

Characterizing the deep insular shelf coral reef habitat of the Hind Bank marine conservation district (US Virgin Islands) using the Seabed autonomous underwater vehicle

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Received 14 January 2005; received in revised form 24 October 2005; accepted 26 October 2005

Available online 4 January 2006

Abstract

The benthic communities of the deep insular shelf at the Hind Bank marine conservation district (MCD), an important spawning aggregation site for groupers, were studied with the Seabed autonomous underwater vehicle (AUV) at depths between 32 and 54 m. Four digital phototransects provided data on benthic species composition and abundance of the insular shelf off St. Thomas, US Virgin Islands. Within the western side of the MCD, well-developed coral reefs with 43% mean living coral cover were found. The *Montastrea annularis* complex was dominant at all four sites between 33 and 47 m, the depth range where reefs were present. Maximum coral cover found was 70% at depths of 38–40 m. Quantitative determinations of sessile benthic populations, as well as the presence of motile megabenthic invertebrates and algae were obtained. The Seabed AUV provided new quantitative and descriptive information of a unique coral reef habitat found within this deeper insular shelf area.

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Keywords: Atlantic; US Virgin Islands; Coral reef; Deep hermatypic corals; AUV

1. Introduction

Shallow coral reefs in the tropical West Atlantic Ocean have experienced living coral cover declines of up to 80% in the last 30 yr (Gardner et al., 2003).

Pollution, sedimentation, hurricanes and coral disease are all contributors to the decline in living coral cover. While numerous assessments of coral reef habitat have been conducted throughout the tropical western Atlantic and elsewhere using SCUBA, there is limited information on the deeper reefs zones, up to 100 m, which lie beyond the range of safe diving operations. Mapping and monitoring deeper hermatypic (zooxanthellate) coral reefs is necessary for selecting and protecting unique areas

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of high-living coral cover, diversity and structural complexity that could aid in the recovery of the shallower fish and benthic communities.

In the past, an evaluation of deep-water fish habitats and abundance around Puerto Rico and the US Virgin Islands, at depths ranging from about 100–450 m, was conducted using the *Johnson-Sea-Link II* submersible (Nelson and Appeldoorn, 1985). To this day, the upper insular slope reefs of Puerto Rico and the Virgin Islands, found at intermediate depths (30–100 m) remain largely undescribed.

The Seabed autonomous underwater vehicle (AUV) is a new imaging platform designed for high-resolution optical and acoustic sensing (Singh et al., 2004). The Seabed was tested over the insular shelf slope off southwestern Puerto Rico in March 2002 to a maximum depth of 125 m (Armstrong et al., 2002; Singh et al., 2004). This test dive established the potential of this new tool for mapping and characterizing the upper insular slope coral reef habitat.

During June 2003, we used the Seabed for imaging the benthic habitats of the shelf edge and upper insular slope of the Hind Bank marine conservation district (MCD), South of St. Thomas, US Virgin Islands. The MCD is a non-fishing area that was established as per recommendation of fishers, scientists and government officials in 1999, to conserve and manage representative samples of marine habitats and ecosystems and to maintain marine biodiversity. The area was originally managed as a seasonal closure for the protection of the red hind (*Epinephelus guttatus*) spawning aggregation on the eastern side of the MCD. The spawning aggregation primary site was described by Beets and Friedlander (1997). The dominant coral present was flattened colonies of *Montastrea annularis*. More recently, a limited number of diver surveys at depths of 38–39 m were conducted by Nemeth et al. (2004).

Up to now, very little quantitative information has been available on the structure and composition of the coral reefs at the MCD due to the depth of these reefs. The goal of this study was to characterize the benthic community structure and biodiversity of these deeper insular shelf coral reefs. The Seabed high-resolution color images were used to describe the major components of the coral reef community of the MCD, which includes corals, gorgonians, sponges, other macro-invertebrates and algae, and to quantify living coral cover, species richness, diversity and evenness.

2. Study area

The Hind Bank MCD is located approximately 12 km South of St. Thomas, US Virgin Islands, at the shelf edge encompassing an area of approximately 41 km² (Fig. 1). According to the bathymetry map of this area, depth ranges within the MCD from about 30 m on the western part to more than 430 m off the shelf edge. Within the insular shelf area of the MCD the maximum depth is approximately 62 m, with an average depth of 42 m on the eastern half. Four, 1-km-long transects were selected for the AUV surveys based on the known distribution of coral reef habitats and fish spawning grounds provided by previous SCUBA assessments. The two transects on the western side of the MCD were parallel to the shore over areas dominated by coral reefs. The eastern transects were oriented perpendicular to shore at known fish spawning sites.

