DISTRIBUTION OF FORAMINIFERA IN PAMLICO SOUND, NORTH CAROLINA, OVER THE PAST CENTURY

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ABSTRACT

Foraminiferal and radionuclide data have been used to investigate environmental change that has occurred within Pamlico Sound, North Carolina, over the last century. Environmental conditions were evaluated for three time slices; (1) the modern environment as determined by surficial (0–1 cm) sediments, (2) short-core intervals representing approximately 40 years BP, as determined by ¹³⁷Cs activity, and (3) short-core intervals representing approximately 120 years BP, as determined by ²¹⁰Pb activity.

Cluster analysis distinguished four foraminiferal assemblages at the surface (0–1 cm): (1) Marsh Biofacies, (2) Estuarine Biofacies A, (3) Estuarine Biofacies B, and (4) Marine Biofacies. The Marsh Biofacies is characterized by typical marsh foraminifera such as *Tiphotrecha comprimata*, *Trochammina inflata*, *Miliammina fusca* and *Haplophragmoides wilberti*. Estuarine Biofacies A is distinguished from Estuarine Biofacies B by the greater relative abundance of the agglutinated species *Ammotium salsum* and *Ammobaculites crassus* in the former and the greater relative abundance of *Elphidium excavatum* in the latter. The Marine Biofacies is comprised completely of calcareous foraminifera (e.g., *Elphidium excavatum*, *Hanzawaia strattoni*, *Cibicides lobatulus*, *Elphidium subarcticum*, *Quinqueloculina seminula* and *Elphidium galvestonense*) and is restricted to tidal inlets.

Down-core foraminiferal data indicate that approximately 120 years BP, Pamlico Sound was dominated by Estuarine Biofacies A, which is indicative of brackish conditions. Up-core in the 40 years BP and modern time slices, Estuarine Biofacies B is the more prominent assemblage within Pamlico Sound; this is indicative of increased salinity over time. Lowered salinity conditions 120 years BP may be the result of high hurricane activity over a several year period.

INTRODUCTION

The research reported here is part of the North Carolina Coastal Geology Cooperative (NCCGC) program. The goal of this program is to describe the geologic framework and the modern anthropogenic/geologic processes of North Carolina's coastal system (Fig. 1). This information can then be used to help coastal managers make informed decisions concerning this complex system during a time of increasing storminess and continuing sea-level rise. Given the importance of tourism to North Carolina's budget, wise management of coastal resources is of paramount impor-

tance. The specific objectives of the present study are threefold: (1) to map, for the first time, the distribution of modern foraminifera within the entire Pamlico Sound; (2) to create a model to interpret paleoenvironments represented by down-core foraminiferal assemblages; and (3) to describe environmental change that has occurred within Pamlico Sound during the past century.

While much research on modern foraminiferal distributions has been conducted along the Atlantic continental margin of North America (Culver and Buzas, 1980), only one paper (Grossman, 1967) has dealt with the foraminifera in Pamlico Sound (Fig. 1), one of the largest embayments on the U.S. east coast. Grossman's work was restricted to southern Pamlico Sound (southwest of Ocracoke Inlet) where he documented five foraminiferal assemblages/biofacies: estuarine, open-sound, saltwater lagoon, tidal-delta and marsh (Grossman, 1967). *Ammobaculites* and *Elphidium* were the most abundant taxa found throughout the study area. *Ammobaculites* was dominant in the estuarine biofacies, and, together with *Elphidium*, characterized the open-sound biofacies. The presence of *Quinqueloculina* distinguished the tidal-delta biofacies from the saltwater lagoon biofacies of Core Sound, which was distinguished by several species of *Elphidium*, including *E. gunteri* and *E. tumidum* (= *E. excavatum* of this study). Typical marsh foraminifera, such as *Arenoparrella mexicana*, *Trochammina* and *Haplophragmoides wilberti*, distinguished the marsh biofacies. The distribution of these assemblages was considered to be strongly influenced by salinity, vegetation and tidal currents (Grossman, 1967).

At the northern margin of Pamlico Sound, LeFurgey (1976) described a foraminiferal transition zone into the more brackish Albemarle Sound. The upper Roanoke Sound, Croatan Sound, and Stumpy Point Bay contained foraminifera characteristic of a lagoonal environment (*Miliammina fusca* and *Ammobaculites crassus*) where salinities, temperatures and calcium carbonate availability are low. Values for the environmental variables increased towards Oregon Inlet (Fig. 1) where an assemblage dominated by *M. fusca* and *Elphidium selseyense* (= *E. excavatum* of this study) occurred (LeFurgey, 1976).

In the Albemarle Sound estuarine system (including Roanoke and Croatan sounds), five assemblages of foraminifera occur (Vance, 2004; Vance and others, 2006); nearshore marine and inlets, estuarine shoal, estuarine, inner estuarine and marsh biofacies. Sediment type and salinity were determined to be the controlling factors for the distribution of the assemblages. *Ammobaculites crassus* was the most widespread species (present in four out of five biofacies), whereas *Elphidium excavatum*, *Ammonia parkinsoniana* and *Hanzawaia strattoni* were the dominant species of the normal-salinity, nearshore marine and inlet biofacies. Typical marsh foraminifera, *Ammobaculites crassus*, *Miliammina fusca*, *Haplophragmoides wilberti* and *Jadammina*

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macrescens, not surprisingly, characterized the marsh biofacies.

To address the goals of the present study, 40 sites were occupied in Pamlico Sound (Fig. 1). The surface (0–1 cm interval) sediment at each site was used to determine the modern distribution of foraminifera. Sediment from short cores, dated to be approximately 40 and 120 years old (as determined by ^{137}Cs and ^{210}Pb), was used to reconstruct the past distribution of foraminifera.

GEOLOGIC SETTING

Pamlico Sound, North Carolina, is one of the largest embayments along the U.S. east coast, encompassing approximately 5340 km² (Giese and others, 1985; Pietrafesa and others, 1986). The Sound is separated from the ocean by a series of barrier islands, the Outer Banks. Three main inlets, Oregon, Hatteras and Ocracoke, provide access to the Sound from the ocean. Two rivers, the Pamlico and the Neuse, discharge fresh water into the Sound. The low brackish Albemarle Sound, located to the north, also drains into the Sound and affects environmental conditions in its northern section (Fig. 1).

Pamlico Sound is a drowned-river estuary (Riggs and others, 1995; Riggs and Ames, 2003); its bathymetry is controlled by the paleogeomorphology of the river and tributary system that drained the basin during the Pleistocene. (Riggs and others, 1995; Riggs and Ames, 2003). The Sound is relatively shallow, with a maximum depth of 8 m (Giese and others, 1985). Sediments are primarily composed of fine- to very fine-grained sand, with silt- and clay-sized particles concentrated in the basinal regions and in the channels of the Neuse and Pamlico rivers. Medium-grained sand is found at the inlets and in scattered shoals within the Sound. The greatest concentrations of organic matter and carbon correspond to regions of fine-grained material (Giese and others, 1985; Pietrafesa and others, 1986; Wells and Kim, 1989).

