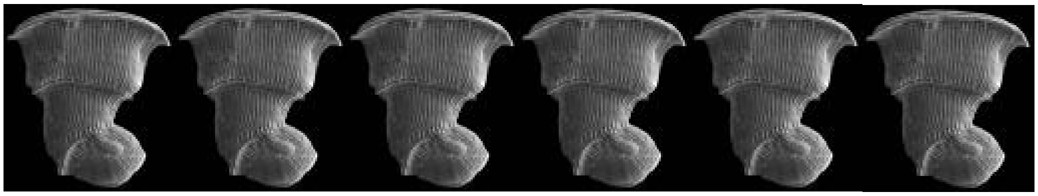

Modern Benthic Foraminifer Distributions in Biscayne Bay: Analogs for Historical Reconstructions

by

Scott E. Ishman, Ian Graham and Jill D'Ambrosio

U.S. Geological Survey, Reston, VA

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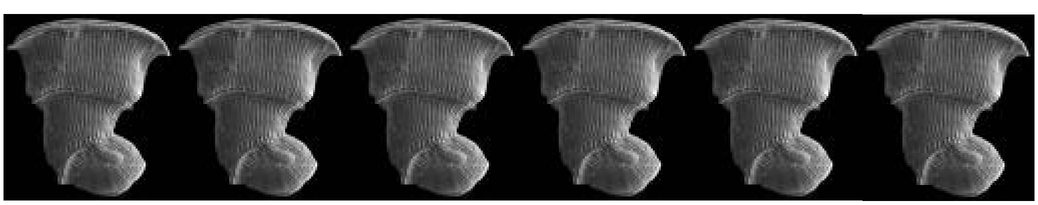

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Introduction

The ecosystems in the Everglades and adjacent regions (Florida and Biscayne Bays) are showing increasing signs of stress: natural vegetation patterns are changing, fisheries are declining, and industrial pollution is increasing. In response to this, the Everglades Forever Act was passed in 1994, and Federal, State, and local jurisdictions are faced with water and land-use management decisions related to the restoration, mediation and monitoring of the South Florida ecosystem. To help make these decisions, the U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), National Park Service (NPS), and Army Corps of Engineers (ACOE), among others, have initiated research programs focused on the restoration of a significant portion of the Everglades ecosystem. An integral part of the restoration effort is a comprehensive understanding of the ecosystem dynamics of South Florida, including evaluation of modern biotic distributions within the South Florida ecosystems and determination of natural versus human-induced variability in the South Florida ecosystem.

The ecosystem of Biscayne Bay includes marginal fresh water and salt water wetlands, intertidal, and off-shore marine communities, many of which are also present in Florida Bay. The health of each of these communities can be linked to the hydrologic regime of South Florida. Major factors that may affect these communities include alteration of fresh-water flow into Biscayne Bay (surface and ground); urbanization of Dade County with resulting increased storm runoff; natural and artificial changes to vegetation; and natural disasters, including hurricanes and prolonged dry and wet seasons. Many of these factors affect not only Biscayne Bay, but the Everglades and Florida Bay as well. In order to understand fully the effect that these, and other conditions may have had on the evolution of the Biscayne Bay and the entire South Florida ecosystem, a thorough understanding of the modern ecosystem is essential.

Benthic foraminifera from marine sediment records have long been used for paleoenvironmental reconstructions. However, a comprehensive understanding of modern foraminiferal distributions is necessary in order to make inferences on past environmental conditions. During August 1996, surficial sediment samples and water column data were collected from 23 sites within Biscayne Bay. The results presented here represent the initial report on benthic foraminiferal distributions in Biscayne Bay sediment samples. This report is produced by the Ecosystem History of South Florida component of the USGS's Ecosystem Program, and is one of a series of U.S. Geological Survey Open-File Reports on the ecosystem history of the South Florida region (Wingard and others, 1995; Brewster-Wingard and others, 1997; Ishman and others, 1996).

Acknowledgments

We would like to acknowledge Sue Kim and Tricia Stone, Metro-Dade Department of Environmental Resources Management, for their logistical support on Biscayne Bay, and Biscayne National Park for providing us with the permits to collect samples within the Park. Thanks are givento William Orem and G. Lynn Brewster-Wingard for their thoughtful and helpful comments on the manuscript. Additional thanks goes to Neil Waibel who assisted in the collection of the modern samples.

Setting

Biscayne Bay can be divided up into three regions, Northern, Central and Southern Biscayne Bay (South Florida Water Management District, 1994) (Fig. 1).

