1	32	subrounded quartz grains, organic materials, few mica, few ostracods, small clams
	HIFO 2	33	subrounded quartz grains, organic materials, little mica, few Gastropoda, clams, ostracods

Continued

Subenvironments	Sample	St. No.	Sediment descriptions
Outer fringe marsh	SI 1	34	subangular and subrounded quartz grains, large amount of organic materials, fecal pellets, shell fragments, ostracods, Gastropoda, snails
	SI 2	35	subangular quartz grains, large amount of organic materials, worms, ostracods
	WI 1	36	angular and subangular quartz grains, large amount of organic materials, mica, ostracods
	WI 2	37	angular and subangular quartz grains, algae, Periwinkles, mica, Ostracods
Tidal channel margin	WIMFO 3	38	subangular quartz grains, small amount of organic materials, shell fragments, worms, few ostracods, snails, small clams
	PCSM 3	39	subangular quartz grains, organic materials, ostracods, mica, some heavy minerals
	EMCM 3	40	subangular and subrounded quartz grains, small amount of organic materials, shell fragments, worms, mica, few ostracods
	HIFO 3	41	subangular and subrounded quartz grains, small amount of organic materials, little mica, small crab legs, worms, ostracods
Intermediate tidal channel	SSTC 4	42	subangular quartz grains, organic materials, large size of shell fragments, worms, Echinoid spines, few ostracods
	SSTC 3	43	subangular quartz grains, organic materials, large size of shell fragments, worms, few ostracods, snails
Deep tidal channel	SSTC 2	44	subangular and subrounded quartz grains, organic materials, small size of shell fragments, worms, few ostracods, snails, echinoid spines
	SSTC 1	45	subangular and subrounded quartz grains, organic materials, clams, worms, few ostracods, echinoid spines
Washover fan	CIWF 1	46	subrounded quartz grains, no organic materials, worms, small shell fragments, some heavy minerals, no ostracods
	CIWF 2	47	subangular and subrounded quartz grains, small amount of organic materials, worms, small shell fragments, heavy minerals, few ostracods
	CIWF 3	48	subangular and subrounded quartz grains, small amount of organic materials, worms, small shell fragments, heavy minerals, ostracods, small clams
Ebb delta, axial channel	SSIC 5	49	subangular quartz grains, small amount of organic materials, shell fragments, few worms, few ostracods, echinoid spines
	SSIC 4	50	subangular and subrounded quartz grains, very small amount of organic materials, oyster and shell fragments, echinoid spines, few worms and ostracods
Ebb delta, inlet shoals	SSIC 3	51	subangular and subrounded quartz grains, small amount of organic materials, shell fragments, echinoid spines, worms, no ostracods
	SSIC 1	52	subangular and subrounded quartz grains, small amount of organic materials, shell fragments, echinoid spines, worms, few ostracods
	SSIC 2	53	subangular quartz grains, small amount of organic materials, shell fragments, echinoid spines, worms, ostracods, small clams and Gastropoda
	SSIC 6	54	subangular quartz grains, very small amount of organic materials, shell fragments, echinoid spines, worms, few ostracods
Barrier island shoreface	CISF 1	55	subangular quartz grains, small amount of organic materials, shell fragments, echinoid spines, worms, few ostracods
	CISF 2	56	subangular and subrounded quartz grains, small amount of organic materials, shell fragments, echinoid spines, worms, few ostracods, small crabs and clams
	CISF 3	57	subangular and subrounded quartz grains, no organic materials, shell fragments, echinoid spines, worms, few ostracods, small clams and crabs, heavy minerals

Appendix B. Group means of ten environmental variables for the 19 *a priori* subenvironments. ID refers to *a priori* subenvironments (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 5: the inner sand flat, 6: the middle sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: the tidal channel margin, 15: the intermediate tidal channel, 16: the deep tidal channel, 17: the washover fan, 18: the axial channel, 19: inlet shoals, 20: barrier island shoreface).

GROUP MEANS

ID	Depth (m)	Organic (%)	Sand (%)	Silt (%)	Clay (%)	Mean (phi)	Sorting (phi)	DFM (km)	DFI (km)	BD (g/ml)
2	1.20000	0.36000	22.37333	49.14667	28.71667	6.23813	2.41700	3.61700	-7.51767	0.56777
3	1.23333	0.26667	26.05667	53.02333	20.48000	5.45863	2.37237	3.08533	-11.73767	0.75997
4	1.55000	0.16550	66.01000	20.33500	12.73000	4.46835	2.12370	10.37250	-6.75500	0.90870
5	1.20000	0.10000	83.65000	9.34500	5.41000	3.64075	1.48960	6.99450	-5.18600	1.10065
6	1.30000	0.00000	95.93500	1.92000	1.46500	3.08805	0.92525	8.03200	-4.73400	1.39235
7	1.79000	0.07750	87.87500	6.95000	4.06000	3.15155	1.42150	11.43500	-2.34050	1.18870
8	1.02000	0.18933	56.76333	33.62000	9.07333	4.48433	1.81907	1.59600	-10.79800	0.98700
9	1.33000	0.14100	80.36000	11.93500	6.93500	3.82385	1.78615	10.31900	-2.18050	1.12645
10	0.60000	0.13400	7.16500	55.74000	37.13500	6.98135	2.15275	1.59550	-13.00550	0.57440
11	0.56000	1.24060	49.60800	25.43600	23.72200	4.73160	2.63270	1.45580	-14.21220	0.66262
12	0.60000	0.61050	10.60000	58.28500	31.60500	6.53870	2.29915	6.80850	-6.14350	0.62410
13	0.70000	2.01167	41.82167	28.93667	28.42500	5.59622	2.60350	10.62050	-2.89033	0.54128
14	1.49750	0.15150	59.04000	22.97000	17.21250	4.68277	1.98915	8.44400	-6.13050	0.92137
15	8.95000	0.39050	82.35500	9.74500	6.61500	3.22675	2.11145	3.35150	-8.80300	1.14625
16	14.90000	0.16850	76.82000	17.12500	5.02500	3.70930	1.77385	8.05850	-4.04250	1.18645
17	0.90000	0.00000	95.56000	1.60667	1.99667	2.86207	1.07323	13.79433	-3.58167	1.35287
18	13.00000	0.11550	95.39000	2.09500	1.96000	2.52030	1.32570	13.82950	1.83500	1.47400
19	7.93750	0.00000	95.90250	1.69000	1.65750	3.03905	0.94875	17.47325	5.75800	1.28540
20	11.90000	0.00000	96.00000	1.34667	1.58000	3.17493	0.97167	19.00700	7.21633	1.31537
Total	3.40630	0.46543	62.61704	22.27074	14.37148	4.39027	1.87619	8.51043	-5.03444	0.95891

Appendix C. The numbers of individuals for the living and total (living+dead) assemblages in the surface sediments from the 57 stations.

Station		MREF 1	MREF 2	MREF 3	BSRB 1	BSRB 2	BSRB 3	EB 3	EB 4	FMFI 3	EB 1	EB 2
Station No.		1	2	3	4	5	6	7	8	9	10	11
No. of species		8	8	10	9	2	5	6	5	3	3	3
(Live/Total)		13	13	17	12	6	10	12	11	7	9	12
No. of individuals per fraction		41	26	52	337	43	225	12	30	25	18	18
picked (Live/Total)		639	319	373	447	60	322	348	289	34	218	377
Extrapolated No. of individuals		164	208	104	2696	43	3600	192	30	25	18	18
per 70 ml (Live/Total)		2556	2552	746	3576	60	5152	5568	289	34	218	377
Depth (m) (MSL datum)		0.6	0	-0.6	-0.3	-0.3	-0.3	-0.2	-0.2	-0.6	-0.8	-0.5
Fraction Picked		1/4	1/8	1/2	1/8	-	1/16	1/16	-	-	-	-
AMMOASTUTA INEPTA	L		4									
	T	13	18	13								
AMMOBACULITES EXIGUUS	L			3	2		1					
	T		2	4	6	1	2			1		
AMMONIA BECCARII	L			18	178	20	148	1	2	14	4	
	T			18	219	23	198	27	9	14	22	27
AMMOTIUM SALSUM	L											
	T			1								
ARENOPARRELLA MEXICANA	L	7	1	3								
	T	95	66	58						1		
BOLIVINA STRIATULA	L											1
	T											1
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T							11	1		4	2
BUCCELLA INUSITATA	L											
	T								1			
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											
CIBICIDES LOBATULUS	L											
	T											
EGGERELLA ADVENA	L											
	T											
ELPHIDIUM ADVENUM	L											
	T											
ELPHIDIUM ARTICULATUM	L				2		4					
	T				2		4					
ELPHIDIUM BARTLETTI	L				4							
	T				8		2	3	1		13	1
ELPHIDIUM DISCOIDALE	L											
	T											
ELPHIDIUM EXCAVATUM	L			9	146	23	71	6	19	5	13	16
	T			9	201	33	109	278	245	9	158	334
ELPHIDIUM FRIGIDUM	L											
	T											
ELPHIDIUM GALVESTONENSE	L											
	T							1			2	2
ELPHIDIUM GUNTERI	L				1						1	
	T				1			4			16	3
ELPHIDIUM INCERTUM	L											
	T										1	
ELPHIDIUM MARGARITACEUM	L											
	T											
ELPHIDIUM MEXICANUM	L											
	T							1				2
ELPHIDIUM POEYANUM	L							1	1			
	T							7	1			1
ELPHIDIUM SUBARCTICUM	L											
	T											
EOEPONIDELLA PULCHELLA	L											
	T											
EPISTOMINELLA VITREA	L											
	T											
FISSURINA LAEVIGATA	L											
	T											
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L							1	1			1
	T							2	6		1	1

Station		MREF 1	MREF 2	MREF 3	BSRB 1	BSRB 2	BSRB 3	EB 3	EB 4	FMFI 3	EB 1	EB 2
Station No.		1	2	3	4	5	6	7	8	9	10	11
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L						1					
	T						1					
GLOBIGERINA BULLOIDES	L											
	T											
HANZAWAIA CONCENTRICA	L											
	T											
HAPLOPHRAGMOIDES BONPLANDI	L											
	T	40	6	8								
HAPLOPHRAGMOIDES WILBERTI	L	4										
	T	45	6	10								
HAYNESINA GERMANICA	L			1	2			2	7			
	T			1	4			11	19		1	2
HELENIA ANDERSENI	L											
	T											
JADAMMINA MACRESCENS	L	4	1									
	T	73	16	12			1					
JADAMMINA POLYSTOMA	L											
	T	2										
MILIAMMINA EARLANDI	L											
	T											
MILIAMMINA FUSCA	L		4	1	1					6		
	T		7	2	1					7		
MILIOLINELLA FICHTELIANA	L											
	T											
MILIOLINELLA MICROSTOMA	L											
	T											
NEOGLOBOQUADRINA BLOWI	L											
	T											
NONIONELLA ATLANTICA	L											
	T											
QUINQUELOCULINA DIMIDIATA	L											
	T											
QUINQUELOCULINA JUGOSA	L											
	T											
QUINQUELOCULINA LATA	L											
	T											
QUINQUELOCULINA SEMINULA	L				1							
	T				1							1
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L											
	T											
QUINQUELOCULINA sp.	L											
	T											
REOPHAX sp.	L											
	T											
ROSALINA FLORIDANA	L							1				
	T							2				
TEXTULARIA EARLANDI	L	1										
	T	1										
TIPHOTROCHA COMPRIMATA	L			1								
	T	4	1	9		1				1		
TROCHAMMINA ADVENA	L	2										
	T	13	6	12								
TROCHAMMINA INFLATA	L	10	6	2								
	T	277	114	118		1	2					
TROCHAMMINA LAEVIGATA	L		1									
	T		3	4								
TROCHAMMINA LOBATA	L											
	T	2										
TROCHAMMINA OCHRACEA	L											
	T				2		1		2	1		
TROCHAMMINA "SQUAMATA"	L	10	3	6								
	T	29	18	23	1	1			2			
TROCHAMMINA sp. A	L	3	8	8								
	T	45	56	71	1		2	1	2			
Indeterminate calcareous hyaline	L											
	T											
Indeterminate calcareous porcelaneous	L											
	T											

Station		CBSFI 1	CBSFI 2	ECSFM 1	ECSFM 2	CBSFO 1	CBSFO 2	OYMFI 1	OYMFI 2	OYMFI 3
Station No.		12	13	14	15	16	17	18	19	20
No. of species		4	7	2	1	1	10	7	8	10
(Live/Total)		11	17	12	10	6	18	14	20	23
No. of individuals per fraction		6	62	11	2	10	94	83	455	248
picked (Live/Total)		321	487	453	334	272	306	237	692	668
Extrapolated No. of individuals		48	248	88	8	10	94	83	455	496
per 70 ml (Live/Total)		2568	1948	3624	1336	272	306	237	692	1336
Depth (m) (MSL datum)		-0.3	-0.3	-0.4	-0.4	-0.89	-0.89	-0.23	-0.12	-0.01
Fraction Picked		1/8	1/4	1/8	1/4	-	-	-	-	1/2
AMMOASTUTA INEPTA	L									
	T									
AMMOBACULITES EXIGUUS	L						1		2	1
	T			1			1	1	2	3
AMMONIA BECCARII	L	3	10				13	26	225	140
	T	11	54	15	5	4	57	44	261	212
AMMOTIUM SALSUM	L									
	T									
ARENOPARRELLA MEXICANA	L									
	T									
BOLIVINA STRIATULA	L									
	T									
BOLIVINA VARIABILIS	L									
	T		1							
BUCCELLA DEPRESSA	L									
	T				1					
BUCCELLA FRIGIDA	L									
	T		4	2	6	2	2		6	5
BUCCELLA INUSITATA	L									
	T								2	
BULIMINELLA ELEGANTISSIMA	L									
	T		1							
CASSIDULINA SUBGLOBOSA	L									
	T									
CIBICIDES LOBATULUS	L									
	T								1	
EGGERELLA ADVENA	L									
	T								2	1
ELPHIDIUM ADVENUM	L									
	T									
ELPHIDIUM ARTICULATUM	L									
	T									
ELPHIDIUM BARTLETTI	L							6	7	
	T	2	2		1		3	7	10	1
ELPHIDIUM DISCOIDALE	L									
	T	1								
ELPHIDIUM EXCAVATUM	L	1	46	9	2	10	51	38	196	80
	T	298	402	416	309	260	201	160	361	378
ELPHIDIUM FRIGIDUM	L									
	T									
ELPHIDIUM GALVESTONENSE	L									
	T	2		3	1	1	1	1	2	4
ELPHIDIUM GUNTERI	L									
	T	1				1			11	1
ELPHIDIUM INCERTUM	L									
	T		1							
ELPHIDIUM MARGARITACEUM	L									
	T									
ELPHIDIUM MEXICANUM	L									
	T	2	3	2	8	4	1			1
ELPHIDIUM POEYANUM	L		2				2	2	4	6
	T	1	5		1		2	2	4	7
ELPHIDIUM SUBARCTICUM	L									
	T			4				1		1
EOEPONIDELLA PULCHELLA	L									
	T		1							
EPISTOMINELLA VITREA	L									
	T									
FISSURINA LAEVIGATA	L									2
	T									2
FURSENKOINA FUSIFORMIS	L									
	T		2							
GLABRATELLA sp. A	L		1				1	8	14	3
	T		2	1			2	9	14	8

Station		CBSFI 1	CBSFI 2	ECSFM 1	ECSFM 2	CBSFO 1	CBSFO 2	OYMFI 1	OYMFI 2	OYMFI 3
Station No.		12	13	14	15	16	17	18	19	20
GLABRATELLA sp. B	L									
	T									
GLABRATELLINA sp. A	L		1				6			
	T		1				6			
GLOBIGERINA BULLOIDES	L									
	T									
HANZAWAIA CONCENTRICA	L									
	T			1						
HAPLOPHRAGMOIDES BONPLANDI	L									
	T									
HAPLOPHRAGMOIDES WILBERTI	L									
	T									
HAYNESINA GERMANICA	L	1	1	2			1	1		12
	T	1	4	5			3	2	2	23
HELENIA ANDERSENI	L									
	T									
JADAMMINA MACRESCENS	L									
	T							1	1	
JADAMMINA POLYSTOMA	L									
	T									
MILIAMMINA EARLANDI	L									
	T									
MILIAMMINA FUSCA	L							2	6	
	T							2	6	
MILIOLINELLA FICHTELIANA	L									
	T									
MILIOLINELLA MICROSTOMA	L									
	T									
NEOGLOBOQUADRINA BLOWI	L									
	T									
NONIONELLA ATLANTICA	L									
	T			1	1					
QUINQUELOCULINA DIMIDIATA	L									
	T						2			2
QUINQUELOCULINA JUGOSA	L									
	T									
QUINQUELOCULINA LATA	L									
	T									
QUINQUELOCULINA SEMINULA	L						15			2
	T				1		17			4
QUINQUELOCULINA cf. SEMINULA	L						3			
	T						3			
QUINQUELOCULINA SEMINULA var. JUGOSA	L									
	T									
QUINQUELOCULINA sp.	L									
	T									
REOPHAX sp.	L									
	T									
ROSALINA FLORIDANA	L								1	
	T	1	2	2			2		1	2
TEXTULARIA EARLANDI	L		1				1			1
	T		1				1			1
TIPHOTROCHA COMPRIMATA	L									
	T								1	
TROCHAMMINA ADVENA	L									
	T									
TROCHAMMINA INFLATA	L									1
	T						1	1	1	2
TROCHAMMINA LAEVIGATA	L									
	T									
TROCHAMMINA LOBATA	L									
	T									
TROCHAMMINA OCHRACEA	L	1								
	T	1					1	3		5
TROCHAMMINA "SQUAMATA"	L									
	T								1	2
TROCHAMMINA sp. A	L									
	T		1					3	3	2
Indeterminate calcareous hyaline	L									
	T									
Indeterminate calcareous porcelaneous	L									
	T									1

Station		WIMFO 2	WIMFO 1	PCSM 1	PCSM 2	FMFI 1	FMFI 2	RS 1	RS 2	RS 3	EMCM 1	EMCM 2
Station No.		21	22	23	24	25	26	27	28	29	30	31
No. of species		6	11	5	3	1	2	6	5	10	9	4
(Live/Total)		9	15	8	7	7	2	8	7	12	11	7
No. of individuals per fraction		57	215	294	27	34	2	37	127	171	357	30
picked (Live/Total)		125	352	469	50	84	2	299	304	343	447	51
Extrapolated No. of individuals		57	430	294	27	34	2	74	254	228	1428	30
per 70 ml (Live/Total)		125	704	469	50	84	2	598	608	457	1788	51
Depth (m) (MSL datum)		-0.44	-0.42	0.6	0	0.6	0	0.9	0.2	0	0.6	0
Fraction Picked		-	1/2	-	-	-	-	1/2	1/2	3/4	1/4	-
AMMOASTUTA INEPTA	L											
	T											
AMMOBACULITES EXIGUUS	L						1		11	1	2	
	T						1		45	19	3	
AMMONIA BECCARII	L	13	26	173	19			1	64	90	210	13
	T	26	44	262	19	1		1	70	171	249	15
AMMOTIUM SALSUM	L											
	T											
ARENOPARRELLA MEXICANA	L							6				
	T				3	8		121				
BOLIVINA STRIATULA	L											
	T											
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T	2	5									
BUCCELLA INUSITATA	L											
	T											
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											
CIBICIDES LOBATULUS	L											
	T											
EGGERELLA ADVENA	L											
	T											
ELPHIDIUM ADVENUM	L											
	T											
ELPHIDIUM ARTICULATUM	L											
	T											
ELPHIDIUM BARTLETTI	L										4	
	T	1		1							6	
ELPHIDIUM DISCOIDALE	L											
	T											
ELPHIDIUM EXCAVATUM	L	35	148	7	1		1		3	41	126	8
	T	86	251	19	1		1		3	78	168	24
ELPHIDIUM FRIGIDUM	L											
	T											
ELPHIDIUM GALVESTONENSE	L											
	T										1	
ELPHIDIUM GUNTERI	L		1							1	3	
	T		1							1	4	
ELPHIDIUM INCERTUM	L											
	T											
ELPHIDIUM MARGARITACEUM	L											
	T		2									
ELPHIDIUM MEXICANUM	L										3	
	T										3	
ELPHIDIUM POEYANUM	L		5							6		
	T	1	7							6		
ELPHIDIUM SUBARCTICUM	L		1									
	T		1									
EOEPONIDELLA PULCHELLA	L											
	T											
EPISTOMINELLA VITREA	L											
	T											
FISSURINA LAEVIGATA	L											
	T											
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L		4									1
	T		4							1		1

