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Monitoring coral reefs in optically-deep waters

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Abstract. Although remote sensing technology is a useful tool for monitoring shallow (<20 m depth) coral reefs present in clear oligothrophic waters, the large-scale assessment of reefs present in optically-deep waters requires other approaches such as the use of *in situ* platforms for high-resolution optical and acoustic imaging. Optically-deep waters are those where the upwelling radiance received by the airborne or satellite sensor originates from the water column without any bottom signal contribution. The Seabed autonomous underwater vehicle (AUV) is an ideal platform for mapping and characterizing mesophotic reefs, those present between 30 to about 100 m depth, and for shallow reefs in turbid areas. This AUV was utilized to acquire high-resolution digital images to characterize the geomorphology and dominant benthic components present along two long photo-transects in southwestern Puerto Rico. These quantitative AUV surveys also provide a baseline for future evaluation of change in the deeper coral reef zones, which for most areas of the world, remain largely unknown.

Key words: Mesophotic reefs, Seabed AUV, Puerto Rico, optically-deep waters

Introduction

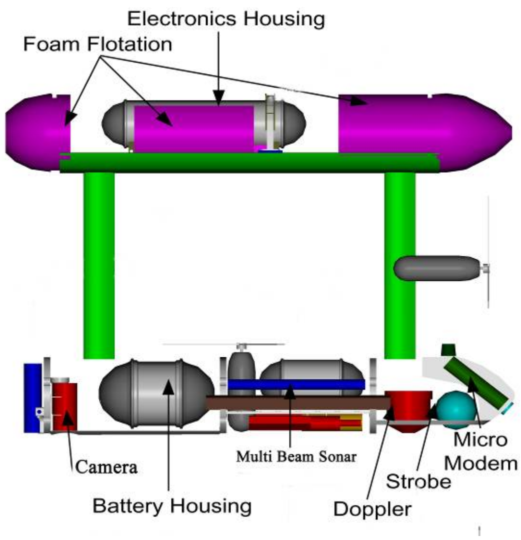
Coral reefs, one of the most productive and diverse of all ecosystems, are increasingly at risk due to anthropogenic effects and global climate change. Although the use of remote sensing from aircrafts and satellites has been successfully used for mapping and monitoring coral reefs, there are many limitations in the use of this technology. For instance, the spectral and spatial resolution of existing sensors, the confounding effects of variable water optical properties and bathymetry are significant obstacles for the implementation of this technology.

Other approaches such as *in situ* platforms and sensors are required for benthic habitat mapping in turbid or optically-deep waters (i.e. where the signal received by the airborne or satellite sensor originates from the water column without any bottom signal contribution). This is also the case for mesophotic coral reefs (30-100 m) present in clear but deep waters, where the exponential attenuation by the water column precludes the use of optical remote sensing. For quantitative assessments of these deeper reefs we have used the Seabed autonomous underwater vehicle (AUV), which was designed for high-resolution optical and acoustic imaging. As a leading instrument in this field, the Seabed AUV has been successfully deployed for characterizing deep coral reef zones in the US Virgin Islands (USVI) and Puerto Rico (Armstrong et al. 2002; Singh et al. 2004; Armstrong et al. 2006; Armstrong 2007). The digital photo transects obtained by the Seabed AUV in these studies provided quantitative data on living coral, sponge, gorgonian, and macroalgal cover as well as coral species richness and diversity. Previously undescribed, well-developed coral reefs with 43% mean living coral cover were found at depths of 40-47 m south of St. Thomas, USVI (Armstrong et al. 2006).

Five digital phototransects of the upper insular slope at La Parguera and Guánica, southwestern Puerto Rico, were obtained in 2004 by the Seabed AUV. Results from the first two AUV transects that have been analyzed are presented here as examples of the capabilities and limitations of this technology.

Methods

The Seabed AUV is a stable platform that can be configured with a wide range of sensors including digital cameras and multi-beam sonars (Fig. 1). The AUV primary mission is to characterize seafloor benthic habitat by providing high resolution, color imagery in areas of steep and rugged terrain in combination with bathymetric and other oceanographic sensors. The Seabed is the only hover capable AUV that is able to conduct linear transects or detailed surveys of specific areas while maintaining a constant distance from the bottom. A Pixelfly 1024 x 1280 pixel resolution CCD camera, with 12 bits of dynamic range, is the primary optical imaging sensor. More information on Seabed components, sensors, control systems, and navigation can be found in Singh et al. (2004).