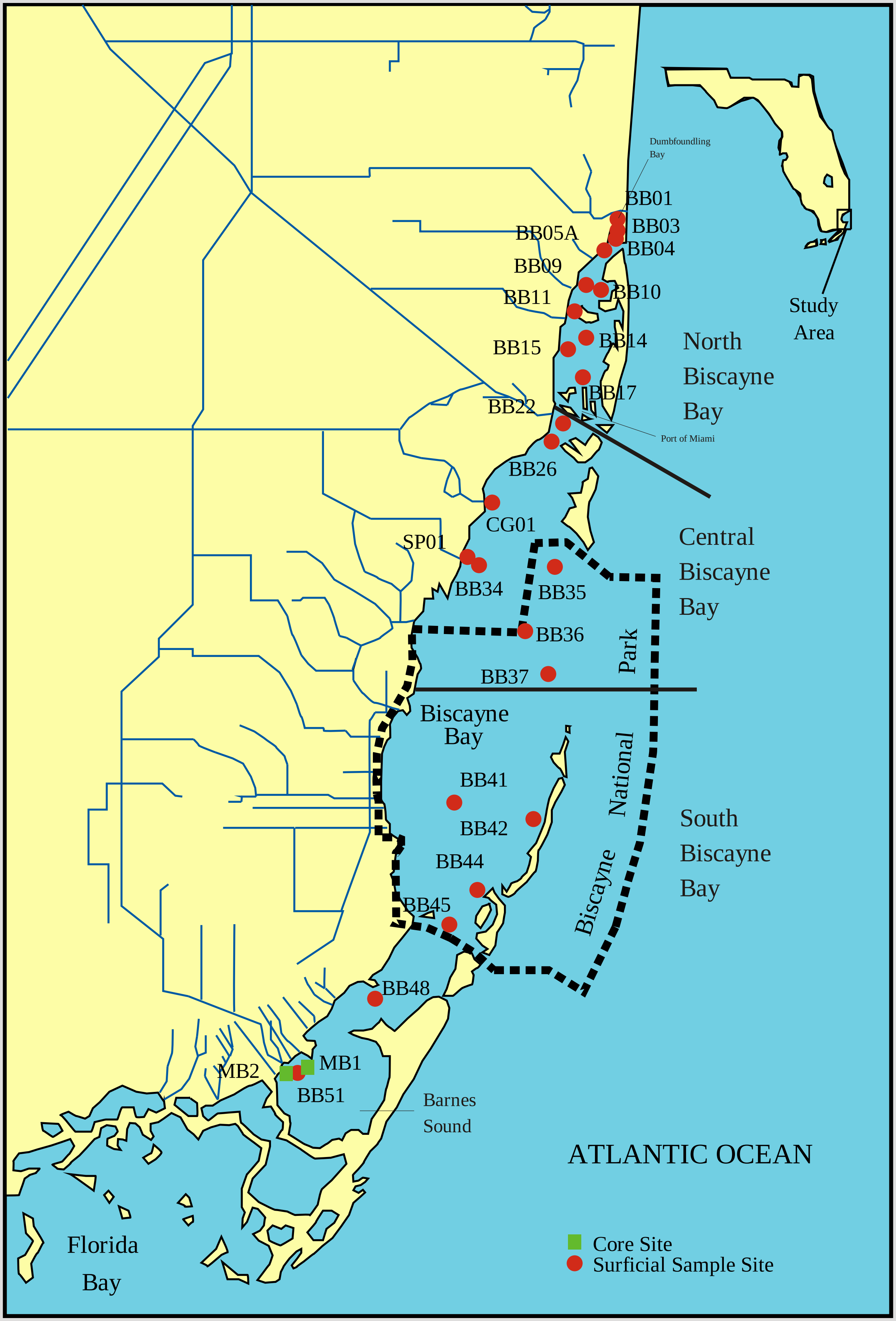

Figure 1: Location map showing surface sediment sample sites within Biscayne Bay.

Northern Biscayne Bay is fairly restricted and extends from Dumbfoundling Bay south to, and including the Port of Miami. The major sediment types within the Northern Bay are quartz and clastic sands (Wanless, 1976) that support hardbottom and bare-bottom benthic communities (SFWMD, 1994). Salinities at sites sampled ranged from 31.1 to 35.2 parts per thousand (ppt) in the Northern Bay (Fig. 2; Table 1). This region of Biscayne Bay has been impacted profoundly by urbanization and development of both the coastal region and waterways. Major coastal development has increased surface and storm runoff and destroyed the natural coastal vegetation patterns. Freshwater and saltwater budgets to Northern Biscayne Bay have been altered with the construction of canals and inlets, respectively. Considerable dredging has destroyed benthic communities, increased turbidity and changed the morphology of the Bay basin. The natural circulation has been disrupted within Northern Biscayne Bay by the construction of the major causeways.

Central Biscayne Bay represents the transition zone between the heavily impacted Northern Biscayne Bay and Southern Biscayne Bay, and includes the northern portion of Biscayne National Park. Four primary benthic communities, bare bottom, hardbottom, seagrass with a hardbottom matrix and seagrass communities (SFWMD, 1994), occur in the Central Bay. These are supported on substrates including calcareous and quartz sands, calcareous mud, and organic-rich muds. Salinities at sites sampled within Central Bay ranged from 32.0 to 37.4 ppt. in the open bay and 29.5 ppt at the discharge of Snapper Creek Canal, site SP01(Figs. 1, 2; Table 1). The northern part of Central Biscayne Bay is strongly influenced by the Miami River, which accounts for the high turbidity, high nutrient, and high pollutant levels in this region of the Central Bay. Further south, Snapper Creek, Coral Gables Waterway and Cutler Drain have been identified as pollutant point sources. However, flushing of these regions occurs on a regular basis due to Government and Norris Cuts. The southern part of Central Bay is increasingly pristine and includes Biscayne National Park. Significant impacts to the ecosystem in this region are localized, many related to watercraft use such as sewage and solid waste, fuel leakage and spillage, and propeller scouring of seagrass beds.