Station		WIMFO 2	WIMFO 1	PCSM 1	PCSM 2	FMFI 1	FMFI 2	RS 1	RS 2	RS 3	EMCM 1	EMCM 2
Station No.		21	22	23	24	25	26	27	28	29	30	31
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L	1										
	T	1										
GLOBIGERINA BULLOIDES	L											
	T											
HANZAWAIA CONCENTRICA	L											
	T											
HAPLOPHRAGMOIDES BONPLANDI	L											
	T							2				
HAPLOPHRAGMOIDES WILBERTI	L											
	T											
HAYNESINA GERMANICA	L		3	112						4	6	8
	T		3	171						4	9	8
HELENIA ANDERSENI	L											
	T											
JADAMMINA MACRESCENS	L							14				
	T			8		1		52			1	
JADAMMINA POLYSTOMA	L											
	T					1						
MILIAMMINA EARLANDI	L							3				
	T							7				
MILIAMMINA FUSCA	L				7	34		1	46	7	1	
	T				22	59		3	168	19	1	
MILIOLINELLA FICHTELIANA	L											
	T											
MILIOLINELLA MICROSTOMA	L											
	T											
NEOGLOBOQUADRINA BLOWI	L											
	T											
NONIONELLA ATLANTICA	L											
	T											
QUINQUELOCULINA DIMIDIATA	L	1	17	1						2		
	T	1	19	1						2		
QUINQUELOCULINA JUGOSA	L		1									
	T		1									
QUINQUELOCULINA LATA	L											
	T											
QUINQUELOCULINA SEMINULA	L	6	8	1						12	2	
	T	6	11	1						13	2	
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L											
	T											
QUINQUELOCULINA sp.	L		1									
	T		1									
REOPHAX sp.	L											
	T								1			
ROSALINA FLORIDANA	L											
	T											
TEXTULARIA EARLANDI	L	1										
	T	1							1			
TIPHOTROCHA COMPRIMATA	L											
	T					2						
TROCHAMMINA ADVENA	L											
	T									1		
TROCHAMMINA INFLATA	L							12	3	7		
	T		1	6	2	12		109	16	28		1
TROCHAMMINA LAEVIGATA	L											
	T											
TROCHAMMINA LOBATA	L											
	T											
TROCHAMMINA OCHRACEA	L											
	T				2							
TROCHAMMINA "SQUAMATA"	L											
	T		1									1
TROCHAMMINA sp. A	L											
	T				1			4				1
Indeterminate calcareous hyaline	L											
	T											
Indeterminate calcareous porcelaneous	L											
	T											

Station		HIFO 1	HIFO 2	SI 1	SI 2	WI 1	WI 2	WIMFO 3	PCSM 3	EMCM 3	HIFO 3	SSTC 4
Station No.		32	33	34	35	36	37	38	39	40	41	42
No. of species		4	10	11	11	10	6	1	7	4	7	6
(Live/Total)		4	11	12	12	13	12	5	9	14	7	15
No. of individuals per fraction		38	259	177	159	136	60	3	157	19	72	13
picked (Live/Total)		48	277	304	290	295	158	87	344	338	88	307
Extrapolated No. of individuals		38	259	177	636	544	60	3	157	25	72	26
per 70 ml (Live/Total)		48	277	304	1160	1180	158	87	344	451	88	614
Depth (m) (MSL datum)		0.6	0	0.6	0	0	0	-0.59	-0.6	-0.6	-0.6	-4.2
Fraction Picked		-	-	-	1/4	1/4	-	-	-	3/4	-	1/2
AMMOASTUTA INEPTA	L											
	T											
AMMOBACULITES EXIGUUS	L	1	14	3	72	8	2				8	
	T	2	15	4	153	30	15				12	
AMMONIA BECCARII	L	32	101	33	38	29	44	3	105	10	11	2
	T	39	106	35	44	29	44	11	202	48	19	13
AMMOTIUM SALSUM	L											
	T											
ARENOPARRELLA MEXICANA	L			11					1			
	T			32		2	5		1	1		
BOLIVINA STRIATULA	L											
	T											
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T							7		2		5
BUCCELLA INUSITATA	L											
	T											
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											
CIBICIDES LOBATULUS	L											
	T									1		
EGGERELLA ADVENA	L				1							
	T				1	1						
ELPHIDIUM ADVENUM	L											
	T											
ELPHIDIUM ARTICULATUM	L											
	T											
ELPHIDIUM BARTLETTI	L											
	T								2	6		1
ELPHIDIUM DISCOIDALE	L											
	T							1				1
ELPHIDIUM EXCAVATUM	L		21		5	14	6		18	6	8	7
	T		21		5	14	7	67	59	268	11	266
ELPHIDIUM FRIGIDUM	L											
	T											
ELPHIDIUM GALVESTONENSE	L		1									
	T		1							3		
ELPHIDIUM GUNTERI	L		5								2	
	T		8					1		1	3	
ELPHIDIUM INCERTUM	L											
	T											
ELPHIDIUM MARGARITACEUM	L											
	T											
ELPHIDIUM MEXICANUM	L		1		1							
	T		1		1					1		3
ELPHIDIUM POEYANUM	L		1	1						2		1
	T		1	1						2		3
ELPHIDIUM SUBARCTICUM	L											
	T											1
EOEPONIDELLA PULCHELLA	L											
	T											
EPISTOMINELLA VITREA	L											
	T											
FISSURINA LAEVIGATA	L					1						
	T					1						
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L								4			1
	T								5	1		2

Station		HIFO 1	HIFO 2	SI 1	SI 2	WI 1	WI 2	WIMFO 3	PCSM 3	EMCM 3	HIFO 3	SSTC 4
Station No.		32	33	34	35	36	37	38	39	40	41	42
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L				1	1						
	T				1	1						
GLOBIGERINA BULLOIDES	L											
	T											
HANZAWAIA CONCENTRICA	L											
	T											
HAPLOPHRAGMOIDES BONPLANDI	L											
	T					1						
HAPLOPHRAGMOIDES WILBERTI	L											
	T						2					
HAYNESINA GERMANICA	L	2	39	1					23	1	26	1
	T	4	41	1					66	2	26	4
HELENIA ANDERSENI	L		7									
	T		7									
JADAMMINA MACRESCENS	L			2	1	1						
	T			14	2	1	4					1
JADAMMINA POLYSTOMA	L											
	T											
MILIAMMINA EARLANDI	L											
	T											
MILIAMMINA FUSCA	L	3	69	16	36	6	2		2		16	
	T	3	70	26	73	41	30		4		16	
MILIOLINELLA FICHTELIANA	L											
	T											
MILIOLINELLA MICROSTOMA	L			1								
	T			1								
NEOGLOBOQUADRINA BLOWI	L											
	T											
NONIONELLA ATLANTICA	L											
	T											
QUINQUELOCULINA DIMIDIATA	L											
	T											
QUINQUELOCULINA JUGOSA	L											
	T											
QUINQUELOCULINA LATA	L											
	T											
QUINQUELOCULINA SEMINULA	L								4			
	T								4			
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L											
	T											
QUINQUELOCULINA sp.	L											
	T											
REOPHAX sp.	L										1	
	T										1	
ROSALINA FLORIDANA	L				1							
	T				1							1
TEXTULARIA EARLANDI	L				2	55	2					
	T				2	112	3					
TIPHOTROCHA COMPRIMATA	L			4								
	T			19								
TROCHAMMINA ADVENA	L											
	T				2		3					
TROCHAMMINA INFLATA	L			102	1	19	4					
	T		6	165	6	59	37					
TROCHAMMINA LAEVIGATA	L											
	T											
TROCHAMMINA LOBATA	L											
	T											
TROCHAMMINA OCHRACEA	L											1
	T									1		3
TROCHAMMINA "SQUAMATA"	L					2						
	T			1		3	6					1
TROCHAMMINA sp. A	L			3								
	T			5			2		1	1		2
Indeterminate calcareous hyaline	L											
	T											
Indeterminate calcareous porcelaneous	L											
	T											

Station		SSTC 3	SSTC 2	SSTC 1	CIWF 1	CIWF 2	CIWF 3	SSIC 5	SSIC 4	SSIC 3	SSIC 1	SSIC 2
Station No.		43	44	45	46	47	48	49	50	51	52	53
No. of species		3	3	3	0	7	10	2	1	2	1	3
(Live/Total)		12	11	15	2	8	13	9	7	12	15	15
No. of individuals per fraction		4	9	9	0	305	245	3	2	6	1	9
picked (Live/Total)		243	310	393	29	486	525	409	439	456	326	378
Extrapolated No. of individuals		4	18	18	0	4880	490	3	8	12	16	9
per 70 ml (Live/Total)		243	620	786	29	7776	1050	409	1756	912	5216	378
Depth (m) (MSL datum)		-11.9	-14	-14	0.6	0	-0.6	-17.2	-7	-4.1	-13.4	-7
Fraction Picked		-	1/2	1/2	-	1/16	1/2	-	1/4	1/2	1/16	-
AMMOASTUTA INEPTA	L											
	T											
AMMOBACULITES EXIGUUS	L						2					
	T						2					
AMMONIA BECCARII	L	1				11	105			2		1
	T	12	18	25	1	14	136	14	9	10	3	16
AMMOTIUM SALSUM	L											
	T											
ARENOPARRELLA MEXICANA	L											
	T			1								
BOLIVINA STRIATULA	L											
	T											
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T	1	2	6					4	7		5
BUCCELLA INUSITATA	L											
	T										2	
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											1
CIBICIDES LOBATULUS	L											
	T			1						1		1
EGGERELLA ADVENA	L											
	T											
ELPHIDIUM ADVENUM	L											
	T									1	1	
ELPHIDIUM ARTICULATUM	L											
	T							1				1
ELPHIDIUM BARTLETTI	L						2					
	T	2	1				5	6	4	4	2	1
ELPHIDIUM DISCOIDALE	L											
	T											
ELPHIDIUM EXCAVATUM	L	2	7	7		6	74	2	2	4	1	2
	T	218	269	342	28	8	109	377	417	418	300	330
ELPHIDIUM FRIGIDUM	L											
	T									1		
ELPHIDIUM GALVESTONENSE	L						7					
	T		1			3	9			1	1	3
ELPHIDIUM GUNTERI	L											
	T	1								1	1	
ELPHIDIUM INCERTUM	L											
	T											
ELPHIDIUM MARGARITACEUM	L											
	T											
ELPHIDIUM MEXICANUM	L						5					6
	T	1		2			9		3	7	2	11
ELPHIDIUM POEYANUM	L					1						
	T					1	2					
ELPHIDIUM SUBARCTICUM	L											
	T	1		1							1	
EOEPONIDELLA PULCHELLA	L											
	T			1								
EPISTOMINELLA VITREA	L											
	T										1	
FISSURINA LAEVIGATA	L											
	T											
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L		1									
	T	1	3	1								

Station		SSTC 3	SSTC 2	SSTC 1	CIWF 1	CIWF 2	CIWF 3	SSIC 5	SSIC 4	SSIC 3	SSIC 1	SSIC 2
Station No.		43	44	45	46	47	48	49	50	51	52	53
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L											
	T											
GLOBIGERINA BULLOIDES	L											
	T											1
HANZAWAIA CONCENTRICA	L											
	T							1		1	1	1
HAPLOPHRAGMOIDES BONPLANDI	L											
	T											
HAPLOPHRAGMOIDES WILBERTI	L											
	T											
HAYNESINA GERMANICA	L		1	1								
	T	1	7	4			2	3		4		2
HELENIA ANDERSENI	L											
	T											
JADAMMINA MACRESCENS	L											
	T											
JADAMMINA POLYSTOMA	L											
	T											
MILIAMMINA EARLANDI	L											
	T											
MILIAMMINA FUSCA	L						4					
	T						4					
MILIOLINELLA FICHTELIANA	L					1						
	T					1						
MILIOLINELLA MICROSTOMA	L											
	T											
NEOGLOBOQUADRINA BLOWI	L											
	T										1	
NONIONELLA ATLANTICA	L			1								
	T			1					1			
QUINQUELOCULINA DIMIDIATA	L					57	5					
	T					115	29				1	
QUINQUELOCULINA JUGOSA	L											
	T											
QUINQUELOCULINA LATA	L											
	T										1	
QUINQUELOCULINA SEMINULA	L	1				217	40					
	T	1				325	215					1
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L					12						
	T					19	2					
QUINQUELOCULINA sp.	L											
	T											
REOPHAX sp.	L											
	T											
ROSALINA FLORIDANA	L											
	T	2		4				1	1		8	3
TEXTULARIA EARLANDI	L											
	T											
TIPHOTROCHA COMPRIMATA	L											
	T											
TROCHAMMINA ADVENA	L											
	T											
TROCHAMMINA INFLATA	L											
	T		1									
TROCHAMMINA LAEVIGATA	L											
	T											
TROCHAMMINA LOBATA	L											
	T											
TROCHAMMINA OCHRACEA	L							1				
	T		3	2				3				
TROCHAMMINA "SQUAMATA"	L											
	T		1	1				3				
TROCHAMMINA sp. A	L											
	T	2	4	1								1
Indeterminate calcareous hyaline	L						1					
	T						1					
Indeterminate calcareous porcelaneous	L											
	T											

Station		SSIC 6	CISF 1	CISF 2	CISF 3
Station No.		54	55	56	57
No. of species		1	5	2	2
(Live/Total)		11	18	8	4
No. of individuals per fraction		1	26	3	2
picked (Live/Total)		429	393	291	148
Extrapolated No. of individuals		4	104	3	2
per 70 ml (Live/Total)		1716	1572	291	148
Depth (m) (MSL datum)		-3.65	-12	-7	-4
Fraction Picked		1/4	1/4	-	-
AMMOASTUTA INEPTA	L				
	T				
AMMOBACULITES EXIGUUS	L				
	T				
AMMONIA BECCARII	L				
	T	4	5	7	2
AMMOTIUM SALSUM	L				
	T				
ARENOPARRELLA MEXICANA	L				
	T				
BOLIVINA STRIATULA	L				
	T				
BOLIVINA VARIABILIS	L				
	T				
BUCCELLA DEPRESSA	L				
	T				
BUCCELLA FRIGIDA	L				
	T	5	1	4	
BUCCELLA INUSITATA	L				
	T		2		
BULIMINELLA ELEGANTISSIMA	L				
	T				
CASSIDULINA SUBGLOBOSA	L				
	T				
CIBICIDES LOBATULUS	L				
	T		1		
EGGERELLA ADVENA	L				
	T		1		
ELPHIDIUM ADVENUM	L				
	T				
ELPHIDIUM ARTICULATUM	L				
	T				
ELPHIDIUM BARTLETTI	L				
	T	2	2		
ELPHIDIUM DISCOIDALE	L		2		
	T	2	3		
ELPHIDIUM EXCAVATUM	L	1	12	2	1
	T	406	346	269	142
ELPHIDIUM FRIGIDUM	L				
	T				
ELPHIDIUM GALVESTONENSE	L		2		
	T	2	6	2	
ELPHIDIUM GUNTERI	L				
	T		2		
ELPHIDIUM INCERTUM	L				
	T				
ELPHIDIUM MARGARITACEUM	L				
	T				
ELPHIDIUM MEXICANUM	L		9	1	1
	T	3	14	6	3
ELPHIDIUM POEYANUM	L				
	T				
ELPHIDIUM SUBARCTICUM	L				
	T				
EOEPONIDELLA PULCHELLA	L				
	T		1	1	
EPISTOMINELLA VITREA	L				
	T				
FISSURINA LAEVIGATA	L				
	T				
FURSENKOINA FUSIFORMIS	L				
	T				
GLABRATELLA sp. A	L				
	T		1		

Station		SSIC 5	CISF 1	CISF 2	CISF 3
Station No.		54	55	56	57
GLABRATELLA sp. B	L				
	T		1		
GLABRATELLINA sp. A	L				
	T				
GLOBIGERINA BULLOIDES	L				
	T				
HANZAWAIA CONCENTRICA	L				
	T	2			
HAPLOPHRAGMOIDES BONPLANDI	L				
	T				
HAPLOPHRAGMOIDES WILBERTI	L				
	T				
HAYNESINA GERMANICA	L		1		
	T	1	1		
HELENIA ANDERSENI	L				
	T				
JADAMMINA MACRESCENS	L				
	T				
JADAMMINA POLYSTOMA	L				
	T				
MILIAMMINA EARLANDI	L				
	T				
MILIAMMINA FUSCA	L				
	T				
MILIOLINELLA FICHTELIANA	L				
	T				
MILIOLINELLA MICROSTOMA	L				
	T				
NEOGLOBOQUADRINA BLOWI	L				
	T				
NONIONELLA ATLANTICA	L				
	T			1	
QUINQUELOCULINA DIMIDIATA	L				
	T			1	
QUINQUELOCULINA JUGOSA	L				
	T				
QUINQUELOCULINA LATA	L				
	T	1	2		
QUINQUELOCULINA SEMINULA	L				
	T	1	3		
QUINQUELOCULINA cf. SEMINULA	L				
	T				
QUINQUELOCULINA SEMINULA var. JUGOSA	L				
	T				
QUINQUELOCULINA sp.	L				
	T				
REOPHAX sp.	L				
	T				
ROSALINA FLORIDANA	L				
	T				1
TEXTULARIA EARLANDI	L				
	T				
TIPHOTROCHA COMPRIMATA	L				
	T				
TROCHAMMINA ADVENA	L				
	T				
TROCHAMMINA INFLATA	L				
	T				
TROCHAMMINA LAEVIGATA	L				
	T				
TROCHAMMINA LOBATA	L				
	T				
TROCHAMMINA OCHRACEA	L				
	T		1		
TROCHAMMINA "SQUAMATA"	L				
	T				
TROCHAMMINA sp. A	L				
	T				
Indeterminate calcareous hyaline	L				
	T				
Indeterminate calcareous porcelaneous	L				
	T				

Appendix D. Relative abundance (percent frequency) for the living and total (living+dead) assemblages in the surface sediments from the 57 stations.

Station		MREF 1	MREF 2	MREF 3	BSRB 1	BSRB 2	BSRB 3	EB 3	EB 4	FMFI 3	EB 1	EB 2
Station No.		1	2	3	4	5	6	7	8	9	10	11
No. of species		8	8	10	9	2	5	6	5	3	3	3
(Live/Total)		13	13	17	12	6	10	12	11	7	9	12
No. of individuals per fraction		41	26	52	337	43	225	12	30	25	18	18
picked (Live/Total)		639	319	373	447	60	322	348	289	34	218	377
Relative abundance (%)		6.4	8.2	13.9	75.4	71.7	69.9	3.4	10.4	73.5	8.3	4.8
(Live/Dead)		93.6	91.8	86.1	24.6	28.3	30.1	96.6	89.6	26.5	91.7	95.2
Depth (m) (MSL datum)		0.6	0	-0.6	-0.3	-0.3	-0.3	-0.2	-0.2	-0.6	-0.8	-0.5
Fraction Picked		1/4	1/8	1/2	1/8	-	1/16	1/16	-	-	-	-
AMMOASTUTA INEPTA	L		15.4									
	T	2	5.6	3.5								
AMMOBACULITES EXIGUUS	L			5.8	0.6		0.4					
	T		0.6	1.1	1.3	1.7	0.6			2.9		
AMMONIA BECCARII	L			34.6	52.8	46.5	65.8	8.3	6.7	56	22.2	
	T			4.8	49	38.3	61.5	7.8	3.1	41.2	10.1	7.2
AMMOTIUM SALSUM	L											
	T			0.3								
ARENOPARRELLA MEXICANA	L	17.1	3.9	5.8								
	T	14.9	20.7	15.6						2.9		
BOLIVINA STRIATULA	L											5.6
	T											0.3
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T							3.2	0.4		1.8	0.5
BUCCELLA INUSITATA	L											
	T								0.4			
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											
CIBICIDES LOBATULUS	L											
	T											
EGGERELLA ADVENA	L											
	T											
ELPHIDIUM ADVENUM	L											
	T											
ELPHIDIUM ARTICULATUM	L				0.6		1.8					
	T				0.5		1.2					
ELPHIDIUM BARTLETTI	L				1.2							
	T				1.8		0.6	0.9	0.4		6	0.3
ELPHIDIUM DISCOIDALE	L											
	T											
ELPHIDIUM EXCAVATUM	L			17.3	43.3	53.5	31.6	50	63.3	20	72.2	88.9
	T			2.4	45	55	33.9	79.9	84.8	26.5	72.5	88.6
ELPHIDIUM FRIGIDUM	L											
	T											
ELPHIDIUM GALVESTONENSE	L											
	T							0.3			0.9	0.5
ELPHIDIUM GUNTERI	L				0.3						5.6	
	T				0.2			1.2			7.3	0.8
ELPHIDIUM INCERTUM	L											
	T										0.5	
ELPHIDIUM MARGARITACEUM	L											
	T											
ELPHIDIUM MEXICANUM	L											
	T							0.3				0.5
ELPHIDIUM POEYANUM	L							8.3	3.3			
	T							2	0.4			0.3
ELPHIDIUM SUBARCTICUM	L											
	T											
EOEPONIDELLA PULCHELLA	L											
	T											
EPISTOMINELLA VITREA	L											
	T											
FISSURINA LAEVIGATA	L											
	T											
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L							8.3	3.3			5.6
	T							0.6	2.1		0.5	0.3

