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Patch Reefs in Biscayne National Park, FL:

Sediments, Foraminiferal Distributions,

and a Comparison of Three Biotic Indicators of Reef Health

by

Alexa Ramirez

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
College of Marine Science
University of South Florida

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PATCH REEFS IN BISCAYNE NATIONAL PARK, FL: SEDIMENTS, FORAMINIFERAL DISTRIBUTIONS AND A COMPARISON OF THREE BIOTIC INDICATORS OF REEF HEALTH

Alexa Ramirez

ABSTRACT

Coral cover remains highest on patch reefs at the northern end of the Florida reef tract. The reasons for this trend are not well understood, but may be related to the protection from extreme variations in water quality parameters provided by the near constant presence of islands at the north extent of the Florida Keys.

Three indices have been developed based on Foraminifera and sediment constituents. Two of the indices, the FORAM Index and the SEDCON Index, were developed to indicate the suitability of a reef environment for continued reef accretion. The third index, the Photic Index, is an assessment of photic stress on reefs based on incidence of bleaching in a species of Foraminifera, *Amphistegina gibbosa*, which is known to experience loss of algal endosymbionts similar to bleaching in corals.

Patch reefs were sampled in Biscayne National Park, FL to assess sediment characteristics and foraminiferal assemblages, as well as to examine trends in the three indices. Sediments associated with a majority (59%) of reefs were coarse sands; muddy sediments were restricted to a few inner patch reefs that were isolated from the influence of Caesar's Creek, which flushes water from inside Biscayne Bay onto the open shelf. Unidentifiable grains predominated in the sediment constituents, along with calcareous algae and molluskan debris. Shells from 82 genera of Foraminifera were identified in the sediments. *Quinqueloculina* was the most consistently common genus. Percent mud was the single most influential measured variable on the distribution of both sediment constituents and foraminiferal assemblages. Analysis of bleaching in the foraminifer *Amphistegina gibbosa* revealed that photo-oxidative stress was chronic at 94% of the sites.

Patterns of FORAM and SEDCON Index values and their similarity to temperature, salinity, and percent mud distributions show that Caesar's Creek is affecting the benthic community in its immediate vicinity by providing flow that limits the accumulation of mud and potentially other anthropogenic stressors. Overall this study suggests that the reefs in this area are marginal for continued reef growth. A more detailed study of water quality through Caesar's Creek should be conducted to determine exactly how it is affecting the reefs in Biscayne National Park.

INTRODUCTION

Reef Decline in the Florida Keys

Coral reefs worldwide are in a state of decline. Reefs are of immense economic importance to the human populations around them. They absorb wave energy, protecting islands and coastal areas from erosion and storm surge; they are a key source of jobs in tourism and fisheries; and they potentially harbor cures for many diseases (Lidz 1997, Reaser et al. 2000). Corals are not only biologically important in nutrient-poor waters; they also provide the substrate upon which much of the community around them is based (Hallock et al. 2006). The Florida reef tract is no exception to the aforementioned benefits.

In 1996, stony coral cover on the Florida Keys' reefs was estimated at 11.9 percent. As of 2004, coral cover had declined to 6.6%, with patch reefs having the highest at 16% (Beaver et al. 2005). The industries that depend on the reefs may be contributors to this decline, along with the general urbanization of Miami and the Keys (LaPointe and Clark 1992, Porter and Meier 1992, Lidz 1997).

Many factors have contributed to the loss of coral cover, complicating the task of understanding and managing coral-reef ecosystems. One result of developed coastlines is often an increase in sedimentation to the offshore environment. While the reefs in Biscayne National Park are relatively removed from direct influences of coastal sedimentation, their proximity to heavily used boat channels (Hawk Channel and

Caesar's Creek) may leave them susceptible to sedimentation as a result of resuspension. Within Biscayne Bay, sedimentation rates have been measured to be 50-100mg cm^{-2} day^{-1} (Lirman et al. 2003). Lirman also measured higher rates of sedimentation in the vicinity of Caesar's Creek, a very active boating channel.

Frequently associated with sedimentation as a result of coastal runoff are excess nutrients from agricultural and suburban fertilizers, as well as from human waste. This is especially important in areas similar to Biscayne National Park that are in close proximity to major urban areas (i.e., Miami). Carnahan et al. (2008) found evidence of elevated levels of certain heavy metals in the mud fractions of sediments collected throughout Biscayne Bay. In southern Biscayne Bay she noted an area of "remarkably high toxicity" that could not be explained through her study. Because of the high potential for sediment resuspension as a result of currents, hurricanes, and boat traffic in Biscayne National Park, sediments cannot be considered a permanent sink for contaminants. Resuspended sediments may also be an indirect source of pollution and stress in impacted marine environments (Latimer et al. 1999, Lirman et al. 2003).

Turbid, nutrient-rich waters are not suitable habitat for mixotrophic organisms like corals (i.e., that host algal endosymbionts), which historically thrived in clear, oligotrophic environments. Elevated nutrient exposure can have direct effects on a coral such as increased symbiont densities that result in slower growth rates as a result of competition for CO_2 and/or carbonate between photosynthesis and calcification (Szmant 2002). Indirect effects include increased biomass of fleshy algae that may over grow and smother corals (Szmant 2002). In this way, nutrient loading tends to favor growth of macroalgae over hermatypic corals (Hallock et al. 1993). The end result is a community phase shift from stony coral-dominated reefs to communites dominated by soft coral, sponges, and algae (Hallock et al. 1993; Dustan 1999).

In addition to local anthropogenic stressors, global stressors such as increased sea surface temperatures and ozone depletion have led to higher frequencies and intensities of coral bleaching that are detrimental to coral reefs (Hoegh-Guldberg 1999). Bleaching is a natural response to stress in corals that can occur for several reasons including sedimentation, temperature extremes, and solar radiation (Talge and Hallock 2003, Hallock et al. 2006). Beaver et al. (2005) recorded an eight-year decline in stony coral cover in the Florida reef tract from 1996 to 2004. Of the eight years the only period of significant coral-cover decline occurred between 1997 and 1999. This coincided with a world-wide bleaching event in 1998 as a result of warmer-than-normal sea surface temperatures (at least 1°C higher than the summer maximum) due to an El Niño Southern Oscillation perturbation (Hoegh-Guldberg 1999).

Bleaching may also occur as a result of increased solar radiation caused by ozone depletion. Since the 1970's, measurements of stratospheric ozone have shown a trend of decreasing ozone at mid to high latitudes (Randel et al. 1999). The ozone anomaly from the long-term mean at 45° N latitude is currently about -6% per decade (Randel et al. 1999, Hallock et al. 2006). Addition of anthropogenic chlorine is thought to be a main cause leading to the destruction of the ozone (Molina and Rowland 1974). Large-scale volcanic eruptions (like that of Mt. Pinatubo in 1991) can amplify the effects of increased atmospheric chlorine through the injection of SO_2 into the stratosphere, which then reacts to create more reactive chlorine compounds (Fig. 1) (Roscoe 2001).

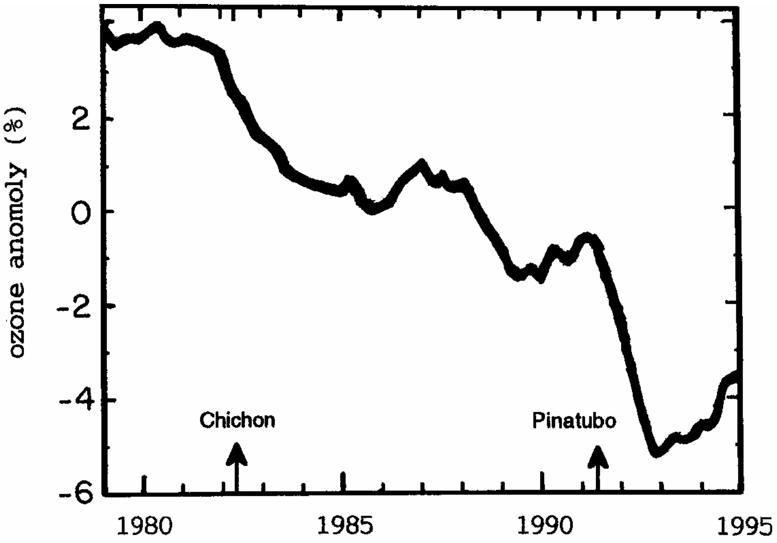


Figure 1. Ozone anomaly at 45° N. Two major volcanic events are noted to illustrate the effect on ozone depletion (modified from Roscoe 2001).

For every 1% decrease in ozone then, the levels of UV-B reaching the sea surface increases by 2% (Shick et al. 1996). This implies that the 10-15% decrease in stratospheric ozone that has occurred since the 1960's has resulted in a 20-30% increase in UV-B reaching the oceans at Florida Keys latitudes (Hallock et al. 2006).

While the aforementioned stressors hardly begin to encompass the spectrum of factors resulting in the degradation of reefs, they do play an important role. This is especially true near the highly urbanized areas of Miami and Key Largo.

Patch Reefs in Biscayne National Park

Patch reefs range from isolated coral heads a few meters wide to topographic features hundreds of meters in diameter. They are found between the mainland and bank or barrier reefs and are usually surrounded by halos of bare sand (Shinn et al. 1989, Brock et al. 2004). Because sea level limits the vertical growth of patch reefs, they typically occupy a range from 2 to 9m of water depth (Marszalek et al. 1977). In theory, patch reefs should be most susceptible to anthropogenic effects due to their proximity (3-7 km) to shore (Ginsburg et al. 2001, Brock et al. 2004).

The most concentrated area of patch reefs on the Florida reef tract is within the boundaries of Biscayne National Park (BNP) at the northern extent of the Florida reef tract (Fig. 2). The near continuous presence of Elliot Key and Old Rhodes Key act as a buffer between the confined waters of Biscayne Bay and the open marine environment, thereby protecting the patch and bank reefs from natural variations in temperature and salinity, as well as anthropogenic pollutants (Ginsberg and Shinn 1993). Seaward of Elliot Key approximately 4000 patch reefs have been identified using aerial photography (Marszalek et al. 1977). Extreme water-quality variations and the presence of tidally influenced mobile sands have limited reef growth north of Elliot Key (Ginsberg and Shinn 1993, Lidz 1997). The physical barrier provided by the Keys are a likely reason that patch reef coral cover in Biscayne National Park is relatively high and that patch reefs account for some of the healthiest reefs left in South Florida (Beaver et al. 2005).

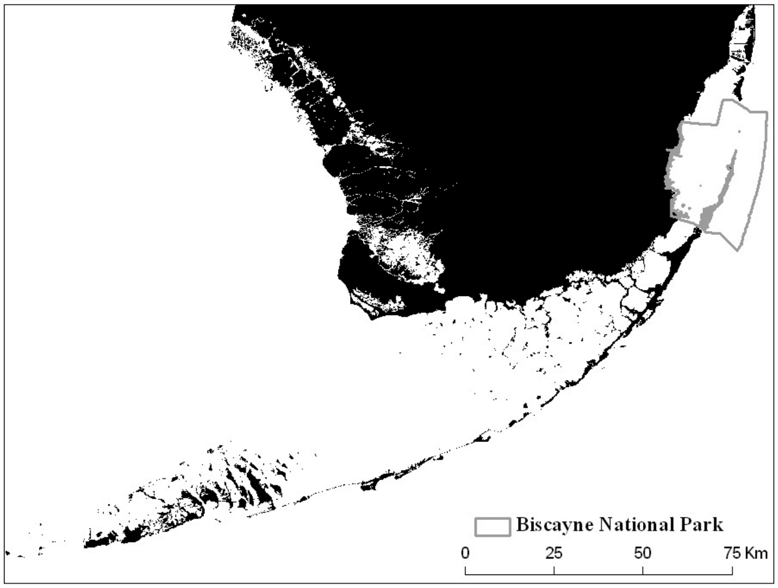


Figure 2. South Florida; Biscayne National Park boundary shown in gray.

Foraminifera

The Foraminifera are a class of small shelled protists that exist in nearly all coastal and marine environments (SenGupta 1999). One informal group, known as larger benthic foraminifers, has evolved symbiotic relationships with algae analogous to those in corals (Lee and Anderson 1991, Hallock 1999). The success of symbiont-bearing foraminifers is highly dependent on nutrient flux, especially nitrogen. The holobiont (host plus symbionts) functions optimally when the algal symbionts are deprived of nitrogen. When light is available, the symbionts produce large amounts of simple sugars during photosynthesis, which are translocated for use by the host foraminifer. Therefore, food captured by the foraminifer can be used primarily for growth and reproduction. However, in the presence of excess fixed nitrogen, the symbionts are able to grow and reproduce, potentially causing harm to the foraminiferal host (Hallock 1999). More importantly, smaller foraminifers are able to out-compete the larger symbiont-bearing foraminifers for space and microalgae are able to over-grow the slower growing foraminifers (Cockey et al. 1996, Fujita and Hallock 1999, Hallock 1999).

Increasing human populations have also increased the amount of nitrogen reaching coastal areas, resulting in either nutrification or eutrophication. Human activities, including burning of fossil fuels and changes in land use world-wide, have caused an increase in atmospheric CO_2 (Houghton et al. 2001), which increases ocean acidity and promotes dissolution of $CaCO_3$ found in both coral skeletons and foraminiferal shells (Kleypas et al. 2006). Both scenarios have produced changes in the benthic communities of tropical to subtropical waters where symbiont-bearing organisms have adapted to oligotrophic environments (Cockey et al. 1996, Hallock 1999, Hallock et al. 2003). Along the Florida reef tract over the past 30 years, foraminiferal assemblages have shifted from dominance of symbiont-bearing taxa to smaller heterotrophic taxa (Cockey et al. 1996), which has occurred in conjunction with coral-cover decline (Porter and Meier 1992, Dustan 1999).

In addition to the shift in assemblage composition, other changes have been documented in the foraminiferal community. Beginning in June 1991, the foraminifer *Amphistegina gibbosa* experienced a population-wide bleaching event in the Florida Keys. By 1992, population densities of *A. gibbosa* at depths to 20m decreased to less than 5% of densities from the previous year (Hallock and Talge 1993). The onset of this bleaching event coincided with stratospheric ozone depletion following eruptions of Mt Pinatubo in the Philippines in May and June of 1991 (Hallock et al. 1995). Subsequent studies have shown foraminiferal bleaching to correspond closely to the summer solstice, with populations beginning to recover by late summer when temperatures peak (Hallock and Talge 1993; Williams and Hallock 2004, Hallock et al. 2006). Some coral bleaching was also present on the reefs where the bleached foraminifers were observed (Hallock and Talge 1993). By 1992, bleaching in *Amphistegina spp.* was observed on reefs from Australia to Hawaii and Jamaica (Hallock et al. 2006). These observations reveal the potential importance of symbiont-bearing foraminifera to predict when photo-oxidative stress may impact the overall health of reef environments (Hallock 2000a, Hallock et al. 2006).

Biotic Indicators

Water samples are often taken to assess the water quality of the reef environment. However, the results can often be misleading as excess nutrients are quickly taken up by biological systems (Laws and Redalje 1979). While water samples may indicate normal nutrient concentrations, the effect of increased nutrient flux into an ecosystem typically results in a community change (e.g., Hallock 1988) known as a phase shift (Done 1992; McManus and Polsenberg 2004). By the time a water sample indicates a change in nutrients, the community has long been impacted (Hallock and Schlager 1986, Hallock et al. 1993, Hallock et al. 2006).

Symbiont-bearing benthic foraminifera require similar water-quality parameters as corals and are typically abundant on healthy coral reefs. Because of their relatively short life cycles and sensitivity to environmental conditions, the foraminiferal community can respond more quickly than corals to changes in water quality (Hallock 2000b, Hallock et al. 2003). Foraminifers can be quickly and inexpensively collected to provide a statistically significant analysis of chronic reef stress (Hallock et al. 2003).

As a consequence, two indices have been developed to relate the response of the calcifying benthic community to the status and suitability of the environment for future reef growth. The FORAM Index (Hallock et al. 2003) and SEDCON Index (Daniels 2005) were developed separately and each approaches the foraminifer-coral relationship from a slightly different perspective.

Based on observations of coral-reef communities, including foraminiferal assemblages and sediment constituents, under a wide range of natural (e.g., Hallock 1987, 1988) and anthropogenic (e.g., Hallock et al. 1993, Cockey et al. 1996) nutrient fluxes, Hallock (1995, 2000b, Hallock et al. 2003) proposed that foraminiferal assemblages and reef sediment constituents could provide low cost indicators of the potential for the environment to support mixotrophic, calcifying organisms (i.e., corals and foraminifers dependant on algal symbiosis). Moreover, sediment constituents might further provide a relative indicator of bioerosion rates. Bioerosional processes are major determinants of whether a reef is accreting or eroding.

A common scenario occurring along with and as a result of reef decline is the failure of reef communities to recover after a disturbance (e.g., hurricanes, bleaching or disease outbreaks, and ship groundings), which results in the decimation of large coral colonies decades to hundreds of years old. Because large coral colonies can persist in conditions where coral larvae cannot recruit and therefore cannot replace previous colonies, the question arose: "How can scientists and resource managers predict if the environment can support continued coral dominance, including recovery following a catastrophic mortality event?"

The FORAM (Foraminifera in Reef Assessment and Monitoring) Index (FI) focuses on assemblage changes within foraminiferal populations as reflected in reef sediments. The short lifespan and large numbers of foraminifers within an assemblage allows for a differentiation between chronic reef decline and acute mortality events (Cockey et al. 1996, Hallock et al. 2003). The basic underlying observation for this index is that sediments on healthy reefs have a larger proportion of shells of symbiont-bearing foraminifers compared to other smaller foraminifers and stress-tolerant foraminifers (Hallock 1988, Hallock et al. 2003). The presence of excess nutrients allows smaller heterotrophic foraminifers to bloom which causes their shells to dominate over the larger taxa (Cockey et al. 1996). In the calculation of the FORAM Index, a value of 2 would result from the presence of 100% other smaller foraminifers, indicating heterotrophic processes dominate on the reef. To increase the FI value from 2, some symbiont-bearing species must be present. In an environment that supports abundant calcifying mixotrophs, at least 25% of the foraminiferal assemblage are likely to be symbiont-bearing taxa, resulting in an FI value greater than 4. The presence of stress-tolerant taxa in a sample results in a lowering of the FI value (Hallock et al. 2003, Carnahan et al. *submitted*). As such, a differentiation between coral decline due to local nutrification or episodic events, like hurricanes or temperature extremes, is possible using the FORAM Index. If chronic nutrification is present, as indicated by the foraminiferal assemblage, coral reefs will likely be unable to recover from and continue to decline after a short term stress event (Hallock et al. 2003).

The SEDCON (Sediment Constituent) Index also uses reef sediment composition to assess the integrity of the reef system in the vicinity of the sample site (Daniels 2005). As previously noted, nutrification causes a phase shift in benthic community composition (LaPointe and Clark 1992; Porter and Meier 1992, Done 1992, McManus and Polsenberg 2004). In a reef environment, evidence for this shift should be observable in the carbonate-sediment composition (Hallock 1988). Foraminifers are an important contributor to reef sediments, especially larger, symbiont-bearing foraminifers (Cockey et al. 1996). Hallock (1988) noted that shells of large foraminifers, along with physically eroded, identifiable coral fragments, are characteristic in oligotrophic waters conducive to reef accretion. Meanwhile, the presence of smaller foraminiferal tests, unidentifiable carbonate grains, and calcareous algal fragments are indications of higher nutrient flux to the system (Hallock 1988, 2000b; Cockey et al. 1996). The potential for reef recovery following an acute event is dependent on water quality and rates of bioerosion (Hallock et al. 2006). Both of these should be reflected in the composition of sediments.

The FORAM and SEDCON indices are based upon constituents in the sediments which accumulate over weeks to years and therefore these indices represent conditions on time frames of months to years.

A third index, based on the abundance and condition of populations of *Amphistegina spp*., has been proposed (Hallock 1995, Hallock et al. 2004), but not yet fully developed. *Amphistegina spp*. are abundant and nearly ubiquitous members of the benthic biota on coral reefs and warm water carbonate shelves world-wide. The two most common species, *A. gibbosa* in the Western Atlantic and *A. lessonii* in the Indo-Pacific, are very similar in habitat and habitat requirements (Hallock et al. 1986, 2004; Hallock 1999). In 1991, *Amphistegina gibbosa* were first observed to be experiencing bleaching in the Florida Keys (Hallock et al. 1995). However, foraminiferal bleaching precedes coral bleaching as they respond quickly to photo-oxidative stress that occurs during maximum solar radiation, rather than at maximum sea-surface temperatures (Hallock et al. 2006). Since 1991, *A. gibbosa* populations have been monitored for size, symbiont loss (bleaching), and shell condition (Hallock et al. 1995, Williams et al. 1997, Hallock 2000a, Fisher 2007). Williams (2002) reported that during periods of acute photic stress there was a correlation with low population densities and large specimen diameters, indicating suppressed reproduction. Conversely, when photic stress was absent or chronic, population densities increased and mean diameter decreased (Williams et al. 1997, Williams 2002).

The proposed index, variously referred to as *Amphistegina* Photic Index or the Amphi Index, requires examination of *Amphistegina* specimens collected live and would utilize both log-normalized abundance of *Amphistegina* (e.g., Hallock 1995) and degree of bleaching (absent, chronic, or acute). Because response to increased radiation occurs over periods of days to weeks, this index could provide an assessment of environmental conditions over shorter time periods of weeks to months as opposed to the annual or inter-annual time scales of the FORAM and SEDCON indices.

The potential benefit of these three indices is the ease with which they can be applied and that they do not require touching or disrupting the actual reef. A simple collection of reef rubble or a small sediment sample is all that is necessary and can easily be incorporated into a preexisting monitoring program (Hallock et al. 2003). In many cases, sediments are routinely collected for grain size or chemical analysis. Sample processing for each index is kept as simple as possible in order to make them economically viable options for reef-monitoring programs throughout the world. A stereomicroscope and a technician trained in identification are the main necessities (Hallock et al. 2003, Daniels 2005).

PROJECT OBJECTIVES

The first goal of this project was to describe and characterize sediments and rubble samples at selected patch reefs in Biscayne National Park with respect to:

- grain size distribution
- total foraminiferal assemblages
- sediment constituents
- abundance of *Amphistegina gibbosa* and other live symbiont-bearing foraminifera
- and the presence and prevalence of bleaching in *A. gibbosa*

The second goal of this project was to characterize spatial variability in the above parameters and compare them with selected measured environmental parameters.

The final goal was to test the three indices (FORAM, SEDCON, and Photic) on the BNP patch reefs to determine if they are comparable and useful in characterizing the patch reefs.

METHODS

Field Area

Sampling for this project was conducted in Biscayne National Park seaward of Elliot Key. This area is affected by water emerging from Biscayne Bay in two areas: the main pass (also known as the Safety Valve), north of Elliot Key, and Caesar's Creek between Elliot Key and Old Rhode's Key (Wang et al. 2003). USGS-LIDAR data and Landsat imagery were used to determine sampling sites (Fig. 3). A total of 32 reefs along ten roughly east-west transects were sampled, including 30 patch reefs and two bank-barrier reefs (Pacific and Lugano). Individual reefs were chosen to conform as much as possible to linear transects and were identified by the characteristic sand halos. Several sites correspond to named reefs where past reef assessments have been conducted (Nirvana, Bug Reefs [Ginsburg et al. 2001] and Dome, Star, Elkhorn [Jaap and Wheaton 1977, Dupont et al. *in press*]) and/or buoyed reefs marked by Biscayne National Park.

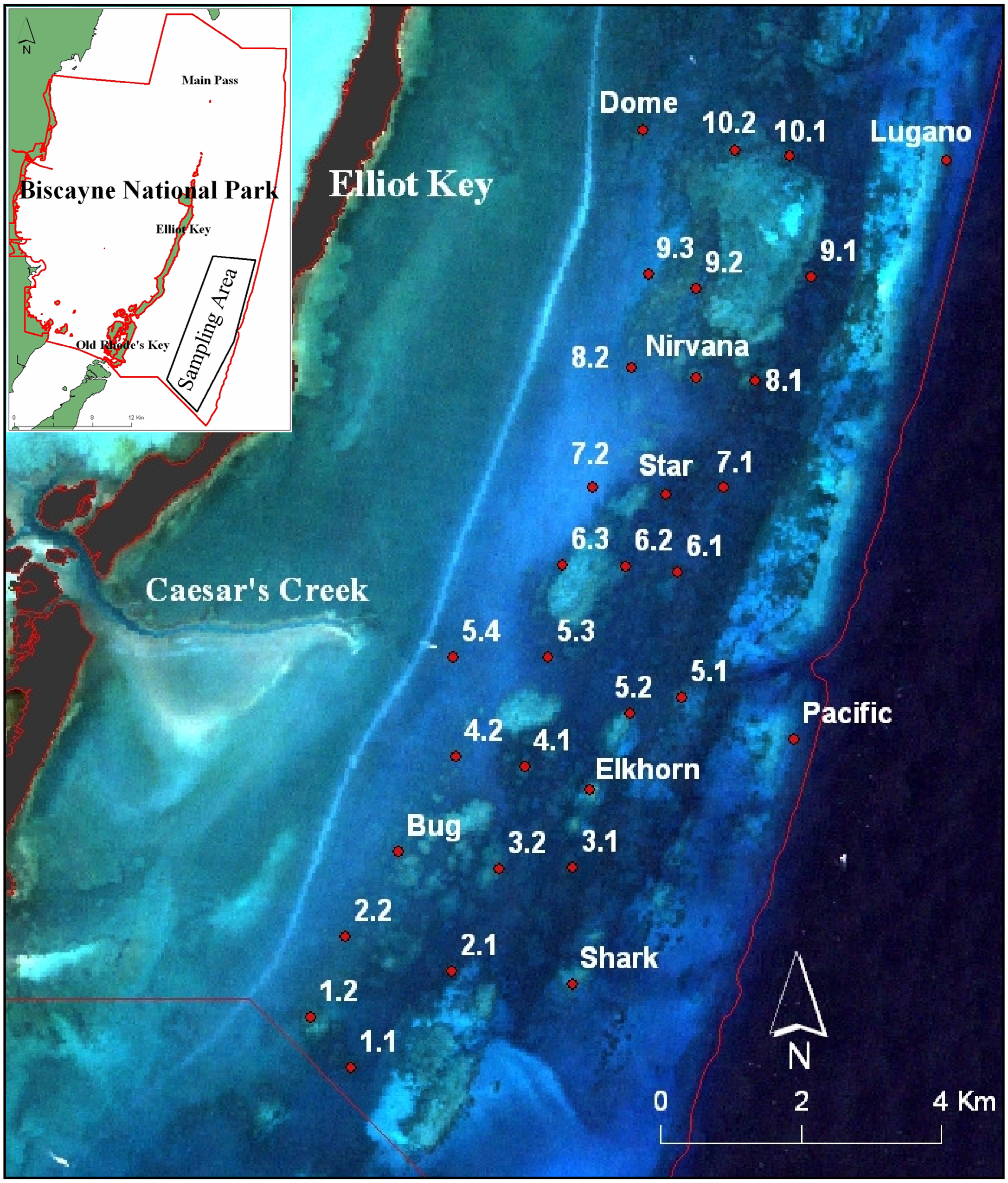


Figure 3. Sampling sites in Biscayne National Park

Sampling Methods

Sampling was conducted in early May 2007. At each reef, the following samples or environmental data were collected by SCUBA divers:

- three replicates of ~3 pieces of coral rubble in a plastic Ziploc bag (for the Photic Index)
- three replicates of ~15cm^3 of sediment in plastic vials (for the FORAM and SEDCON Indices)
- depth, dissolved oxygen, temperature, salinity, and pH

Sediment samples were stored in a -40°C freezer until processed (Hallock et al. 2003, Daniels 2005). During collection, reef rubble samples were kept in a shaded area of the boat until they were able to be scrubbed with a soft toothbrush to remove sediment, algae, and attached fauna. The resulting mix of sediment and seawater was stored in 1-liter, wide-mouth containers for transport to the laboratory.

In the laboratory, excess water was poured out of the containers and the sediment was distributed into large Petri dishes and covered with fresh seawater, and then maintained in a culture chamber set on a 12-hour light/dark cycle at 25°C until assessed. Further sampling details can be found in Williams et al. (1997) and Hallock et al. (2006).

Sample Processing

SEDCON and FORAM Indices

Each sediment sample was washed with deionized water over a 63µm sieve into 100 ml beakers to separate the mud from the sand-sized fraction of the sample. Weights for the empty beakers were recorded prior to sieving so the dry weight of each sample could be determined. All were placed in a 60°C drying oven until dry. After gently but thoroughly mixing the dried sample, a 1-gram sub-sample was taken for the FORAM Index analysis. Depending upon the grain size of the sample, a small scoop (~0.1g) was weighed, sprinkled over a gridded tray, and observed under a stereomicroscope (Hallock et al. 2003).

A very fine artist's brush (size 5/0), moistened with water, was used to pick foraminiferal specimens from the tray and place them on a micropaleontological faunal slide coated in water-soluble glue. Additional portions of the 1-gram sub-sample were picked until a sample size of approximately 150-200 specimens was reached or the entire 1-gram sample was analyzed. A sample of this size has been shown to be a statistically similar to a sample size of 300 while also conserving processing time (Dix 2001, Hallock et al. 2003). Each foraminifer was identified to the genus level to minimize inconsistencies in species identification. Test deformities among the specimens were also noted.

The remaining portion of the dried sediment was used for grain-size analysis (Folk 1974) and the SEDCON Index (Daniels 2005). Grain-size analysis was conducted by sorting sediment samples through a set of sieves on a shaker table at medium strength for 10 minutes. Percent weights of each of the following size fractions were determined: > 2mm (-1 φ), 1-2 mm (0 φ), 0.5-1 mm (1 φ), 0.25-0.50 mm (2 φ), 0.125-0.250mm (3 φ), 63 µm-0.125 mm (4 φ), < 63 µm (>4 φ). For the sediment constituent analysis, the size fraction of 0.5-2mm was recombined for examination. Using this size fraction reduces errors of misidentification (Daniels 2005). A 1-gram sub-sample was sprinkled onto a gridded tray; 300 calcareous grains were selected using a point-count method and transferred to a micropaleontological slide (as in the FORAM procedure) and identified.

Live Symbiont-bearing Foraminifera (LSF)

All *Amphistegina gibbosa* specimens were picked using forceps from the Petri dishes stored in the culture chambers. Live individuals were determined by color and pseudopodial activity and were then counted, measured (maximum diameter to the nearest 50µm), and characterized. Symbiont color was noted as normal, partly bleached (less than 50% loss of symbiont color), or bleached (more than 50% loss of symbiont color). Other physical abnormalities, such as breakage, were noted (Williams et al. 1997, Hallock et al. 2006).

The rubble, from which the sediment slurry was scrubbed, was photographed over gridded paper with centimeter squares. The photographs were analyzed to determine surface area using Coral Point Count with Excel Extensions. The surface areas were used to calculate densities of live foraminifers per $100cm^2$.

Data Analysis

Statistical Analysis

After the raw data were collected and recorded, the assemblage data were standardized and square-root transformed to create cluster analyses and MDS (multi-dimensional scaling) plots using the statistical package PRIMER v6 (Plymouth Routines In Multivariate Ecological Research, 2006). This determined how the samples clustered (Q-mode analysis) as well as how the variables (foraminiferal genera) clustered (R-mode analysis). Square-root transformations were carried out on the assemblage data to down weigh the presence of highly abundant taxa/sediment constituents. Two-dimensional MDS plots were used in this analysis, which showed similarity between sites based on a Bray-Curtis similarity matrix. For an MDS plot, the proximity between sites represented similarity and a stress level of ≤ 0.2 was considered to be a useful representation of relationships (Clarke and Warwick 2001). The same process was carried out for R-mode analysis to define groupings of taxa.

To enhance the interpretation of the MDS plots, the SIMPER (similarity percentages) routine was also performed in PRIMER. This analysis identified clustering of samples and also the taxa or sediment constituents that contributed to the similarity within a group and the dissimilarity between groups. This analysis is especially useful when the stress level of an MDS plot is high because it represents group structure based on the actual similarity matrix, not the MDS representation (Clarke and Gorley 2006).

Another procedure included in PRIMER is known as BIO-ENV. This procedure was used to determine relationships between environmental data (temperature, salinity, dissolved oxygen, and pH) and the assemblage data, and was used to detect which environmental parameters matched variation in assemblage data between sites.

Pearson's correlation matrices were also created using Statistica 8.0 (2007) statistical software to further aid the interpretation of the data.

Index Calculations

Foraminifers identified to genus for the FORAM Index (FI) were separated into three functional groups: larger symbiont-bearing foraminifers, stress-tolerant taxa, and other smaller foraminifers. The percent abundance of each of these groups was used to calculate the FORAM Index (Hallock et al. 2003) (Table 1). An FI value greater than 4 indicates environments suitable for reef growth. An FI value between 2 and 4 indicates marginal reef environments that may not be able to recover from a stress event. Below 2, the environmental condition is poor and unsuitable for reef growth (Hallock et al. 2003).