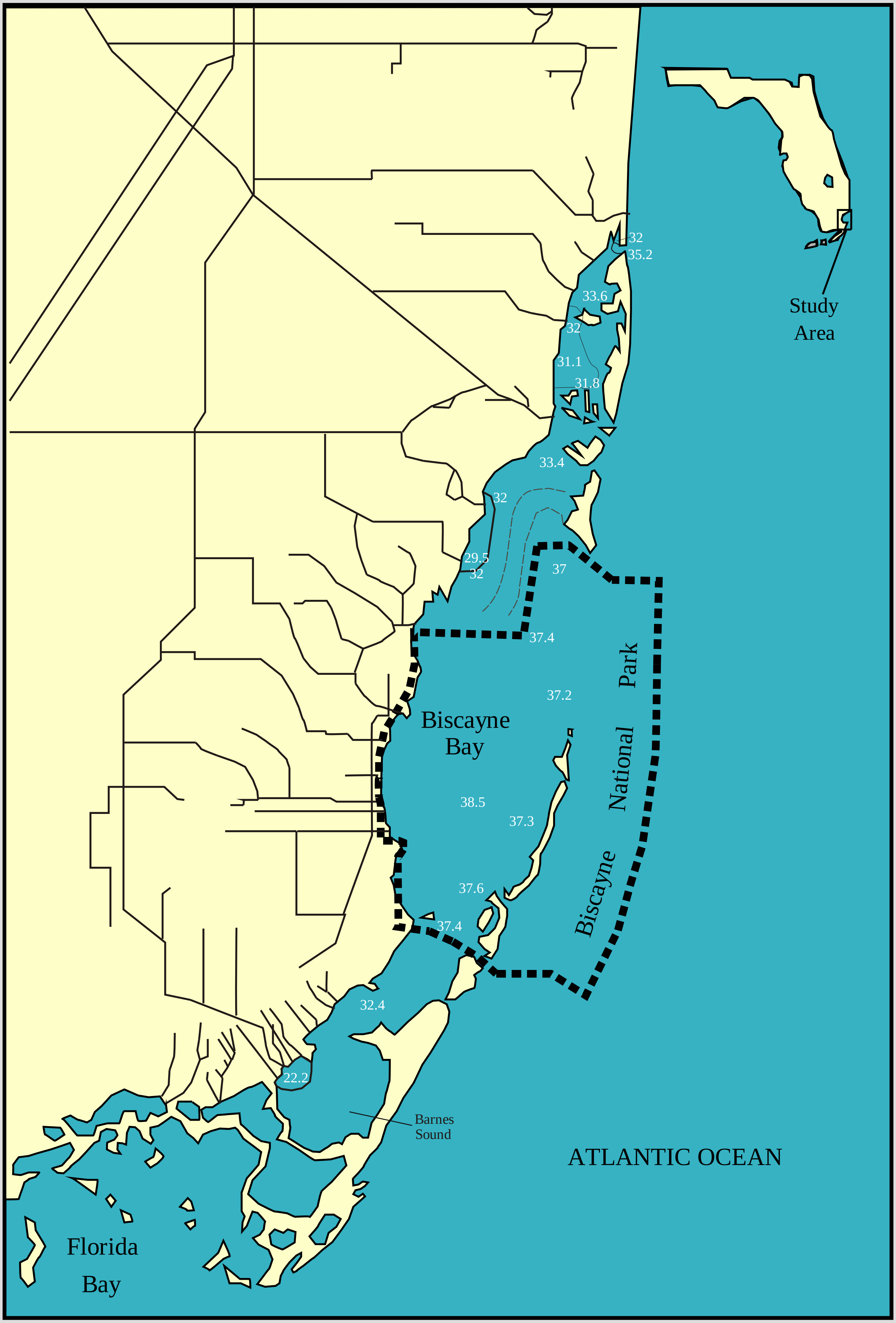

Figure 2: Map showing bottom water salinity values collected in August 1996 used as control points throughout Biscayne Bay.

Southern Biscayne Bay includes the southern portion of Biscayne National Park and the northern part of the Florida Keys National Marine Sanctuary (Barnes and Card Sounds). Sediments in Southern Bay include non-tidal mud banks, calcareous mud, and sands (Wanless, 1976), and support seagrass and seagrass with hardbottom matrix communities (SFWMD, 1994). Salinities at sites sampled ranged from between 38.5 and 37.3 ppt. north of Card Sound, to as low as 22.2 ppt. in Barnes Sound (Fig. 2; Table 1). Although not as severely affected by urbanization as the Northern and Central Bay, Southern Biscayne Bay is impacted by channelized fresh water input and nutrient enrichment from the canal systems. In addition, Card and Barnes Sounds are very restricted, thus reducing their flushing cycles. Other factors that influence the ecosystem of Southern Biscayne Bay are pollutants from adjacent landfills and propeller scour in shallow regions.

An additional consideration with respect to the Biscayne Bay ecosystem is the impact of ground water. Ground water seepage at the coastal margins and from subsurface springs has been noted historically (Kohout and Kolipinski, 1967). This acts as an additional source of fresh water, but also may provide an additional source of contaminants by pollutant enriched ground water.

The factors listed above are the primary controls on the distribution of organisms whose balance creates the ecosystem of Biscayne Bay. The identification of the factors significant in controlling the distributions of the Bay's biogenic components is critical for our interpretation and understanding of the evolution of the Biscayne Bay ecosystem.

Methods

A total of 23 sampling sites (Figure 1; Table 1) within Biscayne Bay were sampled for surficial sediments and water quality using an Eckman Grab sampler and Hydrolab Surveyor, respectively. A grab sample collected from this region typically represents accumulation of the past 5 years or less (based on accumulation rates on the order of 1 cm/yr.), however, in regions where sediment thickness is very thin (see Wanless, 1976) the age of the surface sediments are undetermined. The sediment samples were recorded, packaged and shipped to the USGS, Reston, Virginia, for processing. The bottom water quality data (temperature, salinity, dissolved oxygen, redox potential and clarity) were hand recorded, as well as stored electronically for later downloading. The surficial sediment samples were processed for biogenic analyses by washing them through a 63µm sieve. The ≥63µm residue was then dried (at <50°C) and analyzed for foraminifers. Each sample was picked for a minimum of 250 identifiable specimens. The specimens were identified, based on Loeblich and Tappan (1988), and counted. The data were standardized by converting the counts to relative abundance (Table 1), on which any further statistical analyses will be applied.

Results

A total of 69 taxa of benthic foraminifers common to the North American southeast coast and Gulf of Mexico were identified from the Biscayne Bay modern sediment samples (Table 1). Species diversity, as measured using Simpson's index (Simpson, 1949), ranged from .080 to .493 (the closer the diversity index is to 1 the greater the species dominance). The foraminiferal assemblages are dominated by calcareous forms with agglutinated taxa constituting a minor component in most of the assemblages. Species dominance varies considerably throughout the Bay with *Ammonia parkinsoniana* forms *typica* and *tepida* and *Elphidium galvestonense mexicanum* constituting over 50% of the assemblage in restricted regions of Biscayne Bay. Conversely, *Archaias angulatus* is dominant (up to 45%) in samples collected from the open regions of Biscayne Bay. Other calcareous hyaline forms include *Bolivina* spp., *Elphidium delicatulum*, *Rosalina floridana* and *R. globularis*. Common miliolids include *Articulina mucronata*, *Miliolinella circularis, M. labiosa*, *Peneroplis proteus*, *Pyrgo subsphaerica, Quinqueloculina agglutinans, Q. bosciana, Q. poeyana, Q. polygona, Q. seminulum, Q. tenagos* and *Triloculina tricarinata*. Agglutinated taxa in Biscayne Bay include *Ammobaculites* sp., *Clavulina* sp., *Pseudoclavulina gracilis, Textularia candeiana, T. conica,* and *Trochammina* spp.