3. Materials and methods

The Seabed AUV is composed of two torpedo-like body sections fixed to each other with vertical structural members (Fig. 2). The AUV was designed to operate up to 2000 m depth, to carry out photo transects, side-scan sonar and bathymetric surveys. A Pixelfly 1024 × 1280 pixel resolution CCD camera, with 12 bits of dynamic range, is the primary optical imaging sensor.

The camera was pointed straight down. A 150 W s strobe is used for photographic illumination. The strobe is mounted 1.4 m aft of the camera to reduce the effects of lighting backscatter in the images (Fig. 2a). The frequency of photos is a function of strobe recharge time (2.5 s). The size of the image was determined based on the altitude of the vehicle to the bottom and the field of view of the camera.

Measurements of velocity over the bottom, heading, altitude, pitch, roll and integrated position are provided by a 300 kHz acoustic Doppler current profiler (ADCP), which projects four sonar beams into the water. These are arranged in a Janus configuration pointing 30° fore, aft, to port and to starboard. We utilize the forward pointing beam for obstacle avoidance. A Paroscientific Model 8DP depth sensor provides depth information that, when combined with a dedicated vertical thruster, delivers depth accuracies in the order of 3.5 cm during our missions. More information on Seabed components, sensors, control systems and navigation can be found in Singh et al. (2004).

reprocessed the raw imagery to obtain three channel, $1280 \times 1024 \times 12$ bit RGB images. The 12 bits of dynamic range provided by the camera that is part of Seabed allow us to compensate and color balance the imagery, as shown in Fig. 3.

The enhanced benthic imagery was analyzed for percent cover of living corals and other benthic components using random points generated by the *Point Count for Coral Reefs* software (P. Dustan, personal communication). The clearest, best quality images (50–70 per transect) were selected and individually analyzed using 50 random points, and the percent cover of corals, sponges, algae and bare substrate was recorded. From images acquired within coral reef areas the diversity index for corals was calculated using the Shannon–Weaver diversity index

$$H' = - \sum P_i \ln P_i, \quad (1)$$

where $P_i = n_i/n$ and n = total number of coral colonies. Evenness was calculated using Pielou's

evenness index

$$J = H' / \ln H_{\max}, \quad (2)$$

where H_{\max} = total number coral species.

4. Results

At the western side of the MCD, the reef at PR-03 had a depth range from 33 to 42 m (Fig. 4a) while, at PR-04, the reef extended from 36 to 41 m in depth (Fig. 4b). Higher depths were found at the eastern side of the MCD where the transect lines were perpendicular to the coast and extended beyond the shelf edge. At PR-07 the reef was restricted to a narrow zone, 45 to 47 m deep, in a transect that exceeded 60 m in depth (Fig. 4c). In a similar way, at PR-08, coral reefs were only present in the middle of the transect at depths from 41 to 46 m (Fig. 4d). In all cases, the AUV followed the bottom contour maintaining a distance of approximately 4 m from the bottom. In addition to depth, bottom composition varied considerably between the East and the West transects of the MCD. Transects PR-03 and PR-04 were mainly composed of coral reef areas (97% and 100%, respectively), whereas transects PR-07 and PR-08 consisted of small coral reef patches separated by hardground areas along with algal mats, sand and sparse seagrasses (Fig. 5). Hardgrounds are low-relief areas where sediments have been lithified into rock. In these consolidated substrates sparse sponges, gorgonians and algae may be present. Algal mats are a dense layer of algae that blanket the bottom, while “sand” refers to substrates of unconsolidated calcium carbonate grains. Seagrasses were only present within the algal mats and sand bottom categories. Within the reef areas, coral cover at PR-04 was significantly higher ($p < 0.05$) than at the other three sites, with coral cover ranging from 29% to 43% (Fig. 6). Bare substrate was the second most important category, in terms of percent cover within coral reefs areas, except for PR-03 where macro-algae was the dominant component. Macro-algae was characterized by green, brown and red algae, while the bare substrate category includes dead coral colonies, uncolonized hard-bottom and sand.