Similarly, the 300 grains of sediment previously identified were grouped into four functional groups for the SEDCON Index (SI) (Table 2). The percent abundances of the functional groups were used to calculate an index value (Daniels 2005) (Table 3). Several texts were used to aid in the identification of sediment constituents (e.g., Bathurst 1976; Scoffin 1987). This index is a modified version of the FORAM Index to include the range of sediments in addition to foraminiferal tests. Like the FORAM Index, lower values indicate declining potential for reef accretion.

The third index, the Photic Index, is based on the density of *Amphistegina* and the percent experiencing bleaching in a sample (Table 4). Density of *Amphistegina*, like the FI and the SI, should reflect the suitability of the habitat for mixotrophic, calcifying organisms, though on a scale of weeks to months rather than months to years. The incidence and intensity of bleaching relates only to photic stress on time scales of days to weeks and therefore can’t be directly compared to the sediment-based indices.

Table 1. Calculation of the FORAM Index

$FI = (10*P_s)+(P_o)+(2*P_h)$	
Where,	$P_s= N_s/T$ $P_o= N_o/T$ $P_h= N_h/T$
And,	T = total number of specimens counted
	N_s= number of symbiont-bearing Foraminifera
	N_o=number of stress-tolerant Foraminifera*
	N_h= number of other small, heterotrophic Foraminifera

* “Opportunistic” as defined by Hallock et al. 2003 is changed to “stress-tolerant” in this paper (Yanko et al. 1999, Carnahan 2005, Carnahan et al. *submitted*).

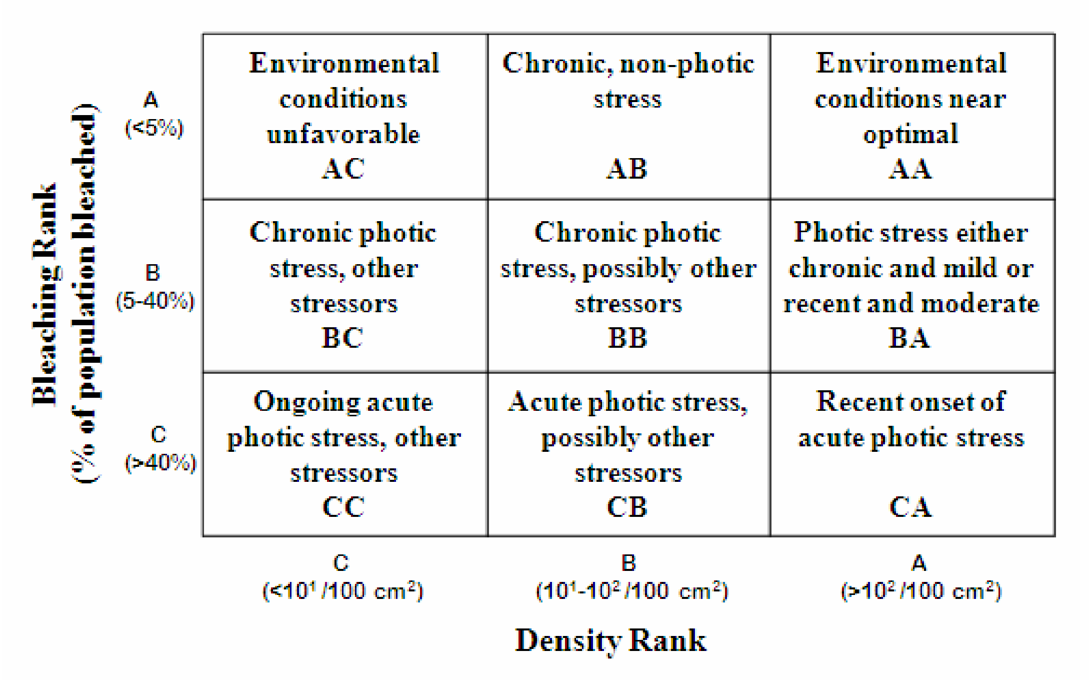
Table 2. Division of grains for sediment constituent analysis modified from Daniels (2005); exemplary photos of major sediment constituents can be found in Appendix V-b

SI functional group	Sediment grain	Community Role/ Feeding mode	Interpretation
P_c	Scleractinian Coral	Primary reef builder, mixotrophic	Area suitable for calcification by algal symbiosis
P_f	Larger, symbiont-bearing foraminifers	Sediment producer, mixotrophic	Area suitable for calcification by algal symbiosis
P_{ah}	Coralline algae	Framework builder, autotrophic	Varies with other components
	Calcareous algae	Sediment producers, autotrophic	Nutrient signal, high CaCo3 saturation
	Molluscs	Grazers/predators, heterotrophic	Food resources plentiful, nutrient signal
	Echinoid Spines	Bioeroders/grazers, heterotrophic	Bioerosion, nutrient signal
	Worm Tubes	Heterotrophic	Abundant food resources
	Other (smaller foraminifers, bryozoans, fecal pellets, etc)	Sediment producers, heterotrophic	Abundant food resources
P_u	Unidentifiable	Bioerosion proxy	Bioerosion proxy

Table 3. Calculation of the SEDCON Index (Daniels 2005)

$SI = (10*P_c)+(8*P_f)+(2*P_{ah})+(0.1*P_u)$	
Where,	$P_c = N_c/T$ $P_f = N_f/T$ $P_{ah} = N_{ah}/T$ $P_u = N_u/T$
And,	T = toal number of grains counted (300)
	N_c= number of coral grains
	N_f=number of symbiont-bearing Foraminifera
	N_{ah}=number of coralline algae, calcareous algae, and heterotrophic skeletal grains
	N_u= number of unidentifiable grains

Table 4. Matrix describing the proposed Photic Index.



Bleaching Rank (% of population bleached)	C ($<10^1$/100 cm^2)	B (10^1-10^2/100 cm^2)	A ($>10^2$/100 cm^2)
A (<5%)	Environmental conditions unfavorable AC	Chronic, non-photic stress AB	Environmental conditions near optimal AA
B (5-40%)	Chronic photic stress, other stressors BC	Chronic photic stress, possibly other stressors BB	Photic stress either chronic and mild or recent and moderate BA
C (>40%)	Ongoing acute photic stress, other stressors CC	Acute photic stress, possibly other stressors CB	Recent onset of acute photic stress CA

Density Rank

Pattern Analysis

Spatial patterns between the two sediment-based indices were compared based on their actual index values and also on the distribution of their SIMPER groupings. The Kriging method of interpolation was used in Surfer v8.05, surface mapping system (Golden Software 2004), to create contours of SEDCON Index values and FORAM Index values. In addition, contours were created for several of the measured water-quality parameters (salinity, temperature, % mud, etc.). Maps were produced using ArcMap v9.2 (ESRI 2006).

GeoDA 0.9.5-i, geostatistical analysis software (Anselin et al. 2006), was used to determine if there was spatial autocorrelation and multivariate spatial correlation within and between each of the parameters and to what extent the correlations were significant. To do this, Moran's I was calculated. This procedure was similar to calculating a Pearson's correlation except that a point's value was compared to a weighted average of its neighboring points' values, such that there was spatial autocorrelation if a point was surrounded by points with similar values and further from points with a large difference in value. This provided a spatial analysis of relationships between the calculated indices and the water-quality parameters to support the BIO-ENV procedure.

Table 5. List of common abbreviations used in summarizing the results.

Abbreviation	Definition
BNP	Biscayne National Park
FI	FORAM Index
SI	SEDCON Index
PI	Photic Index
DO	Dissolved Oxygen
LSF	Live Symbiont-bearing Foraminifera
Density	# of foraminiferal shells per gram of sediment
Genera	# of genera

RESULTS

Grain-Size Analysis

Grain size was calculated as a weight-percent distribution as defined by the Wentworth scale (Table 6). Median grain size was calculated for samples from each reef site and a median Phi size class was determined. At the majority of reef sites (59%), sediments had a median Phi size of 1 (coarse sand). This size class, along with very coarse sand (accounting for 19% of sites), represented the range of sediment analyzed for the SEDCON Index. Of the samples from the remaining sites, 16% had a median Phi of 2 (medium sand) and 6.3% had a median Phi of 3 (fine sand) (Appendix I).

Table 6. Size classifications of sediments and summary of median grain size.

Size Description	Size range	Phi (Φ) size class	# of sites with median grain size
Gravel/Granule	>2mm	-1	0
Very coarse sand	1-2mm	0	6
Coarse sand	0.5-1mm	1	19
Medium sand	0.25-0.5mm	2	5
Fine sand	0.125-0.25mm	3	2
Very fine sand	63um-0.125mm	4	0
Silt/clay/mud	<63um	>4	0

Samples from five sites (16%) contained more than 10% mud, with the highest percentage of mud being 33% at Bug Reef. Contours of percent mud throughout the sampling area are illustrated in Figure 4.

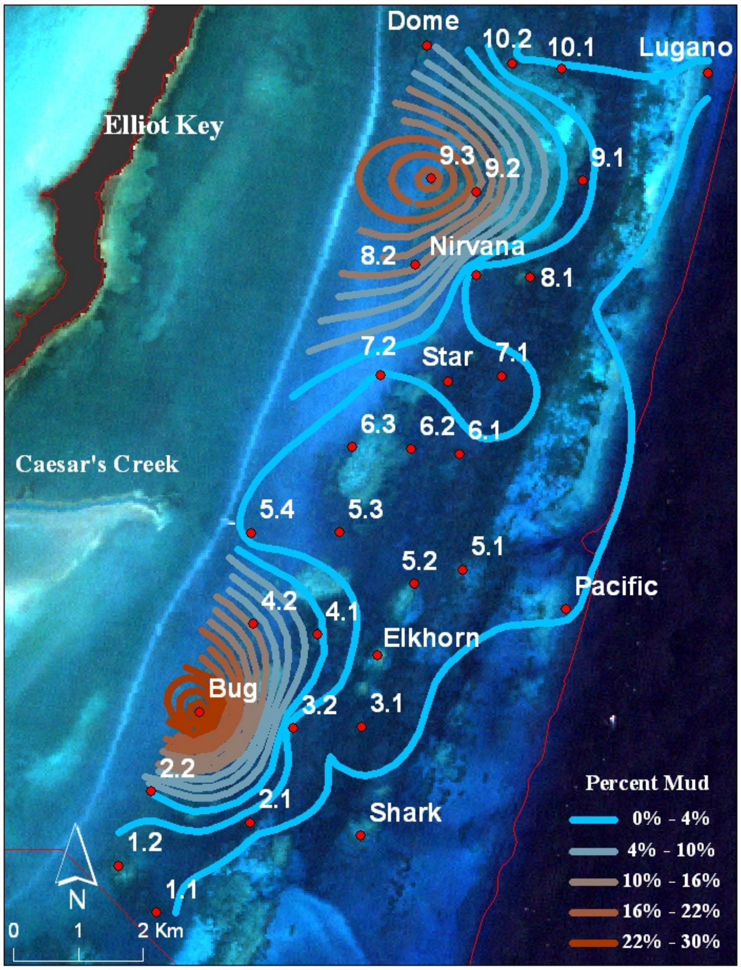


Figure 4. Percent mud in sediments from patch reefs of Biscayne National Park

Environmental Data

Temperature, salinity, dissolved oxygen (DO), and pH were measured at each site during sample collection. Temperature varied only slightly with less than a 2°C range, while salinity varied less than 1‰. However, both temperature and salinity showed evidence of a spatial pattern (Fig. 5) with significant ($p<0.01$) Moran's I values (0.31 and 0.27 respectively). The two patterns also negatively correlated with each other, which can be seen in the Pearson's correlation matrix constructed for relationships between environmental parameters (Table 7). This is also supported by a significant bivariate Moran's I (-0.33). Since DO and pH had insignificant spatial autocorrelation, these parameters were excluded from further analysis because individually these parameters cannot effect spatial distribution of reefs if there is no pattern to their values.

Salinity contours have an inshore-offshore trend, meaning salinity decreased offshore. Off the mouth of Caesar's Creek, a 'bump' in the salinity contours indicated a tongue of lower salinity waters (Fig. 5a). The temperature contours also showed an inshore-offshore trend, warming offshore. Further, the temperature contours also displayed a "bump' similar to salinity in that warmer waters were in the same area that the lower salinity waters were located (Fig. 5b). Both temperature and salinity significantly correlated with percent mud and density of forams, while salinity negatively correlated with depth.

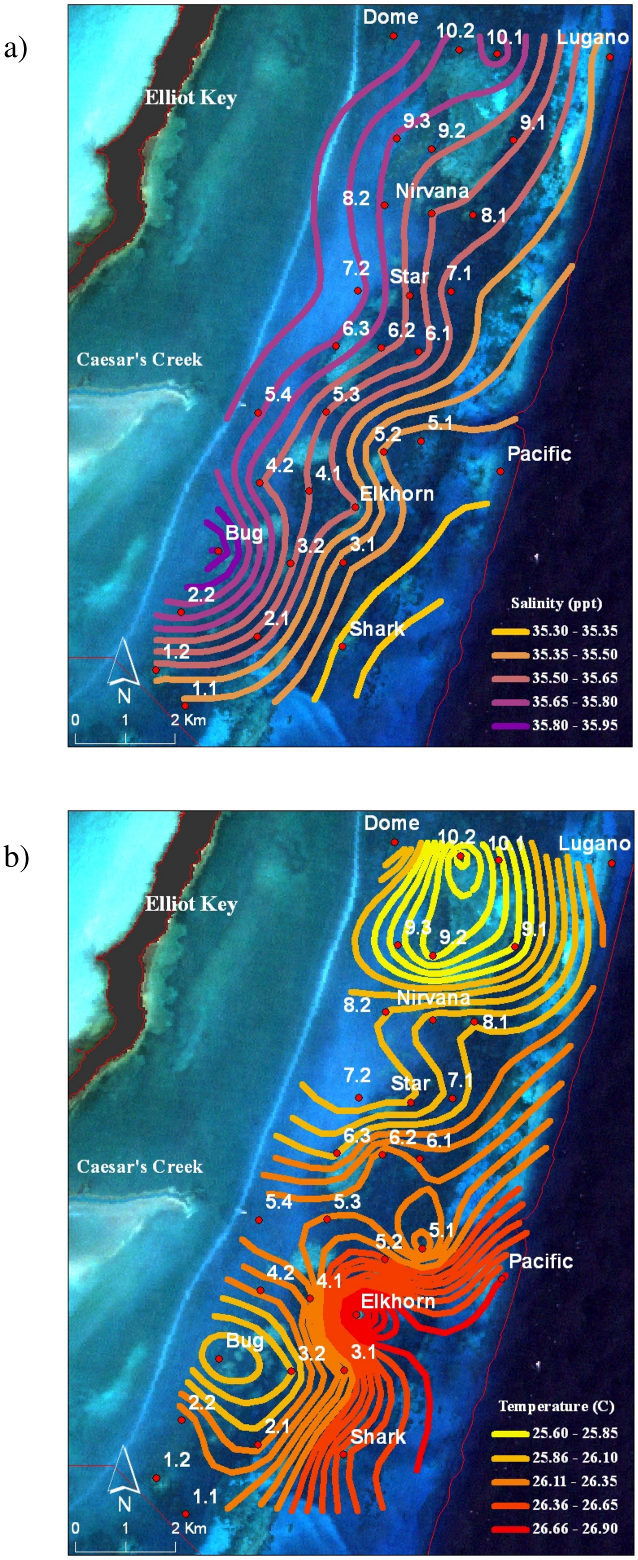


Figure 5. Contours of a) salinity and b) temperature data collected during sampling

Table 7. Pearson's correlation coefficients between environmental data (abbreviations as in Table 5) (**Bold** indicates significance at $p<0.05$)

	FI	SI	% Mud	Depth	LSF	Phi	Density	Genera	Temperature	Salinity
FI	1.00									
SI	**-0.53**	1.00								
% Mud	**-0.62**	**0.66**	1.00							
Depth	0.06	-0.25	-0.29	1.00						
LSF	0.16	-0.19	-0.24	-0.18	1.00					
Phi	**-0.40**	**0.42**	**0.73**	-0.15	-0.07	1.00				
Density	**-0.55**	**0.60**	**0.79**	-0.17	**-0.32**	**0.69**	1.00			
Genera	**-0.64**	**0.37**	0.24	0.11	-0.01	0.09	**0.32**	1.00		
Temperature	**0.33**	**-0.61**	**-0.42**	0.14	-0.09	**-0.42**	**-0.46**	-0.12	1.00	
Salinity	**-0.47**	**0.46**	**0.53**	**-0.45**	0.28	**0.43**	**0.35**	0.26	**-0.48**	1.00

Foraminiferal Assemblages

Among the 32 reefs, a total of 82 genera of Foraminifera were identified. The raw data for these analyses, including counts and density, can be found in Appendix II. In Table 7, density (# of foraminiferal shells per gram of sediment) and genera (# of genera found at each site) were included as environmental data as they gave a very general view of the foraminiferal assemblage. Note that the two variables had a significant positive correlation.

The cluster and SIMPER analyses were run only on those foraminiferal assemblages where more than 50 specimens were present in a gram of sample. Replicates were analyzed separately so that out of 64 possible samples, 44 remained after removing those samples that did not contain sufficient specimens. The resulting analysis showed that sites clustered into five major groups (A, B, C, D, E). Each group had a within group similarity higher than 59% based on the SIMPER results.

Figure 6 is the MDS plot of the foraminiferal assemblage data symbolized by their SIMPER groups. Because the SIMPER groups generally match the clustering of the

MDS plot (stress value = 0.18), this is a viable representation of similarity between sites. Table 8 is the SIMPER output showing the average within group similarity, the percent that each genus contributes to the group's similarity, and which FORAM Index functional group each genus belongs to. SIMPER-generated dissimilarity tables between groups can be found in Appendix III. Environmental data were averaged among sites within a group and are reported in Table 9.

Group A consists of six sites with a similarity of 68%. These sites dominate the area most immediately affected by Caesar's Creek and also the upper and lower most edges of the sampling area (Fig. 7). Other smaller foraminifers make up about 50% of the contribution while symbiont-bearing taxa account for approximately 35%. Only one stress-tolerant genus is present in this group's contributing taxa (*Elphidium*). Group A sites are characterized as having very little mud, low densities of foraminifers, and the lowest diversity, with the second highest average FI value.

Group B was the biggest cluster with nine sites having both replicates within it. This group represented the most intermediate of sites with all environmental parameters being right in the middle of their ranges and all replicates having a similarity of 67%. It had a slightly higher contribution by stress-tolerant taxa (*Elphidium, Bolivina*, and *Ammonia*) as well as a higher contribution of other smaller foraminifers, and fewer symbiont-bearing Foraminifera. Because group B represented the most intermediate group, any site that had one replicate in group B and one replicate in another group was graphically displayed as the other group to represent the transition away from intermediate. These sites included 2.1, 2.2, 3.1, 9.1, 9.2, and 9.3.

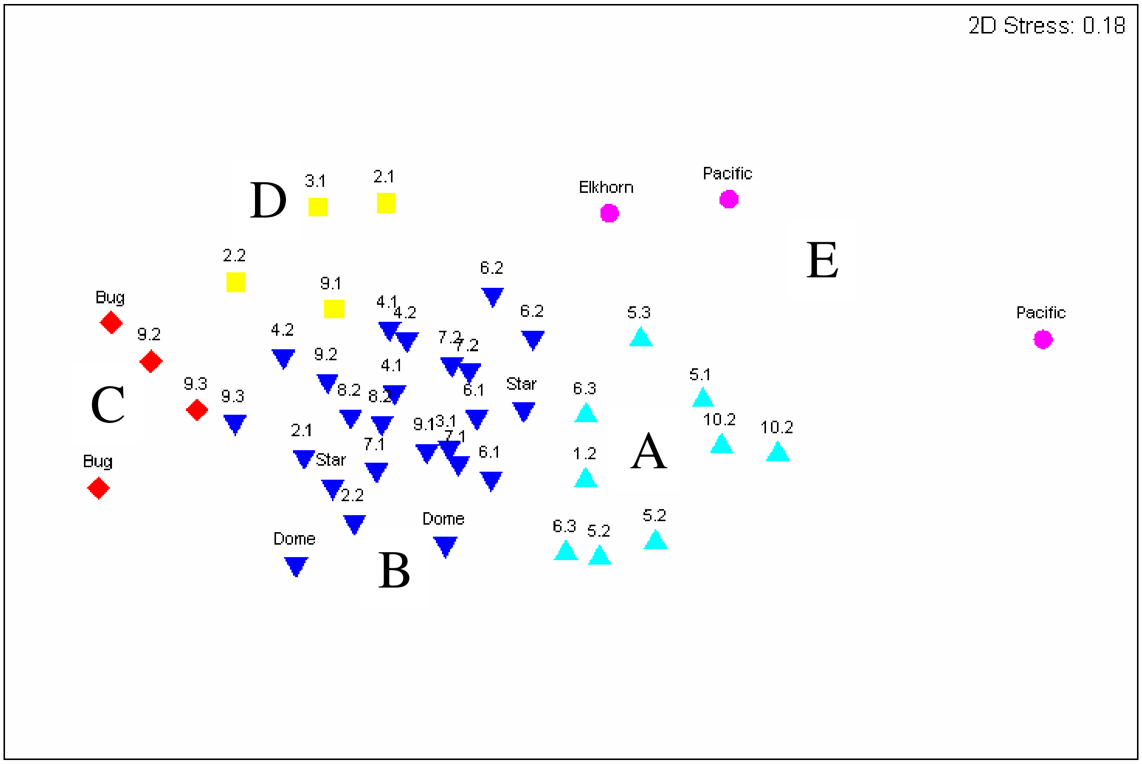


Figure 6. MDS plot of reefs represented by their SIMPER groups defined by similarity of foraminiferal assemblages.

Table 8. Within-group similarity of the SIMPER-defined groups for the foraminiferal assemblage. (*FI group refers to FORAM Index functional group where SB-symbiont-bearing, ST-stress-tolerant, and HT-heterotrophic)

Group A - n=9				**Average similarity: 68%**		
Genus	**FI group***	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Quinqueloculina	HT	4.08	9.64	8.49	14.2	14.2
Archaias	SB	4.25	9.57	3.29	14.1	28.2
Discorbis	HT	3.63	8.33	5.87	12.2	40.5
Laevipeneroplis	SB	2.87	6.22	4.22	9.14	49.6
Triloculina	HT	2.63	5.43	3.69	7.98	57.6
Siphonaperta	HT	2.54	5.01	2.97	7.36	64.9
Rosalina	HT	1.87	4.25	6.6	6.24	71.2
Elphidium	ST	1.62	3.57	4.89	5.24	76.4
Amphistegina	SB	1.68	3.33	3.44	4.89	81.3
Cyclorbiculina	SB	1.49	3.12	3.32	4.58	85.9
Textularia	HT	1.27	2.21	1.56	3.24	89.1
Asterigerina	SB	0.85	1.41	1.13	2.07	91.2

Table 8. (Continued)

Group B - n=24						**Average similarity: 67%**
Genus	**FI group***	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Quinqueloculina	HT	5.36	10.8	9.94	16.1	16.1
Triloculina	HT	3.09	6.02	5.81	8.95	25.0
Laevipeneroplis	SB	2.99	5.72	6.33	8.51	33.5
Rosalina	HT	2.51	4.71	5.63	7.01	40.6
Archaias	SB	2.05	3.58	3.44	5.33	45.9
Siphonaperta	HT	1.81	3.25	3.3	4.83	50.7
Discorbis	HT	1.81	3.09	2.4	4.6	55.3
Elphidium	ST	1.35	1.98	1.6	2.95	58.3
Amphistegina	SB	1.22	1.96	1.94	2.92	61.2
Cycloforina	HT	1.18	1.94	1.92	2.88	64.1
Triloculinella	HT	1.1	1.78	1.65	2.65	66.7
Textularia	HT	1.3	1.73	1.3	2.57	69.3
Miliolinella	HT	1.04	1.51	1.32	2.25	71.5
Articulina	HT	1.01	1.45	1.33	2.15	73.7
Peneroplis	SB	0.95	1.4	1.37	2.09	75.8
Bolivina	ST	1.05	1.3	1	1.93	77.7
Broekina	SB	1.02	1.29	1.01	1.91	79.6
Haynesina	ST	0.97	1.22	0.92	1.82	81.4
Spiroloculina	HT	0.83	1.21	1.22	1.8	83.2
Ammonia	ST	0.74	0.89	0.94	1.33	84.6
Hauerina	HT	0.7	0.85	0.86	1.26	85.8
Adelosina	HT	0.66	0.75	0.77	1.11	86.9
Cribroelphidium	ST	0.69	0.73	0.68	1.09	88.0
Cyclorbiculina	SB	0.66	0.69	0.75	1.03	89.0
Nonionoides	ST	0.56	0.62	0.77	0.91	90.0
Asterigerina	SB	0.65	0.6	0.6	0.89	90.8

Table 8. (Continued)

Group C - n=4					**Average similarity: 74%**	
Genus	**FI group***	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Quinqueloculina	HT	6.59	15.3	16.0	20.8	20.8
Rosalina	HT	3	6.63	20.8	9.02	29.8
Triloculina	HT	2.42	5.16	7.13	7.02	36.8
Bolivina	ST	2.23	4.75	7.49	6.45	43.3
Miliolinella	HT	2	4.4	85.4	5.98	49.3
Laevipeneroplis	SB	1.84	3.8	4.87	5.16	54.4
Elphidium	ST	1.94	3.79	5.56	5.15	59.6
Cribroelphidium	ST	1.38	2.86	5.55	3.89	63.5
Haynesina	ST	1.35	2.68	3.42	3.65	67.1
Discorbis	HT	1.32	2.4	2.88	3.26	70.4
Articulina	HT	1.14	2.14	5	2.91	73.3
Sigmiolina	HT	1.35	1.92	0.91	2.61	75.9
Bulimina	ST	1.03	1.91	12.9	2.59	78.5
Cibicides	HT	0.7	1.57	9.38	2.14	80.6
Eponides	HT	0.75	1.57	9.38	2.14	82.8
Pseudohauerina	HT	0.71	1.5	5.74	2.04	84.8
Cycloforina	HT	0.92	1.44	0.91	1.96	86.8
Cornuspira	HT	0.95	1.38	0.9	1.87	88.6
Nonionoides	ST	0.94	1.29	0.88	1.75	90.4

Table 8. (Continued)

Group D - n=4						**Average similarity: 64%**
Genus	**FI group***	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Quinqueloculina	HT	5.24	10.0	9	15.5	15.5
Rosalina	HT	2.91	5.44	5.57	8.42	23.9
Laevipeneroplis	SB	2.75	4.93	7.17	7.63	31.6
Siphonaperta	HT	2.24	4.11	17.9	6.36	37.9
Archaias	SB	1.95	3.5	6.98	5.41	43.3
Discorbis	HT	2.09	3.45	3.8	5.34	48.7
Sigmiolina	HT	1.67	3.2	11.8	4.95	53.6
Triloculina	HT	1.83	3.17	4.64	4.9	58.5
Ammonia	ST	1.74	2.77	2.94	4.29	62.8
Cycloforina	HT	1.17	2.02	4.48	3.12	65.9
Haynesina	ST	1.29	1.96	5.7	3.04	69.0
Eponides	HT	1.17	1.91	6.06	2.95	71.9
Elphidium	ST	1.26	1.84	2.69	2.84	74.8
Peneroplis	SB	1.06	1.83	6.11	2.83	77.6
Cornuspira	HT	1.09	1.81	4.63	2.79	80.4
Textularia	HT	1.16	1.24	0.91	1.91	82.3
Articulina	HT	1.11	1.08	0.91	1.67	84.0
Miliolinella	HT	1	0.97	0.84	1.51	85.5
Bulimina	ST	0.85	0.96	0.89	1.49	87.0
Wiesnerella	HT	0.82	0.9	0.87	1.39	88.3
Cibicides	HT	0.62	0.8	0.91	1.24	89.6
Adelosina	HT	0.67	0.8	0.91	1.23	90.8

Group E - n=3						**Average similarity: 59%**
Genus	**FI group***	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Archaias	SB	4.52	8.08	7.44	13.7	13.7
Discorbis	HT	3.37	7.51	15.0	12.7	26.4
Asterigerina	SB	2.43	5.23	6.8	8.84	35.2
Laevipeneroplis	SB	2.52	5.18	25.5	8.76	44.0
Cyclorbiculina	SB	2.52	4.8	3.77	8.11	52.1
Amphistegina	SB	2.32	4.41	5.77	7.45	59.5
Quinqueloculina	HT	2.77	4.39	1.75	7.42	66.9
Neocornorbina	HT	1.35	2.73	8.86	4.61	71.5
Siphonaperta	HT	1.32	2.5	6.53	4.23	75.8
Heterostegina	SB	1.27	2.47	7.34	4.18	80.0
Rosalina	HT	2.27	2.26	0.58	3.83	83.8
Borelis	SB	1.32	2.22	3.19	3.76	87.5
Triloculina	HT	0.99	2.06	4.76	3.49	91.0

Table 9. Means for diversity, density, and environmental data for foraminiferal assemblage SIMPER groups.

Group	FI	density (forams/g)	# of genera	pH	Temperature	DO	Salinity	% Mud	Phi
A	4.85	126	21.7	8.31	26.09	6.32	35.57	0.55	1.11
B	3.60	957	31.7	8.32	26.08	6.25	35.66	5.76	1.33
C	2.22	5518	29.8	8.22	25.83	6.42	35.82	26.4	2.75
D	3.13	1015	33.0	8.26	26.11	6.46	35.60	1.95	0.75
E	6.36	123	25.3	8.29	26.81	6.79	35.44	0.30	0.67

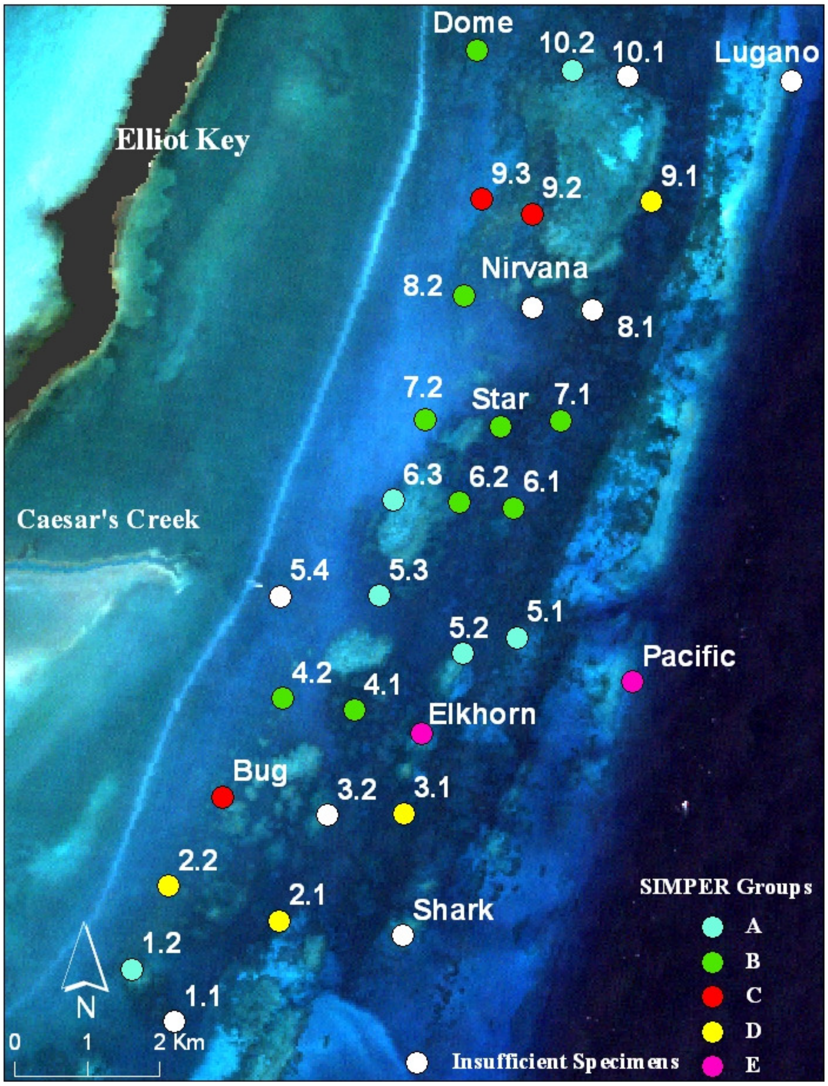


Figure 7. Sample sites with more than 50 foraminifers represented by their foraminiferal assemblage SIMPER groups.

Group C included the sites with the lowest FORAM Index values and highest percent mud by far. The contribution of symbiont-bearing foraminifers in this group was only 5%, while almost 22% of the defining taxa were stress-tolerant, representing 5 different genera. Spatially, these sites were located close to shore, and near the most interior portions of both Old Rhode's Key and Elliot Key and furthest from direct sources of water flow.

The fourth group, Group D, appeared to be a transitional group between Groups B and C. Each of the four sites that fell in this cluster had a replicate also in B. The average FI was only slightly lower, and the average density and diversity of Foraminifera was only slightly higher (Table 9).

