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Benthic Foraminiferal Communities of a Barrier-Lagoon System, Virginia, U.S.A.

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ABSTRACT

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Foraminifera have a fundamental role in the trophic structure of marine communities and may be used to assess primary stresses affecting environmental quality. In coastal barrier lagoons their distribution can provide a framework for future assessment of environmental quality. To establish a baseline for the barrier-lagoon system of the southern Delmarva Peninsula, 20 subenvironments were sampled and proved to contain 44 species of living benthic foraminifera. Densities of species were related to variations in substratum, salinity and organic-matter content. Not all of the 20 subenvironments could be recognised based on variations in foraminiferal community composition; only seven subenvironments were distinguished on the basis of the distribution of dominant living species. Foraminiferal community composition appeared to be closely tied to the natural variations of physical stresses produced by the interrelationship of landscape and flow dynamics.

ADDITIONAL INDEX WORDS: *Environmental quality, marsh.*

INTRODUCTION

Along the middle Atlantic coast of the United States, coastal barrier lagoons and associated marshes are important habitats for a wide variety of organisms including benthic foraminifera. In common with other coastal environments, rising land values along the margins of Virginia barrier lagoons are increasing the pressures for seaside development. Thus it is timely to provide a baseline useful for assessing future changes in lagoonal community structure and/or composition that might result from development activities. The benthic foraminiferal populations that inhabit the Virginian lagoonal environments occupy a low trophic level. Given the role of foraminifera as both predators and prey in shallow marine communities (*e.g.*, LIPPS and VALENTINE, 1970; BUZAS, 1978; BUZAS and CARLE, 1979; LIPPS, 1983), changes in community composition and structure may reflect early stages of ecological impacts caused by development stresses. Indeed, benthic foraminifera have proven to be sensitive indicators of organic and inorganic pollutants (*e.g.*, BOLTOVSKOY *et al.*, 1991; YANKO *et al.* 1994; ALVE, 1995; CULVER and BUZAS, 1995) and so can provide information on geographically-restricted, point-source disturbance as well as broader, community-wide perturbations.

Although over 700 papers (CULVER, 1980) have been published on the modern benthic foraminifera of the Atlantic continental margins of North America, WOO (1992) provided the first detailed work on the distribution of foraminifera in Virginia barrier-lagoon systems. The distribution of total (live plus dead) foraminiferal assemblages in this region was described and analyzed in CULVER *et al.* (in press). That work built upon earlier studies of marginal marine foraminifera along the North American Atlantic coast (*e.g.*, PHLEGER, 1952; PARKER and ATHEARN, 1959; ELLISON and NICHOLS, 1970; KRAFT and MARGULES, 1971; SCOTT and MEDIOLI, 1980; GOLDSTEIN and HARBEN, 1993; see CULVER and BUZAS, 1980 and included references) and was designed to test the utility of modern benthic foraminiferal assemblages as palaeoenvironmental indicators.

The purpose of this paper is to document the foraminiferal communities of the Virginia barrier-lagoon system, and the distribution of individual species adjacent to lagoonal shorelines. These data will provide an important baseline for future assessments of environmental quality.

METHODS

The study area was located between Smith Island and Parramore Island in the southern Delmarva Peninsula (Figure 1). Twenty subenvironments were defined based on differences in landscape characterization (sediment texture, tidal inundation, flora, wave exposure, apparent flushing, current flow, salinity) and were sampled between 1989 and 1991. A minimum of two replicates were taken at each station for a total of 57 samples. Seven of the stations were specific to the upper part of the tidal zone. Six upper tidal zone stations