Within the scleractinian cover composition, the image data analysis revealed dominance by *M. annularis* complex at all transects, but particularly at PR-03 (Fig. 7) where the average cover of *M. annularis* was about 90% and this dominance was nearly constant with depth. At PR-04, the reef was

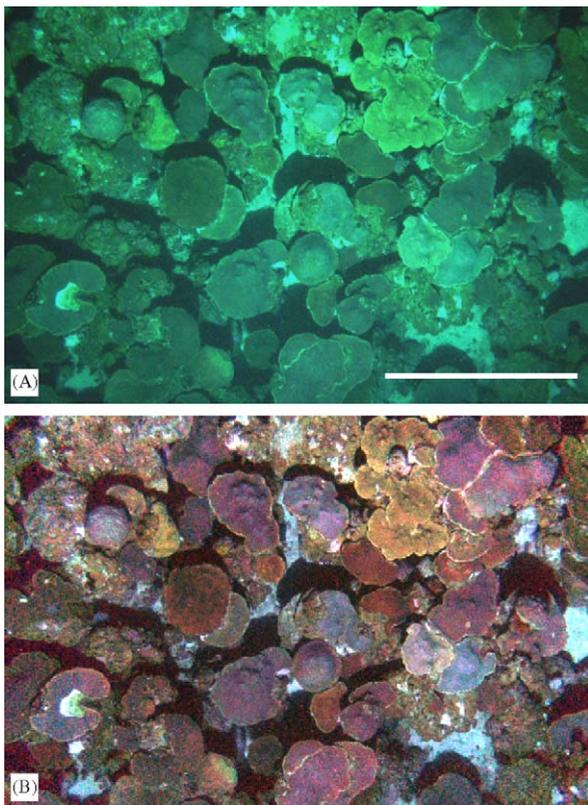


Fig. 3. Reef at a depth of 40 m at PR-04 before (A) and after (B) color enhancement. Scale bar = 1 m.

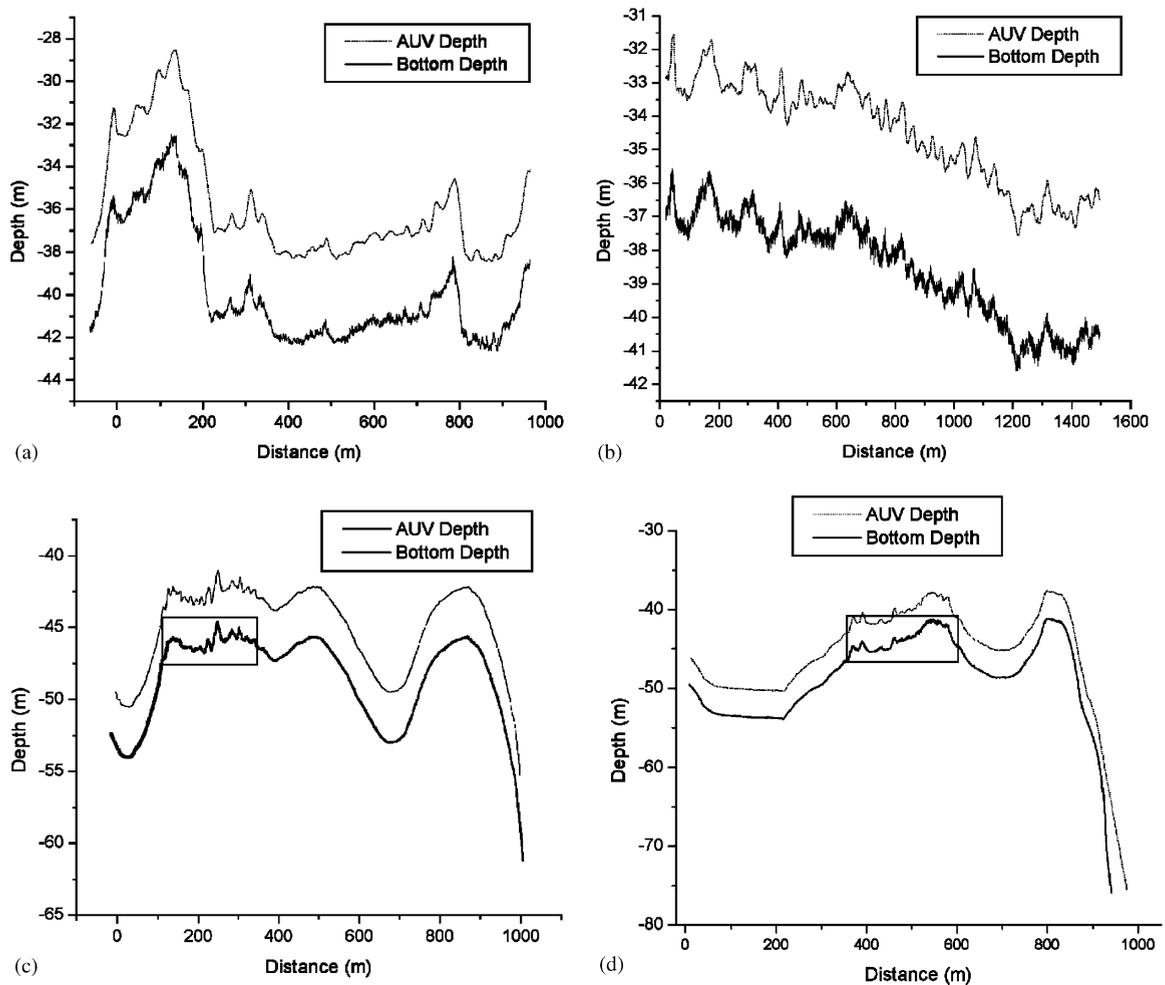


Fig. 4. (a)–(d). Depth profiles of the AUV transects: (a) PR-03, (b) PR-04, (c) PR-07, and (d) PR-08. The box in (c) and (d) indicate where the coral reef was located within the transect. The reef was continuous over the entire transect in (a) and (b).