Station		MREF 1	MREF 2	MREF 3	BSRB 1	BSRB 2	BSRB 3	EB 3	EB 4	FMFI 3	EB 1	EB 2
Station No.		1	2	3	4	5	6	7	8	9	10	11
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L						0.4					
	T						0.3					
GLOBIGERINA BULLOIDES	L											
	T											
HANZAWAIA CONCENTRICA	L											
	T											
HAPLOPHRAGMOIDES BONPLANDI	L											
	T	6.3	1.9	2.2								
HAPLOPHRAGMOIDES WILBERTI	L	9.8										
	T	7	1.9	2.7								
HAYNESINA GERMANICA	L			1.9	0.6			16.7	23.3			
	T			0.3	0.9			3.2	6.6		0.5	0.5
HELENIA ANDERSENI	L											
	T											
JADAMMINA MACRESCENS	L	9.8	3.9									
	T	11.4	5	3.2			0.3					
JADAMMINA POLYSTOMA	L											
	T	0.3										
MILIAMMINA EARLANDI	L											
	T											
MILIAMMINA FUSCA	L		15.4	1.9	0.3					24		
	T		2.2	0.5	0.2					20.6		
MILIOLINELLA FICHTELIANA	L											
	T											
MILIOLINELLA MICROSTOMA	L											
	T											
NEOGLOBOQUADRINA BLOWI	L											
	T											
NONIONELLA ATLANTICA	L											
	T											
QUINQUELOCULINA DIMIDIATA	L											
	T											
QUINQUELOCULINA JUGOSA	L											
	T											
QUINQUELOCULINA LATA	L											
	T											
QUINQUELOCULINA SEMINULA	L				0.3							
	T				0.2							0.3
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L											
	T											
QUINQUELOCULINA sp.	L											
	T											
REOPHAX sp.	L											
	T											
ROSALINA FLORIDANA	L							8.3				
	T							0.6				
TEXTULARIA EARLANDI	L	2.4										
	T	0.2										
TIPHOTROCHA COMPRIMATA	L			1.9								
	T	0.6	0.3	2.4		1.7				2.9		
TROCHAMMINA ADVENA	L	4.9										
	T	2	1.9	3.2								
TROCHAMMINA INFLATA	L	24.4	23.1	3.9								
	T	43.4	35.7	31.6		1.7	0.6					
TROCHAMMINA LAEVIGATA	L		3.9									
	T		0.9	1.1								
TROCHAMMINA LOBATA	L											
	T	0.3										
TROCHAMMINA OCHRACEA	L											
	T				0.5		0.3		0.7	2.9		
TROCHAMMINA "SQUAMATA"	L	24.4	11.5	11.5								
	T	4.5	5.6	6.2	0.2	1.7			0.7			
TROCHAMMINA sp. A	L	7.3	23.1	15.4								
	T	7	17.6	19	0.2		0.6	0.3	0.7			
Indeterminate calcareous hyaline	L											
	T											
Indeterminate calcareous porcelaneous	L											
	T											

Station		CBSFI 1	CBSFI 2	ECSFM 1	ECSFM 2	CBSFO 1	CBSFO 2	OYMFI 1	OYMFI 2	OYMFI 3
Station No.		12	13	14	15	16	17	18	19	20
No. of species		4	7	2	1	1	10	7	8	10
(Live/Total)		11	17	12	10	6	18	14	20	23
No. of individuals per fraction		6	62	11	2	10	94	83	455	248
picked (Live/Total)		321	487	453	334	272	306	237	692	668
Relative abundance (%)		1.9	12.7	2.4	0.6	3.7	30.7	35	65.8	37.1
(Live/Dead)		98.1	87.3	97.6	99.4	96.3	69.3	65	34.2	62.9
Depth (m) (MSL datum)		-0.3	-0.3	-0.4	-0.4	-0.89	-0.89	-0.23	-0.12	-0.01
Fraction Picked		1/8	1/4	1/8	1/4	-	-	-	-	1/2
AMMOASTUTA INEPTA	L									
	T									
AMMOBACULITES EXIGUUS	L						1.1		0.4	0.4
	T			0.2			0.3	0.4	0.3	0.5
AMMONIA BECCARII	L	50	16.1				13.8	31.3	49.5	56.5
	T	3.4	11.1	3.3	1.5	1.5	18.6	18.6	37.7	31.7
AMMOTIUM SALSUM	L									
	T									
ARENOPARRELLA MEXICANA	L									
	T									
BOLIVINA STRIATULA	L									
	T									
BOLIVINA VARIABILIS	L									
	T		0.2							
BUCCELLA DEPRESSA	L									
	T				0.3					
BUCCELLA FRIGIDA	L									
	T		0.8	0.4	1.8	0.7	0.7		0.9	0.8
BUCCELLA INUSITATA	L									
	T								0.3	
BULIMINELLA ELEGANTISSIMA	L									
	T		0.2							
CASSIDULINA SUBGLOBOSA	L									
	T									
CIBICIDES LOBATULUS	L									
	T								0.2	
EGGERELLA ADVENA	L									
	T								0.3	0.2
ELPHIDIUM ADVENUM	L									
	T									
ELPHIDIUM ARTICULATUM	L									
	T									
ELPHIDIUM BARTLETTI	L							7.2	1.5	
	T	0.6	0.4		0.3		1	3	1.5	0.2
ELPHIDIUM DISCOIDALE	L									
	T	0.3								
ELPHIDIUM EXCAVATUM	L	16.7	74.2	81.8	100	100	54.3	45.8	43.1	32.3
	T	92.8	82.6	91.8	92.5	95.6	65.7	67.5	52.2	56.6
ELPHIDIUM FRIGIDUM	L									
	T									
ELPHIDIUM GALVESTONENSE	L									
	T	0.6		0.7	0.3	0.4	0.3	0.4	0.3	0.6
ELPHIDIUM GUNTERI	L									
	T	0.3				0.4			1.6	0.2
ELPHIDIUM INCERTUM	L									
	T		0.2							
ELPHIDIUM MARGARITACEUM	L									
	T									
ELPHIDIUM MEXICANUM	L									
	T	0.6	0.6	0.4	2.4	1.5	0.3			0.2
ELPHIDIUM POEYANUM	L		3.2				2.1	2.4	0.9	2.4
	T	0.3	1		0.3		0.7	0.8	0.6	1.1
ELPHIDIUM SUBARCTICUM	L									
	T			0.9				0.4		0.2
EOEPONIDELLA PULCHELLA	L									
	T		0.2							
EPISTOMINELLA VITREA	L									
	T									
FISSURINA LAEVIGATA	L									0.8
	T									0.3
FURSENKOINA FUSIFORMIS	L									
	T		0.4							
GLABRATELLA sp. A	L		1.6				1.1	9.6	3.1	1.2
	T		0.4	0.2			0.7	3.8	2	1.2

Station		CBSFI 1	CBSFI 2	ECSFM 1	ECSFM 2	CBSFO 1	CBSFO 2	OYMFI 1	OYMFI 2	OYMFI 3
Station No.		12	13	14	15	16	17	18	19	20
GLABRATELLA sp. B	L									
	T									
GLABRATELLINA sp. A	L		1.6				6.4			
	T		0.2				2			
GLOBIGERINA BULLOIDES	L									
	T									
HANZAWAIA CONCENTRICA	L									
	T			0.2						
HAPLOPHRAGMOIDES BONPLANDI	L									
	T									
HAPLOPHRAGMOIDES WILBERTI	L									
	T									
HAYNESINA GERMANICA	L	16.7	1.6	18.2			1.1	1.2		4.8
	T	0.3	0.8	1.1			1	0.8	0.3	3.4
HELENIA ANDERSENI	L									
	T									
JADAMMINA MACRESCENS	L									
	T							0.4	0.2	
JADAMMINA POLYSTOMA	L									
	T									
MILIAMMINA EARLANDI	L									
	T									
MILIAMMINA FUSCA	L							2.4	1.3	
	T							0.8	0.9	
MILIOLINELLA FICHTELIANA	L									
	T									
MILIOLINELLA MICROSTOMA	L									
	T									
NEOGLOBOQUADRINA BLOWI	L									
	T									
NONIONELLA ATLANTICA	L									
	T			0.2	0.3					
QUINQUELOCULINA DIMIDIATA	L									
	T						0.7			0.3
QUINQUELOCULINA JUGOSA	L									
	T									
QUINQUELOCULINA LATA	L									
	T									
QUINQUELOCULINA SEMINULA	L						16			0.8
	T				0.3		5.6			0.6
QUINQUELOCULINA cf. SEMINULA	L						3.2			
	T						1			
QUINQUELOCULINA SEMINULA var. JUGOSA	L									
	T									
QUINQUELOCULINA sp.	L									
	T									
REOPHAX sp.	L									
	T									
ROSALINA FLORIDANA	L								0.2	
	T	0.3	0.4	0.4			0.7		0.2	0.3
TEXTULARIA EARLANDI	L		1.6				1.1			0.4
	T		0.2				0.3			0.2
TIPHOTROCHA COMPRIMATA	L									
	T								0.2	
TROCHAMMINA ADVENA	L									
	T									
TROCHAMMINA INFLATA	L									0.4
	T						0.3	0.4	0.2	0.3
TROCHAMMINA LAEVIGATA	L									
	T									
TROCHAMMINA LOBATA	L									
	T									
TROCHAMMINA OCHRACEA	L	16.7								
	T	0.3					0.3	1.3		0.8
TROCHAMMINA "SQUAMATA"	L									
	T								0.2	0.3
TROCHAMMINA sp. A	L									
	T		0.2					1.3	0.4	0.3
Indeterminate calcareous hyaline	L									
	T									
Indeterminate calcareous porcelaneous	L									
	T									0.2

Station		WIMFO 2	WIMFO 1	PCSM 1	PCSM 2	FMFI 1	FMFI 2	RS 1	RS 2	RS 3	EMCM 1	EMCM 2
Station No.		21	22	23	24	25	26	27	28	29	30	31
No. of species		6	11	5	3	1	2	6	5	10	9	4
(Live/Total)		9	15	8	7	7	2	8	7	12	11	7
No. of individuals per fraction		57	215	294	27	34	2	37	127	171	357	30
picked (Live/Total)		125	352	469	50	84	2	299	304	343	447	51
Relative abundance (%)		45.6	61.1	62.7	54	40.5	100	12.4	41.8	49.9	79.9	58.8
(Live/Dead)		54.4	38.9	37.3	46	59.5	0	87.6	58.2	50.1	20.1	41.2
Depth (m) (MSL datum)		-0.44	-0.42	0.6	0	0.6	0	0.9	0.2	0	0.6	0
Fraction Picked		-	1/2	-	-	-	-	1/2	1/2	3/4	1/4	-
AMMOASTUTA INEPTA	L											
	T											
AMMOBACULITES EXIGUUS	L						50		8.7	0.6	0.6	
	T						50		14.8	5.5	0.7	
AMMONIA BECCARII	L	22.8	12.1	58.8	70.4			2.7	50.4	52.6	58.8	43.3
	T	20.8	12.5	55.9	38	1.2		0.3	23	49.9	55.7	29.4
AMMOTIUM SALSUM	L											
	T											
ARENOPARRELLA MEXICANA	L							16.2				
	T				6	9.5		40.5				
BOLIVINA STRIATULA	L											
	T											
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T	1.6	1.4									
BUCCELLA INUSITATA	L											
	T											
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											
CIBICIDES LOBATULUS	L											
	T											
EGGERELLA ADVENA	L											
	T											
ELPHIDIUM ADVENUM	L											
	T											
ELPHIDIUM ARTICULATUM	L											
	T											
ELPHIDIUM BARTLETTI	L										1.1	
	T	0.8		0.2							1.3	
ELPHIDIUM DISCOIDALE	L											
	T											
ELPHIDIUM EXCAVATUM	L	61.4	68.8	2.4	3.7		50		2.4	24	35.3	26.7
	T	68.8	71.3	4.1	2		50		1	22.7	37.6	47.1
ELPHIDIUM FRIGIDUM	L											
	T											
ELPHIDIUM GALVESTONENSE	L											
	T										0.2	
ELPHIDIUM GUNTERI	L		0.5							0.6	0.8	
	T		0.3							0.3	0.9	
ELPHIDIUM INCERTUM	L											
	T											
ELPHIDIUM MARGARITACEUM	L											
	T		0.8									
ELPHIDIUM MEXICANUM	L										0.8	
	T										0.7	
ELPHIDIUM POEYANUM	L		2.3							3.5		
	T	0.8	2							1.8		
ELPHIDIUM SUBARCTICUM	L		0.5									
	T		0.3									
EOEPONIDELLA PULCHELLA	L											
	T											
EPISTOMINELLA VITREA	L											
	T											
FISSURINA LAEVIGATA	L											
	T											
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L		1.9									3.3
	T		1.1							0.3		2

Station		WIMFO 2	WIMFO 1	PCSM 1	PCSM 2	FMFI 1	FMFI 2	RS 1	RS 2	RS 3	EMCM 1	EMCM 2
Station No.		21	22	23	24	25	26	27	28	29	30	31
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L	1.8										
	T	0.8										
GLOBIGERINA BULLOIDES	L											
	T											
HANZAWAIA CONCENTRICA	L											
	T											
HAPLOPHRAGMOIDES BONPLANDI	L											
	T							0.7				
HAPLOPHRAGMOIDES WILBERTI	L											
	T											
HAYNESINA GERMANICA	L		1.4	38.1						2.3	1.7	26.7
	T		0.9	36.5						1.2	2	15.7
HELENIA ANDERSENI	L											
	T											
JADAMMINA MACRESCENS	L							37.8				
	T			1.7		1.2		17.4			0.2	
JADAMMINA POLYSTOMA	L											
	T					1.2						
MILIAMMINA EARLANDI	L							8.1				
	T							2.3				
MILIAMMINA FUSCA	L				25.9	100		2.7	36.2	4.1	0.3	
	T				44	70.2		1	55.3	5.5	0.2	
MILIOLINELLA FICHTELIANA	L											
	T											
MILIOLINELLA MICROSTOMA	L											
	T											
NEOGLOBOQUADRINA BLOWI	L											
	T											
NONIONELLA ATLANTICA	L											
	T											
QUINQUELOCULINA DIMIDIATA	L	1.8	7.9	0.3						1.2		
	T	0.8	5.4	0.2						0.6		
QUINQUELOCULINA JUGOSA	L		0.5									
	T		0.3									
QUINQUELOCULINA LATA	L											
	T											
QUINQUELOCULINA SEMINULA	L	10.5	3.7	0.3						7	0.6	
	T	4.8	3.1	0.2						3.8	0.5	
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L											
	T											
QUINQUELOCULINA sp.	L		0.5									
	T		0.3									
REOPHAX sp.	L											
	T								0.3			
ROSALINA FLORIDANA	L											
	T											
TEXTULARIA EARLANDI	L	1.8										
	T	0.8							0.3			
TIPHOTROCHA COMPRIMATA	L											
	T					2.4						
TROCHAMMINA ADVENA	L											
	T									0.3		
TROCHAMMINA INFLATA	L							32.4	2.4	4.1		
	T		0.3	1.3	4	14.3		36.5	5.3	8.2		2
TROCHAMMINA LAEVIGATA	L											
	T											
TROCHAMMINA LOBATA	L											
	T											
TROCHAMMINA OCHRACEA	L											
	T				4							
TROCHAMMINA "SQUAMATA"	L											
	T		0.3									2
TROCHAMMINA sp. A	L											
	T				2			1.3				2
Indeterminate calcareous hyaline	L											
	T											
Indeterminate calcareous porcelaneous	L											
	T											

Station		HIFO 1	HIFO 2	SI 1	SI 2	WI 1	WI 2	WIMFO 3	PCSM 3	EMCM 3	HIFO 3	SSTC 4
Station No.		32	33	34	35	36	37	38	39	40	41	42
No. of species		4	10	11	11	10	6	1	7	4	7	6
(Live/Total)		4	11	12	12	13	12	5	9	14	7	15
No. of individuals per fraction		38	259	177	159	136	60	3	157	19	72	13
picked (Live/Total)		48	277	304	290	295	158	87	344	338	88	307
Relative abundance (%)		79.2	93.5	58.2	54.8	46.1	38	3.4	45.6	5.6	81.8	4.2
(Live/Dead)		20.8	6.5	41.8	45.2	53.9	62	96.6	54.4	94.4	18.2	95.8
Depth (m) (MSL datum)		0.6	0	0.6	0	0	0	-0.59	-0.6	-0.6	-0.6	-4.2
Fraction Picked		-	-	-	1/4	1/4	-	-	-	3/4	-	1/2
AMMOASTUTA INEPTA	L											
	T											
AMMOBACULITES EXIGUUS	L	2.6	5.4	1.7	45.3	5.9	3.3				11.1	
	T	5.3	5.4	1.3	52.8	10.2	9.5				13.6	
AMMONIA BECCARII	L	84.2	39	18.6	23.9	21.3	73.3	100	66.9	52.6	15.3	15.4
	T	81.3	38.3	11.5	15.2	9.8	27.8	12.6	58.7	14.2	21.6	4.2
AMMOTIUM SALSUM	L											
	T											
ARENOPARRELLA MEXICANA	L			6.2					0.6			
	T			10.5		0.7	3.2		0.3	0.3		
BOLIVINA STRIATULA	L											
	T											
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T							8.1		0.6		1.6
BUCCELLA INUSITATA	L											
	T											
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											
CIBICIDES LOBATULUS	L											
	T									0.3		
EGGERELLA ADVENA	L				0.6							
	T				0.4	0.3						
ELPHIDIUM ADVENUM	L											
	T											
ELPHIDIUM ARTICULATUM	L											
	T											
ELPHIDIUM BARTLETTI	L											
	T								0.6	1.8		0.3
ELPHIDIUM DISCOIDALE	L											
	T							1.2				0.3
ELPHIDIUM EXCAVATUM	L		8.1		3.1	10.3	10		11.5	31.6	11.1	53.9
	T		7.6		1.7	4.7	4.4	77	17.2	79.3	12.5	86.7
ELPHIDIUM FRIGIDUM	L											
	T											
ELPHIDIUM GALVESTONENSE	L		0.4									
	T		0.4							0.9		
ELPHIDIUM GUNTERI	L		1.9								2.8	
	T		2.9					1.2		0.3	3.4	
ELPHIDIUM INCERTUM	L											
	T											
ELPHIDIUM MARGARITACEUM	L											
	T											
ELPHIDIUM MEXICANUM	L		0.4		0.6							
	T		0.4		0.4					0.3		1
ELPHIDIUM POEYANUM	L		0.4	0.6						10.5		7.7
	T		0.4	0.3						0.8		1
ELPHIDIUM SUBARCTICUM	L											
	T											0.3
EOEPONIDELLA PULCHELLA	L											
	T											
EPISTOMINELLA VITREA	L											
	T											
FISSURINA LAEVIGATA	L					0.7						
	T					0.3						
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L								2.6			7.7
	T								1.5	0.3		0.7

Station		HIFO 1	HIFO 2	SI 1	SI 2	WI 1	WI 2	WIMFO 3	PCSM 3	EMCM 3	HIFO 3	SSTC 4
Station No.		32	33	34	35	36	37	38	39	40	41	42
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L				0.6	0.7						
	T				0.4	0.3						
GLOBIGERINA BULLOIDES	L											
	T											
HANZAWAIA CONCENTRICA	L											
	T											
HAPLOPHRAGMOIDES BONPLANDI	L											
	T					0.3						
HAPLOPHRAGMOIDES WILBERTI	L											
	T						1.3					
HAYNESINA GERMANICA	L	5.3	15.1	0.6					14.7	5.3	36.1	7.7
	T	8.3	14.0	0.3					19.2	0.6	29.6	1.3
HELENIA ANDERSENI	L		2.7									
	T		2.5									
JADAMMINA MACRESCENS	L			1.1	0.6	0.7						
	T			4.6	0.7	0.3	2.5					0.3
JADAMMINA POLYSTOMA	L											
	T											
MILIAMMINA EARLANDI	L											
	T											
MILIAMMINA FUSCA	L	7.9	26.6	9	22.6	4.4	3.3		1.3		22.2	
	T	6.3	25.3	8.6	25.2	13.9	19		1.2		18.2	
MILIOLINELLA FICHTELIANA	L											
	T											
MILIOLINELLA MICROSTOMA	L			0.6								
	T			0.3								
NEOGLOBOQUADRINA BLOWI	L											
	T											
NONIONELLA ATLANTICA	L											
	T											
QUINQUELOCULINA DIMIDIATA	L											
	T											
QUINQUELOCULINA JUGOSA	L											
	T											
QUINQUELOCULINA LATA	L											
	T											
QUINQUELOCULINA SEMINULA	L								2.6			
	T								1.2			
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L											
	T											
QUINQUELOCULINA sp.	L											
	T											
REOPHAX sp.	L										1.4	
	T										1.1	
ROSALINA FLORIDANA	L				0.6							
	T				0.4							0.3
TEXTULARIA EARLANDI	L				1.3	40.4	3.3					
	T				0.7	38	1.9					
TIPHOTROCHA COMPRIMATA	L			2.3								
	T			6.3								
TROCHAMMINA ADVENA	L											
	T				0.7		1.9					
TROCHAMMINA INFLATA	L			57.6	0.6	14	6.7					
	T		2.2	54.3	2.1	20	23.4					
TROCHAMMINA LAEVIGATA	L											
	T											
TROCHAMMINA LOBATA	L											
	T											
TROCHAMMINA OCHRACEA	L											7.7
	T									0.3		1
TROCHAMMINA "SQUAMATA"	L					1.5						
	T			0.3		1	3.8					0.3
TROCHAMMINA sp. A	L			1.7								
	T			1.6			1.3		0.3	0.3		0.7
Indeterminate calcareous hyaline	L											
	T											
Indeterminate calcareous porcelaneous	L											
	T											

