DISTRIBUTION AND DIVERSITY OF BENTHIC FORAMINIFERA WITHIN THE NEARSHORE RIDGE COMPLEX OFF POMPANO BEACH, BROWARD COUNTY, FLORIDA

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Anton Oleinik, Department of Geosciences, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

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Title: Distribution and Diversity of Benthic Foraminifera Within the Nearshore Ridge Complex off Pompano Beach, Broward County, Florida.

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Benthic foraminifera are exceptional organisms with distinctive features that allow for interpretation of both past and present environmental conditions. Some benthic foraminifera are widely distributed while some are restricted to specific environments due to their way of life. Foraminiferal assemblages south of Biscayne Bay and north of Cape Canaveral have previously been investigated; however, a gap exists in data covering a transitional zone along the Florida coast between the tropical waters of the western Atlantic and the cooler coastal waters along the North American coast. The purpose of this study was to collect baseline data on the benthic foraminifera of the small marine environment off of Pompano Beach that falls within this zone. This environment has a very particular relict reef system that includes a near-shore ridge complex, the unique foraminiferal assemblage of which has not been documented. Thirteen rubble samples were collected from this near shore ridge complex between October 2013 and

April 2015 from depths of 2.5m – 9m. Abundances and diversity indices were calculated, and multivariate analysis and SHEBI analysis carried out to summarize baseline data for the area. Substrate types and seasonal collections were compared with foraminiferal abundances to determine if benthic foraminifera diversity varied between the four substrate types found on the near-shore ridge and between wet and dry seasons in Florida. Results revealed a variation in abundances for both substrates and seasons with the dominant genera being *Quinqueloculina, Laevipeneroplis,* and *Archaias*. Multivariate analysis displayed dissimilarities between substrates colonized by corals and those that were uncolonized. Comparison of studies from surrounding areas revealed fewer, however similar, species and different dominant genera. Overall, this area has proven to be a different environment compared to surrounding coastal areas and merits further investigation.

Distribution and diversity of Benthic foraminifera within the nearshore Ridge complex off Pompano Beach, Broward County, Florida.

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Introduction

Foraminifera

Foraminifera or “forams” (Lipps *et al.*, 2011) are a clade of single-celled eukaryotes that branches within the more inclusive clade Rhizaria (Nikolaev *et al.,* 2004; Parfrey *et al.,* 2010; Sierra *et al.,* 2013). The most likely sister groups to Foraminifera are Acantharea or Polycistinea (Nikolaev *et al.,* 2004; Parfrey *et al.*, 2010; Sierra *et al.*, 2013). Two diagnostic traits are commonly used to distinguish foraminifera from other rhizarians: granuloreticulose pseudopodia, which are fine strands of granular cytoplasm that branch and merge forming nets (Bowser & Travis, 2002); and an outer covering (test) that can be either organic, calcium carbonate, agglutinated, or rarely silica (Goldstein, 1999). The tests examined in this study were predominantly calcium carbonate (high-Mg calcite or low-Mg calcite) and relatively small, ranging from 0.1mm to 2mm in diameter. Taxonomic identification of foraminifera is generally based on morphological features of the text such as: test wall composition, chamber arrangement, number of chambers, type and location of primary and secondary apertures and aperture tooth plates (Sen Gupta, 1999). However, gene sequencing of living foraminifera is now used to separate some morphologically similar species in the genera *Ammonia* (Hayward *et al.,* 2004), and *Elphidium* (Pillet, *et al.*, 2013).

Benthic foraminifera can live in and around sediments, epiphytically on seagrass or macroalgae, epifaunal attached to marine animals, and attached to non-living hard substrates. Planktonic foraminifera live floating throughout the water column until they die and test settle to the seafloor. The majority of modern foraminiferal species are benthic, with the oldest fossils being Cambrian in age. There are only 40-50 modern planktonic species (Sen Gupta, 1999) with origin events estimated to have occurred in the Oligocene and Miocene (Darling *et al.*, 1997; de Vargas *et al.*, 1997). There are an estimated >10,000 described species of extant foraminifera (Adl *et al.*, 2007) and an estimated ~2140 hard-shelled species of living benthic foraminifera by Murray (2007). Foraminifera are widely distributed and can be found in all of the world oceans from the polar regions of the Arctic and Antarctica to the tropical waters of the Indo-Pacific. Species of planktonic foraminifera are much more widely distributed, while the distribution of benthic foraminifera is more restricted with higher diversities in tropical and subtropical areas. Some benthic species are restricted to the Atlantic Ocean (i.e., *Archaias angulatus* and *Cyclorbiculina compressa),* while others (i.e., *Sorites orbiculus* and *Borelis* spp.) can be found in the Atlantic, Pacific, and Indian Oceans (Langer & Hottinger, 2000).

Foraminifera are an important factor for reef substrates by contributing to the cementation and stability of reefs (Hohenegger, 2006; Hallock, 2000; Yamano *et al.*, 2000; Langer *et al.*, 1997). Langer (2008) estimates that benthic and planktonic foraminifera together produce 1.4 billion tons of calcium carbonate per year accounting for 25% of the present day carbonate production to oceans. Alone benthic foraminifera produce 200 million tons of calcium carbonate with large symbiont-bearing foraminifera contributing 5% of the $CaCO_3$ to reef and shelf areas (Langer, 2008). Living benthic foraminifera can host endosymbionts with rhodophytes, chlorophytes, dinoflaggelates, and diatoms (Lee and Anderson 1991; Hallock 1999). Symbiosis in benthic foraminifera has been hypothesized to be advantageous in three ways: energy from photosynthesis, enhancement of calcification, and uptake of host metabolites by symbiotic algae (Hallock, 1999). Endosymbiosis has also been found to play a role in the evolution and diversification of symbiont-bearing soritacean forams (Richardson, 2001).

In paleoecological research, modern foraminiferal distributions have been used to aid in the understanding of marine environmental changes in both the present and geological past (Sen Gupta, 1999). In near shore ecological studies, symbiont bearing foraminifera have been used as indicators of environmental and anthropogenic changes because of their ease of collection, relatively short life spans, sharing similar water quality requirements with zooxanthellate corals, and narrow environmental ranges due to the symbiotic relationships they share with algae (Hallock *et al.*, 2003). Environmental changes such as increase of temperature, nutrients, wave energy, or UV light have caused physiological stress to symbiont bearing benthic foraminifera, allowing small infaunal species to dominate (Hallock, 1999). Stress-related bleaching in populations of diatom and dinoflagellate bearing foraminifera such as *Amphistegina* and *Sorites* have been associated to increase UV, influx of freshwater, and increased water temperatures (Richardson, 2009; Williams & Hallock, 2004). Local distribution of benthic foraminifera is also affected by these factors along with environmental features. Depth plays a role in distributions, where large benthic foraminifera (LBF) are opportunistic in shallow waters when conditions are favorable (Murray, 2006). Stephenson et al. (2011) measured benthic foraminiferal assemblages in sand and rubble samples and found that substrate type also influences the distribution of benthic foraminifera. For this study, temperature, nutrients, wave energy, light, depth, and substrate type were used to interpret results from surveys of benthic foraminiferal assemblages found on a near-shore ridge complex.

Study Area

The city of Pompano Beach, located in Broward County, Florida, hosts a unique marine environment that has been the focus of previous geomorphological and ecological research (Banks *et al.*, 2007; Banks *et al.*, 2008; Walker, 2012; Walker *et al.*, 2008). Pompano Beach is completely developed with residential housing and businesses running along the beach (Figure 1).

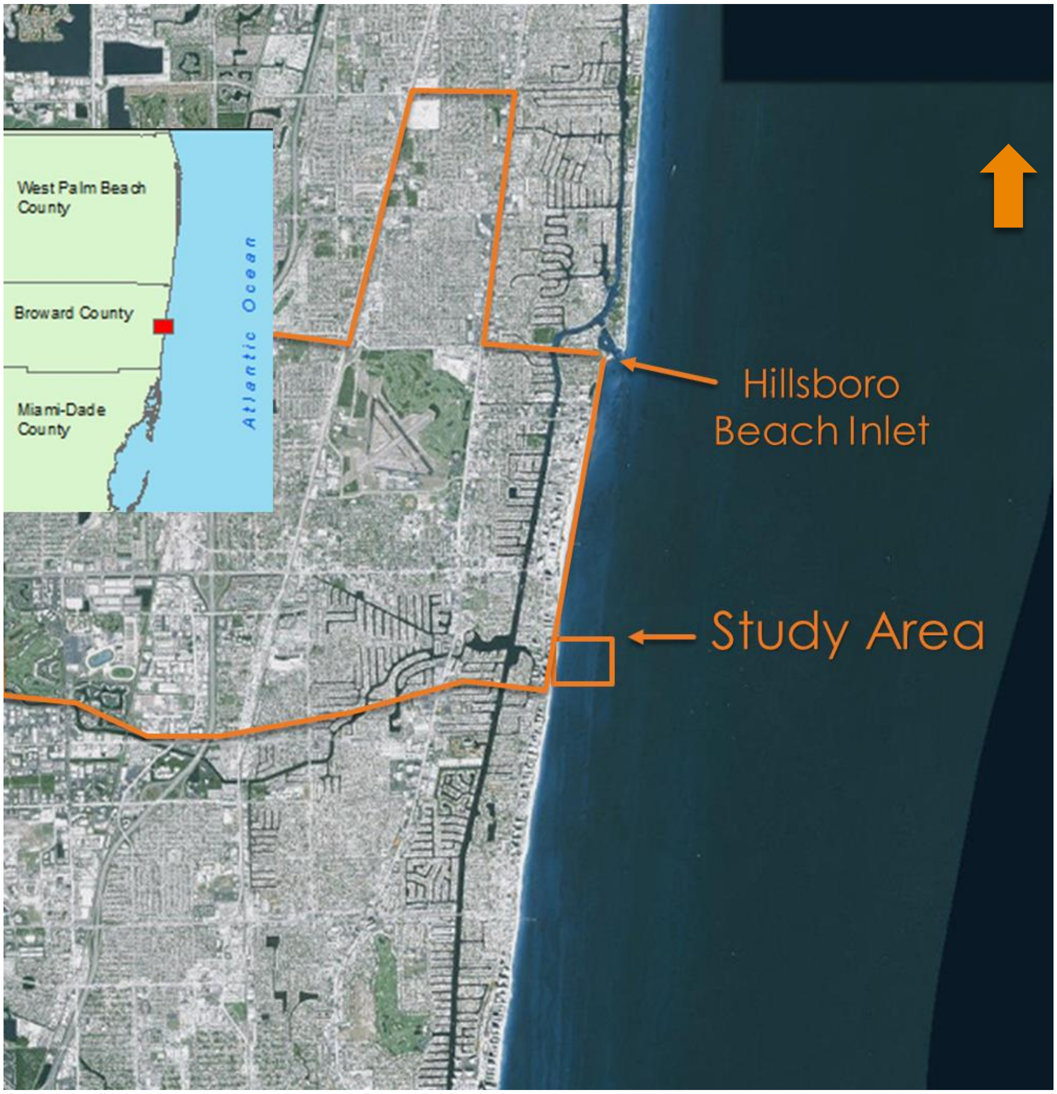

Figure 1: Aerial photograph of South east Florida coast. Outlined in orange is the city of Pompano Beach. Smaller orange box outlines the study area. Figure created in ArcMap 10.2.2. by Caitlin Hanley Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

The Intracoastal Waterway runs through the city with the Hillsboro Beach Inlet located on the northern city limits. Waters from the Intracoastal Waterway flow in and out twice a day with the low and high tides supplying fresh water and nutrients to the coastal reef system, especially during the heavy rains Florida receives in its wet season from April through September. The Hillsboro Beach Inlet directly affects the study area and creates low water visibility when runoff is high, making this area eutrophic compared to the oligotrophic waters of the Florida Keys. Due to the levels of nutrients and substrate types, Pompano Beach coral growth and benthic marine life are not as diverse or abundant on the reef tract as in the Florida Keys.

Extending along Pompano Beach's shoreline is a segment of the Florida Reef Tract which runs from Boynton Beach in the north to the Florida Keys in the south. The tract consists of 3 linear relict Holocene reefs that run parallel to shore and a ridge-complex. The outer reef extends from Biscayne Bay to its terminus in Boynton Beach (Banks *et al.,* 2007). The middle reef extends from South Miami-Dade to the Boca Raton Inlet (Banks *et al.,* 2007). The inner reef extends from North Miami-Dade and terminates at the Hillsboro Inlet (Banks *et al.,* 2007). The ridge-complex begins approximately 100m from the shoreline and starts at the Hillsboro Inlet and terminates in North Miami-Dade (Banks *et al.,* 2007). Pompano Beach was chosen as the study site due to a distinctive near-shore ridge feature found just offshore and its close proximity to the Hillsboro Inlet, making it a unique system for the study of benthic foraminifera.

Origin, Structure, and Composition of the Nearshore Ridge Complex

The Northern extension of the Florida Reef Tract is composed of relict Holocene reefs and lithified sand ridges that run parallel to shore and are underlain by Pleistocene substrate (Banks *et al.* 2007). The three noticeable ridges, named the outer reef, middle reef, and inner reef as seen in Appendix B1, formed during back stepping of the reefs due to sea-level rise (Banks *et al.*, 2007; Walker *et al.*, 2008; Monaco *et al.*, 2012). The nearshore ridge complex (NRC) consists of sediment deposits of coarse sands and ridges of coquina and carbonate/quartz sandstone cemented ridges (Banks *et al.*, 2007).

Appendix B2 is a bathymetric block diagram illustrating the relief and structure of the ridge complex (Banks, 2007).

In Walker's (*et al.*, 2008) coral reef habitat classification he interpreted the ridges to be early Holocene cemented shoreline deposits. The largest outer ridge, seen in Appendix B Figure B2, resembles a wave-cut cliff presumably from when the inner reef was accreting (Banks *et al.*, 2007). The sand deposits were described by Banks *et al.* (2007) to be reworked Pleistocene Anastasia Formation and Holocene deposits. Other features within the ridge complex include areas of dead coral rubble consisting of *Acropora cervicornis, Acropora palmata,* or reworked reef deposits. These features are not easily seen with remote sensing techniques and are usually not mentioned in the literature (Banks *et al.*, 2007; Walker *et al.*, 2008; Monaco *et al.*, 2012).

PROJECT OBJECTIVES

Objectives

The objectives of this research were to collect, document, and evaluate species of foraminifera from the shallow water near-shore ridge complex off Pompano Beach in Broward County. Samples were used to compare foraminiferal assemblage abundance on four different benthic habitats with varying coral, algae, and macroinvertebrate cover within the ridge complex. Three ecological indices were used to provide statistical data on foraminiferal diversity. Multivariate analysis was used to measure distribution between and within samples. Finally, samples were assessed based on the seasons in which they were collected to determine variabilities in foraminiferal abundance during the wet and dry seasons. A summary of this data was compiled for future research.

Hypothesis

Overall abundance, diversity, and distribution of foraminiferal assemblages will reflect the dissimilarity found between the substrates across the NRC, which will be further affected by seasonal variation.

Relevance

Pompano Beach is a unique and understudied area with a complex relict reef system just off shore bordered by an inlet that discharges nutrient rich water. This complex substrate provides multiple habitat types for benthic foraminifera that are not seen in other areas to the north and south of the location this study site. The foraminiferal assemblages of areas such as the Florida Keys, Biscayne Bay, and on the northern American Atlantic coast, are well known; however, the foraminiferal assemblages found between these areas, specifically Pompano Beach, are not known. The foraminifera here are entirely benthic, and could add to an understanding of the biogeography of these species found in similar areas. Benthic foraminifera are known to be sensitive to environmental changes such as temperature, light, and nutrients, which vary seasonally in this environment. Studying the benthic foraminiferal species in this area could in fact shed light on how far some species found in the Caribbean can extend. This study of recent foraminiferal assemblages along the densely populated coast of Pompano Beach will provide important comparative material for future studies of species distribution in the western Atlantic Ocean.

MATERIALS AND METHODS

Sample Collection and Survey Methods

Thirteen sampling points across four substrate types were collected during Florida's wet (April-September) and dry (October-March) seasons in 2013, 2014, and 2015 at depths between 2.5 m and 9 m from the NRC in Pompano Beach, FL (Figure 1). At least three samples were taken from each substrate type, given fair weather conditions for diving, over the course of the study. One traverse of samples was taken in April 2015 for analysis of biofacies. It should be noted that there were no sampling patterns for when samples would be collected. Table (1) gives a detailed list of when and where samples were taken including depth, substrate type, and season. SCUBA divers, under the auspices of the Florida Atlantic University (FAU) Scientific Diving Program collected samples, which consisted of fist-sized pieces of reef rubble averaging 130-150 g, which were placed into re-sealable plastic bags without disturbing the sediment that accumulated naturally atop each piece. Permits to collect live rock were obtained from the Florida Department of Environmental Protection and Florida Fish and Wildlife Conservation Commission. Field notes were taken at each collection site to record the depth, morphology, dominant macroinvertebrates, dominant coral, algal cover and substrate material to compare foraminiferal assemblages with benthic cover and aid in the design of a classification scheme for nearshore benthic habitats off Pompano Beach.