also highly dominated by the *M. annularis* complex, but with increasing cover of the genus *Agaricia* with increasing depth (Fig. 8). The *M. annularis* complex was less dominant at PR-07 (Fig. 9) at around 50–63% of the total coral cover. The least dominance of this species was found at 46m in PR-08 where its coverage was reduced to less than 40% and the genus *Agaricia* covered up to 30% of the substrate (Fig. 10). Overall, *M. annularis* complex was the dominant coral species representing 92% of the coral cover.

One-way ANOVA showed statistical differences in coral cover among depths at PR-03 and PR-04 ($p = 0.0006$ and $p = 0.005$, respectively), but no significant differences were found at PR-07 and PR-08 ($p = 0.138$ and $p = 0.194$, respectively).

The relatively small index of diversity (range 1.48–1.85, Table 1) further validates the dominance of the *M. annularis* complex over the rest of the species. Species richness was highest on the western side of the MCD, with 14 identifiable coral species at PR-04 followed by 11 at PR-03. On the eastern side of the MCD, the coral reef at PR-07 and PR-08 consisted of only seven and nine coral species, respectively (Table 1).

Within coral reef and hard ground areas, the benthic cover of other macro-invertebrates was dominated by sponges and gorgonians at all sites (Table 2). The most dominant sponges were the giant barrel (*Xestospongia muta*) and rope sponges of the genus *Aplysina*. A total of 17 species of sponges, two hydrozoan corals (*Millepora* sp.),

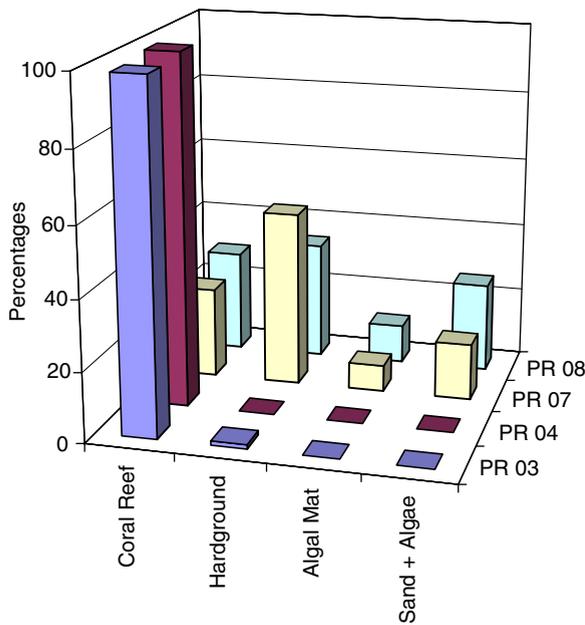


Fig. 5. Percent distribution of various bottom types along the four transects.

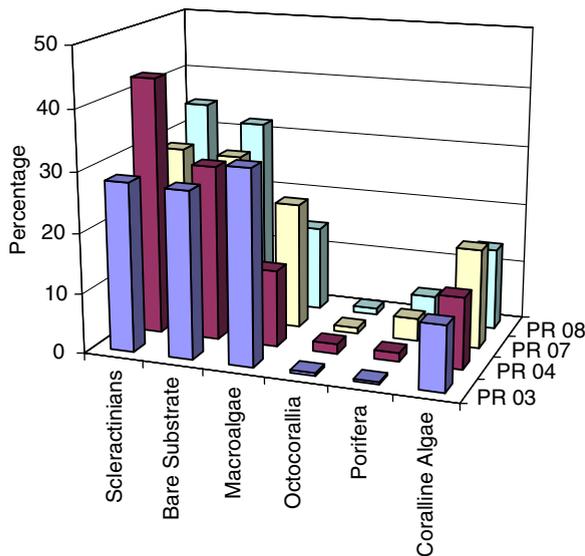


Fig. 6. Bottom composition within the coral reef areas of each transect. Bare substrate category includes dead coral colonies, uncolonized hard-bottom and sand.