Discussion

Preliminary analysis of the benthic foraminiferal distributions within Biscayne Bay suggest the presence of three distinct assemblages; an *Ammonia-Elphidium* assemblage, an *Archaias*-miliolid assemblage, and a Bolivinid assemblage (Fig. 3). These assemblages can be fairly restricted within Biscayne Bay and appear to be controlled by several factors.

Ammonia-Elphidium assemblage

The *Ammonia-Elphidium* assemblage (*A-E* assemblage) is dominated by *Ammonia parkinsoniana* formas *tepida* and *typica* and *Elphidium galvestonense* forms *mexicanum* and *typicum*, composing greater than 50% of the assemblage. The A-E assemblage typically represents a high dominance assemblage with a diversity index >0.20. This assemblage is predominant in Northern Biscayne Bay, Barnes Sound and adjacent freshwater discharge points (site SP01 at Snapper Creek Canal) (Fig. 3). These regions typically display the lowest salinities (<34 ppt.) within the Bay (Fig. 2). Exceptions to this are samples BB04, represented by the *Archaias*-miliolid assemblage and the salinity is 35 ppt. (Fig. 2), and BB02 represented by the Bolivinid assemblage (Fig. 3). The *A-E* assemblage is also present in Florida Bay, where its occurrence is restricted to regions of low (<25 ppt) but highly variable salinities (Brewster-Wingard and others, 1997). The distribution of the *A-E* assemblage is similar to the distribution of the *Ammonia - Elphidium* predominance facies described from the Gulf of Mexico (Poag, 1981), where it is typically found in estuarine and lagoonal environments.

Archaias - miliolid assemblage

The *Archaias*-miliolid assemblage (*A*-m assemblage) is dominated (>20%) by *Archaias angulatus* and a variety of miliolid forms (mostly *Quinqueloculina* spp.). Other important taxa in the *A*-m assemblage are *Peneroplis proteus, Triloculina tricarinata* and *Miliolinella circularis*. This assemblage is associated with samples collected from the unrestricted, open marine Central and Southern Biscayne Bay (Fig. 3). *A. angulatus* is common to reef environments and therefore normal marine conditions. Within Biscayne Bay the distributions of *A. angulatus, Triloculina tricarinata* and *Miliolinella circularis*

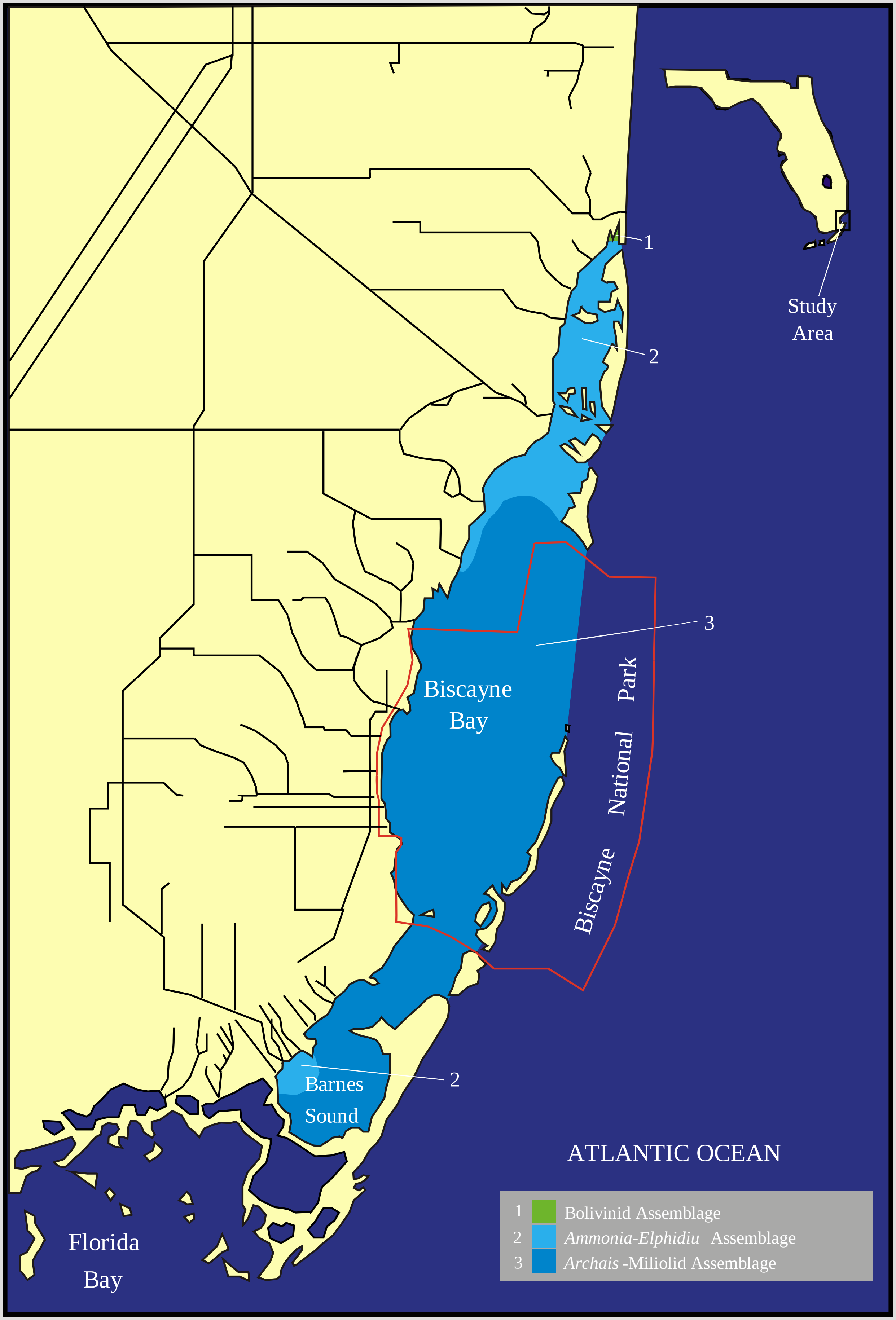

Figure 3: Distribution of the three dominant benthic foraminifer assemblages; *Ammonia-Elphidium* assemblage, *Archais* -Miliolid assemblage, and Bolivinid assemblage throughout Biscayne Bay.

