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Biological and physical characteristics of a mesophotic coral reef: Black Jack reef, Vieques, Puerto Rico

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Abstract. For six decades Vieques Island was used for US Navy military activities. While several studies have addressed the possible impact on shallow coral reefs, mesophotic reefs (30-100 m deep) have been largely overlooked. This study provides an extensive baseline qualitative and quantitative characterization of Black Jack Reef including variations in the light attenuation coefficients, which serve as a proxy for changes in water quality. Operational limitations due to depth were solved using the Seabed Autonomous Underwater Vehicle (AUV). This AUV specifically designed for benthic surveys, was used to obtain two perpendicular phototransects covering a total of 5km at depths ranging 30-51 m. Mean live coral cover was 32% with *Montastraea* and *Agaricia* as the dominant genera. Very low levels of bleaching or diseases were found. Sponges were present in both transects with an average cover of 7-9%. The most common sponges were *Amphimedon compressa, Aiolochroia crassa, Agelas*, *Aplysina* and *Xestospongia muta*. Gorgonians and Black corals were present in very low abundance. Extensive areas of rhodolith beds were found. Turbidity does not appear to be a determinant factor at Black Jack Reef.

Key words: mesophotic reefs, Seabed AUV, Vieques

Introduction

The islands of Vieques and Culebra are in the northeastern Caribbean within the Puerto Rico- Virgin Island geological platform. Culebra and Vieques were used for US Navy military activities for many decades. Military activity at Vieques began in the 1940's and has just recently ended with the hand over of military owned lands to the Department of the Interior in May of 2003, becoming part of the Vieques National Wildlife Refuge. Vieques coral reefs are considered among the best in Puerto Rico in terms of live coral cover (greater than 30%) (García-Saís et al. 2001, 2004).

During the military occupation much of its area was closed to the public and little scientific research was permitted. Ecosystem damage has long been recognized by Rogers et al. (1978) and military debris can still be seen today (Riegl et al. 2008). However, decline in coral cover has been attributed to hurricanes (Antonius and Weiner 1982), sea surface temperature (Dodge 1981), turbidity (Deslarzes et al. 2006) or more recently the combination of hurricanes and diseases (Riegl et al. 2008). Riegl et al. 2008 concluded that the impact of bombing in the coral reef was negligible and, even more, suggested that the military occupation prevented further damage derived from land-based development.

In 2001 García-Saís et al. performed a baseline study outside the shooting range followed by monitoring in 2004. Deslarzes et al. (2006) compared Vieques and Culebra concluding that Vieques reefs were in worst condition. Bombing activities in Culebra stopped in 1975. Riegl et al. (2008) studied the geomorphology and coral assemblage structure and found that Vieques reefs are comparable to those of St. Croix, US Virgin Islands. Recent reef mapping efforts in these areas have been carried out by Hernandez-Cruz et al. (2006), Kendall and Eschelbach (2006), and Monaco et al. (2001). Although shallow reefs (upto 15 m depth) have received much attention, especially within the US Navy shooting range, no studies have taken deep reefs into account. Deeper reefs are typically unaffected by hurricanes or high sea surface temperatures (Riegl and Piller 2003; West and Salm 2003). Practically all mesophotic (30-100 m) coral reef communities of Vieques have not been properly characterized (García-Saís et al. 2008). The only exception to this has been Black Jack Reef (30-40 m depth), which was described in 2001 and characterized in 2004 using five 10 m transects (García-Saís et al. 2004). Further exploratory surveying, mapping, and monitoring of Vieques deep coral reef systems is needed (García-Saís et al. 2008). On the other hand, none of the previous studies has detailed the sponge species found considering they could be an important reef component.

The transparency of the surrounding waters and the relatively wide insular platform of Vieques create the potential for numerous mesophotic reefs, especially in

the south. However, operational limitations due to depth require the use of new technologies for fast and safe assessment and monitoring. Satellite and airborne techniques are limited to the first 20 m and submersibles are generally too costly for most monitoring programs. The Seabed Autonomous Underwater Vehicle (AUV) was specifically designed for benthic surveys up to 2000m deep. It has proved succesful in previous studies in southwestern Puerto Rico (Armstrong et al. 2002; Singh et al. 2004) and in the Hind Bank Marine Conservation District (MCD), USVI (Armstrong et al. 2006).