Pamlico Sound is a microtidal estuary with an astronomical tidal range of 10–100 cm. Strong winds associated with storms have a dramatic effect on the tidal range by increasing the water buildup in the direction of the wind (Wells and Kim, 1989; Riggs and Ames, 2003). Salinity generally decreases with increasing distance from the inlets westward (Roelofs and Bumpus, 1953; Wells and Kim, 1989).

The Pamlico and Neuse rivers, whose peak discharge is during the spring, are the main source of freshwater for the Sound. The direction of the wind and the volume of water within the rivers control the extent of freshwater into the sound. Winds are generally from the south/southwest during the spring and summer. The increased amount of water draining from the rivers and the general wind direction form a freshwater wedge that extends far into

the northern section of the Sound during the spring and early summer seasons (Fig. 1; Wells and Kim, 1989).

Tidal exchange between the Sound and the Atlantic Ocean occurs at the inlets. The extent that the saline waters disperse into the sound is also controlled by wind direction. Northerly winds dominate during the fall and winter seasons. Wind direction and low flow from the rivers allow saline water to disperse throughout the sound and to extend further up into the rivers (Fig. 1; Wells and Kim, 1989). The salinity range for the entire sound is between 0.5 ppt (at the rivers) and 36 ppt (at the inlets) with an average of 20 ppt (Marshall, 1951; Roelofs and Bumpus, 1953; Pietrafesa and others, 1986; Wells and Kim, 1989).

METHODS

FIELD METHODS

Samples were collected from 40 sites during the summers of 2002 and 2003 using a 1-m length manual push coring device (plastic tube equipped with a one-way valve and extension rods) and a Ponar grab sampler. Separate samples were collected for geochemical and foraminiferal analysis. For geochemical analysis, cores were sectioned into 2-cm intervals between 0 and 30 cm, then 3-cm intervals for the remainder of each core. Sediment to be analyzed for ^{137}Cs and ^{210}Pb was placed into plastic bags. For foraminiferal analysis, the top of each core was divided into 0–1 cm and 1–2 cm intervals, then into 2-cm intervals for the remainder of the first 30 cm, and 3-cm intervals for the remainder of the core below 30 cm. Approximately 20-ml of sediment was placed into bottles and preserved in 70% alcohol for foraminiferal analysis. At sites where short cores were not collected, 20-ml samples from the top 1 cm (0–1 cm interval) of sediment were taken from Ponar grab samples. Each site was visited once and the temperature, salinity, water depth and position were recorded (Appendix 1).

ESTABLISHING A GEOCHRONOLOGY

^{210}Pb ($t_{1/2} = 22.3$ years) and ^{137}Cs ($t_{1/2} = 30.2$ years) were used to evaluate two historic time slices (120 and 40 years BP, respectively) down-core. These radionuclides associate strongly with particles and are therefore useful tracers of particle transport and fate. Many investigators have used these tracers in both coastal and open-ocean environments (McKee and others, 1984, 1986; DeMaster and others, 1986; Moore and others, 1996; Smoak and others, 1996; Baskaran and others, 1997; Feng and others, 1999). ^{137}Cs was supplied to the earth's surface by precipitation and dry deposition. ^{137}Cs is an anthropogenic tracer associated with atmospheric nuclear testing that was introduced into the environment beginning in the mid-1950's and peaked in the early 1960's. This peak in ^{137}Cs activity is present within most accumulating sediments and is designated the 40 year BP time slice in this study. ^{210}Pb is typically used to measure

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Figure 1. Location of study area and sample sites, Pamlico Sound, North Carolina. Surface samples taken from all sites. Closed triangles represent sites analyzed for down-core foraminiferal assemblages. Location of tidal exchange, freshwater sources, wind direction and typical seasonal isohalines for Pamlico Sound are indicated (modified from Wells and Kim, 1989). Inset shows location in North America.

sediment accumulation rates averaged over about a century (~ 5 times its half-life). Excess ^{210}Pb activity is absorbed by sediment particles in the water column or in the watershed, and decay occurs with depth in the sediment column. Below the layer of exponentially decreasing excess activity is a layer of uniform activity supported by the decay of ^{226}Ra (Nittroer and others, 1979; Jaeger and others, 1998). Therefore, the shallowest depth that no excess ^{210}Pb activity is present was determined to be the 120 year BP time slice in this study.

Samples from sediment cores were analyzed for ^{137}Cs ($t_{1/2} = 30.2$ years) and ^{226}Ra ($t_{1/2} = 1600$ years) by direct gamma counting following similar methods of Corbett and others (2004). Samples were initially dried, homogenized and packed into standardized vessels for approximately 24 hours before counting. Sample size ranged between approximately 2 g and 40 g, depending on counting geometry (vial or tin, respectively). Gamma counting was conducted on one of two low-background, high-efficiency, high-purity Germanium detectors (Coaxial- and Well-type) coupled with a multi-channel analyzer. Detectors were calibrated using a natural matrix standard (IAEA-300) at each energy of interest in the standard counting geometry for the associated detector. ^{137}Cs activities were measured using the net counts at the 661.7 keV photopeak. ^{226}Ra activities were determined by allowing samples to equilibrate for greater than three weeks and recounting. ^{226}Ra was then determined indirectly by counting the gamma emissions of its grand daughters, ^{214}Pb (295 and 351 keV) and ^{214}Bi (609 keV).

Total ^{210}Pb was measured by alpha spectroscopy following the methodology of Nittroer and others (1979). Approximately 1.5 g of sediment was spiked with ^{209}Po , as a yield determinant, and partially digested with 8M HNO_3 by microwave heating. $^{210}, ^{209}\text{Po}$ from the solution was then electrodeposited onto nickel planchets in a dilute acid solution (modified from Flynn, 1986). Excess ^{210}Pb activities were determined by subtracting the total ^{210}Pb from that supported by ^{226}Ra .

FORAMINIFERAL PROCESSING

Forty surface samples (0–1 cm interval) were used for analysis of the modern distribution of foraminifera. Preparation of the samples followed the procedure used by Culver and others (1996) and Woo and others (1997). Rose Bengal (Walton, 1952) was added to all surface samples. The samples were washed over a nest of 710- μm and 63- μm sieves to remove mud (silt and clay), coarse material (mostly shell fragments), and alcohol. The remaining material was soaked overnight in water with a small amount (<1 g) of sodium metaphosphate ($(\text{NaPO}_3)_x \cdot \text{Na}_2\text{O}$ calgon) and sodium hydroxide (NaOH) to help break apart mud aggregates.

Foraminifera were separated from samples containing a high amount of sand using a sodium polytungstate floating technique (Munsterman and Kerstholt, 1996). Approximately 300 foraminifera were picked from each sample (Buzas, 1990). Down-core foraminiferal assemblages from two intervals representing approximately 40 and 120 years ago (based on ^{137}Cs and ^{210}Pb data,

respectively) were studied in 12 cores (Fig. 1). The lack of geochemical indicators (e.g., cesium peak) in a few cores reduced the number of down-core samples from 24 to 21. Down-core samples were prepared as for surface samples except they were not stained with rose Bengal. Foraminiferal identifications were confirmed by comparison with type, figured and unfigured specimens lodged in the Cushman Collection, Smithsonian Institution. Foraminiferal census data are given in Appendix 2 (surface 0–1 cm) and Appendix 3 (down-core).