show positive correlations (R>0.60, 0.45 and 0.30 respectively) with salinity greater than 37 ppt. This suggests that the *A*-m assemblage can be associated with a well circulated Biscayne Bay with salinities within the range of normal marine conditions and better water quality (increased water clarity and health and abundance of seagrass).

Bolivinid assemblage

The third assemblage recognized within Biscayne Bay occurs in the northernmost sample collected (Fig. 3), BB02, and will be referred to as the Bolivinid assemblage. This assemblage has a low diversity index (0.114) suggesting low dominance, and a species number (number of species present) of 30, larger than any of the other samples analyzed. The abundance of Bolivinids is highest in this sample. Studies on morphotype and habitat preference of benthic foraminifers indicate that Bolivinids prefer organic-rich sediments (Corliss and Chen, 1988). In addition, this sample includes the presence of *Bulimina marginata* and *Uvigerina* sp. Both of these taxa are common in high productivity, organic rich regions throughout the world (Lutze and Coulbourn, 1984; Mackensen and others, 1993; Ishman and Domack, 1994). Sample BB02 is rich in diatom fragments (*Cheatoceros* spore spines) further corroborating high surface water productivity.

Summary

Surface sediment samples collected from 23 sites within Biscayne Bay were analyzed for benthic foraminifera. A total of 72 taxa were identified and their abundances tabulated and standardized as relative abundance (percent occurrence). Preliminary analysis of the benthic foraminiferal data suggests three dominant benthic foraminiferal assemblages are present within Biscayne Bay: *Ammonia-Elphidium* assemblage, *Archaias*-miliolid assemblage, and Bolivinid assemblage. The *Ammonia-Elphidium* assemblage occurs in restricted environments with relatively low salinities (<35 ppt.) and regions with frequent point-source fresh water input. The *Archaias*-miliolid assemblage is associated with marine salinities (37-38 ppt.), high water clarity and well circulated environments. The Bolivinid assemblage occurs in the northernmost Biscayne Bay and is associated with diatomaceous muds that are rich in organic matter, suggesting high productivity.

Further analyses of the benthic foraminiferal and environmental data are in progress. In addition, the modern sediment samples are being analyzed for molluscs, palynomorphs, ostracodes, diatoms and trace element geochemistry. The sum of these analyses will result in a comprehensive database that will serve as modern analogues for the analysis of the historical evolution of Biscayne Bay.

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Table 1: Location, relative abundance (%) and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

Sample	Latitude (degrees W)	Longitude (degrees N)	Temp (C)	Salinity (ppt)	Dissolved Oxygen	Oxygen Reduction Potential (ORP)	Depth (m)	Simpson's diversity index	*Ammonia parkinsoniana*	*Ammobaculites exiguus*	*Amphistegina lessonii*	*Archaias angulatus*	*Articulina mucronata*	*Astigerina* sp.
North Biscayne Bay														
BB02	25° 56'40	80° 07'40	30.73	32.1	5.82	454	3.6	0.114	9.75	0.31	0.00	0.00	0.00	0.00
BB03	25° 55'44	80° 07'53	30.49	33.5	5.89	470	1.4	0.319	54.43	0.00	0.00	0.00	0.00	0.00
BB04	25° 55'02	80° 07'33	29.92	35.2	5.52	462	4.4	0.148	29.41	1.73	3.81	15.92	0.00	2.42
BB05A	25° 54'04	80° 08'32	30.12	33.5	5.89	401	0.9	0.250	60.17	0.00	0.00	0.00	0.00	0.00
BB09	25° 52'15	80° 09'19	30.50	32.7	5.71	459	1.9	0.399	50.14	0.00	0.00	0.00	0.00	0.00
BB10	25° 52'09	80° 08'38	30.22	33.6	6.21	460	2.2	0.170	34.08	0.00	0.00	2.24	1.79	0.00
BB11	25° 50'46	80° 10'01	30.31	32.0	5.60	450	1.5	0.388	49.58	0.00	0.00	0.00	0.85	0.00
BB14	25° 49'46	80° 09'31	29.37	32.4	4.54	433	0.6	0.347	46.39	0.00	0.00	0.00	1.88	0.00
BB15	25° 48'52	80° 10'31	29.90	31.1	3.74	461	3.2	0.493	65.26	0.60	0.00	0.00	0.00	0.00
BB17	25° 48'08	80° 09'58	29.96	31.8	6.00	440	0.9	0.348	52.15	0.00	0.00	0.33	0.99	0.00
Central Biscayne Bay														
BB22	25° 45'21	80° 10'28	30.00	33.8	5.60	458	1.9	0.222	42.28	0.00	0.00	0.00	1.68	0.00
BB26	25° 44'50	80° 11'06	29.87	33.4	5.55	473	2.0	0.128	36.33	0.96	0.00	0.00	0.64	0.00
BB34	25° 39'03	80° 15'33	30.25	32.0	4.34	419	2.1	0.113	0.00	0.00	0.00	12.58	3.23	0.00
BB35	25° 38'37	80° 11'30	30.01	37.0	5.71	449	1.7	0.080	4.69	0.00	0.00	12.64	2.17	1.08
BB36	25° 35'58	80° 14'11	29.90	37.4	5.82	439	2.3	0.153	0.00	0.00	0.00	32.23	0.66	0.00
BB37	25° 34'13	80° 11'31	29.54	37.2	5.56	451	1.8	0.079	0.00	0.00	0.00	18.18	4.17	0.00
South Biscayne Bay														
BB41	25° 28'20	80° 17'04	29.76	38.5	6.04	310	2.1	0.124	0.27	0.00	0.00	26.08	0.27	0.00
BB42	25° 27'23	80° 11'59	29.19	37.3	5.63	455	1.3	0.236	0.00	0.00	0.00	45.23	0.00	0.00
BB44	25° 24'02	80° 15'20	29.67	37.6	5.53	448	2.1	0.147	0.33	0.00	0.00	32.89	1.00	0.00
BB45	25° 22'09	80° 16'48	29.60	37.4	5.37	458	2.4	0.107	0.00	0.00	0.00	20.86	1.71	0.00
BB48	25° 18'29	80° 20'56	29.37	32.4	5.38	415	2.6	0.144	0.95	0.00	0.00	1.59	4.76	0.00
BB51	25° 15'04	80° 24'51	29.72	22.2	7.11	444	1.5	0.258	25.00	0.00	0.00	0.00	0.82	0.00
SP01	25° 39'28	80° 16'06	30.25	29.5	4.18	393	3.1	0.226	50.48	0.00	0.00	0.00	0.00	0.63