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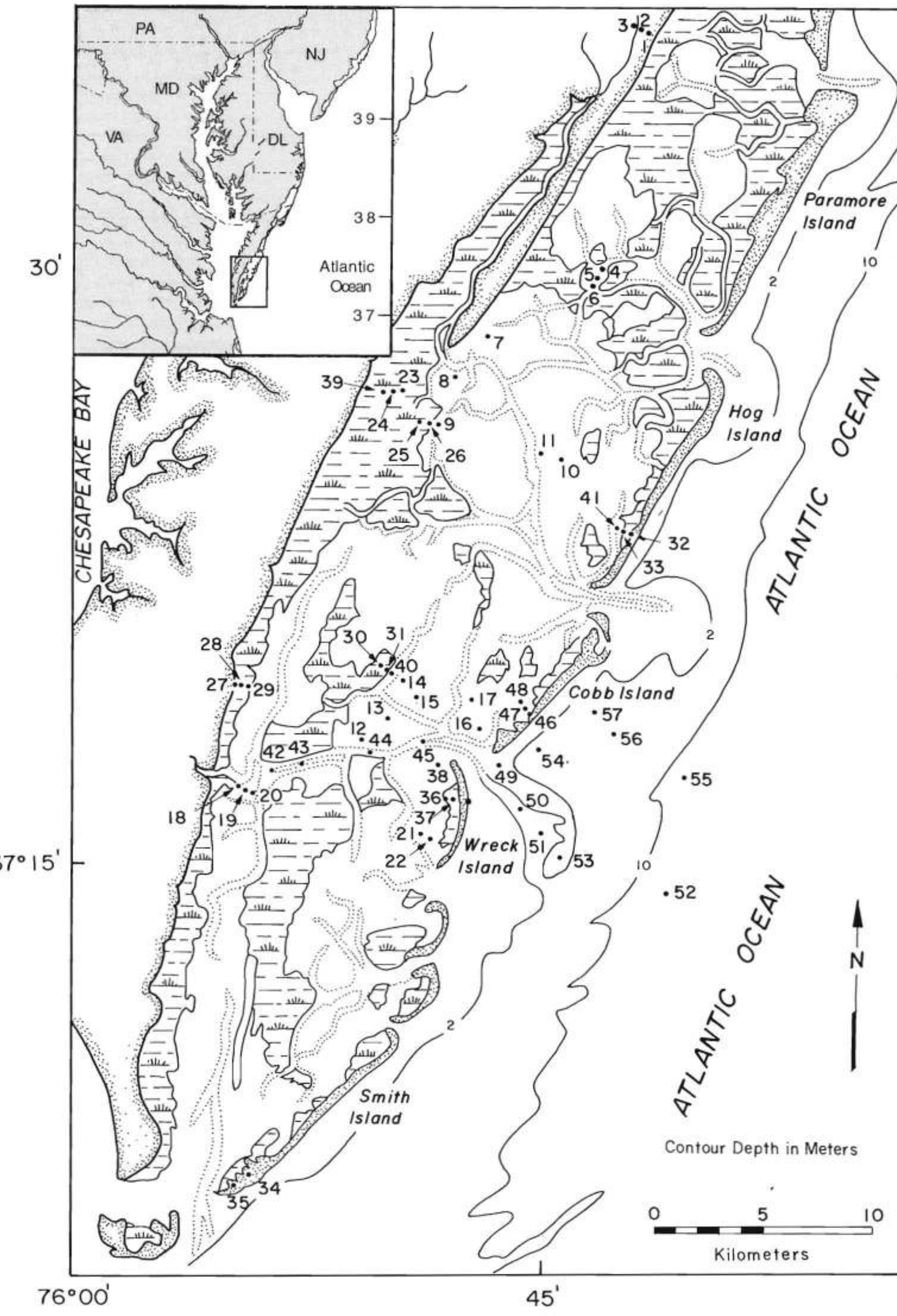

Figure 1. Location map of the study area showing sample stations. Numbers on the map represent stations at specific subenvironments. DL, Delaware; MD, Maryland; NJ, New Jersey: VA, Virginia.

occurred in different marsh landscapes. Terminology for the lagoonal marshes follows OERTEL and WOO, 1994. The seventh upper tidal zone station occurred on a washover fan. Eight stations were located on flats in the lower intertidal to subtidal zones. Five stations were on the floors of tidal channels, ebb deltas and on the upper shoreface.

Samples were collected using a push corer during low water except at depths of greater than two meters where a box

Table 1. Proportions for the living foraminiferal populations in surface samples from 57 stations (expressed as percent abundance per sample).