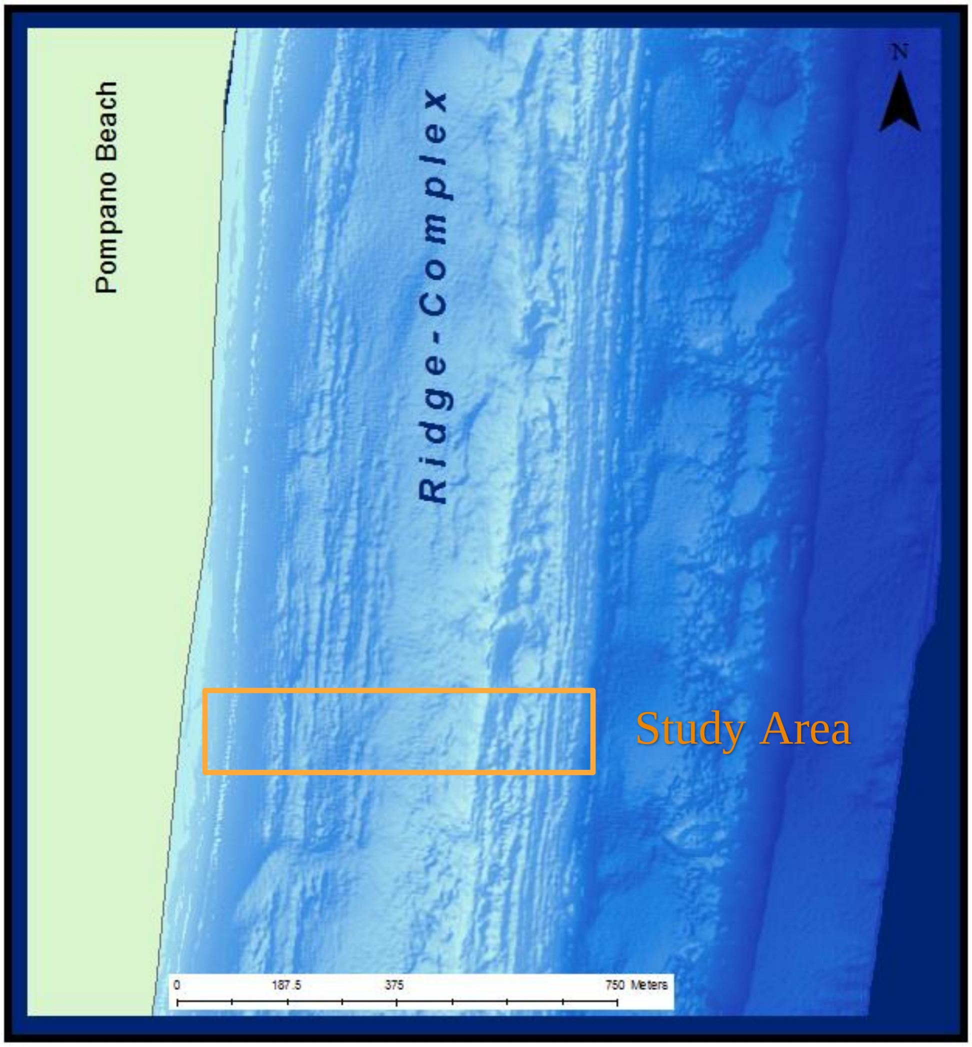

Figure 2: DEM of reef tract off Pompano Beach, F.L. Figure created in ArcMap 10.2.2 by Caitlin Hanley using raw data provided by Ken Banks from the Broward County Environmental Protection Department.

Table 1. Summary of Sample Collection Data.

Sample	Date	Depth (m)	Substrate	Season
1	10/12/2013	4	CP	D
2	10/12/2013	8	URD	D
3	1/27/2014	6	URD	D
4	1/27/2014	2.5	CP	D
9	5/31/2014	4.8	CP/R	W
11	5/31/2014	4.8	CP/R	W
13	9/16/2014	4.5	URS	W
14	9/16/2014	9	URD	W
26	4/21/2015	5	URS	W
27	4/21/2015	4	CP/R	W
28	4/21/2015	3	URS	W
29	4/21/2015	3.5	CP	W
30	4/21/2015	8.2	URD	W

Note. CP=Colonized Pavement, URD=Uncolonized Rubble Deep, CP/R=Colonized Pavement/Rubble, URS=Uncolonized Rubble Shallow, D=Dry, W=Wet

Seasonal Collection

Local monthly averages of precipitation during this study are given in Figure 2 to illustrate when the rainy/wet season occurs. The high point of the wet season in 2014 was during the month of July. For the time span of this study the wet season was considered April 2014 to September 2014. The first dry season was October 2013 to March 2014 and the second was October 2014 to March 2015. The last month of this study occurred during the beginning of the wet season. During the wet season torrential rains can leave communities flooded, making runoff high and turning the coastal waters a murky green with visibility ranging from 2 - 5m. Comparatively, during the dry season coastal waters are clear with water visibility up to 30 meters. Coastal water temperatures during the wet season can range from 26 ˚C to 30 ˚C and 21 ˚C to 24 ˚C in the dry season.

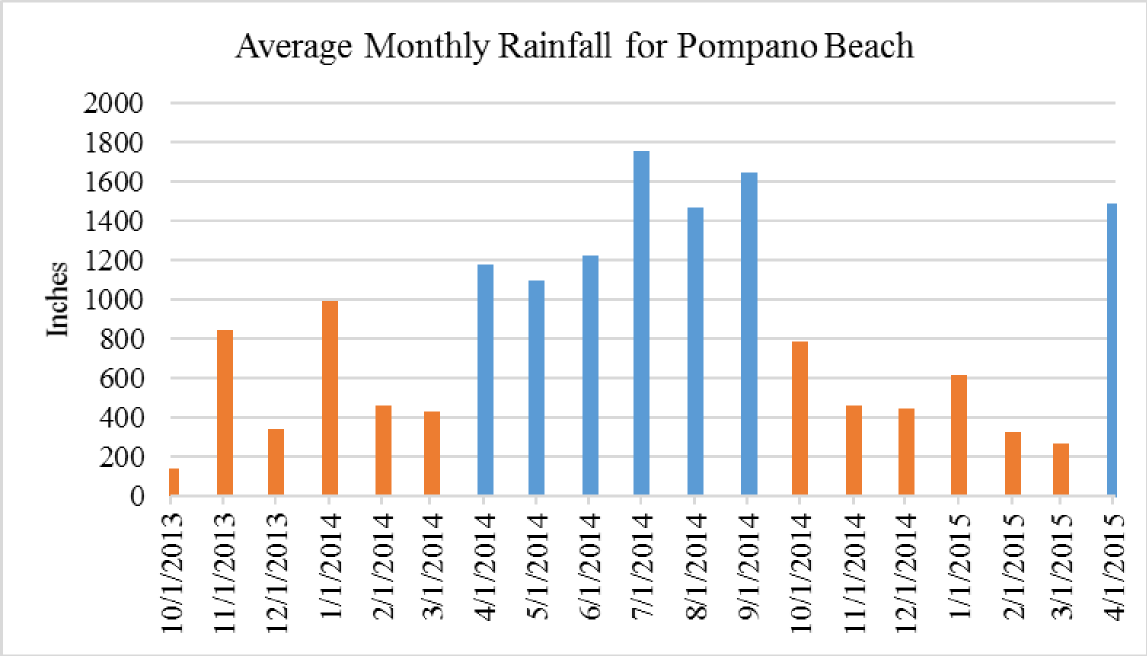

Figure 3. Monthly average rainfall for three stations in Pompano Beach Florida. Data provided by NOAA.

Lab Processing

Rubble samples were placed in a larger glass container and carefully brushed using a stiff bristled brush to remove microorganisms and sediment from the surface of the rock. Loose sediments were then washed with fresh water over a 63 µm sieve to remove silt and mud-size particles and then dried in a fume hood at 21 °C. This process prevents the sample from decaying, acquiring an odor, dark color, and salt crystallization. A 2000 µm sieve was used to remove any large debris or macro algae. In cases of large quantities of macro algae, hydrogen peroxide was used to remove the organic material.

Dried samples were then split in half on a sheet of paper using methods adapted from those used by Gerlach and Nocerino (2003), with one half saved as backup. The other half was then divided until an approximately 3g portion had been reached to be examined microscopically in order to quantify the foraminiferal assemblages (#/g of sediment). With a fine spatula, a small scoop of the sample was weighed to the nearest milligram, sprinkled over a small gridded tray and examined using a conventional stereomicroscope. Foraminiferal specimens were removed from sediments and attached to a cardboard micro paleontological faunal slide using gum tragacanth. Foraminiferal shells were sorted and identified to genus and species using characteristics defined by Loeblich and Tappan (1987). Heavily reworked and broken specimens were excluded due to difficulties in identification. A Species Accumulation Curve (SAC) allowed for proper representation of species found at each site by quantifying how much of each sample needed to be picked through, approximately 0.2g to 3g. Individual rarefaction curves can be found in Appendix C.

Data Analysis

Foraminiferal assemblage data was represented in three ways for analytical and multivariate analysis: (1) as relative abundance expressing genera as a percentage of total foraminifers counted, (2) absolute abundance expressed as the number of grams per unit mass of sediment picked (#/g), (3) total raw counts where applicable. Diversity indices were calculated using raw counts of foraminiferal genera in PAST3, a paleontological statistics software (Hammer 2015). These indices included the total number of individuals (n), Taxonomic richness (S), Shannon index (H), and Buzas and Gibson evenness (E). Taxonomic richness (S) is simply the number of taxa present within a sample. The Shannon index (H) is a measure of uncertainty in predicting the abundance of species, with maximum values representing evenly distributed samples. It calculates the proportion of species and then multiplies that proportion by the natural log of this proportion. The resulting product is summed across species and multiplied by -1 (equation 1).

$$H = -\sum_i \frac{n_i}{n} \ln \frac{n_i}{n} \qquad (1)$$

Evenness (E) is a measure of how an assemblage is spread over the observed species in a sample and is represented in equation (2). Values range from 0 to 1; the higher the value the more evenly the taxa are distributed in a sample, while lower values represent dominance by one or more taxa in a sample.

$$e^H/_S \qquad (2)$$

The combination of the three is also known as SHE Analysis or SHEBI Analysis for Biofacies Identification, a quantitative methodology to distinguish possible biofacies between stations along a gradient (Buzas & Hayek, 1998). SHEBI analysis was used in PAST3 following the procedures of Buzas and Hayek (1998) on a traverse of samples (S26, S27, S28, S29, S30) that were taken perpendicular to shore. This analysis calculates the log of species abundance (lnS), Shannon index (H), and the log of evenness (ln E = H – ln S) for the first sample which is then added to the second sample and so on (Hammer 2015). The resulting ln S, H, and ln E are then plotted as a linear graph for interpretation. Any departure from a non-increasing lnE indicates the addition of new species with enough relative abundance to change lnE and categorizes a new biofacies (Buzas & Hayek, 1998). It should be noted that SHE analysis provides a community synthesis that is distribution free due to lnS, H, and lnE being functions of the number of individuals (Hayek & Buzas, 2010). This means that lnS is linear to lnN so that genera found in all samples will not outweigh the analysis. This analysis was chosen as a secondary investigation to suggest possible variations in foraminiferal abundances across the four substrates.

Multivariate Analysis

PAST3 was used to perform multivariate analysis on samples using absolute abundances of genera. Abundances were converted into a Bray-Curtis Similarity matrix which was then used to compute both the Non-Metric Multidimensional Scaling (NMDS) and Hierarchical clustering to determine how samples grouped based on their similarity of foraminiferal abundances. The Bray-Curtis similarity index was used on abundance data using equation (3) to calculate distance and dissimilarity measures.

$$d_{jk} = 1 - \frac{\sum_i |x_{ji} - x_{ki}|}{\sum_i (x_{ji} + x_{ki})} \qquad (3)$$

This equation is a modified Manhattan measurement, where the summed differences between the variables, genera, are standardized by the summed variables of objects, samples. It produces a matrix of distance values ranging from 0 – 1 which can be used for clustering and scaling figures.

NMDS was computed using the Bray-Curtis Similarity matrix with a 2D Dimensionality and Bray-Curtis Similarity Index. Figures with the smallest stress levels < 0.1 and a Shepard plot with points closest to a straight ascending line (x=y) were considered a useful representation of the samples (Hammer 2015). Hierarchical clustering was computed using the same similarity matrix from NMDS using the Paired group (UPGMA) algorithm and Bray-Curtis Similarity index. UPGMA clusters on the average distance between all members. Using these analyses provide data on the distribution of similarities between sample abundances.

To aid in the interpretation of NMDS and hierarchical clustering, SIMPER (Similarity Percentage) was used. SIMPER assesses which taxa are primarily responsible for differences in abundance between groups of samples (Hammer 2015). SIMPER reports the average dissimilarity, the percent a genus contributes to dissimilarities, cumulative %, and the mean abundances of genera for each group. It orders the taxa from most responsible for average dissimilarity to the least responsible. Using this data allows for a quantitative interpretation of which genera are responsible for clustering between and within samples.

RESULTS

Substrate Types and Cover

A classification scheme was adapted from the National Oceanic and Atmospheric Administration (NOAA) shallow-water benthic habitat mapping report (Monaco *et al.*, 2012) and other studies that have mapped the south Florida coral reef habitats (i.e., Walker *et al.*, 2008; Walker, 2012). It follows their general classification on substrate type and only delineates where ground-truthing of the Pompano Beach area has given insight into biological cover and substrate features. Using charts for estimating mineral grain percentage (Compton, 1962), a mixture of siliclastic and carbonate sands was found throughout the benthic habitats with a varying composition of about 30-40% siliclastics. The following sub chapters are the adapted classification scheme from NOAA describing each benthic habitat sampled in this study off of Pompano Beach starting with habitats found closest to shore. Appendix D shows a table of pictures from each substrate illustrating the benthic habitat. It should be noted that depths were recorded via dive computer, distances measured using a 3D analyst profile in ArcGIS 10.2.2, and areas were not explored latitudinally.

Uncolonized rubble shallow (URS). This habitat ranges in depth from 3m to 5m and starts ~300 m offshore and spans approximately ~100 m. The substrate consists of scattered dead coral rubble underlain by unconsolidated shelly sands. Rubble is predominantly mollusk shells, dead *Acropora cervicornis* branches, and small pieces of reworked nearshore deposits seen in Appendix D Figure C. Living macro-invertebrates included, but were not limited to, urchins, bivalves, and gastropods, notably *Eustrombus gigas.* Many of these invertebrates such as *Eucidaris tribuloides, Lima* sp.*, Eustrombus raninus,* and *Tripneustes ventricosus,* were found in surrounding rubble. Brown, green, and red algae heavily cover this area year round. Commonly found algae were *Padina* sp.*, Dictyota* sp.*, Valonia ventricosa, Halimeda* sp.*, Peyssonnelia rubra.*, and *Wrangelia penicillata.* Living corals are not normally found here.

Colonized reef rubble/pavement (CPR). This habitat ranges in depths from 4m to 5m and starts ~450m to ~500m from shore. The substrate consists of a matrix of cemented and loose dead coral rubble, predominantly *Acropora palmata.* The western part of the substrate contains more loose rubble, slowly becoming cemented further east eventually approaching the colonized pavement habitat described below. Between the matrix of *Acropora palmata* branches are coarse sands and dead mollusk shells. Living macro invertebrates are similar to URS except that *Lobatus gigas* is usually absent. An additional macroinvertebrate is *Calliostoma jujubinum.* This area has a much lower coral coverage compared to the colonized pavement but sponges, gorgonians, hydrocorals, and stony corals can be found. Commonly found coral species are *Millepora alcicornis, Gorgonia ventalina, Porites astreoides,* and *Acropora cervicornis* seen in Appendix D Figures D, E, F. Algae lightly covers this habitat and can include *Dictyota* sp.*, Padina* sp., “Y-branched” algae, and *Peyssonnelia rubra*.

Colonized pavement (CP). This habitat is much shallower than the others and can range from 2m to 3.5m in depth starting ~550m from shore for about ~50m. This area has been commonly termed the “Flats” due to its low relief. The substrate is a coquina of the Pleistocene Anastasia Formation covered with filamentous turf algae. There can be a very thin veneer of sediments on top of the substrate that becomes trapped by the turf algae and in scattered pit-like structures where small reef rubble pieces can be found. Living macro invertebrates are similar to CPR, but also include *Pteria colymbus* and *Cyphoma gibbosum*, which can be found attached to gorgonians. Here gorgonians dominate a considerable amount of this area and cover much of the substrate as seen in Appendix D Figures G and H. hydrocorals and stony corals can also be found here, but not in the same numbers as the CPR habitat.

Uncolonized rubble Deep (URD). This habitat follows directly seaward of the colonized pavement at about ~600m from shore. It has been commonly called the "Drop off" because it is where blocks of the Anastasia Formation have broken off and fallen from 2m to about 9m. Figures I and J in Appendix D are views of the drop off showing the relief of this structure. At the base of this feature, about 9m, there is smaller debris from the Anastasia Formation and fallen reef rubble, which eventually terminates into sand. Samples from this habitat were taken east of the base of the structure in patches of reef rubble with no living corals. Living corals, similar to those found at CP, are found on large fallen blocks but are absent from the rubble. Macro invertebrates are similar to CP and the algae that inhabit the area are similar to URS, including *Halimeda* sp. which can be found hanging from under blocks.

