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Using bathymetric lidar to define nearshore benthic habitat complexity: Implications for management of reef fish assemblages in Hawaii

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ABSTRACT

Habitat complexity plays a major role in determining the distribution and structure of fish assemblages in the aquatic environment. These locations are critical for ecosystem function and have significant implications for conservation and management. In this study, we evaluated the utility of remotely sensed lidar (light detection and ranging) data for deriving substrate rugosity (a measure of habitat complexity) on a coral reef in Hawaii. We also assessed the potential application of lidar data for examining the relationship between habitat complexity and Hawaiian reef fish assemblage characteristics. Lidar-derived rugosity (4 m grid size) was found to be highly correlated with *in-situ* rugosity and was concluded to be a viable method for measuring rugosity in analogous coral reef environments. We established that lidar-derived rugosity was a good predictor of fish biomass and demonstrated a strong relationship with several fish assemblage metrics in hard bottom habitat at multiple spatial resolutions. This research demonstrates (i) the efficacy of lidar data to provide substrate rugosity measures at scales commensurate with the resources and their environment (ii) the applicability of lidar-derived rugosity for examining fish–habitat relationships on a coral reef in Hawaii and (iii) the potential of lidar to provide information about the seascape structure that can ultimately be used to prioritize areas for conservation and management.

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1. Introduction

Habitat complexity in the coastal environment plays an important role in structuring nearshore fish assemblages. The relationship between habitat complexity and measures of community structure was first observed in the terrestrial realm (August, 1983; MacArthur & MacArthur, 1961; Murdoch et al., 1972; Rosenzweig & Winakur, 1969). A similar relationship between habitat complexity and fish assemblage characteristics has been well documented in both freshwater (Gorman & Karr, 1978) and marine ecosystems (Caley & St John, 1996; Friedlander & Parrish, 1998; Gratwicke & Speight, 2005; Luckhurst & Luckhurst, 1978; Risk, 1972; Roberts & Ormond, 1987).

Structural complexity, a major component of habitat complexity, can be defined as the architecture of the physical environment (McCoy & Bell, 1991; Sebens, 1991). Structurally complex habitats offer more potential niches and increase survivorship by providing fish additional refuge from predation (Almany, 2004; Beukers & Jones, 1998; Hixon & Beets, 1989). Accordingly, areas of high structural complexity harbor high species richness (Gratwicke & Speight, 2005), species diversity (Almany, 2004) and fish biomass (Friedlander & Parrish, 1998).

There are a number of habitat complexity variables that can be measured *in-situ* (reviewed in McCormick, 1994), and rugosity is the most commonly used *in-situ* measure. For the purposes of this study, rugosity, or vertical relief, was used to represent a measure of structural complexity. The chain transect method measures *in-situ* rugosity by obtaining the ratio of the length of a chain laid across the bottom profile along a transect line to the linear distance of the transect line (Friedlander & Parrish, 1998; Luckhurst & Luckhurst, 1978; Risk, 1972). A limitation of the traditional chain transect method is the restriction of the structural complexity measurements to relatively fine spatial scales. Additionally, field measurements are time-consuming, can have high inter-observer variability, and are difficult to obtain over a broad geographic area.

Considering the documented importance of the relationship between rugosity and fish assemblage structure, it is critical to develop faster methods of determining rugosity in the marine environment at broader geographic extents. The current expansion and wide application of remote sensing technology on coral reef ecosystems were recently reviewed (Mumby et al., 2004). Lidar (Light detection and ranging) is an active remote sensor that allows for spatial analysis of structurally complex habitats (Lefsky et al., 2002).

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Lidar has recently been applied to map coral reef structure (Storlazzi et al., 2003), and to measure reef rugosity (Brock et al., 2004, 2006). Lidar can provide measurements that may be scaled to allow for extraction of information at spatial extents that are more appropriate for coral reef ecosystems and related management actions. Applying remote sensing techniques that can rapidly identify structurally complex habitat may greatly assist resource managers in locating areas that are important to protect and sustain nearshore fish populations.

The goals of this study were (1) to determine whether lidar technology can provide effective rugosity measures on a coral reef in Hawaii and (2) to examine the relationship between reef fish assemblage characteristics and lidar-derived rugosity.

2. Data and methods

2.1. Study area

The study area is located in the Hanauma Bay Marine Life Conservation District (MLCD) on the south shore of the island of Oahu, in the Hawaiian Archipelago (Fig. 1). Hanauma Bay MLCD was designated as the first "no-take" marine protected area (MPA) in Hawaii in 1967 and encompasses approximately 41 ha. This area receives over one million visitors per year and is the most visited MPA in the world (Friedlander et al., in review). The bay was formed by the collapse of two volcanic craters, with the seaward opening of the bay most likely the result of wave erosion. There are extensive coral reef and sandy-bottom habitats throughout the MPA, providing a wide range of structural complexity and habitat types. Hanauma Bay represents a unique location to examine the relationship between a relatively intact fish assemblage and its associated habitat because fishing has been prohibited at this site for approximately forty years.