a priori subenvironment	1	1	1	2	2	2	3	3	3	4	4	5	5	6	6	7	7	8	8	8	9	9	10	10	11	11	11	11	11
Habitat Zone	1	1	1	4	4	4	4	4	4	6	6	4	4	6	6	6	6	4	4	4	6	6	3	3	2	2	2	2	2
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
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	-0.3	-0.3	-0.4	-0.4	-0.9	-0.9	-0.2	-0.1	-0.1	-0.4	-0.4	0.6	0	0.6	0	0.9	0.2	0
# Species	8	8	10	9	2	5	6	5	3	3	3	4	7	2	1	1	10	7	8	10	6	11	5	3	1	2	6	5	10
# Individuals per fraction picked	41	26	52	337	43	225	12	30	25	18	18	6	62	11	2	10	94	83	455	248	57	215	294	27	34	2	37	127	171
Ammoastuta inepta		15.4																											
Ammobaculites exiguus			5.8	0.6		0.4											1.1		0.4	0.4						50.0		8.7	0.6
Ammonia beccarii			34.6	52.8	46.5	65.8	8.3	6.7	56.0	22.2		50.0	16.1				13.8	31.3	49.5	56.5	22.8	12.1	58.8	70.4			2.7	50.4	52.6
Arenoparrella mexicana	17.1	3.9	5.8																								16.2		
Bolivina striatula											5.6																		
Eggerella advena																													
Elphidium bartletti				0.6		1.8																							
Elphidium articulatum				1.2														7.2	1.5										
Elphidium discoidale																													
Elphidium excavatum			17.3	43.3	53.5	31.6	50.0	63.3	20.0	72.2	88.9	16.7	74.2	81.8	100	100	54.3	45.8	43.1	32.3	61.4	68.8	2.4	3.7		50.0		2.4	24.0
Elphidium galvestonense																													
Elphidium gunteri				0.3						5.6												0.5							0.6
Elphidium mexicanum																													
Elphidium poeyanum							8.3	3.3					3.2				2.1	2.4	0.9	2.4		2.3							3.5
Elphidium subarcticum																						0.5							
Fissurina laevigata																				0.8									
Glabratella sp. A							8.3	3.3			5.6		1.6				1.1	9.6	3.1	1.2		1.9							
Glabratellina sp. A						0.4							1.6				6.4				1.8								
Haplophragmoides wilberti	9.8																												
Haynesina germanica			1.9	0.6			16.7	23.3				16.7	1.6	18.2			1.1	1.2		4.8		1.4	38.1						2.3
Helenia anderseni																													
Jadammina macrescens	9.8	3.9																									37.8		
Miliammina earlandi																											8.1		
Miliammina fusca		15.4	1.9	0.3					24.0									2.4	1.3					25.9	100		2.7	36.2	4.1
Miliolinella fichteliana																													
Miliolinella microstoma																													
Nonionella atlantica																													
Quinqueloculina dimidiata																					1.8	7.9	0.3						1.2
Quinqueloculina jugosa																						0.5							
Quinqueloculina seminula				0.3													16.0			0.8	10.5	3.7	0.3						7.0
Quinqueloculina cf. *Q. seminula*																	3.2												
Quinqueloculina seminula jugosa																													
Quinqueloculina sp.																						0.5							
Reophax sp.																													
Rosalina floridana							8.3												0.2										
Textularia earlandi	2.4												1.6				1.1			0.4	1.8								
Tiphotrocha comprimata			1.9																										
Trochammina advena	4.9																												
Trochammina inflata	24.4	23.1	3.9																	0.4							32.4	2.4	4.1
Trochammina laevigata		3.9																											
Trochammina ochracea												16.7																	
Trochammina "squamata"	24.4	11.5	11.5																										
Trochammina sp. A	7.3	23.1	15.4																										
Indeterminate calcareous hyaline																													