Finally, Group E represents offshore sites in near optimal conditions with the highest average FI, lowest foraminiferal density, and lowest percent mud. More than half of the major contributing genera were symbiont-bearing.

Pearson's correlation matrices were made to compare how the taxa represented in the SIMPER analyses correlated with each other (Table 10). All significant correlations between symbiont-bearing Foraminifera were positive as expected. The strongest taxa correlation was between *Quinqueloculina* and *Bolivina* at 0.78 ($p<0.027$), followed by *Quinqueloculina* and *Rosalina* at 0.74. The strongest negative correlation occurred between *Quinqueloculina* and *Archaias* (-0.47). While most significant correlations between smaller heterotrophic foraminifera and symbiont-bearing Foraminifera were negative, several genera had positive correlations, most notably *Neocornorbina,* which had significant positive correlations with *Amphistegina*, *Asterigerina*, and

Cyclorbiculina. R-mode analysis of the foraminiferal assemblage data did not reveal any significant clustering of taxa.

Table 11 is a Pearson's correlation matrix between foraminiferal genera and the environmental data. Density (shells/gram), number of genera, and percent mud almost always negatively correlated with symbiont-bearing foraminifera and positively correlated with the stress-tolerant and heterotrophic foraminifera. *Discorbis*, however, tended to have negative correlations with those environmental parameters, which also agrees with the positive correlations it has with two symbiont-bearing genera (*Amphistegina* and *Archaias*). While it seems circular to include FI as an environmental variable in this context since it is based on the genera, what is shown from this is specifically which of the foraminifers correlated strongest with the FI. For the symbiont-bearing taxa, *Archaias* had the strongest relationship with the FI, while *Quinqueloculina* had the most influence of the smaller foraminifers.

From Table 7, it is possible to see the negative correlation between salinity and temperature. As a result, those taxa that correlated positively with salinity (stress-tolerant and other smaller taxa) also correlated negatively with temperature and vice versa. Depth and density of live symbiont-bearing forams (LSF) did not show strong correlations with other measured parameters.

The BIO-ENV procedure in PRIMER was performed for all replicates with more than 50 foraminifers to determine which environmental parameters could best explain the foraminiferal assemblage. Because number of genera and density were parameters based on the assemblage themselves, they were removed from this analysis as were depth and LSF because their correlations with the assemblage were weak.

Of the five contributing variables, percent mud was the single most influential variable on the distribution of the foraminiferal assemblage (0.49) (Table 12). However, the best combination of variables to explain the assemblage was temperature, salinity, and percent mud, which improved the correlation to 0.55.

Table 10. Correlation matrix of foraminiferal taxa; **bold** type represents correlations significant at $p<0.027$.

	Amphi	*Arch*	*Aster*	*Bor*	*Broek*	*Cyclor*	*Hetero*	*Laevi*	*Pene*
Amphistegina	1.00								
Archaias	**0.40**	1.00							
Asterigerina	0.18	0.22	1.00						
Borelis	0.12	0.14	**0.38**	1.00					
Broekina	-0.05	-0.11	0.12	-0.08	1.00				
Cyclorbiculina	0.29	**0.65**	**0.39**	0.24	-0.13	1.00			
Heterostegina	0.28	0.07	**0.60**	0.25	-0.05	**0.42**	1.00		
Laevipeneroplis	0.19	0.27	0.33	0.14	0.24	0.01	-0.13	1.00	
Peneroplis	0.18	-0.09	0.15	-0.03	0.24	-0.06	0.09	0.28	1.00
Ammonia	-0.15	-0.24	-0.12	-0.09	0.03	-0.27	-0.10	0.01	0.07
Bolivina	**-0.40**	**-0.44**	-0.21	-0.24	-0.14	-0.23	0.12	-0.13	-0.06
Bulimina	-0.31	-0.30	-0.18	-0.17	-0.28	-0.19	0.07	-0.30	-0.16
Cribroelphidium	-0.25	**-0.44**	-0.13	-0.17	-0.20	**-0.36**	-0.09	-0.15	-0.17
Elphidium	-0.31	-0.13	-0.21	-0.21	0.12	-0.16	-0.24	-0.08	-0.03
Haynesina	-0.31	**-0.47**	-0.26	-0.16	-0.10	-0.27	-0.13	-0.02	-0.07
Adelosina	**-0.36**	-0.31	-0.25	-0.15	0.04	-0.18	-0.10	-0.17	-0.01
Articulina	-0.17	-0.30	-0.18	-0.22	0.14	-0.33	-0.15	-0.01	0.05
Cibicides	-0.09	**-0.38**	-0.26	-0.28	0.25	**-0.39**	-0.25	0.02	0.16
Cornuspira	-0.20	**-0.37**	-0.09	-0.10	-0.08	-0.19	0.11	-0.16	0.10
Cycloforina	-0.12	-0.32	-0.19	**-0.41**	**0.35**	-0.30	-0.17	0.04	**0.41**
Discorbis	**0.47**	**0.71**	0.18	0.25	-0.18	0.32	0.21	0.00	-0.09
Eponides	-0.14	-0.17	-0.01	-0.28	-0.11	-0.13	-0.09	0.12	0.24
Hauerina	0.09	-0.16	0.00	0.20	0.07	0.01	-0.03	0.30	**0.50**
Miliolinella	-0.32	**-0.38**	**-0.44**	-0.19	-0.25	-0.33	-0.12	-0.24	-0.24
Neocornorbina	**0.44**	0.29	**0.40**	0.33	-0.13	**0.38**	0.31	0.30	-0.09
Nonionoides	-0.22	-0.13	-0.28	-0.14	-0.06	-0.13	-0.03	-0.16	0.11
Pseudohauerina	-0.08	-0.23	0.06	0.27	0.14	-0.31	-0.09	0.11	0.28
Quinqueloculina	**-0.36**	**-0.47**	**-0.34**	-0.32	-0.06	**-0.40**	-0.18	0.02	0.11
Rosalina	-0.21	**-0.39**	0.01	-0.08	-0.14	-0.11	0.17	0.07	0.09
Sigmoilina	-0.33	-0.30	-0.16	-0.19	-0.30	-0.28	-0.06	0.00	0.05
Siphonaperta	0.14	**0.59**	-0.03	-0.10	0.01	**0.42**	-0.14	0.18	0.01
Spiroloculina	0.02	-0.26	-0.21	-0.16	0.19	-0.25	-0.03	-0.02	0.15
Textularia	0.14	-0.02	0.09	0.30	0.24	-0.03	-0.15	0.21	**0.38**
Triloculina	0.15	**-0.36**	**-0.41**	-0.29	0.28	**-0.41**	**-0.37**	0.08	0.24
Triloculinella	0.06	-0.23	0.10	-0.10	0.15	-0.31	0.04	0.01	0.22
Wiesnerella	-0.22	-0.28	-0.04	0.17	-0.21	-0.23	-0.09	0.13	-0.11

Table 10. (Continued)

	Amm	*Boli*	*Buli*	*Cribro*	*Elph*	*Hayn*	*Adel*	*Arti*	*Cibi*
Amphistegina									
Archaias									
Asterigerina									
Borelis									
Broekina									
Cyclorbiculina									
Heterostegina									
Laevipeneroplis									
Peneroplis									
Ammonia	1.00								
Bolivina	0.18	1.00							
Bulimina	**0.39**	**0.62**	1.00						
Cribroelphidium	0.02	**0.49**	**0.40**	1.00					
Elphidium	-0.07	0.25	0.06	0.30	1.00				
Haynesina	0.27	**0.59**	**0.47**	0.21	0.15	1.00			
Adelosina	0.18	**0.42**	0.29	0.27	0.09	0.16	1.00		
Articulina	0.31	**0.34**	0.19	**0.38**	0.23	0.08	0.30	1.00	
Cibicides	0.31	**0.34**	**0.36**	0.10	0.22	0.33	0.19	**0.37**	1.00
Cornuspira	0.11	**0.53**	0.19	0.22	0.27	0.34	**0.49**	**0.44**	**0.34**
Cycloforina	0.12	0.18	0.09	0.20	**0.35**	0.26	0.14	**0.42**	0.29
Discorbis	-0.09	**-0.38**	-0.10	**-0.41**	-0.10	**-0.39**	-0.29	-0.21	-0.18
Eponides	0.27	0.17	0.28	0.22	0.03	0.06	-0.03	0.33	**0.37**
Hauerina	0.01	0.08	-0.16	0.07	-0.09	0.08	0.11	0.18	0.17
Miliolinella	0.17	**0.64**	**0.64**	**0.47**	0.34	**0.44**	**0.34**	**0.42**	**0.39**
Neocornorbina	0.01	-0.25	-0.21	-0.21	-0.18	-0.27	-0.17	-0.03	-0.31
Nonionoides	-0.27	**0.35**	0.03	**0.35**	**0.49**	0.01	**0.35**	0.16	0.04
Pseudohauerina	-0.07	0.09	-0.02	0.27	0.12	-0.09	0.08	0.19	0.17
Quinqueloculina	0.09	**0.78**	**0.44**	**0.59**	**0.45**	**0.50**	**0.51**	**0.57**	**0.46**
Rosalina	0.16	**0.71**	**0.47**	0.33	0.16	**0.56**	0.22	**0.41**	0.32
Sigmoilina	0.26	**0.62**	**0.59**	**0.43**	0.14	**0.39**	0.26	**0.38**	0.24
Siphonaperta	0.00	**-0.40**	-0.14	**-0.37**	-0.12	-0.25	-0.21	-0.20	-0.20
Spiroloculina	0.30	0.21	0.20	0.21	0.10	0.09	0.03	**0.36**	0.13
Textularia	-0.16	-0.31	-0.22	-0.21	-0.10	-0.14	-0.30	-0.13	0.05
Triloculina	-0.16	0.14	-0.06	0.28	0.15	0.11	0.30	0.30	**0.44**
Triloculinella	0.22	0.13	0.25	0.30	-0.08	-0.14	0.03	0.20	0.33
Wiesnerella	0.16	0.28	**0.35**	0.16	0.03	**0.45**	0.03	0.22	0.17

Table 10. (Continued)

	Cornu	*Cyclof*	*Disc*	*Epon*	*Hauer*	*Milio*	*Neocor*	*Non*	*Pseud*
Amphistegina									
Archaias									
Asterigerina									
Borelis									
Broekina									
Cyclorbiculina									
Heterostegina									
Laevipeneroplis									
Peneroplis									
Ammonia									
Bolivina									
Bulimina									
Cribroelphidium									
Elphidium									
Haynesina									
Adelosina									
Articulina									
Cibicides									
Cornuspira	1.00								
Cycloforina	0.14	1.00							
Discorbis	-0.21	-0.19	1.00						
Eponides	0.14	0.19	-0.11	1.00					
Hauerina	0.00	0.32	-0.13	0.12	1.00				
Miliolinella	**0.44**	0.21	-0.16	0.17	-0.02	1.00			
Neocornorbina	-0.20	-0.13	0.25	-0.26	0.18	-0.17	1.00		
Nonionoides	**0.39**	0.31	-0.10	0.10	-0.03	**0.38**	-0.17	1.00	
Pseudohauerina	0.22	0.15	0.01	0.17	0.32	0.21	-0.18	0.31	1.00
Quinqueloculina	**0.64**	**0.46**	**-0.40**	0.31	0.21	**0.73**	-0.32	**0.55**	0.28
Rosalina	**0.52**	0.31	-0.30	**0.38**	0.20	**0.64**	-0.04	0.25	0.08
Sigmoilina	**0.47**	0.14	-0.24	**0.50**	-0.04	**0.65**	-0.29	0.27	0.29
Siphonaperta	**-0.36**	-0.07	**0.42**	0.08	0.00	-0.23	0.08	-0.14	-0.12
Spiroloculina	-0.15	**0.40**	-0.16	0.06	0.09	0.29	0.03	0.17	0.00
Textularia	-0.09	-0.11	-0.04	0.16	0.17	-0.28	-0.17	-0.14	0.30
Triloculina	0.21	**0.47**	-0.33	0.04	0.32	0.12	-0.26	0.29	0.21
Triloculinella	-0.21	0.15	-0.10	0.14	0.26	-0.03	-0.09	-0.10	0.06
Wiesnerella	0.18	0.17	-0.18	0.27	-0.03	0.33	-0.06	0.08	-0.01

Table 10. (Continued)

	Quinq	*Rosa*	*Sigmo*	*Siphon*	*Spirol*	*Text*	*Triloc*	*Triloc*	*Wies*
Amphistegina									
Archaias									
Asterigerina									
Borelis									
Broekina									
Cyclorbiculina									
Heterostegina									
Laevipeneroplis									
Peneroplis									
Ammonia									
Bolivina									
Bulimina									
Cribroelphidium									
Elphidium									
Haynesina									
Adelosina									
Articulina									
Cibicides									
Cornuspira									
Cycloforina									
Discorbis									
Eponides									
Hauerina									
Miliolinella									
Neocornorbina									
Nonionoides									
Pseudohauerina									
Quinqueloculina	1.00								
Rosalina	**0.74**	1.00							
Sigmoilina	**0.68**	**0.70**	1.00						
Siphonaperta	**-0.37**	-0.31	-0.19	1.00					
Spiroloculina	0.29	0.22	0.12	-0.03	1.00				
Textularia	-0.15	-0.13	-0.15	0.14	0.00	1.00			
Triloculina	**0.42**	0.04	-0.07	-0.24	0.21	0.17	1.00		
Triloculinella	0.06	-0.05	-0.06	-0.19	0.30	0.06	**0.34**	1.00	
Wiesnerella	**0.42**	**0.63**	**0.47**	-0.19	0.18	-0.01	-0.07	-0.17	1.00

Table 11. Correlation matrix of foraminiferal taxa and environmental data; **bold** type represents correlations significant at $p<0.027$

	FI	SI	Depth	% Mud	Phi
Amphistegina	**0.53**	-0.28	-0.26	-0.34	-0.30
Archaias	**0.81**	**-0.38**	-0.02	**-0.50**	-0.27
Asterigerina	**0.55**	**-0.38**	0.20	**-0.43**	-0.33
Borelis	0.38	-0.43	-0.11	-0.30	-0.08
Broekina	0.00	0.12	0.30	-0.10	0.02
Cyclorbiculina	**0.74**	-0.33	0.08	**-0.38**	**-0.35**
Heterostegina	**0.58**	-0.33	-0.16	-0.18	-0.24
Laevipeneroplis	0.15	0.03	0.19	-0.24	-0.06
Peneroplis	-0.10	0.05	0.07	-0.05	-0.07
Ammonia	-0.34	0.22	0.01	0.11	0.10
Bolivina	**-0.57**	**0.57**	-0.24	**0.80**	**0.62**
Bulimina	**-0.48**	**0.37**	-0.32	**0.56**	0.33
Cribroelphidium	**-0.52**	0.27	-0.12	**0.62**	0.31
Elphidium	**-0.38**	0.12	0.17	**0.37**	**0.45**
Haynesina	**-0.55**	0.28	-0.06	**0.47**	**0.40**
Adelosina	**-0.41**	**0.71**	-0.17	**0.47**	0.19
Articulina	**-0.40**	0.28	0.16	0.26	0.32
Cibicides	**-0.47**	**0.59**	-0.25	**0.47**	**0.56**
Cornuspira	**-0.45**	**0.46**	-0.10	**0.44**	0.32
Cycloforina	**-0.46**	0.19	0.14	0.20	0.09
Discorbis	**0.42**	-0.33	**-0.35**	**-0.42**	-0.13
Eponides	-0.31	0.29	0.02	0.12	0.08
Hauerina	-0.16	0.16	0.03	0.09	0.13
Miliolinella	**-0.59**	**0.46**	-0.21	**0.67**	**0.61**
Neocornorbina	**0.41**	-0.25	0.04	-0.26	-0.21
Nonionoides	-0.32	0.30	-0.15	**0.48**	0.33
Pseudohauerina	-0.21	0.06	0.07	0.25	0.33
Quinqueloculina	**-0.69**	**0.63**	-0.11	**0.71**	**0.56**
Rosalina	**-0.51**	**0.40**	-0.09	**0.48**	**0.41**
Sigmoilina	**-0.41**	0.31	-0.10	**0.43**	0.33
Siphonaperta	0.19	-0.12	0.14	**-0.40**	-0.22
Spiroloculina	**-0.37**	0.17	0.05	0.21	0.21
Textularia	0.03	-0.26	**0.45**	-0.32	-0.15
Triloculina	**-0.50**	**0.51**	-0.10	**0.41**	0.20
Triloculinella	-0.29	0.19	-0.17	0.26	0.14
Wiesnerella	-0.29	0.07	-0.07	0.04	0.06

Table 11. (Continued)

	Temperature	Salinity	Density	Genera	LSF Density
Amphistegina	0.18	-0.10	**-0.41**	-0.28	0.27
Archaias	0.07	-0.27	**-0.43**	**-0.61**	0.23
Asterigerina	**0.38**	-0.34	-0.29	0.02	-0.03
Borelis	0.27	-0.12	-0.23	-0.18	0.15
Broekina	-0.06	0.08	-0.11	0.27	0.09
Cyclorbiculina	**0.35**	**-0.41**	-0.33	**-0.43**	0.04
Heterostegina	**0.66**	-0.32	-0.16	-0.20	-0.10
Laevipeneroplis	**-0.43**	0.13	-0.07	0.18	0.14
Peneroplis	-0.06	0.03	-0.03	**0.44**	0.02
Ammonia	-0.13	0.10	0.22	**0.46**	-0.15
Bolivina	**-0.36**	**0.41**	**0.85**	0.34	-0.33
Bulimina	-0.11	0.33	**0.69**	0.27	-0.29
Cribroelphidium	-0.27	**0.35**	**0.53**	**0.35**	-0.15
Elphidium	-0.20	0.11	0.34	0.08	**-0.36**
Haynesina	-0.29	**0.37**	**0.49**	0.32	0.01
Adelosina	**-0.36**	0.21	**0.50**	0.29	-0.18
Articulina	-0.21	-0.03	**0.45**	**0.49**	-0.08
Cibicides	-0.34	**0.34**	**0.49**	**0.39**	-0.16
Cornuspira	-0.24	0.12	**0.47**	0.27	-0.26
Cycloforina	-0.14	0.06	0.18	**0.53**	0.06
Discorbis	0.16	-0.03	-0.33	**-0.35**	0.32
Eponides	-0.22	0.20	0.26	**0.53**	-0.10
Hauerina	-0.13	0.07	0.10	**0.46**	0.20
Miliolinella	-0.31	**0.36**	**0.79**	0.19	-0.10
Neocornorbina	0.21	-0.22	-0.28	-0.12	0.13
Nonionoides	-0.18	0.27	0.32	0.12	-0.05
Pseudohauerina	-0.13	0.20	0.33	0.24	-0.02
Quinqueloculina	**-0.52**	**0.38**	**0.81**	**0.46**	-0.22
Rosalina	-0.28	0.27	**0.66**	**0.48**	-0.08
Sigmoilina	**-0.36**	0.19	**0.74**	0.26	-0.20
Siphonaperta	-0.06	-0.08	**-0.35**	-0.11	0.29
Spiroloculina	-0.07	0.15	0.27	**0.40**	0.04
Textularia	0.09	-0.12	-0.24	0.22	-0.01
Triloculina	**-0.38**	0.33	0.22	**0.40**	0.03
Triloculinella	-0.04	0.16	0.21	**0.52**	-0.04
Wiesnerella	-0.05	0.11	0.28	0.23	-0.09

Table 12. Results of BIO-ENV test of correlation between environmental variables and the foraminiferal assemblage; **bold** type indicates the best variable or combination of variables to explain the assemblage

# of Variables	Correlation	Determining Environmental Variables
1	0.49	% Mud
2	0.52	Temperature, % Mud
2	0.5	Salinity, % Mud
3	**0.55**	**Temperature, Salinity, % Mud**
3	0.48	Temperature, % Mud, phi
3	0.48	Salinity, % Mud, Dissolved Oxygen
3	0.48	Temperature, % Mud, Dissolved Oxygen
4	0.52	Temperature, Salinity, % Mud, phi
4	0.51	Temperature, Salinity, % Mud, Dissolved Oxygen
5	0.49	Temperature, Salinity, % Mud, Dissolved Oxygen, phi

FORAM Index

FORAM Index values were calculated for all replicates containing more than 50 total Foraminifera. The following eight sites were removed from this analysis because they did not meet this criterion in either replicate: 1.1, Shark, 3.2, 5.4, 8.1, Nirvana, Lugano, and 10.2. Values were calculated in accordance to the formula presented in Table 1, modified from Hallock et al. (2003). The reefs in the vicinity of the flow from Caesar's Creek have the highest FI values (Fig. 8). High FI values correspond to SIMPER groups A and E, with Pacific Reef having the highest average FI value (7.0, SD=1.9). Lowest FI values correspond to SIMPER group C. The lowest FI value was at Bug Reef with an FI of 2.1 (SD=0.12).

The Moran's I value for spatial autocorrelation of FI values was not significant (0.254, p=0.054). This indicated that no significant spatial pattern existed in the FI values. However, there was significant bivariate spatial correlation between FI and temperature, salinity, and percent mud (0.314, 0.311, 0.355 respectively, $p<0.05$). Again the significant Moran's I value is supported by a Pearson's correlation that was significant when FI was compared to salinity, temperature, and percent mud (Table 13). Also, Table 13 includes correlations between the functional groups that make up the FI value and all of the environmental parameters. Almost all of the correlations were significant (again except LSF and depth) for each of the components as well as the FI value itself.

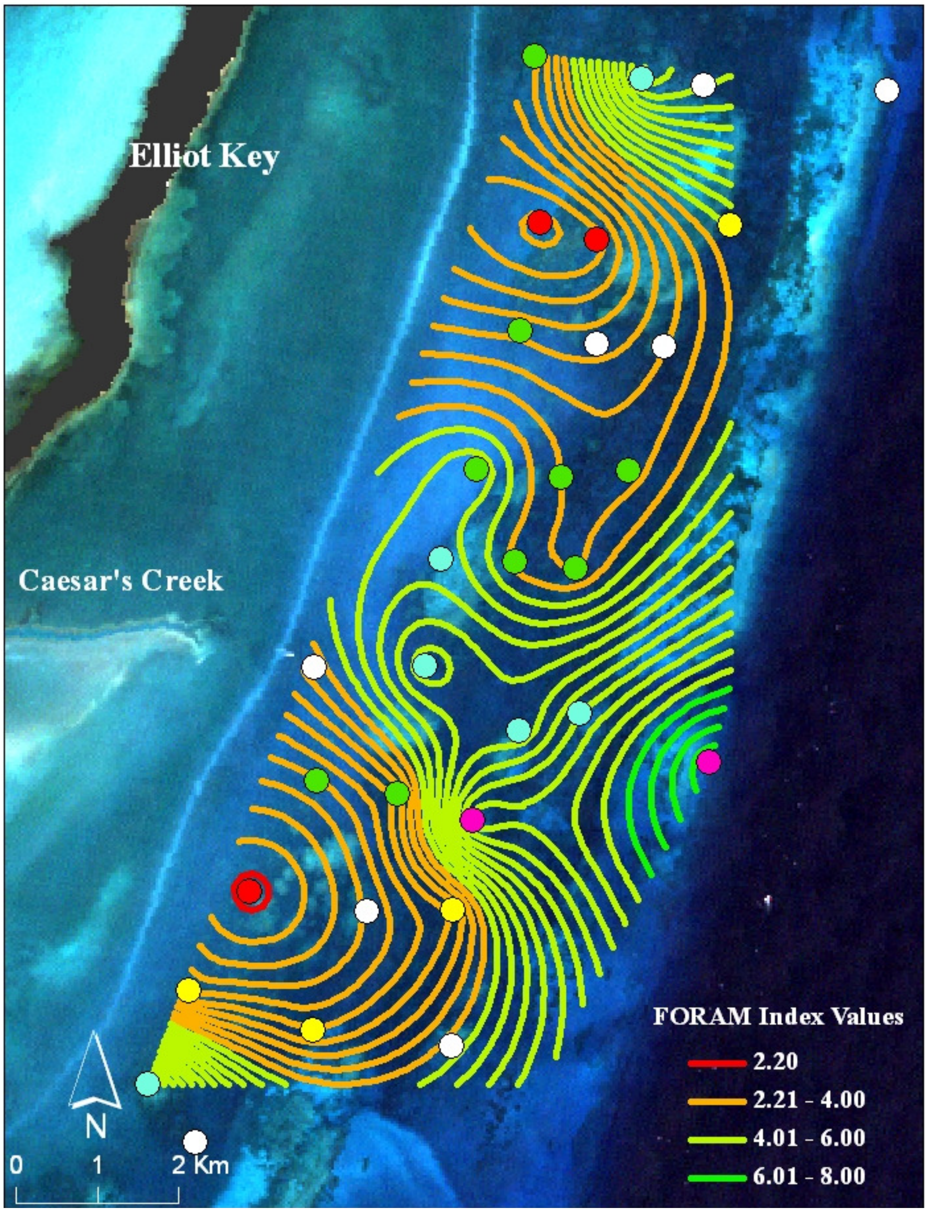


Figure 8. Contours of FORAM Index values. Sites with more than 50 forams/gram of sediment are represented by their SIMPER group.

Table 13. Correlation matrix for FORAM Index functional groups with environmental variables; Ps – percent symbiont-bearing foraminifers, Po – percent stress-tolerant foraminifers, Ph – percent other small foraminifers (**Bold** indicates significance at p<0.05)

	FI	FIPs	FIPo	FIPh
FI	1.00			
FIPs	**1.00**	1.00		
FIPo	**-0.73**	**-0.71**	1.00	
FIPh	**-0.95**	**-0.96**	**0.49**	1.00
% Mud	**-0.62**	**-0.61**	**0.62**	**0.51**
Depth	0.06	0.07	-0.05	-0.06
LSF	0.16	0.15	**-0.38**	-0.04
Phi	**-0.40**	**-0.39**	**0.45**	**0.31**
Density	**-0.55**	**-0.54**	**0.57**	**0.45**
Genera	**-0.64**	**-0.64**	**0.41**	**0.63**
Temperature	**0.33**	**0.33**	-0.22	**-0.33**
Salinity	**-0.47**	**-0.47**	**0.40**	**0.42**

Sediment-Constituent Analysis

The average amount of unidentifiable grains across samples was 52% (SD=18%) ranging from 14% at Dome Reef to 79% at reef 5.1. Where the percent of unidentifiable grains was low, the dominant constituents were calcareous algae and mollusk fragments (Fig. 9). Identifiable coral fragments never contributed more than 3.7% to any one sample. Assemblage composition for each replicate at each site can be found in Appendix V.

The results of the SIMPER analysis on the sediment-constituent assemblage is shown in the MDS plot in Figure 10. Two main groups were identified. The constituents defining group A were dominated by calcareous algae, mollusks, and unidentifiable grains (Table 14). This group represented sites with higher SEDCON Index (SI) values,

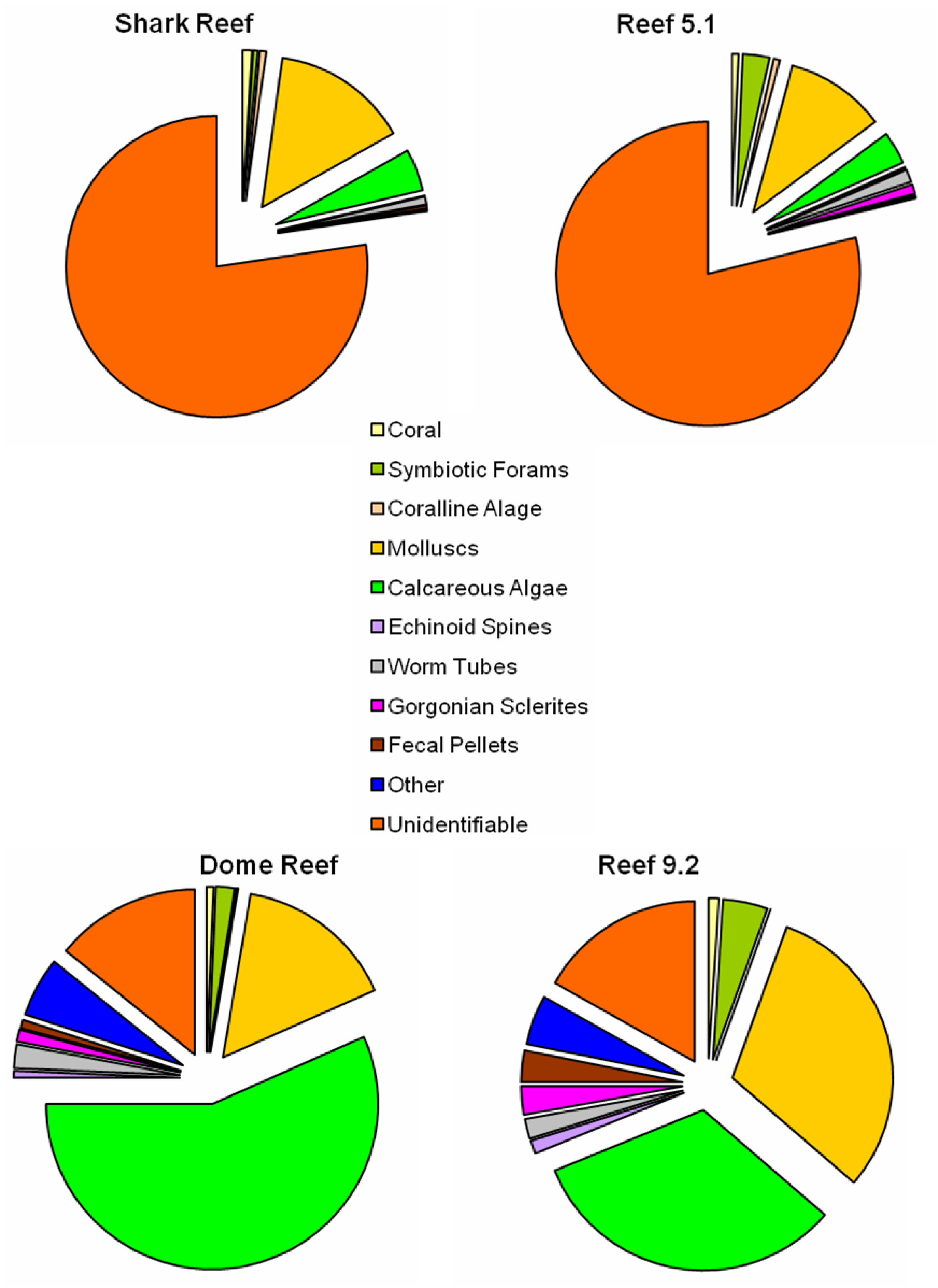


Figure 9. Percentages of sediment constituents for sites with highest and lowest percentages of unidentifiable grains

lower temperatures, and an average percent mud of 17% (Table 15). Group B was dominated by the same three sediment constituents; however, unidentifiable grains played a more important role, contributing 23% to the group's similarity. This group was characterized by lower SI values, higher temperatures, and lower percent mud (1.1%). Nirvana Reef is an outlier; this site had the lowest percent mud and SI value. While the within-group similarity was high for both of the larger groups, 91% for group A and 88% for group B, the dissimilarity between the two groups was only 16% (Table 16).