Foraminiferal Assemblages of the Nearshore Ridge Complex

In the 13 samples examined, 6 orders, 29 families, 47 genera, and 71 species were identified (see Appendix E). Total counts of foraminiferal species from each sample are provided (see Appendix F). The dominant genera of foraminifera tests identified in the near shore ridge complex were *Quinqueloculina* 15%, *Laevipeneroplis* 12%, *Archaias*

11%, *Rosalina* 7%, *Trochulina* 7%, and *Amphistegina* 6%, which together cumulatively make up 58% of the total individuals from all samples. Twenty-four observed genera, including the 6 listed above, constitute 90% of the total individuals leaving 23 rare genera constituting 10% of total individuals. Four genera ranged from < 4% to > 2% relative abundance, while 37 genera each had < 2% relative abundances accounting for 28% of the total assemblage. Figure 9 illustrates the genera cumulatively from all samples with > 2% relative abundance.

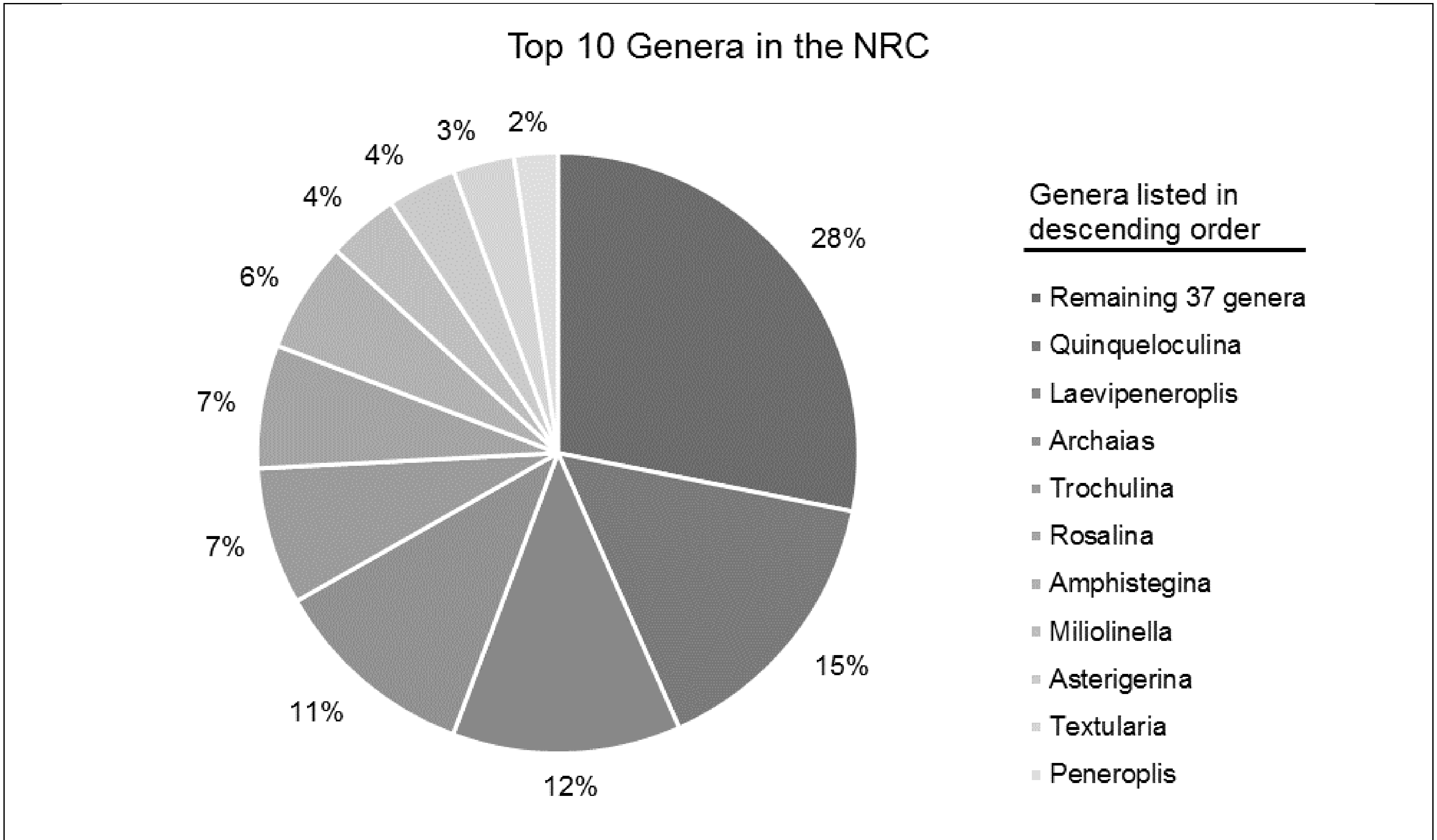

Figure 4. Top 10 genera within the NRC with > 2% relative abundance. The remaining 37 genera make up 28% of the foraminiferal assemblage.

Diversity Indices and SHE Analysis

The mean and standard deviation (±SD) for number of individuals (n) for all samples was 123.92 ± 39.59. The mean (±SD) for taxonomic richness (S) for all samples was 24.85 ± 4.96. The mean Shannon index (H) for all samples was 2.68 ± 0.22. The mean Buzas and Gibson evenness (e^H/S) was 0.60 ± 0.04 for all samples. A summary of these results are listed in (Table 2) with the dominant genera.

Table 2. Summary of foraminiferal biodiversity indices and dominant genera arranged by substrate type.

Sample	Number of Individuals **(n)**	Number of taxa **(S)**	Shannon **(H)**	Evenness **(e^H/S)**	**Dominant Genera**
S13URS	83	14	2.16	0.62	*Archaias, Trochulina*
S28URS	69	21	2.50	0.58	*Archaias*
S26URS	118	27	2.83	0.63	*Quinqueloculina, Laevipeneroplis*
S9CPR	191	26	2.74	0.59	*Laevipeneroplis, Archaias*
S11CPR	142	26	2.79	0.63	*Rosalina, Laevipeneroplis*
S27CPR	143	32	2.88	0.56	*Quinqueloculina, Laevipeneroplis*
S1CP	100	24	2.69	0.61	*Quinqueloculina, Amphistegina*
S4CP	166	30	2.84	0.57	*Quinqueloculina, Rosalina*
S29CP	153	25	2.52	0.50	*Archaias, Laevipeneroplis*
S2URD	56	20	2.50	0.61	*Quinqueloculina*
S3URD	161	22	2.60	0.61	*Quinqueloculina, Archaias, Laevipeneroplis*
S14URD	91	23	2.75	0.68	*Trochulina, Quinqueloculina*
S30URD	138	33	3.06	0.64	*Quinqueloculina, Laevipeneroplis*
Mean	123.92	24.85	2.68	0.60	
SD	39.59	4.96	0.22	0.04	

The results of the SHE Analysis on the traverse (S26, S27, S28, S29, S30) revealed 2 possible biofacies (Appendix G). The increase in lnS represents the increase in individuals (n) which is a normal trend in this logarithmic scale. The first four points of line lnE have a decreasing trend both graphically and numerically (Table 2) due to the increase in H, which constrains lnE to decrease as lnS increases with accumulation (Buzas & Hayek, 1998). Point 5 on lnE is shows a slight increase, indicating the start of a new possible biofacies.

Multivariate Analysis

Absolute abundances were determined to be the best representations of data due to the stress level being <0.10 and a relatively straight ascending line in the Shepard plot (Hammer, 2015). Relative abundances and transformations of data by square root all resulted in stress levels > 0.20. The NMDS that was used reported a stress level of 0.0701. Analysis of absolute abundance revealed 2 main clusters of samples in both the NMDS and Hierarchical clustering (Figure 3 & Figure 4). Clusters could be further broken down into 4 unobtrusive groups within the NMDS. All SIMPER reports are listed in Appendix H.

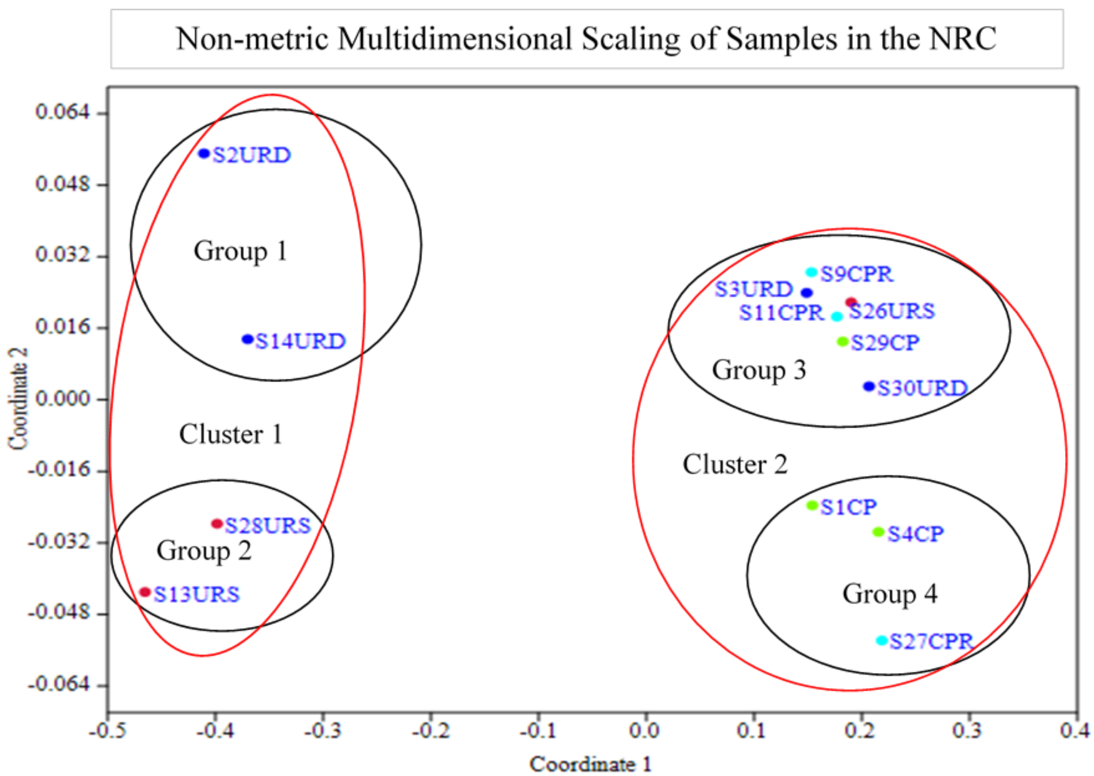

Figure 5. NMDS of samples from NRC. Two main clusters were broken into four groups based on similarities within the groups. Figure produced using PAST3. Note. S = Sample, CP=Colonized Pavement, URD=Uncolonized Rubble Deep, CP/R=Colonized Pavement/Rubble, URS=Uncolonized Rubble Shallow.

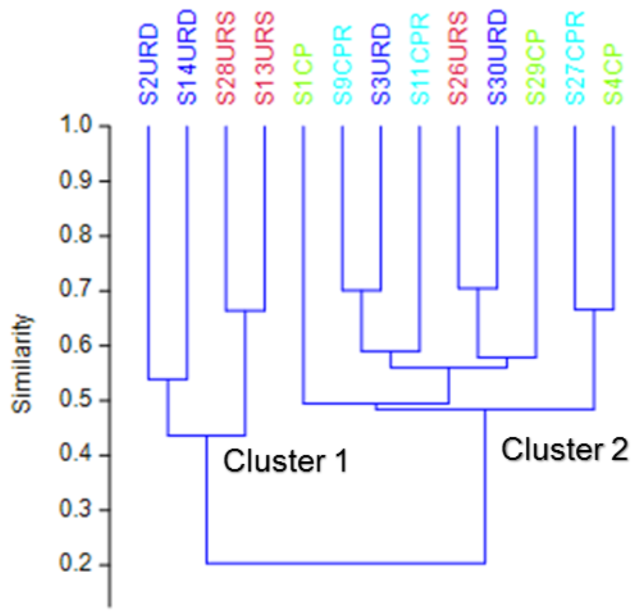

Figure 6. Hierarchical clustering using UPGMA algorithm and Bray-Curtis similarity index. Note. S = Sample, CP=Colonized Pavement, URD=Uncolonized Rubble Deep, CP/R=Colonized Pavement/Rubble, URS=Uncolonized Rubble Shallow.

Separation between the two clusters is due to 5 genera accounting for 50% of the cumulative dissimilarity. The main genera affecting this were *Quinqueloculina* contributing 15% and *Laevipeneroplis* contributing 13%. The overall average dissimilarity between the two Clusters was 79.69. Group 1 and 2 were separated by 6 genera that accounted for 60% of the cumulative dissimilarity with *Archaias* and *Quinqueloculina* being the top contributors and an overall average dissimilarity of 56.93. Cluster 1 contained 4 samples from uncolonized substrates with 2 from URD (Group 1) and 2 from URS (Group 2). The separation between the 2 samples in Group 1 (S2 & S14) are due to 6 genera that accounted for 48% of the dissimilarity with *Trochulina* and *Amphistegina* being the top contributors. The 2 samples from Group 2 (S28 & S13) are separated by 4 genera that account for 51% of the dissimilarity with the top contributor being *Archaias*. Cluster 2 contained the remaining 9 samples which consisted of all CP and CPR samples, 2 URD samples, and 1 URS. The separation between these groups were due to 7 genera accounting for 51% of the dissimilarity with the top contributors being *Quinqueloculina* and *Rosalina* and an overall average dissimilarity of 50.74. There were no major dissimilarities within group 3. However, SIMPER and Hierarchical clustering did show grouping of S30 an S29 with higher abundances of *Quinqueloculina* and S29 and S11 with higher abundances of *Archaias* and *Rosalina*, respectively. In group 4 there was a notable separation between sample S27 and the samples S1 and S4, where 5 genera accounted for 50% separation, with *Quinqueloculina* and *Laevipeneroplis* being the main contributors in S27. Figure 4 showed similar results with 2 main clusters with no noticeable sub groups. However, Figure 5, a multivariate analysis of Cluster 1 showed a better visualization of sub groups similar to those in Figure 3.

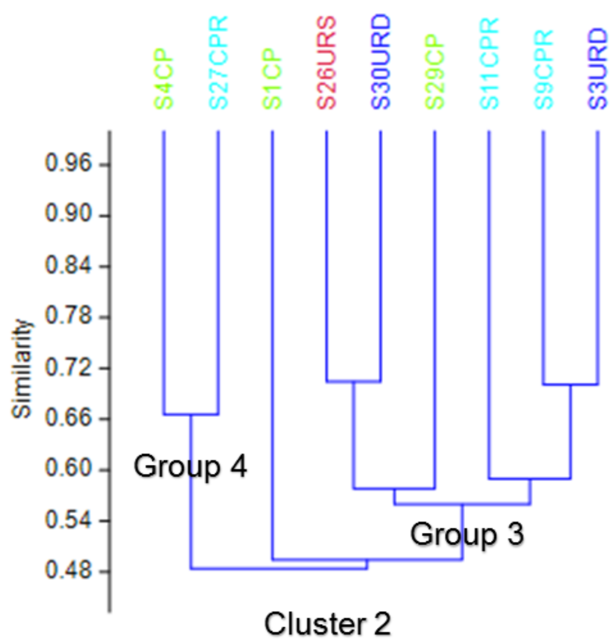

Figure 7. Hierarchical clustering of Cluster 2. Used to better see groupings found in NMDS. Note. S = Sample, CP=Colonized Pavement, URD=Uncolonized Rubble Deep, CP/R=Colonized Pavement/Rubble, URS=Uncolonized Rubble Shallow.

Foraminiferal Analysis of Substrates

Relative abundances were used to illustrate populations of the dominant genera across the four substrates Figure 7. Graphs of dominant genera from each substrate can be found in Appendix I.

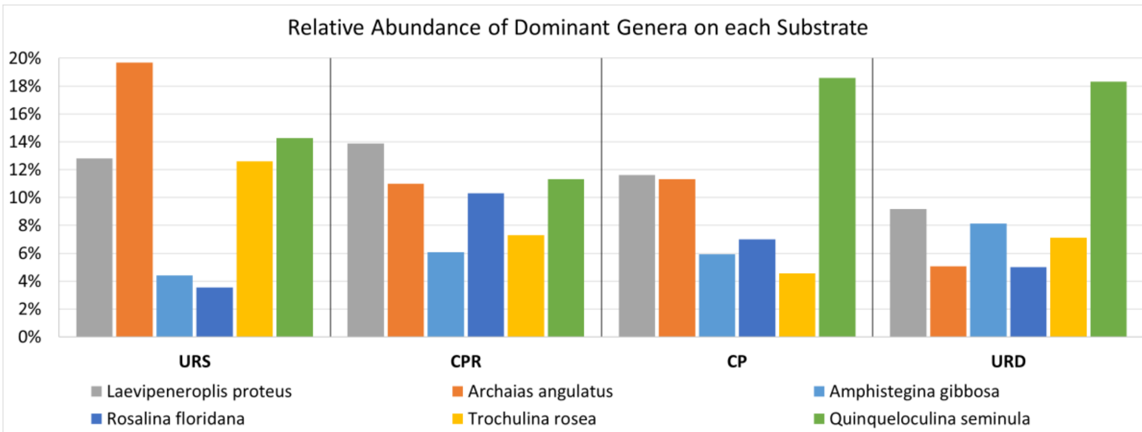

Figure 8: Abundances of dominant genera from all samples illustrating average abundances at each substrate.