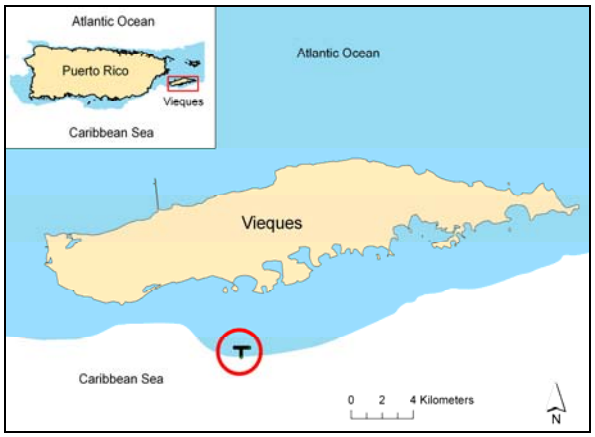

Figure 1. General location of Vieques and transects. The red circle south of the island shows relative position of the two perpendicular transects. Blue shade corresponds to the insular platform.

The aim of this work is: 1) to provide a more extensive (5 km) baseline description of mesophotic reef areas in Black Jack Reef, southern Vieques (Fig.1), 2) to generate a qualitative and quantitative evaluation of coral and sponge taxa, and 3) to describe patterns of light attenuation variation as a proxy for changes in water quality parameters.

Material and Methods

The Seabed AUV is composed of two cylindrical body sections fixed together, coupled with three thrusters and equipped with: a Pixelfly 1024 x 1280 pixel resolution CCD camera with 12 bits of dynamic range, a 150 Ws strobe, a paroscientific depth sensor and a 300 kHz Acoustic Doppler Current Profiler (ADCP). This AUV was designed to be hover capable and to maintain a constant direction and altitude from the bottom. More information on Seabed components and sensors, control and navigational systems can be found in Singh et al. (2004).

During November 2004 we used the Seabed AUV to obtain two long phototransects at Black Jack Reef in southern Vieques Island (based on García-Saís et al. 2004) covering a total of 5 km at depths ranging from 30 to 51 m.

The AUV digital images were analyzed using Coral Point Count with Excel extensions (CPCE, Kohler and Gill 2006). Five major benthic groups were considered: scleractinians, sponges, black corals (Antipatharians), algae and gorgonians. Benthic organisms were identified to the lowest possible taxon and special attention was given to scleractinian and sponge species as well as type of substrate. Coral cover was estimated using the random point method. Since there were large areas of unconsolidated sediment with encrusting algae and cyanobacteria as well as large extensions of rhodolith beds and our main interest was focused on patterns of distribution of benthic mega-invertebrates, bare substrate, algae and cyanobacteria were grouped under the general category: SUBSTRATE+ALGAE+CB (see Figs. 2, 3).

Temporal variation in the light attenuation coefficient (K490) was obtained from MODIS Aqua level 3 imagery at 4 km resolution, producing monthly averages from 2003 to 2008.

During April 2008, salinity, temperature and light attenuation profiles were measured in Vieques using a Satlantic Hyperpro spectroradiometer.

Results

Two phototransects from southern Vieques were analyzed: transect 1 was 1 km long and oriented from north to south (starting at 18.0507N, 65.4633W), while transect 2 was 4 km long and oriented east to west (18.0558N, 65.4586W). A total of 894 and 1540 images, respectively were produced at a constant altitude of 2.5 m from the bottom. Depth ranges were 30-51 m for the North-South transect and 34-43 m for the West-East transect.

The North-South transect (Fig. 2) was composed of about 30% coral reef (defined as areas with a certain structural complexity and some coral cover) and the other two thirds consisted of an extensive rhodolith bed with a few sponges, gorgonians and corals sparsely distributed. The West-East transect (Fig. 3), however consisted of 75% coral reef with 60% coral cover in some areas at 36 m depth. Only the most western part had sand or fine sediment (data not shown). No military debris was identified in any of the phototransects. A substantial amount of rubble and bare substrate could be seen at the southern part of the North-South transect.

At least 36 species of sponges and 17 species of corals were identified. The *Montastraea annularis* species complex, *M. cavernosa* and *Agaricia* spp. were the most common corals found. The most common sponges were *Amphimedon compressa, Aiolochroia crassa, Agelas* sp., *Aplysina* sp. The barrel sponge (*Xestospongia muta*) was also abundant.