Table 1. *Continued.*

a priori subenvironment	12	12	13	13	13	13	13	13	14	14	14	14	15	15	16	16	17	17	17	18	18	19	19	19	19	20	20	20
Habitat Zone	4	4	2	2	2	2	2	2	3	3	3	3	4	4	6	6	5	5	5	6	6	7	7	7	7	7	7	7
Station No.	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Depth(m) (MSL datum)	0.6	0	0.6	0	0.6	0	0	0	-0.6	-0.6	-0.6	-0.6	-4.2	-12	-14	-14	0.6	0	-0.6	-17	-7	-4.1	-13	-7	-3.7	-12	-7	-4
# Species	9	4	4	10	11	11	10	6	1	7	4	7	6	3	3	3	0	7	10	2	1	2	1	3	1	5	2	2
# Individuals per fraction picked	357	30	38	259	177	159	136	60	3	157	19	72	13	4	9	9	0	305	245	3	2	6	1	9	1	26	3	2
Ammoastuta inepta																												
Ammobaculites exiguus	0.6		2.6	5.4	1.7	45.3	5.9	3.3				11.1							0.8									
Ammonia beccarii	58.8	43.3	84.2	39.0	18.6	23.9	21.3	73.3	100	66.9	52.6	15.3	15.4	25.0				3.6	42.9			33.3		11.1				
Arenoparrella mexicana					6.2					0.6																		
Bolivina striatula																												
Eggerella advena						0.6																						
Elphidium articulatum																												
Elphidium bartletti	1.1																		0.8									
Elphidium discoidale																										7.7		
Elphidium excavatum	35.3	26.7		8.1		3.1	10.3	10.0		11.5	31.6	11.1	53.9	50.0	77.8	77.8		2.0	30.2	66.7	100	66.7	100	22.2	100	46.2	66.7	50.0
Elphidium galvestonense				0.4															2.9							7.7		
Elphidium gunteri	0.8			1.9								2.8																
Elphidium mexicanum	0.8			0.4		0.6													2.0					66.7		34.6	33.3	50.0
Elphidium poeyanum				0.4	0.6						10.5		7.7					0.3										
Elphidium subarcticum																												
Fissurina laevigata							0.7																					
Glabratella sp. A		3.3								2.6			7.7		11.1													
Glabratellina sp. A						0.6	0.7																					
Haplophragmoides wilberti																												
Haynesina germanica	1.7	26.7	5.3	15.1	0.6					14.7	5.3	36.1	7.7		11.1	11.1										3.9		
Helenia anderseni				2.7																								
Jadammina macrescens					1.1	0.6	0.7																					
Miliammina earlandi																												
Miliammina fusca	0.3		7.9	26.6	9.0	22.6	4.4	3.3		1.3		22.2							1.6									
Miliolinella fichteliana																		0.3										
Miliolinella microstoma					0.6																							
Nonionella atlantica																11.1												
Quinqueloculina dimidiata																		18.7	2.0									
Quinqueloculina jugosa																												
Quinqueloculina seminula	0.6									2.6				25.0				71.2	16.3									
Quinqueloculina cf. *Q. seminula*																												
Quinqueloculina seminula jugosa																		3.9										
Quinqueloculina sp.																												
Reophax sp.												1.4																
Rosalina floridana						0.6																						
Textularia earlandi						1.3	40.4	3.3																				
Tiphotrocha comprimata					2.3																							
Trochammina advena																												
Trochammina inflata					57.6	0.6	14.0	5.7																				
Trochammina laevigata																												
Trochammina ochracea													7.7							33.3								
Trochammina "squamata"							1.5																					
Trochammina sp. A					1.7																							
Indeterminate calcareous hyaline																			0.4									

corer was used. Samples (70 ml volume) were scraped from the upper one cm of sediment. Thus, deeper infaunal foraminifera are excluded from this study. The sediment was shaken in a 5% buffered formalin and seawater solution to preserve live foraminifera. In the laboratory the sediment was washed over a 63 μm-mesh sieve to remove silt, clay and excess formalin. The residue was stained with rose Bengal (WALTON, 1952) and preserved in isopropyl alcohol. Foraminiferal tests were concentrated using a soap flotation technique (HOWE, 1941). Foraminiferal concentrations in 70 ml samples are expressed as the number of specimens per cubic centimeter. Sample concentrations greater than 1 specimen/cm^3 were rounded to the nearest whole number.

Following the approach of BUZAS (1990), approximately 300 specimens of live and dead foraminifera were picked from randomly split wetted aliquots of each sample. Live foraminifera were recognized by the presence of pink-stained protoplasm visible through the aperture or the chamber walls of individual specimens. Identifications were confirmed via comparisons with type and figured material in the Cushman Collection, National Museum of Natural History, Smithsonian Institution, and in the collections of The Natural History Museum, London.

Because rare species cannot be used reliably as indicators of faunal patterns (*e.g.*, KOCH, 1987), we utilized distributional variations of the dominant species (those comprising 5% or more of the population in any one sample) as a tool for distinguishing and characterizing subenvironments. We had hypothesised that 20 subenvironments (defined on the basis of variations in lagoonal landscape characteristics) could be distinguished based on differences in foraminiferal community composition and structure. To test this hypothesis, cluster analysis (normalized abundance data, Pearson correlation coefficient, complete linkage method) was used to identify groupings of subenvironments.

Stepwise regression analysis was used to predict the relationship between species densities and environmental variables. Twelve environmental variables (salinity, temperature, water depth, percent organic matter, sand, silt, clays mean grain size, sorting, distance from mainland, distance from inlet, sediment bulk density) and the five most frequently recurring species (those occurring at more than 30% of the total stations) were included. The number of individuals in 70 ml of sediment was transformed to $\ln(x + 1)$ to normalize data where x is the number of individuals (BUZAS, 1969).

Grain-size distributions were determined using standard sieving and pipetting techniques at half and one phi intervals respectively (FOLK, 1980). Bulk density was calculated by dividing the dry weight (g) of the sediment by its wet volume (ml). Organic content was determined by ashing samples in a muffle furnace at 400 °C for two hours followed by weighing to determine the ash-free dry weight.