Uncolonized rubble (shallow). From the 3 samples collected within the substrate labeled Uncolonized Rubble Shallow (URS) 52 species and 34 genera were identified. Dominant genera from the combined samples were *Archaias* 17%, *Quinqueloculina* 16%, *Laevipeneroplis* 13%, and *Trochulina* 11%. The remaining 30 genera < 2% accounted for 35% of the total relative abundance (Figure I1). The mean Taxonomic Richness (S) was 28 ± 7.79 for all sample. The mean Shannon Index (H) was 2.77 ± 0.37 for all samples. The mean Buzas and Gibson evenness (e^H/S) was 0.60 ± 0.06 for all samples.

For sample 13 (S13) the dominant genera was *Archaias* 24% and *Trochulina* 20%. For sample 28 (S28) the dominant genera were *Archaias* 29% and *Trochulina* 12% For sample 26 (S26) the dominant genera were *Quinqueloculina* 22% and *Laevipeneroplis* 15%.

Colonized rubble/pavement. From the 3 samples collected within the substrate labeled Colonized Rubble/Pavement (CPR) 61 species and 42 genera were identified. Dominant genera from these samples were *Laevipeneroplis* 14%, *Quinqueloculina* 11%, and *Archaias* 11%. Another 8 genera ranging from 9% to 2% accounted for 39% of the relative abundance and the remaining 31 genera < 1% accounted for 25% (Figure I3). The mean Taxonomic Richness (S) was 38.33 ± 4.11 for all sample. The mean Shannon Index (H) was 3.12 ± 0.17 for all samples. The mean Buzas and Gibson evenness (e^H/S) was 0.60 ± 0.04 for all samples.

For sample 9 (S9) the dominant genera were *Laevipeneroplis* 18% and *Archaias* 15%. For sample 11 (S11) the dominant genera were *Rosalina* 17% and *Laevipeneroplis* 11%. For sample 27 (S27) the dominant genera were *Quinqueloculina* 21% and *Rosalina* 12%.

Colonized pavement. From the 3 samples collected within the substrate labeled Colonized Pavement (CP) 61 species and 41 genera were identified. Dominant genera from these samples were *Quinqueloculina* 18%, *Archaias* 13%, *Laevipeneroplis* 12%, and *Rosalina* 7%. Another 6 genera ranging from 5% to 2% accounted for 21% of the relative abundance and the remaining 31 genera < 1% accounted for 29% (Figure I2). The mean Taxonomic Richness (S) was 37.33 ± 2.62 for all sample. The mean Shannon Index (H) was 3.10 ± 0.25 for all samples. The mean Buzas and Gibson evenness (e^H/S) was 0.61 ± 0.12 for all samples.

For sample 1 (S1) the dominant genera were *Quinqueloculina* 26% and *Amphistegina* 12%. For sample 4 (S4) the dominant genera were *Quinqueloculina* 20%

and *Rosalina* 16%. For sample 29 (S29) the dominant genera were *Archaias* 26% and *Laevipeneroplis* 20%.

Unconlonized rubble (deep). From the 4 samples collected within the substrate labeled Uncolonized Rubble Deep (URD) 63 species and 43 genera were identified. Dominant genera from these samples were *Quinqueloculina* 18%, *Laevipeneroplis* 10%, *Amphistegina* 8%, *Trochulina* 7%, and *Archaias* 7%. Another 9 genera ranging from 6% to 2% accounted for 30% of the relative abundance and the remaining 29 genera < 2% accounted for 20% (Figure I4). The mean Taxonomic Richness (S) was 34.50 ± 8.65 for all sample. The mean Shannon Index (H) was 3.14 ± 0.25 for all samples. The mean Buzas and Gibson evenness (e^H/S) was 0.69 ± 0.05 for all samples.

For sample 2 (S2) the dominant genera were *Quinqueloculina* 24% and *Amphistegina* and *Rosalina* with 14%. For sample 3 (S3) the dominant genera were *Quinqueloculina* 19% and *Archaias* and *Laevipeneroplis* with 14%. For sample 14 (S14) the dominant genera were *Trochulina* 15% and *Quinqueloculina* 14%. For sample 30 (S30) the dominant genera were *Quinqueloculina* 17% and *Laevipeneroplis* 10%.

Seasonal Foraminiferal Assemblages

Samples S13, S28, S26, S9, S11, S27, S29, S14, S30 were taken during the wet season and Samples S1, S4, S2, S3 were taken during the dry season. Both relative and absolute abundances showed the same trend of dominant genera during the wet and dry season and only varied with differences between seasons for the genera (Figure 7 & Figure 8). *Archaias* increased approximately half during the wet season in both relative and absolute abundances. *Rosalina* only showed a slight increase during the dry season in both abundances and stayed relatively constant. Further comparison of relative and absolute abundances between the seasons showed variation; however, *Quinqueloculina*, *Amphistegina*, and *Rosalina* were still more abundant during the dry season while *Archaias*, *Laevipeneroplis*, and *Trochulina* were more abundant during the wet season.

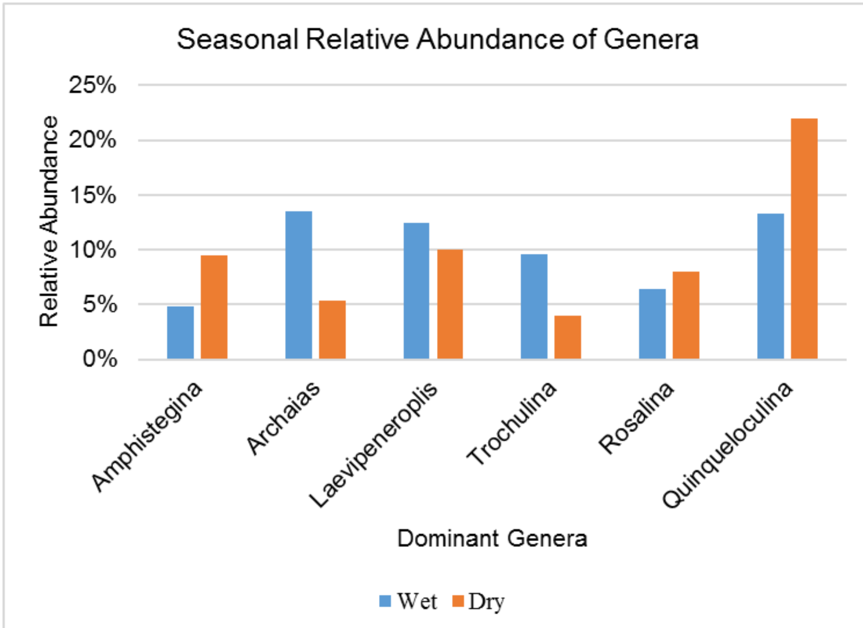

Figure 9. Comparison of dominant genera collected during the wet and dry seasons. Genera are plotted using relative abundances

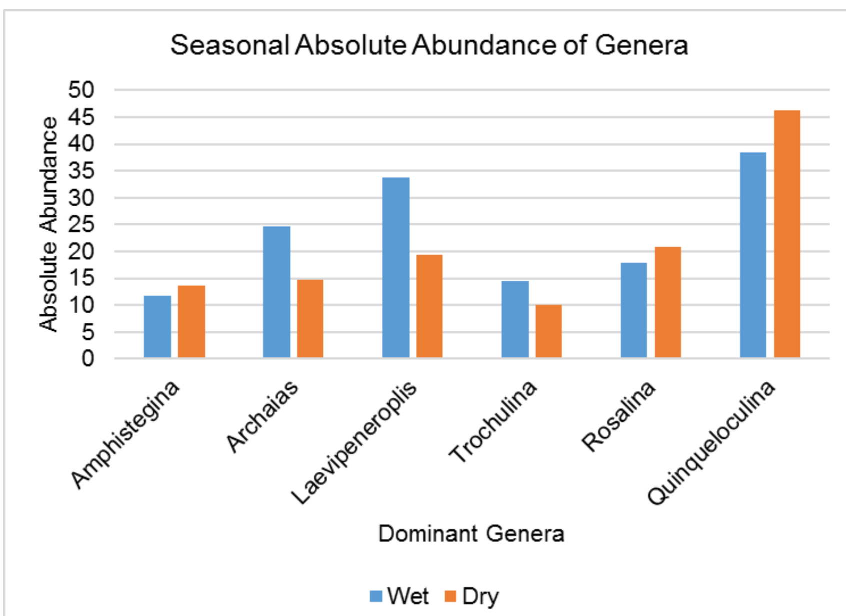

Figure 10. Comparison of dominant genera collected during the wet and dry seasons. Genera are plotted using absolute abundances.

DISCUSSION

Substrate, Depth, and Abundances

The uncolonized rubble closest to shore in approximately 3 – 5m was abundant in green algae, predominantly *Halimeda* sp., and seagrass could occasionally be found scattered along the substrate. This low energy environment, which bears a resemblance to seagrass bed habitats, was dominated by *Archaias angulatus* and other symbiont bearing foraminifera. The abundance of symbiont bearing foraminifera hosting green algae have been found in similar shallow waters associated with abundant *Halimeda* sp. and seagrass, especially in Florida Bay (Fujita & Hallock, 1999).

The uncolonized rubble furthest from shore in approximately 6 – 9m was abundant in *Quinqueloculina* sp. However, *Quinqueloculina* sp. was notably high in abundance across all substrates. This suggests that *Quinqueloculina* sp. is tolerant to many environmental factors, does not prefer a specific substrate, at least from the substrates found in the NRC, and is not a good indicator of substrate type. The URD is less affected by the runoff from the Hillsboro Inlet due to its proximity to the open ocean and on average experiences cooler temperatures compared to substrates closer to shore. *Amphistegina gibbosa* hosts a diatom endosymbionts and in recent research (Williams & Hallock, 2004) has been found to avoid high amounts of ultra-violet radiation, which causes stress and can lead to bleaching. This could account for this species being more abundant in the URD than the other shallower substrate

The colonized pavement was the shallowest of substrates and had the highest abundance of filamentous turf algae. The CP was dominated by gorgonians and characterized by a high density assemblage dominated by *Quinqueloculina*, symbiont bearing foraminifera, and small Miliolida. This shallow and well-lit habitat hosts the largest amount of turf algae allowing medium grained sediment and small foraminifera become trapped even with high wave energy.

The colonized rubble/pavement substrate was characterized by the highest density assemblage dominated by *Laevipeneroplis*, large benthic foraminifera, and small Rotaliida, specifically *Rosalina* and *Trochulina*. This extremely diverse area had a complex substrate of large branches of dead *Acropora palmata* allowing for plenty of surface area for temporarily attached foraminifera to adhere to. This substrate has shown to be an optimal area for a diversity of corals, foraminifera, and marine life.

Comparison of Previous Studies from Surrounding Areas

Modern benthic foraminiferal assemblages and distributions of the North American Atlantic coast and Florida Keys are well known (Culver and Buzas, 1980; Jones and Bock, 1971; Phleger, 1960; Rose and Lidz, 1977; Wilcoxon, 1962). Assemblages found in this study lacked species such as, *Globorotalia* sp., *Fursenkoina* sp., *Hanzawaia* sp., *Brizalina* sp., and *Ammobaculites* sp., found in previous studies in Biscayne Bay Florida Bay and the Florida Keys (Carnahan *et al.*, 2009; Jones, 1971; Lidz & Rose, 1989; Stephenson *et al.*, 2015). The primary difference was in abundances, where in this study dominant genera were a mixture of those found in northern studies and those found in the western Atlantic. Differences could also be due to localities and substrates where this study focused on a near-shore ridge system in Pompano Beach on the northern section of the Florida Reef Tract and previous studies focused on bays, patch reefs, and continental shelves.

Carnahan *et al.* (2009) reported 63 foraminiferal species common to Biscayne Bay and an expansion of *Ammonia* dominated areas that indicate decline in water quality, where as in this study *Ammonia* was a rare species. Jones (1971) compiled reports of foraminiferal distributions in *A Symposium on Recent South Florida Foraminifera* from Florida Bay and adjacent areas. Within this symposium Lynts (1964) reported an abundance of *Quinqueloculina bosciana* and *Quinqueloculina poeyana* in Buttonwood Sound, which are the most abundant species of *Quinqueloculina* in the NRC. Smith (1964) reported 61 genera and 150 species in the lower bay and found abundant species were from the genera *Ammonia, Elphidium, Nonion, Cribroelphidium, Archaias, Quinqueloculina, Milliolinella,* and *Peneroplis.* All of these genera were found on the NRC, but only *Archaias* and *Quinqueloculina* were dominant.

Research by Wright and Hay (1971) reported 117 species found on the back reef of Molasses Reef in the Florida Keys. Of these species, *Peneroplis carinatus, Quinqueloculina bosciana,* and *Quinqueloculina bradyana* were the most abundant. Only *Quinqueloculina* spp. were found on the NRC. Stephenson (2015) reported 72 foraminiferal genera from Conch reef, which is a part of the same chain of patch reefs as Moloasses. Dominant genera in this study were *Laevipeneroplis, Amphistegina, Asterigerina, Quinqueloculina, Rosalina,* and *Planorbulina.* This was similar to what was seen in this study except that *Amphistegina, Asterigerina,* and *Planorbulina* were not as abundant.

Wilcoxon (1962) reported that the most abundant forms of foraminiferal test types occurring off the south Atlantic coast were Hyaline species such as *Hanzawaia concentrica, Cibicides mollis, Nonionella atlantica, Planulina exorna, Elphidium discoidale, and Bolivina paula.* Genera similar to those species were rarely found at this study site, excluding *Hanzawaia,* which was completely absent. Arenaceous species, such as *Textularia,* occurred in greatest abundance off the northern coast of Florida in depths of 15-52m in Wilcoxon (1962) and were in intermediate abundance in the NRC. He also reported dominance of beach fauna in 0-1m off the north Florida coast with the genus *Elphidium* and *Quinqueloculina* being the most dominant; although, it was noted that these genera were not indigenous to the area. Wilcoxon's (1962) foraminiferal assemblages were similar to those in the NRC; however, abundances were extremely different, with *Quinqueloculina* dominating the study area instead of *Elphidium*.

Overall, foraminiferal species adjacent to my study area were similar with a few species not being present in samples. Abundance of *Quinqueloculina* was similar to all previous studies. However, studies from patch reefs in the Florida Keys had the most similarities in genera and species.

Limitations and Recommendations

In this study only 13 samples were taken to describe the foraminiferal assemblages on four different substrates on the NRC. This can sometimes limit statistical analysis or skew data. For this study data was positively skewed. Transformations such as log(x), power square, and inverse x did not make for a normal distribution. Moving forward this can also make multivariate analysis less reliable. However, Shepards plots and stress numbers did meet requirements for reliable data in this study (Hammer, 2015).

More samples may create a more normal distribution of data and better represent the study area.

Seasonal collections are a good method for understanding environmental change and can indicate specific stress events. In this study a method of monthly sampling would make for better interpretation of smaller environmental changes such as months of heavy rain or events of high wave energy from storms that would turn sediments up.

Abundance of large foraminifera such as *Archaias angulatus* could be due to their sturdy tests, which can remain in sediments for long periods without being damaged. Future research of this area should include living vs. dead assemblages to determine what percentage of benthic foraminifera are living on substrates and what percent is residual tests.

CONCLUSION

1. Foraminiferal assemblages on each substrate indicate a variability in dominance of species. The uncolonized rubble substrates had the lowest foraminiferal densities, while the colonized substrates, specifically the CPR, had the highest density of foraminifera. Distributional trends of foraminifera were seen with depth, notably with symbiont bearing foraminifera hosting green algae in shallower substrates and those hosting diatoms in deeper substrates.
2. Calculations of diversity indices indicated an even spread of genera amongst samples and substrates. The homogeneity across substrates may be due to the close proximity of sampling sites, hydrodynamics, and sediment movement and transport to each adjacent substrate. The deep uncolonized rubble was the only area that varied, which could be due to its depth and its distance from shore where runoff from the inlet would mix with water from the open ocean.
3. Cluster and NMDS analysis of absolute abundances from samples revealed two main clusters separating uncolonized substrates from those that were colonized by corals. SIMPER analysis showed inter-site differences and similarities in the foraminiferal assemblages on the NRC. Average dissimilarity among samples was 54%, which indicates variations amongst samples was not great. Variations in collection times and sampling methods may account for the dissimilarities between samples.
4. Seasonal variations revealed a dominance of *Quinqueloculina* during the dry season when water temperatures range from 21˚C to 24˚C. *Archaias* and other symbiont

bearing foraminifera were found to dominate the wet season when runoff to the NRC is higher, mixing coastal waters with nutrient latent waters. This blocks UV light and may account for larger abundances of symbiont bearing foraminifera in shallow areas of the NRC.