10 gorgonians, one black coral (*Cirrhopathes* sp.) and four lobster and crab species (crustaceans) could also be identified in association with coral reef and hardground substrates. Most gorgonian species were found in the western part of the MCD at PR-

03 and PR-04. The only invertebrates associated with sand bottom and algae substrate that could be identified from the images were two species of conch (genus *Strombus*), three species of echinoderms and the upside-down jellyfish *Cassiopea*. The echinoderms consisted of the sea urchin *Meoma ventricosa* and two species of sea cucumbers (holothurians). Seven algae and one seagrass species were identified in the phototransects (Table 3). Only functional groups could be reported for most algae, except for *Udotea cyathiformis* and *Halimeda* sp. that could be distinguished due to their characteristic shape and were only found in the eastern side of the MCD. Turf algae are a multispecific assemblage of filamentous algae. The seagrass *Halophila baillonis* was found in sand bottoms and algal substrates at both PR-07 and PR-08.

5. Discussion

The geomorphology of the eastern side of the MCD, as depicted by the AUV transects, follows the description of Olsen and LaPlace (1978) who described the red hind spawning site with the bottom topography as a series of coral ridges, parallel to the 100 fathom (182 m) curve. These ridges were usually 100 m across and separated by calcareous sand which ranged from 50 to 300 m in width, with the dominant coral, *M. annularis*, measuring less than 1 m in diameter. From a series of SCUBA dives at the red hind spawning site along the shelf edge reef, at depths of 38–48 m, Clavijo and Tobias (1985) described the substrate as dominated by dense scleractinian cover, primarily plates of *M. annularis*. Nemeth (2003) reported *M. franksi* as the dominant species in the MCD and within the spawning aggregation site.

The *M. annularis* species complex is composed of the sibling species *M. annularis*, *M. faveolata* and *M. franksi* (Weil and Knowlton, 1994), which are the dominant reef-building corals in the tropical western Atlantic (Goreau, 1959). While the *M. annularis* complex represented 20–60% of the corals found in near-shore and mid-shelf reef areas in depths of 5–25 m (Herzlieb et al., in press), it dominated in 30–40 m depths with cover ranging from 60% to nearly 100%. In areas deeper than 40 m it still represented 50–60% of the coral cover. Also common in deep reef areas of the Caribbean are several species of the genus *Agaricia* (Lang, 1974; Reed, 1985; Liddell and Ohlhorst, 1988). Within the MCD, *Agaricia* sp. represented up to

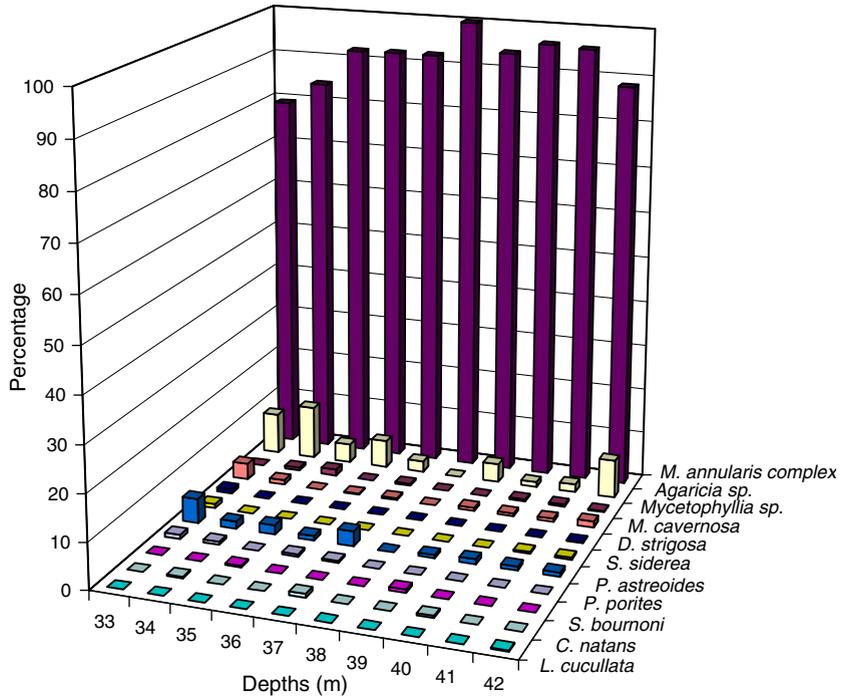


Fig. 7. Coral cover by species and depth at PR-03.