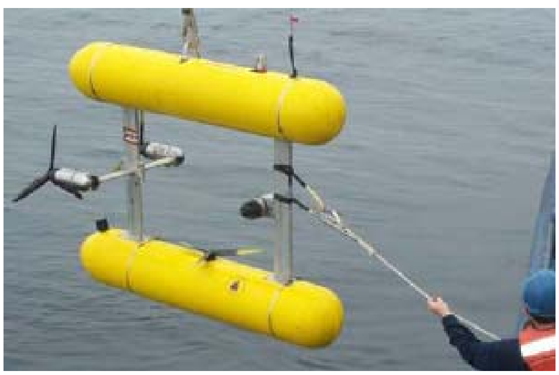


Figure 1. The Seabed AUV. Schematic diagram of the major components (top) and external view during deployment (bottom).

Seabed AUV high-resolution digital images, obtained in November 2004, were used to characterize the dominant components in two photo transects at La Parguera and Guánica, southwestern Puerto Rico. Each transect was approximately 400 m long and produced over 900 images, each measuring about 2.1 m wide by 2.0 m long. Every tenth image (n=90) along each transect were analyzed using 50 random points in the Coral Point Count with Excel extensions software (Kohler and Gill 2006). The dominant benthic categories were divided into: stony corals, gorgonians, sponges, algae/hardground, and unconsolidated sediments. The algae and hardground categories were combined since macro-algae and turf algae cover was extensive in hardground areas and the resolution of the images was inadequate for a more detailed analysis of these categories.

Results

Although the insular platform and shelf edge off La Parguera has the best developed reef system of the island, there is little information on the deeper reef zones in this area. The only published reports of the deep reef communities of La Parguera, to a depth of 125 m, revealed 25% coral cover at depths of 25-30 m but less than 2% coral cover at depths of 30-60 m (Armstrong et al. 2002; Singh et al. 2004).

The insular shelf in this area is 8-10 km wide with an average depth of 15-18 m from near shore to the shelf break (Morelock et al. 1977). The shelf edge has a buttressed-reef formation with channels that allow the movement of sand from the outer shelf to the upper insular slope, which descends at 43˚ in most places (Morelock et al. 1977). These authors report that there are no channels where the upper 30 to 40 m of the slope is vertical. The Parguera AUV transect started at 17°52.6’ N, 60°2.6’W at a depth of 20 m and ended at depth of 94 m (Fig. 2).

The insular shelf south of Guánica Bay, located approximately 13 km to the east of La Parguera, is approximately 3-4 km wide and has average depth of 12 m. Extending southeast across the insular slope there is a submarine canyon that shoals to 12 m at the entrance to Guánica Bay (Morelock et al. 1994). The Guánica AUV transect started at 17°55.5’ N, 66°52.3’W at a depth of 27 m and ended at a depth of approximately 130 meters (Fig. 3).

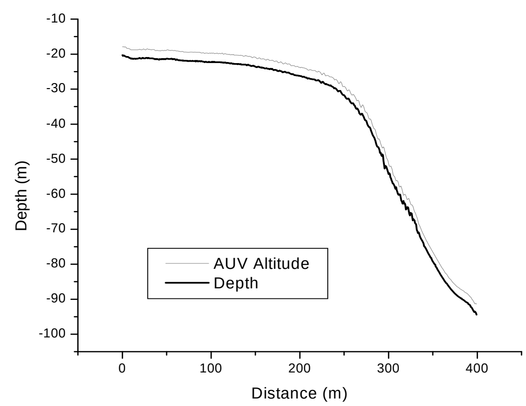


Figure 2. Depth profile and AUV altitude for La Parguera transect.

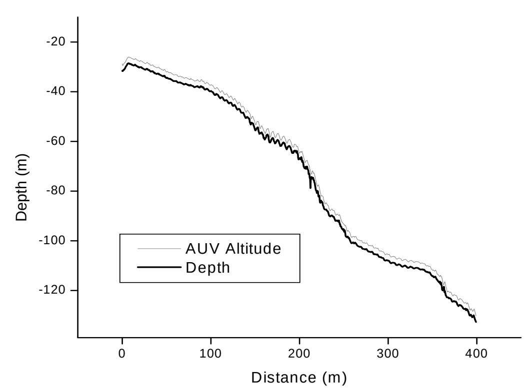


Figure 3. Depth profile and AUV altitude for the Guánica transect.

The La Parguera transect bathymetry reflects the geomorphology described by Morelock et al. (1977). The shelf-edge has a well-defined break from a gentle slope to one that is much steeper beyond the break, at a depth of approximately 30-40 meters (Fig. 2). The bathymetry at the Guánica transect (Fig. 3) is very different from the one observed in Parguera and can be described as a ramp. Ramps have no definite slope break and sediment facies grade evenly from sandier sediments associated with higher energy in shallower environments to muddier sediments in the low energy deeper water environment (Tucker et al. 1990). At both sites coral cover decreased with depth with the maximum percent cover of 7.8 and 4.0 for the Parguera and Guánica transects, respectively (Fig. 4). Notice that the 20-24 m depth interval was not present in Guánica and the 97-110 m depth zone was not sampled in La Parguera (Fig. 4, 6-9). The maximum coral cover in La Parguera was present at the shelf break, at a depth of 25-35 m and consisted of coral-sponge-gorgonian hardgrounds (Fig. 5a).