5. SHE analysis revealed a possible second biofacies starting at the URD. However, more samples would make for a more reliable analysis.
6. Comparison of my data with foraminiferal-assemblage data published on the Florida Keys and surrounding areas indicates a substantial decline of the amount of benthic foraminiferal species found on the northern extension of the Florida Reef Tract. Areas studied north and south of this study area reported higher total taxa and had differences in dominant species such as *Ammonia* spp., *Elphidium* sp., *Hanzawaia* sp., and *Cibicides* sp.. Overall, studies from patch reefs in the Florida Keys shared the most similarities.

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APPENDIX B: BATHYMETRIC MAPS OF STUDY AREA.

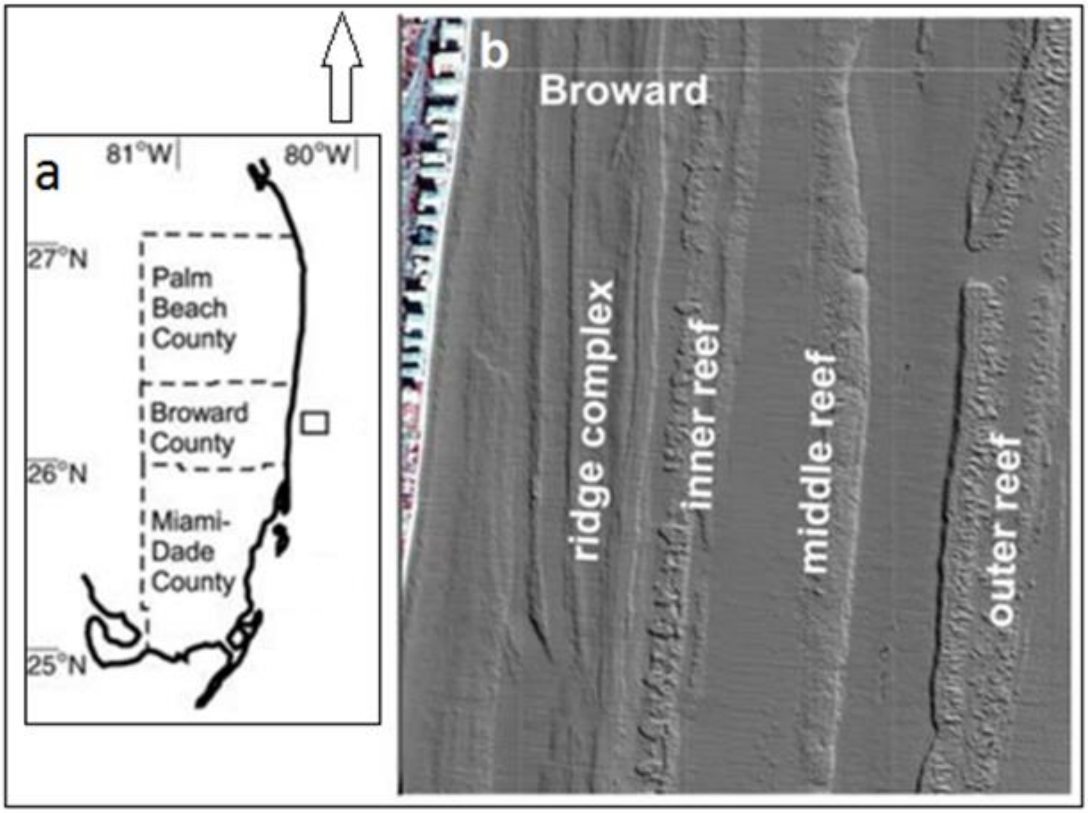


Figure B1: Part of the reef tract, where all three reef lines, as well as the ridge complex can be found. Originally published in: Banks *et al.*, 2007, Geomorphology of the Southeast Florida continental reef tract (Miami-Dade, Broward, and Palm Beach Counties, USA). *Coral Reefs*, *26*(3). Reproduced with permission from (Springer).

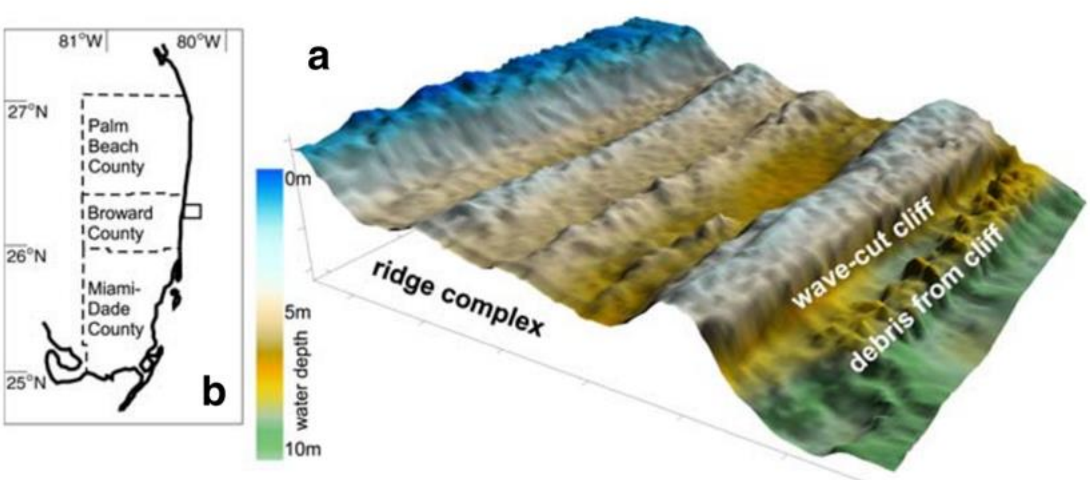
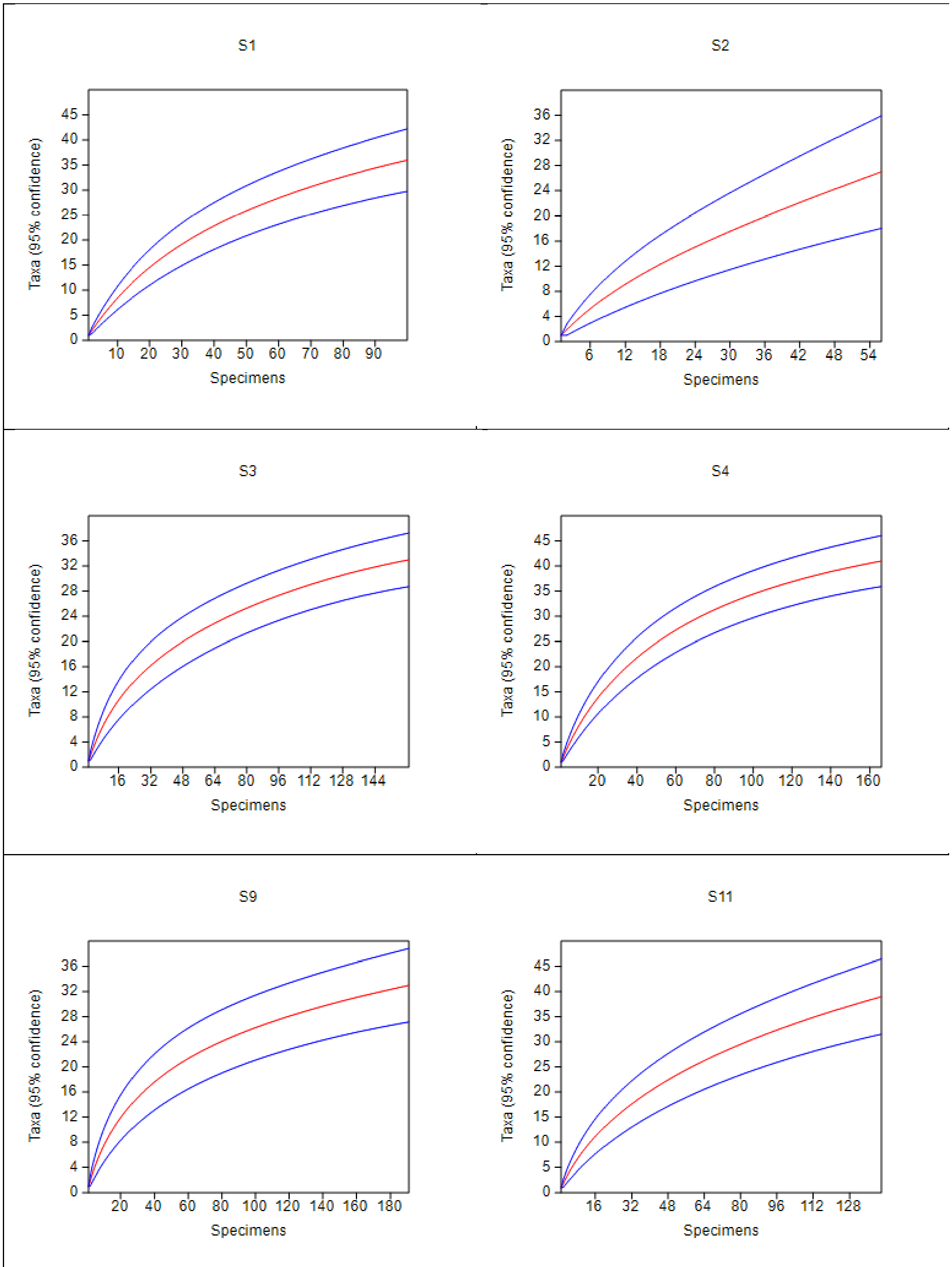


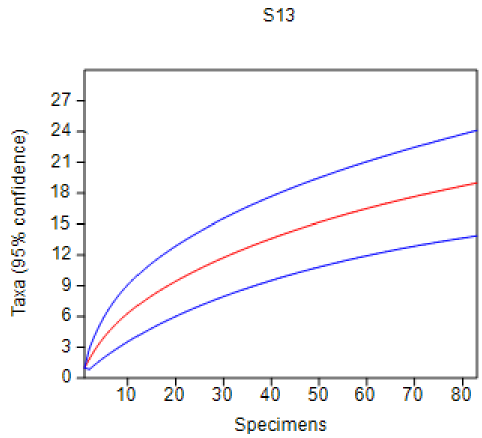
Figure B2: (a) Bathymetric block diagram of ridge complex and (b) map with location of bathymetric data. Originally published in: Banks *et al.*, 2007, Geomorphology of the Southeast Florida continental reef tract (Miami-Dade, Broward, and Palm Beach Counties, USA). *Coral Reefs*, *26*(3). Reproduced with permission from (Springer).

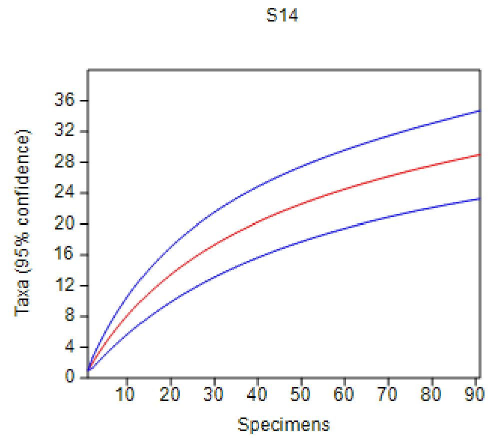
APPENDIX C: INDIVIDUAL RAREFACTION CURVES

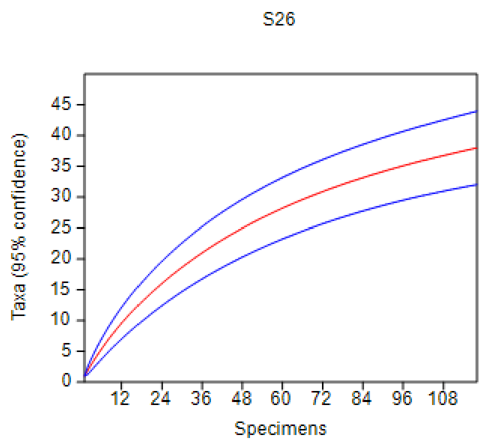


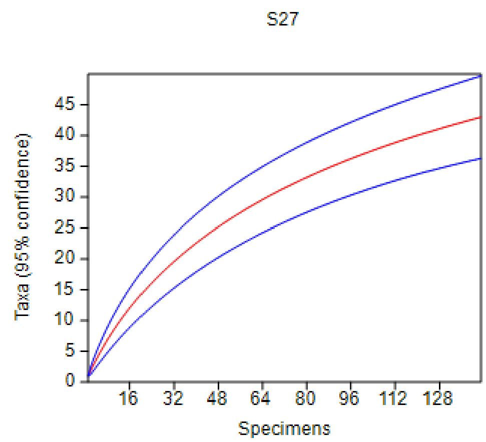
Note. Figures are plotted number of taxa with a 95% confidence (S) by number of speciments (S). The blue lines represent confidence. Figures produced in PAST3.

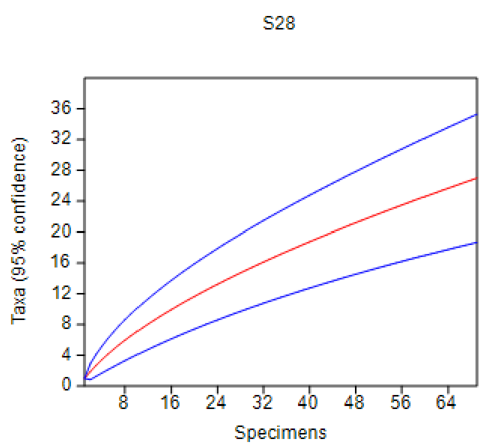
Appendix C: continued

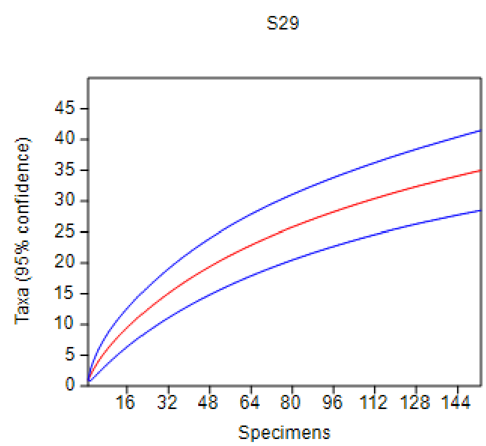






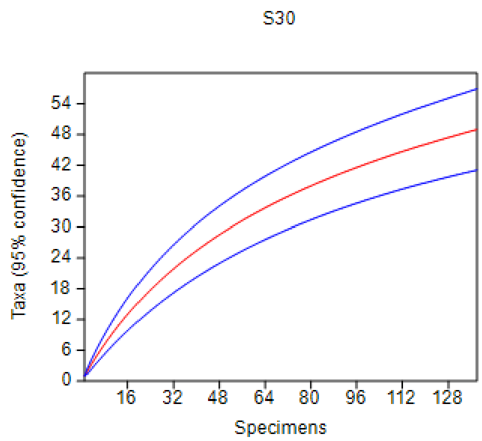






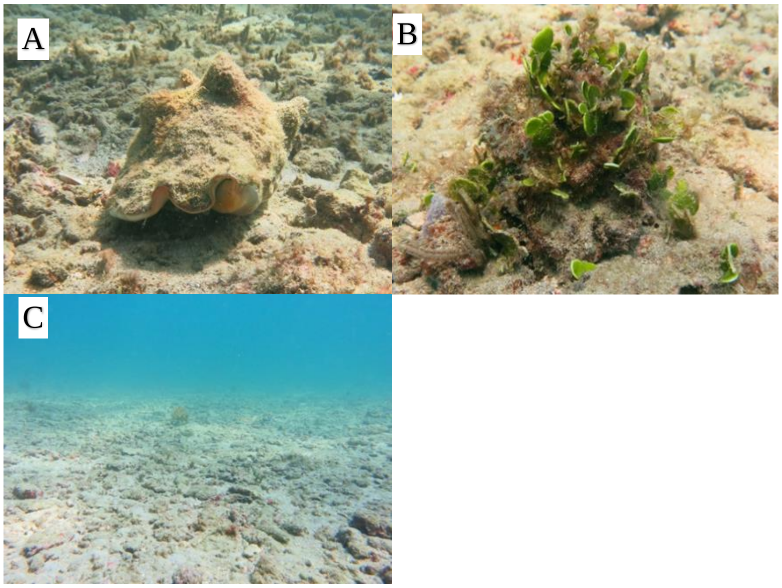
Note. Figures are plotted number of taxa with a 95% confidence (S) by number of speciments (S). The blue lines represent confidence. Figures produced in PAST3.

