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Understanding the Underwater Behaviour of Scuba Divers in Hong Kong

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Abstract Diving-related activities may constitute a major threat to coral reefs. This study aimed to quantify the impact of diving in Hong Kong on hard corals and understand how socio-economic characteristics and experience level of divers influence diver-inflicted damage. We recorded and analysed the underwater behaviour of 81 recreational divers. On average, a diver was in contact with marine biota 14.7 times with about 40 % of contacts involved corals and 38 % were damaging contacts with corals or other biota in a single dive. The most harm-inflicting groups included inexperienced and camera-carrying divers. Although Hong Kong divers did not make many damaging contacts with corals, there is still an imminent need to determine the scale of damage from diving activities on the marine ecosystem given the rapid development of marine-based tourism and the limited coral-inhabited areas in Hong Kong where the marine environment is already under stress from anthropogenic activities.

Keywords Physical carrying capacity · Diving impact · Hong Kong · Eco-tourism · Sustainable · Corals · Marine biota

Introduction

It is generally believed that each ecosystem has a carrying capacity beyond which tourism becomes unsustainable (Mathieson and Wall 1982; O'Reilly 1986). Despite the attempts of previous studies (e.g. Barker 2003; Hawkins and Roberts 1997; Schleyer and Tomalin 2000; Zakai and Chadwick-Furman 2002) to assign numerical values to carrying capacities of a diving site, it is still difficult to accurately determine the carrying capacity of an ecosystem and there are more than one carrying capacity measures (O'Reilly 1986). In general, carrying capacity determination combines both quantitative estimations of the adverse effect of certain activities and an often subjective decision on the acceptable threshold. Notwithstanding this, there is a lack of quantitative estimations of the impact of divers and diving tourism operators on many diving sites. This may be explained by the general belief that scuba diving is compatible with principles of resource sustainability. Yet, with the increase in popularity of scuba diving and other water-based activities in recent decades, some diving sites have already reached or even exceeded their carrying capacities (Guzner and others 2010). A case in point is Eilat, Israel where the breakage of scleractinian coral increased dramatically from 11.2 % in the early 1990s to 40–80 % in 1996 (Guzner and others 2010). The Koror State Government, Palau has acknowledged in the "Rock Islands—Southern Lagoon Area Management Plan" that damage to reef habitat by divers and snorkelers was its primary concern among all impacts of tourism and recreational activities (Poonian and others 2010).

Hong Kong is situated in the sub-tropical region where the climate is highly seasonal with a wet season (May–October) and a dry season (November–February) (Morton and Morton 1983). In the dry season, strong monsoon winds and low temperatures limit all forms of water sports, including diving. In the wet season, when water temperature is high and winds mild, groups of divers are often seen in local diving sites, especially the coral communities in the eastern waters of Hong Kong. Figures from the

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Professional Association of Diving Instructors (PADI) show that the association has certified more than 30,000 new divers from Hong Kong in the past ten years (Nimb, H.C., personal communication with Vice President of PADI, on 14 January, 2011). There are about 33 diving sites clustered in the east and north-eastern regions of Hong Kong. Although coral diversity in Hong Kong is high, with 84 species of hard corals (Chan and others 2005) and 42 species of soft corals (Fabricius and McCorry 2006) in a sea surface area of 1,600 km^2, damaged corals can be found in intensively dived sites such as Sharp Island and Shelter Island. Indeed, there is no room for complacence as marine ecologists have warned that the waters around Hong Kong have been seriously overfished: fish caught today average only about 10 g in weight (i.e. about the length of a finger) (Ko 2011). Thus, the growth of diving tourism in such an already stressed environment could be a disaster. Ang and others (2004) earlier acknowledged that damage by "the so-called" eco-tourists and swimmers standing on coral heads may be substantial. Yet, they also acknowledged that no assessment has been carried out of coral damage and how divers' behaviours have contributed to the damage in diving regions in East Asia, especially Hong Kong. Data on the impact of diving are inadequate and accurate statistics of even the number of diving trip operators and active divers in Hong Kong are not available. Such information gap hampers the estimation of the carrying capacity of local diving sites and sustainable development of marine-based tourism in Hong Kong. This study was, thus, undertaken to provide the data that Hong Kong has so far lacked.

Review of Studies on the Environmental Impacts of Scuba Diving

Scholarly studies have shown that aquatic systems, including coral reefs, are facing varying degrees of pressure from recreational activities, including diving, snorkelling and boating activities (Hawkins and Roberts 1994; Jameson and others 2007; Allison 1996; Liddle 1997; Leujak and Ormond 2008; Plathong and others 2000; Camp and Fraser 2012). In particular, recreational divers can cause damage to corals and coral-associated benthic organisms by breaking coral skeletons or abrading their tissues (Hawkins and Roberts 1992). The damage caused by individual divers and anchoring of diving boats can range from minor (Walters and Samways 2001; Zakai and Chadwick-Furman 2002) to serious localized decline in coral cover (Hawkins and others 1999). Woodland and Hooper (1977) also reported that one reef walker destroys 72 kg of living coral in a single incident. These are examples of direct impact on corals, i.e. impact or damage directly inflicted by divers or snorkelers, including anchoring of boats.

Indeed, there is a positive association between coral breakage and diver visitation with low visitor frequency being related to fewer broken corals (Riegl and Velimirov 1991). Coral coverage is lower and damage rates higher in intensively dived sites (Hasler and Ott 2008). There are also more damaged coral colonies, fragments of live coral and partially dead and abraded corals in heavily dived areas than in lightly dived areas (Hawkins and Roberts 1992). Survival rates of detached fragments of *Acropora* and *Porites* corals vary with the size of fragments of species. Larger fragments, especially those longer than 8 cm, are able to survive better than smaller fragments and more fragments of *Acropora millepora* are able to survive after physical and physiological detachments (Liddle and Kay 1987). However, most studies completed in the last century agree that diving-induced biological damage tends to be relatively unimportant; the major adverse consequence of intensive diving is the reduction in amenity value of heavily dived areas when a pristine marine ecosystem has been degraded into a "diver-damaged" environment (Harriott and others 1997). Yet, localized overuse should be regarded as an early warning of large-scale degradation (Dixon 1993).

Garrabou and others (1998) mapped the density, diameter and height of *Pentapora fascialis* colonies and the number of dives conducted in six locations in Spain. They concluded that, albeit unintentionally, divers damage *P. fascialis* colonies and cause a rapid decline in their density (Garrabou and others 1998). However, Garrabou and others (1998) did not state why they thought the damage caused by divers is unintentional. More convincing evidence of diver-inflicted damage to corals, such as records of direct coral breakage by divers, is available in Harriott and others (1997) and Worachananant and others (2008). Their findings are cited later in this paper.