Station		SSTC 3	SSTC 2	SSTC 1	CIWF 1	CIWF 2	CIWF 3	SSIC 5	SSIC 4	SSIC 3	SSIC 1	SSIC 2
Station No.		43	44	45	46	47	48	49	50	51	52	53
No. of species		3	3	3	0	7	10	2	1	2	1	3
(Live/Total)		12	11	15	2	8	13	9	7	12	15	15
No. of individuals per fraction		4	9	9	0	305	245	3	2	6	1	9
picked (Live/Total)		243	310	393	29	486	525	409	439	456	326	378
Relative abundance (%)		1.6	2.9	2.3	0	62.8	46.7	0.7	0.5	1.3	0.3	2.4
(Live/Dead)		98.4	97.1	97.7	100	37.2	53.3	99.3	99.5	98.7	99.7	97.6
Depth (m) (MSL datum)		-11.9	-14	-14	0.6	0	-0.6	-17.2	-7	-4.1	-13.4	-7
Fraction Picked		-	1/2	1/2	-	1/16	1/2	-	1/4	1/2	1/16	-
AMMOASTUTA INEPTA	L											
	T											
AMMOBACULITES EXIGUUS	L						0.8					
	T						0.4					
AMMONIA BECCARII	L	25				3.6	42.9			33.3		11.1
	T	4.9	5.8	6.4	3.4	2.9	25.9	3.4	2.1	2.2	0.9	4.2
AMMOTIUM SALSUM	L											
	T											
ARENOPARRELLA MEXICANA	L											
	T			0.3								
BOLIVINA STRIATULA	L											
	T											
BOLIVINA VARIABILIS	L											
	T											
BUCCELLA DEPRESSA	L											
	T											
BUCCELLA FRIGIDA	L											
	T	0.4	0.7	1.5					0.9	1.5		1.3
BUCCELLA INUSITATA	L											
	T										0.6	
BULIMINELLA ELEGANTISSIMA	L											
	T											
CASSIDULINA SUBGLOBOSA	L											
	T											0.3
CIBICIDES LOBATULUS	L											
	T			0.3						0.2		0.3
EGGERELLA ADVENA	L											
	T											
ELPHIDIUM ADVENUM	L											
	T									0.2	0.3	
ELPHIDIUM ARTICULATUM	L											
	T							0.2				0.3
ELPHIDIUM BARTLETTI	L						0.8					
	T	0.8	0.3				1	1.5	0.9	0.9	0.6	0.3
ELPHIDIUM DISCOIDALE	L											
	T											
ELPHIDIUM EXCAVATUM	L	50	77.8	77.8		2	30.2	66.7	100	66.7	100	22.2
	T	89.7	86.8	87	96.6	1.7	20.8	92.2	95	91.7	92	87.3
ELPHIDIUM FRIGIDUM	L											
	T									0.2		
ELPHIDIUM GALVESTONENSE	L						2.9					
	T		0.3			0.6	1.7			0.2	0.3	0.8
ELPHIDIUM GUNTERI	L											
	T	0.4								0.2	0.3	
ELPHIDIUM INCERTUM	L											
	T											
ELPHIDIUM MARGARITACEUM	L											
	T											
ELPHIDIUM MEXICANUM	L						2					66.7
	T	0.4		0.5			1.7		0.7	1.5	0.6	2.9
ELPHIDIUM POEYANUM	L					0.3						
	T					0.2	0.4					
ELPHIDIUM SUBARCTICUM	L											
	T	0.4		0.3							0.3	
EOEPONIDELLA PULCHELLA	L											
	T			0.3								
EPISTOMINELLA VITREA	L											
	T										0.3	
FISSURINA LAEVIGATA	L											
	T											
FURSENKOINA FUSIFORMIS	L											
	T											
GLABRATELLA sp. A	L		11.1									
	T	0.4	1	0.3								

Station		SSTC 3	SSTC 2	SSTC 1	CIWF 1	CIWF 2	CIWF 3	SSIC 5	SSIC 4	SSIC 3	SSIC 1	SSIC 2
Station No.		43	44	45	46	47	48	49	50	51	52	53
GLABRATELLA sp. B	L											
	T											
GLABRATELLINA sp. A	L											
	T											
GLOBIGERINA BULLOIDES	L											
	T											0.3
HANZAWAIA CONCENTRICA	L											
	T							0.2		0.2	0.3	0.3
HAPLOPHRAGMOIDES BONPLANDI	L											
	T											
HAPLOPHRAGMOIDES WILBERTI	L											
	T											
HAYNESINA GERMANICA	L		11.1	11.1								
	T	0.4	2.3	1			0.4	0.7		0.9		0.5
HELENIA ANDERSENI	L											
	T											
JADAMMINA MACRESCENS	L											
	T											
JADAMMINA POLYSTOMA	L											
	T											
MILIAMMINA EARLANDI	L											
	T											
MILIAMMINA FUSCA	L						1.6					
	T						0.8					
MILIOLINELLA FICHTELIANA	L					0.3						
	T					0.2						
MILIOLINELLA MICROSTOMA	L											
	T											
NEOGLOBOQUADRINA BLOWI	L											
	T										0.3	
NONIONELLA ATLANTICA	L			11.1								
	T			0.3					0.2			
QUINQUELOCULINA DIMIDIATA	L					18.7	2					
	T					23.7	5.5				0.3	
QUINQUELOCULINA JUGOSA	L											
	T											
QUINQUELOCULINA LATA	L											
	T										0.3	
QUINQUELOCULINA SEMINULA	L	25				71.2	16.3					
	T	0.4				66.9	41					0.3
QUINQUELOCULINA cf. SEMINULA	L											
	T											
QUINQUELOCULINA SEMINULA var. JUGOSA	L					3.9						
	T					3.9	0.4					
QUINQUELOCULINA sp.	L											
	T											
REOPHAX sp.	L											
	T											
ROSALINA FLORIDANA	L											
	T	0.8		1				0.2	0.2		2.5	0.8
TEXTULARIA EARLANDI	L											
	T											
TIPHOTROCHA COMPRIMATA	L											
	T											
TROCHAMMINA ADVENA	L											
	T											
TROCHAMMINA INFLATA	L											
	T		0.3									
TROCHAMMINA LAEVIGATA	L											
	T											
TROCHAMMINA LOBATA	L											
	T											
TROCHAMMINA OCHRACEA	L							33.3				
	T		1	0.5				0.7				
TROCHAMMINA "SQUAMATA"	L											
	T		0.3	0.3				0.7				
TROCHAMMINA sp. A	L											
	T	0.8	1.3	0.3								0.3
Indeterminate calcareous hyaline	L						0.4					
	T						0.2					
Indeterminate calcareous porcelaneous	L											
	T											

Station		SSIC 6	CISF 1	CISF 2	CISF 3
Station No.		54	55	56	57
No. of species		1	5	2	2
(Live/Total)		11	18	8	4
No. of individuals per fraction		1	26	3	2
picked (Live/Total)		429	393	291	148
Relative abundance (%)		0.2	6.6	1	1.4
(Live/Dead)		99.8	93.4	99	98.6
Depth (m) (MSL datum)		-3.65	-12	-7	-4
Fraction Picked		1/4	1/4	-	-
AMMOASTUTA INEPTA	L				
	T				
AMMOBACULITES EXIGUUS	L				
	T				
AMMONIA BECCARII	L				
	T	0.9	1.3	2.4	1.4
AMMOTIUM SALSUM	L				
	T				
ARENOPARRELLA MEXICANA	L				
	T				
BOLIVINA STRIATULA	L				
	T				
BOLIVINA VARIABILIS	L				
	T				
BUCCELLA DEPRESSA	L				
	T				
BUCCELLA FRIGIDA	L				
	T	1.2	0.3	1.4	
BUCCELLA INUSITATA	L				
	T		0.5		
BULIMINELLA ELEGANTISSIMA	L				
	T				
CASSIDULINA SUBGLOBOSA	L				
	T				
CIBICIDES LOBATULUS	L				
	T		0.3		
EGGERELLA ADVENA	L				
	T		0.3		
ELPHIDIUM ADVENUM	L				
	T				
ELPHIDIUM ARTICULATUM	L				
	T				
ELPHIDIUM BARTLETTI	L				
	T	0.5	0.5		
ELPHIDIUM DISCOIDALE	L		7.7		
	T	0.5	0.8		
ELPHIDIUM EXCAVATUM	L	100	46.2	66.7	50
	T	94.6	88	92.4	96
ELPHIDIUM FRIGIDUM	L				
	T				
ELPHIDIUM GALVESTONENSE	L		7.7		
	T	0.5	1.5	0.7	
ELPHIDIUM GUNTERI	L				
	T		0.5		
ELPHIDIUM INCERTUM	L				
	T				
ELPHIDIUM MARGARITACEUM	L				
	T				
ELPHIDIUM MEXICANUM	L		34.6	33.3	50
	T	0.7	3.6	2.1	2
ELPHIDIUM POEYANUM	L				
	T				
ELPHIDIUM SUBARCTICUM	L				
	T				
EOEPONIDELLA PULCHELLA	L				
	T		0.3	0.3	
EPISTOMINELLA VITREA	L				
	T				
FISSURINA LAEVIGATA	L				
	T				
FURSENKOINA FUSIFORMIS	L				
	T				
GLABRATELLA sp. A	L				
	T		0.3		

Station		SSIC 6	CISF 1	CISF 2	CISF 3
Station No.		54	55	56	57
GLABRATELLA sp. B	L				
	T		0.3		
GLABRATELLINA sp. A	L				
	T				
GLOBIGERINA BULLOIDES	L				
	T				
HANZAWAIA CONCENTRICA	L				
	T	0.5			
HAPLOPHRAGMOIDES BONPLANDI	L				
	T				
HAPLOPHRAGMOIDES WILBERTI	L				
	T				
HAYNESINA GERMANICA	L		3.9		
	T	0.2	0.3		
HELENIA ANDERSENI	L				
	T				
JADAMMINA MACRESCENS	L				
	T				
JADAMMINA POLYSTOMA	L				
	T				
MILIAMMINA EARLANDI	L				
	T				
MILIAMMINA FUSCA	L				
	T				
MILIOLINELLA FICHTELIANA	L				
	T				
MILIOLINELLA MICROSTOMA	L				
	T				
NEOGLOBOQUADRINA BLOWI	L				
	T				
NONIONELLA ATLANTICA	L				
	T			0.3	
QUINQUELOCULINA DIMIDIATA	L				
	T			0.3	
QUINQUELOCULINA JUGOSA	L				
	T				
QUINQUELOCULINA LATA	L				
	T	0.2	0.5		
QUINQUELOCULINA SEMINULA	L				
	T	0.2	0.8		
QUINQUELOCULINA cf. SEMINULA	L				
	T				
QUINQUELOCULINA SEMINULA var. JUGOSA	L				
	T				
QUINQUELOCULINA sp.	L				
	T				
REOPHAX sp.	L				
	T				
ROSALINA FLORIDANA	L				
	T				0.7
TEXTULARIA EARLANDI	L				
	T				
TIPHOTROCHA COMPRIMATA	L				
	T				
TROCHAMMINA ADVENA	L				
	T				
TROCHAMMINA INFLATA	L				
	T				
TROCHAMMINA LAEVIGATA	L				
	T				
TROCHAMMINA LOBATA	L				
	T				
TROCHAMMINA OCHRACEA	L				
	T		0.3		
TROCHAMMINA "SQUAMATA"	L				
	T				
TROCHAMMINA sp. A	L				
	T				
Indeterminate calcareous hyaline	L				
	T				
Indeterminate calcareous porcelaneous	L				
	T				

Appendix E. Grain size statistics of three cores (HIFO 2, WIMFO 1 and OYMFI 1), including the weight percent of grain size, Folk inclusive graphic statistics and moment statistics.

Weight Percentage of Grain Size (HIFO 2)

Sample(*cm*)	Sand (%)	Silt (%)	Clay (%)	Ora. Ma.(%)
0-2	56.3107	22.8065	18.9410	2.98
2-4	57.2831	22.9787	18.0360	4.98
4-6	38.8992	35.5120	23.1543	4.40
6-8	28.7760	44.9885	25.1732	3.00
9-11	5.7395	57.3636	36.4554	1.55
20-22	1.2162	59.7973	38.5135	0.74
29-31	2.4359	56.6667	41.1538	0.76
59-61	7.0915	48.6823	43.6512	0.29
74-76	81.7342	9.7999	6.6188	0.26
88-90	89.3104	3.9889	5.0939	

Folk Inclusive Graphic Statistics (HIFO 2)

Sample(cm)	Median	Mode	M_Z	K_G	σ_i	S_K
0-2	3.3879	3.5	4.9425	0.8138	2.7786	0.7445
2-4	3.3705	3.0	4.8583	0.9543	2.7621	0.7263
4-6	4.7334	3.0	5.5719	0.6748	2.8927	0.4030
6-8	5.0774	5.0	5.7677	0.7054	2.7709	0.3453
9-11	6.6045	6.0	6.9813	0.7340	2.3174	0.1952
20-22	6.9045	6.0	7.2536	0.7287	2.1457	0.1988
29-31	7.2022	6.0	7.4346	0.7385	2.0800	0.1227
59-61	7.3756	6.0	7.4424	0.8160	2.3641	-0.0353
74-76	2.9860	3.0	3.4000	3.6799	1.7060	0.6508
88-90	3.0621	3.5	2.9381	3.4019	1.3363	0.1926

Moment Statistics (HIFO 2)

Sample(cm)	M_Z(MON.)	σ_i(MON.)	S_K(MON.)	K_G(MON.)
0-2	4.8619	2.6610	0.9141	2.3875
2-4	4.6590	2.6297	1.0619	2.7212
4-6	5.3822	2.6806	0.6106	2.0438
6-8	5.7440	2.5898	0.4591	1.9913
9-11	6.9452	2.2389	0.1009	1.9295
20-22	7.2325	2.0618	0.1032	1.9855
29-31	7.3871	2.0431	-0.0651	2.2361
59-61	7.3101	2.2774	-0.2803	2.1973
74-76	3.5579	1.8709	2.3722	8.0519
88-90	3.3130	1.6428	3.0427	12.0797

Weight Percentage of Grain Size (WIMFO 1)

Sample(*cm*)	Sand (%)	Silt (%)	Clay (%)	Ora. Ma.(%)
0-2	76.4484	13.1304	9.5349	
14-16	67.3883	18.6256	13.3331	
29-31	55.2506	24.4735	19.1913	
49-51	60.8565	19.8334	18.5736	
59-61	56.3841	24.8056	18.5185	
73-75	56.8177	28.0868	14.8808	
89-91	24.8064	48.7419	26.4516	
98-100	31.3635	44.4010	23.7756	

Folk Inclusive Graphic Statistics (WIMFO 1)

Sample(cm)	**Median**	**Mode**	M_Z	K_G	σ_i	S_K
0-2	3.3180	3.5	3.9417	3.4044	1.7571	0.7412
14-16	3.4551	3.5	4.4561	1.5981	2.1493	0.7520
29-31	3.7217	3.5	5.1652	0.8726	2.5404	0.7678
49-51	3.6836	3.5	5.0821	0.9761	2.5352	0.7477
59-61	3.6706	3.5	5.0810	0.9271	2.4505	0.7879
73-75	3.7732	3.5	4.8354	1.4942	2.2466	0.7060
89-91	5.1522	5.0	5.9073	0.7256	2.5653	0.4128
98-100	4.7838	5.0	5.7368	0.7326	2.5294	0.5188

Moment Statistics (WIMFO 1)

Sample(cm)	M_Z(MON.)	σ_i(MON.)	S_K(MON.)	K_G(MON.)
0-2	4.0480	2.0739	1.8047	5.6921
14-16	4.4803	2.2498	1.5356	4.0582
29-31	5.0686	2.4868	1.0197	2.5825
49-51	4.9230	2.4789	1.1236	2.7950
59-61	5.0188	2.4497	1.0790	2.7150
73-75	4.7497	2.2594	1.3872	3.6465
89-91	5.9710	2.4414	0.5501	1.9570
98-100	5.7021	2.4457	0.6856	2.1932

Weight Percentage of Grain Size (OYMFI 1)

Sample(*cm*)	Sand (%)	Silt (%)	Clay (%)	Ora. Ma.(%)
0-2	59.2706	22.5230	17.0843	0.25
14-16	69.2658	15.8964	13.8133	0.26
29-31	64.0044	19.0294	16.8930	0.29
49-51	54.5616	24.2235	21.0019	0.28
59-61	49.3943	27.2427	23.0937	0.27
73-75	25.4513	39.4622	34.8339	0.29
89-91	21.3248	40.0359	38.4883	0.23
104-106	21.5600	41.3056	36.7665	0.29
119-121	29.8507	38.7857	30.6443	0.29

Folk Inclusive Graphic Statistics (OYMFI 1)

Sample(*cm*)	Median	Mode	M_Z	K_G	σ_i	S_K
0-2	3.8058	3.5	5.1201	1.3094	2.4321	0.7533
14-16	3.4087	3.5	4.6978	1.7717	2.2672	0.8301
29-31	3.7009	3.5	5.0030	1.2644	2.3599	0.7719
49-51	3.8053	3.5	5.2267	0.8382	2.5328	0.7535
59-61	4.0540	4.0	5.4338	0.7417	2.5296	0.7271
73-75	5.9330	5.0	6.3987	0.6229	2.6314	0.2431
89-91	6.4792	5.0	6.6815	0.6279	2.6041	0.1148
104-106	6.3308	5.0	6.5871	0.6472	2.6367	0.1382
119-121	5.5579	4.0	6.1997	0.6582	2.6560	0.3150

Moment Statistics (OYMFI 1)

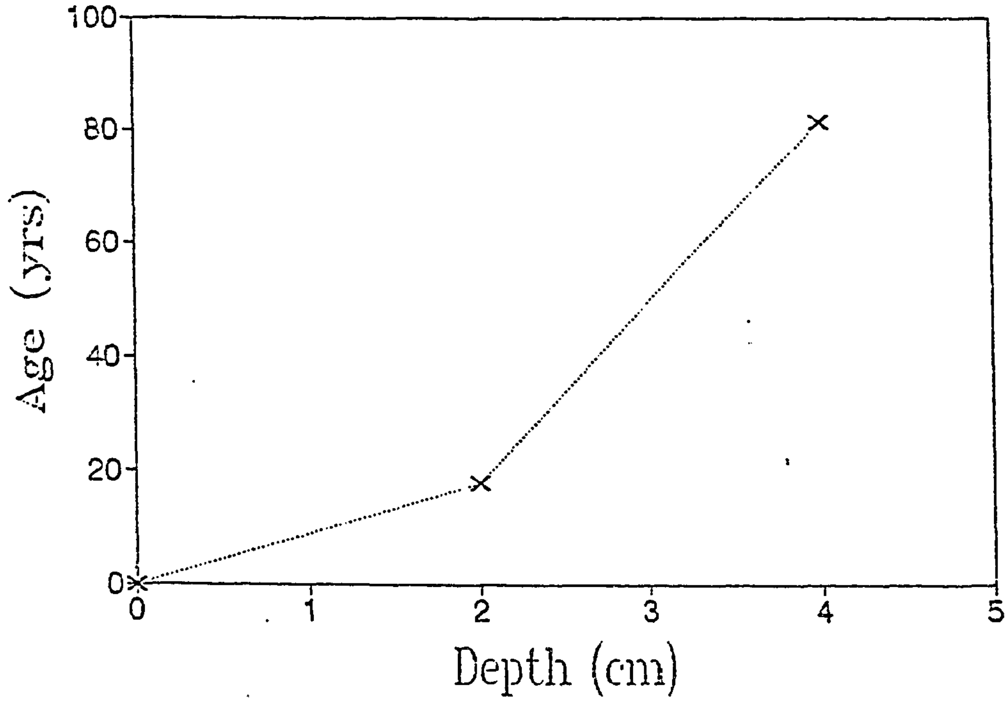
Sample(*cm*)	M_Z(MON.)	σ_i(MON.)	S_K(MON.)	K_G(MON.)
0-2	4.8729	2.3416	1.3148	3.3154
14-16	4.4943	2.2674	1.5761	4.0447
29-31	4.8216	2.3515	1.3272	3.3112
49-51	5.1348	2.5301	0.9901	2.4851
59-61	5.4262	2.5111	0.8607	2.2532
73-75	6.4372	2.5482	0.2477	1.6174
89-91	6.7031	2.5204	0.1036	1.5892
104-106	6.6121	2.5295	0.1257	1.6388
119-121	6.1392	2.5932	0.3206	1.7764

Appendix F. The sedimentation rates based on Pb-210 analysis in a fringe marsh of Hog Island (HIFO 2) and the tidal flat of Mockhorn Bay (OYMFI 1).