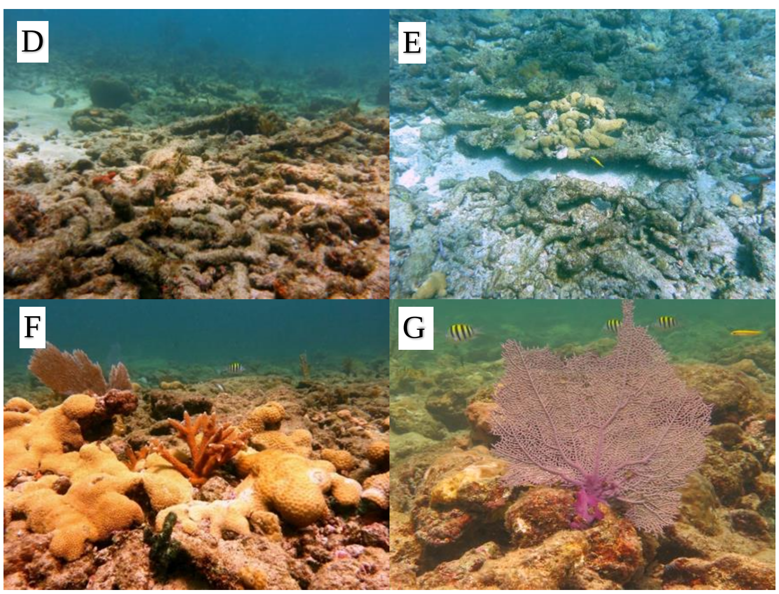
Appendix C: continued



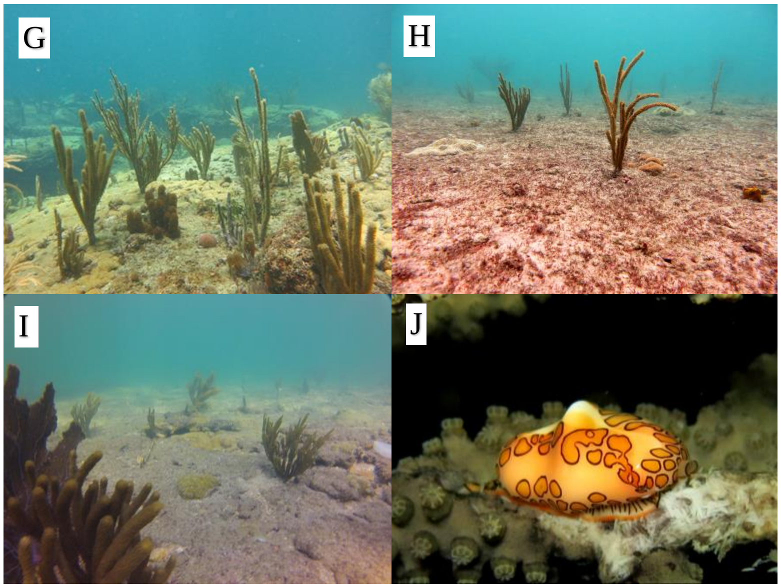
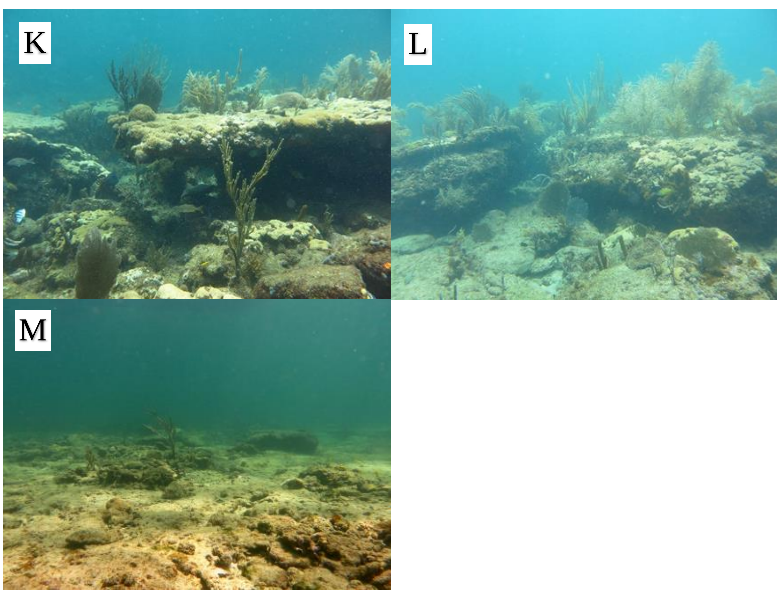
Note. Figures are plotted number of taxa with a 95% confidence (S) by number of speciments (S). The blue lines represent confidence. Figures produced in PAST3.

APPENDIX D: PHOTOGRAPHS OF SUBSTRATE TYPES

<table>
<tr><td>
</td><td>Shallow Uncolonized Reef Rubble (URS)

Figures. (A) *Lobatus gigas* (B) *Halimeda* sp. (C) Picture of Uncolonized reef rubble.</td></tr>
<tr><td>
</td><td>Colonized Reef Rubble/Pavement (CPR)

Figures (D, E) Large branches of dead *Acropora palmata* (F) Living *Acropora cervicornis, Gorgonia ventalina*, and *Porites astreoides.* (G) *Gorgonia ventalina.*</td></tr>
<tr><td colspan="2">**Note.** Photographs illustrating each substrate. Photographs taken by Anton Oleinik.</td></tr>
</table>

Appendix D: continued	
	Colonized Pavement (CP) **Figures.** (G, H, I) Overview of colonized pavement with *Gorgonian* spp. and filamentous turf algae. (J) *Cyphoma gibbosum.*
	Deep Uncolonized Rubble (URD) **Figures.** (K, L) View of drop off. (M) View of rubble area eastward of the drop off.
Note. Photographs illustrating each substrate. Photographs taken by Anton Oleinik.	

APPENDIX E: FORAMINIFERAL SPECIES LIST

Table E1. Foraminiferal Species Identified in all Samples

Order	**Family**	**Genus**	**Species**
Buliminida	Bolibinidae	*Bolivina*	*Bolivina pulchella*
Buliminida	Bolibinidae	*Bolivina*	*Bolivina paula*
Buliminida	Buliminidae	*Globobulimina*	*Globobulimina affinis*
Buliminida	Reussellidae	*Reussella*	*Reussella atlantica*
Miliolida	Alveolinidae	*Borelis*	*Borelis melo*
Miliolida	Cornuspiridae	*Cornuspira*	*Cornuspira involvens*
Miliolida	Hauerinidae	*Pyrgo*	*Pyrgo* sp.
Miliolida	Hauerinidae	*Triloculina*	*Triloculina trigonula*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina seminula*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina candeiana*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina bicostata*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina lamarckiana*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina polygona*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina* cf. *tricarinata*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina* cf. *bradyana*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina poeyana*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina subpoeyana*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina agglutinans*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina parkeri*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina variolata*
Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina* cf. *bosciana*
Miliolida	Hauerinidae	*Triloculina*	*Triloculina oblonga*
Miliolida	Hauerinidae	*Miliolinella*	*Miliolinella circularis*
Miliolida	Hauerinidae	*Miliolinella*	*Miliolinella fichteliana*
Miliolida	Hauerinidae	*Miliolinella*	*Miliolinella* sp.
Miliolida	Hauerinidae	*Hauerina*	*Hauerina ornatissima*
Miliolida	Spiroloculinidae	*Spiroloculina*	*Spiroloculina antillarum*
Miliolida	Tubinellidae	*Articulina*	*Articulina mucronata*
Miliolida	Tubinellidae	*Articulina*	*Articulina pacifica*
Miliolida	Tubinellidae	*Articulina*	*Articularia sagra*
Miliolida	Hauerinidae	*Cycloforina*	*Cycloforina collumnosa*
Miliolida	Hauerinidae	*Pseudotriloculina*	*Pseudotriloculina* cf. *linneiana*
Miliolida	Hauerinidae	*Affinetrina*	*Affinetrina* cf. *planciana*

Appendix E: Continued

Table E1. Continued

Miliolida	Hauerinidae	*Vertebrasigmoilina*	*Vertebrasigmoilina mexicana*
Miliolida	Fischerinidae	*Wiesnerella*	*Wiesnerella auriculata*
Miliolida	Peneroplidae	*Peneroplis*	*Peneroplis pertusus*
Miliolida	Peneroplidae	*Laevipeneroplis*	*Laevipeneroplis proteus*
Miliolida	Soritidae	*Archaias*	*Archaias angulatus*
Miliolida	Soritidae	*Cyclorbiculina*	*Cyclorbiculina compressa*
Miliolida	Soritidae	*Sorites*	*Sorites marginalis*
Miliolida	Peneroplidae	*Euthymonacha*	*Euthymonacha polita*
Rotaliida	Amphisteginidae	*Amphistegina*	*Amphistegina gibbosa*
Rotaliida	Asterigerinidae	*Asterigerina*	*Asterigerina carinata*
Rotaliida	Discorbidae	*Neoeponides*	*Neoeponides antillarum*
Rotaliida	Rosalinidae	*Rosalina*	*Rosalina floridana*
Rotaliida	Rosalinidae	*Neoconorbina*	*Neoconorbina terquemi*
Rotaliida	Discorbidae	*Trochulina*	*Trochulina rosea*
Rotaliida	Discorbidae	*Trochulina*	*Trochulina mira*
Rotaliida	Cancrisidae	*Valvulineria*	*Valvulineria candeiana*
Rotaliida	Nonionidae	*Haynesina*	*Haynesina* cf. *germanica*
Rotaliida	Nonionidae	*Nonionoides*	*Nonionoides grateloupii*
Rotaliida	Nummulitidae	*Heterostegina*	*Heterostegina antillarum*
Rotaliida	Cibicididae	*Cibicidoides*	*Cibicidoides* cf. *pseudoungeriana*
Rotaliida	Cibicididae	*Cibicidoides*	*Cibicidoides cicatricosa*
Rotaliida	Cibicididae	*Cibicidoides*	*Cibicidoides globulosus*
Rotaliida	Cibicididae	*Cibicides*	*Cibicides* sp.
Rotaliida	Planorbulinidae	*Planorbulina*	*Planorbulina mediterranensis*
Rotaliida	Planulinidae	*Planulina*	*Planulina foveolata*
Rotaliida	Cymbaloporidae	*Cymbaloporetta*	*Cymbaloporetta atlantica*
Rotaliida	Elphidiidae	*Elphidium*	*Elphidium advenum*
Rotaliida	Elphidiidae	*Elphidium*	*Elphidium* sp.
Rotaliida	Elphidiidae	*Cribroelphidium*	*Cribroelphidium poeyanum*
Rotaliida	Rotaliidae	*Ammonia*	*Ammonia* cf. *tepida*
Rotaliida	Rotaliidae	*Ammonia*	*Ammonia* cf. *parkinsoniana*
Rotaliida	Siphoninidae	*Siphonina*	*Siphonina pulchra*
Spirillinida	Spirillinidae	*Spirillina*	*Spirillina vivipara*
Textulariida	Valvulamminidae	*Discorinopsis*	*Discorinopsis aguayoi*
Textulariida	Textulariidae	*Textularia*	*Textularia agglutinans*
Textulariida	Textulariidae	*Bigenerina*	*Bigenerina nodosaria*
Trochamminida	Trochamminidae	*Trochammina*	*Trochammina inflata*

APPENDIX F: RAW DATA OF FORAMINIFERAL SPECIES

Table F1. Raw Counts of Foraminiferal Species arranged by Substrate type.

Sample Number	**13**	**28**	**26**	**9**	**11**	**27**	**1**	**4**	**29**	**2**	**3**	**14**	**30**
Substrate Type	URS	URS	URS	CPR	CPR	CPR	CP	CP	CP	URD	URD	URD	URD
Species													
Amphistegina gibbosa	6	3	2	16	6	8	12	2	7	8	17	3	6
Archaias angulatus	20	20	7	29	13	8	0	13	40	0	22	4	3
Cyclorbiculina compressa	1	0	3	6	0	0	0	0	4	0	6	0	6
Heterostegina antillarum	3	0	0	4	1	1	0	4	4	2	2	0	1
Asterigerina carinata	1	3	4	10	5	1	7	5	3	1	9	4	7
Peneroplis pertusus	0	1	6	10	5	2	0	2	7	0	2	1	2
Sorites marginalis	0	0	1	8	1	1	0	1	1	0	1	0	1
Laevipeneroplis proteus	12	6	18	34	16	18	8	12	30	6	22	2	14
Borelis melo	2	1	1	4	1	2	4	2	1	1	4	1	0
Elphidium advenum	0	0	0	0	0	0	0	1	0	0	1	0	0
Elphidium sp.	0	0	0	0	0	1	0	4	0	0	0	0	0
Cribroelphidium poeyanum	0	0	0	1	0	0	0	0	0	0	0	0	1
Trochammina inflata	0	0	0	0	0	0	0	0	0	0	0	0	1
Ammonia cf. *tepida*	0	1	0	0	0	0	0	0	0	0	0	5	3
Ammonia cf. *parkinsoniana*	0	0	1	0	1	0	1	5	1	1	0	0	0
Nonionoides grateloupii	1	0	0	0	0	1	0	0	2	2	0	5	1
Haynesina cf. *germanica*	0	0	2	5	0	4	4	6	0	1	2	0	1
Euthymonacha polita	0	0	1	0	0	1	1	0	0	0	0	0	0
Bolivina pulchella	0	0	1	0	0	2	1	0	0	0	0	0	0
Bolivina paula	0	0	0	0	0	1	1	3	0	0	0	1	0
Globobulimina affinis	0	1	0	1	2	1	0	1	1	0	2	1	1
Planorbulina mediterranensis	0	0	0	0	1	0	0	4	1	0	0	0	0
Planulina foveolata	0	0	0	0	0	4	0	1	1	1	0	4	0
Trochulina rosea	17	8	5	11	10	3	3	6	5	0	10	11	7
Trochulina mira	0	1	0	8	4	0	0	2	4	1	0	3	0
Siphonina pulchra	0	0	0	0	0	0	2	0	0	0	0	0	0
Discorinopsis aguayoi	0	0	0	1	0	8	0	0	2	0	0	0	0
Valvulineria candeiana	0	1	3	0	7	2	1	0	5	0	0	0	3

Note. URS=Uncolonized Rubble Shallow, CPR= Colonized Pavement/Rubble, CP= Colonized Pavement, URD= Uncolonized Rubble Deep.

Appendix F: Continued

Table F1. Continued

Rosalina floridana	0	5	4	4	24	17	1	27	2	8	0	11	4
Neoconorbina terquemi	0	1	4	2	0	3	0	4	4	0	0	1	2
Cymbaloporetta atlantica	0	1	1	0	2	0	0	1	0	1	0	0	1
Neoeponides antillarum	0	0	1	0	0	2	0	0	0	1	0	0	0
Cibicidoides cf. *pseudoungeriana*	0	0	0	1	1	0	0	0	1	0	0	0	0
Cibicidoides cicatricosa	0	1	2	0	4	0	0	0	1	0	0	0	4
Cibicidoides globulosus	0	0	0	0	0	0	2	0	0	0	0	0	0
Cibicides sp.	0	0	1	0	0	0	0	0	0	0	0	0	1
Spiroloculina antillarum	0	1	3	0	0	3	0	0	0	0	0	0	1
Pyrgo sp.	0	0	0	2	0	0	0	0	1	0	1	0	1
Triloculina trigonula	0	0	2	0	4	0	0	5	0	0	2	0	1
Quinqueloculina seminula	1	0	0	0	1	6	2	0	0	0	4	0	1
Quinqueloculina candeiana	0	0	0	0	0	1	1	0	0	0	0	0	1
Quinqueloculina bicostata	0	1	3	0	2	0	0	0	0	1	0	0	2
Quinqueloculina lamarckiana	3	0	3	0	2	0	6	3	1	1	3	1	4
Quinqueloculina polygona	0	0	1	0	1	1	0	4	0	1	1	0	1
Cycloforina collumnosa	0	0	0	1	0	0	1	0	0	1	0	0	0
Quinqueloculina cf. *tricarinata*	2	0	0	3	1	1	1	0	0	0	1	1	3
Quinqueloculina cf. *bradyana*	0	0	2	1	1	0	5	3	1	0	2	2	1
Pseudotriloculina cf. *linneiana*	1	0	0	1	0	1	2	2	0	0	2	0	0
Affinetrina cf *planciana*	0	0	3	0	0	0	1	2	0	0	10	0	1
Quinqueloculina poeyana	0	0	2	1	0	6	2	10	0	1	9	5	4
Quinqueloculina subpoeyana	0	1	0	0	0	5	1	1	2	0	1	0	1
Quinqueloculina agglutinans	0	1	1	0	1	3	2	0	1	3	1	0	0
Quinqueloculina parkeri	1	0	0	0	1	1	0	1	1	1	0	0	0
Quinqueloculina variolata	0	2	1	1	0	1	1	0	8	1	0	0	2
Quinqueloculina cf. *bosciana*	3	1	13	4	1	5	5	10	2	4	7	5	3
Triloculina oblonga	0	0	1	2	2	2	0	2	0	0	1	3	2
Miliolinella circularis	1	2	4	9	3	2	1	3	1	0	1	1	6
Miliolinella fichteliana	1	0	0	1	0	0	0	1	0	0	2	0	1
Miliolinella sp.	0	0	0	1	6	1	2	5	2	0	2	1	2

Note. URS=Uncolonized Rubble Shallow, CPR= Colonized Pavement/Rubble, CP= Colonized Pavement, URD= Uncolonized Rubble Deep.

