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.
(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 up-rooted 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'
Electivity index $D_i$ (Jacobs, 1974) was calculated for each growth form in each site:

$$D_i = \frac{r_i - n_i}{r_i + n_i - 2r_in_i}$$

where $D_i$ is the susceptibility of coral morphological form $i$, $r_i$ the proportion of breakage in coral morphological form $i$, and $n_i$ the relative abundance (cover) of coral morphological form $i$ in the dive site. The index can range from $-1.0$ to $+1.0$, with a negative value indicating low susceptibility while positive values indicating high susceptibility.

### 2.5. Distance to dive sites and intensity of diving activities

The accessibility of the dive sites was represented by its cruising time needed in minutes (estimated using a speed of 8.5 nautical miles per hour, a mean speed used by local dive trip operators) from the Pier to the study site, which ranged from 20 to 180 min (Table 1). A telephone survey of four local leading dive operators...
(Diving Adventure, Diving Express, International Divers Training Centre, and Ocean Sky Divers) was also conducted in March 2011 to determine the number of trips made and number of divers they brought to the seven study sites in 2010. Eight dive boats owned by the four dive operators were deployed in 2010 in Hong Kong. With few exceptions, other dive operators normally subscribed to these eight dive boats when they ran local dive trips. Among the four operators, Ocean Sky Divers did not provide information to us due to a change in management in that year. Despite this, data from the three leading operators for their seven diving vessels should still represent the majority of diving service subscribed by local divers in 2010 to the study sites. These data were used in correlation analyses to assess the significance of the relationship between the number and percentage of damaged colonies and the number of divers visiting the site and distance from Sai Kung Pier.

3. Results

3.1. Substrate composition and coral community structure

Substrate composition varied substantially among the seven sites. Live coral cover ranged from 17.4% at Long Ke to 35% at Bluff Island. In total there were 21 genera of live corals: Acanthastrea, Acropora, Alveopora, Echinophiphylla, Favia, Favites, Galaxea, Goniatrea, Goniopora, Hydnophora, Leptoseris, Leptastrea, Lithophyllon, Montipora, Pavona, Platagynya, Plesiastrea, Psammocora, Porites, Styllocoeniella and Turbinaria. The number of coral genera ranged from 9 at Crescent Island to 15 at Sharp Island and Hoi Ha (Table 1). Coral community composition, based on the nine genera that each covered more than 1% of the total benthic substrate, revealed a clear site-specific pattern of coral dominancy (Fig. 3). Specifically, Sharp Island was co-dominated by Pavona (42.5%) and Porites (22.7%). Shelter Island was dominated by Platagynya (36.2%). Bluff Island was co-dominated by Montipora (43.3%) and Acropora (34.5%). Long Ke and Hoi Ha were dominated by Favites (56.4%) and Pavona (78.4%) respectively. Port Island and Crescent Island was co-dominated by Goniopora (52.7%) and Platagynya (27.1%), and by Goniopora (42.3%), Favites (23.4%) and Favina (21.4%), respectively. Pooling of coral genera based on growth form showed that massive corals were dominant at four study sites (Shelter Island, Long Ke, Port Island and Crescent Island), but co-dominant with plate-like corals at Sharp Island (Fig. 4). At Bluff Island, branching and plate-like corals are co-dominant, and at Hoi Ha, plate-like corals dominated the coral community. Branching corals were present at low abundance at most of the study sites (0–7.9% coral cover), except at Bluff Island, where they accounted for 34.5% of the coral cover. Encrusting corals were rare at six of the seven sites (0–0.9% coral cover), but at Long Ke their cover was 16.2%.