Direct damage caused by divers (e.g. skeletal breakage) may not be the main source of damage to hard corals in intensively dived areas. Indirect impacts of recreational diving on stony corals and other organisms are complex (Guzner and others 2010) and should not be overlooked. Indirect impacts (e.g. tissue lesion) are usually minor impact on or damage to corals that develop subsequently more significant damage. For instance, tissue lesions and compromised physiological conditions together may increase vulnerability of hard corals to predatory attacks (e.g. predation by the corallivourous gastropod *Drupella cornus*) (Guzner and others 2010). Algal colonisation of corals may soon follow tissue damage with algae competing for space with corals and acting as sediment traps, which hinder coral recovery (Hall 2001).

In sum, while the impact of diving and related marine recreational activities on coral communities can be significant and the harm is likely to go beyond direct and overt damage, the levels of environmental damage caused by diving activities tend to vary across sites. Thus, detailed and site-specific studies are needed. In this connection, seven site-specific studies have been identified: Roberts and Harriott (1994) studied New South Wales in Australia, Harriott and others (1997) studied Eastern Australia, Garrabou and others (1998) examined Medes Islands in Spain, Zakai and Chadwick-Furman (2002) studied Eilat of Israel, Barker (2003) studied the Caribbean, Worachananant and others (2008) covered Thailand, Poonian and others (2010) studied Palau and Camp and Fraser (2012) examined the effect of diving in Florida Keys, USA. While findings from the above-mentioned studies are compared with findings of this study, information gaps do exist in the seven studies. For example, Garrabou and others (1998) provided no information on the number of times, and in what ways and why divers were in contact with corals and other reef biota as they did not track divers' behaviour underwater. Similarly, the remaining studies did not investigate why, especially personal reasons, divers made contact with marine biota though such contacts were known to be substantial (Barker 2003). In other words, even where there is irrefutable evidence of concern, it is not easy to relieve the stress caused by diver contact because the cause of environmentally damaging underwater behaviour is not known. It is, therefore, the objective of this study to use Hong Kong diving sites as a case study to investigate the impact of diving tourism on the marine environment and identify factors that may affect the underwater behaviour of scuba divers. In this study, we use the rate of divers' contacts with marine biota to infer impact from recreational diving. While the cruising of boats and activities on board also impact the marine environment, some of these other impacts have been addressed by local management authorities, such as the establishment of no-anchorage zones in areas of high coral coverage (Agriculture, Fisheries and Conservation Department 2004); other impacts warrant separate examination and are proposed to be addressed in the future.

Materials and Methods

Direct Observation of the Entire Dive

Direct observation of recreational diving activities during a day of diving was the main method employed to understand the underwater behaviour of scuba divers. Other than the authors, experienced divers were also recruited to conduct underwater observation on voluntary basis. All volunteer divers were first trained about the purpose, nature and safety of research activities as well as how to fill in the underwater record slate board.

The entire duration of the dive was observed and significant behaviours were recorded in the form of a matrix on a custom-made slate board. Similar to Camp and Fraser (2012), a dive was divided into three stages and behaviours during each were recorded separately. Stage 1, the descent stage, covered the time of descent and the first 5 min of the dive. This is different from that used by Camp and Fraser (2012) who did not use time but the actions divers performed to determine their "start" stage. Stage 3, the ascent stage, covered the period from when the divers signalled or decided to ascend to the end of the dive, including a 3-min safety stop. Camp and Fraser (2012) called this stage, the "end period." Stage 2 was the time between the descent and ascent stages and is called the "middle period" by Camp and Fraser (2012). The rate of contact with marine biota by an average diver could then be worked out for the three separate stages and the stage that was noted to have the highest average rate of contact could be identified. The information provided would be useful for subsequent formulation of awareness training programmes.

However, while interpreting the findings from this study, it needs to be noted that only about 30 % of the divers, we observed were clearly unaware of being watched underwater (see "Selection of Samples and Transparency of the Research" section). Thus, we collected 87 sets of (involving 54 divers) observer-aware behavioural data. The high percent of awareness may be due to the short distance of observation, usually about 3 m, owing to the low underwater visibility at the diving sites in Hong Kong. Statistical tests were subsequently conducted to find out if there are any differences between the total number of contacts made by the two groups (see "Neutrality of the Observation" section).

Study Site

The underwater behaviour records were collected from dives conducted at seven sites in Hong Kong (Item 3, Table 1). All diving sites are located in east and north-east of Hong Kong. Although Hoi Ha Wan is a Marine Park, diving is permitted there. Attributes that affect underwater behaviour and impacts from diving, such as low water visibility, shallow depth of site, predominance of weak-to-moderate currents and boat entry were found in or applied to both the Marine Park and non-Marine Park diving sites covered in this study. Hard coral coverage in these sites varies between 60 and 77.5 % for all sites with the exception of Moon Island in Hoi Ha Wan where the hard coral coverage is only 23.8 % (Agriculture, Fisheries and Conservation Department 2011). These reported coral coverage rates are for selected transect belts, each measuring 20 m in length and 5 m width. Only areas with abundant hard coral were selected for survey in a site.

Table 1 Observation durations and sample sizes in diver impact studies

	Location	Minutes observed per dive	Average duration of dive (min)	No. of samples in the study	Total duration observed (min)	Source
1.	Eilat, Israel	10	n.a.	35	350	Zakai and Chadwick-Furman (2002)
2.	Surin Marine National Park, Thailand	10	n.a.	108	1,080	Worachananant and others (2008)
3.	Hoi Ha Wan Marine Park, Sharp Island, Shelter Island, Port Island, Bluff Island, Long Ke Wan, and Crescent Island, Hong Kong	Entire dive, ranging from 30 to 70 min per dive	25.8	81	3,273	This study
4.	Heron Island, Lady Elliott Island, Gneering Shoals and Solitary Island, Eastern Australia	The first 30 min of each dive after descent	n.a.	4 sites, each site, 25–45 divers were followed	>3,600	Harriott and others (1997)
5.	Rock Islands—Southern Lagoon Area, Palau	10	n.a.	124	1,240	Poonian and others (2010)
6.	Julian Rocks Aquatic Reserve, New South Wales, Australia	Entire dive	32	30	960	Roberts and Harriott (1994)
7.	St. Lucia, West Indies, The Caribbean	Entire dive	42	353	14,826	Barker (2003)
8.	The Florida Keys, USA	Entire dive	54.2	83	4,499	Camp and Fraser (2012)