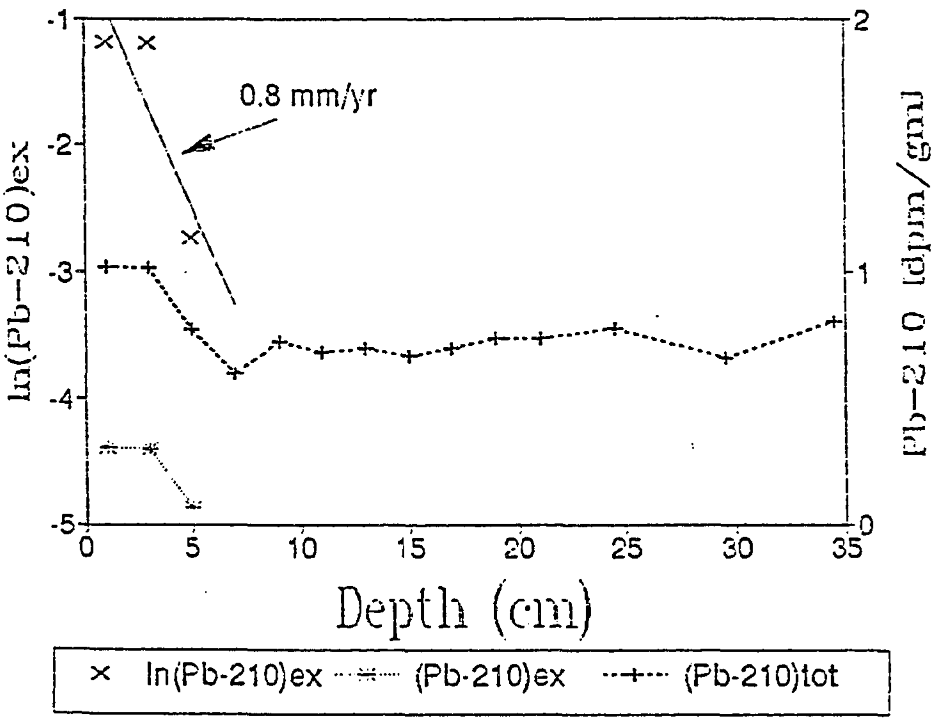
Fringe marsh at Hog Island (HIFO 2)

Depth Interval (cm)	Mass (g/cm^2)	M(Z) (g/cm^2)	Pb(T) (dpm/g)	Pbex1 (dpm/g)	Depth X (cm)	t (x)1 (yrs)
0-2	1.72	0.86	1.017880	0.306744	0	0
2-4	2.01	2.73	1.014152	0.303016	2	17.93951
4-6	1.50	4.48	0.776274	0.065138	4	81.59968
6-8	1.34	5.90	0.604884		6	
8-10	1.49	7.32	0.726482			
10-12	1.34	8.73	0.686333			
12-14	1.31	10.06	0.701254			
14-16	1.32	11.37	0.670906			
16-18	1.29	12.68	0.700937			
18-20	1.40	14.02	0.740563			
20-22	1.46	15.45	0.741688			
22-27	2.60	17.48	0.780467			
27-32	2.99	20.28	0.665142			
32-37	2.72	23.13	0.803841			

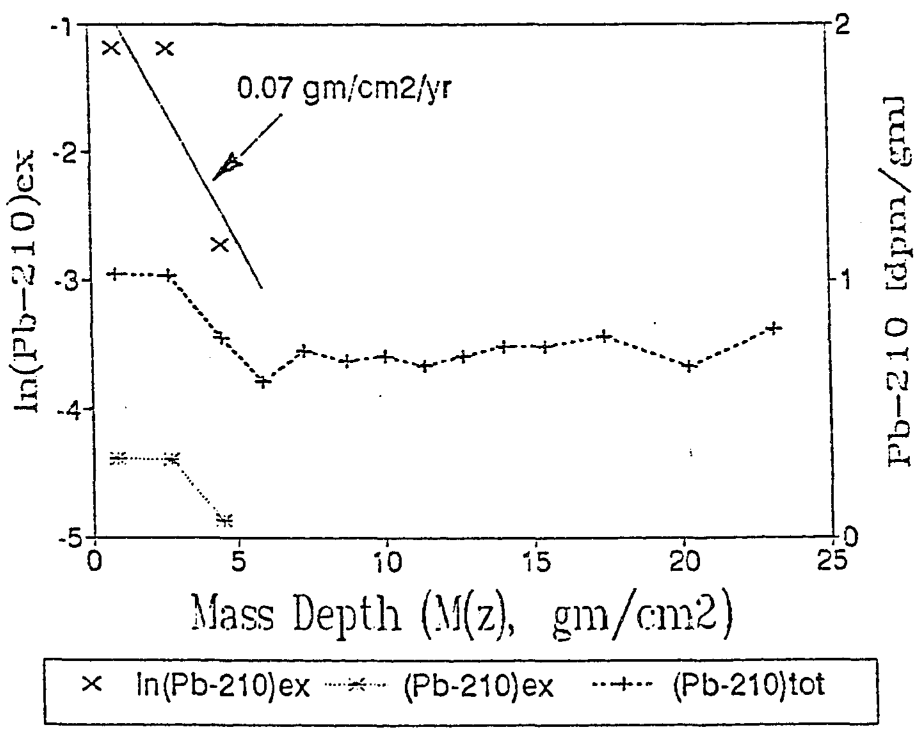
Fringe marsh of Hog Island (HIFO 2)



Fringe marsh of Hog Island (HIFO 2)



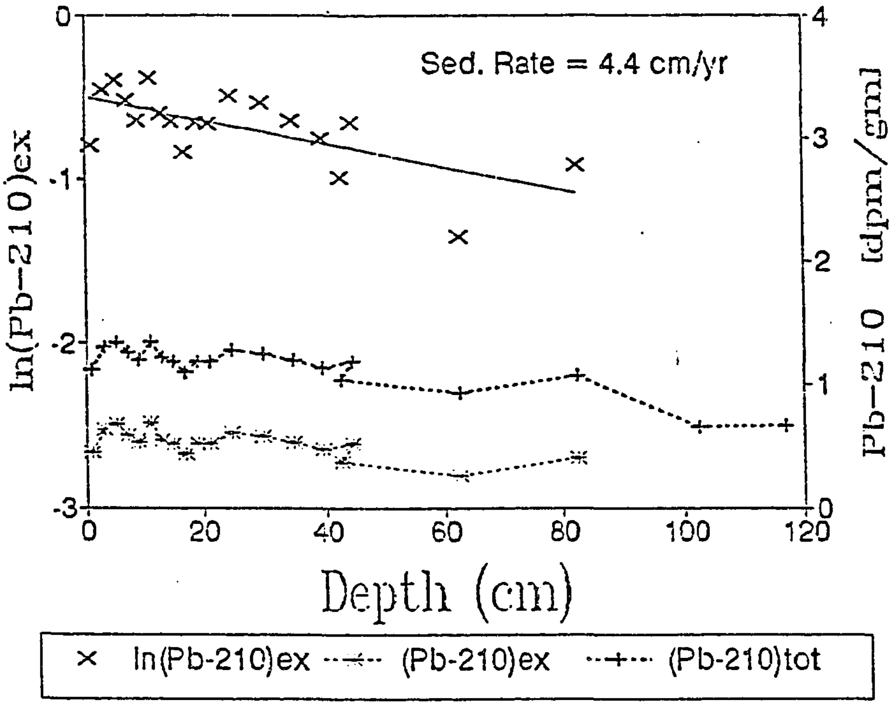
Fringe marsh of Hog Island (HIFO 2)



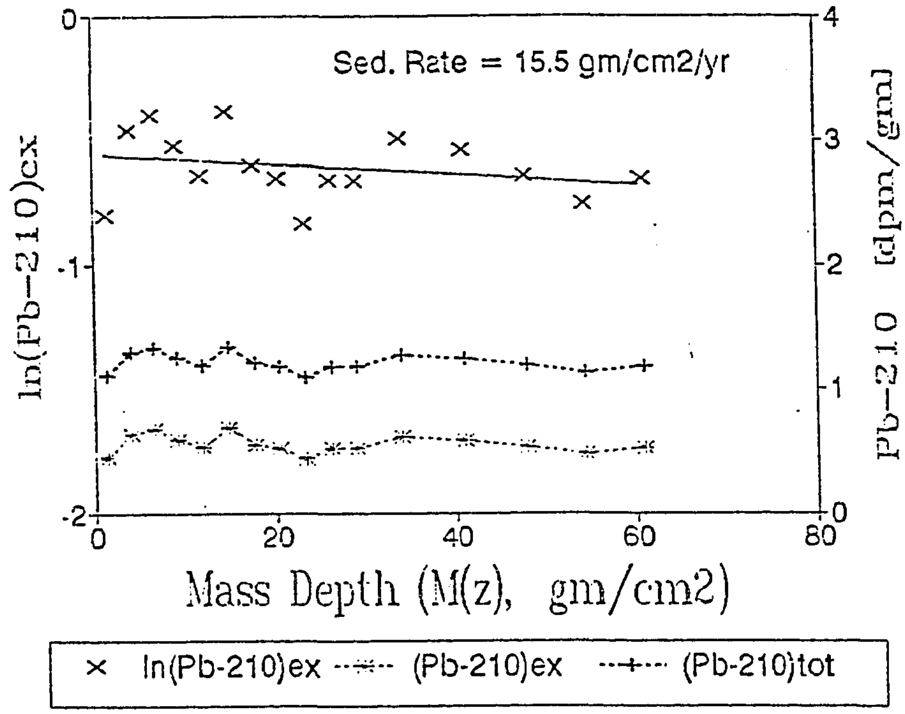
Tidal flat in Mockhorn Bay (OYMFI 1)

Depth (cm)	Pb(T) (dpm/g)	Pbex1 (dpm/g)	M(Z) (gm/cm^2)
0-2	1.109890	0.449319	1.33743
2-4	1.289608	0.629036	4.02782
4-6	1.332057	0.671486	6.71839
6-8	1.251974	0.591403	9.41943
8-10	1.185847	0.525275	12.17587
10-12	1.341097	0.680526	14.96170
12-14	1.207001	0.546429	17.75424
14-16	1.179960	0.519389	20.55034
16-18	1.093726	0.433155	23.35305
18-20	1.178112	0.517540	26.14582
20-22	1.174519	0.513948	28.99211
22-27	1.268838	0.608267	34.01066
27-32	1.242092	0.581520	41.07148
32-37	1.186134	0.525562	47.84099
37-42	1.130176	0.469604	54.43855
42-47	1.179455	0.518883	60.93006
40-45	1.029809	0.369237	
60-65	0.919007	0.258435	
80-85	1.060756	0.400184	
100-105	0.658037		
115-119	0.663106		

Tidal flat of Mockhorn Bay (OYMFI 1)



Tidal flat of Mockhorn Bay (OYMFI 1)



Appendix G. Summarization of the distribution of environmental variables, pollen and foraminifera at the 20 *a priori* subenvironments. Relative abundance of pollen and foraminiferal species is defined in four categories as follows: (1) most abundant, equals more than 50%, (2) abundant, equals 25 to 49%, (3) common, equals 5 to 24%, and (4) rare, equals less than 5% of the living population or the total assemblage in any station within the group. The values of species diversity are defined as low (0-0.7), medium (0.7-1.4), and high (> 1.4) within the group.

Group No.	Subenvironment	Sediment characters	Pollen	Living foraminiferal populations: Dominant species	Living foraminiferal populations: Remarks	Total foraminiferal assemblages: Dominant species	Total foraminiferal assemblages: Remarks
1	Brackish marsh / channel	silt, very poorly sorted, organic rich, clayey sand in the channel	*Pinus*[1] *Quercus*[2] *Carya*[2] *Ambrosia*[2]	*Ammonia beccarii*[2] *Trochammina inflata*[2] *T. "squamata"*[2]	100% agglutinated in marsh, calcareous species in channel low salinity (9.4 psu)	*Trochammina inflata*[2]	high values of H(S), 98% agglutinated, others common to rare
2	Restricted tidal bay	very poorly sorted sandy mud, minor amount of organic matter	*Pinus*[1] *Quercus*[3] Compositaes[3] *Ambrosia*[3]	*Ammonia beccarii*[1] *Elphidium excavatum*[1]	*A. exiguus*[4] *Miliammina fusca*[4] other calcareous rare	*Ammonia beccarii*[1] *Elphidium excavatum*[1]	medium values of H(S), others rare
3	Inner muddy sand flat	very poorly sorted coarse to fine silt, small amounts of organic matter	*Pinus*[1] *Quercus*[3] *Ambrosia*[4]	*Elphidium excavatum*[1]	*H. germanica*[3] *E. poeyanum*[3] *Glabratella* sp. A[3] *R. floridana*[3] *M. fusca*[3]	*Elphidium excavatum*[1] *Ammonia beccarii*[2]	medium values of H(S), *H. germanica*[3] *Miliammina fusca*[3]
4	Middle/outer muddy sand flat	very poorly to poorly muddy sand, small amounts of organic matter		*Elphidium excavatum*[1]	*A. beccarii*[3] *B. striatula*[3] *E. gunteri*[3] *Glabratella* sp. A[3]	*Elphidium excavatum*[1]	medium values of H(S), *A. beccarii*[3] *E. bartletti*[3] *E. gunteri*[3]
5	Inner sand flat	poorly sorted sand, minor amounts of organic matter		*Elphidium excavatum*[1]	no agglutinated *A. beccarii*[3]	*Elphidium excavatum*[1]	low values of H(S) *A. beccarii*[3] other calcareous rare
6	Middle sand flat	moderately sorted sand, no organic		*Elphidium excavatum*[1]	no agglutinated *H. germanica*[3]	*Elphidium excavatum*[1]	low values of H(S) most calcareous dead only and rare

Continued

Group No.	Subenvironments	Sediment characters	Pollen	Living foraminiferal populations Dominant species	Living foraminiferal populations Remarks	Total foraminiferal assemblages Dominant species	Total foraminiferal assemblages Remarks
7	Outer sand flat	poorly sorted sand, minor amounts of organic matter		*Elphidium excavatum*[1]	*A. exiguus*[4] *T. earlandi*[4] *A. beccarii*[3] *Glabratella* sp. A[3]	*Elphidium excavatum*[1]	low to medium values of H(S) *Q. seminula*[3]
8	Inner mud flat	very poorly sorted sandy silt, minor amounts of organic matter		*Ammonia beccarii*[1] *Elphidium excavatum*[2]	*E. bartletti*[3] *Glabratella* sp. A[3] agglutinated rare	*Elphidium excavatum*[1] *Ammonia beccarii*[2]	medium values of H(S), others rare
9	Outer mud flat	poorly sorted muddy sand, minor amounts of organic matter		*Elphidium excavatum*[1]	*Ammonia beccarii*[3] *Q. seminula*[3] *Q. dimidiata*[3] *T. earlandi*[4]	*Elphidium excavatum*[1]	medium values of H(S), *A. beccarii*[3] *Q. dimidiata*[3] dead *T. inflata*[4] and *T. "squamata"*[4]
10	Inner protected fringe marsh	very poorly to poorly sorted mud, moderate amounts of organic matter	*Pinus*[2] *Ambrosia*[3] Compositaes3 *Quercus*[3]	*Ammonia beccarii*[1] *Haynesina germanica*[2] *Miliammina fusca*[2]	high salt content (40-60 psu) *E. excavatum*[4] *Q. seminula*[4] *Q. dimidiata*[4]	*Ammonia beccarii*[1] *Haynesina germanica*[2] *Miliammina fusca*[2]	medium values of H(S), *A. mexicana*[3]
11	Inner exposed fringe marsh	very poorly sorted muddy sand to mud, large amounts of organic matter	*Pinus*[2] *Quercus*[3] *Ambrosia*[3]	*Ammonia beccarii*[1] *Miliammina fusca*[1] *Jadammina macrescens*[2] *Trochammina inflata*[2]	*A. exiguus*[3] *A. mexicana*[3] *E. excavatum*[3] *M. earlandi*[3]	*Miliammina fusca*[1] *Ammonia becarii*[2] *Arenoparrella mexicana*[2] *Trochammina inflata*[2]	medium values of H(S), *A. exiguus*[3] *E. excavatum*[3] *J. macrescens*[3]
12	Middle lagoon marsh	very poorly sorted silt, moderate amounts of organic matter	*Pinus*[2] *Quercus*[3] *Ambrosia*[4]	*Ammonia beccarii*[1] *Elphidium excavatum*[2] *Haynesina germanica*[2]	other agglutinated and calcareous rare	*Ammonia beccarii*[1] *Elphidium excavatum*[2]	medium values of H(S) *H. germanica*[3]

Continued

Group No.	Subenvironments	Sediment characters	Pollen	Living foraminiferal populations Dominant species	 Remarks	Total foraminiferal assemblages Dominant species	 Remarks
13	Outer fringe marsh	very poorly sorted mud to muddy sand, large amounts of organic matter	*Pinus*[2] *Quercus*[3] *Carya*[3] *Myrica*[3] Gramineae[3] Compositaes[3] *Ambrosia*[3] Chenopods[3]	*Ammonia beccarii*[1] *Trochammina inflata*[1] *Ammobaculites exiguus*[2] *Miliammina fusca*[2] *Textularia earlandi*[2]	*A. mexicana*[3] *E. excavatum*[3] *H. germanica*[3]	*Ammobaculites exiguus*[1] *Ammonia beccarii*[1] *Trochammina inflata*[1] *Miliammina fusca*[2] *Textularia earlandi*[2]	high values of H(S) *A. mexicana*[3] *E. excavatum*[3] *H. germanica*[3] *T. comprimata*[3]
14	Tidal channel margin	very poorly sorted mud to sand, small amounts of organic matter		*Ammonia beccarii*[1] *Elphidium excavatum*[2] *Haynesina germanica*[2]	*A. exiguus*[3] *E. poeyanum*[3] *M. fusca*[3]	*Ammonia beccarii*[1] *Elphidium excavatum*[1] *Haynesina germanica*[2]	medium values of H(S) *A. exiguus*[3] *B. frigida*[3] *M. fusca*[3]
15	Intermediate tidal channel	very poorly sorted muddy sand,small amounts of organic matter		*Elphidium excavatum*[1]	*A. beccarii*[3] *E. poeyanum*[3] *Glabratella* sp. A[3] *H. germanica*[3] *T. ochracea*[3]	*Elphidium excavatum*[1]	low values of H(S) other agglutinated and calcareous rare
16	Deep tidal channel	very poorly to poorly sand, minor amounts of organic matter		*Elphidium excavatum*[1]	*Glabratella* sp. A[3] *H. germanica*[3] *N. atlantica*[3]	*Elphidium excavatum*[1]	low values of H(S) *A. beccarii*[3] (dead)
17	Washover fan	moderately to poorly sorted sand, no organic		*Quinqueloculina seminula*[1] *Ammonia beccarii*[2] *Elphidium excavatum*[2]	*Q. dimidiata*[3] *A. exiguus*[4] *M. fusca*[4]	*Quinqueloculina seminula*[1] *Elphidium excavatum*[1] *Ammonia beccarii*[2]	medium values of H(S) *Q. dimidiata*[3]
18	Axial channel	poorly sorted sand, minor amounts of organic matter			low number of living individuals (3-8 specimens/70ml)	*Elphidium excavatum*[1]	low values of H(S) other agglutinated and calcareous rare

Continued

Group No.	Subenvironments	Sediment characters	Pollen	Living foraminiferal populations: Dominant species	Living foraminiferal populations: Remarks	Total foraminiferal assemblages: Dominant species	Total foraminiferal assemblages: Remarks
19	Inlet shoals	poorly to moderately sorted sand, no organic		*Elphidium mexicanum*[1]	low number of living individuals (4-16 specimens/70ml) *A. beccarii*[3] *E. excavatum*[3] no agglutinated	*Elphidium excavatum*[1]	low values of H(S) *Trochammina* sp. A[4] other calcareous rare
20	Shoreface	poorly to moderately sorted sand, no organic		*Elphidium excavatum*[2] *Elphidium mexicanum*[2]	no agglutinated others rare	*Elphidium excavatum*[1]	low values of H(S) *T. ochracea*[4] other calcareous rare

Appendix H. A stepwise regression analysis of the densities of the five most frequently occurring living species with environmental variables.

1. *Ammobaculites exiguus*

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STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050


STEP= 1     ENTER      BD     R= 0.507     RSQUARE= 0.257
STEP= 2     ENTER    SAND     R= 0.618     RSQUARE= 0.382


THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

         CONSTANT
             SAND
               BD

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.



DEP VAR:   AMEXL      N:       54   MULTIPLE R: 0.507  SQUARED MULTIPLE R: 0.257
ADJUSTED SQUARED MULTIPLE R: 0.242      STANDARD ERROR OF ESTIMATE:         1.040

  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T    P(2 TAIL)

CONSTANT            2.305        0.419        0.000      .       5.504    0.000
      BD           -1.742        0.411       -0.507    1.000   -4.238    0.000


                          ANALYSIS OF VARIANCE

   SOURCE  SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO        P

 REGRESSION        19.440     1        19.440     17.959       0.000
   RESIDUAL        56.287    52         1.082

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DEP VAR: AMEXL N: 54 MULTIPLE R: 0.279 SQUARED MULTIPLE R: 0.078
ADJUSTED SQUARED MULTIPLE R: 0.060 STANDARD ERROR OF ESTIMATE: 1.159

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.266	0.340	0.000	.	3.720	0.000
SAND	-0.010	0.005	-0.279	1.000	-2.092	0.041

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	5.880	1	5.880	4.378	0.041
RESIDUAL	69.847	52	1.343		

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2. *Ammonia beccarii*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1	ENTER	BD	R= 0.649	RSQUARE= 0.421
STEP= 2	ENTER	DEPTH	R= 0.693	RSQUARE= 0.480
STEP= 3	ENTER	SAL	R= 0.743	RSQUARE= 0.553

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
SAL
DEPTH
BD .