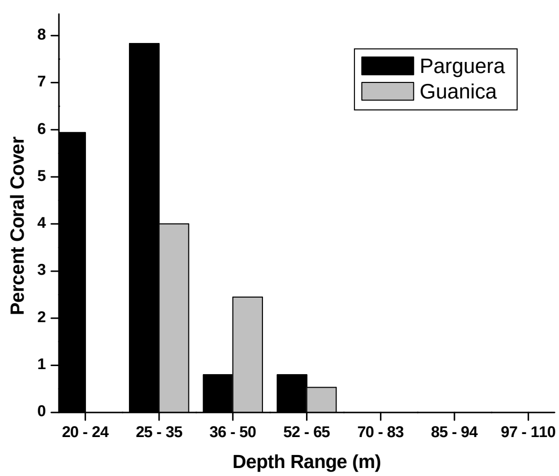


Figure 4. Percent coral cover by depth range for La Parguera and Guánica transects.

Similarly, the Guánica transect also lacked well-defined, structural coral reefs with hardgrounds also dominating the shallower geomorphology. Small isolated coral heads of the genus *Agaricia* were found to a depth of approximately 65 m in Guánica and to 87 m in La Parguera. Acevedo et al. (1989) reported that corals were present to a depth of 70 m in La Parguera.

The percent cover of gorgonians at all depths is more similar between the two transects with the highest values also present at the 25-35 m depth range (Fig. 6). After 65 m depth there is a noticeable decrease in gorgonian cover. Although sponge coverage was higher in La Parguera than in Guánica, dominance by sponges is apparent at both sites and

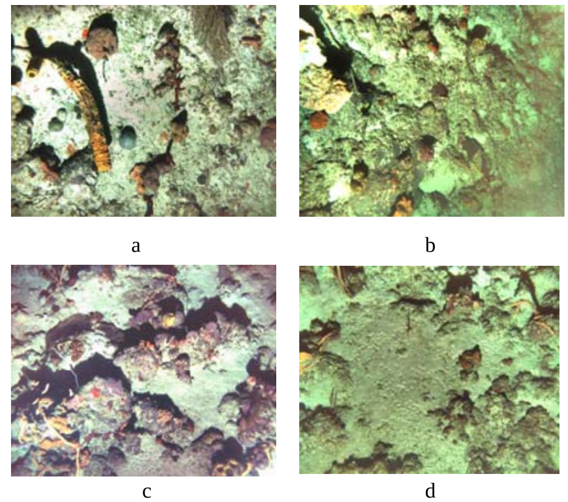


Figure 5. Hardground areas with isolated corals, sponges, and gorgonians dominated the two transects at the shallower to intermediate depths. AUV images from the La Parguera transect at 35 m (a), 67 m (b), 78 m (c), and 84 m (d) depths.

throughout all depths to 94 m (Fig. 7). Dominance by sponges, in the 30-100 m depth range, was also reported by Singh et al. (2004). Hardground areas with algae accounted for approximately 40% of the benthic cover in La Parguera and from about 40-70% in Guánica, both at depths less than 95-100 m (Fig. 8). The amount of unconsolidated sediment increased with depth, particularly at Guánica, where the highest amount of fine-grained sediments (96%) was found at the 97-110 m depth range (Fig. 9). A high degree of bioturbation at the deeper zones of both transects was evident from the AUV images (Fig. 5d).

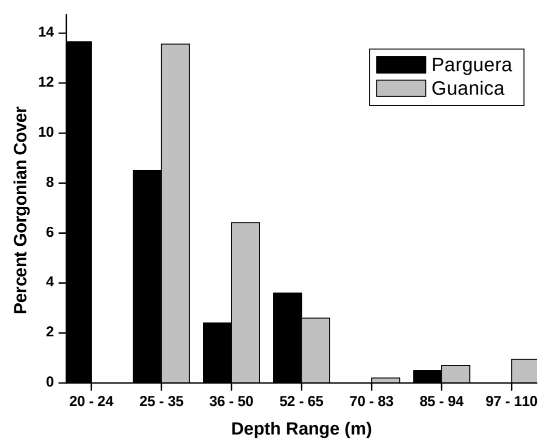


Figure 6. Percent gorgonian cover by depth range for La Parguera and Guánica transects.

Discussion

The high quality digital imagery provided by the Seabed AUV was used to describe and characterize the geomorphology and benthic habitats present to depths of 110 m in southwestern Puerto Rico. These quantitative, geolocated AUV surveys also provide a baseline for future evaluation of change in the deeper coral reef zones.