Data Collection and Response Rate

The major impact of diving activities on the marine ecosystem is mechanical breakage of coral, which can be caused by divers kicking, standing on and trampling coral surfaces. Touching of corals by hand or contact by the scuba unit may also lead to lesions on coral tissues. In addition, large amounts of sedimentation raised by divers can reduce the growth rate of corals. Colony dislodgement can be caused by the anchoring of boats. Other than boat anchorage, all the above causes of damage are directly perpetrated by divers underwater and were recorded by direct observation in this study. All behaviours recorded were immediately characterised by the research divers as either intentional or unintentional. Intentional contacts were those that divers were clearly aware of (i.e. a deliberate contact). An example would be when divers put their hands on the coral mass to steady themselves. Other contacts or behaviours, i.e. other than those that were clearly intentional, were considered unintentional. We included cases where there was uncertainty as to whether the contact was intentional or unintentional in the unintentional category and as a result, our estimate of intentional contact rates was most likely conservative. In addition, our research divers also recorded if there was any collection of materials underwater and if there were any other remarkable behaviours, including good practices, such as releasing trapped fish or picking up litter. We did not video-record the underwater behaviours of scuba divers because the visibility in water around Hong Kong was generally low (~5 m) and people were apprehensive about video-taping.

In addition, we invited all divers who were being observed underwater to participate in a self-administered questionnaire survey after they had finished their diving exercises. We also used this opportunity to ascertain if the divers were aware of being watched underwater. Among others, the questionnaire contained questions relating to diving experience, demographic and socio-economic background, purpose of diving, underwater behaviour, reasons for making contact with marine biota and a self-evaluation of their impact on corals. Only one out of a total of 81 divers refused to answer the questionnaire, which implies a response rate of 98.8 % was achieved.

Selection of Samples and Transparency of the Research

From June to November 2010, we observed 81 scuba divers over a total of 127 diving expeditions in Hong Kong waters. Total observation duration and the sample size of this study are stated in Table 1. Divers with different levels of diving experience and other characteristics (e.g. gender, carrying or not carrying a camera or video-camera) were selected for observation, subject to consent of the diving guides

Table 2 Summary of diver profile

Not yet certified		23 persons
Certified diver		58 persons
Open water/Advanced open water diver		37
Rescue diver		4
Diver master		4
Instructor or above		9
Did not provide the certification level		4
Dive frequency (%)		
0–4 dives/year		36.3
5–10 dives/year		22.5
11–20 dives/year		16.3
21–30 dives/year		8.8
31–40 dives/year		8.8
41–50 dives/year		5.0
>50 dives/year		2.5
Diving experience	**This study**	**Worachananant and others (2008)**
Average duration: 43 months (range: <1 month–35 years)		
Average no. of logged dives: 132 logged dives (%)		
1–25 logged dives	53.8	41
26–50 logged dives	12.9	27
51–100 logged dives	17.9	7
>100 logged dives	15.4	25
Socio-demographic characteristics	**This study[a]**	**HK (mid-2010)**
Gender (%)		
Male	65.8	48.6
Female	34.2	53.2
Age (%)		
<19	1.3	18.3
20–34	54.7	21.9
35–49	29.3	25.9
>50	14.7	33.9
Education (%)		
No education/pre-primary/primary	0	22.3[a]
Secondary	20.8	52.2[a]
Matriculated	6.5	
Tertiary	51.9	25.5[b]
Post-graduate	20.8	
Averaged per capita monthly income (%)		
Below HK$3,999	1.3	Median income:
$4,000–7,999	2.5	$10,500
$8,000–14,999	12.7	
$15,000–29,999	29.1	
$30,000–59,999	20.3	
Over $60,000	11.4	
I don't want to answer this question	22.8	

Sources Census and Statistics Department 2011a, b, c

[a] Sample size = 80; sample size for the data above = 81

[b] Represent percentages of population aged 15 and over

employed by the companies. To begin with, we randomly selected a group of divers on board and approached their guide on the day of survey for permission to observe them underwater. In order to reduce behavioural distortion of the observed divers to the minimum possible extent, research divers explicitly informed and obtained permission from the guides. It was up to the guides whether to tell the divers that some of them would be watched when diving. That said, even if many of the guides did not inform the scuba divers that they would be watched, survey findings suggested that only about 30 % indicated that they were unaware of being watched underwater. However, since we followed the whole dives of individual divers, they were less likely to be able to disguise their behaviour over the course of the dive.

Statistical Analysis

Underwater behaviour records and responses to the questionnaire were organized and analysed using the statistical software, SPSS v.18. Descriptive statistics including means, standard deviations and other inferential statistics such as non-parametric *t* test and correlation coefficients used in this study were also calculated by this software. Non-parametric test is used for non-independent and non-normally distributed data.

Results

The Profile of Recreational Divers

Of the 81 divers observed, 23 (or about 30 %) were not yet certified. The remaining 58 divers had diving experience ranging from just 1 month to 35 years. Similarly, the total number of logged dives declared by the divers varied greatly from 1 to 3,000, with the majority doing less than ten dives per year. Since a substantial proportion of observed dives were training dives, the average dive time was just 25.8 min in our sample. Table 2 summarises the diving experience of the divers surveyed.

On the whole, our sample had a larger proportion of males (52 males vs. 27 females, 2 missing), mostly aged between 20 and 34 and they were better educated and had higher monthly household incomes than the average for Hong Kong citizens.

Diver Behaviour and Consequences

Direct Contacts

For the purpose of this study, behaviour of concern included raising sediments, contact with coral by any part of the diver's body or gear as well as collecting materials or marine organisms. Table 3 details the average number and the form of contact per dive, as observed. On average, a diver was in contact with marine biota 14.7 times per dive with 74 % of

Table 3 Average number of contacts with the marine biota made by Hong Kong divers per dive and per 10-min

	Intentional			Unintentional			
	Damaging contact	Less damaging contact	Leaning	Damaging contact	Less damaging contact	Leaning	Sub-total
Hand	0.80 (3.16)	0.86 (4.15)	0.13 (0.76)	1.11 (6.09)	0.76 (4.89)	0.25 (1.67)	3.91
Fin	0.32 (1.64)	0.11 (0.63)	0.5 (3.44)	2.56 (9.83)	1.19 (5.13)	0.55 (2.47)	5.23
Scuba tank	0 (0)	0 (0)	0 (0)	0 (0)	0.06 (0.62)	0.01 (0.09)	0.07
Hose	0.05 (0.40)	0.02 (0.18)	0 (0)	0.27 (1.55)	0.34 (1.83)	0 (0)	0.68
Body (usually knees)	0.13 (0.80)	0.07 (0.49)	0.10 (0.68)	0.26 (0.95)	1.03 (8.92)	0.22 (1.0)	1.81
Others (e.g. pointers)	0 (0)	0.28 (2.06)	0.41 (4.44)	0.30 (1.99)	1.90 (10.21)	0.06 (0.48)	2.95
Sub-total	1.3	1.34	1.14	4.5	5.28	1.09	
Per dive	3.78			10.87			14.65
Per 10 min	1.47			4.21			5.68