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: ANBEL N: 54 MULTIPLE R: 0.649 SQUARED MULTIPLE R: 0.421
ADJUSTED SQUARED MULTIPLE R: 0.409 STANDARD ERROR OF ESTIMATE: 1.715

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	6.524	0.690	0.000	.	9.450	0.000
BD	-4.163	0.678	-0.649	1.000	-6.144	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	111.049	1	111.049	37.748	0.000
RESIDUAL	152.977	52	2.942		

DEP VAR: ANBEL N: 54 MULTIPLE R: 0.517 SQUARED MULTIPLE R: 0.268
ADJUSTED SQUARED MULTIPLE R: 0.253 STANDARD ERROR OF ESTIMATE: 1.928

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.355	0.323	0.000	.	10.377	0.000
DEPTH	-0.256	0.059	-0.517	1.000	-4.358	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	70.643	1	70.643	18.996	0.000
RESIDUAL	193.383	52	3.719		

DEP VAR: ANBEL N: 54 MULTIPLE R: 0.283 SQUARED MULTIPLE R: 0.080
ADJUSTED SQUARED MULTIPLE R: 0.062 STANDARD ERROR OF ESTIMATE: 2.161

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-19.789	10.507	0.000	.	-1.883	0.065
SAL	0.705	0.332	0.283	1.000	2.125	0.038

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	21.100	1	21.100	4.517	0.038
RESIDUAL	242.926	52	4.672		

---

3. *Elphidium excavatum*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1	ENTER	ORG	R= 0.269	RSQUARE= 0.072
STEP= 2	ENTER	BD	R= 0.428	RSQUARE= 0.183
STEP= 3	ENTER	SAL	R= 0.495	RSQUARE= 0.246

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
SAL
ORG
BD

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: ELEXL N: 54 MULTIPLE R: 0.269 SQUARED MULTIPLE R: 0.072
ADJUSTED SQUARED MULTIPLE R: 0.055 STANDARD ERROR OF ESTIMATE: 1.757

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	2.951	0.259	0.000	.	11.392	0.000
ORG	-0.432	0.214	-0.269	1.000	-2.015	0.049

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	12.532	1	12.532	4.060	0.049
RESIDUAL	160.530	52	3.087		

DEP VAR: ELEXL N: 54 MULTIPLE R: 0.153 SQUARED MULTIPLE R: 0.023
ADJUSTED SQUARED MULTIPLE R: 0.005 STANDARD ERROR OF ESTIMATE: 1.803

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.512	0.726	0.000	.	4.840	0.000
BD	-0.795	0.712	-0.153	1.000	-1.116	0.270

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	4.046	1	4.046	1.245	0.270
RESIDUAL	169.016	52	3.250		

DEP VAR: ELEXL N: 54 MULTIPLE R: 0.165 SQUARED MULTIPLE R: 0.027
ADJUSTED SQUARED MULTIPLE R: 0.008 STANDARD ERROR OF ESTIMATE: 1.799

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	13.275	8.747	0.000	.	1.518	0.135
SAL	-0.333	0.276	-0.165	1.000	-1.204	0.234

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	4.691	1	4.691	1.449	0.234
RESIDUAL	168.371	52	3.238		

---

4. *Haynesina germanica*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1 ENTER MEAN R= 0.411 RSQUARE= 0.169

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
MEAN

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: HAGEL N: 54 MULTIPLE R: 0.411 SQUARED MULTIPLE R: 0.169
ADJUSTED SQUARED MULTIPLE R: 0.153 STANDARD ERROR OF ESTIMATE: 1.203

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-0.560	0.492	0.000	.	-1.138	0.260
MEAN	0.344	0.106	0.411	1.000	3.255	0.002

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	15.322	1	15.322	10.593	0.002
RESIDUAL	75.214	52	1.446		

---

5. *Miliammina fusca*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1	ENTER	SAL	R= 0.607	RSQUARE= 0.368
STEP= 2	ENTER	BD	R= 0.655	RSQUARE= 0.429
STEP= 3	ENTER	SILT	R= 0.691	RSQUARE= 0.477

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
SAL
SILT
BD

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: MIFUL N: 54 MULTIPLE R: 0.607 SQUARED MULTIPLE R: 0.368
ADJUSTED SQUARED MULTIPLE R: 0.356 STANDARD ERROR OF ESTIMATE: 1.097

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-28.495	5.334	0.000	.	-5.343	0.000
SAL	0.927	0.168	0.607	1.000	5.505	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	36.487	1	36.487	30.309	0.000
RESIDUAL	62.599	52	1.204		

DEP VAR: MIFUL N: 54 MULTIPLE R: 0.557 SQUARED MULTIPLE R: 0.311
ADJUSTED SQUARED MULTIPLE R: 0.297 STANDARD ERROR OF ESTIMATE: 1.146

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	2.959	0.461	0.000	.	6.413	0.000
BD	-2.192	0.453	-0.557	1.000	-4.840	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	30.775	1	30.775	23.427	0.000
RESIDUAL	68.312	52	1.314		

DEP VAR: MIFUL N: 54 MULTIPLE R: 0.263 SQUARED MULTIPLE R: 0.069
ADJUSTED SQUARED MULTIPLE R: 0.051 STANDARD ERROR OF ESTIMATE: 1.332

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.469	0.268	0.000	.	1.750	0.086
SILT	0.017	0.009	0.263	1.000	1.967	0.055

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	6.861	1	6.861	3.869	0.055
RESIDUAL	92.226	52	1.774		

Appendix I. A stepwise regression analysis of the densities of the seven most frequently occurring species of total assemblages with environmental variables.

1. *Ammobaculites exiguus*

```
STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050


STEP= 1     ENTER      BD     R= 0.548     RSQUARE= 0.300
STEP= 2     ENTER    SAND     R= 0.619     RSQUARE= 0.383


THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

         CONSTANT
             SAND
               BD

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.
```

```
DEP VAR:   AMEXT      N:      54   MULTIPLE R: 0.548  SQUARED MULTIPLE R: 0.300
ADJUSTED SQUARED MULTIPLE R: 0.287     STANDARD ERROR OF ESTIMATE:         1.288
```

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.232	0.519	0.000	.	6.234	0.000
BD	-2.403	0.509	-0.548	1.000	-4.723	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	37.016	1	37.016	22.307	0.000
RESIDUAL	86.288	52	1.659		

DEP VAR: AMEXT N: 54 MULTIPLE R: 0.347 SQUARED MULTIPLE R: 0.120
ADJUSTED SQUARED MULTIPLE R: 0.103 STANDARD ERROR OF ESTIMATE: 1.444

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.929	0.424	0.000	.	4.548	0.000
SAND	-0.016	0.006	-0.347	1.000	-2.664	0.010

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	14.811	1	14.811	7.099	0.010
RESIDUAL	108.493	52	2.086		

2. *Ammonia beccarii*

```
STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1     ENTER     MEAN     R= 0.433     RSQUARE= 0.187

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

        CONSTANT
            MEAN

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.
```

```
DEP VAR:   ANBET      N:       54   MULTIPLE R: 0.433  SQUARED MULTIPLE R: 0.187
ADJUSTED SQUARED MULTIPLE R: 0.172     STANDARD ERROR OF ESTIMATE:        1.530
```

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.739	0.626	0.000	.	2.780	0.008
MEAN	0.465	0.134	0.433	1.000	3.460	0.001

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	28.026	1	28.026	11.972	0.001
RESIDUAL	121.725	52	2.341		

---

3. *Elphidium excavatum*

```
STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050


STEP=  1     ENTER     SAL     R= 0.694     RSQUARE= 0.482
STEP=  2     ENTER     ORG     R= 0.730     RSQUARE= 0.534


THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

         CONSTANT
              SAL
              ORG

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.
```

```
DEP VAR:   ELEXT      N:      54   MULTIPLE R: 0.694  SQUARED MULTIPLE R: 0.482
ADJUSTED SQUARED MULTIPLE R: 0.472     STANDARD ERROR OF ESTIMATE:         1.698
```

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	62.261	8.253	0.000	.	7.544	0.000
SAL	-1.814	0.261	-0.694	1.000	-6.958	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	139.547	1	139.547	48.416	0.000
RESIDUAL	149.877	52	2.882		

DEP VAR: ELEXT N: 54 MULTIPLE R: 0.495 SQUARED MULTIPLE R: 0.245
ADJUSTED SQUARED MULTIPLE R: 0.231 STANDARD ERROR OF ESTIMATE: 2.049

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	5.336	0.302	0.000	.	17.659	0.000
ORG	-1.027	0.250	-0.495	1.000	-4.112	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	71.008	1	71.008	16.905	0.000
RESIDUAL	218.416	52	4.200		

---

4. *Haynesina germanica*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1 ENTER SILT R= 0.294 RSQUARE= 0.087

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
SILT

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: HAGET N: 54 MULTIPLE R: 0.294 SQUARED MULTIPLE R: 0.087
ADJUSTED SQUARED MULTIPLE R: 0.069 STANDARD ERROR OF ESTIMATE: 1.446

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.941	0.291	0.000	.	3.236	0.002
SILT	0.021	0.010	0.294	1.000	2.220	0.031

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	10.306	1	10.306	4.928	0.031
RESIDUAL	108.741	52	2.091		

---

5. *Miliammina fusca*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1	ENTER	SAL	R= 0.657	RSQUARE= 0.432
STEP= 2	ENTER	BD	R= 0.701	RSQUARE= 0.491
STEP= 3	ENTER	SILT	R= 0.737	RSQUARE= 0.544

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
SAL
SILT
BD.

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: MIFUT N: 54 MULTIPLE R: 0.657 SQUARED MULTIPLE R: 0.432
ADJUSTED SQUARED MULTIPLE R: 0.421 STANDARD ERROR OF ESTIMATE: 1.271

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-37.819	6.180	0.000	.	-6.119	0.000
SAL	1.228	0.195	0.657	1.000	6.293	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	64.000	1	64.000	39.598	0.000
RESIDUAL	84.044	52	1.616		

DEP VAR: MIFUT N: 54 MULTIPLE R: 0.584 SQUARED MULTIPLE R: 0.341
ADJUSTED SQUARED MULTIPLE R: 0.328 STANDARD ERROR OF ESTIMATE: 1.370

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.746	0.551	0.000	.	6.793	0.000
BD	-2.806	0.541	-0.584	1.000	-5.184	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	50.446	1	50.446	26.877	0.000
RESIDUAL	97.598	52	1.877		

DEP VAR: MIFUT N: 54 MULTIPLE R: 0.273 SQUARED MULTIPLE R: 0.074
ADJUSTED SQUARED MULTIPLE R: 0.056 STANDARD ERROR OF ESTIMATE: 1.623

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.564	0.327	0.000	.	1.727	0.090
SILT	0.022	0.011	0.273	1.000	2.043	0.046

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	10.999	1	10.999	4.173	0.046
RESIDUAL	137.045	52	2.635		

---

6. *Trochammina inflata*

STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050

STEP= 1	ENTER	SAL	R= 0.547	RSQUARE= 0.299
STEP= 2	ENTER	ORG	R= 0.640	RSQUARE= 0.410
STEP= 3	ENTER	TEMP	R= 0.675	RSQUARE= 0.455

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

CONSTANT
SAL
TEMP
ORG

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.

DEP VAR: TRINT N: 54 MULTIPLE R: 0.547 SQUARED MULTIPLE R: 0.299
ADJUSTED SQUARED MULTIPLE R: 0.286 STANDARD ERROR OF ESTIMATE: 1.303

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-28.953	6.333	0.000	.	-4.571	0.000
SAL	0.943	0.200	0.547	1.000	4.714	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	37.728	1	37.728	22.226	0.000
RESIDUAL	88.266	52	1.697		

DEP VAR: TRINT N: 54 MULTIPLE R: 0.530 SQUARED MULTIPLE R: 0.281
ADJUSTED SQUARED MULTIPLE R: 0.267 STANDARD ERROR OF ESTIMATE: 1.320

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.557	0.195	0.000	.	2.861	0.006
ORG	0.725	0.161	0.530	1.000	4.505	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	35.375	1	35.375	20.299	0.000
RESIDUAL	90.619	52	1.743		

DEP VAR: TRINT N: 54 MULTIPLE R: 0.353 SQUARED MULTIPLE R: 0.125
ADJUSTED SQUARED MULTIPLE R: 0.108 STANDARD ERROR OF ESTIMATE: 1.456

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-13.113	5.151	0.000	.	-2.546	0.014
TEMP	0.500	0.184	0.353	1.000	2.721	0.009

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	15.706	1	15.706	7.405	0.009
RESIDUAL	110.288	52	2.121		

---

7. *Trochammina* sp. A

```
STEPWISE REGRESSION WITH ALPHA-TO-ENTER=0.050 AND ALPHA-TO-REMOVE=0.050


STEP= 1     ENTER       DFM     R= 0.479      RSQUARE= 0.229
STEP= 2     ENTER       SAL     R= 0.564      RSQUARE= 0.318
STEP= 3     ENTER   SORTING     R= 0.623      RSQUARE= 0.388


THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:

         CONSTANT
              SAL
          SORTING
              DFM

USE THESE PREDICTORS IN A NEW MODEL SENTENCE TO ESTIMATE THE COEFFICIENTS.
```

```
DEP VAR:   TRSPT      N:      54   MULTIPLE R: 0.479  SQUARED MULTIPLE R: 0.229
ADJUSTED SQUARED MULTIPLE R: 0.214     STANDARD ERROR OF ESTIMATE:        0.770
```

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.161	0.185	0.000	.	6.275	0.000
DFM	-0.070	0.018	-0.479	1.000	-3.931	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	9.162	1	9.162	15.452	0.000
RESIDUAL	30.832	52	0.593		

DEP VAR: TRSPT N: 54 MULTIPLE R: 0.070 SQUARED MULTIPLE R: 0.005
ADJUSTED SQUARED MULTIPLE R: 0.000 STANDARD ERROR OF ESTIMATE: 0.875

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	2.724	4.253	0.000	.	0.641	0.525
SAL	-0.068	0.134	-0.070	1.000	-0.509	0.613

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	0.198	1	0.198	0.259	0.613
RESIDUAL	39.796	52	0.765		

DEP VAR: TRSPT N: 54 MULTIPLE R: 0.338 SQUARED MULTIPLE R: 0.114
ADJUSTED SQUARED MULTIPLE R: 0.097 STANDARD ERROR OF ESTIMATE: 0.825

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-0.254	0.334	0.000	.	-0.760	0.451
SORTING	0.435	0.168	0.338	1.000	2.590	0.012

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	4.570	1	4.570	6.708	0.012
RESIDUAL	35.424	52	0.681		

Appendix J. Group means of the 20 most abundant living foraminieral species. Variables included *Ammobaculites exiguus* (V2), *Ammonia beccarii* (V3), *Arenoparrella mexicana* (V5), *Bolivina striatula* (V6), *Elphidium bartletti* (V17), *Elphidium excavatum* (V19), *Elphidium gunteri* (V22), *Elphidium poeyanum* (V26), *Glabratella* sp. A (V32), *Glabratellina* sp. A (V34), *Haynesina germanica* (V39), *Jadammina macrescens* (V41), *Miliammina earlandi* (V43), *Miliammina fusca* (V44), *Nonionella atlantica* (V48), *Quinqueloculina dimidiata* (V49), *Quinqueloculina seminula* (V52), *Rosalina floridana* (V57), *Textularia earlandi* (V58), *Trochammina inflata* (V61). ID refers to the *a priori* subenvironments (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: the tidal channel margin, 16: the deep tidal channel, 17: the washover fan).

GROUP MEANS

ID	V2	V3	V5	V6	V17	V19	V22	V26	V32	V34
2	0.09390	1.67327	0.00000	0.00000	0.07317	1.42373	0.03653	0.00000	0.00000	0.04220
3	0.00000	0.93307	0.00000	0.00000	0.00000	1.44603	0.00000	0.31660	0.31660	0.00000
4	0.00000	0.49060	0.00000	0.23890	0.00000	2.24660	0.23890	0.00000	0.23890	0.00000
7	0.10505	0.38060	0.00000	0.00000	0.00000	2.39925	0.00000	0.14545	0.10505	0.25575
8	0.08440	1.48317	0.00000	0.00000	0.26297	1.37603	0.00000	0.27073	0.40117	0.00000
9	0.00000	0.85310	0.00000	0.00000	0.00000	1.87855	0.07075	0.15225	0.13830	0.13455
10	0.00000	1.86940	0.00000	0.00000	0.00000	0.34910	0.00000	0.00000	0.00000	0.00000
11	0.18847	0.88292	0.20712	0.00000	0.00000	0.33375	0.03877	0.09410	0.00000	0.00000
12	0.07755	1.59205	0.00000	0.00000	0.10505	1.17920	0.08955	0.00000	0.18265	0.00000
13	0.56452	1.43357	0.08388	0.00000	0.00000	0.37135	0.04610	0.04695	0.00000	0.05377
14	0.22643	1.44740	0.05170	0.00000	0.00000	0.85507	0.11207	0.22000	0.10797	0.00000
16	0.00000	0.00000	0.00000	0.00000	0.00000	2.16040	0.00000	0.00000	0.33965	0.00000
17	0.08955	0.90505	0.00000	0.00000	0.08955	0.72370	0.00000	0.05480	0.00000	0.00000
Total	0.16387	1.13682	0.04130	0.01327	0.03882	1.13165	0.04655	0.10514	0.12462	0.03416

ID	V39	V41	V43	V44	V48	V49	V52	V57	V58	V61
2	0.05170	0.00000	0.00000	0.03653	0.00000	0.00000	0.03653	0.00000	0.00000	0.00000
3	0.61650	0.00000	0.00000	0.34130	0.00000	0.00000	0.00000	0.19483	0.00000	0.00000
4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.10505	0.00000	0.00000	0.00000	0.00000	0.00000	0.41150	0.00000	0.10505	0.00000
8	0.22043	0.00000	0.00000	0.17987	0.00000	0.00000	0.05970	0.02983	0.04220	0.04220
9	0.11860	0.00000	0.00000	0.00000	0.00000	0.41945	0.52355	0.00000	0.13455	0.00000
10	0.66525	0.00000	0.00000	0.53395	0.00000	0.05480	0.05480	0.00000	0.00000	0.00000
11	0.07612	0.33107	0.14430	1.29267	0.00000	0.05487	0.13387	0.00000	0.00000	0.48250
12	0.67375	0.00000	0.00000	0.05480	0.00000	0.00000	0.07755	0.00000	0.00000	0.00000
13	0.23632	0.08878	0.00000	0.67363	0.00000	0.00000	0.00000	0.02585	0.32857	0.52818
14	0.84690	0.00000	0.00000	0.40323	0.00000	0.00000	0.10797	0.00000	0.00000	0.00000
16	0.67930	0.00000	0.00000	0.00000	0.33965	0.00000	0.00000	0.00000	0.00000	0.00000
17	0.00000	0.00000	0.00000	0.12685	0.00000	0.58910	1.41995	0.00000	0.00000	0.00000
Total	0.31702	0.05158	0.01603	0.37574	0.01887	0.06517	0.17008	0.02303	0.07159	0.14516

Appendix K. Group means of the 29 most abundant species of total foraminieral assemblages. Variables included *Ammobaculites exiguus* (V2), *Ammonia beccarii* (V3), *Arenoparrella mexicana* (V5), *Buccella frigida* (V9), *Elphidium bartletti* (V17), *Elphidium excavatum* (V19), *Elphidium gunteri* (V22), *Elphidium mexicanum* (V25), *Elphidium poeyanum* (V26), *Glabratella* sp. A (V32), *Glabratellina* sp. A (V34), *Haplophragmoides bonplandi* (V37), *Haplophragmoides wilberti* (V38), *Haynesina germanica* (V39), *Helenia anderseni* (V40), *Jadammina macrescens* (V41), *Miliammina earlandi* (V43), *Miliammina fusca* (V44), *Quinqueloculina dimidiata* (V49), *Quinqueloculina seminula* (V52), *Quinqueloculina seminula jugosa* (V54), *Rosalina floridana* (V57), *Textularia earlandi* (V58), *Tiphotrocha comprimata* (V59), *Trochammina advena* (V60), *Trochammina inflata* (V61), *Trochammina ochracea* (V64), *Trochammina "squamata"* (V65), *Trochammina* sp. A (V66). ID refers to the *a priori* subenvironments (2: the restricted tidal bay, 3: the inner muddy sand flat, 4: the middle/outer muddy sand flat, 5: the inner sand flat, 6: the middle sand flat, 7: the outer sand flat, 8: the inner mud flat, 9: the outer mud flat, 10: the inner protected fringe marsh, 11: the inner exposed fringe marsh, 12: the marsh island, 13: the outer fringe marsh, 14: the tidal channel margin, 15: the intermediate tidal channel, 16: the deep tidal channel, 17: the washover fan, 18: the axial channel, 19: inlet shoals, 20: barrier island shoreface).