Figure 10. MDS plot of reefs represented by their SIMPER groups defined by similarity of sediment constituents

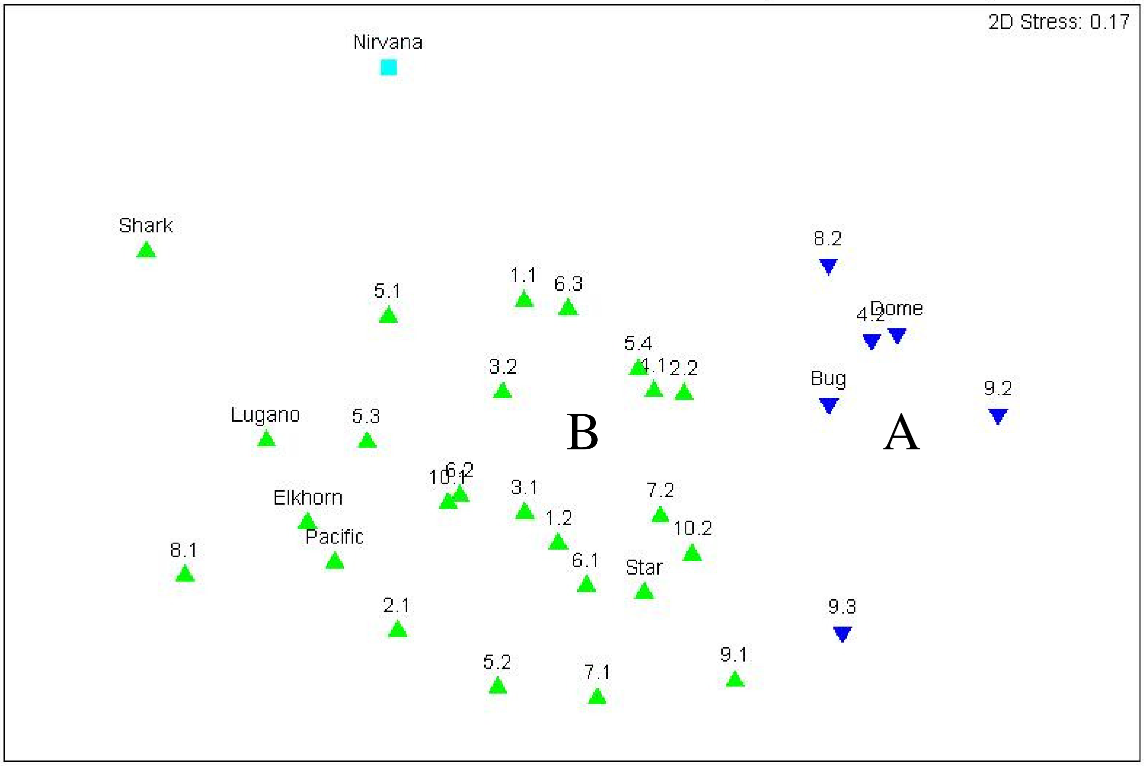


Table 14. Within-group similarity of the two main SIMPER-defined groups for the sediment constituents

Group A n-6					**Average similarity: 90.6%**	
Species	**SI group**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Calcareous Algae	Pah	2.46	15.8	48.8	17.4	17.4
Molluscs	Pah	2.19	13.8	13.0	15.2	32.6
Unidentifiable	Pu	2.17	13.6	15.5	15.0	47.7
Other	Pah	1.42	8.83	19.2	9.74	57.4
Symbiotic Forams	Pf	1.36	7.88	11.9	8.7	66.1
Worm Tubes	Pah	1.2	7.34	10.6	8.1	74.2
Gorgonian Sclerites	Pah	1.08	6.15	5.13	6.78	81.0

Group B n-25					**Average similarity: 88.3%**	
Species	**SI group**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Unidentifiable	Pu	2.76	20.2	13.1	22.9	22.9
Molluscs	Pah	2.13	15.2	15.2	17.2	40.1
Calcareous Algae	Pah	1.76	11.9	6.83	13.4	53.5
Worm Tubes	Pah	1.08	7.46	9.88	8.45	62.0
Coral	Pc	1.08	7.4	7.47	8.38	70.4
Symbiotic Forams	Pf	1.11	6.99	2.83	7.93	78.3
Other	Pah	0.99	6.03	4.41	6.83	85.1

Table 15. Means for environmental data for sediment constituent SIMPER groups

Group	SI	pH	Temperature	DO	Salinity	% Mud	Phi
A	1.89	8.26	25.95	6.29	35.75	17.3	2.00
B	1.13	8.29	26.20	6.38	35.58	1.10	0.88
Nirvana	0.85	8.25	26.09	6.43	35.60	0.06	1.00

Table 16. Dissimilarity between the two main groups defined by the SIMPER analysis of sediment constituents

Groups B & A						**Average dissimilarity = 16.2**	
		Group B	**Group A**				
Constituent	**SI group**	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Fecal Pellets	Pah	0.24	0.97	2.83	1.71	17.5	17.5
Calcareous Algae	Pah	1.76	2.46	2.48	2.18	15.4	32.9
Unidentifiable	Pu	2.76	2.17	2.11	2.93	13.0	45.9
Other	Pah	0.99	1.42	1.62	1.63	10.1	56.0
Echinoid Spines	Pah	0.72	0.85	1.4	1.2	8.68	64.6
Coralline Algae	Pah	0.7	0.59	1.29	1.18	7.96	72.6
Symbiotic Forams	Pf	1.11	1.36	1.24	0.96	7.66	80.3

Correlation matrices were created to determine if any of the constituents varied with respect to each other (Table 17). The strongest relationship was between calcareous algae and unidentifiable grains at -0.84. The strongest positive correlation was between calcareous algae and the other category which included smaller foraminifers and bryozoans. Interestingly, there was a significant negative correlation between identifiable coral fragments and symbiont-bearing foraminifers (-0.28), though percentages of both tended to be small.

Constituents were also correlated to environmental data in Table 18. Again, those constituents that correlated positively with salinity, tended to correlate negatively, as expected, to temperature. Unidentifiable grains had a strong negative correlation (-0.72) with percent mud. The other category and the calcareous algae, which positively correlated to each other, also both positively correlated to the SI values.

When the BIO-ENV routine was used to compare water-quality parameters to the sediment constituent assemblage, percent mud again came out as the single most influential environmental parameter with a 0.48 correlation to the assemblage (Table 19). No other variable or combination of variables was able to produce a stronger correlation than percent mud.

Table 17. Correlation matrix for sediment constituents ; **bold** type indicates significance at $p<0.05$

	Coral	SF	Cor. Algae	Molluscs	Cal. Algae	ES	WT	GS	FP	Other	Unid
Coral	1.00										
Symbiotic Forams	**-0.28**	1.00									
Coralline Algae	**0.26**	-0.19	1.00								
Molluscs	0.07	**0.31**	**-0.32**	1.00							
Calcareous Algae	**-0.33**	0.14	-0.20	0.00	1.00						
Echinoid Spines	-0.06	0.11	-0.18	**0.37**	0.08	1.00					
Worm Tubes	0.02	-0.07	-0.06	0.00	**0.28**	0.16	1.00				
Gorgonian Sclerites	-0.08	0.05	-0.15	0.10	**0.31**	0.22	**0.33**	1.00			
Fecal Pellets	-0.24	-0.02	-0.19	0.10	**0.54**	0.15	**0.16**	**0.38**	1.00		
Other	**-0.26**	0.23	-0.03	0.22	**0.62**	0.21	**0.27**	**0.27**	**0.41**	1.00	
Unidentifiable	0.23	**-0.39**	**0.28**	**-0.49**	**-0.84**	**-0.30**	**-0.31**	**-0.39**	**-0.53**	**-0.73**	1.00

Table 18. Correlation matrix for sediment constituents and environmental variables; bold type indicates significance at $p<0.05$

	FI	SI	% Mud	Phi	Depth	LSF	Salinity	Temperature
Coral	-0.09	-0.09	**-0.28**	**-0.44**	-0.03	-0.05	-0.01	0.09
Symbiotic Forams	-0.20	**0.68**	**0.39**	**0.26**	0.11	**-0.29**	0.03	**-0.29**
Coralline Algae	0.13	**-0.32**	-0.23	**-0.33**	-0.02	-0.17	**-0.31**	**0.54**
Molluscs	**-0.40**	**0.57**	**0.31**	**0.27**	**0.28**	-0.04	0.22	**-0.45**
Calcareous Algae	**-0.47**	**0.67**	**0.63**	**0.46**	-0.25	0.07	**0.68**	**-0.39**
Echinoid Spines	**-0.26**	**0.28**	**0.34**	**0.34**	**0.29**	-0.07	0.19	**-0.31**
Worm Tubes	**-0.39**	0.23	0.17	0.23	0.25	-0.08	0.10	0.02
Gorgonian Sclerites	**-0.36**	**0.33**	0.21	**0.33**	0.08	-0.01	**0.28**	-0.25
Fecal Pellets	**-0.36**	**0.38**	**0.57**	**0.57**	-0.18	-0.09	**0.30**	-0.19
Other	**-0.50**	**0.69**	**0.49**	**0.49**	0.25	-0.13	**0.30**	**-0.30**
Unidentifiable	**0.64**	**-0.92**	**-0.72**	**-0.56**	0.00	0.05	**-0.63**	**0.53**

Table 19. Results of BIO-ENV test of correlation between environmental variables and the sediment constituents. Bold indicates the best variable of combination of variables to explain the assemblage.

# of Variables	Correlation	Determining Environmental Variables
1	**0.482**	**% Mud**
2	0.435	Salinity, % Mud
2	0.402	% Mud, phi
2	0.402	Temperature, %Mud
3	0.428	Salinity, % Mud, phi
3	0.393	Temperature, Salinity, %Mud
3	0.366	Temperature, %Mud, phi
4	0.386	Temperature, Salinity, %Mud, phi

SEDCON Index

Because a standard number of sediment grains were picked for each sample (300), all replicates at all sites could be used to calculate SEDCON Index values (SI values). Values were calculated based on the equation derived in Daniels (2005) and shown in Table 3. The range of mean values among the reefs was from 0.64 (SD=0.03) at Shark Reef to 2.48 (SD=0.42) at Reef 9.3. The mean SI value was 1.26.

Figure 11 shows the contour lines of SI values for the study area with each site represented by its SIMPER group. The lowest SI values are found in the vicinity of Caesar's Creek, while the reefs furthest from direct sources of water flow have the highest SI values. The sites with high values are associated with SIMPER group A, while Group B is a catch all for almost everything else.

Moran's I value for spatial autocorrelation was significant for the SI values at 0.21 ($p<0.05$). This indicates there is significant clustering and a pattern exists. The SI significantly co-varied with temperature, salinity, and depth (Moran's I= 0.27, 0.22, 0.19 respectively; $p<0.05$) (Appendix IV). The significant Moran's I value is supported by a

Pearson's correlation that is significant when SI is compared to salinity, temperature (Table 18).

Table 20. Correlation matrix for SEDCON Index functional groups with environmental variables; Pc – percent coral grains, Pf – percent symbiont-bearing foraminifers, Pah – percent autotrophic/heterotrophic grains, Pu – percent unidentifiable grains (**Bold** indicates significance at $p<0.05$)

	SI	SIPc	SIPf	SIPah	SIPu
SI	1.00				
SIPc	**-0.11**	1.00			
SIPf	**0.67**	-0.29	1.00		
SIPah	**0.79**	-0.21	0.13	1.00	
SIPu	**-0.89**	0.21	**-0.31**	**-0.98**	1.00
% Mud	**0.66**	-0.30	**0.32**	**0.69**	**-0.72**
Depth	-0.25	0.16	-0.03	**-0.36**	**0.35**
LSF	-0.19	-0.09	**-0.35**	0.08	0.00
Phi	**0.42**	**-0.38**	0.16	**0.54**	**-0.53**
Density	**0.60**	-0.27	**0.38**	**0.56**	**-0.61**
Genera	**0.37**	0.25	0.06	**0.36**	**-0.37**
Temperature	**-0.61**	0.13	-0.30	**-0.59**	**0.63**
Salinity	**0.46**	-0.10	-0.02	**0.66**	**-0.63**

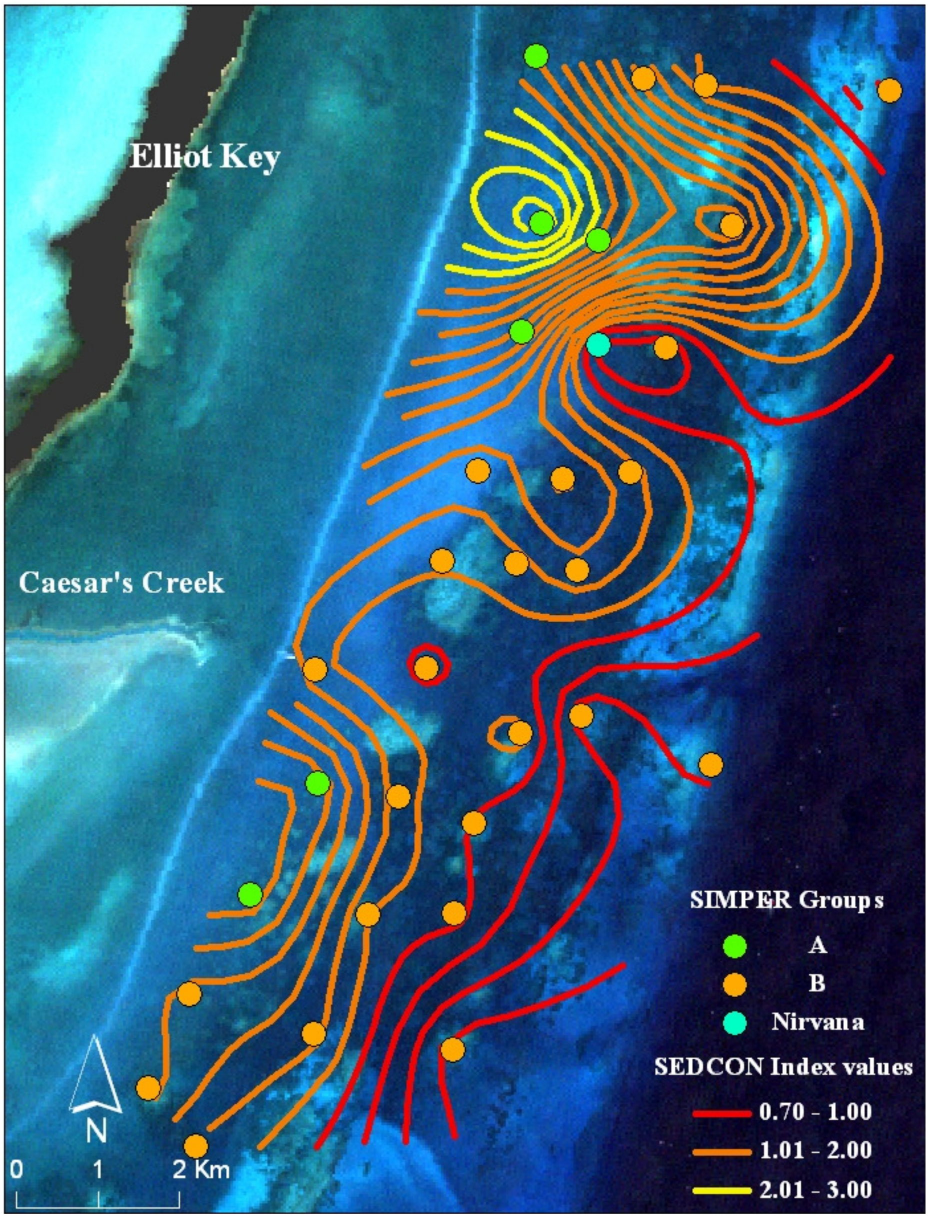


Figure 11. Contours of SEDCON Index values; sites represented by their sediment-constituent assemblage SIMPER group

Live Symbiont-bearing Foraminifera (LSF)

Data for *Amphistegina gibbosa* populations and density of other LSF collected from the reef rubble can be found in Appendix VI. These data did not correlate with most other counts and measures noted previously, with the exception of the assemblage data for symbiont-bearing Foraminifera in the sediment constituent analysis (-0.29, Table 16) and therefore also with the percent of Foraminifera at each site (-0.35, Table 18).

Cluster and MDS analyses of the LSF assemblage data are shown in Figure 12. SIMPER analysis of these clusters revealed three distinct groups, each with ~80% similarity. There were three outlier reefs, 1.1, 5.4, 9.3, which strongly differ from each other as well as from the SIMPER clusters.

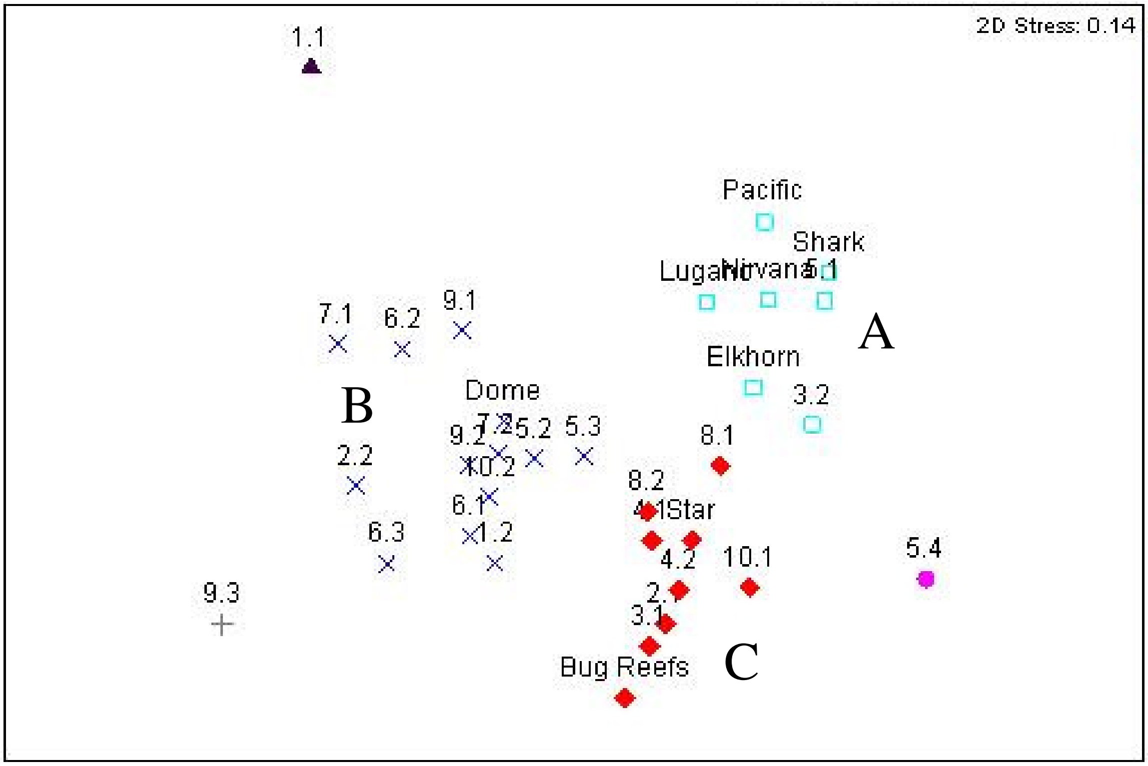


Figure 12. MDS plot of reefs represented by their SIMPER groups defined by similarity of live symbiont-bearing foraminiferal assemblage

Groups A and C are defined by a large contribution to the within group similarity by *Amphistegina gibbosa*. They differ with the second contributing species which is *Archaias angulatus* for group A and *Laevipeneroplis proteus* for group C (Table 21). Group B had the highest contribution by *L. proteus,* followed *A. gibbosa*. Dissimilarities between the groups and the outlier reefs can be found in Appendix VI.

Table 21. Within group similarity of SIMPER defined groups for the live, symbiont-bearing foraminiferal assemblage

Group A - n=7			**Average similarity: 83%**		
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
A. gibbosa	5.27	17.33	7.36	20.9	20.9
A. angulatus	4.34	13.49	5.73	16.3	37.1
L. proteus	3.77	12.04	7.2	14.5	51.7
C. compressus	3.75	11.42	7.8	13.8	65.4
A. carinata	2.73	7.88	3.45	9.5	74.9
Androsina	2.42	6.57	3.02	7.92	82.8
S. marginalis	1.4	3.96	2.52	4.77	87.6
P. pertusus	1.22	3.34	3.48	4.03	91.6

Group B - n=13			**Average similarity: 78.6%**		
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
L. proteus	7.33	29.7	10.39	37.8	37.8
A. gibbosa	3.72	13.51	4.39	17.2	55.0
A. angulatus	3.43	12.03	4.46	15.3	70.3
L. bradyi	2.3	7.68	2.57	9.78	80.1
P. pertusus	1.46	5.05	3.51	6.43	86.5
C. compressus	1.54	3.58	1.15	4.55	91.1

Group C - n=9			**Average similarity: 82.1%**		
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
A. gibbosa	6.73	25.92	6.82	31.6	31.6
L. proteus	5.37	20.63	6.46	25.1	56.7
C. compressus	2.75	8.05	1.83	9.81	66.5
L. bradyi	2.12	7.43	4.74	9.05	75.6
A. angulatus	2	7.36	5.46	8.97	84.6
P. pertusus	1.45	4.67	4.18	5.69	90.2

Environmentally, Group A had the highest mean FI value as well as the highest diversity of symbiont-bearing foraminifera and lowest percent mud (Table 22). Group C had the lowest FI of the major groups as well the lowest diversity and highest percent mud.

Table 22. Means for density, diversity, and environmental data for LSF assemblage SIMPER groups

Group	FI	SI	Density (LSF/100cm^2)	# Genera	pH	Temperature	DO	Salinity	% Mud	Phi
A	6.07	1.76	113	10.7	8.24	26.41	6.54	35.47	0.2%	0.71
B	4.09	1.26	90.9	9.3	8.32	26.08	6.30	35.65	3.0%	1.23
C	3.18	1.36	104	8.8	8.29	26.06	6.27	35.66	7.4%	1.11
1.1	N/A	1.64	146	6.0	8.20	26.21	6.66	35.43	0.4%	1.00
5.4	N/A	1.20	51.2	6.0	8.36	26.32	6.28	35.76	0.7%	1.00
9.3	2.51	1.62	5.7	3	8.10	25.77	6.70	35.69	23.4%	2.00

Photic Index

Calculations of the Photic Index, based on abundance and bleaching of live *Amphistegina gibbosa*, were carried out by multiplying the number of the density rank by the number of the bleaching rank shown in Table 4 such that each box corresponded to a unique number. Again, these numbers were not definitively quantitative and a higher number did not necessarily indicate a better environment.

Most sites (75%) had a Photic Index value of 8 indicating that environmental conditions supported *Amphistegina* but only at intermediate abundances, and that bleaching stress was chronic. Another six sites had a value of 4, indicating poor environmental conditions and chronic photic stress. The remaining two sites (1.1 and 9.3) had a value of 5, representing unfavorable environmental conditions overall. Figure 13 shows a spatial representation of these values.

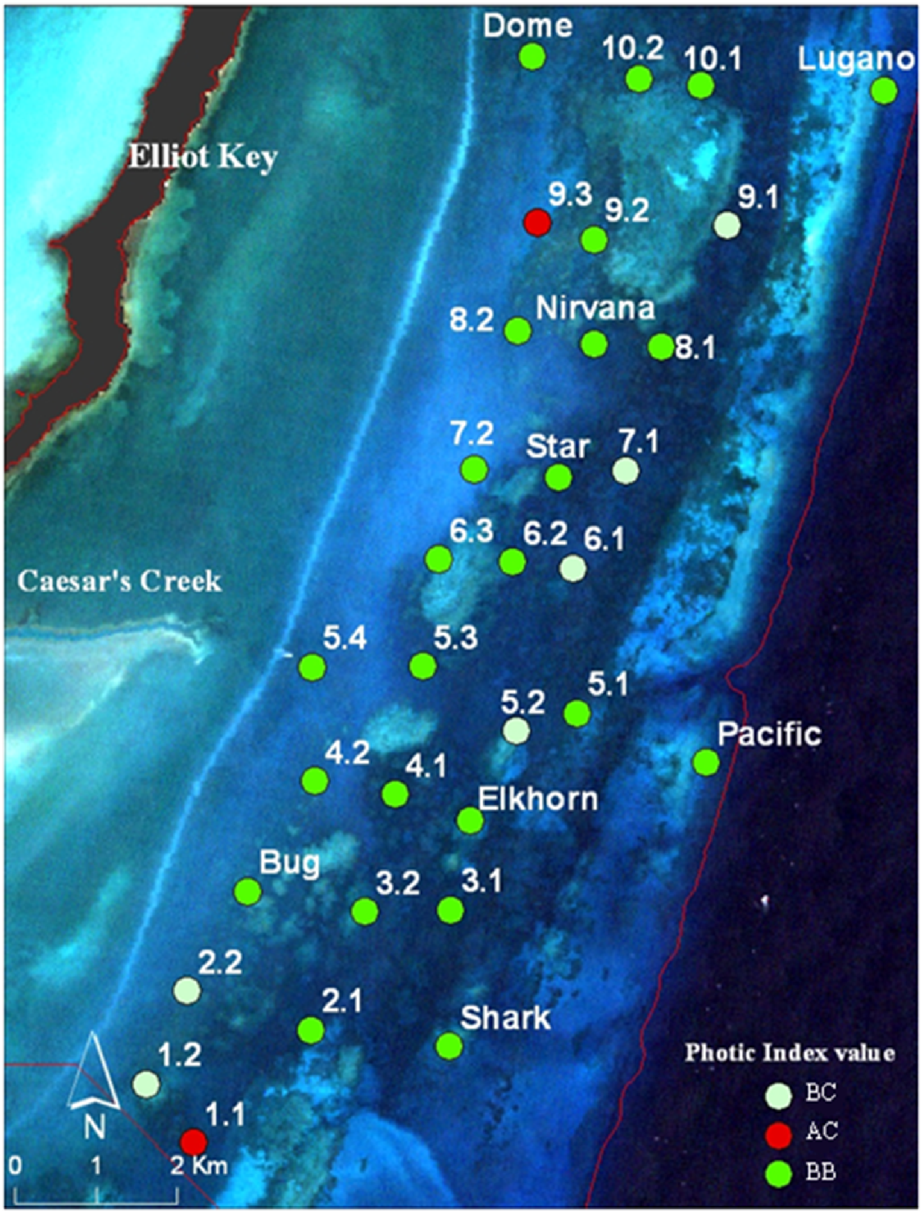


Figure 13. Sites represented by their Photic Index relative value

FORAM Index v SEDCON Index

Table 23 is a Pearson's correlation matrix of foraminiferal taxa to sediment constituents. The most notable trends here were the positive correlations between the symbiont-bearing Foraminifera and the coralline algae and unidentifiable grains. Also noteworthy were the negative correlations between the symbiont-bearing Foraminifera and calcareous algae, fecal pellets, and the "other" category.

The results of these correlations were an overall negative correlation between the FORAM Index and the SEDCON Index (-0.53) as seen in Table 7. Spatially, the patterns between the two indices co-varied significantly with a Moran's I value of -0.399 (p=0.01). Again the Moran's I showed a negative relationship in the variation of the patterns. The contour maps for each index (Figures 8 and 11) also showed reversed patterns.

Table 23. Correlation matrix for foraminiferal taxa and sediment constituents; **bold** type represents a significant correlation at p<0.027

	Coral	Symbiotic Forams	Coralline Algae	Molluscs
Amphistegina	0.08	-0.28	0.19	-0.27
Archaias	-0.12	-0.01	-0.01	-0.12
Asterigerina	0.11	-0.02	**0.50**	-0.04
Borelis	-0.11	-0.15	**0.45**	**-0.43**
Broekina	-0.15	0.13	-0.02	0.01
Cyclorbiculina	-0.05	0.08	**0.35**	-0.22
Heterostegina	-0.08	-0.03	**0.49**	**-0.39**
Laevipeneroplis	0.08	-0.01	-0.20	0.16
Peneroplis	0.05	0.03	0.15	0.07
Ammonia	0.11	0.04	-0.13	0.15
Bolivina	-0.22	0.33	-0.25	0.24
Bulimina	-0.05	0.24	-0.11	0.14
Cribroelphidium	-0.10	-0.02	-0.15	0.28
Elphidium	-0.04	0.08	-0.23	0.29
Haynesina	-0.13	0.08	-0.26	0.14
Adelosina	-0.29	**0.65**	-0.23	0.27
Articulina	-0.06	0.09	-0.10	0.21
Cibicides	0.03	0.24	-0.15	0.19
Cornuspira	-0.11	0.19	0.14	0.23
Cycloforina	0.06	0.02	-0.24	0.26
Discorbis	0.03	-0.19	0.03	-0.06
Eponides	**0.47**	-0.02	0.04	0.31
Hauerina	-0.05	0.13	0.07	-0.02
Miliolinella	-0.08	0.10	-0.19	0.30
Neocornorbina	0.04	-0.07	0.32	-0.18
Nonionoides	-0.17	0.12	-0.05	0.08
Pseudohauerina	-0.06	-0.10	0.18	0.04
Quinqueloculina	-0.13	0.27	-0.27	**0.43**
Rosalina	0.03	0.10	0.01	**0.37**
Sigmoilina	-0.02	0.05	-0.06	0.33
Siphonaperta	0.15	-0.06	-0.06	0.13
Spiroloculina	0.06	-0.03	-0.10	0.11
Textularia	0.22	-0.22	**0.38**	-0.12
Triloculina	-0.05	0.13	-0.30	0.00
Triloculinella	0.10	0.12	-0.08	0.00
Wiesnerella	0.15	-0.02	-0.04	0.07

Table 23. (Continued)

	Calcareous Algae	Echinoid Spines	Worm Tubes	Gorgonian Sclerites
Amphistegina	-0.02	-0.18	-0.04	-0.06
Archaias	**-0.35**	-0.07	-0.14	-0.32
Asterigerina	**-0.52**	-0.01	-0.20	-0.10
Borelis	-0.15	-0.19	-0.10	-0.02
Broekina	0.06	0.20	-0.13	-0.04
Cyclorbiculina	**-0.38**	0.03	-0.11	-0.32
Heterostegina	-0.25	-0.11	0.11	-0.17
Laevipeneroplis	-0.06	-0.06	-0.19	0.26
Peneroplis	-0.03	0.11	0.12	0.26
Ammonia	0.12	0.06	0.17	0.20
Bolivina	**0.40**	0.25	-0.07	0.07
Bulimina	0.25	0.01	-0.07	-0.11
Cribroelphidium	0.30	0.19	-0.08	-0.12
Elphidium	-0.05	**0.44**	-0.18	0.03
Haynesina	0.24	0.06	-0.07	0.28
Adelosina	**0.38**	0.18	-0.09	-0.02
Articulina	0.18	0.26	-0.07	0.00
Cibicides	**0.46**	0.04	-0.07	0.22
Cornuspira	0.33	0.28	-0.10	0.06
Cycloforina	0.06	0.32	0.11	0.04
Discorbis	-0.19	-0.15	-0.10	-0.24
Eponides	0.09	0.04	0.14	0.16
Hauerina	0.13	-0.02	0.03	0.16
Miliolinella	**0.40**	0.17	-0.09	-0.02
Neocornorbina	-0.19	-0.14	-0.11	-0.04
Nonionoides	**0.34**	0.25	0.02	0.01
Pseudohauerina	0.17	0.18	0.17	-0.04
Quinqueloculina	**0.44**	**0.34**	-0.10	0.11
Rosalina	0.23	0.25	-0.23	0.21
Sigmoilina	0.19	0.10	0.01	0.08
Siphonaperta	-0.18	-0.08	-0.07	-0.04
Spiroloculina	0.12	0.14	0.11	0.15
Textularia	-0.04	-0.06	0.00	0.03
Triloculina	**0.58**	0.16	0.02	0.15
Triloculinella	0.13	0.03	-0.03	0.07
Wiesnerella	0.02	-0.08	-0.09	0.22

Table 23. (Continued)

	Fecal Pellets	Other	Unidentifiable
Amphistegina	-0.08	-0.03	0.19
Archaias	**-0.34**	**-0.37**	**0.44**
Asterigerina	**-0.36**	-0.28	**0.50**
Borelis	-0.22	-0.22	**0.37**
Broekina	-0.26	**0.52**	-0.12
Cyclorbiculina	**-0.36**	**-0.34**	**0.46**
Heterostegina	-0.14	-0.22	**0.39**
Laevipeneroplis	-0.11	0.09	-0.02
Peneroplis	-0.09	0.27	-0.07
Ammonia	0.18	0.15	-0.22
Bolivina	**0.51**	0.24	**-0.54**
Bulimina	**0.43**	0.07	-0.33
Cribroelphidium	**0.35**	0.03	**-0.36**
Elphidium	0.17	0.04	-0.11
Haynesina	**0.43**	0.12	-0.31
Adelosina	0.03	0.18	**-0.54**
Articulina	0.33	0.26	-0.31
Cibicides	**0.49**	**0.54**	**-0.60**
Cornuspira	**0.38**	0.29	**-0.47**
Cycloforina	0.10	0.18	-0.21
Discorbis	-0.20	-0.30	0.29
Eponides	0.09	0.09	-0.26
Hauerina	0.01	0.16	-0.16
Miliolinella	**0.59**	0.21	**-0.53**
Neocornorbina	-0.10	-0.27	0.28
Nonionoides	0.12	0.07	**-0.35**
Pseudohauerina	-0.02	0.26	-0.19
Quinqueloculina	**0.52**	0.33	**-0.66**
Rosalina	**0.50**	0.15	**-0.42**
Sigmoilina	**0.38**	0.10	**-0.35**
Siphonaperta	-0.31	-0.11	0.15
Spiroloculina	0.23	0.33	-0.22
Textularia	-0.22	**0.40**	0.06
Triloculina	0.25	**0.55**	**-0.59**
Triloculinella	0.06	0.18	-0.16
Wiesnerella	**0.34**	-0.14	-0.06

DISCUSSION

Limitations of Study

Three rubble and sediment replicates were collected for this study. However, due to the time required to process each index, only two sediment replicates were analyzed. A one way ANOVA calculated for the SEDCON and FORAM index values showed no significant difference between the two replicates so two sediment replicates was deemed sufficient (Table 24).

Table 24. One Way ANOVAs for a) SEDCON Index replicates and b) FORAM Index replicates

a)

One Way ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	10.52316	31	0.339457	9.47591	3.88E-09	1.810379
Within Sites	0.187164	1	0.187164	1.010613	0.318664	3.995887

b)

One Way ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	50.57827	19	2.662014	7.260835	2.41E-05	2.137009
Within Sites	0.128987	1	0.128987	0.084828	0.772443	4.098172

The samples were collected in early May of 2007 prior to heavy rains associated with South Florida summers. Since the environmental data collected with the YSI only represented a snapshot in time, the true effects of environment on the reefs can only be hypothesized. Long-term monitoring of environmental data is needed to make more definitive conclusions. The Southeast Research Center (SERC), which conducts long term monitoring of water quality along the Florida reef tract, has only two monitoring stations within the study area, although four others are in the general vicinity. While this added insight into the environmental conditions of the area, the resolution of their sampling did not provide enough detail for comparison.