Figures in brackets are standard deviations

contacts being unintentional. About 40 % of contacts involved corals. Thus, a diver was in contact with corals 5.9 times per dive on average. Damaging contacts included kicking, trampling and collision. On the other hand, touching was considered a form of less damaging contact. The flippers and hands of divers were the parts that most frequently came in contact with marine biota while scuba tanks were the least likely to make contact with the substratum. While less damaging contacts (6.6 times per dive) were the major form of contact among the three, the number of damaging contacts was also high (5.6 times per dive).

Table 4 Sediment raising by diver in an average dive in Hong Kong ($N = 127$)

	No. of times[a]	Minutes[a]
Fin	1.20 (3.716)	0.55 (2.455)
Hand	0.36 (2.281)	0.09 (0.511)
Hose	0.24 (1.978)	0.14 (1.597)
Body	0.06 (0.432)	0.14 (1.597)
Scuba tank	0.06 (0.539)	0 (0)
Others (e.g. pointers, console)	0.07 (0.566)	0.03 (0.355)
	1.99	0.95

[a] Figures in brackets are standard deviations

Sediment Raised by Divers

Raising sediment is another diver-induced impact (see Table 4). Since all dives we observed were boat dives with no fixed entry point, we were not able to conduct diver-induced sedimentation rate experiments. As a result, our research divers were asked to either record the number of times sediment was raised or the approximate length of time for which sediment was raised. On average, for each dive, sediment was raised on two occasions, for about 1 min each time. Consistent with the findings on contact with marine biota, flippers of divers were the main cause of disturbance. On the effect of diver-induced disturbance of sediment, we found that diver contact reduced underwater visibility and resulted in corals being covered in sediment.

Dive Profile and Contacts with Corals

While it is generally believed that most contact with marine flora and fauna occurs during underwater swimming, some argue that significant impact on the marine environment can be inflicted if a diver does not properly control his/her descent rate and buoyancy. In this study, the observers were asked to record divers' contact with marine biota during each of the three stages of a dive.

Contact was most frequent during the main diving stage (average 11.63 contacts per dive; SD = 24.88) followed by the descent stage (average 2.58 contacts per dive; SD = 4.85). The large disparity in diver-induced impact on marine biota can be clearly seen in Fig. 1. About one-third of the dives observed caused no or insignificant impact on corals while a few disastrous dives accounted for the majority of the contacts. In most cases, few contacts were recorded in the ascent stage of a dive (average 0.4 contacts per dive; SD = 2.64). The large standard deviations for contact numbers in the descent and diving stages showed that some divers were very disciplined and skilful while others were not.

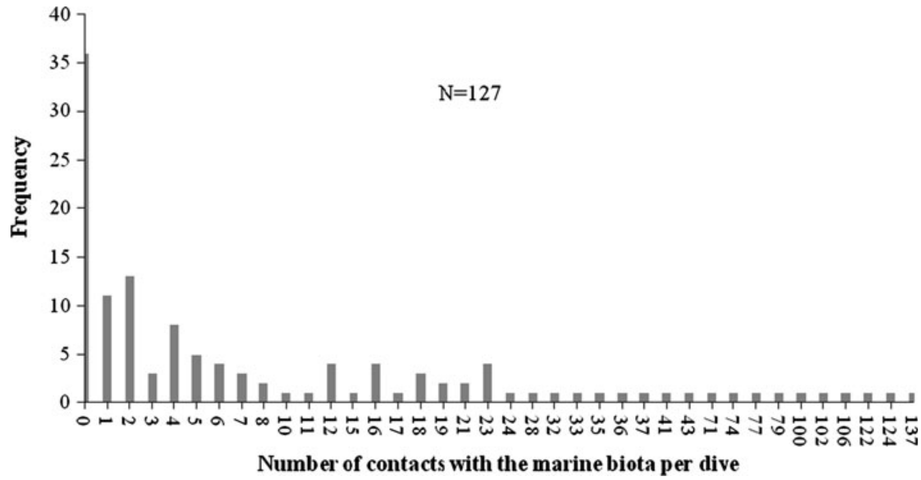

Fig. 1 Frequency chart of contacts made per dive

Diving Skills, Other Diver Attributes and Contact Frequency

The Impact of Underwater Photography

In order to take good pictures, divers need to stabilize themselves underwater by holding on to some fixtures, which often happen to be corals. A Mann–Whitney *U* test (hereafter *U* test) was run to find out if contacts made by photographers (71.5 % of dives) were significantly different from those made by non-photographers (28.5 % of dives). The difference between contact rates of the two groups was statistically significant (U test $= 2089.5$, $P = 0.002$, $N = 123$). Camera-carrying divers made contact with marine biota an average of 23.8 times per dive while divers without cameras only made 11.6 contacts per dive. Thus, it can be concluded that divers who carry cameras make more contact with marine biota than divers who do not carry cameras.

Diving Experience and Diving Impact

In this study, although a very weak negative correlation (Spearman's rank correlation, $r = -0.047$) was noted between the number of logged dives reported by the respondents and the total number of contacts made with marine biota recorded by us, the correlation was not significant ($P = 0.605$, $N = 124$). This did not change even when the correlation was run with the logarithmic form of the logged dive variable (Fig. 2).

Other than corals, we found that some divers also picked up sea cucumbers and touched jelly fish. Good diving practices were also observed, however, with two divers being noted for releasing trapped fish and removing broken fishing nets during their dives.