RESULTS

Geographic Distribution of Foraminifera

Forty-four living benthic foraminiferal species were identified in the study area. The species proportions (expressed as percent of the living populations) are listed in Table 1. The number of live individuals per 70 ml of sediment varied from 0 to 4,880 specimens over the study area. Species densities were low on the ebb delta and the shoreface (stations 49–57) with an average of 0.25 specimens/cm^3, whereas the greatest number of living individuals generally occurred in restricted bays (stations 4–6) with an average of 30 specimens/cm^3. The highest number of specimens occurred at station 47 (70 specimens/cm^3; washover fan) where the genus *Quinqueloculina* dominated.

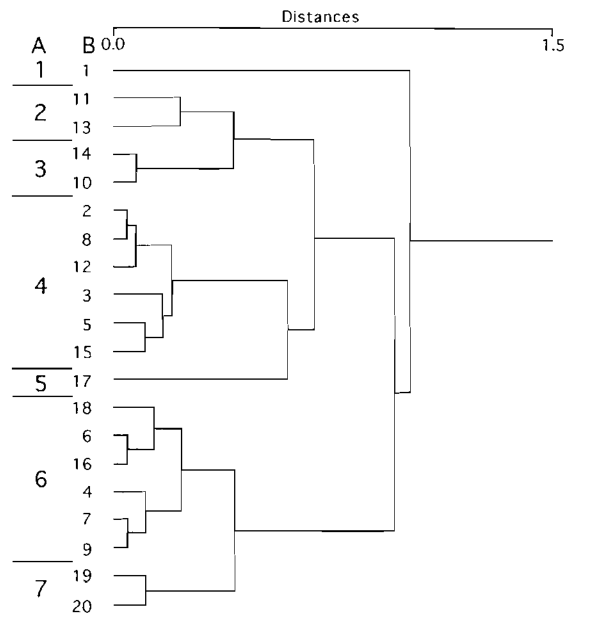

Figure 2. Dendrogram resulting from cluster analysis of foraminiferal population data from twenty *a priori* subenvironments and showing seven groups (habitat zones). A, Habitat Zones; B, *a priori* subenvironments (see Table 2).

The dendrogram (Figure 2) could be interpreted as containing various numbers of groups (four, seven, or nine). Analysis of the foraminifera populations in those three sets of groups indicate that seven groups (indicated on Figure 2) is the most ecologically meaningful. These are referred to below as "habitat zones". The seven habitat zones were characterised by distinctive foraminiferal communities (cooccurrences of abundant species) (Figure 3; Table 2).

Habitat Zone 1 (Figures 2, 3; Table 2) occurred along the mainland side of a coastal barrier lagoon. This habitat zone is in small watersheds that drain into coastal lagoons. The valley marshes in these watersheds are protected from open lagoonal conditions and have muddy substrates. The upper part of the marsh is brackish and has salinities < 10 ppt. This subenvironment is a transitional zone between the near marine conditions of the barrier lagoon (30–32 ppt) and the fresh conditions of terrestrial creeks. The foraminiferal community of Habitat Zone 1 was characterized by the calcareous *Ammonia beccarii* in the brackish channel and the agglutinated *Trochammina inflata* and *Trochammina "squamata"* in the brackish marsh, where the fauna consisted entirely of agglutinated specimens. The low salinity in these areas prob-

