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Scuba diving damage and intensity of tourist activities increases coral disease prevalence

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ABSTRACT

Recreational diving and snorkeling on coral reefs is one of the fastest growing tourism sectors globally. Damage associated with intensive recreational tourist use has been documented extensively on coral reefs, however other impacts on coral health are unknown. Here, we compare the prevalence of 4 coral diseases and 8 other indicators of compromised coral health at high and low use dive sites around the island of Koh Tao, Thailand. Surveys of 10,499 corals reveal that the mean prevalence of healthy corals at low use sites (79%) was twice that at high use sites (45%). We also found a 3-fold increase in coral disease prevalence at high use sites, as well as significant increases in sponge overgrowth, physical injury, tissue necrosis from sediment, and non-normally pigmented coral tissues. Injured corals were more susceptible to skeletal eroding band disease only at high use sites, suggesting that additional stressors associated with use intensity facilitate disease development. Sediment necrosis of coral tissues was strongly associated with the prevalence of white syndromes, a devastating group of diseases, across all sites. We did not find significant differences in mean levels of coral growth anomalies or black band disease between high and low use sites. Our results suggest that several indicators of coral health increase understanding of impacts associated with rapid tourism development. Identifying practical management strategies, such as spatial management of multiple reef-based activities, is necessary to balance growth of tourism and maintenance of coral reefs.

1. Introduction

Global decline in coral reef health is a critical conservation concern, especially for the estimated 275 million people that live within 30 km of coral reefs and draw extensively on them for livelihood and food security (Bellwood et al., 2004; Burke et al., 2011). There is pressing demand to find income-generating alternatives to destructive and extractive uses of marine resources (Birkeland, 1997). Tourism is generally considered a favorable alternative, typically providing an incentive to preserve natural areas, thereby contributing to environmental protection, sustainable use practices, and the restoration of biological diversity (Buckley, 2012). Coral reef-based tourism is one of the fastest growing tourism sectors worldwide (Ong and Musa, 2011). However, because the majority of coral reefs are located in developing and often undermanaged island and coastal regions (Donner and Portere, 2007), the unrestricted growth and rapid development of reef-based tourism often undermines the conservation priorities necessary to sustain it.

Coral disease outbreaks are now recognized as a significant factor in the accelerating degradation of coral reefs, and it is commonly assumed that a variety of human-related activities have altered environmental conditions, potentially impairing coral resistance to microbial infections or increasing pathogen virulence (Altizer et al., 2013). Anthropogenic activities implicated in disease outbreaks and rising prevalence levels (i.e., the number of cases of a disease in a given population at a specific time) include proximity to human population centers (Aeby et al., 2011a), coastal land alteration and dredging (Guilherme Becker et al., 2013; Pollock et al., 2014), terrestrial runoff of sediment or agricultural herbicides (Owen et al., 2002; Haapkylä et al., 2011), sewage outfalls containing human enteric microorganisms (Patterson et al., 2002), increases in nutrient concentrations (Bruno et al., 2003), aquaculture and fish farms (Harvell et al., 1999; Garren et al., 2009), a reduction in the diversity of reef fish assemblages (Raymundo et al., 2009), and sunscreens (Danovaro et al., 2008).

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Until recently, recreational reef-based activities, such as diving and snorkeling, were thought to have little direct impact on coral assemblages. However, over the past two decades, numerous studies have been conducted on the physical impacts and management of diving on coral reefs worldwide. Most concluded that diving could adversely affect coral assemblages through physical injury (e.g., Hawkins and Roberts, 1992, 1993; Davis and Tisdell, 1995; Hawkins et al., 1999, 2005) or sediment deposition (Zakai and Chadwick-Furman, 2002). In a few studies, coral disease has been associated with the presence of concentrated tourist activities (Hawkins et al., 1999; Winkler et al., 2004; Lamb and Willis, 2011), however no studies have attempted to directly link coral susceptibility or disease prevalence with measures of dive site use intensity, such as levels of physical injury or sediment deposition. Minor damage and resuspension of sediment by most divers may seem trivial, but by compounding other reef stresses associated with tourism, they could undermine the resilience of local reef ecosystems (Nyström et al., 2000) and reduce recovery rates following natural disturbances (Connell, 1997). In addition, a variety of other factors could increase coral disease prevalence and reduce health at intensively dived tourist sites in rapidly developing regions, including possible increases in nutrients from vessel sewage and wastewater and elevated levels of resuspended sediment associated with shoreline erosion from boat wakes and crowding.

The island of Koh Tao, located in the western Gulf of Thailand, has rapidly grown as a tourist and recreational destination, leading to the replacement of small-scale hook-and-line or traditional hand net fisheries by reef-related tourist activities (Yeemin et al., 2006). From 1992 to 2003, the number of tourists increased by 375% and now considered the hub of scuba diving certification in Southeast Asia, estimated to generate US$62 million per year to the local economy (Larpnun et al., 2011). At present, the island has approximately 50 dive operators that accommodate greater than 300,000 visitors per year to a total reef area of 2 km^2 (Weterings, 2011; Larpnun et al., 2011), reaching intensities of use beyond levels seen even in regions heavily impacted by damage, such as the Red Sea (<250,000 divers/year to 4 km^2 of reef area: Zakai and Chadwick-Furman, 2002).