MULTIVARIATE ANALYSIS

Q-mode cluster analysis (Mello and Buzas, 1968) based on transformed abundance data was used to recognize foraminiferal biofacies (assemblages) within Pamlico Sound. Analyses were run using the program SYSTAT for surficial live and dead assemblages. Only those taxa comprising 2% or more of the assemblage at any one site were used in the cluster analysis; thus rare species were excluded. Biofacies Fidelity (BF), Constancy (C) and Occurrence (O) were calculated (Hazel, 1977) to determine which species dominate within each assemblage. Occurrence is defined herein as the number of times a species occurred in a cluster group, Constancy is the percentage of sample in which the species occurred in each group. Biofacies Fidelity is a measure of species faithfulness to a cluster group and is calculated by the following equation:

$$BF_{ji} = \frac{P_i}{\sum_{j=1}^p P_i}$$

where j is the species ($j = a, b, c, n$) and P_i is the percentage of occurrences of a species in a cluster group ($i = 1, 2, 3, p$). Biofacies Fidelity and Constancy are expressed in tens rounded to the nearest whole number. The spatial distribution of species diversity (Fishers α) was compared against the distribution of biofacies.

Multivariate discriminant (canonical variate) analysis was used to test the hypothesis that the groups defined a priori by the cluster analysis are distinguishable statistically. The analysis, based on the amount of variability and similarity between groups (Davis, 1973; Buzas, 1979; Hayek and Buzas, 1997), determines which species contribute most to the discrimination between the a priori groups. A second discriminant analysis was run on the same data with subsurface (down-core) samples included as “unknowns”. The analysis classifies “unknowns” into the a priori groups; thus, these surficial sediment groups (biofacies) comprise the model by which down-core samples are interpreted. SPSS (Statistical Package for the Social Sciences) version 12 was used to run the analyses.

RESULTS

CLUSTER ANALYSIS

A cluster analysis using only live foraminifera revealed no meaningful patterns, probably due to the low number of specimens involved. Several cluster analyses were run using

FIGURE 2. Cluster analysis of dead foraminiferal data from all surface samples. Dendrogram from cluster analysis of transformed abundance data of those species comprising 2% or more of the assemblage in any one sample.

the dead foraminifera surface (0–1 cm) data; one analysis included all species (44) and others used only the dominant species. All of the analyses displayed similar patterns. Since rare species are not reliable indicators of foraminiferal patterns (Koch, 1987), the results of the analysis that utilizes only those species comprising 2% or more of the assemblage in any one sample are presented. The resulting dendrogram divided the sites into two main groups (Fig. 2); one group contains two subgroups. A nested set of four samples within one subgroup is geographically distinct from other samples in that subgroup (Fig. 2) and, hence, is treated as distinct. The four groups, therefore, are: (1) Marsh Biofacies, (2) Estuarine Biofacies A, (3) Estuarine Biofacies B, and (4) Marine Biofacies (Fig. 2).

The Marsh Biofacies (9 samples) is dominated by *Ammonia parkinsoniana* (33%) and *Ammotium salsum* (13%). However, this biofacies is distinguished from the others by the presence of typical finely agglutinated marsh foraminifera (e.g., *Trochammina inflata* and *Haplophragmoides wilberti*). Many of the species present in this group are not found in any of the other biofacies. The

nine sites assigned to this group are generally found close to shores of the Sound (Fig. 3), with two exceptions (S5 and S14).

Estuarine Biofacies A contains 16 samples and is dominated by the agglutinated species *Ammotium salsum* (approximately 83%). Approximately 10% of the assemblage was comprised of calcareous foraminifera; *Ammonia parkinsoniana* (6%) and *Elphidium excavatum* (4%) are dominant. Estuarine Biofacies A is located along the margins and in the north-central basin of Pamlico Sound (Fig. 3).

Estuarine Biofacies B is comprised of ten samples. Approximately 77% of the assemblage is comprised of calcareous foraminifera. *Elphidium excavatum* (65%), *Ammotium salsum* (15%) and *Ammonia parkinsoniana* (12%) are the dominant species. Estuarine Biofacies B, with the exception of S30, is located in the south and central sections of Pamlico Sound (Fig. 3).

The four sites comprising the Marine Biofacies are located at Ocracoke and Hatteras Inlets (Fig. 3), and are composed completely of calcareous foraminifera; *Elphidium excavatum* (70%) is the dominant species. Many of the

FIGURE 3. Distribution of four biofacies (assemblages) in Pamlico Sound resulting from the cluster analysis of dead foraminifera. Values for Fisher's α for each sample are in parentheses beneath sample number.

species (*Cibicides lobatulus*, *Cibicides refulgens*, *Elphidium subarcticum*, *Quinqueloculina lamarckiana* and *Quinqueloculina seminula*) found within this assemblage are not found in any of the other assemblages and are typical, normal-marine-salinity, open-shelf species (Schnitker, 1971; Workman, 1981).

BIOFACIES FIDELITY AND CONSTANCY

In order to determine which taxa were most important in distinguishing biofacies, Biofacies Fidelity and Constancy (Hazel, 1977) were calculated. A species was considered to be characteristic for the assemblage if it received a score of 6 or greater for both Constancy (C) and Biofacies Fidelity (BF). *Haplophragmoides wilberti*, *Miliammina fusca*, *Tiphotrocha comprimata* and *Trochammina inflata* are characteristic of the Marsh Biofacies (Table 1).

Ammonoastuta inepta and *Haplophragmoides bonplandi* are restricted to this assemblage, but they occur at few sites (Table 1). In general, the foraminifera of this assemblage are finely agglutinated. No species are characteristic for Estuarine Biofacies A (Table 1). However, *Ammobaculites dilatatus*, *Ammobaculites exiguus* and *Textularia earlandi*, although occurring rarely, are present only in this assemblage. *Ammonium salsum* occurs at every site within this assemblage, but it has a BF of only 4. In comparison to other assemblages, coarsely agglutinated foraminifera dominate Estuarine Biofacies A.

Estuarine Biofacies B, like Estuarine Biofacies A, does not contain characteristic species (C and BF values >6; Table 1). However, *Ammonium salsum* and *Elphidium excavatum* occur at all ten sites within the assemblage but they have a low BF value. *Elphidium* cf. *E. mexicanum* is restricted to this assemblage but it occurs only at one site.

TABLE 1. Biofacies Fidelity and Constancy for the four biofacies, using dead species comprising 2% or more of the assemblage in any one sample. O = Occurrence, C = Constancy and BF = Biofacies Fidelity. Boxed values indicate characteristic species, defined herein as those species with values of >6 for C and BF.