Mean live coral cover at reefal sites was lower in the North-South transect (3-11%) than in the West-East transect (10-48%) (Figs. 2 and 3, respectively). In the North-South transect (Fig. 2), the non-reefal part of the transect was composed of a rhodolith bed (98% cover), hardly any macroalgae, some sparse sponges (2% cover) and corals (less than 1% cover). Gorgonian cover was quite low (6 % cover) at reefal sites, and was nearly zero in the non-reefal zone. Black coral cover was less than 1% in both transects.

The West-East transect (Fig. 3), shows remarkable high average mean coral cover at the end of the transect (48%) with an average of 25% live coral cover for the entire 4 km transect. Algae and bare substrate covered an average of 64% of the substrate. Sponges had an average cover of 9%, reaching 20% for the western part of the transect. Gorgonian cover however was less than 1% throughout the entire transect. The westernmost part of the transect consisted of large areas of sand/sediment accumulation.

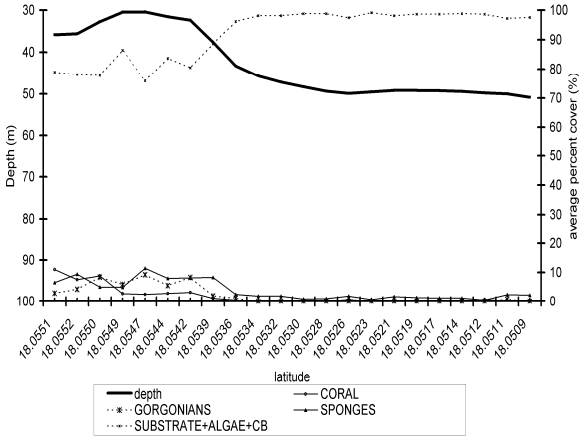

Figure 2. North-South transect average percent cover of each category (obtained every ten frames).

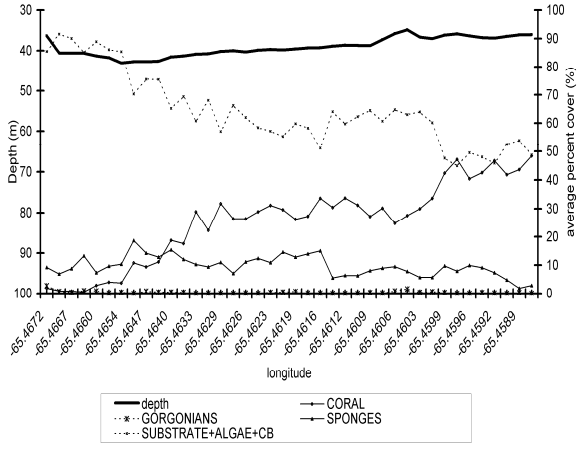

Figure 3. West-East transect average percent cover of each category (obtained every ten frames).

The relationship between coral cover and depth show a negative correlation for both transects (Fig.4, 5), indicating that coral cover decreases with increasing depth. The relationship (R^2) is stronger for the West-East transect (0.33 vs. 0.25).

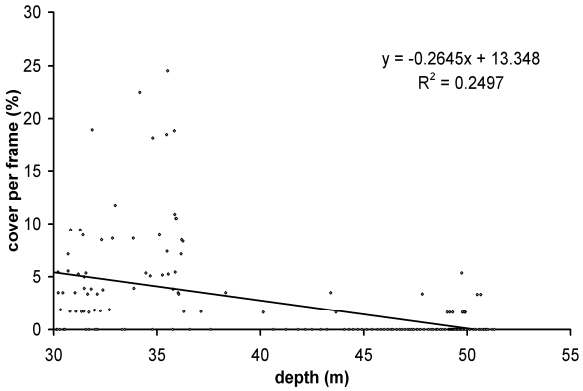

Figure 4. Live coral cover percentage per frame vs. depth in the North-South transect.

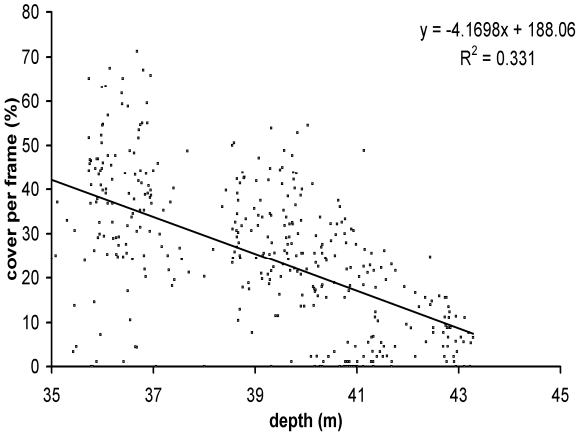

Figure 5. Live coral cover per frame vs. depth in West-East transect.