As mentioned in Daniels (2005), an issue that is involved with most indices that require identification training is an improved familiarity as samples are processed. To minimize the effect of having more unidentifiables (for the SEDCON Index) or improperly identified foraminifera (for the FORAM Index) in early samples, care was taken to have an experienced technician provide a thorough training. At the conclusion of identifications, early samples were revisited for a final count. Books and picture taxonomic aides were also used to assure proper identifications and minimize error.

The Offshore Environment

Figures 4 and 5, which illustrate percent mud, salinity, and temperature distributions, provide an overview of the environment offshore of the Keys in Biscayne National Park, which provide shelter from direct influence (good or bad) of Biscayne Bay. All three variables showed a similar pattern, an anomalous bump near the outflow of Caesar's Creek. Because temperature and salinity are frequently used as tracers of water masses, I deduced that the contours reflect a plume of water emerging from Biscayne Bay. The force of the tidal flow in this area appears to also influence grain-size distribution.

Foraminiferal Assemblages

The foraminiferal assemblage data allowed for the creation of a Q-mode cluster analysis and then SIMPER grouping of sites. Five groups were distinguished through this procedure (Fig. 7). Groups A and E represented sites with FI values greater than four, where the environmental conditions were, in theory, favorable for mixotrophic, calcifying organisms. These sites were characterized by very low percent mud, low foraminiferal densities, and low foraminiferal diversity. The map in Figure 7 shows that these SIMPER groups were most likely being influenced by the net outflow of water from Caesar's Creek (Wang et al. 2003). The same scenario is likely to be occurring at the south end of the study area, with water exchange through the inlet south of Old Rhode's Key. Only one genus of stress-tolerant foraminifer was present in Group A (*Elphidium*) and none in Group E. Carnahan et al. (*submitted*) also found in their study of foraminiferal assemblages from within Biscayne Bay, that while *Elphidium* is a stress-tolerant genus, it tended to group with the "other smaller" foraminifers in statistical analyses.

Conversely, Group C reefs occur closest to shore and towards the interior of the islands where they are sheltered from constant intense water exchange. This resulted in reefs characterized by high percent mud and low percentages of symbiont-bearing Foraminifera contributing to the assemblage. This group also had the highest contribution of stress-tolerant taxa (Table 25).

Carnahan et al. (*submitted*) conducted a study of foraminiferal assemblages within Biscayne Bay. They recognized three distinct foraminiferal assemblages within the Bay, freshwater influenced, urban pollution influenced, and oceanic influenced. When compared to the data from this thesis, the oceanic-influenced assemblage (B-2) most closely resembled Group C. Percent mud for Group B-2 (from Carnahan 2005) and Group C (from this data) were 30% and 26.4% respectively and the mean FORAM Index values were 2.74 and 2.22. In combination the two datasets may represent the full spectrum of foraminiferal assemblages from highly impacted, near-shore environments, to open bay environments, to coral reef/open shelf assemblages.

The SIMPER data combined with the contour lines created for the FI value showed a similar pattern to what has been observed in previous variables, the influence of Caesar's Creek outflow (Fig. 8). The Moran's I value for the FI was insignificant (0.25, p=0.054), indicating no significant clustering of FI values. However, the significant relationship between FI and salinity, temperature, and mud did imply that a pattern exists. The lack of significance in the FI pattern could be attributed to the fact that eight sites had to be removed from analysis due to low numbers of specimens.

Table 25. Summary table for percent contribution of foraminiferal taxa to each SIMPER group.

Group	Stress-tolerant	Smaller Miliolids	Smaller Rotalids	Agglutinated	Symbiont-bearing Miliolids	Symbiont-bearing Rotalids
(parentheses indicate # of genera/group)						
A	5.24 (1)	22.1 (2)	18.5 (2)	10.6 (2)	27.8 (3)	6.96 (2)
B	9.12 (5)	39.1 (9)	12.5 (3)	7.4 (2)	18.9 (5)	3.81 (2)
C	21.7 (5)	45.2 (8)	18.3 (5)	0 (0)	5.16 (1)	0 (0)
D	11.7 (4)	37.1 (9)	18.0 (4)	8.27 (2)	15.9 (3)	0 (0)
E	0 (0)	10.9 (2)	21.1 (3)	4.23 (1)	34.3 (4)	20.5 (3)

Hallock et al. (2003) determined that the FI was relatively unaffected by grain size in the samples they analyzed, especially in the most common median grain sizes for reef samples (Phi of 1 and 2). The majority of Biscayne reefs also fell within this range. The range of FI values for 1 and 2 phi between the two studies were very similar (~2.5 to

6). This study even had a site approaching an FI value of 7. However, when the whole range of phi values was considered, there seemed to be some dependence on grain size that is not observed in the 2003 study (Fig. 14). This could be a result of the detail in which this study area was sampled allowing for more minute changes to be observed over a distance of one to two kilometers as opposed to tens of kilometers. It could also be due to the variation in flow patterns affecting the reefs in Biscayne National Park.

One aspect of the FORAM Index that has been adjusted since its inception is the definition of "opportunistic" taxa. In Hallock et al. (2003), only two genera (*Ammonia* and *Elphidium*) were specifically listed as opportunistic. However, four families under which several genera may be opportunistic were also listed, including Bolivinidae and Buliminidae. For index calculations in this project *Ammonia*, *Ammobaculites, Bolivina, Bulimina, Cribroelphidium*, and *Elphidium* were all considered opportunistic or stress-tolerant. Moreover, in Carnahan (2005), genera included in the stress-tolerant category did not include *Bolivina* or *Bulimina*, but did include *Nonion*, *Nonionoides*, and *Nonoinella*. To compare the difference, a second index value was conducted excluding *Bolivina* and *Bulimina* and including *Nonion*, *Nonionoides*, and *Nonoinella*. Both values are reported in Table 26. Another affect on the FI value was the presence of a particular genus of symbiont-bearing foraminifera that is not common in the western Atlantic, *Monalysidium*. This genus was originally left out of the FORAM Index calculation for that reason, but a third calculation of FI values was done including all of the genera of previously mentioned stress-tolerant taxa (as suggested by Carnahan et al. (*submitted*) as well as including *Monalysidium* as a symbiont-bearing foraminifer. This value is also listed in Table 26.

The differences among all three calculations are minimal. The only site with a difference above 0.09 was replicate one of Reef 5.4 at 0.33 for the first calculation and 0.38 for the second calculation. The relatively large deviation is a result of the extremely low numbers of Foraminifera in this sample (27 foraminifers total). As a result, this sample is one of the eight that was removed from other analyses. Thus, whether the less common genera are considered as "other smaller" taxa or not has minimal influence on the FI where a sufficient sample size is present.

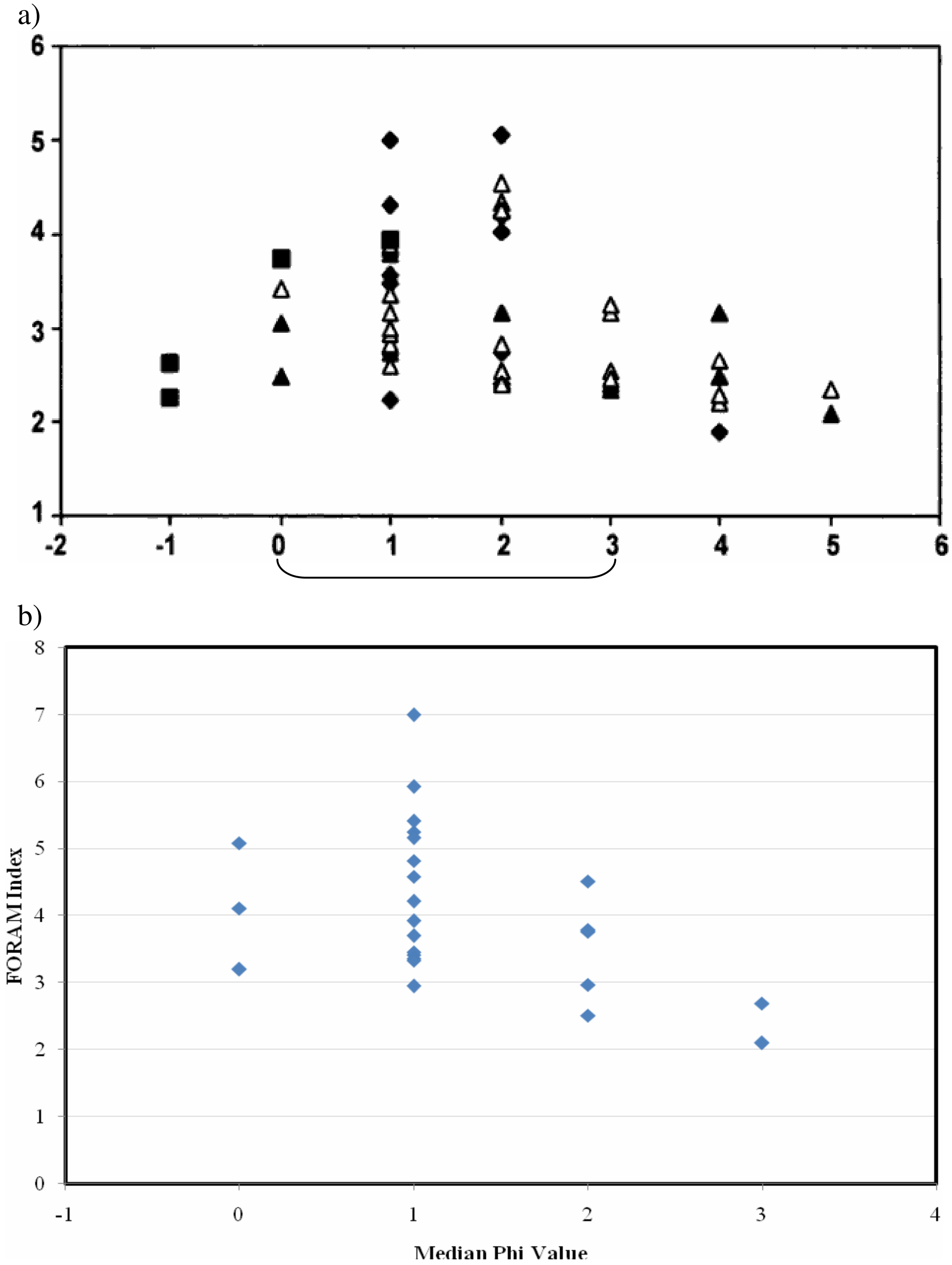


Figure 14. FORAM Index values plotted against median grain size represented by Phi values. a) is Figure 3 from (Hallock et al. 2003) with range of Phi sizes from this study noted, b) is grain-size data from this study.

Table 26. Comparison of three different methods of calculating the FORAM Index.

Site	Rep	FI Value	FI value (Carnahan 2005)	Difference	FI Value (all stress tolerant genera and *Monalysidium* as symbiont-bearing)	Difference
1.1	R1	5.33	5.33	0.00	5.33	0.00
1.1	R2	5.25	5.25	0.00	5.25	0.00
1.2	R1	8.67	8.67	0.00	8.67	0.00
1.2	R2	4.11	4.12	-0.01	4.11	0.00
Shark	R1	7.71	7.71	0.00	7.71	0.00
Shark	R2	9.11	9.11	0.00	9.11	0.00
2.1	R1	3.23	3.25	-0.02	3.23	0.00
2.1	R2	3.17	3.25	-0.08	3.24	-0.07
2.2	R1	3.25	3.26	-0.01	3.24	0.01
2.2	R2	2.65	2.73	-0.08	2.69	-0.04
3.1	R1	3.65	3.65	0.00	3.65	0.00
3.1	R2	3.18	3.17	0.01	3.16	0.01
3.2	R1	7.33	7.33	0.00	7.33	0.00
3.2	R2	6.00	6.00	0.00	6.00	0.00
Bug	R1	2.02	2.07	-0.05	2.01	0.02
Bug	R2	2.19	2.27	-0.09	2.18	0.01
Elkhorn	R1	6.44	6.44	0.00	6.44	0.00
Elkhorn	R2	5.08	5.13	-0.05	5.08	0.01
4.1	R1	3.34	3.36	-0.02	3.34	0.01
4.1	R2	3.58	3.59	-0.01	3.58	-0.01
4.2	R1	3.44	3.43	0.02	3.43	0.02
4.2	R2	2.50	2.57	-0.07	2.50	0.00
Pacific	R1	8.36	8.36	0.00	8.36	0.00
Pacific	R2	5.63	5.62	0.01	5.62	0.01
5.1	R1	5.22	5.17	0.05	5.17	0.05
5.1	R2	5.60	5.62	-0.02	5.60	0.00
5.2	R1	4.55	4.55	0.00	4.53	0.02
5.2	R2	5.09	5.09	0.00	5.08	0.02
5.3	R1	3.80	3.79	0.02	3.79	0.02
5.3	R2	6.52	6.52	0.00	6.52	0.00
5.4	R1	4.86	4.53	0.33	4.48	0.38
5.4	R2	4.33	4.33	0.00	4.33	0.00
6.1	R1	3.38	3.39	-0.01	3.38	0.00
6.1	R2	4.15	4.14	0.01	4.14	0.01
6.2	R1	3.95	4.03	-0.08	4.01	-0.07
6.2	R2	3.90	3.89	0.01	3.89	0.01
6.3	R1	3.97	3.97	-0.01	3.97	0.00
6.3	R2	5.06	5.04	0.01	5.04	0.01
7.1	R1	3.46	3.47	-0.01	3.45	0.01
7.1	R2	3.94	3.92	0.02	3.91	0.02
Star	R1	3.58	3.62	-0.04	3.57	0.01
Star	R2	4.00	3.99	0.01	3.99	0.01
7.2	R1	4.35	4.36	-0.01	4.35	0.01
7.2	R2	4.81	4.82	-0.01	4.81	0.00
8.1	R1	6.70	6.70	0.00	6.70	0.00
8.1	R2	4.24	4.24	0.00	4.24	0.00
Nirvana	R1	4.67	4.67	0.00	4.67	0.00
Nirvana	R2	10.00	10.00	0.00	10.00	0.00
8.2	R1	3.50	3.48	0.02	3.47	0.03
8.2	R2	3.21	3.26	-0.06	3.25	-0.04
9.1	R1	3.51	3.61	-0.09	3.57	-0.05
9.1	R2	4.91	4.93	-0.01	4.91	0.00
9.2	R1	2.36	2.40	-0.05	2.35	0.01
9.2	R2	3.03	3.06	-0.03	3.01	0.02
9.3	R1	2.32	2.34	-0.02	2.30	0.02
9.3	R2	2.70	2.77	-0.07	2.71	-0.01
Lugano	R1	9.47	9.47	0.00	9.47	0.00
Lugano	R2	7.33	7.33	0.00	7.33	0.00
10.1	R1	2.00	2.00	0.00	2.00	0.00
10.1	R2	8.00	8.00	0.00	8.00	0.00
10.2	R1	5.80	5.80	0.00	5.80	0.00
10.2	R2	6.05	6.05	0.00	6.05	0.00
Dome	R1	3.05	3.07	-0.01	3.04	0.01
Dome	R2	3.61	3.55	0.05	3.55	0.05

Sediment-Constituent Assemblages

The underlying premise of the SEDCON Index was based on models first published by Hallock (1988). On subtropical Pacific atolls, which tend to be in very low-nutrient oceanic waters, symbiont-bearing foraminifers (i.e., mixotrophs) tend to be the dominant sediment constituent, followed by identifiable bits of coral (mixotrophs) and coralline algal (autotrophs) fragments, and with much smaller proportions of debris from calcareous algae (autotrophs), gastropods, echinoids and smaller foraminifers (heterotrophs) (e.g., Hallock 1988). In areas with continental or upwelling influence that provides additional nutrient flux, the benthic community becomes less dominated by mixotrophs, as calcareous, filamentous and fleshy algae become more prevalent, along with the gastropods and echinoids that feed upon the algae. The skeletal debris of the autotrophic and heterotrophic carbonate producers should become more prevalent in the sediments. There will be more carbonate mud production, both through the breakdown of calcareous algal skeletons to aragonite needles, and also because the gastropods and echinoids are bioeroding the carbonate substrate. As nutrient flux further increases, plankton densities increase, providing more food for filter-feeding sponges and bivalves, some of whom are very active bioeroders. In low energy environments, bioerosional debris includes large volumes of carbonate muds. Hallock (1988) and Lidz and Hallock (2000) postulated that the proportion of unidentifiable fragments should increase in higher energy environments, where muds are swept away.

Thus, the formula Daniels (2005) proposed for the SEDCON index is based on the premise that if 100% of the sediments were identifiable coral fragments (not realistic), the SEDCON value would be 10. More realistic is the possibility that 95% of the sediments could be shells of symbiont-bearing foraminifers, which would give a minimum SI value of 7.6, and up to 8.1 if the other 5% was coral fragments. If the sediments were 100% identifiable coralline and calcareous algae and molluscan and echinoid fragments, the SI value would be 2. Sediment composed 100% of unidentifiable carbonate grains would have a SI value of 0.1. Thus, there must be mixotrophic contributors for the SI to be greater than 2, and there must be unidentifiable debris for the SI to be less than 2.

In the sediments collected from all of my sites, unidentifiable grains typically were the most common constituent, so most of the SI values I calculated were <2. Where unidentifiable grains played a smaller role, calcareous algae and mollusks played larger roles. Two sample groups were identified using the SIMPER procedure on the sediment constituent assemblage. Group A samples tended to have high mud fractions (17%) compared to Group B (1.1%). However, it is Group A that had the higher average SI value (Table 15), probably because the low energy environment and abundant mud protected identifiable grains from further breakdown. The overall range of SI values was very small, from 0.64 to 2.48. Thus, if the assumptions upon which the SI is based are valid, these SEDCON Index values indicate a benthic environment that is dominated by autotrophic and heterotrophic carbonate producers rather than mixotrophs.

There appears to be a problem in the underlying assumptions of the SEDCON Index as it applies to the reefs in Biscayne National Park, and possibly to other areas with extremes in hydrodynamic setting. The unidentifiable category had significant negative correlations with all of the other constituents that represented nutrient signals and abundant food resources (Table 17). In an environment where bioerosion is a dominant process there should also be other indicators of increased food sources that would stimulate the bioeroders and so one would expect this relationship to be positive. Also, the positive correlation mentioned earlier between the calcareous algae, the “other” category, and the SI indicate another problem. This correlation implies that where autotrophy and heterotrophy were high, the SI was higher than elsewhere. This should not be the case since these constituents represent nutrification, which is detrimental to reef accretion.

However, none of the reefs in BNP can be deemed “healthy” due to the narrow range of SI values, which may also pose a problem in determining solutions to adjust the SEDCON Index. However, Daniels (2005), which is the document defining the SEDCON Index, had a similar range of SI values from 0.92 to 2.58 across patch reefs and offshore reef sites in the Florida Keys. To more adequately test this index, a gradient from healthy reef to degraded reef must be examined.

An Index Comparison

Looking at Figures 8 and 12, the similarity between the two indices is obvious in their pattern, but inverse in their values. The two indices had a -0.53 Pearson’s correlation coefficient and a -0.40 Moran’s I. One index appears to be missing or misreading an important component that is causing this inverse relationship.

The problem appears to be in the SEDCON Index, within grain size and the role of unidentifiable grains. Group A from the SEDCON SIMPER groups had three of the same reefs from Group C in the FORAM SIMPER grouping. Both of these groups had the highest percent mud, but while the FORAM group has the lowest FI values, the SEDCON group had the highest SI values. Table 23, the correlation matrix between foraminiferal taxa and sediment constituents, showed that unidentifiable grains positively correlate with those foraminifers that support algal symbionts while negatively correlated with heterotrophic Foraminifera. This implies that areas with high percentages of unidentifiable grains are also suitable for algal symbiosis in foraminifera thereby indicating that conditions would also be favorable for algal symbiosis in corals. This may also be supported by the presence of a positive relationship between unidentifiables, symbiont-bearing and coralline algae, which is thought to provide a favorable substrate for juvenile corals to settle (Morse and Morse 1984, Raimondi and Morse 2000).

The SEDCON Index provides a fast and easy assessment of the reef environment making it a simple and useful tool to add to a monitoring plan. But the point must be emphasized that it is a highly simplified, new analysis and some adjustments may need to be made in order for it to provide useful results. The SEDCON Index identifies the autotrophic/heterotrophic functional group as a combined indicator of nutrient levels and food resources. At the same time, it separately identifies percentages of unidentifiable grains as indicative of bioerosion, another proxy of food resources.

The problem identified by this research lies in this definition. The muddiest reefs were considered by the SEDCON Index to be the healthiest because they had the least amount of unidentifiable grains. However, muddy sediments are likely an indication of calmer waters, and in calmer waters sediments are less likely to be affected by physical erosion thereby allowing more grains to be identifiable. Conversely, lack of mud in a sediment sample may be an indication of a higher energy environment. In this case, grains in the analyzed size fraction would be more likely to mobilize and experience physical erosion, thereby making them unidentifiable.

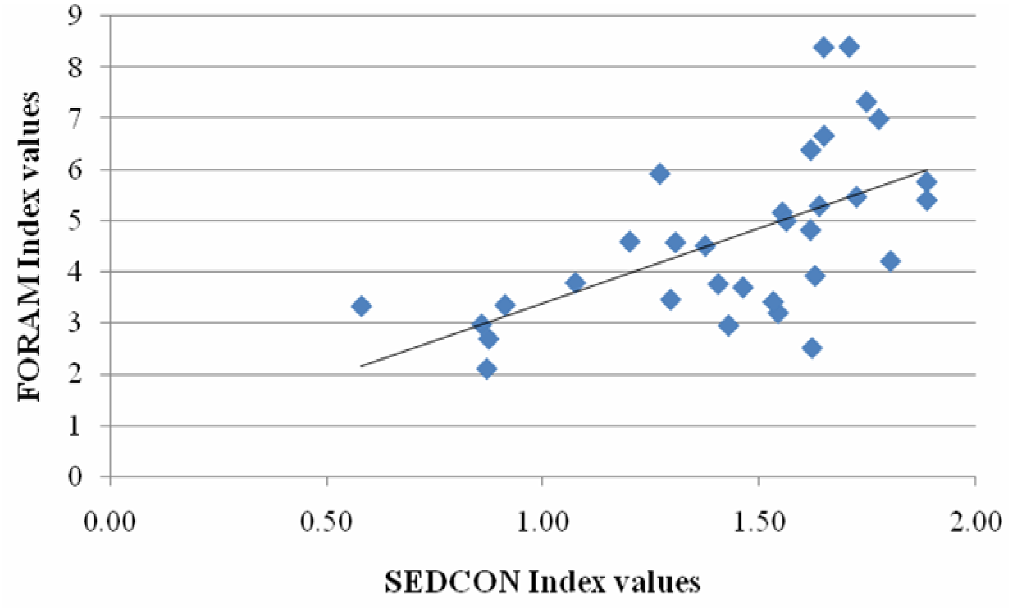
Because there is an outflow of water from Biscayne Bay through Caesar's Creek and because this creek is tidally dominated, the reefs in transect 5 must experience near constant water exchange. Since these reefs correspond to SIMPER groups A and E in the FORAM analysis, I deduced that these groups represent reefs in higher energy environments. Likewise, those reefs most dissimilar to groups A and E likely represent reefs in the lowest energy environment, i.e., group C.

Following this logic, since Group C from the FORAM analysis overlaps with Group B from the SEDCON analysis, the reefs in Group B must also represent low energy environments. This is supported by the presence of mud accumulated in the sediment sample.

In a simple attempt to validate this hypothesis, the coefficients for the P_{ah} and the P_u functional groups in the SEDCON Index equation were reversed. This increased the weighting of unidentifiables to now represent relative wave or current energy and down weighs the influence of indicators of increased nutrients. The results of this simple change as compared to the FORAM Index values can be seen in Figure 15. Thus, the two indices had a correlation coefficient of 0.59.

When the SEDCON Index was originally created by Daniels (2005), the results showed that the equation she developed correlated with percent coral cover for her sampled reefs in the Florida Keys. Also, the SI values she calculated had no correlation with percent mud. This is a likely cause for the deficiencies in the index. The reefs off the Florida Keys, especially off of the middle and lower Keys, are subject to strong currents emerging from Florida Bay (Lidz 2005). Without a large continuous landmass to divert the flow, muddy sediments cannot build up. Thus, the SEDCON Index may provide an accurate depiction of a reef system on an open shelf, but where landmasses prevent adequate circulation though a shallow reef environment, the influence of muddy sediments alters the interpretation of the index values.

Figure 15. FORAM Index values plotted against modified SEDCON Index values



Unfortunately, monitoring of coral cover in Biscayne National Park is sparse and sporadic such that no data were available to compare to the indices. While this would have been an interesting analysis, these indices are meant to describe the ability of a marine environment to support reef growth, not to describe the physical status of present reefs, so this lack of data is not an important issue.

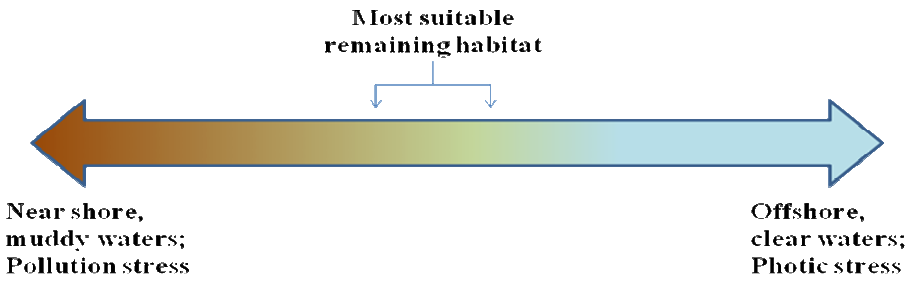
It is not the goal of this thesis to definitively correct the SEDCON Index. Merely, these findings suggest that the correlation between the two indices is strong enough to indicate that the SEDCON index could be viable with some alterations and should not be completely disregarded, but rather adjusted. In the event that the SEDCON Index can be adjusted, the point should be made that the SEDCON Index had the smaller learning curve and also took less time to analyze in comparison to the FORAM Index. Actual microscope time required to process one sample from start to finish was consistently about one hour for the SEDCON Index. The processing time for the FORAM Index, depending on the grain size distribution of the sample, ranged in processing time from 45 minutes to three hours. For both indices, processing time decreased as experience was gained.

Live Symbiont-bearing Foraminifera (LSF)

The larger species diversity, along with the presence of *Asterigerina carinata*, a species thought to be very tolerant of high energy environments (e.g., Crevison et al. 2006), as one of the contributing species to Group A's similarity, indicates that this group is subject to sufficient amounts of water circulation. This may minimize the effect that anthropogenic pollutants entering the reef system may have on these reefs, resulting in a relatively high mean FI value. Five of the seven reefs in this group fall on the eastern most side of the sampling area and so are more exposed to open ocean circulation patterns. Reef 1.1 was the only reef that exceeded Group A's abundance of *A. carinata*. This reef is also located in the vicinity of a tidally influenced creek and would therefore also be exposed to higher energy flow.

Amphistegina gibbosa, the foraminifer on which the Photic Index is based, were the most important contributor to Groups A and C, despite the fact that Group C includes some of the muddiest reefs. This species accounts for the major difference between Groups B and C. *A. gibbosa* abundance never exceeded 61 individuals/100cm^2, a density which Hallock (1995) considered as indicating suboptimal conditions for *Amphistegina*. Still, the relatively high abundance of live *A. gibbosa* specimens in the muddy Group C, as well as its relatively high overall density of LSF, can probably best be explained as a result of the "Goldilocks" nature of both symbiont-bearing foraminifers and corals. While both corals and foraminifers historically thrive on offshore reefs exposed to higher energy environments, and removal from local stressors near shore, the global increase of UV radiation also makes the clearest offshore reefs most vulnerable to photo-oxidative stress. I propose that this leaves the intermediate reefs as the most suitable habitat remaining for continued reef growth (Fig. 16).

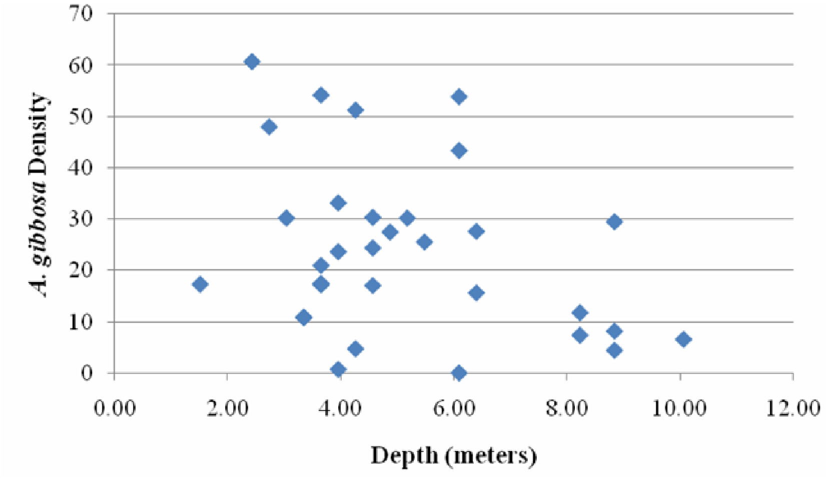
Figure 16. Schematic of "Goldilocks" scenario reefs now face.



Because the Photic Index is intended to detect global stressors and most of the reefs had the same impact level, this index was less useful in defining a spatial pattern. However, the uniformity of the values did indicate that the study area may be suffering from chronic photic stress as well as some level of other stressors. While the other indices were useful in suggesting local incidences of stress, this index shows that the reefs are also subject to the global stress of increased UV radiation. Two reefs (1.1 and 9.3) had a value of five, meaning very few *A. gibbosa* and little or no bleaching. The low densities may indicate environmental conditions that are generally unfavorable for symbiotic organisms. However, Reef 1.1 had a number of LSF that exceeded the overall mean, yet it did not have enough symbiont-bearing forams in the sediment assemblage to include in other analyses. Reef 9.3, however, might have been expected to have a PI value of 5 given its place among SIMPER group C in the foraminiferal assemblage data.

This index seemed to provide some additional qualitative results for assessing the health of Biscayne patch reefs. However, while *Amphistegina gibbosa* can be found in depths less than five meters to depths of 100 meters, they tend to be more abundant from 15 to 40 meters depth (Hallock 1999). The range of depths sampled in Biscayne National Park was less than two meters at Elkhorn reef to ten meters at reef 7.1. Because no reef fell within this zone of preference, the reefs are all comparable to each other. Figure 17 shows no relationship between the density of *A. gibbosa* and depth. Highly variable photic conditions are probably why *A. gibbosa* are generally less abundant at shallower depths. Where water transparency is more consistent, *Amphistegina* abundances tend to be higher, even at depths of 1-2 meters. In regards to the Photic Index, however, there may have been some complications in terms of the density ranking since one would not expect to see large densities of *A. gibbosa* in such shallow waters to begin with. Despite this, the PI does indicate that photic stress was chronic throughout the sampled area in May 2005.

Figure 17. Densities of *Amphistegina gibbosa* (per $100cm^2$) plotted against depth showing no depth dependence for the sampled reefs



Patch Reef Health

An overall assessment of patch reef health in this area of Biscayne National Park would need to include coral cover data. However, based on the indices applied for this project (Table 27), I can conclude that for most of the reefs in the sampled area, reef accretion is negligible and the probability of recovery after an acute event, such as a hurricane, boat grounding, or bleaching, is low. These conclusions are in agreement with Fisher et al. (2007) and Dupont et al. (*in press*), which both include analyses of reef conditions in BNP.

Dupont at al. (*in press*) conducted a comparative analysis of a coral cover data set from 1977 in Biscayne National Park with data sets collected in the 1990's. Their results showed that there has been significant loss of coral cover in that time period and that continued loss is probable. However, they also showed that over that time period species richness was relatively stable and concluded that recovery of the reef system may be possible if environmental conditions are restored.

An interesting analogy to the Dupont et al. (*in press*) observations may be the discrepancy I observed between abundances of live symbiont-bearing foraminifers (LSF), which were quite variable (8-569/100cm^2 of reef rubble), and the relatively few ($\leq$ 10%) shells of symbiont-bearing foraminifers encountered during the SEDCON Index analysis. Results from the SEDCON Index revealed that the majority of the constituents were unidentifiable. The original assumption for the SEDCON Index was that the unidentifiable fraction results primarily from bioeroded material, although certainly a significant component also can be physically abraded fragments. The decadal-scale, precipitous decline in coral cover reported by Dupont et al. (*in press*) and present low coral cover (Miller et al. 2000, Moulding and Patterson 2002) is consistent with the presence of relatively few recognizable coral fragments and shells of symbiont-bearing foraminifers. On the other hand, the presence and variable abundances of LSF are consistent with the Dupont et al. (*in press*) observation that coral species richness has not declined. That is, environmental conditions, including water quality, for the studied patch and bank reefs of Biscayne National Park generally support the survival of calcifying symbioses, including a diversity of coral and LSF species, but not their dominance and production of significant proportions of the carbonate sediments.

