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Diving associated coral breakage in Hong Kong: Differential susceptibility to damage

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ABSTRACT

We conducted the first quantitative assessment of coral breakage along a gradient of diving activities in Hong Kong, the most densely populated city in southern China. A survey of six 1 × 25 m transects at seven sites revealed a total of 81 broken corals, among which 44% were branching, 44% plate-like and 12% massive. There were 3–19 broken colonies per site. At most study sites, the percentage of broken corals exceeded the recommended no-action threshold of 4%, suggesting that management intervention is justified. There was a significant positive correlation between the number of broken coral colonies and the number of divers visiting the site. The branching *Acropora* and the plate-like *Montipora* suffered from much higher frequency of damage than their relative abundance, raising the concern that the cumulative impact of such differential susceptibility to breakage may affect coral community composition.

1. Introduction

Scuba diving is one of the fastest growing sports in the world, with around 1 million new divers being certified annually (Davenport and Davenport, 2006). According to the Professional Association of Dive Instructors (PADI), its certified divers have increased from 81,321 in 1996 to 135,710 in 2012, with an annual increment of 4.2% (PADI, 2012). The increased popularity of SCUBA diving in recent years can be attributed to a number of factors: growing interest in marine environment, higher accessibility of dive sites, and availability of safe and affordable diving equipment (Musa and Dimmock, 2012).

There has been concern about the negative impact of SCUBA diving on coral reefs around the world (Gladstone et al., 2012; Musa and Dimmock, 2012), such as Red Sea (Riegl and Velimirov, 1991; Hawkins and Roberts, 1992; Hasler and Ott, 2008), the Caribbean (Tratalos and Austin, 2001), the USA (Talge, 1993), Australia (Rouphael and Inglis, 1997; Dimmock, 2004), Malaysia (Ong and Musa, 2011), and Thailand (Worachananant et al., 2008). Divers can damage corals through direct physical contact with their body parts and diving equipment such as camera and fins (Barker and Roberts, 2004; Chung et al., 2013), or through diving associated activities such as anchoring (Jameson et al., 1999), and stirring up sediment (Zakai and Chadwick-Furman, 2002; Hasler and Ott, 2008). The damage caused by individual divers is often minor (Walters and Samways, 2001; Zakai and Chadwick-Furman, 2002), but the cumulative impact can reduce the esthetic value of the dive site, and alter the community structure. In some Red Sea reefs frequented by divers, up to 60.6% branching corals and 57.2% of massive corals were damaged (Zakai and Chadwick-Furman, 2002). Tissue loss and abrasion caused by divers can invite attack by coral predators (Guzner et al., 2010), facilitate disease transmission (Hawkins et al., 1999) and enhance macroalgal growth (Hall, 2001), leading to a reduction in hard coral cover by as much as 43% (Jameson et al., 2007).

Located just south of the Tropic of Cancer at 22°10′ to 22°30′N, Hong Kong's climate is subtropical, with distinct seasonal changes in water temperature. The high temperatures (25–29 °C) prevailing throughout the wet season (May–October) satisfy the growth conditions for coral communities. But the low temperatures during the dry season (November–April), sometimes down to 18 °C, prevent corals from forming massive reef structures. Nevertheless, corals in some protected bays of Hong Kong are able to develop into fringing coral communities with up to 2 m thick calcium carbonate substrate overlying volcanic bedrock. Although the underwater attractions cannot be compared with those in the famous dive sites such as Sipadan and Palau in more tropical locations (Lew, 2012), Hong Kong is an ideal dive training area and one-day diving trips are very popular as most dive sites are within two hours of travel by boat, and coral communities are available for observation in shallow waters (<10 m) (Chan et al., 2005). There were at least 20,000 certified divers in the 1990s (Morton, 1995), and approximately 3,000 newly certified divers are noted per year in the past ten years in Hong Kong (H.C. Nimb, Vice President of PADI Hong Kong). Concern has been raised about the impact of diving and other forms of marine tourism on hard corals in Hong Kong

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(Ang et al., 2005), but there are no quantitative data on the level and spatial pattern of coral damage.

2. Materials and methods

2.1. Study sites

Hong Kong waters can be roughly divided into an estuarine zone in the west, an oceanic zone in the east and a transitional zone between them (Fig. 1). There are approximately 20 popular dive sites located in the eastern oceanic waters where the influence of the discharge of Pearl River is limited (Chan et al., 2005). Seven sites with relatively high coral cover (>15%) (Fig. 1) were visited in September to October 2010. While they were all popular dive sites to local divers, their distance from Sai Kung Pier (hereafter the Pier), the most common departure point of local dive tours, varies substantially between only around 20 min of cruising time to Sharp Island and 180 min to Crescent Island, using a mean boat speed of 8.5 nautical miles h^{-1}. While the annual Hong Kong Reef Check (HKRC, 2013) provides coral coverage and health data of these sites, the transect locations of this study were chosen to situate outside the HKRC transects such that information from this study could provide insight on the status of local communities beyond the knowledge gained from the HKRC.