Species:	Marsh Biofacies			Estuarine Biofacies A			Estuarine Biofacies B			Marine Biofacies		
	O	C	BF	O	C	BF	O	C	BF	O	C	BF
<i>Ammonoastuta inepta</i>	2	2	10	0	0	0	0	0	0	0	0	0
<i>Ammonia parkinsoniana</i>	6	7	2	6	4	1	9	9	3	4	10	3
<i>Ammonia tepida</i>	1	1	2	1	1	1	1	1	2	1	3	5
<i>Ammotium salsum</i>	7	8	3	16	10	4	10	10	4	0	0	0
<i>Arenoparrella mexicana</i>	4	4	6	3	2	3	1	1	1	0	0	0
<i>Asterigerina carinata</i>	0	0	0	0	0	0	1	1	2	2	5	8
<i>Ammobaculites crassus</i>	3	3	4	5	3	4	1	1	1	0	0	0
<i>Ammobaculites dilatatus</i>	0	0	0	1	1	10	0	0	0	0	0	0
<i>Ammobaculites exiguus</i>	0	0	0	3	2	10	0	0	0	0	0	0
<i>Cibicides lobatulus</i>	0	0	0	0	0	0	0	0	0	3	8	10
<i>Cibicides refulgens</i>	0	0	0	0	0	0	0	0	0	1	3	10
<i>Elphidium excavatum</i>	5	6	2	11	7	2	10	10	3	4	10	3
<i>Elphidium galvestonense</i>	1	1	1	1	1	1	0	0	0	3	8	8
<i>Elphidium mexicanum</i>	0	0	0	0	0	0	0	0	0	4	10	10
<i>Elphidium cf. E. mexicanum</i>	0	0	0	0	0	0	1	1	10	0	0	0
<i>Elphidium subarcticum</i>	0	0	0	0	0	0	0	0	0	3	8	10
<i>Hanzawaia strattoni</i>	0	0	0	0	0	0	1	1	1	4	10	9
<i>Haplophragmoides bonplandi</i>	2	2	10	0	0	0	0	0	0	0	0	0
<i>Haplophragmoides wilberti</i>	5	6	6	5	3	3	1	1	1	0	0	0
<i>Jadammina macrescens</i>	4	4	7	1	1	1	1	1	2	0	0	0
<i>Miliammina fusca</i>	6	7	6	3	2	2	2	2	2	0	0	0
<i>Quinqueloculina lamarckiana</i>	0	0	0	0	0	0	0	0	0	2	5	10
<i>Quinqueloculina seminula</i>	0	0	0	0	0	0	0	0	0	3	8	10
<i>Quinqueloculina sp. C</i>	0	0	0	0	0	0	0	0	0	1	3	10
<i>Siphotrochammina lobata</i>	4	4	9	1	1	1	0	0	0	0	0	0
<i>Textularia earlandi</i>	0	0	0	4	3	10	0	0	0	0	0	0
<i>Tiphotrocha comprimata</i>	6	7	7	2	1	1	1	1	1	0	0	0
<i>Trochammina inflata</i>	6	7	6	4	3	2	2	2	2	0	0	0
Indeterminate agglutinated	1	1	10	0	0	0	0	0	0	0	0	0
Indeterminate calcareous	0	0	0	0	0	0	3	3	5	1	3	5
Organic lining	4	4	6	3	2	3	1	1	1	0	0	0

Estuarine Biofacies B is distinguished from Estuarine Biofacies A by a greater proportion of calcareous foraminifera (averages of 77% and 10%, respectively).

Six species are characteristic of the Marine Biofacies: *Cibicides lobatulus*, *Elphidium galvestonense*, *Elphidium mexicanum*, *Elphidium subarcticum*, *Hanzawaia strattoni* and *Quinqueloculina seminula* (Table 1). Three additional species, *Cibicides refulgens*, *Quinqueloculina lamarckiana* and *Quinqueloculina sp. C*, are restricted to this assemblage but do not occur in as many samples as the six characteristic species.

SPECIES DIVERSITY

The number of species per sample (S) and number of specimens observed (N) were used to calculate the diversity index Fishers' α (Hayek and Buzas, 1997). Values for α within the Pamlico Sound estuarine system range from 0.46 in the Sound (S59) to 4.15 at the inlets (EB02S3; Table 2; Fig. 3). The Marine Biofacies is the most diverse with an average α value of 3.77, followed by the Marsh

Biofacies with an average α value of 1.93 (Table 2). Estuarine Biofacies A and Estuarine Biofacies B have very similar low α values of 0.99 and 0.90, respectively.

DISCRIMINANT ANALYSIS

Surficial Sample Discriminant Analysis

The cluster analysis of dead foraminifera in surface (0–1 cm) samples distinguished four biofacies. Discriminant analysis was used to test the hypothesis that these four a priori biofacies were statistically distinguishable. All taxa representing 2% or more of the assemblage were included in the analysis. Therefore, there were 28 species (number of variables, $P = 28$), and 39 sites (observations, $N = 39$). Sample S37 was barren of foraminifera. Four groups (h) were analyzed, and since P is greater than h , a total of three canonical variates were possible ($h-1 = 3$).

The first two functions account for 99.6% of the variance between the four a priori groups (Table 3). Since the fourth group (Marine Biofacies) proved to be so different from the

TABLE 2. Species diversity of foraminifera within the Pamlico Sound estuarine system (S = no. of species, N = no. of specimens and α = Fishers' α index). Eight sites (S7, S10, S14, S15, S25, S26, S35 and EB02S2) contained <50 specimens and were excluded from the analysis. The plotted α values can be found on Figure 4.

Site	Biofacies	S	N	α
Marsh Biofacies				
S1		10	287	2.008
S2		9	268	1.792
S5		5	349	0.826
S17A		16	299	3.61
S38		10	194	2.248
S45		7	220	1.378
S46		6	59	1.660
Mean		9	239	1.932
Estuarine Biofacies A				
S4		5	307	0.847
S9		4	249	0.676
S11		11	286	2.263
S12		2	251	0.297
S22		5	297	0.852
S23		6	183	0.953
S27		6	232	1.127
S39		6	216	0.694
S40		4	329	0.688
S44		8	102	2.046
S50		3	317	0.458
S63		6	271	1.087
Mean		6	253	0.999
Estuarine Biofacies B				
S24		3	263	0.476
S30		11	144	2.797
S31		3	282	0.469
S32		8	307	1.510
S41		4	338	0.483
S42		5	306	0.852
S59		3	332	0.455
S60		3	303	0.463
S61		4	250	0.676
Mean		5	281	0.909
Marine Biofacies				
S17		16	272	3.723
EB02S1		12	111	3.430
EB02S3		15	147	4.149

TABLE 3. Canonical discriminant functions including the percent of variability for each eigenvalue. These values result from the discriminant analysis including four a priori groups (Marsh Biofacies, Estuarine Biofacies A, Estuarine Biofacies B and Marine Biofacies).

Function	Eigenvalue	% Variance	Cumulative %
1	1437.128	97.2	97.2
2	35.012	2.4	99.6
3	6.588	0.4	100

other three groups (Table 4), the analysis was re-run excluding those samples belonging to it.

In this second analysis, where $P = 28$, $N = 39$ and $h = 3$, because $P > h$, there are $h - 1 = 2$ canonical variates. The first function accounts for 84% of the variance between the three a priori groups (Estuarine Biofacies A, Marsh Biofacies and Estuarine Biofacies B; Table 5), and discriminates the Marsh Biofacies from Estuarine Biofacies A and B. The second function accounts for approximately 16% of the total variance between the groups (Table 5). *Ammonia* *inepta*, *Haplophragmoides wilberti* and *Haplophragmoides bonplandi* are most responsible for the separation along Function 1, which distinguishes the Marsh Biofacies from the other two biofacies (Tables 6, 7). *Trochammina inflata*, *Elphidium galvestonense* and *Siphonochammina lobata* are most responsible for separation of the groups along Function 2 (Table 7), which distinguishes Estuarine Biofacies A and B (Table 6).