So the question then emerges, are the causes of the decadal-scale decline in coral cover on BNP patch reefs local, regional, or global? Certainly the decline in *Acropora* spp. that once dominated, e.g., Elkhorn Reef, is likely associated with the regional white-band epidemic (Gladfelter 1982, Santavy et al. 2005). Similarly, the evidence for chronic photo-oxidative stress, as indicated by chronic levels of bleaching in live *Amphistegina* *gibbosa*, likely provides further evidence for at least part of the decline being associated with global-change factors.

However, local decline in water quality must also be considered. Fisher et al. (2007) documented that coral-lesion recovery at Alina's Reef in BNP was poor, but that the presence of large coral heads with substantial live tissue indicated that the stress was relatively recent. Alina's Reef lies in the plume from Caesar's Creek. Moreover, Downs et al. (2006) documented evidence for xenobiotic stress in reef fish at Alina's Reef. Additionally, the dredging associated with the maintenance of Hawk Channel could be a major source of mud and re-suspended nutrients and/or toxins.

Finally, assessing the indices themselves, they demonstrated both applications and limitations. First of all, each of the indices indicates something different. The SEDCON Index reflects a) the community structure relative to calcifying symbioses (stony coral and symbiont-bearing foraminifers) versus sediment production by calcifying autotrophs and heterotrophs, and b) the accretion potential as reflected by proportions of coral and calcareous algal production versus bioeroded material. The FORAM Index also indicates the relative suitability of the environment for calcifying symbioses. Unfortunately both indices are influenced by sediment texture, especially sediments with significant proportions of mud. Therefore, comparing sediments of relatively similar textures is advisable. The inverse correlation between the SEDCON and FORAM indices in my samples indicates that, at low SEDCON values, production by calcareous algae can overwhelm production by symbiont-bearing foraminifers, even when live symbiont-bearing foraminifers can be found in some abundance in the environment. Thus, the indices should be evaluated independently and over a general area, and are not sufficiently sensitive enough to reflect subtle differences among similar patch reefs.

Similarly, the three potential indices provided by assessing LSF indicate again somewhat different aspects of the environment. Especially in very shallow environments, *Amphistegina gibbosa* densities can be quite variable, so their widespread presence at intermediate densities on BNP patch and bank reefs indicated that environmental conditions were generally favorable, at least during the time of sampling. Similarly, those densities combined with evidence for chronic bleaching indicated that water quality, including water transparency, was sufficient for photo-oxidative stress to be occurring, but that the stress was not acute. Fisher (2007), reporting on a variety of diagnostic parameters on upper Florida Keys patch reefs, found that chronic bleaching in *A. gibbosa* tended to be most prevalent at the reefs that consistently had the highest densities of *A. gibbosa* and the best rates of recovery of coral lesions. Finally, the overall densities of LSF revealed generally intermediate abundances with substantial variability among reefs. These trends again show that conditions are suitable for their persistence but not dominance as sediment producers. And all of these trends support the assumption, presented in Figure 16, that Florida's coral reefs and reef-associated biota today are being squeezed between the impacts of increasing terrestrial influence as humans alter coastal habitats, and increasing photo-oxidative stresses associated with stratospheric ozone depletion and global climate change.

Islands v Inlet: Sources of Stress or Security?

The two islands that separate Biscayne Bay from the open shelf (Elliot Key and Old Rhode's Key) may be influencing the patch reefs in the sampled area in both positive and negative ways. First, the Keys prevent Biscayne Bay waters from directly influencing the reef environment. However, in doing so, they are also limiting the area of water flow and forcing higher velocity exchange through Caesar's Creek. As velocity decreases with distance from the creek there is likely to be flocculation of muds, and potentially pollutants, out of the water column and on to the reefs more distant from Caesar's Creek. On the other hand, reefs in proximity to the undeveloped islands may be more sheltered from the effects of harmful UV radiation by higher concentrations of colored dissolved organic matter (CDOM) produced by the mangroves on the islands.

Conversely, Caesar's Creek may be the main source of pollution from within Biscayne Bay onto the reefs, which may result in a larger nutrient flux on those reefs in its immediate proximity, however, the constant water motion may prevent any more serious pollutants and heavy metals from settling on the reef. Additionally, turbidity caused by the water motion may also add some protection from the increased levels of UV radiation.

Because my analysis did not include water transparency analyses or sediment toxicology studies, it would be hard to say for sure which, the islands or the inlet, is a greater cause/source of stress and to what degree. However, these would be interesting aspects to research in the future. Also, because the reefs in this area seem to be affected by chronic photic stress, the beneficial effects of the islands and the inlet, relative to water transparency, may be very important to the persistence of the reefs in Biscayne National Park.

Table 27. Summary of data presented in this report as rankings. * indicates insufficient specimens (< 50 per sample) to calculate the index or index ranking.

Rank Definition	FI	SI	*Amphistegina* bleaching	*Amphistegina* density	LSF density
1 - poor	<2	<2	>40%	<10	<10
2 - marginal	2-4	2-4	5-40%	10-100	10-100
3 - good	>4	>4	<5%	>100	>100

Site	**FI Rank**	**SI Rank**	**Bleach Rank**	**Amphi Rank**	**LSF Rank**
1.1	3.00*	1.00	3.00*	1.00	3.00
1.2	3.00	1.00	2.00*	2.00	3.00
Shark	3.00*	1.00	2.00*	2.00	2.00
2.1	2.00	1.00	2.00*	2.00	2.00
2.2	2.00	1.00	2.00*	1.00	2.00
3.1	2.00	1.00	2.00*	2.00	2.00
3.2	3.00*	1.00	2.00*	2.00	3.00
Bug	2.00	1.00	2.00*	2.00	2.00
Elkhorn	3.00	1.00	2.00*	2.00	2.00
4.1	2.00	1.00	2.00	2.00	3.00
4.2	2.00	1.00	2.00*	2.00	2.00
Pacific	3.00	1.00	2.00*	2.00	2.00
5.1	3.00	1.00	2.00*	2.00	2.00
5.2	3.00	1.00	2.00*	1.00	2.00
5.3	3.00	1.00	2.00*	2.00	2.00
5.4	3.00*	1.00	2.00*	2.00	2.00
6.1	2.00	1.00	2.00*	1.00	2.00
6.2	2.00	1.00	2.00*	2.00	3.00
6.3	3.00	1.00	2.00*	2.00	3.00
7.1	2.00	1.00	2.00*	1.00	3.00
Star	2.00	1.00	2.00*	2.00	2.00
7.2	3.00	1.00	2.00*	2.00	3.00
8.1	3.00*	1.00	2.00*	2.00	2.00
Nirvana	3.00*	1.00	2.00	2.00	3.00
8.2	2.00	1.00	2.00	2.00	3.00
9.1	3.00	1.00	2.00*	1.00	2.00
9.2	2.00	2.00	2.00*	2.00	2.00
9.3	2.00	2.00	3.00*	1.00	1.00
Lugano	3.00*	1.00	2.00*	2.00	3.00
10.1	3.00*	1.00	2.00	2.00	2.00
10.2	3.00	1.00	2.00*	2.00	3.00
Dome	2.00	1.00	2.00*	2.00	3.00

CONCLUSIONS

1. The pattern of salinity, temperature, and percent mud indicate waters emerging from Biscayne Bay through Caesar's Creek into the study area.

2. The influence of the water emerging from the bay is reflected in the FORAM and SEDCON Indices.

3. Analyses of both the FORAM Index and the SEDCON Index produced SIMPER groups that seemed to reflect physical processes that are affecting the reefs (i.e., high and low energy environments). The FORAM Index created more distinct groupings that reflected transitional conditions.

4. The SEDCON Index was faster and easier to apply, while the FORAM Index produced more inter-reef detail. Moreover, the BNP samples revealed previously undocumented dependence of both indices on sediment texture.

5. Each of the potential biotic indicators, i.e., the SEDCON Index, the FORAM Index, and each of three parameters associated with living symbiont-bearing foraminifers, reveals slightly different aspects of environmental conditions, providing a potential diagnostic suite that appears more robust for the area than any single parameter.

6. Based on the suite of biotic indicators, environmental conditions throughout most of the high density patch reefs in Biscayne National Park appear to be marginal

for reef growth. The average FI value across all reefs was 4.12; the average SI value was 1.26. *Amphistegina gibbosa* densities averaged 24 specimens per 100 cm^2, while total LSF densities averaged 102 specimens per 100 cm^2.

7. Global and regional stressors, such as white-band disease, increased short-wavelength solar radiation associated with stratospheric ozone depletion, and increasing sea-surface temperatures, are likely compounding the effects of declining local water quality. Reef recovery from an acute event in this area is likely to be poor.

8. Long-term monitoring of environmental variables and coral cover should be conducted to determine if the net effect of the water emerging from Biscayne Bay is positive or negative. This includes but is not limited to monitoring for heavy metals and pesticides that are known to accumulate within the Bay.

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APPENDICES

Appendix I. Results of grain-size analysis, percent weight of size fraction. Bold indicates median size fraction. Shading represents size fraction analyzed for the SEDCON Index.

		PHI SIZES						
		-1	**0**	**1**	**2**	**3**	**4**	**>4**
Site	Replicate	**> 2mm**	**>1mm**	**>0.5mm**	**>0.25mm**	**>0.125mm**	**>0.063mm**	**<0.063mm**
1.1	R1	21.41%	**44.54%**	31.13%	2.12%	0.26%	0.18%	0.37%
1.1	R2	10.50%	23.50%	**50.72%**	13.28%	1.20%	0.32%	0.48%
1.2	R1	3.69%	**59.40%**	33.05%	3.10%	0.46%	0.16%	0.14%
1.2	R2	10.72%	35.79%	**31.74%**	18.49%	2.49%	0.32%	0.45%
Shark	R1	0.03%	5.64%	**85.36%**	8.77%	0.17%	0.01%	0.01%
Shark	R2	0.67%	13.73%	**74.10%**	11.11%	0.36%	0.02%	0.03%
2.1	R1	46.20%	**37.74%**	11.47%	2.64%	0.95%	0.42%	0.58%
2.1	R2	36.88%	**39.35%**	19.34%	2.88%	0.68%	0.32%	0.55%
2.2	R1	16.53%	27.57%	**33.08%**	14.11%	4.48%	2.50%	1.73%
2.2	R2	10.98%	20.55%	**29.12%**	17.88%	10.05%	5.92%	5.49%
3.1	R1	9.23%	26.95%	**28.28%**	15.96%	13.12%	5.52%	0.95%
3.1	R2	7.66%	20.05%	**34.34%**	21.61%	10.85%	4.10%	1.39%
3.2	R1	41.20%	**51.13%**	7.37%	0.23%	0.04%	0.02%	0.02%
3.2	R2	7.39%	42.19%	**45.61%**	4.67%	0.12%	0.00%	0.02%
Bug	R1	9.42%	9.56%	13.98%	11.94%	**13.47%**	16.81%	24.81%
Bug	R2	7.52%	4.82%	8.94%	11.42%	12.74%	**14.33%**	40.23%
Elkhorn	R1	27.86%	**48.55%**	20.64%	2.11%	0.54%	0.15%	0.14%
Elkhorn	R2	9.70%	22.49%	**42.67%**	18.51%	4.56%	0.96%	1.12%
4.1	R1	10.36%	16.74%	**27.66%**	22.27%	15.71%	3.63%	3.62%
4.1	R2	9.04%	14.66%	25.06%	**23.22%**	17.28%	4.87%	5.88%
4.2	R1	10.10%	8.09%	17.34%	**27.71%**	22.71%	6.48%	7.58%
4.2	R2	6.84%	12.22%	21.57%	**19.77%**	17.25%	6.54%	15.80%
Pacific	R1	1.21%	10.06%	**70.43%**	17.05%	1.08%	0.06%	0.12%
Pacific	R2	6.53%	36.98%	**47.37%**	7.39%	1.38%	0.20%	0.15%
5.1	R1	4.66%	19.83%	**58.52%**	14.89%	1.73%	0.18%	0.18%
5.1	R2	18.05%	**51.45%**	22.01%	5.54%	2.23%	0.39%	0.33%
5.2	R1	8.30%	19.85%	**49.15%**	19.64%	2.16%	0.29%	0.62%
5.2	R2	3.42%	12.08%	**50.02%**	29.07%	3.32%	0.48%	1.62%
5.3	R1	4.55%	25.04%	**54.91%**	12.67%	2.18%	0.30%	0.34%
5.3	R2	14.13%	28.11%	**45.05%**	9.61%	1.69%	0.34%	1.06%
5.4	R1	15.00%	**36.28%**	40.97%	5.35%	1.35%	0.34%	0.71%
5.4	R2	10.44%	36.74%	**40.40%**	8.53%	2.73%	0.51%	0.66%

Appendix I. (Continued) Results of grain-size analysis, percent weight of size fraction. Bold indicates median size fraction.

		PHI SIZES						
		-1	**0**	**1**	**2**	**3**	**4**	**>4**
Site	Replicate	**> 2mm**	**>1mm**	**>0.5mm**	**>0.25mm**	**>0.125mm**	**>0.063mm**	**<0.063mm**
6.1	R1	7.61%	10.51%	21.34%	**27.49%**	27.26%	4.45%	1.35%
6.1	R2	5.99%	14.36%	**29.65%**	24.71%	19.52%	3.74%	2.02%
6.2	R1	17.35%	24.02%	**47.91%**	9.41%	0.89%	0.13%	0.28%
6.2	R2	2.18%	11.32%	**52.32%**	30.15%	3.50%	0.48%	0.06%
6.3	R1	0.58%	2.83%	35.65%	**43.66%**	15.83%	1.16%	0.29%
6.3	R2	1.58%	2.98%	30.50%	**40.90%**	21.10%	1.93%	1.02%
7.1	R1	9.44%	17.65%	**33.51%**	20.31%	9.40%	5.35%	4.34%
7.1	R2	7.16%	20.50%	**37.39%**	20.94%	7.92%	3.55%	2.52%
Star	R1	12.24%	16.04%	**29.54%**	24.42%	13.86%	1.73%	2.16%
Star	R2	5.87%	6.61%	14.92%	**35.07%**	31.99%	2.77%	2.77%
7.2	R1	7.78%	12.97%	**37.10%**	31.62%	7.96%	1.09%	1.47%
7.2	R2	12.83%	12.77%	**40.36%**	25.21%	5.83%	1.04%	1.96%
8.1	R1	5.80%	39.69%	**48.21%**	5.49%	0.49%	0.09%	0.24%
8.1	R2	13.42%	**60.55%**	25.37%	0.51%	0.01%	0.00%	0.15%
Nirvana	R1	8.95%	**45.75%**	40.29%	4.65%	0.26%	0.04%	0.06%
Nirvana	R2	3.07%	32.97%	**60.63%**	3.12%	0.14%	0.02%	0.06%
8.2	R1	16.15%	23.90%	**29.29%**	18.05%	8.91%	2.06%	1.64%
8.2	R2	7.31%	10.27%	17.27%	**17.27%**	15.77%	8.39%	23.71%
9.1	R1	8.42%	15.23%	**37.48%**	23.41%	11.17%	2.97%	1.32%
9.1	R2	9.10%	8.77%	26.75%	**29.70%**	17.20%	4.86%	3.62%
9.2	R1	2.50%	4.44%	10.12%	17.84%	**24.71%**	23.04%	17.34%
9.2	R2	4.70%	6.84%	16.24%	17.18%	**19.25%**	18.47%	17.33%
9.3	R1	6.61%	11.48%	21.75%	**15.59%**	13.72%	12.07%	18.78%
9.3	R2	4.83%	8.51%	19.84%	**14.77%**	12.81%	11.31%	27.92%
Lugano	R1	0.44%	36.20%	**58.31%**	4.72%	0.10%	0.02%	0.21%
Lugano	R2	15.20%	**38.22%**	41.28%	4.84%	0.30%	0.06%	0.10%
10.1	R1	7.09%	**74.84%**	17.54%	0.31%	0.02%	0.01%	0.19%
10.1	R2	3.26%	39.95%	**53.10%**	3.25%	0.31%	0.04%	0.09%
10.2	R1	4.65%	18.02%	**51.43%**	22.00%	3.70%	0.14%	0.05%
10.2	R2	1.00%	13.29%	**58.12%**	23.05%	4.17%	0.23%	0.14%
Dome	R1	6.58%	17.43%	**31.21%**	25.58%	14.24%	1.75%	3.21%
Dome	R2	11.93%	15.32%	**23.92%**	19.95%	15.44%	4.05%	9.39%

Appendix I. (Continued) Average grain-size for each site. Values for percent mud used in correlations and plotting were taken from this table.

	PHI SIZES						
	-1	0	1	2	3	4	>4
Reef Site	**> 2mm**	**>1mm**	**>0.5mm**	**>0.25mm**	**>0.125mm**	**>0.063mm**	**<0.063mm**
1.1	15.95%	34.02%	**40.92%**	7.70%	0.73%	0.25%	0.43%
1.2	7.21%	**47.60%**	32.40%	10.80%	1.47%	0.24%	0.29%
Shark	0.35%	9.68%	**79.73%**	9.94%	0.26%	0.02%	0.02%
2.1	41.54%	**38.55%**	15.40%	2.76%	0.81%	0.37%	0.56%
2.2	13.75%	24.06%	**31.10%**	16.00%	7.27%	4.21%	3.61%
3.1	8.44%	23.50%	**31.31%**	18.79%	11.98%	4.81%	1.17%
3.2	24.30%	**46.66%**	26.49%	2.45%	0.08%	0.01%	0.02%
Bugs	8.47%	7.19%	11.46%	11.68%	**13.11%**	15.57%	32.52%
Elkhorn	18.78%	**35.52%**	31.65%	10.31%	2.55%	0.56%	0.63%
4.1	9.70%	15.70%	**26.36%**	22.74%	16.50%	4.25%	4.75%
4.2	8.47%	10.16%	19.45%	**23.74%**	19.98%	6.51%	11.69%
Pacific	3.87%	23.52%	**58.90%**	12.22%	1.23%	0.13%	0.13%
5.1	11.36%	35.64%	**40.26%**	10.21%	1.98%	0.29%	0.26%
5.2	5.86%	15.97%	**49.58%**	24.35%	2.74%	0.38%	1.12%
5.3	9.34%	26.58%	**49.98%**	11.14%	1.94%	0.32%	0.70%
5.4	12.72%	36.51%	**40.69%**	6.94%	2.04%	0.42%	0.68%
6.1	6.80%	12.43%	25.50%	**26.10%**	23.39%	4.09%	1.69%
6.2	9.77%	17.67%	**50.11%**	19.78%	2.19%	0.31%	0.17%
6.3	1.08%	2.90%	33.07%	**42.28%**	18.46%	1.55%	0.65%
7.1	8.30%	19.08%	**35.45%**	20.62%	8.66%	4.45%	3.43%
Star	9.06%	11.32%	22.23%	**29.74%**	22.93%	2.25%	2.46%
7.2	10.31%	12.87%	**38.73%**	28.41%	6.89%	1.07%	1.72%
8.1	9.61%	**50.12%**	36.79%	3.00%	0.25%	0.05%	0.19%
Nirvana	6.01%	39.36%	**50.46%**	3.88%	0.20%	0.03%	0.06%
8.2	11.73%	17.08%	**23.28%**	17.66%	12.34%	5.23%	12.68%
9.1	8.76%	12.00%	**32.11%**	26.56%	14.18%	3.91%	2.47%
9.2	3.60%	5.64%	13.18%	17.51%	**21.98%**	20.75%	17.33%
9.3	5.72%	9.99%	20.80%	**15.18%**	13.27%	11.69%	23.35%
Lugano	7.82%	37.21%	**49.80%**	4.78%	0.20%	0.04%	0.15%
10.1	5.18%	**57.40%**	35.32%	1.78%	0.17%	0.03%	0.14%
10.2	2.82%	15.66%	**54.78%**	22.53%	3.94%	0.19%	0.10%
Dome	9.25%	16.37%	**27.56%**	22.77%	14.84%	2.90%	6.30%

Appendix II-a. List of foraminiferal genera found within the patch reefs of Biscayne National Park by this study.

Symbiont-bearing

Amphistegina
Androsina
Archaias
Asterigerina
Borelis
Broekina
Cyclorbiculina
Gypsina
Heterostegina
Laevipeneroplis
Monalysidium
Peneroplis
Sorites

Stress-tolerant

Ammonia
Ammobaculites
Bolivina
Bulimina
Cribroelphidium
Elphidium
Haynesina
Nonion
Nonionella
Nonionoides

Heterotrophic

Adelosina
Affinetrina
Anomalinoides
Articulina
Astrononion
Bigenerina
Brizalina
Cancris
Carpenteria
Cibicides
Clavulina
Cornuspira
Cycloforina
Cymbaloporetta
Disconorbis
Discorbinella
Discorbis
Fischerinella
Eponides
Floresina
Fursenkoina
Glabratella
Glabratellina
Globigerinoides
Globocassidulina
Globorotalia
Globulina
Guttulina
Haplophragmoides
Hauerina
Lachlanella
Lobatula
Miliolinella
Montfortella
Neocornorbina
Neoeponides
Patellina
Planorbulina
Polymorphina
Poroepodines
Pseudohauerina
Pyrgo
Quinqueloculina
Rectobolivina
Reophax
Reussella
Rosalina
Sigmavirgulina
Sigmoilina
Sigmoilinita
Siphonaperta
Siphonina
Siphoninoides
Spiroloculina
Textularia
Treromphalus
Triloculina
Triloculinella
Wiesnerella

Appendix II-b. Raw counts of foraminiferal genera from the two sediment replicates of 32 reefs in Biscayne National Park.

	1.1R1	1.1R2	1.2R1	1.2R2	SharkR1	SharkR2	2.1R1	2.1R2
Amphistegina				5		1	1	2
Androsina					1			
Archaias		7	20	22	3	5	2	4
Asterigerina	3	3		1		1	1	4
Borelis								
Broekina								
Cyclorbiculina		1	4	4				1
Gypsina								
Heterostegina								
Laevipeneroplis	2	6	1	4	1		18	11
Monalysidium								1
Peneroplis		1				1		1
Sorites								
Ammonia		1		1				3
Ammobaculites								
Bolivina							2	
Bulimina				1			1	2
Cribroelphidium							2	4
Elphidium				3			1	1
Haynesina							3	1
Nonion								
Nonionella								
Nonionoides								
Adelosina				1			1	
Affinetrina								1
Anomalinoides								
Articulina							1	2
Astrononion								
Bigenerina	1						1	
Brizalina								1
Cancris								
Carpenteria								
Cibicides				1				1
Clavulina		1		1				
Cornuspira				1				1
Cycloforina		2		2			2	1
Cymbaloporetta								
Disconorbis								
Discorbinella								1
Discorbis	2	3	2	19			3	3
Fischerinella								
Eponides				1				4
Floresina								

Appendix II-b. (Continued)

	1.1R1	1.1R2	1.2R1	1.2R2	SharkR1	SharkR2	2.1R1	2.1R2
Fursenkoina								
Glabratella				1				
Glabratellina								2
Globigerinoides							1	
Globocassidulina								1
Globorotalia				1				
Globulina								
Guttulina								
Haplophragmoides								
Hauerina								
Lachlanella				1			1	1
Lobatula							1	
Miliolinella				3			4	
Montfortella								
Neocornorbina		1					1	
Neoeponides								
Patellina								
Planorbulina				3				4
Polymorphina								
Poroepodines		1						
Pseudohauerina								
Pyrgo	1							1
Quinqueloculina		7	3	21	1		54	35
Rectobolivina								1
Reophax								1
Reussella								
Rosalina		1		5	1		7	15
Sigmavirgulina								
Sigmiolina								5
Sigmiolinita							3	
Siphonaperta		2		10			4	6
Siphonina								1
Siphoninoides								1
Spiroloculina				1			2	
Textularia	1	4		3		1	3	7
Treromphalus								1
Triloculina	2	3		16			13	7
Triloculinella				2			2	5
Wiesnerella							1	2
Total Forams	12	44	30	134	7	9	136	146
Density (forams/g)	12	44	30	134	7	9	444	209
Number of genera	7	16	5	27	5	5	28	39
Foram Index	5.33	5.25	8.67	4.11	7.71	9.11	3.23	3.24
SIMPER Group				A			D	B

Appendix II-b. (Continued)

	2.2R1	2.2R2	3.1R1	3.1R2	3.2R1	3.2R2	BugR1	BugR2
Amphistegina		1	2			8		
Androsina								
Archaias	9	4	10	8	2			1
Asterigerina			3					
Borelis	1	1	1					
Broekina	2	1	2	3			1	
Cyclorbiculina	1							
Gypsina			1					
Heterostegina								
Laevipeneroplis	10	7	17	10		1	3	8
Monalysidium								
Peneroplis	1	2	1	1				
Sorites		1	1			1	1	
Ammonia		8	1	7				3
Ammobaculites								
Bolivina	3	4					11	13
Bulimina		3		1			1	5
Cribroelphidium	2		4				5	5
Elphidium	11	4	13	5			13	5
Haynesina	1	7	1	2			5	5
Nonion				2				1
Nonionella								
Nonionoides	3		1				4	
Adelosina	1	2		1				1
Affinetrina				1				
Anomalinoides								
Articulina			5	7			1	2
Astrononion								
Bigenerina	1							
Brizalina		1	1				1	
Cancris								
Carpenteria								
Cibicides		1		1		2	1	1
Clavulina				1				
Cornuspira	1	1		3		2	3	
Cycloforina	2	3	4	3			3	
Cymbaloporetta								1
Disconorbis		3		2			1	5
Discorbinella				1				2
Discorbis	4	12	8	9			4	1
Fischerinella								
Eponides		1		2			1	1
Floresina		1		1				

Appendix II-b. (Continued)

	2.2R1	2.2R2	3.1R1	3.1R2	3.2R1	3.2R2	BugR1	BugR2
Fursenkoina							1	
Glabratella		1						
Glabratellina								2
Globigerinoides				1				
Globocassidulina	1			1				
Globorotalia			1					
Globulina			1					
Guttulina								
Haplophragmoides								
Hauerina			1					
Lachlanella								
Lobatula				2				
Miliolinella	2	3	2	5			6	11
Montfortella								
Neocornorbina			1	1		2		
Neoeponides								
Patellina	1							
Planorbulina	1		1					
Polymorphina								
Poroepodines								
Pseudohauerina				1			1	1
Pyrgo	1						3	1
Quinqueloculina	48	50	51	29	1	3	83	74
Rectobolivina	1	5						
Reophax								
Reussella								
Rosalina	7	14	6	7			15	18
Sigmavirgulina								
Sigmiolina		4		3				8
Sigmiolinita	2		1					
Siphonaperta	5	6	4	11		1		1
Siphonina								1
Siphoninoides								
Spiroloculina	1	3	2				1	2
Textularia			3	2				1
Trerompha lus	1							
Triloculina	11	3	18	3			15	9
Triloculinella	2		4				1	5
Wiesnerella	2	3						
Total Forams	139	160	172	137	3	20	185	194
Density (forams/g)	460	1600	571	685	3	20	1814	7760
Number of genera	31	31	32	33	2	8	26	30
Foram Index	3.24	2.69	3.65	3.16	7.33	6.00	2.01	2.18
SIMPER Group	B	D	B	D			C	C

Appendix II-b. (Continued)

	ElkhornR1	ElkhornR2	4.1R1	4.1R2	4.2R1	4.2R2	PacificR1	PacificR2
Amphistegina		7	3	10	7	1	7	3
Androsina		7						
Archaias	1	17	4	11	5	2	32	13
Asterigerina	2	7					4	8
Borelis		1				1	1	4
Broekina		1	6	1			1	
Cyclorbiculina	1	5	1				8	6
Gypsina								
Heterostegina		2					2	1
Laevipeneroplis	1	10	15	14	15	7	3	9
Monalysidium								
Peneroplis		4	2	3	2	1		
Sorites								2
Ammonia		1		4		5		
Ammobaculites								
Bolivina		6	5	1		7		
Bulimina		2				3		
Cribroelphidium				3		2		1
Elphidium		1	6	1	6	1		
Haynesina			5		4	3		
Nonion			1		1			1
Nonionella								
Nonionoides		1		1				
Adelosina						2		
Affinetrina		1	1	2		1		1
Anomalinoides								
Articulina			3	6	1	3	1	1
Astrononion								
Bigenerina								
Brizalina				1				
Cancris								
Carpenteria								
Cibicides			1	1	2	1		
Clavulina								
Cornuspira		1	1		3	2		2
Cycloforina		2	7	5	1	3		
Cymbaloporetta		1	1	1				1
Disconorbis						3		
Discorbinella		1						
Discorbis	2	21	7	11	6	9	7	11
Fischerinella								
Eponides		1		1				
Floresina					1			

Appendix II-b. (Continued)

	ElkhornR1	ElkhornR2	4.1R1	4.1R2	4.2R1	4.2R2	PacificR1	PacificR2
Fursenkoina								
Glabratella		2						
Glabratellina								1
Globigerinoides							1	
Globocassidulina						1		
Globorotalia								
Globulina								
Guttulina								
Haplophragmoides					1			
Hauerina		1	2	2	1	1		1
Lachlanella			1	1		1		
Lobatula		1						
Miliolinella				3	4	5		1
Montfortella								
Neocornorbina		2	1	1	1	1	1	3
Neoeponides								
Patellina								
Planorbulina			1					
Polymorphina								
Poroepodines								
Pseudohauerina				1				1
Pyrgo			2	2		1		
Quinqueloculina		21	52	54	49	41	1	12
Rectobolivina				1				
Reophax							1	
Reussella			1					
Rosalina	2	16	13	8	15	8		13
Sigmavirgulina								
Sigmiolina								
Sigmiolinita								
Siphonaperta		5	3	5	3	7	1	1
Siphonina		1	1	1		3		
Siphoninoides								
Spiroloculina		1	1	4		2		
Textularia			3		3		1	1
Treromphalus				1		1		
Triloculina		1	20	23	22	17	1	1
Triloculinella		4	2	6	1	4		1
Wiesnerella			1	1	1			1
Total Forams	9	155	173	191	155	150	73	101
Density (forams/g)	9	194	577	478	767	1500	73	101
Number of genera	6	33	32	34	24	33	17	27
Foram Index	6.44	5.08	3.34	3.58	3.43	2.50	8.36	5.62
SIMPER Group		E	B	B	B	B	E	E

Appendix II-b. (Continued)

	5.1R1	5.1R2	5.2R1	5.2R2	5.3R1	5.3R2	5.4R1	5.4R2
Amphistegina	3	2	1	1	2	5	5	2
Androsina								
Archaias	13	4	22	28	2	8	1	4
Asterigerina		1		1	1	3		
Borelis	2	2			2	2		
Broekina				1		1	1	
Cyclorbiculina	1	4	3	6	1	1	2	2
Gypsina		1						
Heterostegina		1						
Laevipeneroplis	4	3	6	14	4	4	4	
Monalysidium								
Peneroplis	1				1	1		
Sorites		1		1				
Ammonia								1
Ammobaculites								
Bolivina		1	2	2			2	
Bulimina								
Cribroelphidium					1			
Elphidium	2		3	6	2	1		
Haynesina			1				2	
Nonion			1					
Nonionella					1		1	
Nonionoides			1	2				
Adelosina				1	1			
Affinetrina								
Anomalinoides								
Articulina					1	1	2	1
Astrononion								
Bigenerina			1					
Brizalina								
Cancris								
Carpenteria								
Cibicides								
Clavulina						1		
Cornuspira								
Cycloforina		1	1			1		
Cymbaloporetta								
Disconorbis					1			
Discorbinella								
Discorbis	9	5	8	8	9	1		
Fischerinella								
Eponides								
Floresina								

Appendix II-b. (Continued)

	5.1R1	5.1R2	5.2R1	5.2R2	5.3R1	5.3R2	5.4R1	5.4R2
Fursenkoina					1		1	
Glabratella			1					
Glabratellina						1		
Globigerinoides								
Globocassidulina								
Globorotalia		1						
Globulina								
Guttulina								
Haplophragmoides								
Hauerina								
Lachlanella	1							1
Lobatula							1	
Miliolinella	1						2	1
Montfortella								
Neocornorbina				1		1	1	
Neoeponides							1	
Patellina								
Planorbulina			3					
Polymorphina								
Poroepodines								
Pseudohauerina					1			
Pyrgo				1				1
Quinqueloculina	8	4	21	26	11			8
Rectobolivina								
Reophax				1				
Reussella								
Rosalina	2	5	3	2	3	1	7	
Sigmavirgulina	1							
Sigmiolina	1							
Sigmiolinita								
Siphonaperta	1	1	4	20	1	3	1	3
Siphonina							1	
Siphoninoides								
Spiroloculina				1			1	
Textularia	1	3	5	2	2	1		
Treromphalus			1	1				
Triloculina	7		9	6	7	5		3
Triloculinella	2	1	1			2	1	
Wiesnerella		1			1		3	
Total Forams	60	42	98	132	56	44	40	27
Density (forams/g)	60	42	98	132	56	44	40	27
Number of genera	18	19	21	22	22	20	20	11
Foram Index	5.17	5.60	4.53	5.08	3.79	6.52	4.48	4.33
SIMPER Group	A		A	A	A			