2.2. Substrate composition

In each dive site, six 1 × 25 m transect lines were set up outside HKRC transect locations but in areas where divers would frequently visit and along areas of comparatively high coral cover. The ends of transects were secured by weight. A floating marker, fixed at each end of the transect, was released to the surface to facilitate GPS reading. The photoquadrat transect method (Hill and Wilkinson, 2004) was deployed to determine substrate composition. The substrate was checked every 1 m along the entire transect, i.e. from 1 to 25 m. A photoquadrat covering an area of 0.5 m × 0.5 m was taken in the beginning of each meter along the transect using a Panasonic LX3 digital camera inside an underwater housing.

In the laboratory, coral colonies in each photoquadrat were identified to genus. The percentage cover of corals and other substrate (i.e. sand, bare rock) in each quadrat was determined after assigning 50 stratified random points on each photograph with the aid of the Coral Point Count software with an Excel extension (CPCe 3.6) (Kohler and Gill, 2006). The relative abundance of each coral genus was calculated as the ratio between the number of points on a particular genus and the total number of points on all hard corals genera at each site.

2.3. Intact and broken coral colonies

Following the photoquadrat survey, a coral head-count survey was conducted along the six transects at each study site to record and identify the colonies of intact and newly broken hard corals. All colonies >10 cm in the longest dimension were recorded. The GPS reading of each broken colony was also taken. Broken corals were identified to genus and then grouped according to their morphological forms.

The characteristics of coral wound and its surrounding are indicative of the possible cause of damage. Coral damaged by natural disasters such as typhoon or tsunami is likely to cover a relatively extensive area. Anchoring damage is often associated with the loss of a large piece of tissue and underlying skeleton, or an uprooted colony or many coral fragments along a trail on the bottom. Diver inflicted damages are usually localized, which affect only a small part of the colony.

Broken coral colonies were grouped into one of the four morphological forms: branching, plate-like, massive and encrusting (Fig. 2). Breakage intensities for each genus and each morphological form were calculated. The intensity of breakage for each genus was expressed as the ratio between the number of broken corals and the total number of broken corals. Similarly, the intensity of breakage for each morphological form was expressed as the ratio between the number of broken corals in a particular morphological form and the total number of broken corals.

2.4. Susceptibility to breakage

Since the number of broken corals was low for most species, we decided to pool the broken corals according to their growth form to determine their relative susceptibility to breakage. Jacobs'

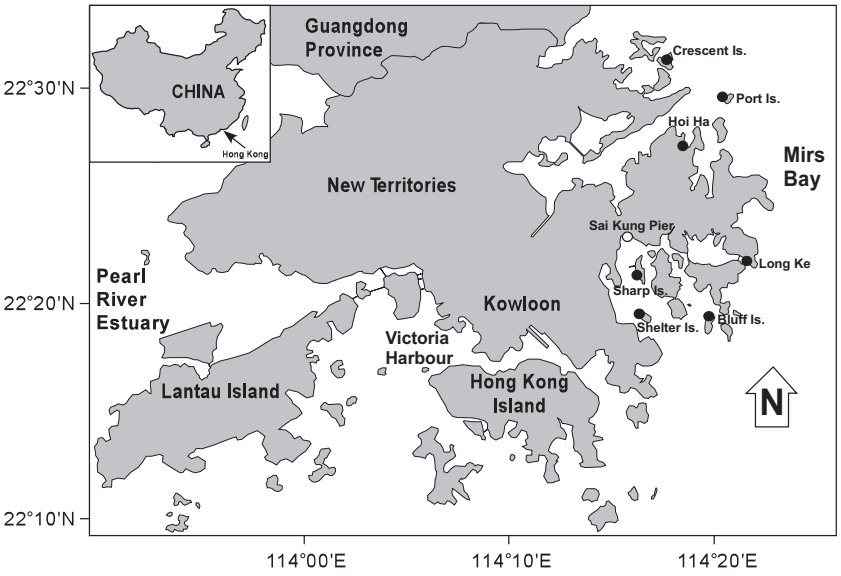

Fig. 1. A map of Hong Kong showing the locations of the seven dive sites in northern and northeastern Hong Kong waters, as well as Sai Kung Pier where most local diving boats are moored.