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Airborne lidar sensing of massive stony coral colonies on patch reefs in the northern Florida reef tract

John C. Brock [a,*], C. Wayne Wright [b], Ilsa B. Kuffner [a], Raquel Hernandez [c], Philip Thompson [a]

[a] U.S. Geological Survey, 600 4th Street South, St. Petersburg, FL 33701, United States
[b] NASA Goddard Space Flight Center, Wallops Island Flight Facility, Wallops Island, VA 23337, United States
[c] National Coral Reef Institute, Nova Southeastern University, 8000 North Ocean Drive, Dania Beach, FL 33004, United States

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Abstract

In this study we examined the ability of the NASA Experimental Advanced Airborne Research Lidar (EAARL) to discriminate cluster zones of massive stony coral colonies on northern Florida reef tract (NFRT) patch reefs based on their topographic complexity (rugosity). Spatially dense EAARL laser submarine topographic soundings acquired in August 2002 were used to create a 1-m resolution digital rugosity map for adjacent NFRT study areas characterized by patch reefs (Region A) and diverse substratums (Region B). In both regions, sites with lidar-sensed rugosities above 1.2 were imaged by an along-track underwater videography system that incorporated the acquisition of instantaneous GPS positions. Subsequent manual interpretation of videotape segments was performed to identify substratum types that caused elevated lidar-sensed rugosity. Our study determined that massive coral colony formation, modified by subsequent physical and biological processes that breakdown patch reef framework, was the primary source of topographic complexity sensed by the EAARL in the NFRT. Sites recognized by lidar scanning to be topographically complex preferentially occurred around the margins of patch reefs, constituted a minor fraction of the reef system, and usually reflected the presence of massive coral colonies in cluster zones, or their derivatives created by mortality, bioerosion, and physical breakdown.

Keywords: Coral reefs; Remote sensing; Lidar; Videography

1. Introduction

The Florida Keys extends over 360 km from just south of Miami to the Dry Tortugas, and protects the broad offshore carbonate platform from inshore bay waters that fluctuate in temperature, salinity, and turbidity (Ginsburg & Shinn, 1964). Variation in the geographic continuity of these Pleistocene limestone islands has controlled Holocene reef development in the Florida reef tract (FRT) by creating three regions of differing long-term water quality, the Upper, Middle, and Lower Keys. Shelfal patch reefs and bank-barrier reefs are most abundant in the Upper Keys, and secondarily in the Lower Keys, seaward of continuous island complexes (Ginsburg & Shinn, 1994). In contrast, limited Holocene reef development off the Middle Keys, cut by broad tidal channels, is attributed to the influx of lagoonal waters from Florida Bay, and the mobility of bottom sands (Ginsburg et al., 2001; Ginsburg & Shinn, 1994; Halley et al., 1997). The northern Florida reef tract (NFRT), off the Upper Keys where reef development is most extensive, is separated from Barnes Sound, Card Sound, and Biscayne Bay by Key Largo and Elliot Key, and is frequently bathed by the Florida Current. Tidal and wind-driven exchange with Biscayne Bay through the Safety Valve, a wide pass just north of Elliott Key and the Ragged Keys, sets the northern limit of the FRT (Ginsburg et al., 2001; Marszalek et al., 1977; Shinn, 1988).

Nearly 4000 of the roughly 6000 patch reefs found in the FRT are concentrated off Elliot Key in 1 to 12 m water depth amid bare sand and seagrass meadows on the 5 to 10 km wide carbonate platform between Hawk Channel and the shelf-margin bank-barrier reefs (Marszalek et al., 1977; Shinn et al., 1989). These patch reefs typically have vertical relief and breadth ranging from 5 m to 100 m, respectively, and based on

* Corresponding author.
E-mail address: jbrock@usgs.gov (J.C. Brock).

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core-sampling, were built by large massive stony corals over roughly the last 6000 years (Shinn et al., 1989).

Although FRT coral cover has declined in general over the last several decades (Jaap et al., 2001), coral cover on NFRT patch reefs has consistently been found to be among the highest observed in the FRT (Burns, 1985; Chiappone, 1996; Chiappone & Sullivan, 1997; Jaap, 1984; Miller et al., 2002). Recent surveys of these reefs found mean stony and mean octocoral cover in excess of 8% and 35%, respectively, have recorded the greatest coral species richness presently found in the FRT, and have documented particularly high gorgonian species diversity (Miller et al., 2002; Moulding & Patterson, 2002).

The maturation–senescence cycle (Jones, 1977) and the physical disturbance by storms (Lirman & Fong, 1995, 1997) of these patch reefs create an associated internal zonation (Ginsburg et al., 2001). Well developed composite NFRT patch reefs are typically divided into a “cluster zone” composed of one or more giant massive coral colonies, a “campus zone” with massive corals scattered among abundant octocorals, and in some cases, a zone dominated by coral rubble and skeletal sands (Ginsburg et al., 2001).

