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Coral reef habitat around New Providence Island, Bahamas

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Abstract. In July 2006, the Academy of Natural Sciences of Philadelphia organized an expedition to New Providence Island, Bahamas. Coral species richness and cover, and reef surface rugosity were examined at Delaport Point (DP), Green Cay (GC), and Long Cay (LC). Greatest number of coral species (27) was observed at DP2 and the fewest (14) at DP3. Rugosity was greatest at GC1 due to the spatial complexity of an *Acropora palmata* reef. Coral cover tracked well with rugosity index (RI); GC1 with an average RI of 1.7 had coral cover (20.56%) superior to the other stations. Algae were the most abundant benthic cover component: mean= 50.99 ± 25.45% (SD); stony coral cover ranged from 0.65 to 20.56%, and the mean was 6.72 ± 6.94%. Bray Curtis similarity was greatest among GC stations and transects. ANOSIM two-way test documented that replicate transects at sampling stations were not different (Global R =0.066); however, site locations were different (Global R = -0.259). SIMPER analysis showed that macro algae genera *Dictyota*, *Lobophora*, and *Stypopodium* were responsible for differences in the station assemblages. Taxonomic Distinctness and Variation in Taxonomic Distinctness evaluations reported that Distinctness is stable but high Taxonomic Variation may indicate community instability.

Key words: New Providence Island, Bahamas; Community structure; Taxonomic distinctness; Rugosity

Introduction

The Bahamas archipelago (260,000 km^2) extends 800 km from SE Florida to northern Hispaniola (Gerace 1988). The majority of The Bahamas is located on two shallow banks, ideal for coral reef development. Land (islands and shoals extending above the highest tides) occupies 11,400 km^2 (4.4% of the Bahamas area). The islands are low with few cases of greater than 30 m elevation. New Providence Island is situated on an east-west axis between Andros Island to the west and Eleuthra Island to the east; the islands are situated on the Great Bahamas Bank.

Engelhard (1915) reported that, of the reefs around New Providence Island, the best coral reef development was at Sandy Cay, due north of the eastern point and Goulding Cay, west of the western point of the island. Goulding Cay was the site of a multi-year coral growth-rate study (Vaughan 1915). From the east end of New Providence a chain of reefs extends to Eleuthera; reefs were also prolific in the region north of Spanish Wells (Haweis 1917; Miner 1924, 1931, 1933). Haweis published a fascinating small book about the coral reefs of Nassau, calling them "sea gardens." He noted that there were five shallow habitats (types of ocean bottom) around the Bahamas: "soft sand; flat, sandy coral rock; coral reef; feather bar; and grass." In those days, visitors could board a glass bottom motor launch at the Colonial Hotel to have a look at the reefs (Haweis 1917).

In July 2006, the Academy of Natural Sciences of Philadelphia organized an expedition to study historical sampling locations based on the Böhlke and Chaplin (1968) field notes obtained from the Academy and the personal recollection of Gordon Chaplin who participated in the original studies (Chaplin 2006). We examined coral reef habitat (coral species diversity, coral cover, and rugosity of the reefs) in conjunction with Kellogg's reef fish studies (in progress).

Material and Methods

Each site (Delaport Point [DP], Green Cay [GC], Long Cay [LC]) included three sampling stations stratified by depth (1: 1.5 to 6.1m; 2: 6.2 to 7.6m; 3: 7.7 to 15.2 m). Three 25m long transects were established at each station (Table 1).

We sampled stony coral species richness with a 20 minute long visual survey. A five mega-pixel digital camera in an underwater housing with a reference rod that positioned the camera 40 cm from the reef surface was used to capture benthic cover (N=40 images per transect); image size was approximately 0.16 m^2. Forty images provide a planar area of 6.4 m^2 per transect and 19.2 m^2 per sampling station. Benthic cover was analyzed using point count analysis (Jaap and McField 2001; Kohler and Gill 2006). Rugosity was measured with a chain along a ten m long path at each transect (Dahl 1973).

Sites:	**Green Cay (GC)**	**Long Cay (LC)**	**Delaport Point (DP)**
Station 1	25°06.283'N 77°11.822'W	25°05.576'N 77°23.899'W	25°04.786'N 77°26.631'W
Station 2	25°06.292'N 77°11.857'W	25°05.539'N 77°23.253'W	25°04.472'N 77°28.210'W
Station 3	25°06.547'N 77°11.762'W	25°05.705'N 77°23.417'W	25°05.279'N 77°26.306'W

Table 1. Sampling station coordinates.