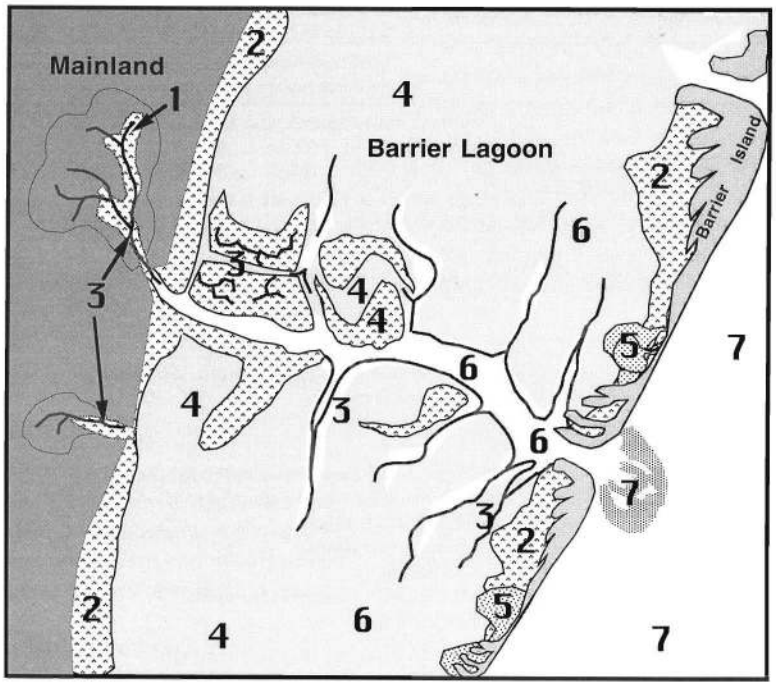

Figure 3. Schematic diagrams of an idealized barrier island system illustrating the distribution of seven habitat zones characterized by different foraminiferal communities. Numbers refer to habitat zones: (1) Brackish environments, *Ammonia beccarii–Trochammina inflata–Trochammina "squamata"* community, (2) Fringe marsh, *Ammobaculites exiguus–Ammonia beccarii–Elphidium excavatum–Jadammina macrescens–Miliammina fusca–Textularia earlandi–Trochammina inflata* community, (3) Valley marsh and tidal channel margins, *Ammonia beccarii–Elphidium excavatum–Haynesina germanica–Miliammina fusca* community, (4) Inner and mid-lagoon environments, *Ammonia beccarii–Elphidium excavatum–Haynesina germanica* community, (5) Washover fan, *Ammonia beccarii–Elphidium excavatum–Quinqueloculina seminula* community, (6) Outer lagoon environments, *Elphidium excavatum* community, (7) Shoreface and delta shoals, *Elphidium excavatum–Elphidium mexicanum* community.

ably restricts calcareous species because of the decreased availability of calcium carbonate (HADA, 1957). This habitat zone was quite distinct from the other subenvironments within the lagoon proper (Figure 2).

Habitat Zone 2 (Figures 2, 3; Table 2) includes exposed headland fringe marsh, and protected and exposed backbarrier fringe marsh. Headland fringe marshes are exposed to open-water lagoonal forces and are distinct from protected counterparts. *Ammonia beccarii, Elphidium excavatum* together with several agglutinated species (*Jadammina macrescens, Miliammina fusca* and *Trochammina inflata*), dominate populations. Five different types of fringe marshes occur along the back-sides of barrier islands (OERTEL and WOO, 1994). *Ammobaculites exiguus, Textularia earlandi* and *Miliammina fusca* dominate at exposed fringe marshes; at protected backbarrier fringe marshes, these three species dominate along with *Trochammina inflata*.

Habitat Zone 3 (Figures 2, 3; Table 2) is composed of two seemingly disparate but adjacent subenvironments (protected valley marsh and tidal channel margin). Three of the four dominant species, *Ammonia beccarii, Elphidium excavatum* and *Haynesina germanica* indicate similarity with inner and mid-lagoon environments of Habitat Zone 4 (Table 2) but the presence of abundant *Miliammina fusca* in both subenvironments resulted in clustering with the marshes of Habitat Zone 2 (Figure 2). The mainland fringe marshes are shielded from open lagoonal conditions by marsh islands and lagoonal hammocks, thus preventing mixing of the water column and substratum by wind-driven waves. Flushing is restricted to small tidal creeks with long pathways to open-water areas. High sediment porewater salinities ($\approx$40–60 ppt), apparently caused by significant evaporation rates from thin lenses of water trapped on marsh surfaces, contribute to environmental stress. The dominant species (Table 2) occur with less common specimens of *Quinqueloculina dimidiata*. Similar populations form important components of foraminiferal communities in hypersaline lagoons of the Middle East (SAID, 1950; MURRAY, 1991).

Several inner and mid-lagoon subenvironments comprise Habitat Zone 4 (Figures 2, 3; Table 2). The water that circulates through these areas has typical coastal lagoon salinities (30–32 ppt). These subenvironments are relatively well-flushed because water is mixed by lagoonal waves, and driven by tidal currents. The extensive open-water areas in the middle parts of the lagoon increases the potential for water exchange and flushing. Shallow flats in the open-water areas of the lagoons also have large wind fetches that permit the development of wind-driven gravity waves. While wave processes may stress the benthic community by constantly reworking the bottom, the associated stirring of the water column also enriches the oxygen content of the benthic boundary and the upper layers of the sea bed. *Ammonia beccarii*

Table 2. *Seven habitat zones (*a priori *subenvironments and groups of* a priori *subenvironments) and the characteristic species of each benthic foraminiferal community (arbitrarily defined as the species that comprise >20 percent of the population in one or more sample).*