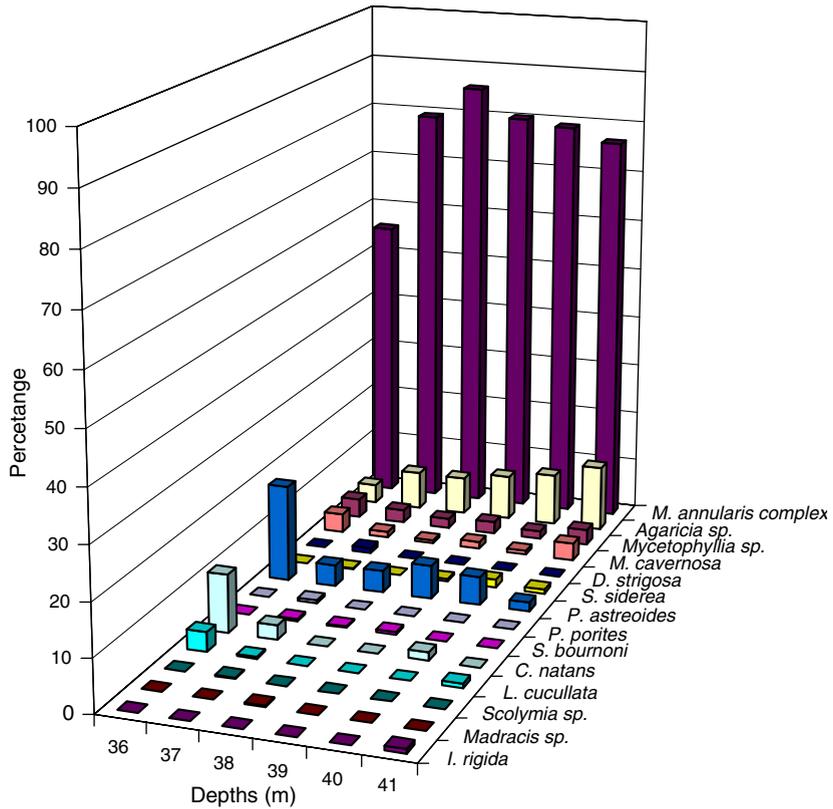


Fig. 8. Coral cover by species and depth at PR-04.

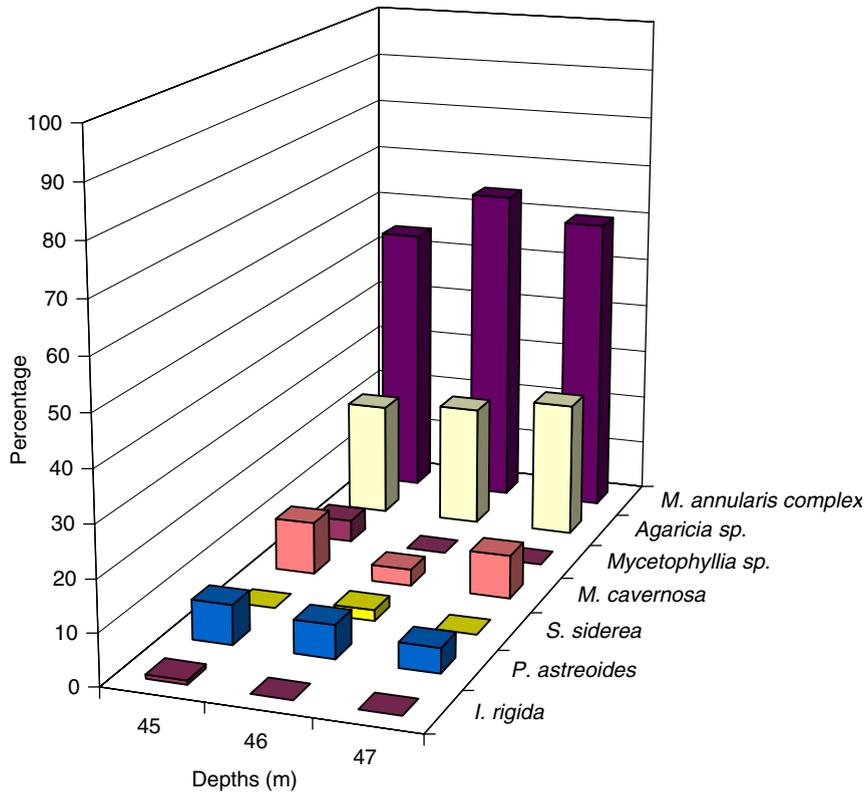


Fig. 9. Coral cover by species and depth at PR-07.