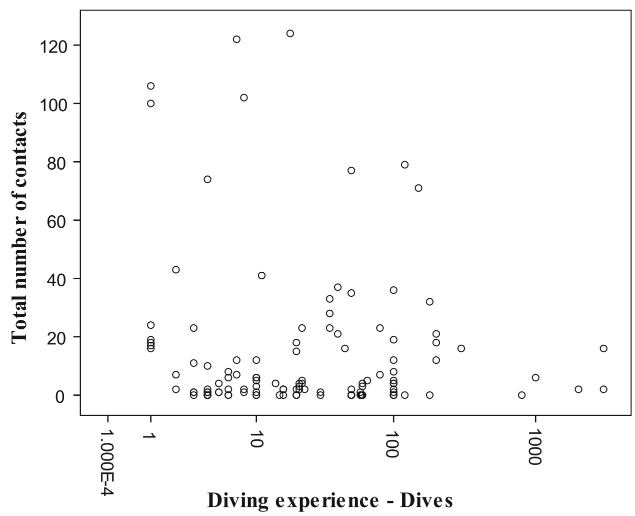

Fig. 2 Scatter plot of diving experience and contacts with marine biota. The *X* axis is in logarithmic form

Gender, Education Levels and Underwater Behaviour

While the average contact rate for female divers was higher than that of male divers (20 vs. 11.15), the difference was not statistically significant (U test $= 1815.0$, $P = 0.239$, $N = 125$). However, the *U* test results showed that divers with tertiary or higher education (11.8 contacts per dive) made significantly fewer contacts with marine biota than divers with secondary and matriculation education (18.6 contacts per dive) (Kruskal–Wallis test $= 9.512$, $P = 0.009$, df $= 2$).

Self Assessment of Underwater Behaviour

As mentioned earlier, one observed diver refused to complete the questionnaire survey. This diver was found to

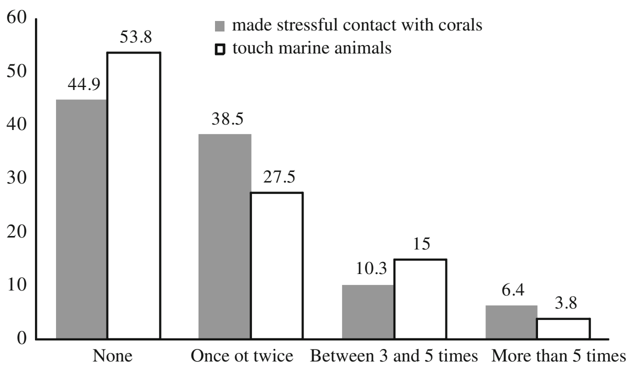

Fig. 3 Self-reported frequency of contact with marine animals and corals ($N = 80$)

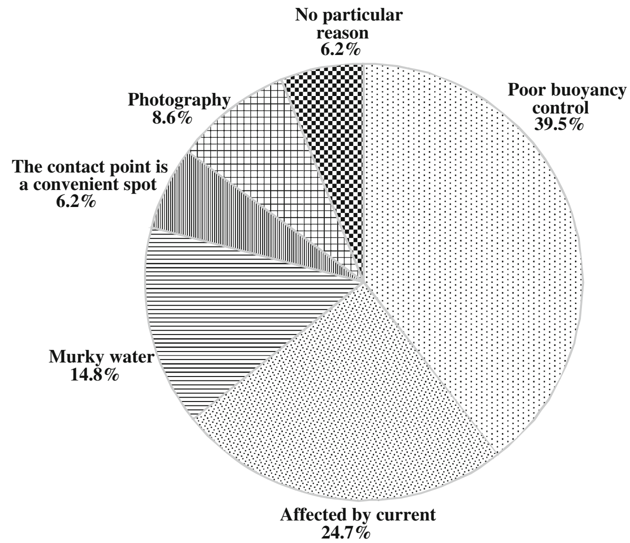

Fig. 4 Reasons for making contact with corals and marine substratum

have made the highest number of contacts with corals among all observed divers. Since the data for this section were collected from the questionnaire survey, the findings in this section have a sample size of 80 only.

Contact and Impacts on Corals and the Marine Substratum

The self-reported data on contacts with marine animals and damaging contacts with coral are given in Fig. 3. While about half of divers said they had not touched any marine animals or made any damaging contact with corals, the other half admitted having touched marine animals and more than half admitted to having made damaging contact with corals.

Reasons for Making Contact with Corals and the Marine Substratum

Divers were explicitly asked to state their reasons for making contact with marine biota on the day of the survey. The most frequently cited reason was inability to control buoyancy (39.5 %), followed by being influenced by current (e.g. to steady themselves in a current) and murky water conditions (Fig. 4). As stated earlier, based on behaviour observation, divers carrying cameras were more likely to make contact with marine biota. Yet, according to divers' self-reflection, underwater photography was the direct cause of contact with the marine substratum only 8.6 % of the time.

Perceived Damage to Corals

Divers were also asked to assess, on a scale of 1–10, the impact they inflicted on corals during the dives they made on the day of the survey. Again, a substantial proportion (92.5 %, $N = 80$) of divers thought damage inflicted on corals by their own underwater activities on that day was either negligible or small (2–4 on the scale). Only six respondents (7.5 %, $N = 80$) thought the damage they had inflicted on corals was substantial ($\geq$5 on the scale).

Divers' Own Perceptions and Reality

To determine if divers' own perceptions of their environmental impact matched reality, a correlation test was run between self-perceived impact on corals (X axis of Fig. 5, data obtained from the questionnaire survey) and the actual number of contacts noted by the research divers. Since both variables are not normally distributed, and one variable contains non-independent observations, a Spearman correlation test was run; the result was not significant ($P = 0.851$, $N = 126$) and the correlation coefficient was low (0.017). Figure 5 shows that both under- and overestimation of actual damage to corals were found. A closer examination of underestimated cases (i.e. where the level of damage perceived by the diver was lower than the actual observed damage) revealed that most of the divers who underestimated damage were beginners with only open water diver qualifications.

Reasons for Diving

The majority of divers (58.8 %) surveyed were diving for fun. About 6 % cited other reasons such as testing equipment and meeting friends as the reasons for diving on that day. The remaining 35 % cited training as the main purpose of diving on that day. This was consistent with our findings that about 36 % of the surveyed divers had fewer than four logged dives and 30 % of them were uncertified divers.

