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# Displacement effects of heavy human use on coral reef predators within the Molokini Marine Life Conservation District

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## ABSTRACT

The impact of marine ecotourism on reef predators is poorly understood and there is growing concern that overcrowding in Marine Protected Areas (MPAs) may disturb the species that these areas were established to protect. To improve our understanding of this issue, we used acoustic telemetry to examine the relationship between human activity at the Molokini Marine Life Conservation District (MLCD) and the habitat use of five reef-associated predators (*Caranx melampygus*, *Caranx ignobilis*, *Triaenodon obesus*, *Carcharhinus amblyrhynchos*, and *Aprion virscens*). During peak hours of human use, there was a negative relationship ($R^2 = 0.77, P < 0.001$) between the presence of bluefin trevally (*Caranx melampygus*) and vessels in subzone A. No other species showed strong evidence of this relationship. However, our results suggest that during this time, the natural ecosystem function that the reserve was established to protect may be compromised and overcrowding should be considered when managing MPAs.

## 1. Introduction

In recent decades, predators have experienced dramatic declines across the world's oceans (Jackson et al., 2001; Friedlander and DeMartini, 2002; Dulvy et al., 2004; Myers and Worm, 2005; Sandin et al., 2008; Codarin et al., 2009). In response to these declines Marine Protected Areas (MPAs) have been promoted as an effective management tool to improve the conservation of fish populations (Russ et al., 2004; Rice et al., 2012; Russ et al., 2015). Numerous studies have documented an increase in both abundance and size of fishes, particularly large predators inside MPAs (McClanahan et al., 2007; García-Rubies et al., 2013). The increase in biomass and diversity of fishes inside MPAs provides a major attraction to the marine tourism industry and the popularity of marine ecotourism (e.g., snorkeling, SCUBA, and boating) within MPAs has increased tremendously in recent years (Garrod and Wilson, 2003; Needham et al., 2011). Marine ecotourism promotes non-consumptive resource use and stimulates local economic enterprises. However, this industry can have negative effects on the socio-ecological ecosystem, including damage to the marine environment and displacement of fisheries (Milazzo et al., 2002; Jentoft et al., 2007; Meyer and Holland, 2008; Charles and Wilson, 2009). Furthermore, the social perception of overcrowding in MPAs is common in the marine ecotourism industry (Bell et al., 2011); however, little information exists on the potential effects of overcrowding on the behavior of marine fishes. Correspondingly, management strategies for non-consumptive recreational activities in MPAs are deficient (Davis and Tisdell, 1995; Harriott et al., 1997; Needham and Szuster, 2011; Thurstan et al., 2012).

In Hawaii, the Marine Life Conservation District (MLCD) program was established in 1967 to conserve and replenish Hawaii's marine resources for the purpose of education and human enjoyment (DAR, 1992). The program has been successful in maintaining high biomass and diversity of fish assemblages within their management boundaries (Friedlander et al., 2003; Friedlander et al., 2007a; Friedlander et al., 2007b). Today, there are 11 MLCDs in the main Hawaiian Islands (MHI) and these locations have some of the most intact populations of reef predators in the region. Friedlander et al. (2007a, 2007b) found that there was a greater abundance (62%) and biomass (52%) of predators inside Hawaii's MLCDs when compared to adjacent outside areas. These predators and the abundant fish life within the MLCDs are a significant

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attraction for Hawaii's marine tourism industry, which is valued at $ 700 million USD per year (Cesar and Van Beukering, 2004). The Molokini Shoals MLCD was established in 1977 and is the second most visited MPA in the state. Currently, there are 40 commercial vessels permitted to operate snorkel and dive tours to the Molokini MLCD and the annual economic benefit of these recreational activities is estimated at $ 20 million USD (Needham and Szuster, 2011). Over the past decade, the number of visitors to the MLCD has been steadily increasing and in 2015, a total of 334,036 people visited the MLCD. The increasing popularity of recreational activities in Hawaii's MLCDs and other MPAs poses the question, is there a relationship between the intensity of anthropogenic use in an ecosystem and the presence of reef predators?

Several studies have documented negative behavioral effects on marine fishes in response to anthropogenic noise (Sarà et al., 2007; Popper and Hastings, 2009; Holles et al., 2013; Voellmy et al., 2014). However, these studies have primarily been conducted on less mobile juvenile fishes or in caged environments, while field experiments in natural settings are deficient. Furthermore, published field research on this subject suffers from the inability to precisely measure human activities at the study sites and often relies on environmental variables that correlate with human activities, such as wind speed to measure the intensity of anthropogenic use in an ecosystem (Chateau and Wantiez, 2008). Direct measures of human activities such as vessel abundance and noise can provide a more accurate reflection of human disturbance on animals. In this study, we examined vessel noise and commercial tour boat logbooks (two measurements of human activities) to relate the presence of humans to the behavior and movement of predatory fishes inside the Molokini MLCD, based on observations from an acoustic telemetry array. Our objectives were to: (1) determine the species of predators that overlap with human use in the MLCD, (2) examine commercial tour operator logbook data to determine if vessel activity patterns correlate with anthropogenic noise in the MLCD, and (3) determine whether predators are displaced from important habitats in the MLCD at varying intensities of anthropogenic use.

