Characterizing Coral Condition Using Estimates of Three-dimensional Colony Surface Area

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Abstract Coral reefs provide shoreline protection, biological diversity, fishery harvests, and tourism, all values that stem from the physically-complex coral infrastructure. Stony corals (scleractinians) construct and maintain the reef through deposition of calcium carbonate. Therefore, assessment of coral reefs requires at least some measurement endpoints that reflect the biological and physical condition of stony corals. Most monitoring programs portray coral quantity as live coral cover, which is the two-dimensional proportion of coral surface to sea floor viewed from above (planar view). The absence of the third dimension, however, limits our ability to characterize coral reef value, physiology, health and sustainability. A three-dimensional (3D) approach more realistically characterizes coral structure available as community habitat and, when combined with estimates of live coral tissue, quantifies the amount of living coral available for photosynthesis, growth and reproduction. A rapid coral survey procedure that coupled 3D coral quantification with more traditional survey measurements was developed and tested in the field. The survey procedure relied on only three underwater observations – species identification, colony size, and proportion of live tissue – made on each colony in the transect. These observations generated a variety of metrics, including several based on 3D colony surface area, that are relevant to reef management.

Keywords Coral colony surface area · Coral condition assessment · Coral monitoring · Coral mortality · Coral reef topographic complexity · Coral three-dimensional surface area · Coral size · Florida Keys

1 Introduction

Coral reefs provide valuable ecosystem services and functions, much of which can be attributed to the reef-building scleractinian (stony) corals. Stony corals are key reef organisms because of high primary productivity and because their complex skeletal structure provides habitat for the high numbers and diversity of marine organisms that support fisheries and tourism (Crossland et al. 1991; Done et al. 1996; Hoegh-Guldberg 1999; Muscatine 1980, 1990; Reaka-Kudla
Coral structures also protect coastal shorelines from wave and current erosion (Costanza et al. 1997; Pernetta 1992). The health, growth and recruitment of stony corals are thus crucial to reef sustainability and future benefits. Yet, coral reefs in Florida and the Caribbean basin have experienced unprecedented levels of bleaching, disease and mortality during the last three decades (Gardner et al. 2003; Jaap et al. 2000; Kramer 2003; Wheaton et al. 2001). Various stressors have led directly or interactively to this decline, and may be linked to global changes in climate, land use or human activities in coastal areas (Atwood et al. 1992; Hoegh-Guldberg 1999). The ultimate consequences of continued stress to corals are diminished growth, loss of coral tissue, overgrowth by macro-algae, and eventual disintegration of calcified coral skeleton. Loss of coral and coral skeleton diminishes the substantial economic and ecological benefits of coral reefs.

Assessment of coral reefs must, at a minimum, provide relevant information on the cumulative consequences of biological and environmental factors on survival, growth and reproduction of stony corals. Described here is a rapid survey procedure for evaluating stony coral condition using estimates of three-dimensional (3D) colony surface area to characterize (1) coral value, particularly the quantity of coral skeleton available for community habitat; (2) coral health, including direct comparison of live and dead coral tissue; and (3) reef and population sustainability, particularly the quantity of live coral available for growth and reproduction. The measurements reflect stony coral status only, and do not indicate any aspect of exposure, vulnerability or risk. However, status measurements over time or space can document changes in coral reef quantity and health, and can be used to evaluate reef decline, resilience and effectiveness of management actions. When combined with measures of exposure (e.g., water quality, disease, human visitation), status measurements can provide information essential to risk and sustainability assessments of coral reef resources.

Although measurement of coral quantity is essential to assessing reef value and sustainability, quantifying corals is not simple. Current monitoring programs estimate live coral coverage, a two-dimensional (2D) planar projection of coral colonies covering the sea floor as viewed from above (Brown et al. 2004; Jaap et al. 2000; Lang 2003; Wheaton et al. 2001). This approach does not account for coral height, which is a component of topographic complexity and essential to flourishing reef communities (Dahl 1973; Ferreira et al. 2001; B. E. Luckhurst and K. Luckhurst 1978; Roberts and Ormond 1987; Scheffers et al. 2003). To better capture topographic complexity, some programs measure height of colonies and some measure a 2D contour (sometimes called ‘rugosity’), which is calculated as the ratio of lengths between a chain draped over coral colonies and a taut chain (Aronson et al. 1994; Jokiel et al. 2004; Lang 2003; B. E. Luckhurst and K. Luckhurst 1978; McCormick 1994; Porter 1972; Risk 1972; Rogers et al. 1994). In one study, a ‘profile gauge’ was used to determine height of corals from a constant reference point (McCormick 1994).

A rigorous quantification of coral should incorporate three dimensions (Alcala and Vogt 1997; Dahl 1973). Two measurements capable of 3D quantification are coral volume and 3D surface area. Surface area is more relevant to resource management because it quantifies the area available as community habitat. Also, 3D surface area quantifies live coral biomass – a large proportion of coral volume is the non-living skeletal core. Biomass is used to characterize a variety of physiological aspects of living corals, including photosynthesis, metabolism, calcification of skeleton (calcium carbonate deposition), and growth rates. Most procedures that estimate 3D surface area have been developed for laboratory studies (e.g., Ben-Zion et al. 1991; Hoegh-Guldberg 1988; Hughes and Jackson 1985; Marsh 1970; Meyers and Schultz 1985; Stimson and Kinzie 1991; Tanner 1995). Yet, the laboratory methods are time-consuming, destructive, and inappropriate for rapid underwater surveys.

A few studies have shown that 3D coral surface areas could be derived from field measurements (Alcala and Vogt 1997; Babcock 1991; Bak and Meesters 1998; Bythell et al. 2001; Cocito et al. 2003; Roberts and Ormond 1987; Szmant-Froelich 1985). In some, geometric shapes were assigned to colonies of different morphological types (e.g., hemisphere for massive colonies) and 3D colony surface areas were calculated from 1D or 2D morphological measurements made in the field. Alcala and Vogt (1997) showed that colony types were 2–6 times greater in 3D surface area compared