Appendix F: Continued

Table F1. Continued

Wiesnerella auriculata	0	0	0	0	1	4	1	2	0	1	0	1	2
Cornuspira involvens	5	0	0	0	3	0	0	1	0	0	0	2	0
Articulina mucronata	0	0	1	0	2	0	0	0	0	0	0	0	1
Articulina pacifica	0	1	2	0	0	0	1	0	1	0	0	0	2
Articularia sagra	0	1	1	0	1	3	3	1	2	0	1	2	5
Vertebrasigmoilina mexicana	0	0	2	2	1	2	5	2	0	1	3	0	3
Hauerina ornatissima	0	2	0	2	0	1	2	0	0	0	0	0	4
Agglutinated sp.	0	0	0	0	0	0	0	0	0	0	0	2	0
Textularia agglutinans	2	1	5	5	2	2	4	1	3	4	7	7	10
Bigenerina nodosaria	0	0	0	0	1	0	3	0	0	1	0	0	2
Spirillina vivipara	0	1	0	0	0	0	0	1	0	0	0	1	0
Reussella atlantica	0	0	0	0	1	1	0	0	0	1	0	0	1

Note. URS=Uncolonized Rubble Shallow, CPR= Colonized Pavement/Rubble, CP= Colonized Pavement, URD= Uncolonized Rubble Deep.

APPENDIX G: SHE ANALYSIS

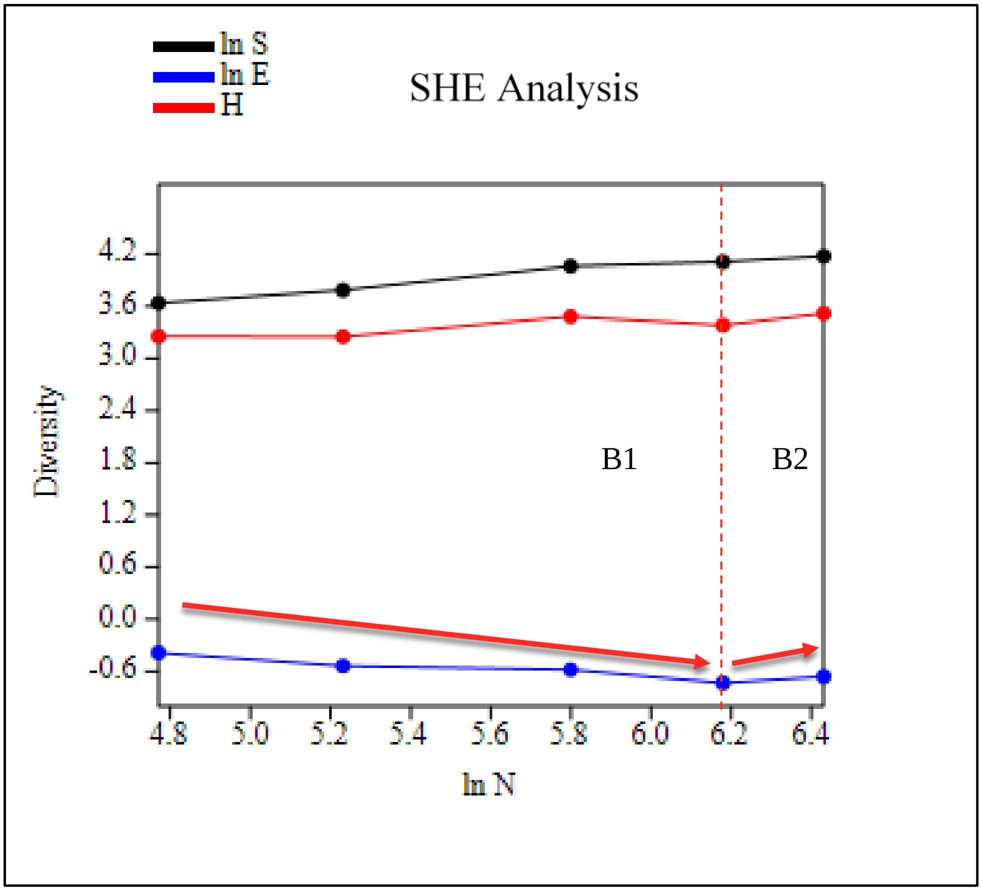


Figure G1: SHE Analysis of a transect of samples in order of 26, 28, 27, 29, 30. Each dot on each line correlates to these samples order. B1=Biofacies 1, B2=Biofacies 2.

Table G1. Quantitative values used in graphing SHE analysis figure.

Sample	N	ln N	ln S	H	ln E
S26URS	118	4.7707	3.6376	3.2547	-0.38286
S28URS	187	5.2311	3.7842	3.2502	-0.53404
S27CPR	330	5.7991	4.0604	3.4817	-0.5787
S29CP	483	6.18	4.1109	3.3811	-0.72976
S30URD	621	6.4313	4.1744	3.5175	-0.65686

APPENDIX H: RAW SIMPER RESULTS

Table H1. SIMPER results from Cluster 1 & 2. Overall Average Dissimilarity = 79.69

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. C1	Mean abund. C2
Quinqueloculina	12.44	15.61	15.61	6.11	56.2
Laevipeneroplis	10.19	12.79	28.4	3.23	40.8
Archaias	7.136	8.955	37.35	5.21	28.9
Rosalina	5.173	6.492	43.84	3.82	25.5
Amphistegina	4.157	5.216	49.06	2.8	16.6
Trochulina	3.431	4.305	53.36	4.98	16.7
Miliolinella	3.425	4.298	57.66	0.759	13.5
Asterigerina	2.998	3.763	61.42	1.31	11
Peneroplis	2.231	2.799	64.22	0.3	7.97
Textularia	2.08	2.61	66.83	2.07	9.37
Articulina	1.913	2.401	69.23	0.599	7.94
Triloculina	1.647	2.067	71.3	0.447	6.81
Haynesina	1.594	2.001	73.3	0.178	6.46
Cyclorbiculina	1.559	1.956	75.26	0.0799	5.05
Valvulineria	1.501	1.883	77.14	0.151	5.74
Vertebrasigmoilina	1.409	1.769	78.91	0.178	5.12
Cibicidoides	1.302	1.634	80.54	0.151	4.6
Neoconorbina	1.284	1.612	82.16	0.3	5.64
Borelis	1.108	1.391	83.55	0.638	4.2
Affinetrina	1.091	1.369	84.92	0	3.12
Heterostegina	0.9274	1.164	86.08	0.596	3.9
Sorites	0.8624	1.082	87.16	0	2.85
Ammonia	0.818	1.026	88.19	1.07	3.51
Discorinopsis	0.7618	0.9559	89.14	0	4.53
Wiesnerella	0.732	0.9186	90.06	0.327	3.71
Bolivina	0.6853	0.86	90.92	0.149	3.17
Hauerina	0.6625	0.8313	91.75	0.302	2.5
Spiroloculina	0.564	0.7077	92.46	0.151	2.62
Planulina	0.5488	0.6886	93.15	0.774	2.52
Pseudotriloculina	0.5372	0.6741	93.82	0.0799	1.94
Globobulimina	0.5222	0.6553	94.48	0.3	2.14
Bigenerina	0.5148	0.646	95.13	0.178	1.6
Nonionoides	0.4658	0.5845	95.71	1.18	1.3
Elphidium	0.4363	0.5475	96.26	0	2.16
Cornuspira	0.4037	0.5066	96.76	0.698	0.961
Planorbulina	0.3794	0.4761	97.24	0	1.7
Cymbaloporetta	0.3794	0.4761	97.72	0.329	1.34
Pyrgo	0.2891	0.3628	98.08	0	0.896
Neoeponides	0.2659	0.3337	98.41	0.178	1.26
Euthymonacha	0.2496	0.3132	98.73	0	1.01
Reussella	0.2423	0.3041	99.03	0.178	1.04
Siphonina	0.1878	0.2357	99.27	0	0.487
Cycloforina	0.1643	0.2062	99.47	0.178	0.353
Spirillina	0.1388	0.1742	99.65	0.3	0.311
Cribroelphidium	0.1212	0.152	99.8	0	0.435
Agglutinated	0.08774	0.1101	99.91	0.298	0
Trochammina	0.07321	0.09187	100	0	0.326

Appendix H: (continued)

Table H2**.** SIMPER results from Group 1 & 2. Overall Average Dissimilarity = 56.39.

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. G2	Mean abund. G1
Archaias	9.873	17.51	17.51	9.23	1.19
Quinqueloculina	6.837	12.13	29.64	3.41	8.8
Rosalina	5.92	10.5	40.13	1.51	6.13
Trochulina	4.881	8.656	48.79	5.43	4.53
Textularia	3.545	6.286	55.08	0.621	3.51
Amphistegina	2.663	4.724	59.8	1.86	3.74
Nonionoides	2.453	4.351	64.15	0.16	2.2
Planulina	1.846	3.274	67.42	0	1.55
Ammonia	1.844	3.269	70.69	0.302	1.85
Laevipeneroplis	1.819	3.227	73.92	3.73	2.73
Asterigerina	1.272	2.256	76.18	1.06	1.55
Cornuspira	1.038	1.842	78.02	0.799	0.596
Triloculina	1.019	1.808	79.83	0	0.893
Heterostegina	0.9095	1.613	81.44	0.48	0.713
Wiesnerella	0.8265	1.466	82.91	0	0.654
Miliolinella	0.7853	1.393	84.3	0.923	0.596
Articulina	0.7427	1.317	85.62	0.603	0.596
Hauerina	0.6847	1.214	86.83	0.603	0
Agglutinated	0.6796	1.205	88.03	0	0.596
Haynesina	0.4867	0.8631	88.9	0	0.356
Neoeponides	0.4867	0.8631	89.76	0	0.356
Bigenerina	0.4867	0.8631	90.62	0	0.356
Vertebrasigmoilina	0.4867	0.8631	91.49	0	0.356
Reussella	0.4867	0.8631	92.35	0	0.356
Cycloforina	0.4867	0.8631	93.21	0	0.356
Cymbaloporetta	0.4591	0.8142	94.03	0.302	0.356
Neoconorbina	0.3713	0.6586	94.69	0.302	0.298
Peneroplis	0.3713	0.6586	95.35	0.302	0.298
Spirillina	0.3713	0.6586	96	0.302	0.298
Globobulimina	0.3713	0.6586	96.66	0.302	0.298
Spiroloculina	0.3423	0.6071	97.27	0.302	0
Cibicidoides	0.3423	0.6071	97.88	0.302	0
Valvulineria	0.3423	0.6071	98.48	0.302	0
Bolivina	0.3398	0.6027	99.09	0	0.298
Cyclorbiculina	0.2193	0.389	99.48	0.16	0
Pseudotriloculina	0.2193	0.389	99.86	0.16	0
Borelis	0.0767	0.136	100	0.621	0.654

Appendix H: (continued)

Table H3. SIMPER results within Group 1. Sample 2 & 14. Overall Average Dissimilarity = 46.16.

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. S14	Mean abund. S2
Trochulina	8.103	17.56	17.56	8.34	0.713
Amphistegina	4.16	9.012	26.57	1.79	5.7
Laevipeneroplis	3.278	7.102	33.67	1.19	4.28
Archaias	2.532	5.485	39.15	2.38	0
Ammonia	2.407	5.215	44.37	2.98	0.713
Triloculina	1.899	4.113	48.48	1.79	0
Asterigerina	1.774	3.844	52.33	2.38	0.713
Planulina	1.774	3.844	56.17	2.38	0.713
Nonionoides	1.65	3.574	59.74	2.98	1.43
Heterostegina	1.515	3.281	63.03	0	1.43
Textularia	1.401	3.035	66.06	4.17	2.85
Miliolinella	1.266	2.742	68.8	1.19	0
Cornuspira	1.266	2.742	71.55	1.19	0
Agglutinated	1.266	2.742	74.29	1.19	0
Articulina	1.266	2.742	77.03	1.19	0
Quinqueloculina	0.9845	2.133	79.16	8.34	9.27
Rosalina	0.9033	1.957	81.12	6.55	5.7
Haynesina	0.7573	1.641	82.76	0	0.713
Neoeponides	0.7573	1.641	84.4	0	0.713
Cymbaloporetta	0.7573	1.641	86.04	0	0.713
Vertebrasigmoilina	0.7573	1.641	87.68	0	0.713
Bigenerina	0.7573	1.641	89.32	0	0.713
Reussella	0.7573	1.641	90.96	0	0.713
Cycloforina	0.7573	1.641	92.6	0	0.713
Neoconorbina	0.6329	1.371	93.98	0.596	0
Peneroplis	0.6329	1.371	95.35	0.596	0
Spirillina	0.6329	1.371	96.72	0.596	0
Globobulimina	0.6329	1.371	98.09	0.596	0
Bolivina	0.6329	1.371	99.46	0.596	0
Wiesnerella	0.1244	0.2695	99.73	0.596	0.713
Borelis	0.1244	0.2695	100	0.596	0.713

Appendix H: (continued)					
Table H4. SIMPER results within Group 2. Sample 28 & 13. Overall Average Dissimilarity = 33.64.					
Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. S13	Mean abund. S28
Archaias	8.318	24.73	24.73	6.4	12.1
Rosalina	4.425	13.15	37.88	0	3.02
Cornuspira	2.346	6.973	44.85	1.6	0
Asterigerina	2.186	6.498	51.35	0.32	1.81
Hauerina	1.77	5.262	56.61	0	1.21
Articulina	1.77	5.262	61.87	0	1.21
Heterostegina	1.407	4.184	66.06	0.959	0
Cibicidoides	0.8849	2.631	68.69	0	0.603
Valvulineria	0.8849	2.631	71.32	0	0.603
Peneroplis	0.8849	2.631	73.95	0	0.603
Globobulimina	0.8849	2.631	76.58	0	0.603
Ammonia	0.8849	2.631	79.21	0	0.603
Spirillina	0.8849	2.631	81.84	0	0.603
Spiroloculina	0.8849	2.631	84.47	0	0.603
Cymbaloporetta	0.8849	2.631	87.1	0	0.603
Neoconorbina	0.8849	2.631	89.73	0	0.603
Miliolinella	0.8318	2.473	92.21	0.639	1.21
Quinqueloculina	0.6191	1.84	94.05	3.2	3.62
Nonionoides	0.4692	1.395	95.44	0.32	0
Cyclorbiculina	0.4692	1.395	96.84	0.32	0
Pseudotriloculina	0.4692	1.395	98.23	0.32	0
Laevipeneroplis	0.3192	0.949	99.18	3.84	3.62
Amphistegina	0.1596	0.4745	99.65	1.92	1.81
Textularia	0.05325	0.1583	99.81	0.639	0.603
Borelis	0.05325	0.1583	99.97	0.639	0.603
Trochulina	0.009683	0.02878	100	5.44	5.43

Appendix H: (continued)

Table H5. SIMPER results within Group 3 & 4. Overall Average Dissimilarity = 50.74.

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. G4	Mean abund. G3
Quinqueloculina	7.866	15.5	15.5	93.3	37.7
Rosalina	5.964	11.76	27.26	51.1	12.8
Archaias	3.827	7.543	34.8	24	31.4
Laevipeneroplis	3.4	6.702	41.5	43.7	39.4
Amphistegina	2.054	4.049	45.55	22.5	13.7
Haynesina	1.648	3.249	48.8	14.4	2.46
Discorinopsis	1.376	2.712	51.51	11.8	0.884
Trochulina	1.274	2.511	54.02	14.1	18
Miliolinella	1.258	2.479	56.5	15	12.7
Triloculina	1.179	2.324	58.83	9.5	5.47
Bolivina	1.12	2.208	61.04	8.7	0.408
Cyclorbiculina	1.093	2.154	63.19	0	7.58
Articulina	1.038	2.047	65.24	8.3	7.76
Peneroplis	1.019	2.008	67.24	4.83	9.54
Wiesnerella	0.963	1.898	69.14	8.52	1.3
Neoconorbina	0.9367	1.846	70.99	8.18	4.38
Textularia	0.9179	1.809	72.8	6.82	10.6
Asterigerina	0.8942	1.762	74.56	11.3	10.9
Vertebrasigmoilina	0.8877	1.75	76.31	8.48	3.44
Valvulineria	0.8513	1.678	77.99	3.69	6.76
Elphidium	0.8017	1.58	79.57	6.15	0.167
Borelis	0.7991	1.575	81.14	7.75	2.42
Planulina	0.778	1.534	82.68	6.85	0.36
Cibicidoides	0.7673	1.512	84.19	1.46	6.17
Ammonia	0.7478	1.474	85.66	5.4	2.56
Heterostegina	0.679	1.338	87	5.22	3.24
Pseudotriloculina	0.6344	1.25	88.25	4.81	0.499
Spiroloculina	0.6113	1.205	89.46	4.44	1.71
Affinetrina	0.5816	1.146	90.6	2.6	3.38
Hauerina	0.5612	1.106	91.71	2.94	2.28
Planorbulina	0.5495	1.083	92.79	3.74	0.684
Bigenerina	0.4776	0.9414	93.73	2.19	1.3
Sorites	0.3877	0.7641	94.5	2.41	3.06
Neoeponides	0.358	0.7057	95.2	2.96	0.408
Siphonina	0.3043	0.5997	95.8	1.46	0
Euthymonacha	0.2983	0.5878	96.39	2.21	0.408
Globobulimina	0.2824	0.5566	96.95	2.41	2
Nonionoides	0.2421	0.4771	97.42	1.48	1.21
Cornuspira	0.2306	0.4546	97.88	0.934	0.974
Cymbaloporetta	0.2305	0.4543	98.33	0.934	1.55
Reussella	0.2177	0.429	98.76	1.48	0.813
Pyrgo	0.1972	0.3888	99.15	0	1.34
Cycloforina	0.1537	0.303	99.45	0.731	0.164
Spirillina	0.1278	0.2519	99.71	0.934	0
Cribroelphidium	0.08895	0.1753	99.88	0	0.653
Trochammina	0.06048	0.1192	100	0	0.488

Appendix H: (continued)

Table H6**.** SIMPER results within Group 4. Samples 1,4 vs 27. Overall Average Dissimilarity = 45.13.