The three groups are clearly distinguished from each other when plotted with 95% confidence circles (Fig. 4). Therefore, the hypothesis that the three a priori groups Estuarine Biofacies A, Marsh Biofacies and Estuarine Biofacies B are statistically different can be accepted.

Down-core Sample Discriminant Analysis

The combined results of the cluster analysis and discriminant analysis of the surface data provide a model that was used to interpret foraminiferal assemblages down-

TABLE 4. Canonical discriminant function scores for group means (group centroids) along the three canonical variate axes (functions). These values result from the discriminant analysis including all four a priori groups.

a priori group	Function		
	1	2	3
Marsh Biofacies	-13.132	-9.756	1.004
Estuarine Biofacies A	-11.415	4.663	1.952
Estuarine Biofacies B	-12.402	1.436	-4.007
Marine Biofacies	106.213	-0.29	-0.051

TABLE 5. Canonical discriminant functions including the percent of variability for each eigenvalue. These values result from the analysis of three a priori groups (Marsh Biofacies, Estuarine Biofacies A and Estuarine Biofacies B).

Function	Eigenvalue	% Variance	Cumulative %
1	35.443	84.2	84.2
2	6.659	15.8	100

core. Discriminant analysis was used to assign down-core samples into surface biofacies.

To determine the change in environmental conditions over the last approximately 120 years, two intervals, representing two separate time slices, were chosen from each core. Sediment dated using ^{137}Cs represents approximately 40 years BP, whereas sediment dated using ^{210}Pb represents approximately 120 years BP. The average sediment accumulation rate for Pamlico Sound is approximately 0.25 cm/yr, although the rate varies spatially and presumably temporally (Tully, 2004). Therefore, the 2-cm sample intervals most likely represent approximately 8 years.

Twenty-one taxa were found in 21 down-core samples (Appendix 3). These data were included as "unknowns" in a discriminant analysis including three biofacies (Estuarine Biofacies A, Marsh Biofacies and Estuarine Biofacies B) defined at the surface. The Marine Biofacies was excluded from consideration because none of the species restricted to this group were found down-core. Thus, it was assumed that none of the down-core samples represented an inlet assemblage. In this analysis, $N = 60$, $P = 28$ and $h = 3$. Since $P > h$, a total of two canonical variates is possible ($h - 1 = 2$).

Site numbers labeled 'a' correspond to samples dated by peak ^{137}Cs activity corresponding to the early 1960's (Fig. 4). The distribution pattern of the foraminiferal assemblages (Fig. 5) is similar to that of surficial (0–1 cm) assemblages (Fig. 3), with a few exceptions. The presence of marsh foraminifera at site S9a changes assignment of the assemblage from the dominantly coarsely agglutinated Estuarine Biofacies A at the surface to a Marsh Biofacies

TABLE 6. Canonical discriminant function scores for group means (group centroids) along two canonical variate axes (functions). These values result from the discriminant analysis of Marsh Biofacies, Estuarine Biofacies A and Estuarine Biofacies B.

a priori group	Function	
	1	2
Marsh Biofacies	-9.405	0.984
Estuarine Biofacies A	4.481	1.859
Estuarine Biofacies B	1.295	-3.861

TABLE 7. Standardized canonical discriminant function coefficients from the discriminant analysis of three a priori groups. Foraminifera listed are the source of variability along each axis (see text).

	Function	
	1	2
<i>Ammonoastuta inepta</i>	-9.645	-0.199
<i>Ammonia parkinsoniana</i>	-0.082	0.214
<i>Ammonia tepida</i>	4.336	0.357
<i>Ammotium salsum</i>	3.48	0.538
<i>Arenoparrella mexicana</i>	3.911	0.079
<i>Asterigerina carinata</i>	-0.693	-0.518
<i>Ammobaculites crassus</i>	-0.866	-0.363
<i>Ammobaculites dilatatus</i>	2.417	0.262
<i>Ammobaculites exiguus</i>	2.166	0.098
<i>Elphidium excavatum</i>	2.885	-0.812
<i>Elphidium galvestonense</i>	-1.123	-1.261
<i>Hanzawaia strattoni</i>	-0.661	-0.29
<i>Haplophragmoides bonplandi</i>	8.163	-0.515
<i>Haplophragmoides wilberti</i>	-6.196	1.1
<i>Jadammina macrescens</i>	-1.92	0.233
<i>Miliammina fusca</i>	4.857	0.403
<i>Siphonotrochammina lobata</i>	-0.144	3.261
<i>Textularia earlandi</i>	0.66	1.123
<i>Tiphrocha comprimata</i>	1.947	0.184
<i>Trochammina inflata</i>	-0.781	-2.625

down-core. At the surface, site S30 is included in Estuarine Biofacies B, comprised mostly of calcareous foraminifera. Down-core, typical marsh foraminifera are present and thus sample S30a is classified as Marsh Biofacies. At site S60, the environment changes from Estuarine Biofacies B at the surface, to Estuarine Biofacies A down-core. This is due to the increased proportion of agglutinated foraminifera down-core. In general, during the early 1960's, the Estuarine Biofacies B (dominated by calcareous taxa) was not as widespread throughout Pamlico Sound as it is today. Marsh foraminifera were also present further into the central sound, as seen at sites S9 and S30. It is likely that

FIGURE 4. Plot of Canonical Discriminant Function 1 versus Canonical Discriminant Function 2 including three a priori groups and 21 "unknown" down-core samples. 'a' denotes the ^{137}Cs peak interval samples (approximately 40 years) and 'b' denotes samples from the interval where ^{210}Pb activity was absent (approximately 120 years). Symbols for each "unknown" down-core sample correspond to the biofacies that each sample was most similar to. Dashed line represents the group territory boundaries determined by the statistical program.

these foraminifera were transported to these sites from another location.

Site numbers labeled 'b' correspond to down-core intervals lacking excess ^{210}Pb activity, which indicates deposition approximately 120 years before present (Fig. 4). A significant change in assemblage characteristics down-core is indicated by the analysis (Fig. 5). Estuarine Biofacies A dominates the Sound. Only two sites were classified with Estuarine Biofacies B (S12 and S30), and one site (S11) was classified with the Marsh Biofacies.

DISCUSSION

Comparison of the modern surficial assemblages with down-core data gives an indication of paleoenvironmental

changes in Pamlico Sound over the past approximately 120 years. The distribution of four biofacies, Marine Biofacies, Estuarine Biofacies B, Estuarine Biofacies A and Marsh Biofacies, defined by cluster analysis and discriminant analysis (Fig. 4), can be related to the distribution of sediments, variation in salinity (Fig. 1), and, to some extent, depth (Ellison and Nichols, 1970).