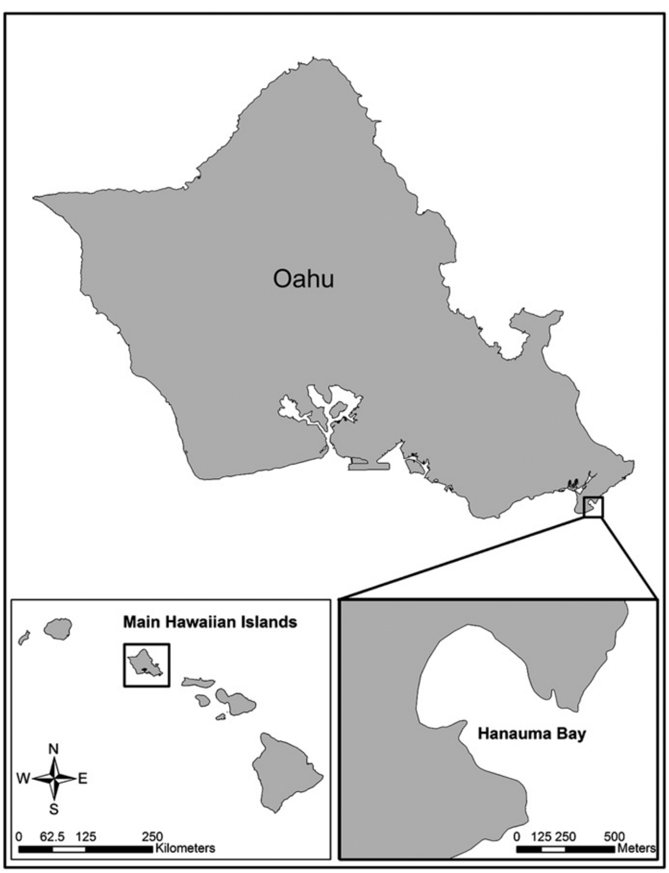

Fig. 1. Location of the study area, Hanauma Bay Marine Life Conservation District on the island of Oahu. Hanauma Bay was the first "no-take" marine protected area in Hawaii designated in 1967, and encompasses approximately 41 ha.

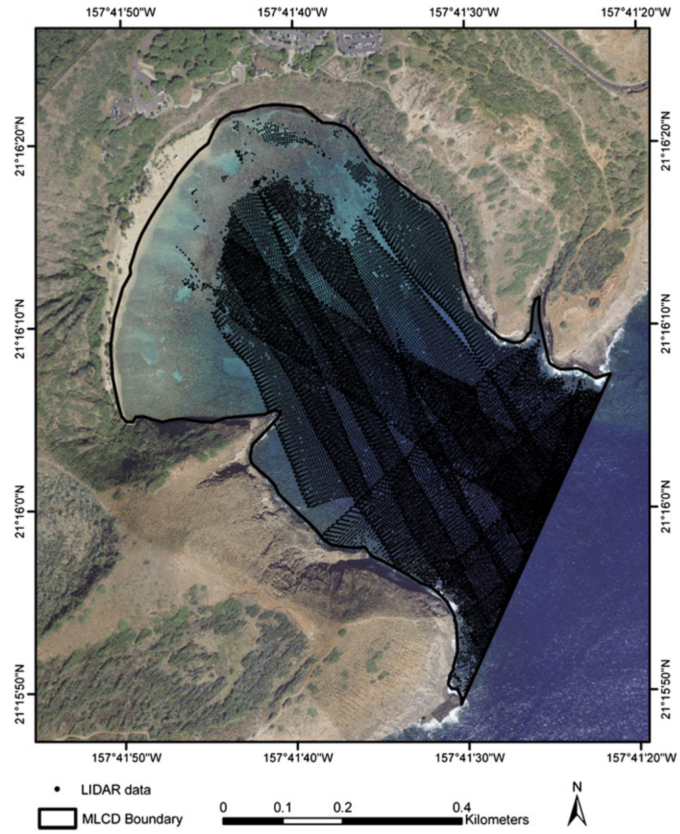

Fig. 2. U.S. Army Corps of Engineers SHOALS lidar data for Hanauma Bay Marine Life Conservation District (MLCD). MLCD boundary is denoted by the bold black line.

2.2. Lidar data

The U.S. Army Corps of Engineers SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system is an airborne lidar bathymeter utilized to remotely collect topographic and bathymetric measurements using infrared (1064 nm) and blue-green (532 nm) scanning laser pulses. SHOALS typically operates at an altitude of 200 m allowing for a horizontal spot density of 4 m with a vertical accuracy of ±20 cm and a horizontal accuracy of ±1.5 m (Irish & Lillycrop, 1999). The minimum depth detection for the SHOALS sensor is typically less than 1 m, with a maximum depth detection of approximately 40 m in locations with optimal water clarity. The SHOALS lidar sensor accuracy and system performance capabilities have been summarized in detail by several authors (Guenther et al., 2000; Irish & Lillycrop, 1999; Irish & White, 1998).

SHOALS lidar data was collected in Hawaii between 1999 and 2000. A total of 38,743 lidar depth measurements were collected at the study site, but did not cover the entire bay. The shallow, nearshore areas with depths of 0.0–1.5 m and portions of the reef crest had data gaps, most likely due to the SHOALS sensor performance limitations in shallow water, where wave action and turbidity might have been present during data collection (Fig. 2).

2.3. Fish assemblage data

Field surveys were conducted at 33 transects in Hanauma Bay during May 2004 using a stratified random sampling design. The habitat strata [sand (UCS), colonized (CHB) and uncolonized hard bottom habitats (UCH)] were based on NOAA's Biogeography Branch benthic habitat maps (Table 1, Fig. 3) (Coyne et al., 2003). This

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