Multivariate analyses, based on benthic components (species and genera), used Clarke's (1993) non-parametric approach, implemented in the PRIMER-E 6 software (Clarke and Gorley 2006). All point-count values were square-root transformed, so that the multivariate analyses would draw on species from across the whole assemblage rather than being either dominated only by the two or three species with the highest cover or overly influenced by rare species (Clarke and Green 1988). Bray-Curtis similarities were then computed to compare transects and station samples (Bray and Curtis 1957; Bloom 1981). Finally, triangular matrices were input to non-metric multidimensional scaling ordination (MDS) (Kruskal 1964) and ANOSIM test for establishing differences between habitat or location groups (Clarke and Green, 1988; Clarke 1993). The SIMPER procedure (Clarke 1993) was used to identify species most responsible for observed differences in assemblage structure.

TAXDTEST was employed to evaluate the taxonomic distinctness of the species assemblages (Clarke and Warwick 1998; Warwick and Clarke 1998; Warwick and Clarke 2001). The procedure evaluates taxonomic distinctness (TD, Î+) of the sample, compares it to a regional pool of all species and to the variance in taxonomic distinctness (VarTD, Lambda+). The method is robust, and independent of sampling effort (Clarke and Warwick 1998, 2001; Warwick and Clarke 2001). Data were exhibited in a confidence funnel and ellipse graphics. The regional Scleractinia database includes a comprehensive 1975 study at Grand Bahama (Jaap and Olson 2000) and compiled distribution data from Atlantic, Caribbean, and Gulf of Mexico locations; it was used as a comparison with the New Providence data set. The TAXDTEST was also used for regional comparison, including the Gulf of Mexico, eastern Atlantic, Bermuda, Brazil, and Caribbean.

Results

Stony coral species richness was greatest (27) at DP2 (Table 2) and the poorest (14) at DP3. Six species (*Millepora alcicornis, Siderastrea siderea, Porites astreoides, Diploria labyrinthiformis, Diploria strigosa*, and *Montastraea annularis*) occurred at all sites and stations. *Acropora cervicornis, Scolymia lacera, Scolymia cubensis,* and *Mycetophyllia ferox* were only seen at one station.

Site and Station	RI	S	Algal cover	Coral cover
DP1	1.47	16	28.26	2.04
DP2	1.44	27	51.85	11.95
DP3	1.20	14	2.83	0.65
GC1	1.77	18	32.22	20.56
GC2	1.83	18	72.06	6.29
GC3	1.43	22	73.19	12.98
LC1	1.49	15	57.10	2.99
LC2	1.22	19	81.68	1.81
LC3	1.15	21	59.80	1.23

Table 2. Mean Rugosity Index (RI), species richness (S), algal and coral cover (%) for the New Providence stations.

Rugosity was greatest at GC1 and GC2; the complexity of the *Acropora palmata* habitat was a contributing factor at GC1 (Table 2). Stations with RI values exceeding 1.4 had the greater number of stony coral species; however, the station with the highest RI values (GC2) had fewer coral species than several other stations. Coral cover generally matches well with rugosity; GC1 with an average RI of 1.71 had coral cover that was superior to the other stations. The exception occurs at station GC2 with an average RI of 1.83 but relatively low coral cover (Table 2). Spearman rank correlation for coral cover, number of species, rugosity, and taxonomic distinctness documented mediocre correlations.

Macro algae dominated benthic cover (Table 2); however, it was quite variable, ranging from 81.68% at LC2 to 2.83% at DP3. Coral cover (principally dense thickets of *Acropora palmata*) was greatest at GC1. Sponges contributed 4.84 (DP1) to 0.31 (GC3) % cover, octocorals contributed 8.00 (LC1) to 0 (DP1) % cover, and zooanthids provided 0.09 (LC3) to 0 (several stations) %cover.

Benthic community structure characterized by species cover depicts that fidelity is greatest among the GC stations (Fig. 1); GC1 (*Acropora palmata* community) and DP1, expressed the greatest similarity of the sampling transects; DP3 transects had the greatest dissimilarity (Fig. 1).

Analysis of Similarity (ANOSIM) two-way crossed test documented the differences between location and habitat. Replicate transects at sampling stations are similar (Global R=0.066); however, the site locations are different (Global R= -0.259).

Macro algae genera *Dictyota, Lobophora*, and *Stypopodium* were most responsible for differences in the assemblages (SIMPER, one-way test). When the algae genera were removed from the analysis, coral species and genera were responsible for the dissimilarity. *Acropora palmata* contributed 20 to 30% of dissimilarity, setting GC1 apart from other stations.