Table 1: Location, relative abundance (%) and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

Sample	*Astrononion stellatum*	*Bolivina lowmani*	*Bolivina pseudoplicata*	*Bolivina pseudopunctata*	*Bolivina* sp.	*Bolivina striatula*	*Bulimina marginata*	*Bulimina striata*	*Buliminella elegantissima*	*Cassidulina* sp.	*Cibicides* sp.	*Clavulina tricarinata*	*Cribrostomoides* sp.	*Cyclogyra planorbis*	*Discorbis mira*	*Elphidium* cf. *advenum*
North Biscayne Bay																
BB02	0.00	0.31	0.94	5.66	0.00	4.09	1.89	0.00	1.57	0.00	0.63	0.00	0.00	1.26	4.72	0.00
BB03	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	3.80
BB04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.38	0.35
BB05A	10.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB09	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB10	0.00	0.00	0.45	0.90	0.00	0.45	0.00	0.00	0.45	1.35	0.00	0.00	0.00	0.00	4.48	0.00
BB11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB14	0.00	0.00	0.00	0.00	0.00	1.25	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Central Biscayne Bay																
BB22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00
BB26	0.00	1.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00
BB34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00	0.00	2.26
BB35	0.00	0.00	0.00	0.00	0.00	1.81	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.33
BB37	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89	0.00	0.00	0.00	0.38
South Biscayne Bay																
BB41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
BB42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	1.00	0.00
BB45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	1.43
BB48	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63
BB51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP01	0.00	0.32	0.00	0.00	0.32	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 1: Location, relative abundance (%) and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

Sample	*Elphidium delicatulum*	*Elphidium galvesonense typicum*	*Elphidium galvestonense mexicanum*	*Elphidium poeyanum*	*Florilus auriculus*	*Fursenkoina* sp.	*Gaudryina exilis*	*Globocassidulina subglobosa*	*Miliolinella circularis*	*Miliolinella fichteliana*	*Miliolinella labiosa*	*Nodobaculariella* sp.	Nodosariidae	*Nonionella* sp.	*Nubecularia lucifuga*	*Patellina corrugata*
North Biscayne Bay																
BB02	2.52	0.00	0.94	0.00	0.00	2.20	2.83	1.26	1.26	0.00	0.94	0.00	0.94	8.18	0.00	0.31
BB03	0.00	7.28	5.70	0.32	0.95	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB04	0.00	0.00	14.88	0.35	0.35	0.00	0.69	0.00	0.00	0.00	2.08	0.00	0.00	0.00	0.00	0.00
BB05A	0.00	0.00	21.80	0.00	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB09	0.00	0.00	37.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB10	8.07	0.00	0.00	0.45	0.00	0.90	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB11	0.00	0.28	37.18	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB14	0.00	2.19	35.74	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.94	0.00	0.00	0.00	0.00	0.00
BB15	1.81	0.00	25.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.81	0.00	0.00	0.00	0.00	0.00
BB17	0.00	0.00	24.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.56	0.00	0.00	0.00	0.00	0.33
Central Biscayne Bay																
BB22	0.00	6.04	16.11	0.00	0.67	0.00	0.00	0.00	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB26	1.61	9.65	13.18	0.00	2.89	0.32	0.00	0.00	1.61	0.00	0.64	0.00	0.00	0.00	0.00	0.00
BB34	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.65	0.65	1.61	0.00	0.00	0.00	0.00	0.00
BB35	0.00	10.83	1.81	0.00	1.81	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00
BB36	0.00	0.00	2.99	0.00	0.00	0.00	0.00	0.00	2.99	0.00	1.33	0.00	0.00	0.00	0.00	0.00
BB37	0.00	0.00	0.00	1.52	0.00	0.00	0.00	0.00	8.33	0.38	0.00	0.00	0.00	0.00	0.00	0.00
South Biscayne Bay																
BB41	0.00	0.00	2.42	1.08	0.00	0.00	0.00	0.00	11.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB42	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	0.00	0.35	0.00	0.00	0.00	0.00	0.00
BB44	2.33	0.00	1.00	0.66	0.00	0.00	0.00	0.00	3.99	0.00	0.00	0.33	0.00	0.00	0.00	0.00
BB45	8.86	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.57	0.00	0.86	0.00	0.00	0.00	0.00	0.00
BB48	27.30	0.00	3.17	0.00	0.00	0.00	0.00	0.00	13.02	0.00	0.00	0.00	0.00	0.32	0.32	0.00
BB51	0.00	0.00	41.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00
SP01	0.00	25.71	1.27	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 1: Location, relative abundance (%) and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