Profiles of temperature and salinity, which were measured every meter from the surface to 45m depth, ranged from 25.8-26.2 ºC, and 37-38.5 psu, respectively. The Ed PAR (downwelling irradiance) profile (Fig. 6) demonstrates the transparency of these waters with 10% of the surface Ed present at 39 m. The surface Ed is approximately 1500 $\mu W/cm^2/nm$. Satellite derived K490 show little variation from 2003 to 2008, with average values ranging from 0.03 to 0.04 m^{-1} (Fig. 8). Higher values were present in July 2006 (over 0.05 m^{-1}) whereas April 2007 had particularly low values at 0.02 m^{-1}.

Southern Vieques waters are very clear throughout the year although they become slightly more turbid during the rainy season (July to December). Gaps in June are due to high cloud cover in the satellite images.

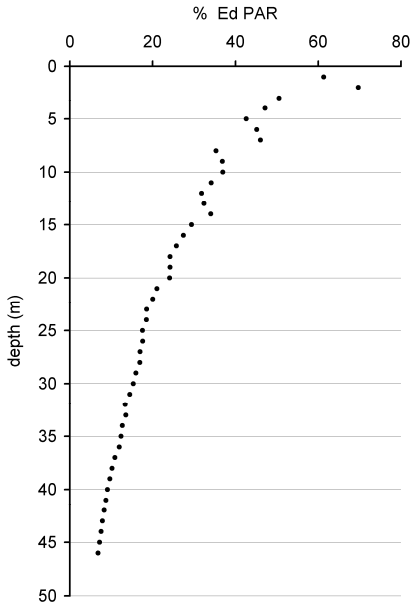

Figure 6. Light attenuation with depth. Percentage of Photosynthetically Available Radiation (PAR 400-700nm) per depth in South Vieques during April 2008.

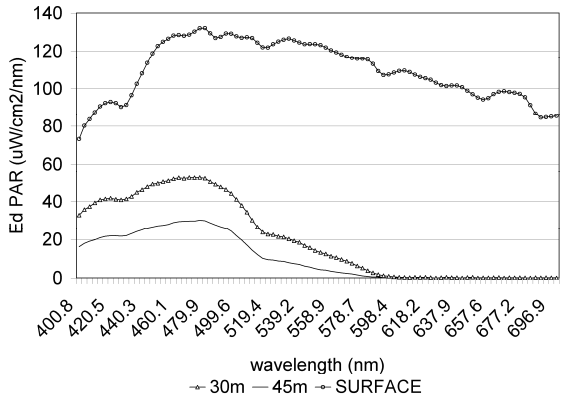

Figure 7. Downwelling PAR irradiance spectra at surface, 30 and 45 meters deep in South Vieques during April 2008.

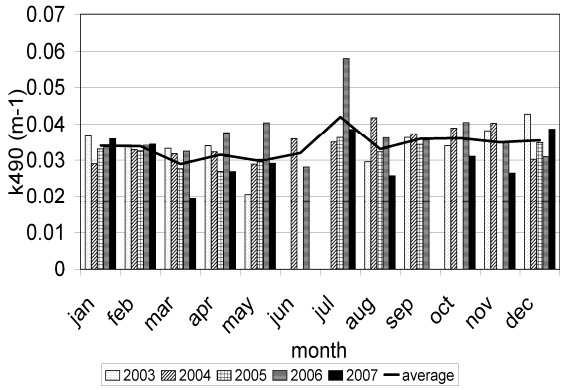

Figure 8. Temporal variation of light attenuation coefficient at 490 nm (K490). Average value per month per year from 2003-2008 calculated using MODIS Aqua data south of Vieques at 18.05N, 65.46W.