Appendix II-b. (Continued)

	6.1R1	6.1R2	6.2R1	6.2R2	6.3R1	6.3R2	7.1R1	7.1R2
Amphistegina	3	2	2	2	3	3	2	2
Androsina		1						
Archaias	6	8	7	12	16	35	5	15
Asterigerina	2	4	3		1	2	3	3
Borelis	1		3	2		2		
Broekina	3	5	1		2	1	1	6
Cyclorbiculina	1		1	4	1	1	3	4
Gypsina							1	
Heterostegina								
Laevipeneroplis	13	21	22	12	6	16	11	10
Monalysidium			1					
Peneroplis	1	5		1		1	3	3
Sorites	1				1		2	1
Ammonia	1	1	2	1				2
Ammobaculites								
Bolivina	1		2				3	1
Bulimina			1		1			
Cribroelphidium	2						1	1
Elphidium	8	6	1	3	4	2	4	7
Haynesina			6		3		7	
Nonion								
Nonionella								3
Nonionoides		1		1		2	1	1
Adelosina				1		1	1	2
Affinetrina							1	
Anomalinoides								
Articulina	4	1		3		2		5
Astrononion							1	
Bigenerina		1	1		1		1	2
Brizalina								
Cancris								
Carpenteria								
Cibicides	1	2			1			
Clavulina	1	2				2	1	
Cornuspira							2	1
Cycloforina	2	4	1	1	2	1	4	5
Cymbaloporetta	1		1	1			3	
Disconorbis							1	
Discorbinella								2
Discorbis	14	7	6	9	21	28	3	3
Fischerinella								
Eponides	3	2	1	1				
Floresina	1							

Appendix II-b. (Continued)

	6.1R1	6.1R2	6.2R1	6.2R2	6.3R1	6.3R2	7.1R1	7.1R2
Fursenkoina			2	1				
Glabratella		1						1
Glabratellina								
Globigerinoides		1						
Globocassidulina			1				1	
Globorotalia	1			1				
Globulina								
Guttulina								
Haplophragmoides								
Hauerina	2	1		3		1	2	
Lachlanella		2					1	
Lobatula	1		2					
Miliolinella	1	1	2	6	5	2	2	1
Montfortella								
Neocornorbina			1	3		1		1
Neoeponides								
Patellina								
Planorbulina	2	4	1		1			2
Polymorphina								
Poroepodines								
Pseudohauerina	2	1				1	1	
Pyrgo	2	2		1				2
Quinqueloculina	41	38	28	33	19	28	53	45
Rectobolivina								
Reophax								
Reussella								
Rosalina	6	8	19	15	6	6	13	16
Sigmavirgulina								
Sigmiolina							1	
Sigmiolinita								
Siphonaperta	10	6	7	9	17	8	5	9
Siphonina	1	3						
Siphoninoides	1							
Spiroloculina	2	1	1	2	1	1		3
Textularia	10	10	12	3		1	4	2
Treromphalus				1				
Triloculina	16	13	10	4	4	8	12	13
Triloculinella	3	3	1		2	3		2
Wiesnerella			4	1				
Total Forams	171	168	153	137	118	159	160	176
Density (forams/g)	1676	560	180	137	118	177	1584	587
Number of genera	37	33	32	29	22	26	35	33
Foram Index	3.38	4.14	4.01	3.89	3.97	5.04	3.45	3.91
SIMPER Group	B	B	B	B	A	A	B	B

Appendix II-b. (Continued)

	StarR1	StarR2	7.2R1	7.2R2	8.1R1	8.1R2	NirvanaR1	NirvanaR2
Amphistegina	5	6	5	2				
Androsina	1		2					
Archaias	5	9	23	10	3	2	1	1
Asterigerina	2	1		4	1			
Borelis	1	3	1	3	1	2		
Broekina	3	5		4				
Cyclorbiculina	3	1	6	1				1
Gypsina		1						
Heterostegina	1					1		
Laevipeneroplis	11	14	18	28	1	2		
Monalysidium								
Peneroplis		5	4	2				
Sorites	1	1						
Ammonia	1		1	2	1			
Ammobaculites								
Bolivina	8		2	2				
Bulimina			1					
Cribroelphidium	2			3				
Elphidium	1	2	5	1				
Haynesina	4		4	3				
Nonion								
Nonionella								
Nonionoides	1	1	1					
Adelosina	2			1				
Affinetrina		1						
Anomalinoides								
Articulina	2	1	1	1		1		
Astrononion								
Bigenerina								
Brizalina								
Cancris								
Carpenteria								
Cibicides		1	1	1				
Clavulina		1						
Cornuspira	3	2	1					
Cycloforina		1	3	2		1		
Cymbaloporetta		1		1				
Disconorbis								
Discorbinella								
Discorbis	2	9	11	5		5	1	
Fischerinella								
Eponides			3			1		
Floresina	1		2					

Appendix II-b. (Continued)

	StarR1	StarR2	7.2R1	7.2R2	8.1R1	8.1R2	NirvanaR1	NirvanaR2
Fursenkoina	1							
Glabratella								
Glabratellina								
Globigerinoides								
Globocassidulina								
Globorotalia	1							
Globulina	1							
Guttulina								
Haplophragmoides								
Hauerina		2	2	3		1		
Lachlanella		1	3					
Lobatula								
Miliolinella	4	1	2		2			
Montfortella								
Neocornorbina				1		1		
Neoeponides								
Patellina								
Planorbulina	2							
Polymorphina								
Poroepodines								
Pseudohauerina		2		2				
Pyrgo	1	1		1				
Quinqueloculina	49	43	44	33		1	1	
Rectobolivina								
Reophax								
Reussella	1							
Rosalina	17	6	13	7		1		
Sigmavirgulina								
Sigmiolina	3		2	1				
Sigmiolinita								
Siphonaperta	4	7	11	7				
Siphonina		3						
Siphoninoides								
Spiroloculina	2	2						
Textularia	1	25	5	1				
Treromphalus						1		
Triloculina	10	21	17	14		4		
Triloculinella		3	1	3	1	1		
Wiesnerella				1				
Total Forams	157	183	195	150	10	25	3	2
Density (forams/g)	781	458	195	250	10	25	3	2
Number of genera	35	33	30	31	7	15	3	2
Foram Index	3.57	3.99	4.35	4.81	6.70	4.24	4.67	10.00
SIMPER Group	B	B	B	B				

Appendix II-b. (Continued)

	8.2R1	8.2R2	9.1R1	9.1R2	9.2R1	9.2R2	9.3R1	9.3R2
Amphistegina	3	3		1		1		
Androsina	1					1		
Archaias	4	4	9	12	3	1	2	5
Asterigerina			3	4		1		
Borelis						1	1	
Broekina		1		6		2		3
Cyclorbiculina		1		1		1		2
Gypsina	1							
Heterostegina								
Laevipeneroplis	13	12	23	24	16	17	10	8
Monalysidium		1	1					1
Peneroplis	4	2	4	2	1	2	2	1
Sorites	1	1						1
Ammonia		2	2	2	1	6	1	1
Ammobaculites								
Bolivina	1	3	8	2	15	9	9	9
Bulimina					3		2	3
Cribroelphidium	2	4			4		4	2
Elphidium	1		1	5	7	6	12	2
Haynesina	1	2	2	1	6	4	2	4
Nonion		1				1		4
Nonionella								
Nonionoides	4				3	1	5	1
Adelosina	1	3	1	2	1	2	7	5
Affinetrina		1						
Anomalinoides								
Articulina	1	1	2	2	9	3	4	4
Astrononion								
Bigenerina								
Brizalina			1		1			
Cancris								
Carpenteria								
Cibicides				1	2	2	1	2
Clavulina	1	1						
Cornuspira			3	1	4	2	6	1
Cycloforina	4	3	2	2	5	1	4	3
Cymbaloporetta	1					1		1
Disconorbis								
Discorbinella		1						
Discorbis	3	1	5	2	5	4	10	
Fischerinella								
Eponides	2	1	2	1	3	1	1	1
Floresina					8			

Appendix II-b. (Continued)

	8.2R1	8.2R2	9.1R1	9.1R2	9.2R1	9.2R2	9.3R1	9.3R2
Fursenkoina				1	1		3	2
Glabratella		1						
Glabratellina			1					1
Globigerinoides			2					
Globocassidulina								
Globorotalia					1			
Globulina								
Guttulina								
Haplophragmoides								
Hauerina	1	3	2		1	2	1	2
Lachlanella			1		1			
Lobatula						1		1
Miliolinella	1	2	1		13	3	10	4
Montfortella								
Neocornorbina	1	1		1		1		
Neoeponides								
Patellina								
Planorbulina		1	1	1		2	1	
Polymorphina								
Poroepodines								
Pseudohauerina	1		1		1		2	
Pyrgo								
Quinqueloculina	41	54	67	37	154	67	129	75
Rectobolivina								
Reophax								
Reussella								
Rosalina	6	13	20	5	41	17	20	14
Sigmavirgulina						1		
Sigmiolina	3		6		11	1	7	
Sigmiolinita								
Siphonaperta	9	6	9	1	2	1	1	6
Siphonina	1				1			
Siphoninoides								
Spiroloculina	3	1		2	3	2		1
Textularia	4	2	3	1		2		
Treromphalus						1		
Triloculina	19	16	10	12	14	11	20	24
Triloculinella	2	2	2	2		5	1	5
Wiesnerella			1		5		1	1
Total Forams	141	151	196	134	346	187	279	200
Density (forams/g)	564	1007	1568	1340	6920	3740	5580	4000
Number of genera	32	33	31	28	33	38	30	34
Foram Index	3.47	3.25	3.57	4.91	2.35	3.01	2.30	2.71
SIMPER Group	B	B	D	B	C	B	C	B

Appendix II-b. (Continued)

	LuganoR1	LuganoR2	10.1R1	10.1R2	10.2R1	10.2R2	DomeR1	DomeR2
Amphistegina	3	4			3	12	3	3
Androsina								
Archaias	10	4		1	41	35	4	5
Asterigerina					2	3	1	
Borelis				1	1	1		
Broekina					1		2	6
Cyclorbiculina					5	4		
Gypsina	1			1			1	
Heterostegina								
Laevipeneroplis					21	25	8	13
Monalysidium								
Peneroplis					1		1	
Sorites						1	1	2
Ammonia					1	1	1	1
Ammobaculites								1
Bolivina							4	
Bulimina								
Cribroelphidium					1		2	
Elphidium					2	3		1
Haynesina							2	
Nonion							1	
Nonionella								
Nonionoides							1	2
Adelosina							3	1
Affinetrina								1
Anomalinoides								
Articulina							6	
Astrononion								
Bigenerina					1			
Brizalina								
Cancris							1	
Carpenteria							1	
Cibicides							1	1
Clavulina						2	1	1
Cornuspira							4	
Cycloforina			1					3
Cymbaloporetta								2
Disconorbis								1
Discorbinella								
Discorbis		1	1		20	21	6	9
Fischerinella								1
Eponides		1			1		1	1
Floresina								

Appendix II-b. (Continued)

	LuganoR1	LuganoR2	10.1R1	10.1R2	10.2R1	10.2R2	DomeR1	DomeR2
Fursenkoina							2	
Glabratella								
Glabratellina							1	
Globigerinoides								
Globocassidulina						1	1	
Globorotalia					1	2		2
Globulina								
Guttulina					1	1		
Haplophragmoides								
Hauerina								
Lachlanella								
Lobatula							1	
Miliolinella								4
Montfortella								
Neocornorbina		1				4		
Neoeponides								
Patellina								
Planorbulina							2	1
Polymorphina					1			
Poroepodines								
Pseudohauerina								1
Pyrgo								2
Quinqueloculina	1				28	15	54	34
Rectobolivina							1	
Reophax								
Reussella								
Rosalina		1			4	6	5	9
Sigmavirgulina								
Sigmiolina								
Sigmiolinita							1	
Siphonaperta				1	14	10	1	6
Siphonina						1		4
Siphoninoides								2
Spiroloculina								1
Textularia					4	1	3	1
Trerompalus								
Triloculina					3	10	21	22
Triloculinella							2	2
Wiesnerella								
Total Forams	15	12	2	4	157	159	151	146
Density (forams/g)	15	12	2	4	157	199	755	365
Number of genera	4	6	2	4	22	21	36	33
Foram Index	9.47	7.33	2.00	8.00	5.80	6.05	3.04	3.55
SIMPER Group					A	A	B	B

Appendix III. SIMPER results for dissimilarity between groups based on foraminiferal assemblages.

Groups A & B
Average dissimilarity = 40.22

	Group A	Group B				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Archaias	4.25	2.05	2.65	2.3	6.6	6.6
Discorbis	3.63	1.81	2.12	2.19	5.28	11.87
Quinqueloculina	4.08	5.36	1.5	1.84	3.73	15.6
Siphonaperta	2.54	1.81	1.17	1.34	2.92	18.52
Bolivina	0.3	1.05	1.11	1.34	2.76	21.28
Cyclorbiculina	1.49	0.66	1.07	1.51	2.66	23.93
Haynesina	0.29	0.97	1.05	1.34	2.61	26.54
Articulina	0.27	1.01	1.05	1.55	2.6	29.14
Miliolinella	0.66	1.04	1.01	1.44	2.5	31.64

Groups A & C
Average dissimilarity = 53.51

	Group A	Group C				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Archaias	4.25	0.62	4.47	3.36	8.35	8.35
Quinqueloculina	4.08	6.59	3.08	4.54	5.75	14.1
Discorbis	3.63	1.32	2.82	3.35	5.27	19.37
Siphonaperta	2.54	0.52	2.49	2.08	4.65	24.02
Bolivina	0.3	2.23	2.36	2.99	4.42	28.43
Amphistegina	1.68	0	2.05	2.87	3.84	32.27
Cyclorbiculina	1.49	0	1.82	3.44	3.41	35.68
Miliolinella	0.66	2	1.69	1.77	3.15	38.83
Sigmiolina	0.14	1.35	1.55	1.61	2.89	41.72
Cribroelphidium	0.24	1.38	1.43	2.41	2.67	44.39
Rosalina	1.87	3	1.39	2.61	2.59	46.99
Haynesina	0.29	1.35	1.39	2.13	2.59	49.58
Textularia	1.27	0.18	1.38	1.73	2.59	52.16
Laevipeneroplis	2.87	1.84	1.35	1.52	2.53	54.69
Articulina	0.27	1.14	1.17	2.08	2.19	56.88
Cornuspira	0.1	0.95	1.12	1.58	2.1	58.97
Bulimina	0.2	1.03	1.05	1.84	1.96	60.93
Asterigerina	0.85	0	1.04	1.71	1.94	62.87

Appendix III. (Continued)

Groups A & D
Average dissimilarity = 45.72

	Group A	Group D				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Archaias	4.25	1.95	2.66	2.56	5.83	5.83
Discorbis	3.63	2.09	1.77	2.04	3.87	9.7
Sigmiolina	0.14	1.67	1.72	3.45	3.77	13.47
Ammonia	0.27	1.74	1.65	2.2	3.61	17.08
Cyclorbiculina	1.49	0.21	1.46	2.25	3.2	20.28
Amphistegina	1.68	0.49	1.38	1.62	3.02	23.31
Quinqueloculina	4.08	5.24	1.34	1.65	2.92	26.23
Haynesina	0.29	1.29	1.26	1.87	2.75	28.97
Rosalina	1.87	2.91	1.19	2.05	2.61	31.58
Articulina	0.27	1.11	1.14	1.3	2.49	34.06
Cornuspira	0.1	1.09	1.13	2.54	2.48	36.55
Eponides	0.19	1.17	1.11	2.17	2.43	38.98
Triloculina	2.63	1.83	1.07	1.41	2.34	41.32
Bolivina	0.3	0.9	1.04	1.05	2.28	43.6
Miliolinella	0.66	1	1.01	1.36	2.21	45.82

Groups A & E
Average dissimilarity = 43.09

	Group A	Group E				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Rosalina	1.87	2.27	2.04	3.44	4.74	4.74
Archaias	4.25	4.52	1.99	1.57	4.61	9.34
Triloculina	2.63	0.99	1.98	2.17	4.59	13.94
Asterigerina	0.85	2.43	1.95	2.64	4.52	18.46
Quinqueloculina	4.08	2.77	1.82	1.1	4.22	22.68
Elphidium	1.62	0.27	1.69	2.37	3.93	26.61
Siphonaperta	2.54	1.32	1.6	1.43	3.7	30.31
Heterostegina	0	1.27	1.58	3.04	3.68	33.99
Cyclorbiculina	1.49	2.52	1.37	1.34	3.17	37.16
Neocornorbina	0.36	1.35	1.28	2.1	2.97	40.13
Amphistegina	1.68	2.32	1.09	1.25	2.52	42.65
Borelis	0.72	1.32	1.09	1.48	2.52	45.17

Appendix III. (Continued)

Groups B & C
Average dissimilarity = 40.11

	Group B	Group C				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Archaias	2.05	0.62	1.62	1.92	4.03	4.03
Siphonaperta	1.81	0.52	1.46	2.16	3.64	7.67
Quinqueloculina	5.36	6.59	1.38	2.14	3.44	11.12
Bolivina	1.05	2.23	1.38	1.61	3.43	14.55
Amphistegina	1.22	0	1.37	2.24	3.41	17.96
Sigmiolina	0.26	1.35	1.36	1.63	3.4	21.36
Textularia	1.3	0.18	1.33	1.38	3.32	24.68
Laevipeneroplis	2.99	1.84	1.32	1.71	3.28	27.96
Miliolinella	1.04	2	1.09	1.6	2.72	30.68
Broekina	1.02	0.18	1.04	1.41	2.59	33.27

Groups B & D
Average dissimilarity = 37.40

	Group B	Group D				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sigmiolina	0.26	1.67	1.48	2.81	3.96	3.96
Triloculina	3.09	1.83	1.35	2.12	3.61	7.57
Ammonia	0.74	1.74	1.12	1.57	2.99	10.56
Bolivina	1.05	0.9	1.01	1.4	2.71	13.27

Appendix III. (Continued)

Groups B & E
Average dissimilarity = 49.41

	Group B	Group E				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Quinqueloculina	5.36	2.77	3.03	1.77	6.14	6.14
Archaias	2.05	4.52	2.94	1.35	5.94	12.08
Triloculina	3.09	0.99	2.36	3.99	4.78	16.86
Cyclorbiculina	0.66	2.52	2.16	1.89	4.37	21.23
Asterigerina	0.65	2.43	2.01	2.42	4.07	25.3
Discorbis	1.81	3.37	1.74	2.35	3.53	28.83
Rosalina	2.51	2.27	1.7	1.42	3.44	32.27
Heterostegina	0.03	1.27	1.42	2.87	2.87	35.13
Amphistegina	1.22	2.32	1.34	1.41	2.7	37.84
Elphidium	1.35	0.27	1.3	1.42	2.63	40.46
Bolivina	1.05	0.66	1.16	1.41	2.35	42.81
Haynesina	0.97	0	1.1	1.37	2.22	45.04
Borelis	0.45	1.32	1.07	1.55	2.17	47.21
Cycloforina	1.18	0.38	1.05	1.53	2.12	49.34

Groups C & D
Average dissimilarity = 38.24

	Group C	Group D				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Siphonaperta	0.52	2.24	1.9	3.48	4.96	4.96
Archaias	0.62	1.95	1.47	2.45	3.84	8.8
Quinqueloculina	6.59	5.24	1.47	2.44	3.84	12.64
Bolivina	2.23	0.9	1.46	1.45	3.82	16.46
Ammonia	0.59	1.74	1.29	1.74	3.38	19.84
Cribroelphidium	1.38	0.42	1.23	1.96	3.22	23.06
Textularia	0.18	1.16	1.17	1.46	3.06	26.12
Miliolinella	2	1	1.12	1.4	2.92	29.04
Nonionoides	0.94	0	1.04	1.56	2.72	31.76
Laevipeneroplis	1.84	2.75	1.02	1.49	2.67	34.43

Appendix III. (Continued)

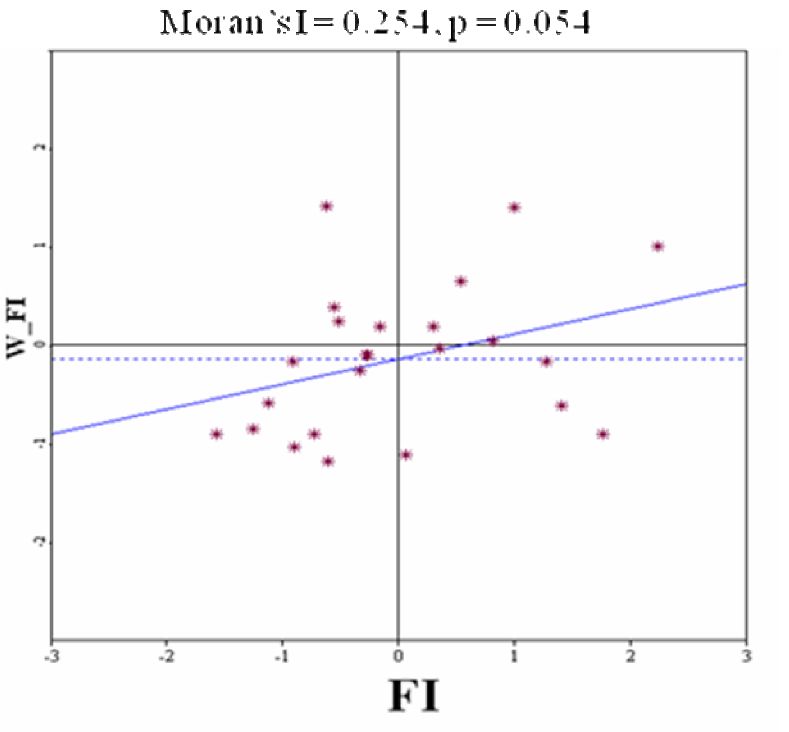
Groups C & E Average dissimilarity = 62.77						
	Group C	Group E				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Archaias	0.62	4.52	4.8	1.93	7.65	7.65
Quinqueloculina	6.59	2.77	4.66	2.42	7.43	15.08
Cyclorbiculina	0	2.52	3.07	2.84	4.88	19.96
Asterigerina	0	2.43	2.9	6.77	4.61	24.57
Amphistegina	0	2.32	2.82	2.81	4.49	29.06
Discorbis	1.32	3.37	2.41	4.66	3.83	32.9
Elphidium	1.94	0.27	2.03	2.31	3.23	36.12
Miliolinella	2	0.33	2	2.84	3.19	39.31
Bolivina	2.23	0.66	1.96	1.59	3.13	42.44
Triloculina	2.42	0.99	1.7	3.57	2.7	45.14
Rosalina	3	2.27	1.68	0.96	2.67	47.81
Haynesina	1.35	0	1.61	3.73	2.57	50.38
Neocornorbina	0	1.35	1.59	5.09	2.54	52.92
Sigmiolina	1.35	0	1.59	1.61	2.53	55.44
Heterostegina	0	1.27	1.53	3	2.44	57.89
Borelis	0.15	1.32	1.4	2.07	2.22	60.11
Cribroelphidium	1.38	0.33	1.27	1.8	2.02	62.13

Appendix III. (Continued)

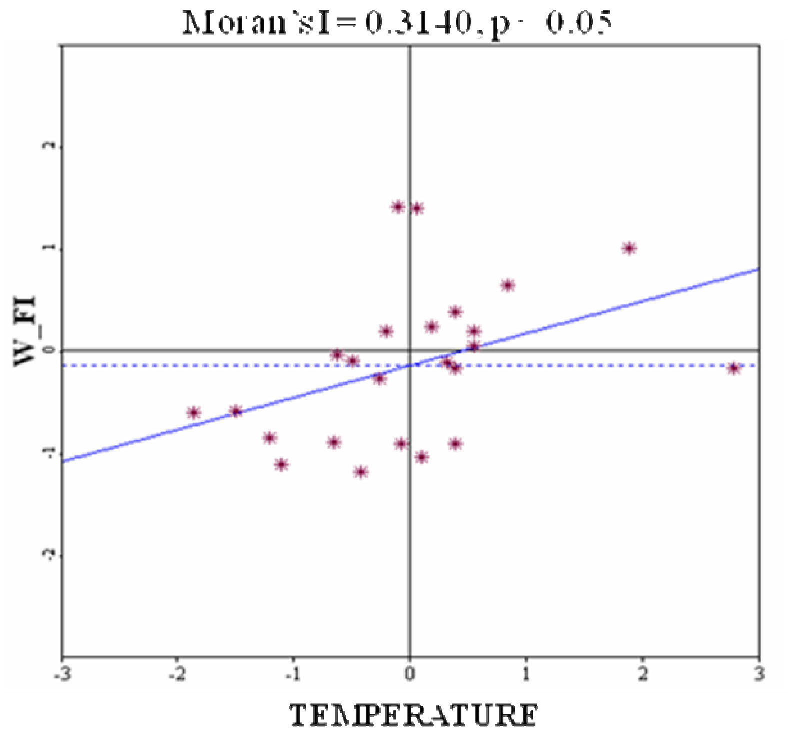
Groups D & E Average dissimilarity = 53.32						
	Group D	Group E				
Genera	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Archaias	1.95	4.52	2.97	1.4	5.56	5.56
Quinqueloculina	5.24	2.77	2.84	1.64	5.33	10.9
Cyclorbiculina	0.21	2.52	2.62	2.44	4.91	15.8
Amphistegina	0.49	2.32	2.07	1.94	3.89	19.69
Asterigerina	0.73	2.43	1.88	2.04	3.53	23.23
Sigmiolina	1.67	0	1.84	7.85	3.45	26.68
Ammonia	1.74	0.27	1.64	2.04	3.07	29.75
Rosalina	2.91	2.27	1.53	0.97	2.88	32.62
Haynesina	1.29	0	1.42	2.42	2.67	35.29
Heterostegina	0	1.27	1.42	3.05	2.66	37.96
Discorbis	2.09	3.37	1.39	2.04	2.62	40.57
Neocornorbina	0.21	1.35	1.25	2.38	2.34	42.91
Borelis	0.2	1.32	1.24	1.83	2.32	45.24
Elphidium	1.26	0.27	1.13	1.56	2.11	47.35
Bolivina	0.9	0.66	1.07	1	2.01	49.36
Siphonaperta	2.24	1.32	1.02	1.77	1.91	51.28
Eponides	1.17	0.27	1.01	1.73	1.89	53.17
Peneroplis	1.06	0.54	1	2.18	1.87	55.04

Appendix IV. Moran's I values and plots for both the FORAM Index and the SEDCON Index. Scales are in standard deviations from the mean.

a) Insignificant spatial autocorrelation of FORAM Index (FI) values.

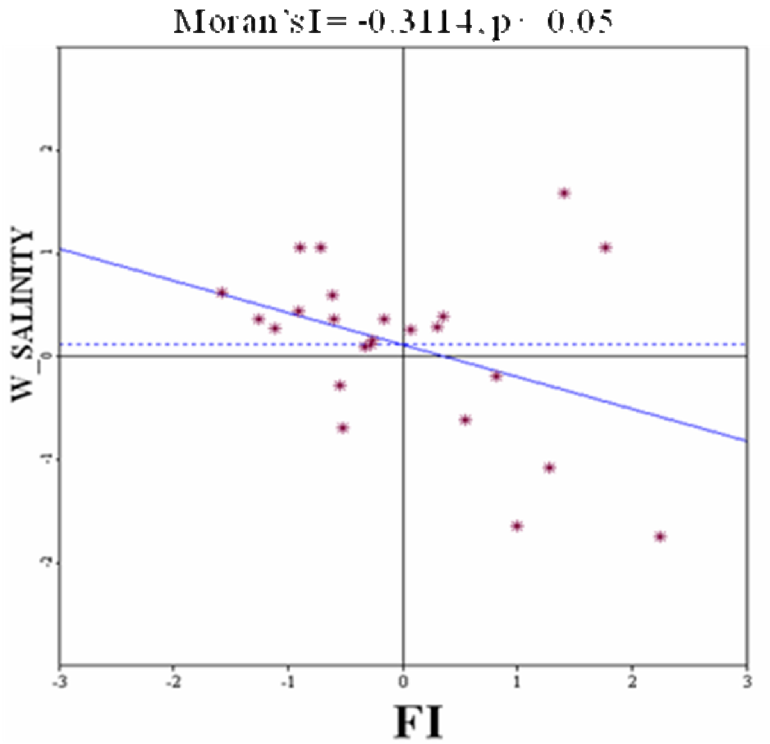


b) Significant bivariate spatial correlation of FI and Temperature.

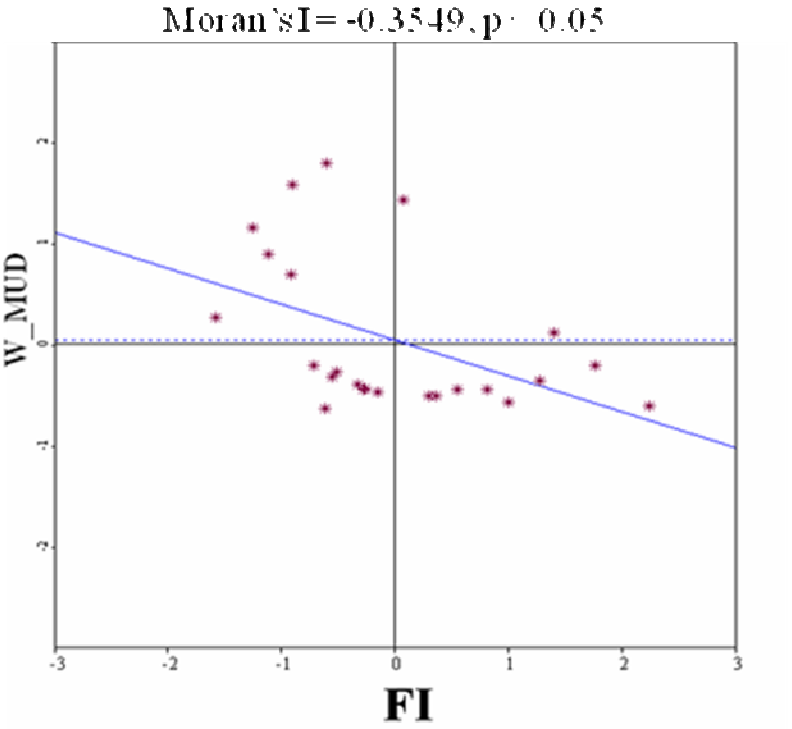


Appendix IV. (Continued)

c) Significant bivariate spatial correlation of FI and Salinity.

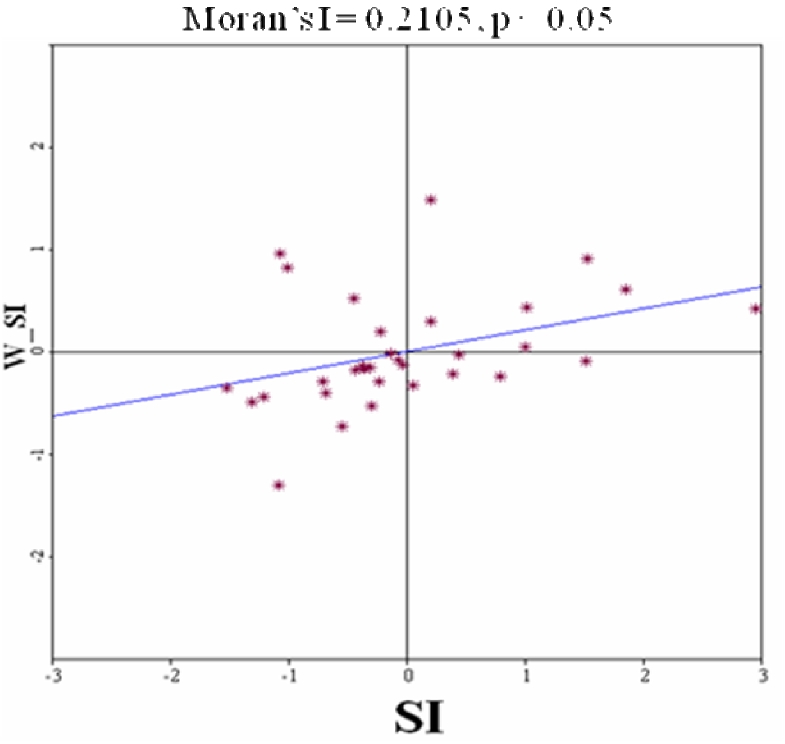


d) Significant bivariate spatial correlation of FI and Percent Mud.