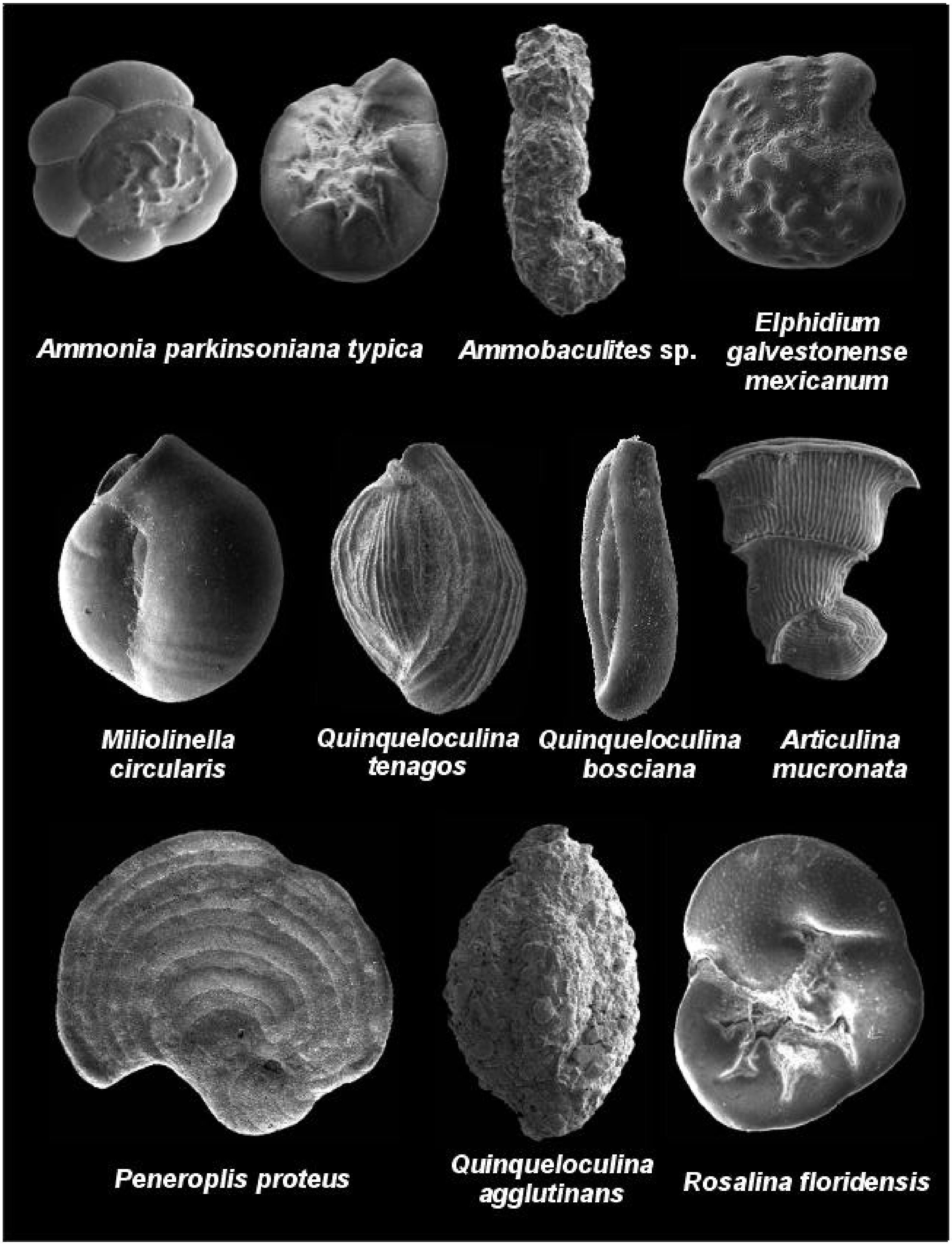
Sample	*Peneroplis proteus*	Planktonic	*Pseudoclavelina gracilis*	*Pyrgo denticulata*	*Pyrgo serrata*	*Pyrgo subsphaerica*	*Quinqueloculina agglutinans*	*Quinqueloculina bosciana*	*Quinqueloculina poeyana*	*Quinqueloculina polygona*	*Quinqueloculina seminula*	*Quinqueloculina subpoeyana*	*Quinqueloculina tenagos*	*Rectobolivina advena*	*Recurvoides* sp.	*Rosalina floridana*
North Biscayne Bay																
BB02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.72	1.26	0.00	27.67	0.00	0.00	0.00	0.00	9.75
BB03	0.00	0.63	0.00	0.00	0.00	0.32	0.00	0.63	0.63	0.63	4.11	0.00	6.96	0.32	0.32	2.22
BB04	0.00	0.00	0.00	0.00	0.00	2.77	3.11	1.73	0.35	2.08	0.69	0.00	1.73	0.00	0.00	2.08
BB05A	0.00	0.00	0.00	0.00	0.00	2.03	0.29	1.45	0.87	0.00	1.45	0.00	0.58	0.00	0.00	0.00
BB09	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.29	1.45	0.29	2.32	0.00	1.45	0.00	0.00	0.29
BB10	0.45	0.00	0.00	0.00	0.00	0.00	1.35	5.38	2.24	0.90	17.94	0.00	4.48	0.00	0.00	6.73
BB11	0.00	0.00	0.00	0.00	0.00	0.28	0.85	0.00	0.00	0.00	0.85	0.00	3.94	0.00	0.00	0.00
BB14	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.31	3.45	0.00	4.39	0.00	0.00	0.63
BB15	0.00	0.00	0.00	0.00	0.00	0.30	0.91	0.00	1.21	0.00	1.81	0.00	0.30	0.00	0.00	0.00
BB17	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.33	0.66	0.00	0.00	0.00	2.97	0.00	0.00	0.00
Central Biscayne Bay																
BB22	1.68	0.00	0.00	0.00	0.00	4.03	2.35	5.70	1.34	0.00	7.38	0.00	1.34	0.00	0.00	2.35
BB26	0.32	0.32	0.00	0.00	0.32	1.29	0.64	6.11	4.18	3.22	6.43	0.00	0.32	0.00	0.00	1.61
BB34	0.00	0.00	0.00	2.26	0.00	6.13	3.87	1.61	3.87	3.87	0.00	0.00	8.71	0.00	0.00	20.97
BB35	0.00	0.00	0.00	0.00	0.00	0.72	6.14	9.03	8.66	5.05	7.58	0.00	0.36	0.00	0.00	6.50
BB36	2.66	0.00	0.00	0.00	0.33	0.33	2.99	3.32	10.63	7.97	13.62	0.00	1.00	0.00	0.00	1.99
BB37	7.58	0.00	1.52	0.38	0.76	0.76	3.41	3.41	3.03	3.79	0.76	1.89	9.09	0.00	0.00	9.47
South Biscayne Bay																
BB41	1.61	0.00	0.00	0.27	0.00	2.15	2.69	4.03	5.38	8.06	8.87	0.00	1.88	0.00	0.00	4.57
BB42	8.13	0.00	0.00	0.00	0.35	2.83	8.48	2.83	2.83	4.59	8.13	0.00	2.12	0.00	0.00	2.12
BB44	1.00	0.00	0.00	0.33	0.00	1.99	6.31	5.32	6.31	3.65	4.65	0.00	2.33	0.00	0.00	2.33
BB45	2.00	0.00	0.00	0.00	0.00	3.43	2.00	7.43	6.86	6.86	5.71	0.00	2.29	0.00	0.00	3.71
BB48	0.32	0.00	0.00	0.63	0.00	0.32	0.63	18.41	8.89	2.54	2.54	0.00	0.32	0.00	0.00	5.71
BB51	0.00	0.00	0.00	0.00	0.00	1.23	4.51	0.00	7.79	2.46	10.25	0.00	0.00	0.00	0.00	2.87
SP01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	13.02	0.00	0.95	0.00	0.00	2.54