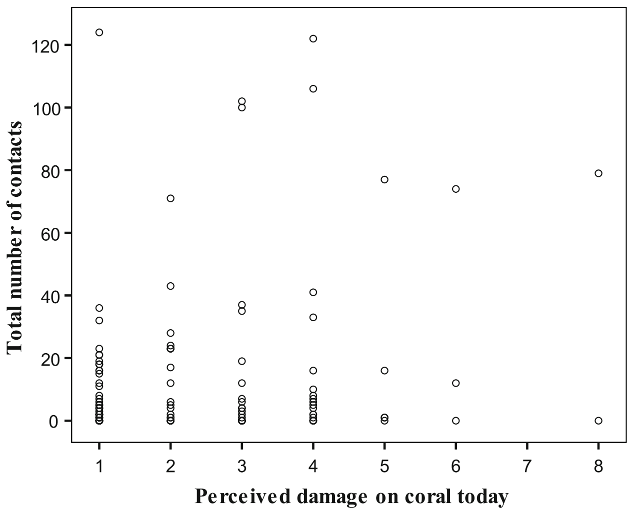

Fig. 5 Scatterplot of observed contact and self-perceived damage on corals ($N = 126$)

Discussion

Samples in This Study

While we sought to compare the profiles in our samples with other similar studies to determine if our samples were consistent with diver profiles studied elsewhere, we were able to make a comparison with only one study because other studies did not include detailed diver profiles (Table 2). In terms of diving experience, both Worachananant and others (2008) and this study were dominated by beginner level divers; however, there were more divers of other levels in our study than in Worachananant and others (2008).

The demographic characteristics in our sample were not representative of Hong Kong citizens (Table 2). Yet, we believe the sample had typical socio-demographic attributes of recreational divers as they were similar to those others had found. Among the 370 scuba divers surveyed by Thapa and others (2006) in Florida Gulf, 76 % were males, well educated (34% had completed tertiary education and 20% had attended graduate school) and fairly affluent. Similarly, the 500 divers surveyed in Medes Islands, Spain, were predominantly male and middle-aged, with middle or university-level education (Mundet and Ribera 2001). Mundet and Ribera (2001) pointed out that the small percentages of very young (<25) and very old divers (>50) in their study were indications that scuba diving was a relatively expensive activity that required a level of physical fitness that was not always found in more senior citizens. Thus, while the respondents in this survey were mainly local Hong Kong citizens, as opposed to the majority being foreigners in the other surveys mentioned, their socio-economic attributes remained similar.

The Strengths and Weaknesses in the Methodology in this Study

A comparison of methodologies used in this and other similar studies is given in Table 1. When we designed the survey methodologies for this study, we tried not to repeat the shortcomings of other studies. Zakai and Chadwick-Furman (2002) conducted a study of the impact on coral reefs from intensive diving by spending 10 min observing each of 35 divers. Similarly, Worachananant and others (2008) investigated scuba divers' impact on coral reefs in Thailand by spending 10 min observing each of 108 divers. However, with a typical duration of 40–45 min per dive, an observation of 10 min is likely to leave a large margin of error if the observed behaviour is used to extrapolate for the entire dive unless the 10-min observations are performed randomly during each dive and on a large number of samples. As a result, in our study, the entire duration of the dive was observed. Longer observation time also reduces the chance of recording unnatural behaviour even if the observed diver is aware of being watched. On the whole, even though we were not able to observe as many divers as Barker (2003), Worachananant and others (2008) and Harriott and others (1997) did, the total observation time in this study was three times that of Worachananant and others (2008) and more than nine times that of Zakai and Chadwick-Furman (2002).

While Barker (2003) recorded the largest number of hours of observation among the seven studies, it would appear that only one observer was involved in recording the diving behaviour of a pair of divers. This raises the concern of missed observation of contacts in that study. Harriott and others (1997) made the second largest number of total hours of observation, yet their observation started only after the descent stage. As mentioned, despite being a short stage in the diving process, contacts with corals during descent should not be ignored. Surely, our samples could have been more representative if we had increased the sample size to match that of Barker. However, unlike in St. Lucia where tourists arrive all year round to dive, the diving season in Hong Kong is short. It runs from mid-May to early October of each year and generally involves recreational diving on weekends only because the main participants of dive tourism in Hong Kong come from the local working class. These constraints limited the sample size. For a sample size similar to Barker (2003), it would have taken several diving seasons and, therefore, several years to complete the study, which was unaffordable in terms of time and funding.

Neutrality of the Observation

The influence of an observer on the observed subject should be of concern to all studies that use systematic observation to collect essential data. However, none of the studies reviewed has mentioned any effective, yet ethically acceptable precautions that can be applied to reduce the influence (of observation) on the observed subjects. This influence may have been less serious in other studies for two reasons. First, the underwater visibility in those research environments was good and, therefore, observers could conduct their observation from a distance. Second, some studies involved only observing a particular diver for 10 or 30 min. Thus, divers might not be aware that they were being watched in water. None of these conditions applied to this study because we undertook to record the entire dive in poor underwater visibility conditions. Also, we needed to adhere to research ethics and, therefore, could not follow what others had done to ensure natural behaviour. For instance, Zakai and Chadwick-Furman (2002) and Barker (2003) kept their observations secret and Roberts and Harriott (1994) did not tell the divers the true purpose of their study until after the dive. While we could have, as Poonian and others (2010), Worachananant and others (2008) and Camp and Fraser (2012) did, simply abandon the cases where the observed diver appeared to be aware of being watched, we could not afford to abandon the data only because we found out later that the diver had been aware of being watched because of the time-consuming and labour intensive nature of the observation. As a result, we decided to observe the entire dive to boost data accuracy and at the same time examine if there were any significant differences in behaviours of divers who were aware of being watched and those who were not.

To determine whether divers who were aware of the presence of an observer might be more disciplined and cause fewer contacts than they normally would have, we compared the total number of contacts of those who were aware of being watched (54 divers) with those who were not (25 divers, missing value is 2). Since the observations were not totally independent of each other, a U test was run and the result showed that the difference between the two groups was not significant (U test $= 1379.5$, $P = 0.295$, $N = 123$).

The finding that only 30% of divers were unaware of being watched underwater was telling too. As mentioned, Poonian and others (2010), Worachananant and others (2008) and Camp and Fraser (2012) did not use data of divers who appeared to have been aware of being watched. Yet, none of the three studies stated clearly the percentage of cases that they had to abandon because of possible behaviour distortion of observed divers. They simply lightly brushed this issue off by saying that the majority of their observations were conducted without the divers being aware of being observed. From our experience, we surmise that either these authors were more successful at keeping their observation secret than we were or they might actually have underestimated the ability of recreational divers to detect uncommon diving activities (i.e. the observer). In fact, it is not too difficult to tell if observer divers are around because to record diver behaviour underwater, research divers typically carry with them a large slate board which recreational divers do not normally carry.