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. S27	Mean abund. S1 & S4
Quinqueloculina	6.432	14.25	14.25	133	73.4
Laevipeneroplis	5.753	12.75	27	79.9	25.6
Rosalina	4.3	9.527	36.52	75.5	38.9
Discorinopsis	3.693	8.182	44.71	35.5	0
Archaias	2.122	4.7	49.41	35.5	18.2
Amphistegina	1.897	4.204	53.61	35.5	16
Planulina	1.719	3.809	57.42	17.8	1.4
Wiesnerella	1.463	3.242	60.66	17.8	3.9
Spiroloculina	1.385	3.068	63.73	13.3	0
Asterigerina	1.074	2.38	66.11	4.44	14.7
Triloculina	1.008	2.234	68.34	8.88	9.81
Miliolinella	0.936	2.074	70.42	13.3	15.9
Neoeponides	0.9232	2.045	72.46	8.88	0
Neoconorbina	0.8751	1.939	74.4	13.3	5.61
Trochulina	0.8086	1.791	76.19	13.3	14.5
Valvulineria	0.7948	1.761	77.95	8.88	1.1
Ammonia	0.7655	1.696	79.65	0	8.11
Bolivina	0.7458	1.652	81.3	13.3	6.4
Articulina	0.7438	1.648	82.95	13.3	5.79
Elphidium	0.6952	1.54	84.49	4.44	7.01
Peneroplis	0.6684	1.481	85.97	8.88	2.8
Haynesina	0.5683	1.259	87.23	17.8	12.8
Heterostegina	0.5678	1.258	88.49	4.44	5.61
Planorbulina	0.5097	1.129	89.62	0	5.61
Nonionoides	0.4616	1.023	90.64	4.44	0
Reussella	0.4616	1.023	91.66	4.44	0
Bigenerina	0.3852	0.8534	92.52	0	3.29
Affinetrina	0.3832	0.8491	93.37	0	3.9
Sorites	0.3342	0.7404	94.11	4.44	1.4
Globobulimina	0.3342	0.7404	94.85	4.44	1.4
Euthymonacha	0.3332	0.7382	95.58	4.44	1.1
Textularia	0.2822	0.6253	96.21	8.88	5.79
Vertebrasigmoilina	0.2709	0.6001	96.81	8.88	8.29
Cibicidoides	0.2568	0.5689	97.38	0	2.19
Siphonina	0.2568	0.5689	97.95	0	2.19
Hauerina	0.2048	0.4538	98.4	4.44	2.19
Borelis	0.1548	0.3429	98.74	8.88	7.19
Cycloforina	0.1284	0.2845	99.03	0	1.1
Cymbaloporetta	0.1274	0.2823	99.31	0	1.4
Spirillina	0.1274	0.2823	99.59	0	1.4
Cornuspira	0.1274	0.2823	99.88	0	1.4
Pseudotriloculina	0.05618	0.1245	100	4.44	5

Appendix H: (continued)

Table H7. SIMPER results within Group 3. Samples 3, 9, 11, 26, 29, and 30 were pooled together. Overall Average Dissimilarity = 41.33.

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. S26	Mean abund. S3	Mean abund. S30	Mean abund. S9	Mean abund. S11	Mean abund. S29
Quinqueloculina	5.142	12.4	12.4	63.7	29.1	67.4	9.86	21.4	34.5
Archaias	4.904	11.82	24.22	17.1	22.1	8.79	28.6	25.3	86.3
Rosalina	3.305	7.968	32.19	9.79	0	11.7	3.94	46.7	4.32
Laevipeneroplis	3.237	7.803	39.99	44.1	22.1	41	33.5	31.2	64.7
Articulina	1.676	4.04	44.03	9.79	1	23.4	0	5.84	6.47
Miliolinella	1.66	4.002	48.03	9.79	5.01	26.4	10.8	17.5	6.47
Textularia	1.655	3.989	52.02	12.2	7.02	29.3	4.93	3.89	6.47
Trochulina	1.45	3.495	55.52	12.2	10	20.5	18.7	27.3	19.4
Valvulineria	1.324	3.191	58.71	7.35	0	8.79	0	13.6	10.8
Cibicidoides	1.25	3.014	61.72	7.35	0	14.6	0.986	9.74	4.32
Peneroplis	1.189	2.865	64.59	14.7	2.01	5.86	9.86	9.74	15.1
Cyclorbiculina	1.103	2.659	67.25	7.35	6.02	17.6	5.91	0	8.63
Triloculina	1.022	2.464	69.71	7.35	3.01	8.79	1.97	11.7	0
Affinetrina	1.002	2.416	72.13	7.35	10	2.93	0	0	0
Amphistegina	0.9876	2.381	74.51	4.9	17	17.6	15.8	11.7	15.1
Neoconorbina	0.9788	2.36	76.87	9.79	0	5.86	1.97	0	8.63
Asterigerina	0.782	1.885	78.75	9.79	9.03	20.5	9.86	9.74	6.47
Hauerina	0.7003	1.688	80.44	0	0	11.7	1.97	0	0
Vertebrasigmoilina	0.6092	1.469	81.91	4.9	3.01	8.79	1.97	1.95	0
Heterostegina	0.6025	1.453	83.36	0	2.01	2.93	3.94	1.95	8.63
Ammonia	0.587	1.415	84.78	2.45	0	8.79	0	1.95	2.16
Spiroloculina	0.5423	1.307	86.08	7.35	0	2.93	0	0	0
Sorites	0.5284	1.274	87.36	2.45	1	2.93	7.88	1.95	2.16
Haynesina	0.5087	1.226	88.58	4.9	2.01	2.93	4.93	0	0

Appendix H: (continued)

Table H7. (continued)

Bigenerina	0.3848	0.9275	89.51	0	0	5.86	0	1.95	0
Wiesnerella	0.3848	0.9275	90.44	0	0	5.86	0	1.95	0
Cymbaloporetta	0.38	0.916	91.36	2.45	0	2.93	0	3.89	0
Cornuspira	0.363	0.8751	92.23	0	0	0	0	5.84	0
Nonionoides	0.3449	0.8314	93.06	0	0	2.93	0	0	4.32
Borelis	0.3186	0.7681	93.83	2.45	4.01	0	3.94	1.95	2.16
Globobulimina	0.3162	0.7622	94.59	0	2.01	2.93	0.986	3.89	2.16
Discorinopsis	0.2922	0.7044	95.3	0	0	0	0.986	0	4.32
Pyrgo	0.2668	0.6431	95.94	0	1	2.93	1.97	0	2.16
Reussella	0.2338	0.5637	96.5	0	0	2.93	0	1.95	0
Planorbulina	0.2018	0.4864	96.99	0	0	0	0	1.95	2.16
Cribroelphidium	0.1992	0.4803	97.47	0	0	2.93	0.986	0	0
Pseudotriloculina	0.1822	0.4392	97.91	0	2.01	0	0.986	0	0
Trochammina	0.1509	0.3639	98.27	0	0	2.93	0	0	0
Neoeponides	0.1492	0.3598	98.63	2.45	0	0	0	0	0
Bolivina	0.1492	0.3598	98.99	2.45	0	0	0	0	0
Euthymonacha	0.1492	0.3598	99.35	2.45	0	0	0	0	0
Planulina	0.1236	0.2979	99.65	0	0	0	0	0	2.16
Elphidium	0.07464	0.1799	99.83	0	1	0	0	0	0
Cycloforina	0.07045	0.1698	100	0	0	0	0.986	0	0

APPENDIX I: DOMINANT GENERA FROM EACH SUBSTRATE

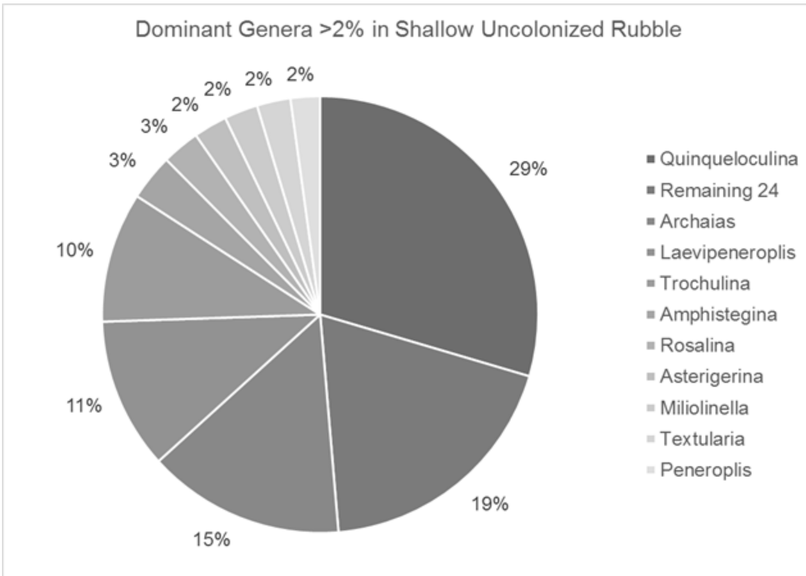


Figure I1. Dominant genera in URS.

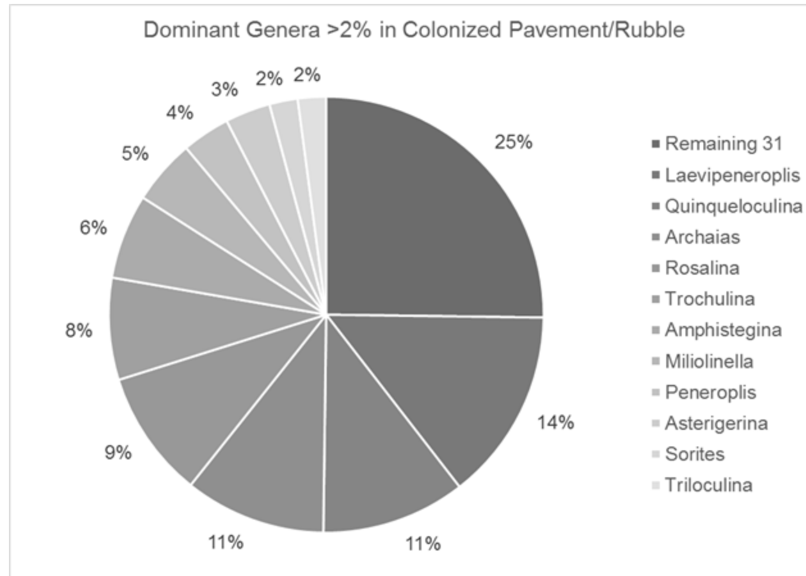


Figure I2. Dominant genera in CPR.

APPENDIX I: (CONTINUED)

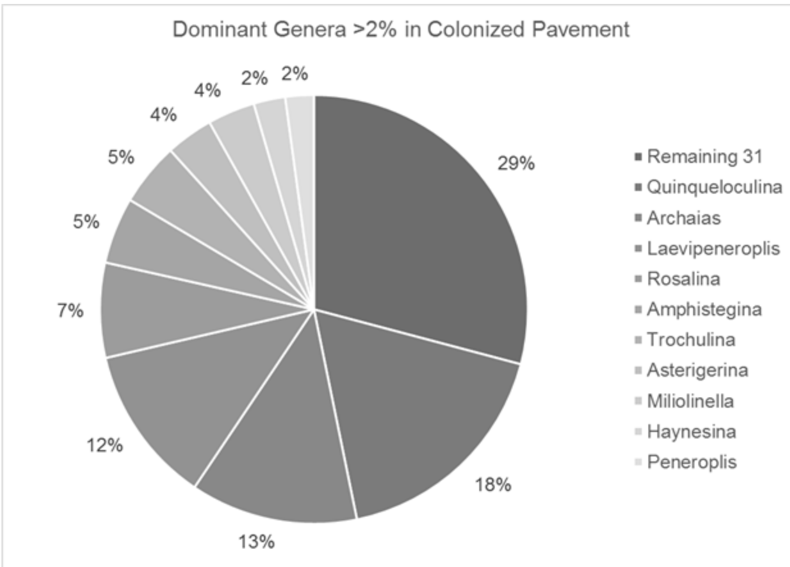


Figure I3. Dominant genera in CP.

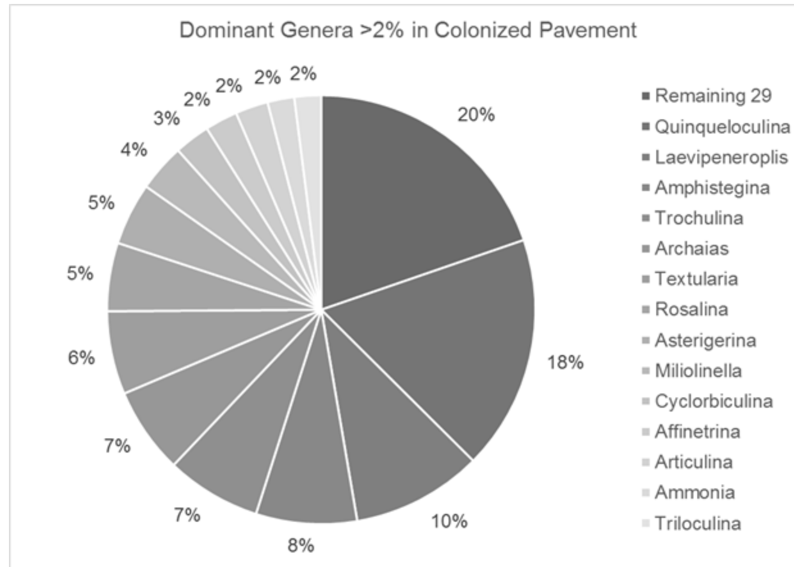


Figure I4. Dominant genera in URD.

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Anton Oleinik <aoleinik@fau.edu>

Fri, Apr 15, 2016 at 2:46 PM

To: "chanley3@my.fau.edu" <chanley3@my.fau.edu>

Dear Ms. Hanley,

My name is Anton Oleinik and apparently I happen to be the author of the photographs carefully listed in your email from Figures A through Figure L, which appears to be, to the best of your and my knowledge, pictures of the Nearshore ridge complex off Pompano Beach, Florida. With this email, you definitely have my permission to use these photographs as you see fit in your thesis, publications, wall posters, or backgrounds on your smart phone with absolutely no restrictions whatsoever. I extend this permission to all publications in the future in all languages including, but not limited to Faroese, Tok Pisin, Shona, Tsuu Tina, Basque, Frisian, Sentinelise, Yupik, and Dungan.

I completely agree with all conditions associated with the named above figures from A to L and further following all letters of the Roman alphabet, if necessary, listed in your email. Use of Cyrillic, Arabic and Kanji alphabets is also accepted and does not interfere with my agreement to the conditions outlined in your email.

Sincerely,

Anton E. Oleinik, PhD
Associate Professor of Geology
Chair of the Diving and Boating Safety Committee
Department of Geosciences
Florida Atlantic University
777 Glades Road
Boca Raton, FL 33431

P.S. Person responsible for writing this email was sacked

p.p.s. Person responsible for sacking the person who was responsible for writing this email was sacked

p.p.p.s The entire crew of typists who was responsible for typing this message was sacked but later rehired at the lower per hour rate and by a different outfit

p.p.p.p.s We apologize for any potential inconvenience which may arise from the attempt to publish the pictures in a Swahili version

From: Caitlin Hanley [mailto:chanley3@my.fau.edu]
Sent: Friday, April 15, 2016 10:15 AM
To: Anton Oleinik <aoleinik@fau.edu>
Subject: Copyright

April 15, 2016

Dear Dr. Anton Oleinik:

My name is Caitlin Hanley, and I am completing a doctoral dissertation/master's thesis at Florida Atlantic University, entitled " Distribution and Diversity of Benthic Foraminifera Within the Nearshore Ridge Complex off Pompano Beach, Broward County, Florida." I kindly request your permission to reprint in my thesis your photographs listed below.

Figures. (A) *Lobatus gigas* (B) *Halimeda* sp. (C) Picture of Uncolonized reef rubble.

Figures (D, E) Large branches of dead *Acropora palmata* (F) Living *Acropora cervicornis, Gorgonia ventalina,* and *Porites astreoides.* (G) *Gorgonia ventalina.*

Figures. (G, H, I) Overview of colonized pavement with *Gorgonian* spp. and filamentous turf algae. (J) *Cyphoma gibbosum.*

Figures. (K, L) View of drop off. (M) View of rubble area eastward of the drop off.

My thesis will be published through ProQuest Information and Learning Company (PQIL), and an electronic version will be archived in the digital collection at Florida Atlantic University. The requested permission extends to any future revisions of my thesis, including non-exclusive world rights in all languages. These rights will in no way restrict republication of the material in any other form by you or by others authorized by you. Your reply to this email will also confirm that you own the copyright to the below-described material. If these conditions meet your approval, please reply to this email.

Sincerely,

Caitlin Hanley
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