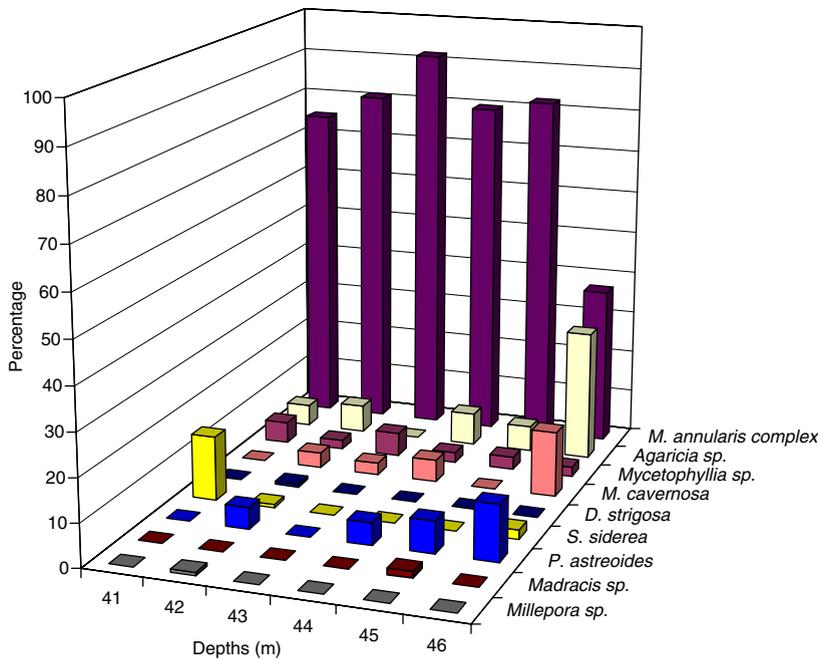


Fig. 10. Coral cover by species and depth at PR-08.

Table 1
Species richness, diversity and evenness at the four transects

Transect	Species richness	Diversity index (H')	Evenness (J)
PR-03	11	1.48	0.615
PR-04	14	1.73	0.655
PR-07	7	1.85	0.949
PR-08	9	1.50	0.684

10% of the coral cover at depths less than 41 m, and over 20% of the cover in depths greater than 45 m. The *M. annularis* complex and *Agaricia* sp. both grew as plate-like formations. The plate-like morphology is an adaptation to reduced sunlight at deeper depths (Grauss and Macintyre, 1982). *Porites astreoides* and *Mycetophyllia* sp. were found at all depths between 33 and 47 m. *Agaricia* sp. was only found in small colonies that were easily identified by their spiraling ridge pattern and brownish color. The average living coral cover seen in the photo transects was 43%, with maximum cover of 70% found in some areas at 40 m. Also found in abundance was an encrusting sponge, which is most likely a species of *Cliona*. This sponge accounted for 96% of all the sponges found, while most of the other sponges present were columnar. *Cliona* is a brown–black sponge that grows over corals as it dissolves them, which may account for the high percentage of bare substrate.

In Bermuda, most deep-water hermatypic corals grow on reef substrate down to 60 m (Fricke and Meischner, 1985). The coral growth in the deeper reef areas in Bermuda appeared to be controlled by macro-algae growth. In the Bahamas, coral assemblages less than 30 m depth represented 3–25% of benthic cover, and were dominated by *Agaricia agaricites*, *M. cavernosa*, *M. annularis*, *P. astreoides* and *P. porites* (Liddell et al., 1997). The deeper (30–50 m) coral assemblages represented less than 3% of the benthic cover and were dominated by *M. cavernosa* and *Agaricia* spp. (Liddell et al., 1997). Low water temperatures favor macro-algae growth leading to a reduction of coral growth (Johannes et al., 1983). In the fore-reef slope of Jamaica, the flattened growth form of *M. annularis* is the dominant species of coral above 45 m (Goreau and Land, 1974).

At a study site close to the PR-07 transect in this study, Nemeth et al. (2004) reported mean values of 28% living corals, 35% macro-algae, 20% dead coral with turf algae, 7% sand/sediment, 4%

sponges and 0% gorgonians. This compares favorably with the AUV estimates of living coral (29%) and sponges (3.8%) at PR-07. The bare substrate category was 28.5%, coralline algae (16.6%), macro-algae (21.2%) and gorgonians (1%). In a separate study, Herzlieb et al. (in press) found coral cover on the western end of the MCD to be 44.8%, with coral cover of the *M. annularis* complex near 80%. Nemeth et al. (2004) also reported dominance by the *M. annularis* complex at 76% of total living coral cover, a 1.4 diversity index, coral bleaching at 6.5% and incidence of diseased corals at 1.4%. The present study could not detect any evidence of coral disease in any of the phototransects and, at PR-07, the diversity index was 1.8 with dominance of *M. annularis* complex at 50–60%. The reefs at PR-07 are substantially deeper (45–47 m) than the reef area described by Nemeth et al. (2004) at 38–39 m. This could account for the observed differences in some of these coral reef parameters.