3.2. Coral breakage

Broken corals found in this study belonged to seven genera and three growth forms (Fig. 3). The number of damaged colonies ranged from 19 at Sharp Island to 3 at Port Island and Crescent Island. The percentage of broken colonies showed an identical spatial trend, which ranged from 21.8% at Sharp Island to 3.7% at Crescent Island (Table 1). Branching (Acropora, 36 colonies) and plate-like (Montipora, 27 colonies; Pavona, 6 colonies; Lithophyllon, 3 colonies) corals each accounted for 44% of the total number of broken colonies (Table 2). Massive corals (Favites, 1 colony; Platagynya, 6 colonies; Leptastrea, 2 colonies) accounted for 12% of the total number of broken corals. Most of the breakages were minor (Fig. 2) and were likely caused by direct physical contact by divers, except for few cases where the skeletal loss in massive corals was substantial (e.g. Fig. 21), which might be caused by the direct hit of an anchor.

A correlation analysis showed that the number of damaged corals was negatively correlated with the distance from the Pier (r = 0.963, p < 0.001), positively correlated with the number of divers visiting the site (r = 0.775, p = 0.04), but had no significant correlation with the number of coral genera at the site (r = 0.569, p = 0.18) (Fig. 4). Similarly, the percentage of broken coral colonies was negatively correlated with the distance from the Pier (r = 0.899, p = 0.006), positively correlated with the number of divers visiting the site (r = 0.963, p < 0.001), but had no significant correlation with the number of coral genera (r = 0.621, p = 0.14) at the site (Fig. 4).

3.3. Susceptibility to breakage

The Jacobs’ electivity index revealed a clear differential susceptibility among coral growth forms (Fig. 5). For the branching form, the values were >0.5 at all of the six sites where Acropora was present. For the plate-like form, the Jacobs’ index appeared to be related to the relative abundance of the coral and whether the coral plate was horizontal (Montipora and Lithophyllon) or vertical (Pavona): it was >0.5 at three sites where plate-like corals were rare (4.1% coral substrate at Shelter Island, 9.2% at Long Ke, 4.2% at Crescent Island) and coral plates were horizontal; but the index was <0.5 at a site where this growth form was very rare (0.2%, Port Island) and at a site where the corals were mainly Pavona (78.4%, Sharp Island). Compared with Montipora and Lithophyllum, Pavona thus appeared less susceptible to breakage by divers. The index for the massive and encrusting growth forms was negative for all sites where they were present.

4. Discussion

Our study has shown that there was a clear spatial pattern of diving-associated coral damage, with a negative correlation between percent breakage and distance from Sai Kung. This significant correlation was due to the fact that diving sites closer to Sai Kung are more accessible, thus more divers visit them. The level of coral damage caused by diving associated activities in Hong Kong was usually low for each colony, involving the breakage of...
only a minor portion of the colony. The fact that few anchor damaged colonies were recorded in our study indicates that the Agriculture, Fisheries and Conservation Department’s “no-anchoring” areas, established since 2001 at several sites frequented by divers (i.e. Bluff Island, Port Island and Sharp Island), has been effective in protecting corals from anchor damage. Nevertheless, the percentage of damaged coral colonies varied quite substantially from 3.7% to 21.8% among the seven study sites. Although these percentages were still much lower than those reported for reefs frequented by divers in Red Sea where more than 50% coral colonies were broken (Jameson et al., 1999; Zakai and Chadwick-Furman, 2002), in six of the seven sites the percentage of damaged corals exceeded the threshold (4%) recommended for management intervention in Red Sea reefs (Jameson et al., 1999).

Grouping coral abundance by genus and growth form allowed us to determine their susceptibility to breakage. In all study sites where Acropora was present, this branching coral suffered from breakage that was disproportionally higher than its percent substrate cover at that site. Similarly, in at least three of our study sites, the plate-like Montipora and Lithophyllon also suffered disproportionally higher extent of damage than their percent cover. It should be noted that the corals that are susceptible to diver

Fig. 3. Composition of coral communities (only coral genera >1% substrate cover are shown), and the number of damaged coral colonies at the seven study sites (in bracket).
damage, especially the branching coral *Acropora*, are rare in most of our study sites in terms of both substrate cover and coral colony counts. Therefore past damages on these branching and plate-like species may have already led to the dominance by massive corals which are more resistant to diving related activities. In fact, in Daya Bay that borders Hong Kong, there was also a dramatic shift in dominant coral species, with the branching *Acropora pruinosa* being replaced by the massive *Favites abdita* during the period from 1983/84 to 2008 (Chen et al., 2009). In Moorea, French Polynesia, diving associated damage of branching acroporid corals has been reported to result in their replacement by pocilloporids (branching but opportunistic) and/or massive poritids which are slow growing but more resistant to mechanical damage caused by divers (Lenihan et al., 2011). In order to determine if coral composition change will indeed occur, a longer term monitoring of coral morphological forms in these 7 sites is needed.