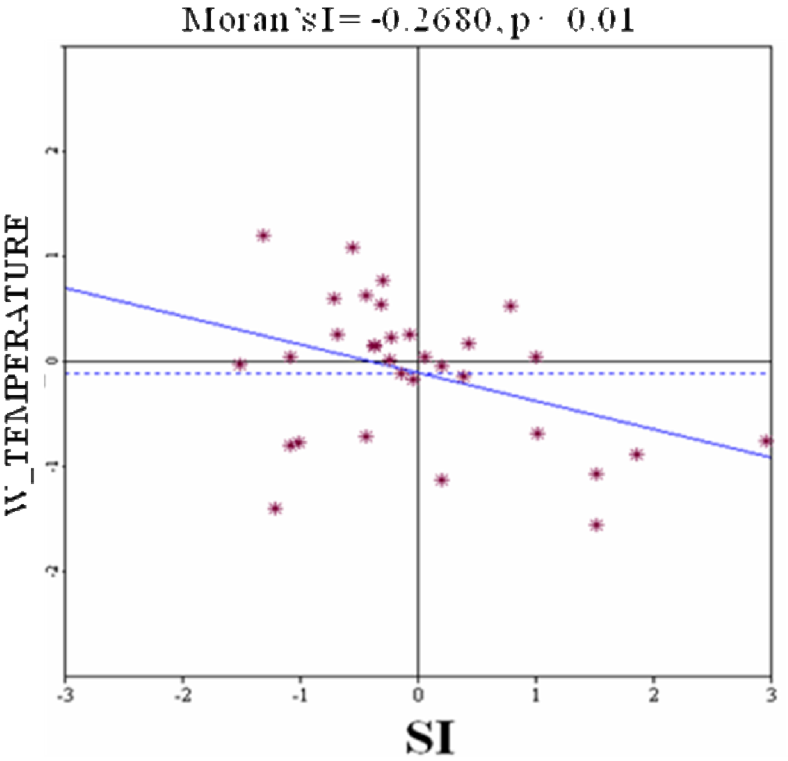


Appendix IV. (Continued)

e) Significant spatial autocorrelation of SEDCON Index (SI) values.

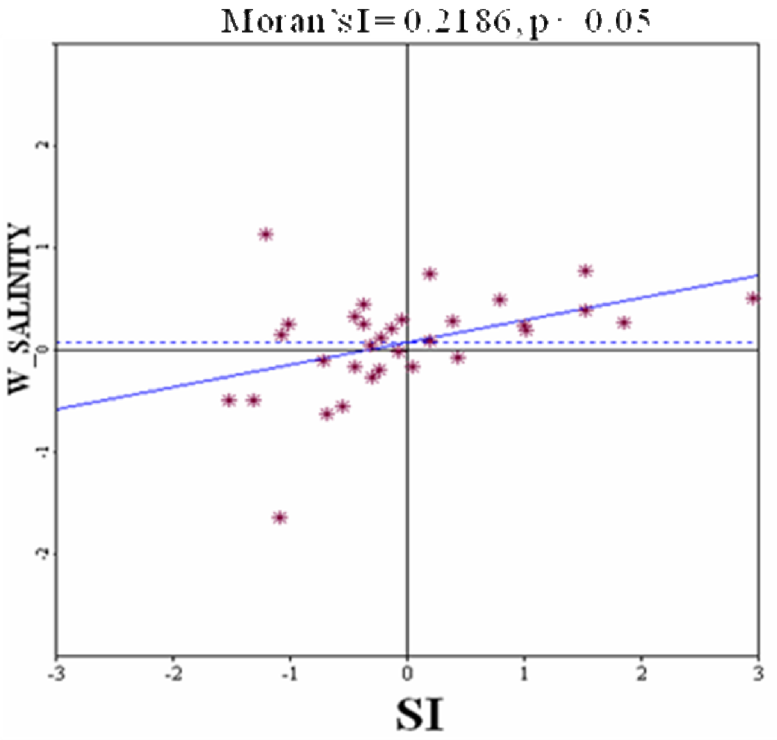


f) Significant bivariate spatial correlation of SI and Temperature

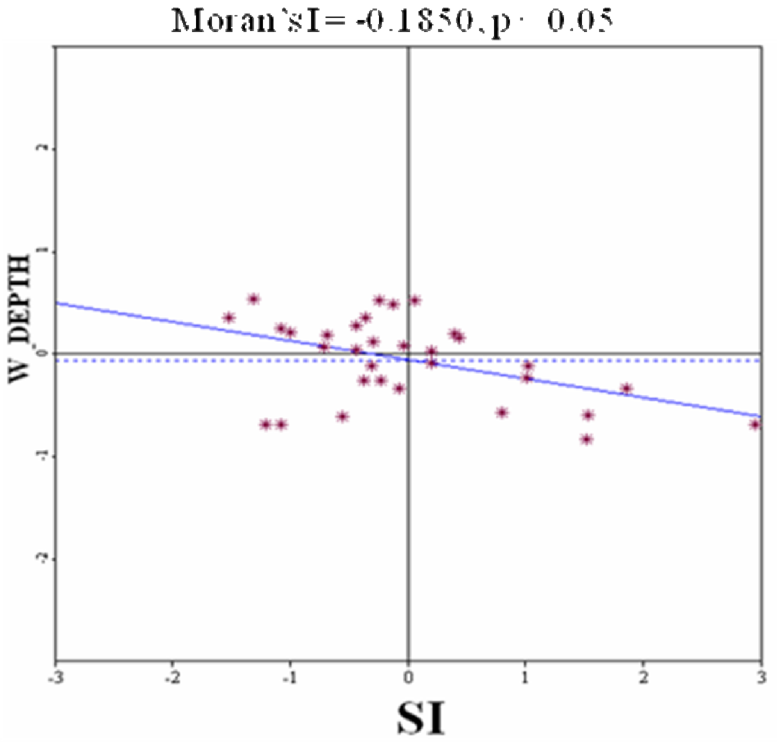


Appendix IV. (Continued)

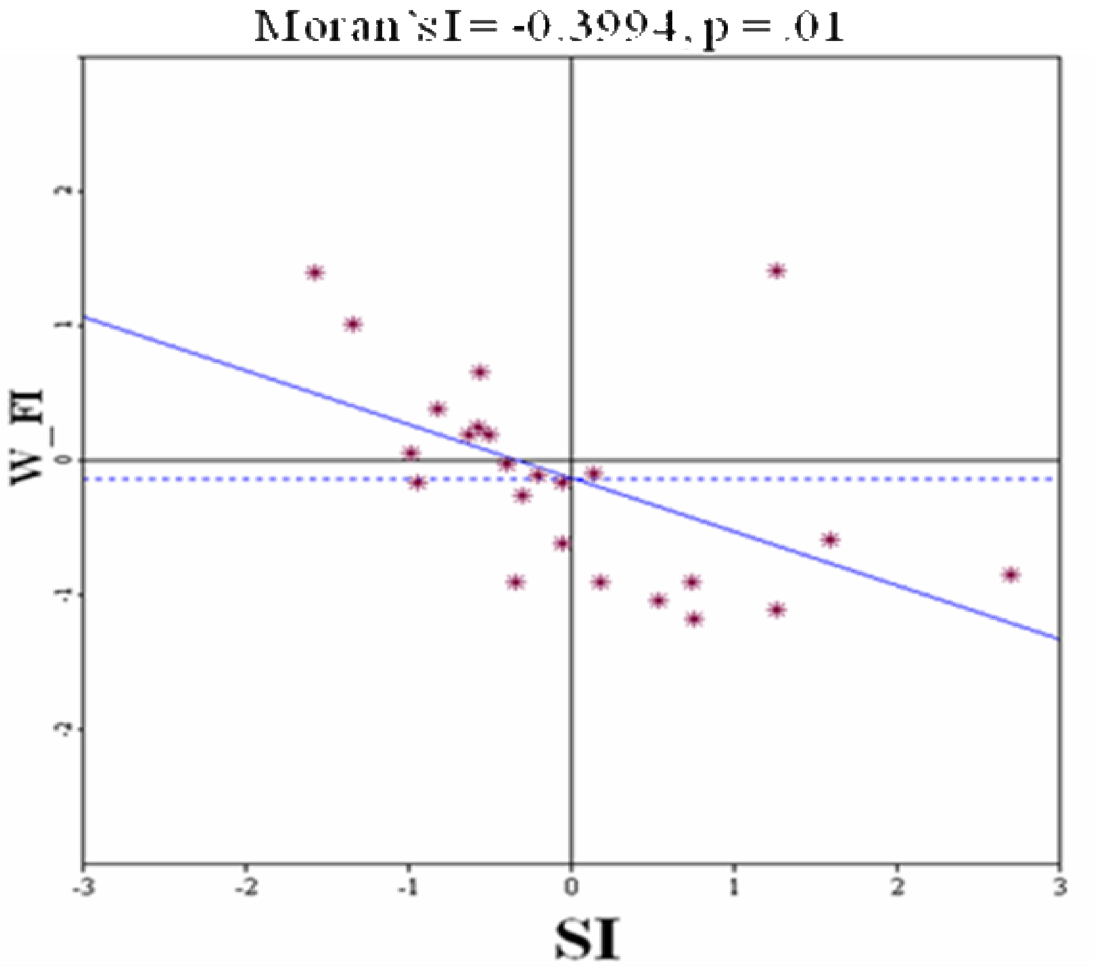
g) Significant bivariate spatial correlation of SI and Salinity.



h) Significant bivariate spatial correlation of SI and Depth.



Appendix IV. (Continued) Moran's I value and plot for spatial correlation between the SEDCON Index and the FORAM Index.



Appendix V-a. Raw counts of sediment constituents from the two sediment replicates of 32 reefs in Biscayne National Park.

	1.1R1	1.1R2	1.2R1	1.2R2	SharkR1	SharkR2	2.1R1
Coral (Pc)	8	5	4	12	2	4	11
Symbiotic Forams (Pf)	8	6	10	11	1	2	0
Coralline Algae (Pah)	0	0	0	1	1	3	0
Molluscs (Pah)	73	95	73	86	52	36	90
Calcareous Algae (Pah)	17	14	30	40	12	15	9
Echinoid Spines (Pah)	0	3	2	1	0	0	1
Worm Tubes (Pah)	1	3	1	4	1	4	10
Gorgonian Sclerites (Pah)	1	2	1	0	0	0	1
Fecal Pellets (Pah)	0	1	0	0	1	1	0
Other (Pah)	1	2	7	8	1	0	3
Unidentifiable (Pu)	191	169	172	137	229	235	175
Pc	2.67%	1.67%	1.33%	4.00%	0.67%	1.33%	3.67%
Pf	2.67%	2.00%	3.33%	3.67%	0.33%	0.67%	0.00%
Pah	31.00%	40.00%	38.00%	46.67%	22.67%	19.67%	38.00%
Pu	63.67%	56.33%	57.33%	45.67%	76.33%	78.33%	58.33%
SEDCON Index	1.16	1.18	1.22	1.67	0.62	0.66	1.19
SIMPER group	C	C	C	C	C	C	C

	2.1R2	2.2R1	2.2R2	3.1R1	3.1R2	3.2R1	3.2R2
Coral (Pc)	11	5	3	2	6	7	5
Symbiotic Forams (Pf)	1	8	11	5	5	7	5
Coralline Algae (Pah)	5	0	1	0	3	2	0
Molluscs (Pah)	97	50	68	66	77	42	84
Calcareous Algae (Pah)	17	46	64	13	25	22	34
Echinoid Spines (Pah)	1	4	0	1	1	1	1
Worm Tubes (Pah)	3	7	9	1	8	0	5
Gorgonian Sclerites (Pah)	1	6	5	2	2	1	0
Fecal Pellets (Pah)	0	2	3	0	0	1	1
Other (Pah)	2	3	6	4	10	1	4
Unidentifiable (Pu)	162	169	130	206	163	216	161
Pc	3.67%	1.67%	1.00%	0.67%	2.00%	2.33%	1.67%
Pf	0.33%	2.67%	3.67%	1.67%	1.67%	2.33%	1.67%
Pah	42.00%	39.33%	52.00%	29.00%	42.00%	23.33%	43.00%
Pu	54.00%	56.33%	43.33%	68.67%	54.33%	72.00%	53.67%
SEDCON Index	1.29	1.22	1.48	0.85	1.23	0.96	1.21
SIMPER group	C	C	C	C	C	C	C

Appendix V-a. (Continued)

	BugR1	BugR2	ElkhornR1	ElkhornR2	4.1R1	4.1R2	4.2R1
Coral (Pc)	5	0	11	4	2	6	2
Symbiotic Forams (Pf)	6	7	2	12	2	2	3
Coralline Algae (Pah)	1	0	7	5	1	0	2
Molluscs (Pah)	91	68	55	49	48	68	54
Calcareous Algae (Pah)	94	110	8	11	53	57	105
Echinoid Spines (Pah)	6	3	1	0	2	2	1
Worm Tubes (Pah)	6	5	0	3	7	8	4
Gorgonian Sclerites (Pah)	0	2	0	3	1	2	12
Fecal Pellets (Pah)	6	8	0	0	0	3	14
Other (Pah)	5	14	0	1	11	6	15
Unidentifiable (Pu)	80	83	216	212	173	146	88
Pc	1.67%	0.00%	3.67%	1.33%	0.67%	2.00%	0.67%
Pf	2.00%	2.33%	0.67%	4.00%	0.67%	0.67%	1.00%
Pah	69.67%	70.00%	23.67%	24.00%	41.00%	48.67%	69.00%
Pu	26.67%	27.67%	72.00%	70.67%	57.67%	48.67%	29.33%
SEDCON Index	1.75	1.61	0.97	1.00	1.00	1.28	1.56
SIMPER group	B	B	C	C	C	C	B

	4.2R2	PacificR1	PacificR2	5.1R1	5.1R2	5.2R1	5.2R2
Coral (Pc)	2	2	3	3	1	1	1
Symbiotic Forams (Pf)	7	9	6	10	7	7	19
Coralline Algae (Pah)	0	3	10	2	2	0	2
Molluscs (Pah)	41	19	49	41	23	64	54
Calcareous Algae (Pah)	114	14	17	15	6	31	34
Echinoid Spines (Pah)	4	3	1	1	0	0	0
Worm Tubes (Pah)	12	15	6	6	2	6	5
Gorgonian Sclerites (Pah)	4	1	0	6	0	0	1
Fecal Pellets (Pah)	10	0	0	1	0	0	0
Other (Pah)	17	0	1	0	1	6	8
Unidentifiable (Pu)	89	234	207	215	258	185	176
Pc	0.67%	0.67%	1.00%	1.00%	0.33%	0.33%	0.33%
Pf	2.33%	3.00%	2.00%	3.33%	2.33%	2.33%	6.33%
Pah	67.33%	18.33%	28.00%	24.00%	11.33%	35.67%	34.67%
Pu	29.67%	78.00%	69.00%	71.67%	86.00%	61.67%	58.67%
SEDCON Index	1.63	0.75	0.89	0.92	0.53	1.00	1.29
SIMPER group	B	C	C	C	C	C	C

Appendix V-a. (Continued)

	5.3R1	5.3R2	5.4R1	5.4R2	6.1R1	6.1R2	6.2R1
Coral (Pc)	3	5	2	2	8	8	7
Symbiotic Forams (Pf)	4	4	2	2	3	2	3
Coralline Algae (Pah)	0	1	1	1	2	2	1
Molluscs (Pah)	72	38	68	41	67	87	47
Calcareous Algae (Pah)	25	49	74	70	28	21	33
Echinoid Spines (Pah)	0	0	1	2	6	1	1
Worm Tubes (Pah)	8	4	6	2	11	6	4
Gorgonian Sclerites (Pah)	2	0	6	2	7	4	9
Fecal Pellets (Pah)	0	0	3	0	0	0	0
Other (Pah)	1	0	4	1	13	16	0
Unidentifiable (Pu)	185	199	133	177	155	153	195
Pc	1.00%	1.67%	0.67%	0.67%	2.67%	2.67%	2.33%
Pf	1.33%	1.33%	0.67%	0.67%	1.00%	0.67%	1.00%
Pah	36.00%	30.67%	54.33%	39.67%	44.67%	45.67%	31.67%
Pu	61.67%	66.33%	44.33%	59.00%	51.67%	51.00%	65.00%
SEDCON Index	0.99	0.95	1.25	0.97	1.29	1.28	1.01
SIMPER group	C	C	C	C	C	C	C

	6.2R2	6.3R1	6.3R2	7.1R1	7.1R2	StarR1	StarR2
Coral (Pc)	7	3	0	2	3	3	2
Symbiotic Forams (Pf)	9	7	6	13	7	3	8
Coralline Algae (Pah)	4	0	0	2	1	3	7
Molluscs (Pah)	63	106	61	83	105	72	49
Calcareous Algae (Pah)	46	27	40	8	3	63	99
Echinoid Spines (Pah)	0	0	1	6	13	0	1
Worm Tubes (Pah)	2	4	5	4	3	1	5
Gorgonian Sclerites (Pah)	2	3	0	5	4	2	0
Fecal Pellets (Pah)	0	0	1	0	0	0	0
Other (Pah)	2	0	3	8	9	16	30
Unidentifiable (Pu)	165	150	183	169	152	137	99
Pc	2.33%	1.00%	0.00%	0.67%	1.00%	1.00%	0.67%
Pf	3.00%	2.33%	2.00%	4.33%	2.33%	1.00%	2.67%
Pah	39.67%	46.67%	37.00%	38.67%	46.00%	52.33%	63.67%
Pu	55.00%	50.00%	61.00%	56.33%	50.67%	45.67%	33.00%
SEDCON Index	1.32	1.27	0.96	1.24	1.26	1.27	1.59
SIMPER group	C	C	C	C	C	C	C

Appendix V-a. (Continued)

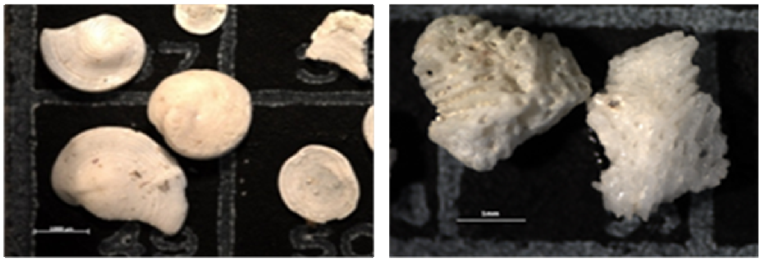
	7.2R2	8.1R1	8.1R2	NirvanaR1	NirvanaR2	8.2R1	8.2R2
Coral (Pc)	1	5	10	5	4	4	1
Symbiotic Forams (Pf)	5	0	0	3	7	2	13
Coralline Algae (Pah)	0	3	3	1	0	3	0
Molluscs (Pah)	54	47	43	37	52	49	96
Calcareous Algae (Pah)	69	26	20	23	28	97	107
Echinoid Spines (Pah)	0	0	1	2	2	0	0
Worm Tubes (Pah)	3	0	3	0	0	14	9
Gorgonian Sclerites (Pah)	5	3	0	1	2	11	3
Fecal Pellets (Pah)	0	0	0	1	0	0	4
Other (Pah)	4	1	0	0	0	7	12
Unidentifiable (Pu)	159	215	220	227	205	113	55
Pc	0.33%	1.67%	3.33%	1.67%	1.33%	1.33%	0.33%
Pf	1.67%	0.00%	0.00%	1.00%	2.33%	0.67%	4.33%
Pah	45.00%	26.67%	23.33%	21.67%	28.00%	60.33%	77.00%
Pu	53.00%	71.67%	73.33%	75.67%	68.33%	37.67%	18.33%
SEDCON Index	1.12	0.77	0.87	0.76	0.95	1.43	1.94
SIMPER group	C	C	C	A	A	B	B

	9.1R2	9.2R1	9.2R2	9.3R1	9.3R2	LuganoR1	LuganoR2
Coral (Pc)	2	2	4	1	1	4	2
Symbiotic Forams (Pf)	40	10	17	27	57	1	5
Coralline Algae (Pah)	0	0	0	1	0	1	1
Molluscs (Pah)	95	100	85	100	74	46	47
Calcareous Algae (Pah)	17	104	91	94	94	19	32
Echinoid Spines (Pah)	1	3	5	6	1	1	0
Worm Tubes (Pah)	4	4	8	5	0	3	4
Gorgonian Sclerites (Pah)	3	5	12	1	2	0	0
Fecal Pellets (Pah)	0	15	4	0	0	0	0
Other (Pah)	15	16	14	5	10	0	1
Unidentifiable (Pu)	123	41	60	60	61	225	208
Pc	0.67%	0.67%	1.33%	0.33%	0.33%	1.33%	0.67%
Pf	13.33%	3.33%	5.67%	9.00%	19.00%	0.33%	1.67%
Pah	45.00%	82.33%	73.00%	70.67%	60.33%	23.33%	28.33%
Pu	41.00%	13.67%	20.00%	20.00%	20.33%	75.00%	69.33%
SEDCON Index	2.07	1.99	2.07	2.19	2.78	0.70	0.84
SIMPER group	C	B	B	B	B	C	C

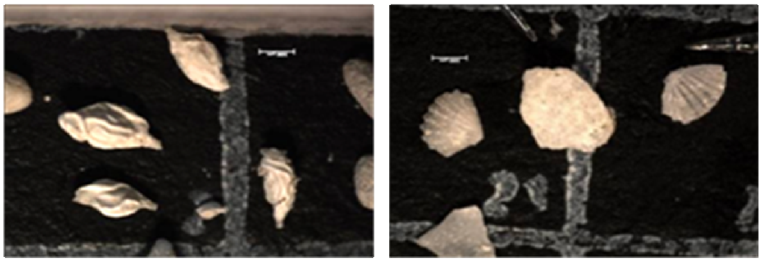
Appendix V-a. (Continued)

	10.1R1	10.1R2	10.2R1	10.2R2	DomeR1	DomeR2
Coral (Pc)	14	2	0	5	1	3
Symbiotic Forams (Pf)	2	1	8	8	7	4
Coralline Algae (Pah)	4	2	0	0	1	0
Molluscs (Pah)	36	55	87	82	47	47
Calcareous Algae (Pah)	58	42	54	57	160	180
Echinoid Spines (Pah)	1	2	4	2	1	3
Worm Tubes (Pah)	7	0	3	2	5	9
Gorgonian Sclerites (Pah)	2	3	3	2	4	3
Fecal Pellets (Pah)	0	0	0	0	4	1
Other (Pah)	0	3	3	3	14	21
Unidentifiable (Pu)	176	190	138	139	56	29
Pc	4.67%	0.67%	0.00%	1.67%	0.33%	1.00%
Pf	0.67%	0.33%	2.67%	2.67%	2.33%	1.33%
Pah	36.00%	35.67%	51.33%	49.33%	78.67%	88.00%
Pu	58.67%	63.33%	46.00%	46.33%	18.67%	9.67%
SEDCON Index	1.30	0.87	1.29	1.41	1.81	1.98
SIMPER group	C	C	C	C	B	B

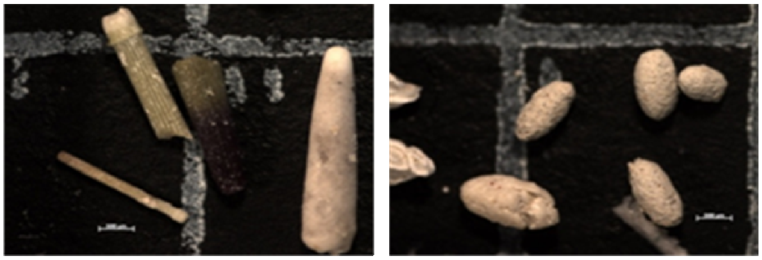
Appendix V-b. Visual identification aid for major sediment constituents.



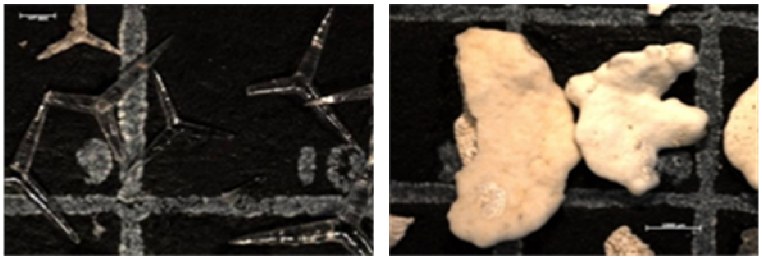
a. symbiont-bearing foraminifera b. coral



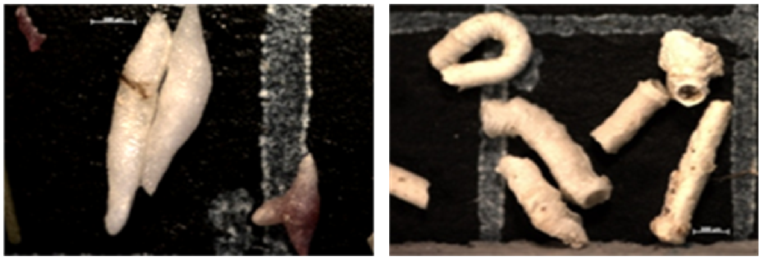
c. heterotrophic foraminifera d. mollusk shell



e. echinoid spines f. fecal pellets



g. sponge spicules h. calcareous algae



i. gorgonian sclerites j. worm tubes

Appendix VI. SIMPER results for dissimilarity between groups based on LSF assemblages.

Groups A & B				**Average dissimilarity = 36.3%**		
	Group B	**Group A**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
L. proteus	7.33	3.77	6.88	4.39	18.9	18.9
C. compressus	1.54	3.75	4.5	1.77	12.4	31.3
Androsina	0.09	2.42	4.48	2.56	12.4	43.7
A. carinata	1.27	2.73	3.54	1.73	9.76	53.4
A. gibbosa	3.72	5.27	3.14	1.6	8.63	62.1
A. angulatus	3.43	4.34	2.6	1.6	7.15	69.2
L. bradyi	2.3	1.36	2.23	1.46	6.14	75.4
B. orbitolitoides	1.15	0.11	2.05	1.52	5.63	81.0
S. marginalis	0.43	1.4	2.01	1.8	5.53	86.5
H. antillarium	0.03	0.83	1.55	2.08	4.28	90.8

Groups A & C				**Average dissimilarity = 31.3%**		
	Group A	**Group C**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
A. angulatus	4.34	2	4.45	2.67	14.2	14.2
Androsina	2.42	0.09	4.44	2.6	14.2	28.4
A. carinata	2.73	0.72	3.83	2.11	12.2	40.7
L. proteus	3.77	5.37	3.17	2.17	10.1	50.8
A. gibbosa	5.27	6.73	2.9	1.66	9.26	60.1
C. compressus	3.75	2.75	2.74	1.18	8.76	68.8
B. orbitolitoides	0.11	1.09	1.96	1.78	6.27	75.1
S. marginalis	1.4	0.46	1.95	1.63	6.24	81.3
L. bradyi	1.36	2.12	1.7	1.3	5.45	86.8
B. pulchra	0.83	0.4	1.47	1.32	4.7	91.5

Reef 1.1 & Group A				**Average dissimilarity = 49.4%**		
	Reef 1.1	**Group A**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
A. gibbosa	0	5.27	10.78	6.7	21.8	21.8
A. carinata	6.67	2.73	8.07	4.25	16.3	38.2
C. compressus	0	3.75	7.66	3.77	15.5	53.7
Androsina	0	2.42	4.91	2.66	9.96	63.7
L. bradyi	3.52	1.36	4.41	2.98	8.94	72.6
L. proteus	5.58	3.77	3.69	3.02	7.47	80.1
S. marginalis	0	1.4	2.87	2.71	5.81	85.9
A. angulatus	3.15	4.34	2.56	1.71	5.18	91.1

Group A & Reef 5.4				**Average dissimilarity = 35.9%**		
	Group A	**Reef 5.4**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
A. angulatus	4.34	0	8.68	5.36	24.2	24.2
Androsina	2.42	0	4.83	2.66	13.5	37.6
C. compressus	3.75	6.01	4.53	2.42	12.6	50.3
L. proteus	3.77	5.65	3.76	3.13	10.5	60.7
L. bradyi	1.36	0	2.73	1.88	7.59	68.3
A. carinata	2.73	1.46	2.64	1.86	7.35	75.7
P. pertusus	1.22	2.53	2.62	2.74	7.3	83.0
B. pulchra	0.83	0	1.65	1.27	4.6	87.6
H. antillarium	0.83	0	1.65	1.97	4.6	92.2

Appendix VII. Results of bleaching surveyed in live specimens of *Amphistegina gibbosa* and density of live symbiont-bearing foraminifera (per 100cm^2).

	Amphistegina gibbosa			Total Live Symbiont-bearing Forams	
Site	%Adults	%Bleached	Density	Density	Raw Count
1.1	0.00	0.00	0.00	146.4	201
1.2	88.9	33.3	10.8	112.0	114
Shark	39.7	32.8	27.5	97.2	182
2.1	48.0	24.7	43.4	75.2	127
2.2	50.0	40.0	4.71	47.3	99
3.1	88.9	33.3	29.5	57.2	132
3.2	43.9	27.6	48.0	165.3	330
Bug	31.7	6.67	30.2	53.0	100
Elkhorn	47.5	10.0	17.3	44.5	101
4.1	42.9	17.5	53.8	129.2	156
4.2	49.4	18.8	33.1	67.4	173
Pacific	67.7	16.1	15.6	92.6	178
5.1	71.4	28.6	20.9	62.1	102
5.2	15.4	15.4	4.40	27.6	76
5.3	50.0	5.56	17.0	68.2	72
5.4	20.0	40.0	10.9	51.2	47
6.1	72.2	33.3	7.34	37.2	80
6.2	31.3	18.8	11.7	148.0	391
6.3	59.5	23.8	17.2	271.4	569
7.1	50.0	20.0	6.54	139.8	218
Star	57.7	28.9	27.6	75.0	143
7.2	39.3	16.7	30.3	177.3	492
8.1	43.1	19.6	30.2	86.6	150
Nirvana	47.8	28.4	60.7	217.5	489
8.2	63.4	26.8	51.2	175.2	228
9.1	40.0	26.7	8.14	50.4	109
9.2	31.8	22.7	17.4	90.5	123
9.3	100.0	0.00	0.71	5.70	8
Lugano	46.3	29.3	25.5	111.5	177
10.1	52.9	22.1	54.2	98.9	124
10.2	44.7	13.2	23.6	104.5	174
Dome	38.7	9.68	24.4	165.1	213

Appendix VIII. Environmental data and comments from divers and boat captain.

Site	Depth (m)	pH	Temperature	DO	Salinity	Comments
1.1	6.10	8.2	26.21	6.66	35.43	
1.2	3.35	8.29	26.26	6.78	35.52	
Shark	4.88	8.17	26.61	6.36	35.33	
2.1	6.10	8.27	26.12	6.64	35.58	
2.2	4.27	8.3	26.26	7.06	35.78	
3.1	8.84	8.19	26.26	6.23	35.41	red grouper
3.2	2.74	8.27	26.04	6.38	35.61	abundant, high diversity coral
Bug Reefs	5.18	8.26	25.94	6.45	35.96	
Elkhorn	1.52	8.34	27	7.86	35.56	lots of diadema, grunts w/ parasites
4.1	6.10	8.34	26.2	6.29	35.6	lots of broken coral heads, known fishing spot
4.2	3.96	8.35	26.17	6	35.65	
Pacific	6.40	8.27	26.72	6.25	35.38	good visability, lots of garbage on bottom, known fishing spot
5.1	3.66	8.26	26.16	6.2	35.36	good visability, near boat channel (marker 4), minimal thalasia
5.2	8.84	8.26	26.4	6.1	35.37	near boat channel (marker 3)
5.3	4.57	8.32	26.31	6.45	35.6	
5.4	3.35	8.36	26.32	6.28	35.76	
6.1	8.23	8.39	26.24	6.21	35.63	
6.2	8.23	8.46	26.31	6.36	35.66	black band disease prevalent on corals
6.3	3.66	8.46	26.08	6.58	35.74	
7.1	10.06	8.22	26.06	6.22	35.52	lots of relief, juvenile fishes
Star	6.40	8.35	25.99	6.13	35.64	
7.2	4.57	8.41	25.95	5.93	35.77	
8.1	3.05	8.22	26.1	6.34	35.59	nicest reef (Jim), some small cervicornis
Nirvana	2.44	8.25	26.09	6.43	35.6	lots of new growth coral, including cervicornis, nicest reef (Mel)
8.2	4.27	8.28	26.01	6.35	35.69	red grouper
9.1	8.84	8.28	25.8	5.9	35.61	mostly gorgonians and fire coral
9.2	3.66	8.24	25.68	6.08	35.66	
9.3	3.96	8.1	25.77	6.7	35.69	
Lugano	5.49	8.11	26.27	6.27	35.45	ship wreck (1913), sediment sample very orange
10.1	3.66	8.32	25.74	6	35.78	
10.2	3.96	8.25	25.57	6.04	35.71	
Dome	4.57	8.3	26.11	6.18	35.86	high relief, large boulder corals, red grouper