The Marine Biofacies, located at Hatteras and Ocracoke inlets (Fig. 3), was composed of calcareous foraminifera such as *Cibicides lobatulus*, *Elphidium galvestonense*, *Elphidium mexicanum*, *Elphidium subarcticum*, *Hanzawaia strattoni* and *Quinqueloculina seminula*. *Quinqueloculina seminula* is typical of inlet environments (Grossman and Benson, 1967; Robinson and McBride, 2003). The salinity of these sites tends to be the greatest in comparison to the rest of the

FIGURE 5. Foraminiferal assemblage changes over time. Bottom box for each site represents approximately 120 years BP, the middle box represents approximately 40 years BP, and the top box represents the present day. Arrows indicate direction of increasing salinity based on foraminifera present. Arrow is dashed at site S12 because the discriminant analysis plots the 40- and 120-year-old samples very close to each other but on either side of the territory boundary between Estuarine Biofacies A and B (see Fig. 4).

sites given the proximity to the ocean (Fig. 1). The sediment type recorded at the inlets is medium-grained sand, which is indicative of relatively high-energy environments.

The central and southern sections of Pamlico Sound contain Estuarine Biofacies B (Fig. 3), which also defines the deepest sections of the Sound. The average salinity for this biofacies varies over the year, but is typically greater than the rest of the Sound, with the exception of the inlets (Fig. 1). Calcareous foraminifera are found in great abundance as well as a significant amount of coarsely agglutinated foraminifera. Typical foraminifera present within this biofacies are *Elphidium excavatum*, *Ammonia parkinsoniana* and *Ammotium salsum*. The surface sediment for the majority of these sites is silt. Environmental conditions associated with this biofacies agree with those associated with the basin biofacies located in the Rappahannock Estuary (Ellison and Nichols, 1970).

Estuarine Biofacies A, generally located along the platforms of the basins, surrounds Estuarine Biofacies B (Fig. 3). Average salinities are similar to Estuarine Biofacies B, but they tend to be slightly more brackish during the spring and summer months (Fig. 1), and the substrate is generally fine to very fine sand. Typical foraminifera belonging to this biofacies include coarsely agglutinated forms such as *Ammotium salsum* and *Ammobaculites crassus*, as well as some calcareous foraminifera, such as *Elphidium excavatum* (Table 1). The environmental conditions for this biofacies are equivalent to those of the shoal biofacies located in the Rappahannock Estuary (Ellison and Nichols, 1970).

The Marsh Biofacies is located along the perimeter of the Sound (Fig. 3) and is typically found at and immediately adjacent to marsh locations. The Marsh Biofacies is comprised primarily of finely agglutinated foraminifera,

TABLE 8. Dates of hurricanes that affected coastal North Carolina between the years 1876 and 1899 (Barnes, 2001).

Year	Date(s) of Hurricane
1876	September 17
1879	September 18
1881	September 9
1882	September 11
	September 22
	October 22
1883	September 11
1885	August 25
1893	August 27-29
	October 13
1899	August 16-18
	October 30-31

such as *Trochammina inflata*, *Tiphotrecha comprimata*, *Miliammina fusca* and *Haplophragmoides wilberti*, although *Ammonia parkinsoniana* is also relatively abundant. The faunal composition of the Pamlico Sound Marsh Biofacies is comparable to other marsh biofacies described along the east coast of the United States (e.g., Ellison and Nichols, 1970; Goldstein and others, 1995; Collins, 1996; Woo and others, 1997; Saffert and Thomas, 1998; Robinson and McBride, 2003; Culver and Horton, 2005; Horton and Culver, in press).

The distribution of foraminiferal assemblages representing approximately 120 years BP (Fig. 5) is different from the distribution of modern-day surface assemblages (Fig. 3). Estuarine Biofacies A, with a high abundance of *Ammonium salsum*, characterizes the majority of the sound at this time. Just two sites (S12 and S30) were classified with Estuarine Biofacies B, and one site (S11) classified with the Marsh Biofacies (Fig. 5). Calcareous foraminifera in down-core assemblages are well preserved and so dissolution of the shells is not considered to have affected the assemblage compositions.

The distribution of foraminiferal assemblages at the 40 years BP interval is similar to the modern-day surficial assemblage. The exceptions are two central Sound sites, S9 and S30, which are classified with the Marsh Biofacies (Fig. 5). Therefore, it is likely that marsh foraminifera present at these locations were transported into the Sound from a marginal location. The smaller geographic area

classified as Estuarine Biofacies B (Fig. 5) may suggest that the Sound was not as saline as it is today.

A comparison of the three times slices analyzed for surface and down-core foraminifera provide a summary of the environmental change (Fig. 5). In general, Estuarine Biofacies B has foraminifera characteristic of a slightly greater salinity in comparison to Estuarine Biofacies A (Figs. 1, 3). This suggests that there has been an increase in salinity in Pamlico Sound over the last 120 years. Recorded storm events provide a possible explanation for this change.

During the late 1870's to 1900 (approximately 120 years ago), 12 hurricanes reached the shores of eastern North Carolina (Table 8). During some years, two or three hurricanes were reported within a two-month interval. Increased amounts of freshwater have been reported to have entered Pamlico Sound via the Pamlico and Neuse rivers for an extended period of time after a wetter than average spring (Pietrafesa and others, 1986) and after hurricanes (e.g., 1999's Hurricanes Dennis, Floyd and Irene; Paerl and others, 2001; Burkholder and others, 2004). It is possible that the brackish conditions indicated by the foraminiferal assemblage that accumulated approximately 120 years ago was caused by one or more of the many hurricanes.

Marsh foraminifera present at depth at sites S9 and S30 may be indicative of another storm event about 40 years ago. The Ash Wednesday Storm was a class 5 nor'easter (as determined by the Dolan/Davis Northeast Intensity scale, 1-5) that impacted coastal North Carolina for two days in March 1962. Ranked as extreme, class 5 storms often cause up to 50 m of beach erosion, extensive and widespread destruction of dunes, massive overwash and inlet formation (Pilkey and others, 1998). The Ash Wednesday Storm is considered the most destructive nor'easter of the twentieth century. Strong winds and waves caused flooding and overwashing for large portions of the Outer Banks. Several breaches were cut into the barrier islands, including Buxton Inlet, exposing the once protected Pamlico Sound to the Atlantic Ocean (Pilkey and others, 1998).

Strong northeasterly winds push estuarine water to the southernmost section of Pamlico Sound. As a result, high standing water in the south floods the area while low standing water in the north erodes the marsh shoreline (Riggs and Ames, 2003). The affects of the Ash Wednesday storm could explain the presence of marsh foraminifera found down-core at the 40-year-old-interval sites S9 and S30. These foraminifera may have been transported into the center of the Sound following severe erosion of the marsh shoreline.

CONCLUSIONS

Significant paleoenvironmental changes for Pamlico Sound, North Carolina, are observed in down-core foraminiferal assemblages. These changes were evaluated at three time slices; (1) present day environment, as determined by the surficial (0-1 cm) sediments, (2) the intervals representing approximately 40 years BP, as determined by ^{137}Cs activity, and (3) the intervals representing approximately 120 years BP, as determined by ^{210}Pb activity.

The change in the foraminiferal assemblage patterns observed at these intervals indicates that salinity has

increased over the last century within Pamlico Sound. Estuarine Biofacies A, which is indicative of a more brackish environment, was the dominant assemblage within Pamlico Sound approximately 120 years BP. The foraminiferal assemblage representing approximately 40 years BP is comparable to the modern-day assemblage. However, Estuarine Biofacies B, which is characteristic of higher salinity, was not as widespread throughout the Sound as it is today. It is possible to attribute these foraminiferal assemblage changes to the major storm activity of hurricanes 120 years ago and the Ash Wednesday nor'easter 40 years ago.