**Table 2**

Distribution of the growth forms and generic composition of damaged coral colonies in the seven study sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Branching</th>
<th>Plate-like</th>
<th>Massive</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acropora</td>
<td>Montipora</td>
<td>Pavona</td>
<td>Lithophyllon</td>
</tr>
<tr>
<td>Sharp Island</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Shelter Island</td>
<td>5</td>
<td>9</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Bluff Island</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Long Ke</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hoi Ha</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Port Island</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Crescent Island</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>27</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

**Fig. 4.** Relationship between coral damage (A–C, number of damaged coral colonies; D–F, percentage of damaged coral colonies) and site characteristics (distance from the pier of Sai Kung, number of divers visiting the site, number of coral genera found at the site). Data were collected from seven dive sites. A regression line was added when the correlation was significant ($p < 0.05$).
Morton (1995) reported that “all the branching acroporids and plate-forming montiporids have gone from local waters, leaving behind an undulating seascape of encrusting faviids and poritids, which are not popular in the aquarium trade”, indicating that collection of branching and plate-like corals was mainly responsible for the change in coral community structure in the 1990s in Hong Kong. However, no live corals have been reported to be collected for aquarium trade since the enactment of two ordinances: Marine Parks Ordinance (Cap. 476) (enacted in 1995) forbids collection of marine life including corals in marine parks without a permit; and Schedule 2 of the Protection of Endangered Species of Animals and Plants Ordinance (Cap. 586) (enacted in 2006) prohibits import, export and possession of many types of corals. The enactment of these ordinances may thus have allowed the development of branching and plate-like corals into dominant growth forms in some locations, such as Sharp Island, Bluff Island and Hoi Ha. Although diving associated coral breakage is usually not as damaging to coral ecosystems as coral collecting for aquarium trade, our study has indicated that, in Hong Kong dive sites frequented by divers, this type of coral damage has become a potential threat to the health of local coral ecosystems.

Overall, our study has provided the first set of quantitative data on diving associated coral breakage in Hong Kong, and revealed a need for follow-up actions in both the diving industry and marine protection authority to reduce the coral breakage in diving sites close to Sai Kung. Given that hard corals in Hong Kong are facing...
a number of other problems, such as sedimentation due to coastal development (Ang et al., 2005), abnormal coral growth (Sun et al., 2013) and bioerosion by sea urchins (Dumont et al., 2013; Qiu et al., 2013). Setting quota of dives/divers during the peak season and declaring diving moratorium for the most severely damaged sites (Needham and Szuster, 2011) and designating no dive training areas as a means to match diver’s expectation while minimizing the impact created (Worachananant et al., 2008), are among the most commonly adopted management measures to reduce diving associated coral damages elsewhere. In Hong Kong, dive sites most proximate to Sai Kung, especially in areas with a relatively high density of branching and plate-like corals, can be considered as candidates of “no-go” areas for snorkelers and training divers. A case in point is Sharp Island where the coverage of hard corals was high among the surveyed sites, but coral degradation was also high with the branching and plate-like corals suffered disproportionately. In addition, coral growth along some sections of Sharp Island, i.e. northern part, extends to less than 1.5 m deep, making it easy for divers especially novice divers to lose control of their buoyancy, resulting in unintended contacts and even breakage of the fragile corals. For ease of identification, it is suggested that “no entry” buoys be moored to define the zone. Publicity leaflets of the zone should also be made available to divers and dive operators as in the case of no anchoring areas.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.marpolbul.2014.01.024.

References


Diadema setosum