Contacts Made by Divers and Factors Affecting Contact Rates

The Behaviour of Hong Kong Divers and Divers' Impact

A study of the reef areas in Florida Keys concluded that between 4 and 6 % of the corals there were touched each week by divers (Talge 1993). However, most studies describe diver impacts in terms of number of contacts or breakage per period of time. Thus, we also present our findings in the same way to enable direct comparison (Table 5). A study of an aquatic reserve in northern New South Wales, Australia, found that during each dive an average of 35 contacts with the substratum were made by divers. About 7 % of these contacts caused some visible damage to the biota (Roberts and Harriott 1994). The findings of this study lie somewhere between the rates obtained in study six (see Table 5) (Roberts and Harriott 1994) and study four (Harriott and others 1997). Although the contact rate we found is twice that of study seven, it is considered reasonable and just marginally higher than study one. This study also concurs with study six's finding (Roberts and Harriott 1994) that the scuba tank is the part of a diver that makes the least number of contacts with corals and that most of the contacts made are unintentional.

On the other hand, Worachananant and others (2008) found that for each 10 min of a dive, 3.1 coral damages were found on average, which translates into 19 breakages per dive. Thus, even if it is assumed that each contact with coral made by Hong Kong divers results in coral breakage (i.e. 5–6 breakages per dive), each Hong Kong diver causes much less damage than divers in the Surin Marine National Park. Lower reef density in Hong Kong diving sites may be a reason for the seemingly better behaviour of Hong Kong divers who simply have fewer opportunities to come into contact with corals during a dive. Indeed, the coral breakage rate recorded by Worachananant and others (2008) is the highest among all studies reviewed.

Another commonality between findings from this study and the two Australian studies is that the majority of divers cause insignificant harm to marine biota; the majority of damage is inflicted by a small number of divers. For instance, Harriott and others (1997) witnessed a single diver break 11–15 corals at each of the four sites that they covered. Similarly, based on the written comments of

Table 5 Diver-induced damage compared

	Impact per dive	Place[a]
1.	2.5–5.5 contacts with corals per 10 min of diving; 1.7 breakage of corals and raised 9.4 sediment clouds per 60-min dive at 4–8 m	Eilat, Israel
2.	19 breakage of corals	Thailand
3	14.65 contacts with the substratum or 5.7 contacts per 10 min; 5.86 contacts with coral per dive	Hong Kong
4.	4.9–33.1 contacts with corals with 0.6–1.9 coral breakages per 30 min of diving	Eastern Australia
5.	0.95–3.17 contacts with corals per 10 min	Rock Islands, Palau
6.	35 contacts with the substratum; 2.45 causing visible damage	NSW, Australia
7.	0.25 contact with the substratum per minute	St Lucia
8.	3.3 contacts and 0.96 coral touch per 10 min	Florida Keys

[a] Refer to Table 1 for other study detail

research divers who collected data for our study, three to four divers can be identified as having made a lot of unnecessary contacts. As a result, the remarks made by Rouphael and Inglis (1995) that most damage (70 %) to the Great Barrier Reef was attributable to only a small number of divers (4 %) still seems valid. If there is an effective way to identify these divers and conduct education programmes tailored to their diving-related behavioural problems, then diver-induced damage to marine biota can perhaps be kept to a minimum. However, none of the above-mentioned studies specified who the careless divers were. While we have attempted to search for commonalities among these careless divers in our samples, it has proven to be impossible because the number of individuals in the high-impact diver group is too small to make statistical comparisons with other groups.

Other findings common between our study and others, including Barker (2003), Worachananant and others (2008), Zakai and Chadwick-Furman (2002), Poonian and others (2010), Hawkins and Roberts (1992), Harriott and others (1997) and Camp and Fraser (2012) are that the most frequent form of contact is by flippers and most of the reef damage is accidental. Similarly, our findings on contact rates of camera-carrying divers are also consistent with the conclusion reached by Worachananant and others (2008) who found that non-photographer divers caused less damage than divers with cameras. This study and Camp and Fraser (2012) both note that diver impact at the descent stage can also be significant.

Worachananant and others (2008) found that female divers tended to cause more damage than male divers. Such a trend was not statistically supported by this study. Yet, we found that divers with tertiary or higher education tended to make less contact with marine biota than divers with secondary- and matriculation-level education. Since no other studies have shown similar findings, it cannot be concluded that educational attainment is a universal factor influencing a diver's underwater discipline.

Is Diving Behaviour Influenced by Diving Experience?

One factor that is generally believed to influence diver contact rates is diving experience. In support of this general belief, Thapa and others (2006) showed that the level of recreational specialisation was positively correlated with the environment friendliness of divers and it was confirmed by Worachananant and others (2008) that there was a negative correlation between the number of logged dives and the number of contacts with corals. These findings may provide justification for excluding untrained divers from environmentally vulnerable reef areas to restore the carrying capacity of a given reef area (Tratalos and Austin 2001). But the same as Camp and Fraser (2012), we were not able to statistically confirm the relationship between diving experience and diver contact rates. For our case, it was probably because our sample size was small and the variance was large. But as is evident from our observations, many novice divers were already capable of controlling their movements underwater. Having said that, it is also notable from Fig. 2 that divers having more than 500 logged dives make far fewer, if any, contacts with marine biota and those making the most contacts are the less experienced divers whose contact rates are more variable, a phenomenon also discovered by Barker (2003). As a result, it is still appropriate to suggest discouraging inexperienced divers to train in reef areas by holding the instructors responsible for selecting sandy or non-reef areas to conduct training dives (Barker 2003) on one hand, and promote continuous diving training on the other. The latter suggestion is also a response to ours and Roberts and Harriott's (1994) findings that many divers are unaware of or have the wrong impression of the number of contacts they make during dives and that new divers are less aware of their own behaviour underwater. As a diver gets more training and gains more experience, his/her own perception of the damage can become more accurate and it will be more possible to convince them to change.

Another explanation for the discrepancy between our findings and those of Thapa and others (2006) is that the latter relied only on self-reported beliefs and values while we directly observed the actual behaviour of divers. In particular, since it is found that camera-carrying divers tend to make more contact with coral and that in general, camera-carrying divers are more experienced divers, it is possible that the presence of cameras has obscured the correlation between diving skills and environment friendliness in our study. Our findings are also different from those of Worachananant and others (2008) probably because of the more sparse distribution of corals in Hong Kong and that those who are most likely to cause damage to corals (i.e. beginners) are usually trained by instructors in sandy grounds far away from coral formations. Our failure to connect diver behaviour with diving experience is, however, not unique. Earlier, Harriott and others (1997) and Roberts and Harriott (1994) also concluded that there was no significant difference between the total number of contacts and uncontrolled contacts made by experienced and novice divers. Barker (2003) similarly could not find any statistically significant relationship between level of diver qualification and diver contact rates.