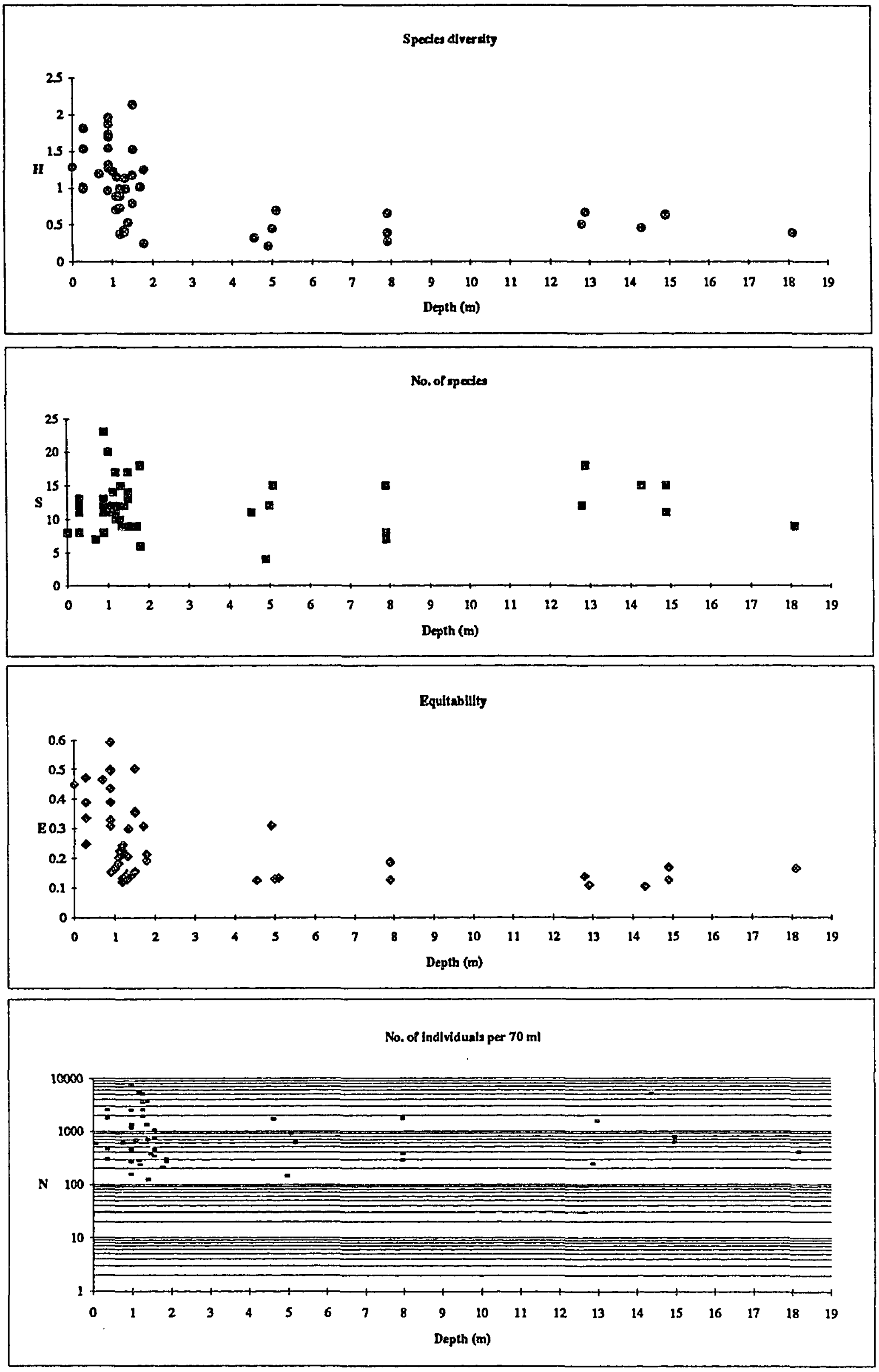
GROUP MEANS

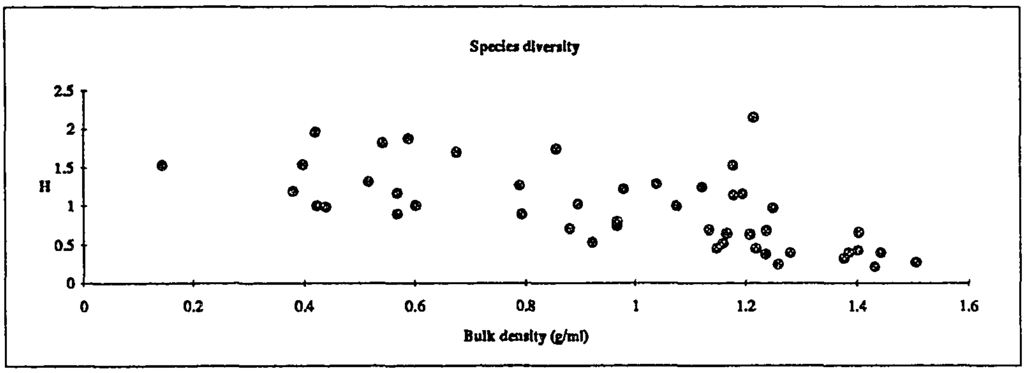
ID	V2	V3	V5	V9	V17	V19	V22	V25	V26	V32
2	0.21503	1.56277	0.00000	0.00000	0.14140	1.46153	0.02983	0.00000	0.00000	0.00000
3	0.11410	0.77133	0.11410	0.16210	0.10553	1.87797	0.07317	0.03653	0.13680	0.14867
4	0.00000	0.59510	0.00000	0.20530	0.30225	2.24520	0.36315	0.07075	0.05480	0.12555
5	0.00000	0.52510	0.00000	0.08955	0.14085	2.43965	0.05480	0.15510	0.15495	0.06330
6	0.04475	0.30545	0.00000	0.19785	0.05480	2.57375	0.00000	0.21885	0.05480	0.04475
7	0.05480	0.56870	0.00000	0.16750	0.10015	2.30455	0.06330	0.17760	0.08375	0.08375
8	0.12590	1.13670	0.00000	0.12303	0.22777	1.74880	0.11440	0.02983	0.18143	0.29857
9	0.00000	0.83490	0.00000	0.24545	0.08955	1.98360	0.05480	0.00000	0.23145	0.10505
10	0.00000	1.50875	0.24745	0.00000	0.04475	0.34580	0.00000	0.00000	0.00000	0.00000
11	0.56682	0.57966	0.40124	0.00000	0.00000	0.55286	0.02192	0.00000	0.05382	0.02192
12	0.08375	1.41555	0.00000	0.00000	0.11425	1.41650	0.09500	0.08375	0.00000	0.14190
13	0.67760	1.13705	0.19787	0.00000	0.00000	0.27998	0.05705	0.04220	0.03937	0.00000
14	0.18885	1.05272	0.05480	0.18307	0.10605	1.47902	0.17500	0.02740	0.03877	0.08880
15	0.00000	0.42960	0.00000	0.19015	0.14435	2.44160	0.06330	0.16345	0.10015	0.14705
16	0.00000	0.49895	0.05480	0.20655	0.05480	2.40090	0.00000	0.07075	0.00000	0.15495
17	0.04220	0.59370	0.00000	0.00000	0.06677	1.32643	0.00000	0.08717	0.07203	0.00000
18	0.00000	0.33090	0.00000	0.09500	0.21780	2.63305	0.00000	0.08375	0.00000	0.00000
19	0.00000	0.37747	0.00000	0.17340	0.14905	2.55262	0.04977	0.22762	0.00000	0.00000
20	0.00000	0.25893	0.00000	0.11560	0.04717	2.58533	0.04717	0.31883	0.00000	0.03653
Total	0.17617	0.78588	0.08073	0.10042	0.09840	1.65074	0.06543	0.08775	0.05909	0.06757

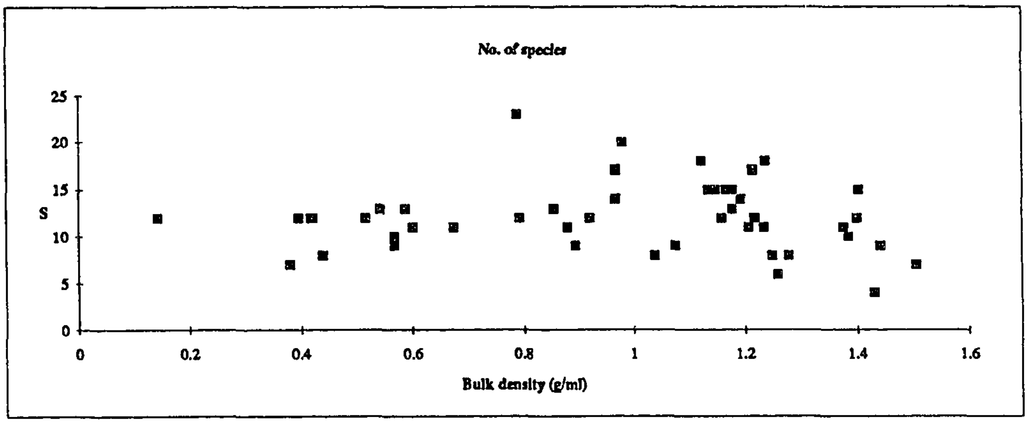
ID	V34	V37	V38	V39	V40	V41	V43	V44	V49	V52
2	0.03653	0.00000	0.00000	0.06333	0.00000	0.03653	0.00000	0.02983	0.00000	0.02983
3	0.00000	0.00000	0.00000	0.29310	0.00000	0.00000	0.00000	0.31407	0.00000	0.00000
4	0.00000	0.00000	0.00000	0.14150	0.00000	0.00000	0.00000	0.00000	0.00000	0.05480
5	0.04475	0.00000	0.00000	0.14435	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6	0.00000	0.00000	0.00000	0.10505	0.00000	0.00000	0.00000	0.00000	0.00000	0.05480
7	0.14190	0.00000	0.00000	0.10015	0.00000	0.00000	0.00000	0.00000	0.08375	0.23890
8	0.00000	0.00000	0.00000	0.21987	0.00000	0.07203	0.00000	0.12303	0.03653	0.05170
9	0.08955	0.00000	0.00000	0.09500	0.00000	0.00000	0.00000	0.00000	0.32405	0.39790
10	0.00000	0.00000	0.00000	0.64870	0.00000	0.13075	0.00000	0.72525	0.04475	0.04475
11	0.00000	0.03350	0.00000	0.04390	0.00000	0.21602	0.06090	0.86750	0.03102	0.07848
12	0.00000	0.00000	0.00000	0.54930	0.00000	0.04475	0.00000	0.04475	0.00000	0.07075
13	0.03937	0.01827	0.03808	0.24732	0.05293	0.17117	0.00000	0.81247	0.00000	0.00000
14	0.00000	0.00000	0.00000	0.55317	0.00000	0.00000	0.00000	0.27525	0.00000	0.05487
15	0.00000	0.00000	0.00000	0.17755	0.00000	0.05480	0.00000	0.00000	0.00000	0.06330
16	0.00000	0.00000	0.00000	0.25240	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17	0.00000	0.00000	0.00000	0.04220	0.00000	0.00000	0.00000	0.05970	0.49680	1.10180
18	0.00000	0.00000	0.00000	0.08375	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19	0.00000	0.00000	0.00000	0.10525	0.00000	0.00000	0.00000	0.00000	0.02740	0.04977
20	0.00000	0.00000	0.00000	0.03653	0.00000	0.00000	0.00000	0.00000	0.03653	0.05970
Total	0.01663	0.00513	0.00423	0.20181	0.00588	0.05358	0.00564	0.24876	0.05332	0.11834

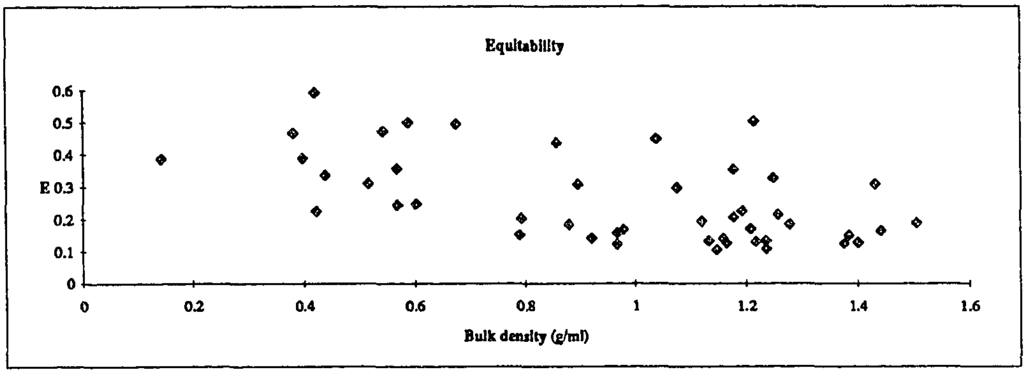
ID	V54	V57	V58	V59	V60	V61	V64	V65	V66
2	0.00000	0.00000	0.00000	0.08717	0.00000	0.13887	0.08370	0.11700	0.08153
3	0.00000	0.05170	0.00000	0.11410	0.00000	0.00000	0.16993	0.05583	0.09237
4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5	0.00000	0.11810	0.04475	0.00000	0.00000	0.00000	0.05480	0.00000	0.04475
6	0.00000	0.06330	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.00000	0.08375	0.05480	0.00000	0.00000	0.05480	0.05480	0.00000	0.00000
8	0.00000	0.06637	0.02983	0.02983	0.00000	0.10857	0.13587	0.06637	0.15490
9	0.00000	0.00000	0.08955	0.00000	0.00000	0.05480	0.00000	0.05480	0.00000
10	0.00000	0.00000	0.00000	0.00000	0.00000	0.31560	0.20135	0.00000	0.14190
11	0.00000	0.00000	0.02192	0.06222	0.02192	0.62368	0.00000	0.00000	0.04570
12	0.00000	0.00000	0.00000	0.00000	0.00000	0.14190	0.00000	0.14190	0.14190
13	0.00000	0.02110	0.29542	0.08457	0.07402	0.69710	0.00000	0.11705	0.08037
14	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02740	0.00000	0.05480
15	0.00000	0.14435	0.00000	0.00000	0.00000	0.00000	0.10015	0.05480	0.17330
16	0.00000	0.10015	0.00000	0.00000	0.00000	0.05480	0.32565	0.10960	0.16905
17	0.17473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18	0.00000	0.08950	0.00000	0.00000	0.00000	0.00000	0.08375	0.08375	0.00000
19	0.00000	0.12417	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02740
20	0.00000	0.05583	0.00000	0.00000	0.00000	0.00000	0.03653	0.00000	0.00000
Total	0.00971	0.04339	0.04351	0.02800	0.01025	0.17198	0.05609	0.04277	0.06236

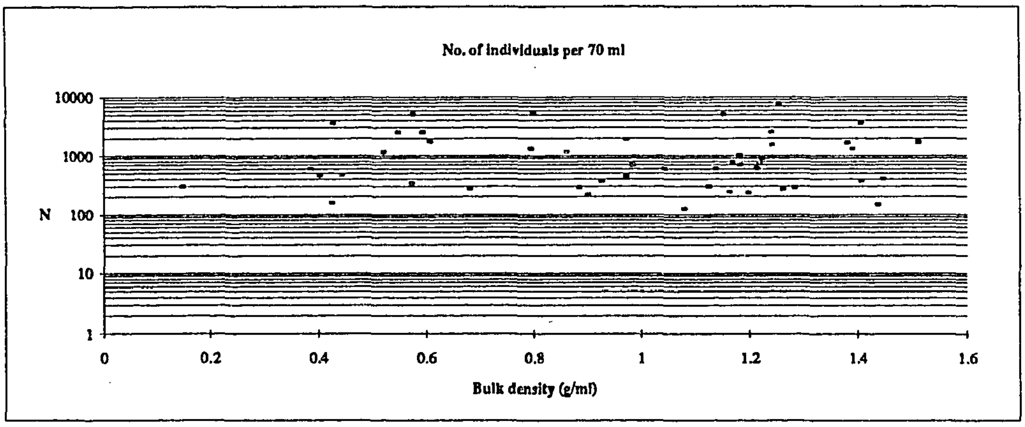
Appendix L. Plots of the diversity analyses (H(S), S, E and N) against environmental variables (water depth, bulk density, percent sand, mean-grain size, sorting, distance from mainland and inlet).

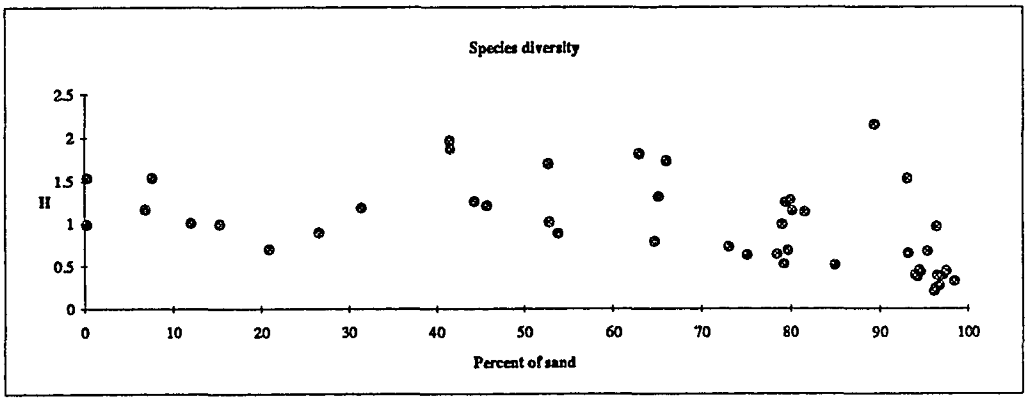

Species diversity
H
Depth (m)
No. of species
S
Depth (m)
Equitability
E
Depth (m)
No. of individuals per 70 ml
N
Depth (m)

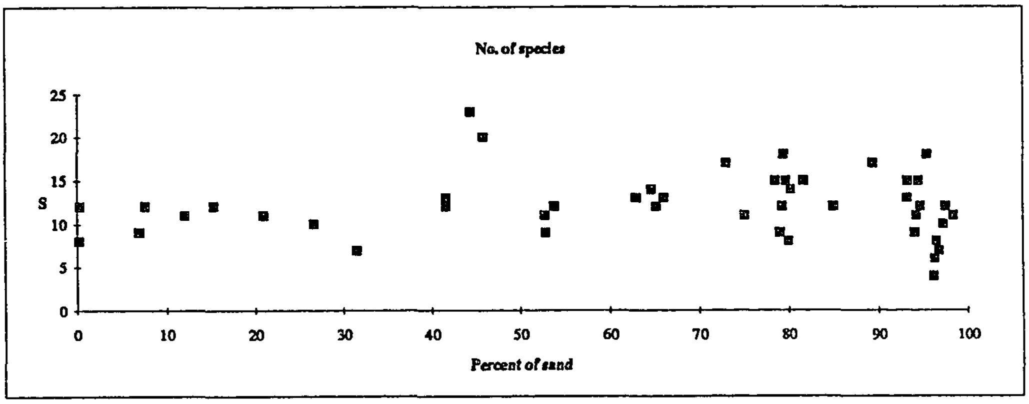

Species diversity
H
Bulk density (g/ml)

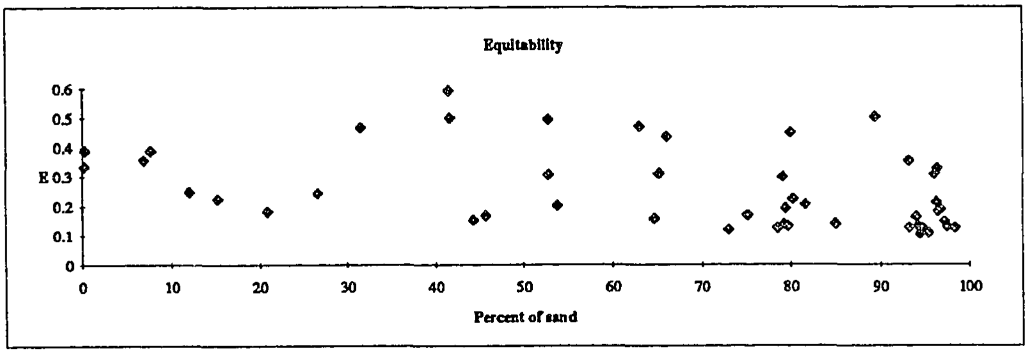

No. of species
S
Bulk density (g/ml)

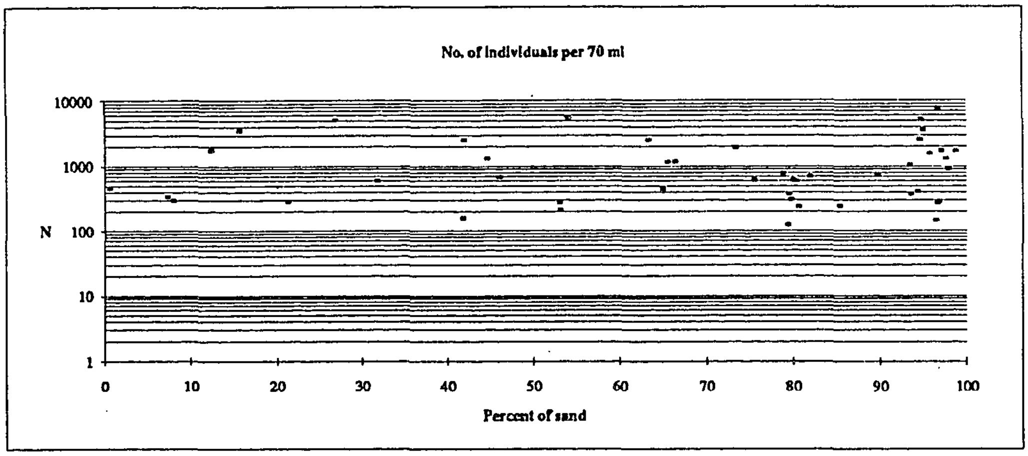

Equitability
E
Bulk density (g/ml)

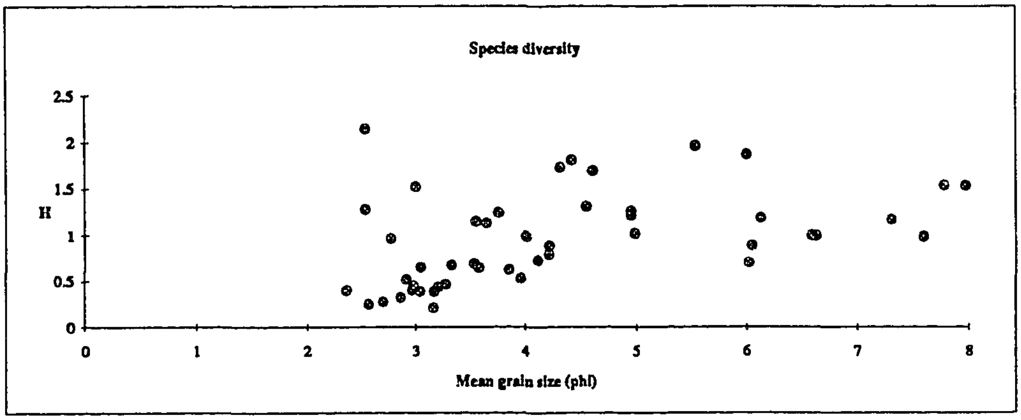

No. of individuals per 70 ml
N
Bulk density (g/ml)

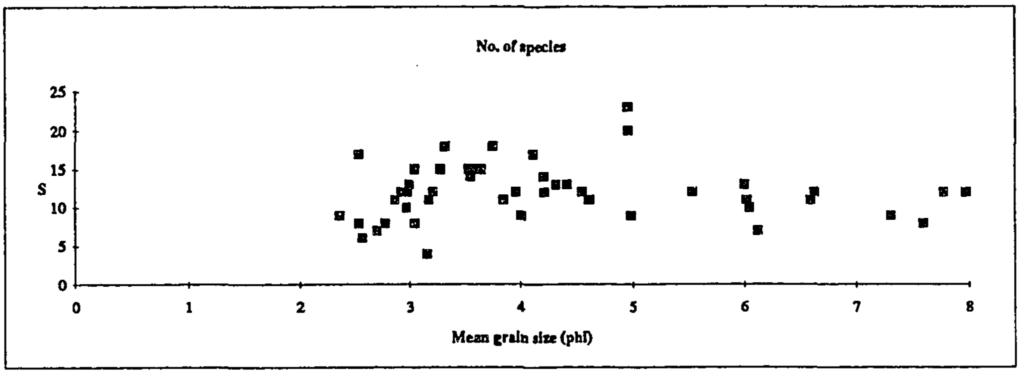

Species diversity
H
0
0.5
1
1.5
2
2.5
0
10
20
30
40
50
60
70
80
90
100
Percent of sand