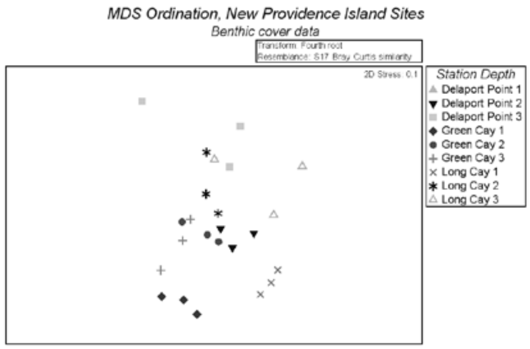

Figure 1. Multi-Dimensional Scaling (MDS) Ordination of Transects, Species Cover Attributes Used as Input for the Bray-Curtis Similarity Analysis.

Taxonomic distinctness (Delta+) values (TAXDTEST) ranged from 59.68 (GC2) to 65.28 (DP1); Lambda+ values range from 283.85 (LC3) to 614.96 (LC1). Taxonomic distinctness has not declined remarkably at these sites (Fig. 2). There is a high degree of variance in taxonomic distinctness at GC1 and LC1, likely because several of the species that occurred there were rare or nonexistent at the other sites.

Discussion

Few pre-1970 studies quantitatively assessed coral diversity and cover in the Bahamas. Photographs in these studies show evidence of coral cover; however, photos often featured the premiere attributes of the sites at that time; it is surmised from this that, typically, coral cover exceeded 30 to 40% in many locations in the Bahamas, especially in areas where *Acropora palmata* predominated.

In a study conducted in 1975 off Freeport, Grand Bahama (Jaap and Olson 2000), coral cover ranged from 1.48 to 30.28%. This was, however, for the most part in depths (30 to 70 m) that exceed the present study.

Chiappone et al. (1997) surveyed reefs in depths of 3 to 15 m along the Exuma Cays (south of New Providence Island) in 1995. Algae cover ranged from 20 to 80%, sponge cover from 10 to 40%, octocoral cover from 2 to 5%, and scleractinian coral cover from 2 to 40%. The survey reported 43 species of sponges, 29 octocoral species, and 39 stony coral species. This current study identified 32 stony coral species (Milleporina and Scleractinia) from the three sites around New Providence Island.

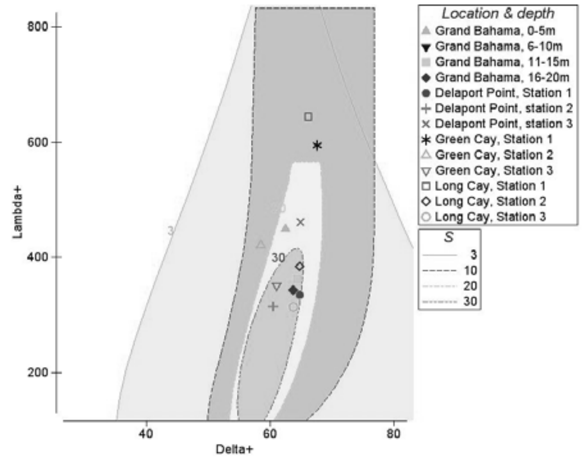

Figure 2. Taxonomic Distinctness (Delta+) and Variation in Taxonomic Distinctness (Lambda+) for the New Providence and Lucaya, Grand Bahama, Sampling Stations.

Zooxanthellate Scleractinia (ZS) distribution and taxonomic distinctiveness for the Gulf of Mexico, Florida, Bahamas, Caribbean, and south Atlantic localities are related to spatial distances: the southeastern and southwestern GMEX regions have a high degree of faunal similarity with SE Florida, the Bahamas, and the Caribbean; however, there is a low similarity with southeastern USA (North of the St. Lucie Inlet to Cape Hatteras), south Atlantic, and the eastern Atlantic (Figs. 3 & 4). Ocean current patterns within the Gulf and Caribbean provide a source of connectivity for Bahamas, Cuba, Florida, and Mexico. The cluster pattern (Fig. 3) is consistent with connectivity in the region and isolation from distant locations.

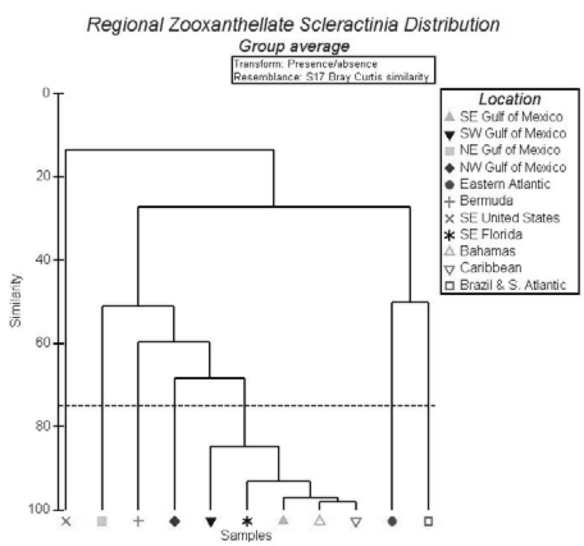

Figure 3. Cluster diagram of the distribution of zooxanthellate Scleractinia in the Atlantic Ocean and Gulf of Mexico; presence or absence of species at these locations. Bray Curtis Similarity coefficient and group average sorting.