Although the coral reefs of the MCD are largely unknown, they appear to be relatively undisturbed by anthropogenic factors due to the considerable distance to land sources of runoff and pollution (Herzlieb et al., in press). Their greater depth also protects them from wave damage from storm surge. Intermediate depth coral reefs, such as those of the MCD, could serve as refugia for shallow water species in times of environmental stress (*sensu* Riegl and Piller, 2003).

The high coral cover throughout the MCD suggests that these reefs are largely unaffected by natural and human disturbances. Since the late 1970s, hurricanes (Woodley et al., 1981; Edmunds and Witman, 1991) and disease (Gladfelter, 1982) have devastated shallow water reef communities throughout the Caribbean. Edmunds and Witman (1991) reported that hurricane Hugo destroyed over 33% of the live cover of *M. annularis* on shallow (10 m) reefs off St. John, US Virgin Islands. Although the turbulence from large hurricane waves can cause fragmentation and abrasion damage in many shelf edge reefs, these effects are limited to depths of 30 m (Blanchon and Jones, 1997). The relatively high depths present at the MCD protects these coral reefs from the high turbulence generated by hurricane waves, since the minimum depth of the surveyed reefs was 33 m, and most reefs were present at depths of 40 m or more. Recently, the mortality rate of shallow water corals in the Caribbean has increased dramatically due to a variety of diseases (Richardson et al., 1998a, b;

Table 3

Plants identified in the phototransects (CR—coral reef, HG—hardground, AM—algal mat, SA—sand bottom + algae)

Group/scientific name	PR 03		PR 4	PR 07				PR 08			
	CR	HG	CR	CR	HG	AM	SA	CR	HG	AM	SA
CYANOBACTERIA ALGAE					+	+					
Brown algae	+	+	+	+	+	+		+	+	+	
Red algae						+		+		+	
Red coralline algae	+	+	+	+	+			+	+		
Green algae			+	+	+						
<i>Udotea cyathiformis</i>							+	+		+	+
<i>Halimeda</i> sp.					+	+	+	+	+		
Turf algae	+	+	+	+	+			+	+		
ANGIOSPERMAE											
<i>Halophila baillonis</i>						+	+			+	+

Harvell et al., 1999). Although no disease was evident in the Seabed AUV digital imagery, Nemeth et al. (2004) reported that low levels of disease occurred within the MCD in spring 2003, but higher levels of disease (over 10%) occurred on similar deep reefs outside the MCD. They speculated that the unprotected deep reefs may have higher incidence of disease due to commercial fish traps, which not only injure corals but may act as vectors of disease when fishermen transfer traps from shallow to deep reefs.

There are numerous reports in the literature describing intermediate depth coral reefs (30–50 m) present in the deep fore-reef and upper insular slopes of many Caribbean Islands. However, the coral reefs of the MCD described here are present within the deeper zones of the insular shelf, a unique habitat that has not been described elsewhere. The distribution and characterization of similar habitats at other locations needs to be established before meaningful comparisons with similar coral communities can be made.

In summary, the quantitative characterization of benthic communities associated with the deep coral reef habitats of the MCD, as provided by the four AUV phototransects, compares favorably with the available information from previous diving surveys in this area. In most cases, the resolution of the Seabed digital imagery was adequate to identify the organisms to the species level. In other cases, only genera could be identified, and for most of the algae, only major groups could be identified. This study demonstrates that the high quality digital imagery provided by the Seabed AUV can be used to

characterize the deeper zooxanthellate coral reef habitat present at depths greater than 30 m, which for most areas of the world remain largely unknown. Quantitative determinations of sessile benthic populations, as well as the presence of motile megabenthic invertebrates and algae were obtained.

Our initial results show that the deeper reefs of the MCD are largely unaffected by hurricane disturbances, human impacts and disease. Therefore, they could serve as a potential refuge areas and a source of larvae for the recovery of shallower coral reef communities present downstream, and may play a critical role in the re-establishment of fish populations in adjacent insular shelf areas.

Acknowledgments

We thank Captain Harry Montalvo and the crew of the *R/V Chapman*, and the field and technical assistance of members of the Seabed AUV operations team. We appreciate the recommendations for transect locations provided by Elizabeth Whiteman, the field assistance by Stacy Albritton, Elizabeth Kadison, Yasmín Detrés, Fernando Gilbes, Liane Guild and Jeannette Arce, and the helpful comments and corrections of two anonymous reviewers. Funding was provided in part by the CenSSIS ERC of the National Science Foundation under Grant EEC-9986821 and by the Caribbean Fishery Management Council. University of the Virgin Islands staff time was supported by a grant from Sea Grant (R-101-1-02) to R. Nemeth.

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