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APPENDIX 1. List of sample sites and their locations, water depths (below mean sea level) and salinity values.

Site	Latitude	Longitude	Depth (m)	Salinity (‰)	Site	Latitude	Longitude	Depth (m)	Salinity (‰)
S1	N 35.6940°	W 75.7753°	0	24	S31	N 35.34603°	W 75.94363°	6.4	26
S2	N 35.6451°	W 75.8914°	0	24	S32	N 35.29535°	W 75.87637°	7	30
S3	N 35.51042°	W 75.98697°	0	26	S33	N 35.25113°	W 75.82771°	5.5	28
S3A	N 35.35791°	W 76.10907°	0	16	S34	N 35.13003°	W 76.02969°	1.5	26
S4	N 35.68793°	W 75.75547°	1.7	22	S35	N 35.12618°	W 76.08553°	1.2	25
S5	N 35.67148°	W 75.65901°	4.4	22	S36	N 35.15801°	W 76.09608°	3	25
S6	N 35.67869°	W 75.59872°	3.5	23	S37	N 35.15912°	W 76.13049°	1.2	25
S7	N 35.6834°	W 75.56065°	1.3	24	S38	N 35.3634°	W 76.24002°	0.6	21
S8	N 35.60858°	W 75.60394°	4.6	24	S39	N 35.34747°	W 76.23984°	2.4	21
S9	N 35.4974°	W 75.6513°	5.5	25	S40	N 35.27138°	W 76.2247°	4.9	21
S10	N 35.57163°	W 75.86568°	2.4	24	S41	N 35.22116°	W 76.1569°	5.8	22
S11	N 35.60148°	W 75.87746°	1.5	22	S42	N 35.29221°	W 75.99912°	5.8	24
S12	N 35.51545°	W 75.91422°	3.7	22	S43	N 35.10183°	W 76.09635°	0.6	25
S13	N 35.4768°	W 75.94882°	1.8	24	S44	N 35.07515°	W 76.08677°	0.6	27
S14	N 35.44416°	W 75.54765°	2.4	27	S45+S46	N 35.65611°	W 75.48625°	0	32
S15	N 35.4368°	W 75.5099°	1.2	29	S50	N 35.29803°	W 76.42251°	5.5	7
S16	N 35.4316°	W 75.49172°	0	26	S51	N 35.21441°	W 76.33443°	6.1	12
S17	N 35.20628°	W 75.79137°	0.6	35	S52	N 35.1854°	W 76.58114°	4.3	10
S17A	N 35.4316°	W 75.49172°	0.3	26	S53	N 35.18962°	W 76.54868°	0	--
S18	N 35.21962°	W 75.80856°	3.4	30	S54	N 35.15794°	W 76.42567°	6.1	11
S18A	N 35.2250°	W 75.6440°	0	30	S55	N 35.0649°	W 76.52741°	6.1	9
S19	N 35.22698°	W 75.78673°	3.4	30	S56	N 35.05875°	W 76.43626°	0.6	--
S19A	N 35.2250°	W 75.6440°	0.6	30	S57	N 35.00747°	W 76.39252°	5.2	14
S20	N 35.22892°	W 75.75966°	1.8	34	S58	N 34.98787°	W 76.42416°	0.6	15
S21	N 35.2145°	W 75.77483°	1.2	25	S59	N 35.18759°	W 76.23262°	5.8	15
S22	N 35.45942°	W 75.83843°	6.1	25	S60	N 35.11848°	W 76.3481°	6.1	14
S23	N 35.53572°	W 75.75035°	5.8	25	S61	N 35.0830°	W 76.23878°	5.8	15
S24	N 35.39815°	W 75.76017°	6.4	25	S62	N 35.05497°	W 76.15221°	0.9	14
S25	N 35.35028°	W 75.70927°	7	25	S63	N 35.03543°	W 76.12321°	0.6	20
S26	N 35.28321°	W 75.61676°	2.1	27	EB02S1	N 35.06444°	W 76.02306°	1.5	32
S27	N 35.28683°	W 75.6237°	4.3	27	EB02S2	N 35.05901°	W 76.00251°	4	34
S28	N 35.29211°	W 75.63078°	0.9	26	OFF02S1	N 35.13699°	W 75.88988°	2.4	36
S29	N 35.2552°	W 76.08944°	2.7	25	OFF02S2	N 35.16516°	W 75.82207°	1.8	35
S30	N 35.40123°	W 76.03094°	2.7	27	EB02S3	N 35.18333°	W 75.76167°	2.4	36

APPENDIX 2. Numbers of live and dead foraminifera for surface samples in Pamlico Sound.

Sample No.		S1	S2	S4	S5	S7	S9	S10	S11	S12	S14	S15	S17	S17A	S22	S23	S24	S25	S26	S27	S30	S31
<i>Ammonia parkinsoniana</i>	L	1	37																			
	D																					
<i>Ammonia tepida</i>	L	20		26	1	1		1	1		2		1	3			5				1	
	D	100		57	282		1	3	35		19		8	4	14		18				6	33
<i>Ammotium salsum</i>	L							7	6				2									
	D	15		4								1		3	5					2	3	1
<i>Arenoparrella mexicana</i>	L	18	75	188	56	2	234		220	216	12	18		4	218	148	19	11	24	203	33	4
	D							1	1	1				28							6	
<i>Asterigerina carinata</i>	L																					
	D												1									
<i>Ammobaculites crassus</i>	L																					
	D	2		7	1			1	6							5				1	8	
<i>Ammobaculites dilatatus</i>	L																					
	D											1										
<i>Ammobaculites exiguus</i>	L												1									
	D											2								15		
<i>Buccella frigida</i>	L																					
	D																					
<i>Buccella inusitata</i>	L																					
	D												2									
<i>Cibicides lobatulus</i>	L																					
	D												5									
<i>Cibicides refulgens</i>	L																					
	D												4									
<i>Elphidium advenum</i>	L																					
	D																					
<i>Elphidium excavatum</i>	L	3						1						6	3			1	5		10	8
	D	6			7		13	1	10	35	1		146		55	27	220	5	3	2	59	236
<i>Elphidium galvestonense</i>	L																					
	D												2									
<i>Elphidium gunteri</i>	L	3							1													
	D								1													
<i>Elphidium mexicanum</i>	L												1	69								
	D											1	6									
<i>Elphidium cf. E. mexicanum</i>	L																					
	D																					
<i>Elphidium subarcticum</i>	L	3																				
	D												9									
<i>Hanzawaia strattoni</i>	L																					
	D												9								2	
<i>Haplophragmoides bonplandi</i>	L																					
	D																					
<i>Haplophragmoides wilberti</i>	L	1																				
	D	3	5	1				9	1			2		114						2	4	
<i>Haynesina germanica</i>	L																					
	D																					
<i>Jadammina macrescens</i>	L																					
	D		39					2	1					10							2	
<i>Miliammina fusca</i>	L	68																				
	D	42	53	24	1			1	1							1					3	
<i>Miliammina petila</i>	L																					
	D																					
<i>Nonionella atlantica</i>	L																					
	D																					
<i>Poroeponides lateralis</i>	L																					
	D																					
<i>Pseudoclavulina gracilis</i>	L																					
	D																					
<i>Quinqueloculina lamarckiana</i>	L																					
	D																					
<i>Quinqueloculina jugosa</i>	L																					
	D																					
<i>Quinqueloculina seminula</i>	L																					
	D												2									
<i>Quinqueloculina sp. C</i>	L																					
	D																					
<i>Reophax sp.</i>	L							1														
	D																					
<i>Siphotrochammina lobata</i>	L													1								
	D													3		1						
<i>Textularia earlandi</i>	L																					
	D																					
<i>Textularia cf. T. gramen</i>	L																					
	D												2									
<i>Textularia sp.</i>	L																					
	D																					
<i>Tiphotocha comprimata</i>	L																					
	D		41					1						1							4	
<i>Trochammina inflata</i>	L																					
	D	2						4	1			2		87				1	2		3	
<i>Trochammina irregularis</i>	L																					
	D																					
<i>Trochammina sp.</i>	L																					
	D																					
<i>Indeterminate agglutinated</i>	L																					
	D																					
<i>Indeterminate calcareous</i>	L																					
	D																					
<i>Organic lining</i>	L																					
	D																					
Total foraminifera (Live and Dead):		287	268	307	349	3	249	33	286	251	37	31	272	299	297	183	263	19	35	232	144	282