Sediments Raised by Divers

Different ways were used to measure diver-induced sediment disturbance. Barker (2003) measured how many times sediment was raised by different parts of a diver and her finding was similar to ours, i.e. flippers and hands were the parts of divers' body that most frequently raised sediment. However, since Barker (2003) presented her findings in a diagram and did not state the average figures for raising sediment by each diver, we were not able to make a detailed comparison with her results. On the other hand, Zakai and Chadwick-Furman (2002) measured sediment disturbance by the number of sediment clouds raised, a term that was not defined in their study. Furthermore, there was no discussion on the adverse impact of diver-induced sediment disturbance in their paper.

Hasler and Ott (2008), however, were able to measure sedimentation rates with the use of sediment traps. They concluded that sedimentation rates were higher at diving site entrances but decrease as the distance from entrance increases. Even when measured, since different units of measurements were used by different studies, it was difficult to compare the findings. As a result, diver-induced sediment disturbance remains an information lacuna in diving tourism impact studies.

Balancing Affordability of Research with Quality of Data

While direct observation that uses systematic records is a relatively objective and accurate way of examining divers' underwater behaviour, it is also a time-consuming process. Obviously, it is much easier to get a greater number of samples if only 10 min of each dive are observed and recorded. Thus, if this inexpensive approach does not lead to biased results, the cost of diver studies can be affordable in terms of the effort expended. Further studies would be needed to objectively identify the most cost-effective duration of observation (entire dive vs. 10 min). In order to do so, in future studies, diver behaviour should be recorded separately for every 10-min segment so that comparisons between diver behaviour during each segment and in the whole dive can be made to draw a conclusion. However, because the variances of key variables are usually large, in accordance with fundamental sampling principles, a large sample size and preferably with stratification of samples by education levels, diving experience or the purpose of the dive (e.g. bringing vs. not bringing a camera) would be advisable. Among all the studies, only Barker (2003) employed a stratified sampling method. This may indicate that researchers have generally considered it unaffordable to sample a sufficiently large number of divers through direct underwater observation.

Comparatively speaking, a large number of samples can be gathered in a short period of time by administering a questionnaire to divers, a method that is less labour intensive. Thus, if it can be shown that self-reported data from divers and their assessment of their own impact on the marine environment are accurate, then questionnaire surveys would be a much more affordable and efficient way to obtain high quality data. However, we were unable to show that the self-perception of divers in our samples was in line with reality. Thus, it seems that there is no short cut available to understand divers' underwater behaviour other than direct observation.

Limitations of the Study and Areas for Further Research

Although not the only one (see "Is Diving Behaviour Influenced by Diving Experience?" section), we failed to confirm the general belief that diving experience is connected with the level of damage a diver causes underwater. However, it is worth mentioning that Roberts and Harriott (1994) may have used the wrong test instrument, independent samples *t* tests which assume that the distribution of the variable is normal. However, our experience was that the distribution of contacts made by divers was not normally distributed. There are also signs showing that the data obtained by Roberts and Harriott (1994) were not normal because the authors admitted that the variation from the mean contact number (in their case, 35) was very high with a minimum of two and a maximum of 121 contacts per dive. Using the correct statistical tool for testing non-normally distributed variables, we managed to show that camera-carrying divers making more contacts than those without a camera is statistically valid despite an unreported independent samples *t* test result that showed otherwise.

We were also unable to deduce the contact rate on a per minute basis with respect to different stages of the dive as we did not record the exact minutes of time for each descent and ascent we observed. Since it is now known that significant damage to marine biota may be caused during the descent stage also, future research should be planned to track the contact rate (per minute) during descent.

While this study may fill the information gap by depicting quantitatively the potential damage inflicted on the marine ecosystem in Hong Kong, it is still only a snapshot of the big picture and yields little information about other related important issues such as coral breakage rates, most vulnerable coral types, the effect of improved diving education or intervention by diving guides, regenerative capacity and other responses of different types of coral over time to anthropogenic damage. Low water visibility and the need to follow the entire dive hampered the ability of our research divers to keep more detailed records of the type of coral contacted or damaged. Night diving is also an activity that we were not able to address in this study. Yet, with the exception of Barker (2003), none of the other studies reviewed covered night dives. It is common knowledge that under reduced visibility, divers make more contact with the substratum during night dives. This is also supported by Barker (2003) who found that more than twice the number of contacts per 40 min dive occurred during night diving than during day diving. The main reason for not being able to track the behaviour of night divers in this study is that organized night dives are not common in Hong Kong and, therefore, it would take several diving seasons before an adequate sample size can be obtained if we included night dives in our study as well.

We also failed to translate the amount of damage into measurable long-term impact on marine biota. Despite evidence of the resilience of some coral reefs, new research to determine the last aspect mentioned is particularly important because of the emergence of a new threat—ocean acidification. As acidification intensifies, will those corals be as resilient as before? Will the generally perceived negligible impact grow beyond the threshold level? More research is needed to provide answers to these important questions.

Conclusions

While local marine ecosystems can tolerate some degree of damage inflicted by scuba diving activities, considering the increasing number of diving activities and the potential synergistic effect of other anthropogenic stressors, there is an imminent need to determine the scale of damage from such activities on marine biota before it is too late to do so. Wide differences among divers in terms of the number of contacts and diver-induced damage to corals and marine biota were noted between this and other studies. This indicates that diver-induced damage is inflicted by certain groups of divers only and this also implies that a large sample size is required to estimate the representative damage caused by diving tourism. Study results also confirm that direct observation is still the most reliable method of understanding divers' underwater behaviour.

Informed by this and other similar studies, the damage-inflicting groups are likely to include inexperienced divers and divers doing underwater photography. In addition, this study also concurs with previous studies that flipper kicks are the most frequent type of contact with corals. However, some findings are unique to this study:

- better educated divers are better behaved;
- as long as observation duration is long enough, the influence of an observer on observed subjects is likely to be insignificant;
- new divers are likely to be less aware of the impact of their diving; and
- the descent stage of a dive also impacts marine biota, which should not be ignored.

The rate of contacts made by Hong Kong divers is within the range of contact rates documented in other similar studies. On the whole, while Hong Kong divers may disturb the underwater environment more than their counterparts in St. Lucia, they are not making as much impact as divers in Australia and Thailand. Despite this, it is evident that promoting good reef etiquette is still a sensible and correct approach within diving tourism management. Effective ways to reduce diver damages include intervention by guides (Barker 2003), administration of pre-dive briefings that remind divers not to harm underwater living creatures (Camp and Fraser 2012), moving all training divers to sandy areas and imposing a diving moratorium on dive sites that are seriously damaged.

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