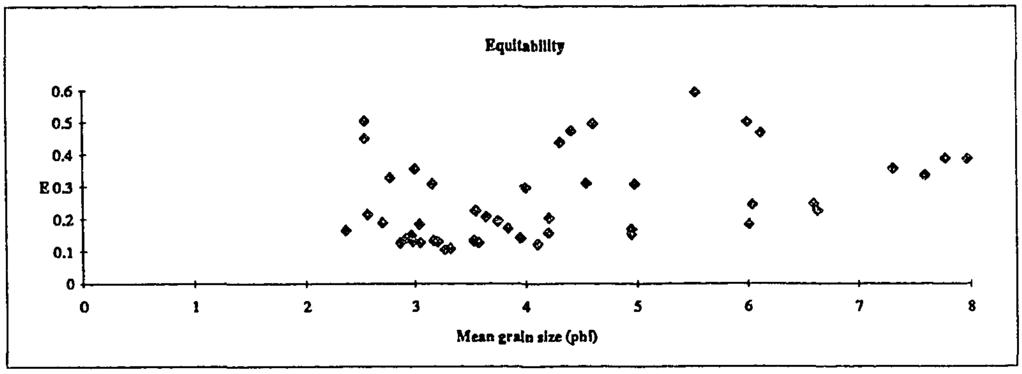

No. of species
S
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100
Percent of sand

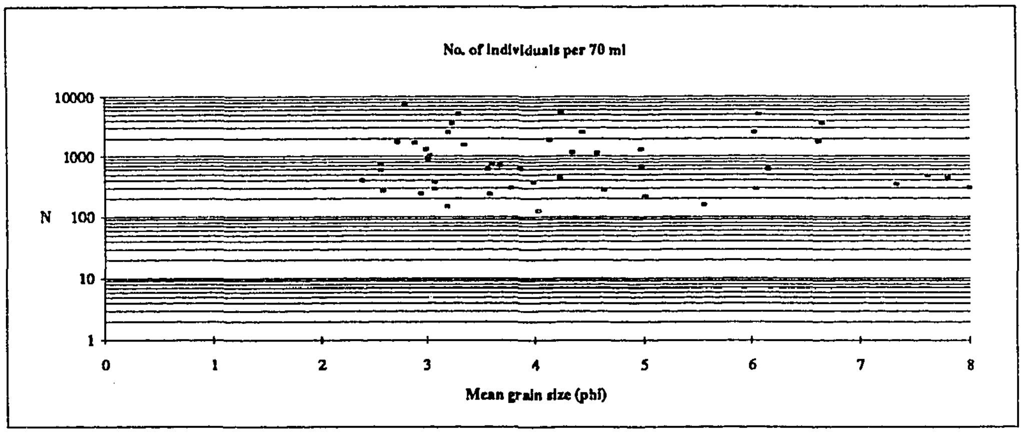

Equitability
E
0
0.1
0.2
0.3
0.4
0.5
0.6
0
10
20
30
40
50
60
70
80
90
100
Percent of sand

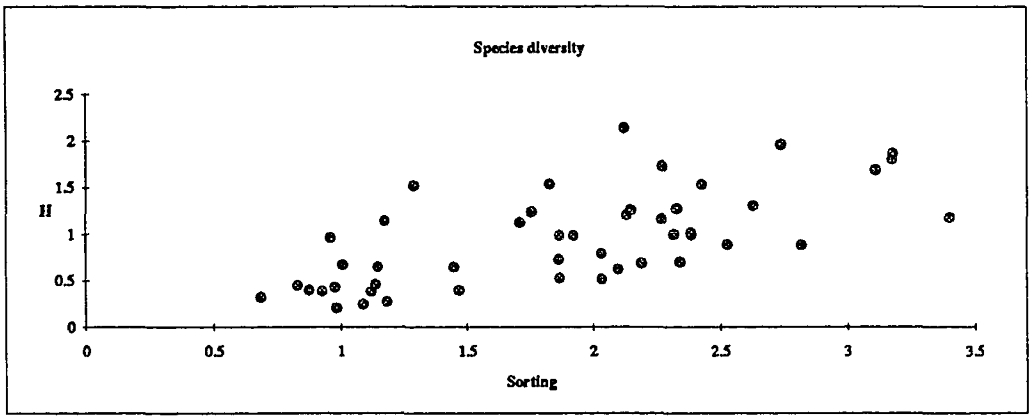

No. of individuals per 70 ml
N
1
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100
Percent of sand

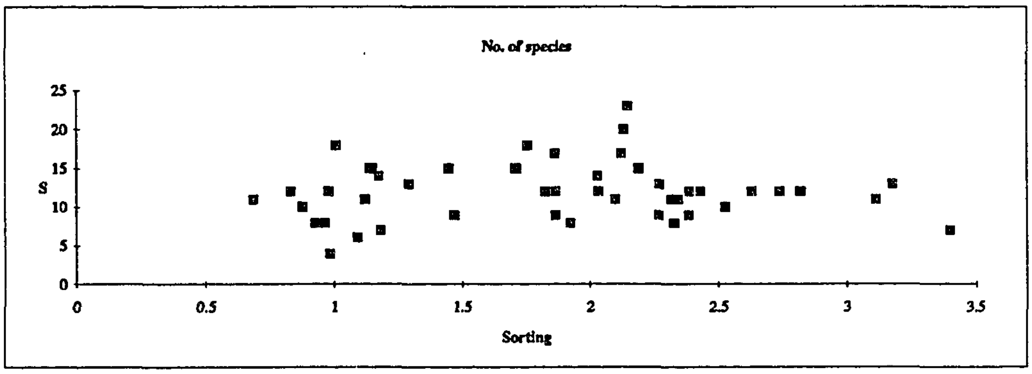

Species diversity
H
Mean grain size (phi)

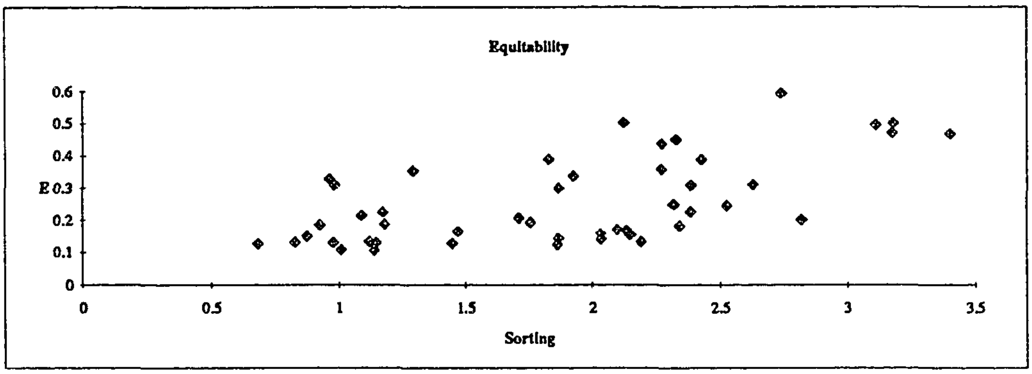

No. of species
S
Mean grain size (phi)

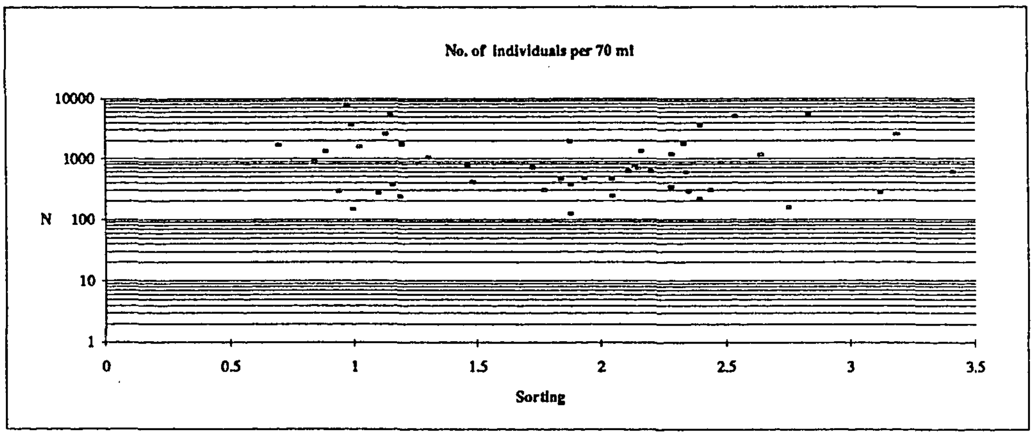

Equitability
E
Mean grain size (phi)

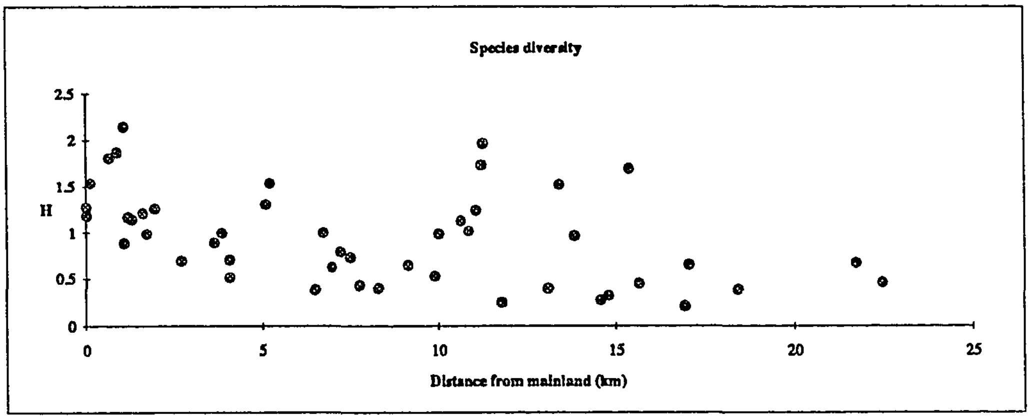

No. of individuals per 70 ml
N
Mean grain size (phi)

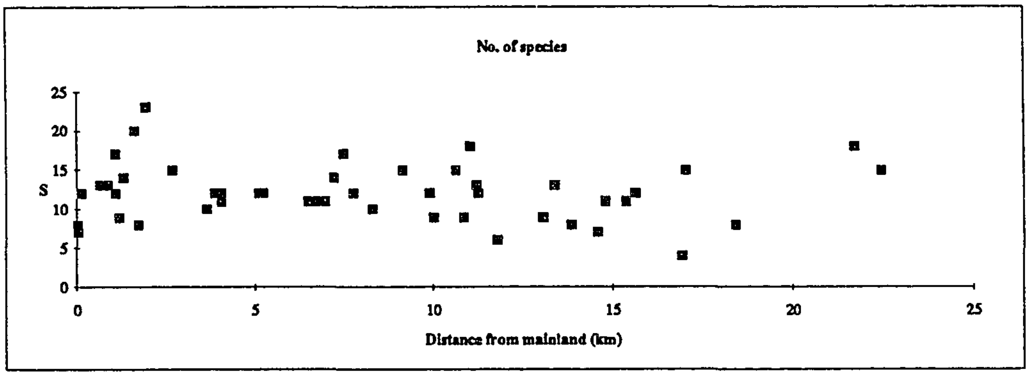

Species diversity
H
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
Sorting

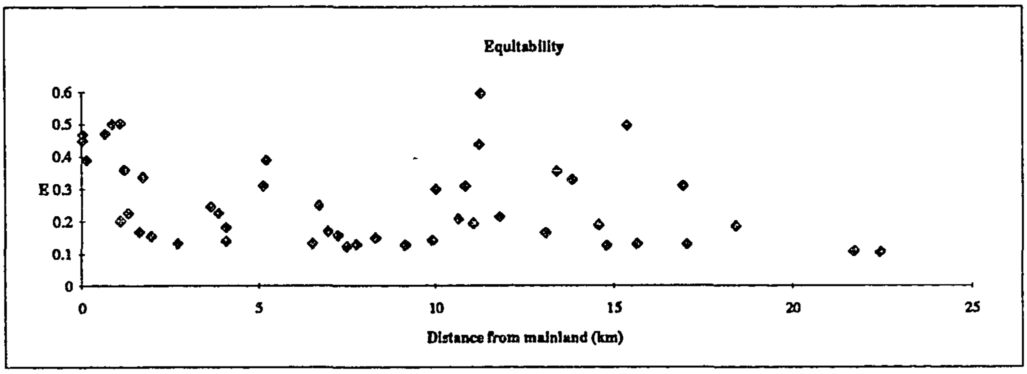

No. of species
S
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
Sorting

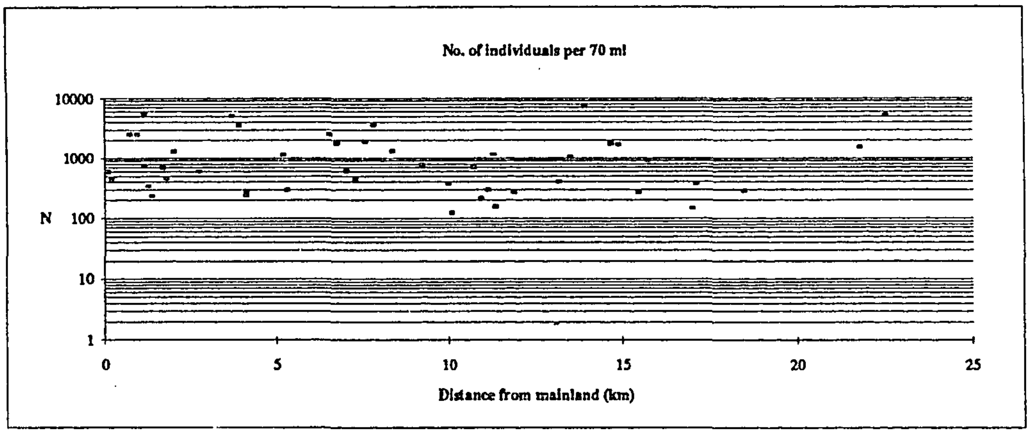

Equitability
E
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
Sorting

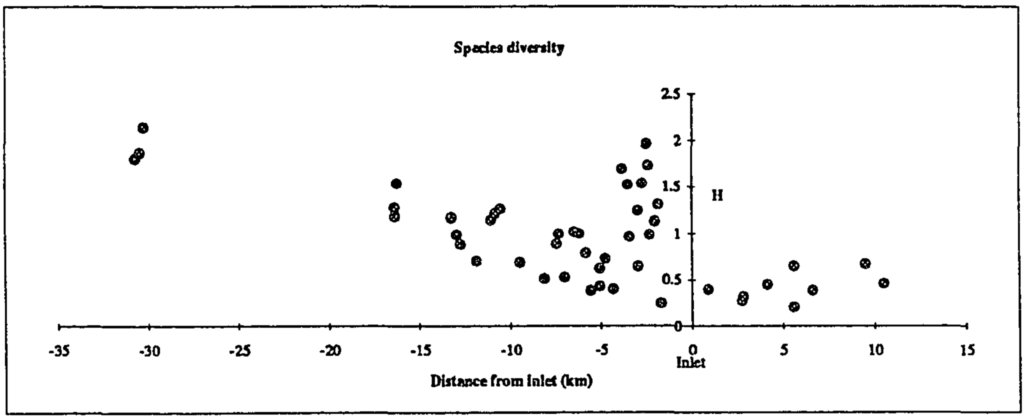

No. of individuals per 70 ml
N
10000
1000
100
10
1
0
0.5
1
1.5
2
2.5
3
3.5
Sorting

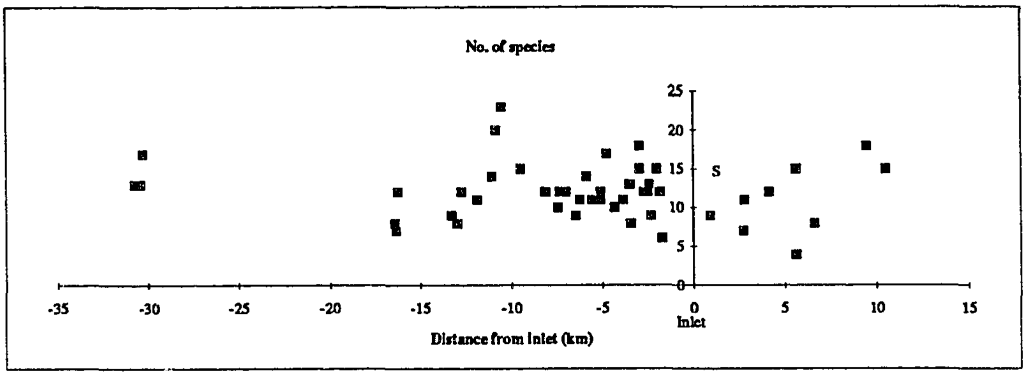

Species diversity
H
Distance from mainland (km)

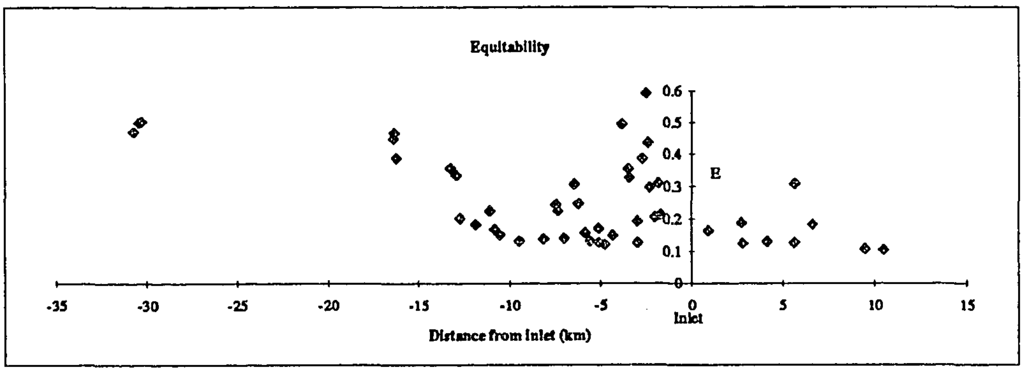

No. of species
S
Distance from mainland (km)

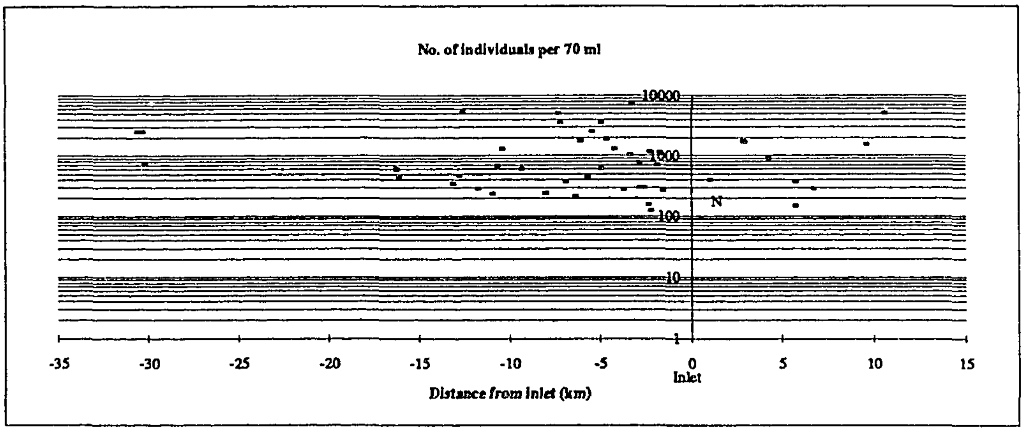

Equitability
E
Distance from mainland (km)


No. of individuals per 70 ml
N
Distance from mainland (km)


Species diversity
2.5
2
1.5
1
0.5
0
H
-35
-30
-25
-20
-15
-10
-5
0
Inlet
5
10
15
Distance from Inlet (km)


No. of species
25
20
15
10
5
0
S
-35
-30
-25
-20
-15
-10
-5
0
Inlet
5
10
15
Distance from Inlet (km)


Equitability
0.6
0.5
0.4
0.3
0.2
0.1
0
E
-35
-30
-25
-20
-15
-10
-5
0
Inlet
5
10
15
Distance from Inlet (km)


No. of individuals per 70 ml
10000
1000
100
10
1
N
-35
-30
-25
-20
-15
-10
-5
0
Inlet
5
10
15
Distance from Inlet (km)

AUTOBIOGRAPHICAL STATEMENT

Han Jun Woo

Born:

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Education:

B.S. Oceanography, February, 1984

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Professional Experience:

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Professional Societies:

Cushman Foundation

Coastal Education and Research Foundation

Publication:

Oertel, G. F., Kearney, M. S., Leatherman, S. P. and Woo, H. J., 1989. Anatomy of a barrier platform: outer barrier lagoon, southern Delmarva Peninsula, Virginia. In: L. G. Ward and G. M. Ashley (Editors), Physical Processes and Sedimentology of Siliciclastic-Dominated Lagoonal Systems. Marine Geology, v. 88, p. 303-318.

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