Here, we use the prevalence of four coral diseases and eight additional indicators of compromised coral health to assess the effects of recreational diving intensity on coral reefs surrounding Koh Tao. To date, the concurrent use of multiple field-based signs of disease and other indicators of compromised health to classify stress associated with human activities on reef corals has not been undertaken. Using a multitude of indicators to assess coral health may, for the first time, improve our capacity to identify more specific sources of impacts from tourism on reef corals. In light of predicted increases in tourism and recreational activities globally, the results of this study will aid in the development of practical management strategies to mitigate the impacts of frequent visitation that increase the likelihood of coral disease outbreaks and ensure long-term persistence of corals reefs and livelihoods in developing coastal regions.

2. Methods

2.1. Data collection

We conducted surveys around the island of Koh Tao in September 2011, approximately 1 year following a bleaching event and subsequent wet season in the Gulf of Thailand (Fig. 1 and Supplementary Material). We selected a total of 10, 90 m^2 sites distributed around the island and located approximately 100 m from shore. Based on questionnaires from 23 of the largest dive operators on the island, Weterings (2011) found that most of the dive sites around Koh Tao were unevenly visited and a select number were often frequented by up to 10 dive operators in a single day. Due to ease of access, dive sites with the highest levels of use are often located nearest to the large number of operators located in the west and southwest regions of the island (Fig. 1). We surveyed the top 5 dive sites that are heavily and constantly used by visitors throughout the year (i.e., more than 5 boat operators with a minimum of 50 in-water visitors/site/day) (high use sites), and 5 sites that had similar coral assemblages but had few to no in-water visitors each year (low use sites).

At each site, three 15 m × 2 m belt transects were laid randomly along reef contours at 3–6 m in depth and approximately 5 m apart, consistent with standardized protocols developed by the Global Environment Facility (GEF) and World Bank Coral Disease Working Group (Beeden et al., 2008), which allow the data from this study to be directly compared to other coral disease datasets collected globally. Specifically, within each 30 m^2 belt transect (90 m^2 per dive site), every scleractinian coral over 5 cm in diameter was identified to genus and further classified as either diseased (i.e., affected by one or more of the following disease classes recorded in the Indo-Pacific region (see Fig. 1): white syndromes, skeletal eroding band, black band disease, brown band disease, and/or growth anomalies); showing other signs of compromised health (i.e., affected by one or more of the following: tissue necrosis due to sediment, bleaching, non-normal pigmentation of tissue, overgrowth by sponges, red or green algae, and cuts and scars from predation by crown-of-thorns starfish and corallivorous marine snails); physically damaged (recently exposed skeleton from breakage or severe abrasions); or healthy (i.e., no visible signs of disease lesions, other compromised health indicators or physical damage) (Willis et al., 2004; Lamb and Willis, 2011). Standard line-intercept surveys were used to determine coral cover and community composition by estimating the linear extent of each coral to the nearest centimeter along the central line of each 15 m transect.

2.2. Data analyses

The prevalence of coral disease and other signs of compromised health was calculated within each 30 m^2 belt transect by dividing the number of colonies with one of the four diseases or eight other compromised health categories recorded in this study by the total number of colonies present, i.e., 15 prevalence values per disease or category, both for the group of high use and low use sites.

Differences in overall disease assemblages were investigated using multivariate community analyses. A nested permutational multivariate analysis of variance (Anderson et al., 2008) was used to test for differences between high and low use levels, with site (random factor) nested within use-level (fixed factor). The analysis was based on a zero-adjusted Bray–Curtis similarity matrix (Clarke and Gorley, 2006), type III partial sums of squares, and 999 random permutations of the residuals under the reduced model. To identify indicators of disease and other signs of compromised coral health between the two use-levels (those contributing most to the patterns in multivariate space), we used a principal coordinates analysis (PCO) performed on a Bray–Curtis similarity matrix using square root transformed data due to strong linear pairs of variables (Clarke and Gorley, 2006; Anderson et al., 2008). We calculated Pearson correlations of the ordination axes with the original disease and other compromised health data, where indicators with strong correlations (defined in this study as $\geqslant 0.6$) were then overlaid as vectors on a bi-plot.

Similarities between coral communities at the family-level were illustrated using a non-metric multidimensional scaling plot (nMDS), with hierarchical clusters overlaid from dendrograms based on a Bray–Curtis similarity matrix from square-root transformed data at the transect level (Clarke and Gorley, 2006). We used a nested analysis of similarity (ANOSIM) to test differences in coral assemblages between use-levels, where we nested