1.1. Objectives

Topographic complexity, or rugosity, is an element of habitat complexity, and is a fundamental ecological factor on coral reefs that is relevant to species diversity and richness, herbivore shelter, predation, recruitment, metabolic processes, hydrodynamics, and nutrient fluxes (McCormick, 1994; Sale, 1991; Sebens, 1991; Szmant, 1997). NFRT patch reef internal heterogeneity and zonation are likely to be reflected by the spatial pattern of topographic complexity, because the cluster and campus zones represent two different size populations and spatial densities of predominately 9 species of massive stony corals (Ginsburg et al., 2001).

The NASA Experimental Advanced Airborne Research Lidar (EAARL) is a temporal waveform-resolving, blue-green wavelength lidar (light detection and ranging) designed to measure the sub-meter scale topography of shallow reef substratums (Wright & Brock, 2002). Recently, we demonstrated that this airborne laser altimeter is capable of detecting overall rugosity differences between NFRT bank-barrier reefs and patch reefs (Brock et al., 2004). The objectives of this paper are to:

(1) evaluate the capability of the NASA EAARL lidar to discriminate cluster zones of stony coral colonies on NFRT patch reefs, and
(2) identify other NFRT substratums that also display high topographic complexity as sensed by the NASA EAARL airborne blue-green laser altimeter.

2. Materials and methods

The study area is located in the NFRT within Biscayne National Park, on White Bank, the inner ridge of the platform seaward of Hawk Channel, and landward of Ajax Reef, an elongated bank-barrier shoal mainly composed of coral rubble and skeletal sand (Halley & McPherson, 1997) (Fig. 1). The broad shelf that hosts the study area is covered by *Thalassia testudinum* seagrass meadows and bare calcareous sand regions, and is studded by numerous patch reefs, transitional reefs, and hardground communities (Jaap, 1984; Jones, 1963). Although quite numerous, patch reefs on White Bank appear to survive under marginal environmental conditions, and typically occur in 2 to 9 m base water depth as roughly circular domes. These patch reefs have internal topographic relief up to 3 m, and range from several meters to over 700 m in diameter (Jaap, 1984). The upper surfaces of these reefs may be close to emergent at low tide, and support various stony corals, notably *Montastraea annularis*, *M. faveolata, M. cavernosa*, *Porites porites*, *P. astreoides*, *Siderastrea radians*, *S. siderea*, *Diploria clivosa*, and *Acropora cervicornis*. *Acropora palmata* is lacking on these patch reefs, but octocorals are abundant, many octocoral skeletons are covered with the hydrozoan *Millepora alcicornis*, and *M. complanata* is common (Jaap, 1984; Jones, 1963).

4. Conclusions

Nearly 4000 patch reefs occur off Elliot Key in the northern Florida reef tract (NFRT), creating topographic variability across a 10 km wide carbonate platform. The resulting topographic complexity, or rugosity, ranges from centimeters to kilometers in spatial scale, and either influences or reflects many ecological variables, including community composition, herbivory, predation, metabolic processes, hydrodynamics, and nutrient fluxes. The NASA Experimental Advanced Airborne Research Lidar (EAARL) was designed to measure the sub-meter scale topography of shallow reef substratums. This study evaluated the capability of the NASA EAARL lidar to discriminate cluster zones of massive stony coral colonies on NFRT patch reefs, and identified other NFRT substratums that also display high topographic complexity as sensed by the EAARL.

Using dense EAARL laser submarine topographic soundings, a 1-m resolution digital substratum rugosity map was created for 2 adjacent NFRT study areas, a region studded with patch reefs on a seagrass meadow (A), and a larger region with diverse substratums (B). The results obtained for both regions support the hypothesis that massive coral colony formation, modified by subsequent by physical and biological processes that breakdown patch reef framework, is the primary source of NFRT topographic complexity. Sites with lidar-sensed rugosity above 1.2 comprised only a minor fraction of the total area on the NFRT platform, and nearly always occurred about the margins of patch reefs (Fig. 9). Elevated substratum rugosity in both regions mostly reflected the presence of massive coral colonies in cluster zones, or their derivatives created by mortality, degradation, physical breakdown, and secondary overgrowth. In both regions combined, rubble and hardground substratums derived from massive coral colony cluster-zones, combined with parent cluster zone live or dead colonies, accounted for 79% of the HLR videography sites. More specifically, in the heterogeneous Region B, these substratum types accounted for all but 1% of the HLR substratums recognizable on the along-track video images. Thus, the along-track videography and lidar methodology examined here show great promise for identifying, mapping, and perhaps even the monitoring of massive coral colony clusters and derivative high rugosity substratum.