Table 1: Location, relative abundance (%) and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

Sample	*Rosalina globularis*	*Sorites marginalis*	*Spiroloculina antillarium*	*Spiroloculina* sp.	*Stainforthia complanata*	*Textularia candeiana*	*Textularia conica*	*Triloculina lineiana*	*Triloculina planciana*	*Triloculina rotunda*	*Triloculina trilocullina*	*Trochammina inflata*	*Trochammina* sp.	*Trochammina squamata*	Unidentified
North Biscayne Bay															
BB02	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	2.20	0.00	0.00	0.00	0.00
BB03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	6.96	0.00	0.00	0.00
BB04	0.00	0.00	0.00	0.00	0.00	2.77	0.00	0.35	0.00	0.69	8.30	0.00	0.00	0.00	0.00
BB05A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.22	0.00	0.00	0.00	0.00
BB10	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.45	3.59	0.00	0.00	0.00	0.00
BB11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	3.94	0.00	0.00	0.00	0.00
BB14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.63	0.00	0.00	0.00	0.00
BB15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00
BB17	1.32	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.62	0.00	0.00	0.00	0.00
Central Biscayne Bay															
BB22	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.67	0.00	1.34	2.68	0.00	0.00	0.00	0.00
BB26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.50	0.00	0.00	0.00	0.00
BB34	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.65	0.00	0.00	16.13	0.00	0.00	0.00	0.00
BB35	0.00	0.36	0.00	0.00	0.72	0.00	0.72	1.08	1.44	1.08	12.64	0.00	0.00	0.00	0.00
BB36	0.00	0.33	0.00	0.66	0.00	0.00	0.66	0.33	0.00	0.66	8.64	0.00	0.00	0.00	0.00
BB37	0.00	0.76	1.89	1.14	0.00	0.00	3.79	7.20	1.89	1.14	1.14	0.00	0.00	0.00	0.00
South Biscayne Bay															
BB41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	12.90	0.00	0.27	0.00	0.00
BB42	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	1.06	0.00	0.00	0.00	0.00
BB44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	2.33	12.96	0.00	0.00	0.00	0.33
BB45	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	17.71	0.00	0.00	0.00	0.00
BB48	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.00	0.00	2.86	3.49	0.00	0.00	0.00	0.00
BB51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.00	0.00	0.00	0.00
SP01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	0.00	0.32	0.00

Table 1: Location, relative abundance (%) and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

Sample	*Uvigerina* sp.	*Valvulina* sp.	*Valvulineria laevigata*	*Wiesnerella* sp.
North Biscayne Bay				
BB02	0.94	0.00	0.00	0.63
BB03	0.00	0.00	0.00	0.00
BB04	0.00	0.00	0.00	0.00
BB05A	0.00	0.00	0.00	0.00
BB09	0.00	0.00	0.00	0.00
BB10	0.00	0.00	0.00	0.00
BB11	0.00	0.00	0.00	0.00
BB14	0.00	0.00	0.00	0.00
BB15	0.00	0.00	0.00	0.00
BB17	0.00	0.00	0.00	0.00
Central Biscayne Bay				
BB22	0.00	0.00	0.00	0.00
BB26	0.00	0.00	0.00	0.64
BB34	0.00	9.35	0.00	0.00
BB35	0.00	0.00	0.00	0.00
BB36	0.00	1.00	0.00	1.33
BB37	0.00	0.00	0.00	0.00
South Biscayne Bay				
BB41	0.00	4.84	0.00	0.00
BB42	0.00	7.42	0.00	0.00
BB44	0.00	5.32	0.00	0.33
BB45	0.00	1.14	0.00	0.00
BB48	0.00	0.00	0.00	0.00
BB51	0.00	0.41	0.00	0.00
SP01	0.00	0.00	1.59	0.00



Appendix 1: Scanning electronmicrographs of commonly occurring benthic foraminifera in Biscayne Bay. *Ammonia parkinsoniana typica* (x42), *Ammonbaculites* sp. (x63), *Elphidium galvestonense mexicanum* (x46) *Miliolinella circularis* (x72), *Quinqueloculina tenagos* (x42), *Quinqueloculina bosciana* (x41), *Articulina mucronata* (x38), *Peneroplis proteus* (x20), *Quinqueloculina agglutinans* (x30), *Rosalina floridensis* (x55)