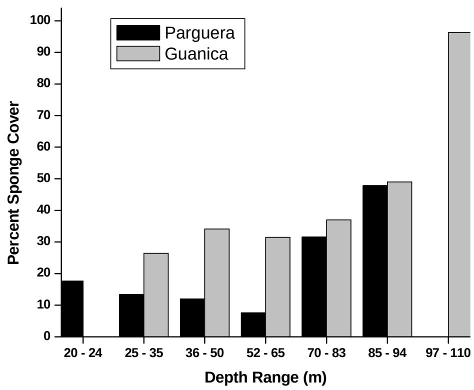


Figure 7. Percent sponge cover by depth range for both transects.

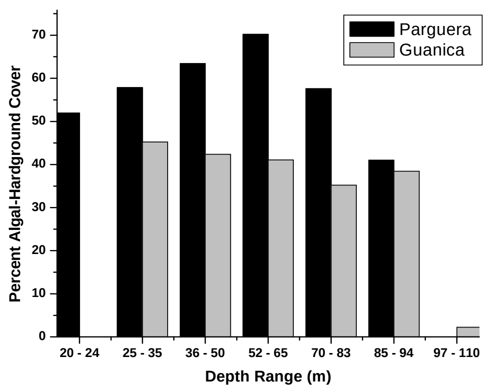


Figure 8. Percent algal-hardground cover by depth range for La Parguera and Guánica transects.

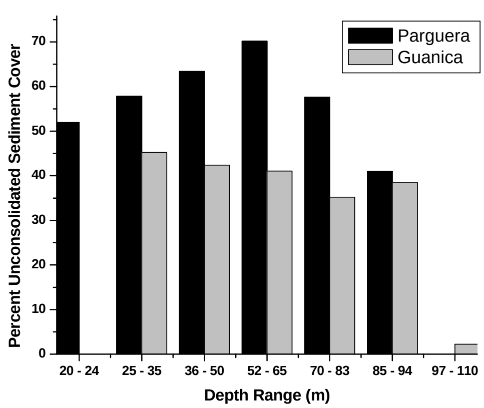


Figure 9. Percent unconsolidated sediment cover by depth range for La Parguera and Guánica transects.

Similar transects could also be used for large-scale mapping and monitoring of shallow (<20 m) reefs present in turbid insular shelf areas. In this case the AUV altitude from the substrate needs to be substantially reduced to minimize the light absorption of the water column allowing the capture of high contrast images. Besides benthic imaging, other sensors on the AUV such as fluorometers and turbidimeters can be used for monitoring changes in water quality parameters that are known to impact coral reef areas.

Reports on upper insular slope communities, from the shelf edge to 100 m depth, are scarce for the US Caribbean. Most of the research in this zone has been focused on fishery resources (Garcia-Sais 2005). The only published reports for Puerto Rico are from La Parguera, where coral cover was found to decrease from 24% at 25-30 m to less than 2% at 30-60 m (Armstrong et al. 2002; Singh et al. 2004). The results presented here from these two transects agree with the previous reports.

The depth limitations of conventional diving have left mesophotic reefs largely unexplored. Even though technical diving has extended the depth range of diving surveys, the large-scale assessments and monitoring of mesophotic reefs by divers remain impractical. The Seabed AUV has the distinct advantage of allowing frequent access to large areas of mesophotic reefs with an endurance of up to 8 hrs producing transects that could be several kilometers in length. In addition, data from Seabed AUV sensors and related imaging technologies can be used to conduct multi-beam sonar surveys, photo mosaicking, and multisensor fusion of acoustic and optical data.

Although the AUV uses a high resolution and dynamic range camera, the relatively high altitude of the vehicle from the bottom makes identification of certain algae, sponges, disease and other substrate types difficult. A comparison between the AUV and a diver-held video camera method showed similar percent cover values for scleractinian corals but increasing variation in other categories such as macroalgae, coralline algae, gorgonians, and sponges (Nemeth et al. 2009). The diver held video camera provided closer images which enhanced the ability to identify benthic organisms but greatly underestimated the percent cover of gorgonians (Nemeth et al. 2009). Also, detection of coral disease was most effective with direct visual assessment of individual coral colonies by divers.

The large-scale characterization and monitoring of coral reefs in optically-deep waters requires the use of *in situ* platforms equipped with optical and acoustic sensors. Optically-deep waters are present over large coastal areas of Puerto Rico where coral reefs are known to exist. Approximately 43% of the potential reef habitat within the Puerto Rico-USVI insular shelf and slope is found between 30-100 m. The Seabed AUV has proven to be ideally suited for mapping and monitoring mesophotic reefs, which for most areas of the world remain largely unknown.

Acknowledgments
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