## 2. Methods

### 2.1. Study site

Molokini is a small (31 ha) crescent shaped volcanic islet located in the Alalakeiki Channel between the islands of Maui and Kahoolawe (Friedlander et al., 2006). The inside of Molokini's crater is characterized by a shallow coral reef (< 30 m) protected from major ocean swells, while the backside of the islet forms a steep vertical wall that descends to approximately 100 m. The Molokini MLCD is comprised of two management zones, subzone A and subzone B (Fig. 1). Subzone A includes the inside of the crater bounded by a line extending from the end of the submerged coral ridge on the west side of the crater to the east side of the crater. The harvest of marine life is prohibited in subzone A, with most of the boating and recreational activities occurring in this subzone. To accommodate visitation of the MLCD, the State of Hawaii maintains 26 day use mooring buoys inside subzone A that are used by commercial tour vessels on a daily basis. Subzone B extends ~91 m (100 yards) seaward of subzone A and encompasses the entire perimeter of the islet, and only fishing using trolling gear is allowed in subzone B (DAR, 1981).

### 2.2. Acoustic array design

A VR2W passive acoustic monitoring array was used to track the movements of tagged predators at the Molokini MLCD from November 14th, 2013 to August 28th, 2015. Seven VR2W acoustic receivers (308 mm long × 73 mm diameter, Vemco, Halifax, Nova Scotia) were deployed in strategic locations that enabled the observation of fish movements within the MLCD. In locations with sandy substrate, the VR2W receivers were secured to the bottom with sand screws (2 m long × 10 cm diameter) and attached to a 2-m section of 2 cm diameter polypropylene rope suspended by a small crab float (35 cm long × 15 cm diameter). At receiver sites where the substrate consisted of hard rock, the moorings were secured to the bottom by passing a section of 6 mm stainless steel wire rope covered by hydraulic hose, through a natural benthic feature and fastened with two stainless steel wire crimps. Three receivers were stationed inside subzone A and four receivers were stationed along the back side of Molokini crater in subzone B. The arrays design, management subzones, location of the Ecological Acoustic Recorder (EAR, see description below), and estimates of VR2W detection ranges are depicted in Fig. 1.

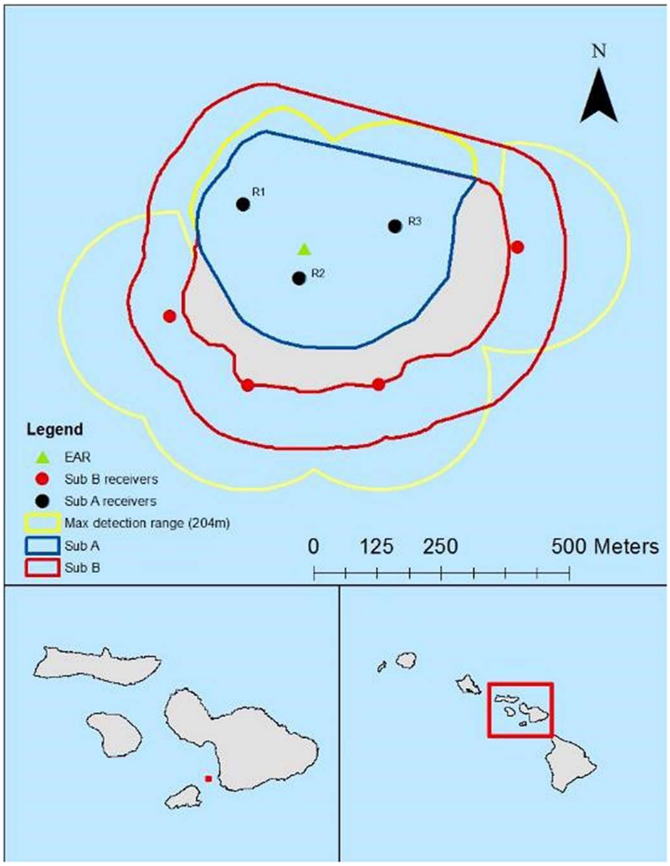

**Fig. 1.** The location of the Molokini MLCD and acoustic array. Red lines indicate subzone demarcation. Black dots indicate locations of subzone A receivers, red dots represent subzone B receivers, green triangle indicates the location of the ecological acoustic recorder (EAR) and yellow bands represent the 204 m theoretical maximum detection range of the receivers in the acoustic array. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

### 2.3. Fish capture and transmitter deployment

Five species of reef-associated predators including, whitetip reef shark (*Triaenodon obesus*, n = 13), grey reef shark (*Carcharhinus amblyrhynchos*, n = 5), giant trevally (*Caranx ignobilis*, n = 16), bluefin trevally (*Caranx melampygus*, n = 15) and green jobfish (*Aprion virscens*, n = 10) were captured with hook and line inside the MLCD. The captured sharks were tail roped and restrained alongside the research vessel where they were induced into tonic immobility (Henningsen, 1994). Teleost fishes were brought onboard the research vessel, inverted, and placed into a padded V board with a hose circulating sea water over the gills. Once catalepsy was achieved, the specimens were measured, sexed (sharks only), and tagged with Vemco V-13 coded transmitters (13 mm diameter, 45 mm long, Vemco, Halifax, Nova Scotia) programmed to transmit an individual identification number via a 69-kHz pulse, every 80 to 160 s for up to 1019 days. The transmitters