Habitat Zone	Subenvironments (*a priori* nos. in parens.)	Characteristic Species
1. Brackish environments	(1) Mainland valley marsh and Channel (brackish and protected)	*Ammonia beccarii* *Trochammina inflata* *Trochammina "squamata"*
2. Fringe marsh	(11) Mainland fringe marsh (exposed headland) (13) Back-barrier fringe marsh (protected and exposed)	*Ammobaculites exiguus* *Ammonia beccarii* *Elphidium excavatum* *Jadammina macrescens* *Miliammina fusca* *Textularia earlandi* *Trochammina inflata*
3. Valley marsh and tidal channel margins	(10) Mainland valley marsh (protected, low runoff) (14) Tidal channel margin	*Ammonia beccarii* *Elphidium excavatum* *Haynesina germanica* *Miliammina fusca*
4. Inner and mid-lagoon environments	(2) Tidal bays and flats (restricted circulation) (3) Muddy sand flat (inner lagoon) (5) Sand flat (inner lagoon) (8) Mud flat (inner lagoon) (12) Island marsh (15) Tidal channel (intermediate depth)	*Ammonia beccarii* *Elphidium excavatum* *Haynesina germanica*
5. Washover fan	(17) Washover fan	*Ammonia beccarii* *Elphidium excavatum* *Quinqueloculina seminula*
6. Outer lagoon (sandy)	(4) Muddy sand flat (mid and outer lagoon) (6) Sand flat (middle lagoon) (7) Sand flat (outer lagoon) (9) Mud flat (outer lagoon) (16) Deep tidal channel (18) Ebb delta axial channel	*Elphidium excavatum*
7. Shoreface and delta shoals	(19) Ebb delta inlet shoals (20) Shoreface	*Elphidium excavatum* *Elphidium mexicanum*

and *Elphidium excavatum* dominate low diversity populations in Habitat Zone 4. *Haynesina germanica* occurs as an important subsidiary species in all subenvironments except the muddy tidal flats of *a priori* subenvironments 2 and 8 where it is less abundant.

Habitat Zone 5 (Figures 2, 3; Table 2) occurred in the sediment of the intertidal part of a washover fan on the back-barrier side of a barrier island. *Quinqueloculina seminula, Ammonia beccarii* and *Elphidium excavatum* characterise this subenvironment. The density of living *Quinqueloculina seminula* was higher than elsewhere and was an effective tool for distinguishing this from other habitat zones. The fan was located on a topographically low section of an island that was overwashed frequently during moderate storms. The sediment on the surface of the fan was 93–97% sand. However, thin lenses of mud separated beds below the fan surface. During washover events the fan surface is stressed by turbulent slurries of sand and water which surge across the island from the marine side. During non-storm conditions the slow inundation and drainage of lagoonal tidal-water is much more quiescent. Thus, the distinct foraminiferal community in this environment appears to be related to marine/outer lagoon environmental conditions stressed by turbulent flows, periodic exposure, and mobile benthic boundaries. Habitat Zone 5 had a very distinctive fauna but clustered at a low level of similarity with Habitat Zone 4 because of the presence, albeit in low abundance, of a few specimens of *Quinqueloculina seminula* in three Habitat Zone 4 samples.

Habitat Zone 6 is comprised of middle to outer lagoon subenvironments characterised by sandy substrates. This habitat zone experiences similar hydrographic conditions as Habitat Zone 4 but the foraminiferal populations are characterised by the extreme dominance of *Elphidium excavatum*. The result of stepwise regression analysis (see below) indicated that the density of *Elphidium excavatum* was correlated with organic content of sediment (Table 3). The open bays and tidal channels of Habitat Zone 6 are characterised by sandy substrates (generally more than 70 percent sand) with very low amounts of organic matter (< 0.3 percent), probably reflecting the relatively regular wave stirring and current mixing in these areas.

Habitat Zone 7 (Figures 2, 3; Table 2) encompassed ebb delta shoals and the seafloor of the barrier island shoreface. These sandy environments (> 95 percent sand) have low density, low diversity foraminiferal populations dominated by *Elphidium excavatum* and *Elphidium mexicanum*. The ebb deltas are one of the most dynamic areas of the coastal region where the seafloor continuously responds to wave and tidal current forces. The surface of the delta is generally rough with numerous bedforms that migrate in response to reversing tidal currents in an inlet jet field. Wave currents are the major agents of sediment transport in the farfield of the jet,

Table 3. *Results of stepwise regression analysis showing the relationship between the significant environmental variables and densities of the five most frequently occurring living species at the 95% level (probabilities of F-ratio (P) < 0.055).*

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

and tidal currents are the major agents of transport in the nearfield of the jet. The high energy environment of the shoreface also results in a highly mobile sandy substratum. These conditions are harsh for foraminifera and result in the very sparse population dominated by two species.