APPENDIX 2. Continued.

Sample No:		S32	S35	S38	S39	S40	S41	S42	S44	S45	S46	S50	S59	S60	S61	S63	EB02 S1	EB02 S2	EB02 S3
<i>Ammoastuta inepta</i>	L																		
	D																		
<i>Ammonia parkinsoniana</i>	L	2					6		5		9			3	5	18			
	D	37					5	49	4		2	6	18	58	69		12	1	5
<i>Ammonia tepida</i>	L	1																	
	D	24																	
<i>Ammotium salsum</i>	L				3			4	6			85		4	8	14			
	D	9	1	5	200	225	129	93	56	8		144	6	42	16	232			
<i>Arenoparrella mexicana</i>	L									1									
	D			21	1						4								
<i>Asterigerina carinata</i>	L																		
	D	1																	
<i>Ammobaculites crassus</i>	L															1			3
	D																		
<i>Ammobaculites dilatatus</i>	L				3														
	D																		
<i>Ammobaculites exiguus</i>	L								2										
	D								4										
<i>Buccella frigida</i>	L																		
	D																		
<i>Buccella inusitata</i>	L																		
	D																		
<i>Cibicides lobatulus</i>	L																		
	D																2		6
<i>Cibicides refulgens</i>	L																		
	D																		
<i>Elphidium advenum</i>	L																		
	D																		
<i>Elphidium excavatum</i>	L	38			2	11	16					34	2	54	8				1
	D	84			4	89	181	153	3	1		48	306	131	143		69	6	97
<i>Elphidium galvestonense</i>	L								1			10				4			
	D								1			1					1		3
<i>Elphidium gunteri</i>	L																		
	D	1							1										
<i>Elphidium mexicanum</i>	L			2					11										
	D																1	3	2
<i>Elphidium</i> cf. <i>E. mexicanum</i>	L	7																	
	D	100																	
<i>Elphidium subarcticum</i>	L																		
	D																3		1
<i>Hanzawaia strattoni</i>	L																		
	D																4	1	11
<i>Haplophragmoides bonplandi</i>	L																		
	D																		
<i>Haplophragmoides wilberti</i>	L			1															
	D			20	1														
<i>Haynesina germanica</i>	L																		
	D	3																	
<i>Jadammina macrescens</i>	L																		
	D			17															
<i>Miliammina fusca</i>	L																		
	D			7						2					1				
<i>Miliammina petila</i>	L																		
	D																		
<i>Nonionella atlantica</i>	L																		
	D																		1
<i>Poroepionides lateralis</i>	L																		
	D																		1
<i>Pseudoclavulina gracilis</i>	L																		
	D																		
<i>Quinqueloculina lamarckiana</i>	L																		
	D																3		2
<i>Quinqueloculina jugosa</i>	L																	1	1
	D																		1
<i>Quinqueloculina seminula</i>	L																		3
	D																12		8
<i>Quinqueloculina</i> sp. C	L																		
	D																3		
<i>Reophax</i> sp.	L																		
	D																		
<i>Siphotrochammina lobata</i>	L					3		1				2							
	D			4						22	8								
<i>Textularia earlandi</i>	L								2										
	D					1			2							1			
<i>Textularia</i> cf. <i>T. gramen</i>	L																		
	D																		
<i>Textularia</i> sp.	L																		
	D							1											
<i>Tiphotocha comprimata</i>	L			2															
	D			23	2					8	1								
<i>Trochammina inflata</i>	L			10						53	1								
	D			82						122	18					1			
<i>Trochammina irregularis</i>	L																		
	D																		
<i>Trochammina</i> sp.	L									1									
	D									2									
Indeterminate agglutinated	L																		
	D																		
Indeterminate calcareous	L																		
	D							6						11			1		
Organic lining	L																		
	D																		
Total foraminifera (Live and Dead):		307	1	194	216	329	338	306	102	220	59	317	332	303	250	271	111	12	147

APPENDIX 3. Number of foraminifera for subsurface core samples in Pamlico Sound.

Sample No: core interval (cm):	S9a 8-10	S9b 18-20	S11b 14-16	S12a 16-18	S12b 20-22	S24a 12-14	S24b 28-30	S27b 12-14	S30a 10-12	S30b 16-18	S31a 16-18	S31b 51-54	S32a 10-12	S41a 12-14	S41b 24-26	S50a 16-18	S50b 36-39	S59a 4-6	S59b 20-22	S60a 12-14	S60b 28-30
<i>Ammoastuta inepta</i>			1																		
<i>Ammonia parkinsoniana</i>						20	7	1	7	37	13	29	118	1		21		17	3	25	2
<i>Ammonia tepida</i>							2			3		2									
<i>Ammotium salsum</i>	281	276	281	313	256	33	288	112	253	126	88	180	3	151	249	240	277	133	66	249	272
<i>Arenoparrella mexicana</i>		1																			
<i>Ammobaculites crassus</i>	2	5	11	10	13		6	2	9	2	1	3		1							
<i>Ammobaculites dilatatus</i>																					
<i>Ammobaculites exiguus</i>																					1
<i>Elphidium excavatum</i>		4			2	274	24	7	14	187	176	96	271	132	34	7		255	37	6	6
<i>Elphidium galvestonense</i>										1											
<i>Elphidium gunteri</i>													1					1			
<i>Elphidium mexicanum</i>							1														
<i>Elphidium</i> cf. <i>E. mexicanum</i>													2								
<i>Haplophragmoides wilberti</i>	4								3												
<i>Jadammina macrescens</i>	1	1																			
<i>Reophax</i> sp.	2								1												
<i>Textularia</i> sp.																			1		
<i>Tiphotrocha comprimata</i>																			1		
<i>Trochammina inflata</i>	2					1			7												
<i>Trochammina</i> sp.		1																		1	
Organic lining	2																1				
Total foraminifera:	294	288	293	323	271	328	328	122	294	356	278	310	395	285	283	268	278	408	107	280	281