Discussion

The two AUV transects provided detailed information on benthic cover and geomorphology of a Vieques mesophotic coral reef complex. In most cases, the AUV imagery resolution was adequate to identify organisms to at least genus level if not species level, for both corals and sponges as well as other non-motile mega-invertebrates. These mesophotic reefs appear not to be as extensive as those described for the Hind Bank MCD (17 km east of Vieques) by Armstrong et al. (2006) with mean live coral cover of 32% as opposed to 43%, respectively. Coral cover values are similar to the 28.8% reported at Black Jack Reef by García-Saís et al. (2004). In all three cases, *Montastraea annularis* species complex dominated live coral cover.

Sponges were continuously present in both transects with an average cover of 7-9% and up to a maximum of 26.9% at the western part of West-East transect at a depth of 43 m. Average sponge cover values are similar but slightly higher than the 5.8% reported at Black Jack Reef by García-Saís et al. (2004) and 3.8% at the Hind Bank MCD (Armstrong et al. 2006). *Cliona* was not the dominant species as in the MCD where it accounted for 96% of the sponges found (Armstrong et al. 2006). The morphology of the most frequent sponges found was usually tube or rope-like, except for the massive *Xestospongia muta*, and a few encrusting or spherical-forms.

Gorgonians showed very low cover in both transects, similar to the Hind Bank MCD (Armstrong et al. 2006) and to what was reported at Black Jack Reef by García-Saís et al. (2004). Black corals were present in very low abundance (less than 1%) coinciding with García-Saís et al. (2004).

The distribution of live coral cover appeared to be related to the geomorphology and weakly related to depth. Coral cover was higher in areas of topographic relief. However, sponges were also present over unconsolidated sediments due to their faster growth rates. This pattern was more evident in West-East transect where the western side had an elevated dense coral reef (up to 50% live coral cover) whereas the eastern side accumulated sand and had sparse coral colonies and sponges.

Very low levels of coral disease or bleaching could be seen in the AUV images. This agrees with Armstrong et al. (2006) results from similar depths at the MCD.

Water quality, at least in terms of turbidity, does not appear to be a determinant factor at Black Jack Reef, contrary to what Deslarzes et al. (2006) suggested for Vieques reefs. This is to be expected since Black Jack Reef is deeper and farther from the coast. As in the MCD, most corals presented a plate

shape in response to the low-light environment at these depths. As in shallow water reefs, increases in light attenuation could serve as a precursor of change in mesophotic reefs, where incident irradiance levels could be near the lower limit for coral growth.

Since Black Jack Reef is outside the bombing range, military debris was not expected and was not observed in the AUV imagery. Additional transects within the bombing range will be required to ascertain the possible impact of past military activities in both shallow and deep reef areas.

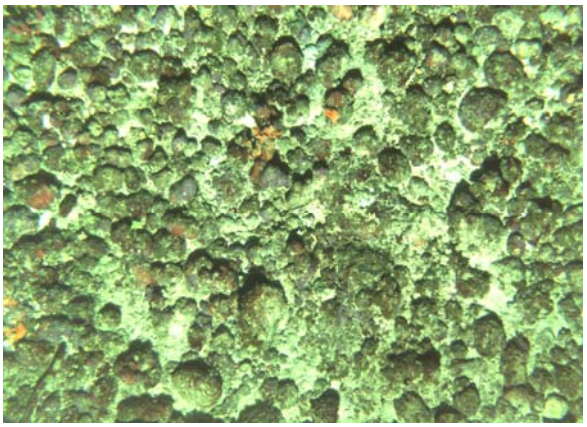

Figure 9. Rhodolith beds found at the end of the North-South transect.

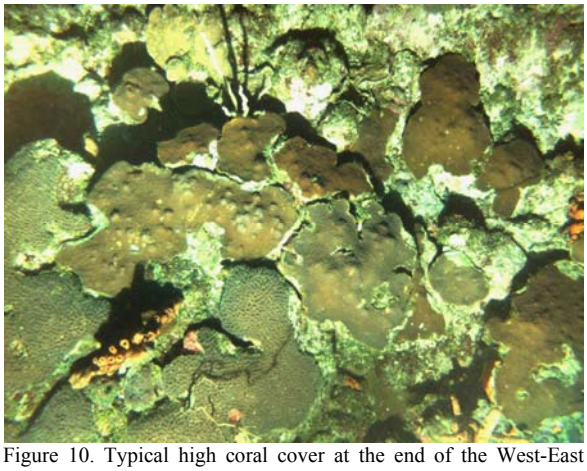

Figure 10. Typical high coral cover at the end of the West-East Transect.

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