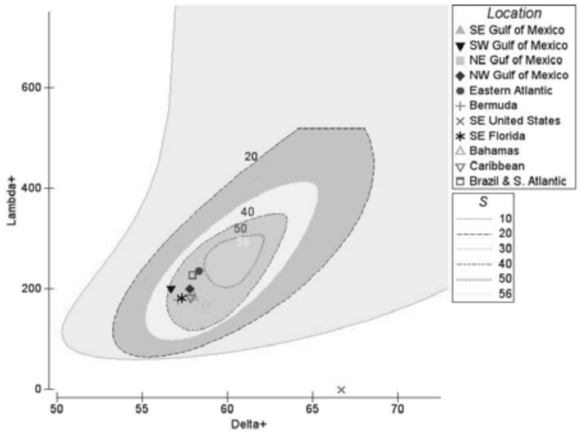

Figure 4. Taxonomic Distinctness (Delta +) and Variation in Taxonomic Distinctness (Lambda+); regional comparison of zooxanthellate Scleractinia.

We interpret the high VarTD to be the result of a reduction in certain habitats that are obligatory for some species at some sites, the abundance and competition by algae for space, and the result of tropical storm disturbances in 2004 and 2005. A comparison of the New Providence Island Site VarTD with regional VarTD (Figs. 2 & 4) shows relatively lower values for VarTD at the regional level. TD distinctness and variation (Fig. 4) in contrast to the cluster analysis (Fig. 3) shows that the zooxanthellate Scleractinia do not exhibit a large range of Delta+ and Lambda+ in the remote locations, such as Brazil, Azores, and Bermuda. This is due in part to very few endemic species and to the wide distribution of many species in the region.

Decline in coral reefs around New Providence Island may be caused by runoff and groundwater seepage from the surrounding highly populated areas. Runoff carries nutrients, metals, pesticides, chemicals, and biocides, all of which are detrimental to the vitality of the coral reef communities. We noted that there are virtually no attached organisms at DP1 and DP3 sites, which are in close proximity to densely populated urban areas and are situated near a channel facilitating transport from the shoreline. Green Cay sites are located a moderate distance from the urban developments on New Providence, and the typical epibenthic reef flora and fauna are common.

Nutrient enrichment often results in increases in macroalgal growth, particularly in areas near coastal development and increased sewage outflow (Smith et al. 1981; Birkeland 1988; Pastorak and Bilyard 1985). Macro algae were the most prevalent biotic cover component at all nine of the sampling stations. We also suspect that the large algae population is related to a decrease in herbivores (e.g., fish and *Diadema antillarum*).

Comparisons of reefs in Montagu Bay (New Providence Island) with 1943 aerial photos documents that startling declines in stony coral cover have occurred over the last half century (Sullivan Sealey 2004). Patch reefs in the bay decreased from 214 to 133 in 52 years. Aerial photographs also indicate that many coastal construction projects were undertaken between 1943 and 1995, significantly altering the coastline and, most likely, increasing the physical destruction of reefs through increased sedimentation and turbidity. Bahamian reefs were recently listed as over 60% degraded, trailing Jamaican and Panamanian reefs in total loss (Pandolfi et al. 2003). The Bahamas have made a commitment to conserve 20% of their coral reef ecosystems in the form of no-take areas or marine protected areas (Pandolfi et al. 2003), although no timeline has been directly specified. No-take reserves and marine protected areas have been shown to be effective mitigation and replenishment measures, and it is important that they are established in heavily populated areas such as New Providence Island, where unsustainable development has already led to significant declines in fish, corals, and other benthic invertebrates. These measures are limited, however, in their ability to combat the effects of degraded water quality. The Bahamian government needs to implement a new sewage treatment system. Continued degradation of water quality will occur unless significant improvements are made in the infrastructure.

Status of reefs in the Bahamas is far better in remote areas such as Cay Sal Bank than in highly urbanized islands such as New Providence. Reef degradation around New Providence is mostly the result of urban development pressures in the coastal zone. Status and trends of mangroves, sea grasses, and coral reefs in the Bahamas is similar to other Caribbean countries where coastal resources have been used as a tourist attraction for economic stimulus. This, coupled with radical declines in *Acropora* reefs (the causes of which are enigmatic), has resulted in coral reefs that are degraded and covered with algae. Monitoring programs can determine the status and future trends of resources; however, they can only serve as an ecological warning system. Basic research, management, conservation, and social action are required to resolve the problems, be they local, regional, or global.

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