Influence of Environmental Variables

The five most frequently occurring species were *Ammobaculites exiguus, Ammonia beccarii, Elphidium excavatum, Haynesina germanica* and *Miliammina fusca.* The results of stepwise regression analysis of the relationship between the significant environmental variables and the densities of the five species at the 95% level ($P < 0.05$) are shown in Table 3.

Two species, *Elphidium excavatum* and *Haynesina germanica,* correlate with a specific environmental variable. The percentage of organic matter in the sediment was significantly correlated with *Elphidium excavatum,* whereas mean-grain size was significantly correlated with *Haynesina germanica. Elphidium excavatum* generally occurred in high densities (3–17 specimens/cm^3) at tidal flats consisting of fine sandy sediment with low percentages of organic matter (about 0.1–0.5%). This species occurred in lower densities at marshes characterised by mud with a moderate percentage of organic matter (> 1%).

Haynesina germanica occurred in maximum densities (2 specimens/cm^3) at the inner protected fringe marsh (station 23) where the mean grain size was very fine silt (Mz = 7.6 phi). However, this species also occurred in lower densities (0.3–0.6 specimens/cm^3) 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 two to three environmental variables (Table 3). Bulk density of the sediment appeared to be a significant environmental variable influencing all three species. Sediment bulk density and percent sand show a strong relationship with *Ammobaculites exiguus. Ammobaculites exiguus* had maximum density (4 specimens/cm^3) at a backbarrier fringe marsh (station 35) which was characterised by low sediment-bulk density (0.52 g/cm^3) and moderately high percentage of sand (65%). Water depth, sediment bulk density and salinity show a strong relationship with *Ammonia beccarii. Ammonia beccarii* occurred in high densities (20–34 specimen/cm^3) in a restricted tidal bay (stations 4 and 6), which was 30 cm below mean sea level and was composed of soft sediment with low bulk densities (0.4–0.6 g/cm^3) and normal lagoon salinities (≈ 31 ppt). Sediment bulk density, percent silt and salinity show a strong relationship with *Miliammina fusca.* Mainland and backbarrier fringe marshes (stations 28, 33 and 35) had high densities of living *Miliammina fusca* (1–2 specimens/cm^3). These stations were characterised by normal salinities (32–33 ppt) and low sediment bulk densities (0.38–0.67 g/cm^3).

DISCUSSION

Foraminifera have a fundamental role in the trophic structure of planktic and shallow to deep benthic marine communities and can be used to assess primary stresses affecting environmental quality. Coastal barrier lagoons provide habitats for abundant and diverse benthic foraminiferal faunas and changes in community composition can, therefore, provide an evaluation tool for the environmental health of these regions. This research has attempted to provide a baseline, at a relatively pristine locality, for future assessment of environmental quality including identification of some of the natural variations in community composition so they will not be confused with any future anthropogenic change.

The lagoons contain a mosaic of different foraminiferal communities controlled by the physical and geochemical characteristics of each habitat zone. Initially, 20 different subenvironments were identified within the coastal lagoon and we considered the possibility of 20 different foraminiferal communities associated with the subenvironments. However, while the foraminifera were quite sensitive to different combinations of physical and geochemical characteristics, only seven different communities and habitat zones could be distinguished.

The seven habitat zones and associated foraminiferal communities (Figure 2.3; Tables 1, 2) are discriminated on the basis of the associations of characteristic dominant species. The most abundant 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 it was absent in the shoreface. *Elphidium excavatum* was dominant in the outer part of the lagoon and outside of the inlet and decreased in importance toward the inner part of the lagoon. The ebb delta and shoreface were characterised by a sparse living community probably as a result of the high-wave turbulence and tidal currents that sweep these areas. *Elphidium excavatum* and *Elphidium mexicanum* were the dominant taxa in these areas.

Generally, the faunas of normal salinity marshes were characterized by the calcareous *Ammonia beccarii* and various agglutinated species. *Trochammina inflata, Miliammina fusca, Ammobaculites exiguus, Trochammina "squamata"* and *Arenoparrella mexicana* were restricted to marsh subenvironments. Hyposaline marshes (less than 10 ppt) were characterised by distinctive totally agglutinated populations. *Quin-*

quloculina seminula was generally restricted to the distinctive washover fan habitat zone.

CONCLUSIONS

Although it is possible to define 20 subenvironments in the barrier island-lagoon system of Virginia on the basis of landscape characterization, only seven groups of subenvironments are recognised on the basis of the benthic foraminiferal populations. These habitat zones contain distinctive cooccurrences of abundant species even though several of these species are abundant in several habitat zones. Because the study area has been little affected by human activity, the foraminiferal distributions described herein provide a baseline for future environmental monitoring that will be necessary as the region is developed.

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