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Scuba diver behaviour and the management of diving impacts on coral reefs

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Abstract

Coral reefs worldwide are attracting increasing numbers of scuba divers, leading to growing concern about damage. There is now a need to manage diver behaviour closely, especially as many dive companies offer unlimited, unsupervised day and night diving from shore. We observed 353 divers in St. Lucia and noted all their contacts with the reef during entire dives to quantify rates of damage and seek ways of reducing it. Divers using a camera caused significantly more contacts with the reef than did those without cameras (mean 0.4 versus 0.1 contacts min^{-1}), as did shore versus boat dives (mean 0.5 versus 0.2 contacts min^{-1}) and night versus day dives (mean 1.0 versus 0.4 contacts min^{-1}). We tested the effect of a one-sentence inclusion in a regular dive briefing given by local staff that asked divers to avoid touching the reef. We also examined the effect of dive leader intervention on rates of diver contact with the reef. Briefing alone had no effect on diver contact rates, or on the probability of a diver breaking living substrate. However, dive leader intervention when a diver was seen to touch the reef reduced mean contact rates from 0.3 to 0.1 contacts min^{-1} for both shore and boat dives, and from 0.2 to 0.1 contacts min^{-1} for boat dives. Given that briefings alone are insufficient to reduce diver damage, we suggest that divers need close supervision, and that dive leaders must manage diver behaviour in situ.

Keywords: Scuba diving; Coastal management; Ecotourism; Environmental impact; Tourism

1. Introduction

Coral reefs are renowned for their beauty, diversity and the spectacular array of life that they support and for their provision of many important services to people. These include coastal defence, fisheries, a focus for tourism and products for construction and medicinal compounds. Despite their obvious value, coral reefs are in global decline from a wide range of anthropogenic stresses. Pollution from sediment (Hodgson, 1993; Sladek Nowlis et al., 1997; Carias, 1998; Nemeth and Nowlis, 2001), chemicals (Guzmán and Holst, 1993; Negri et al., 2002) and sewage (Walker and Ormond, 1982; Bell, 1992; Koop et al., 2001) has led to a decrease in growth, reproduction and survival rates of corals and other reef-associated species. This decline in reefs comes when marine tourism is expanding. Technical advances in equipment in addition to a rising interest in nature, conservation and environmental matters (Ceballos-Lascuráin, 1993; Orams, 1999) have resulted in the increased popularity of coral reef recreation, particularly scuba diving.

Financial gains from coral reef tourism can be significant, ranging from US$2million per year for the tiny 11 km^2 Caribbean island of Saba (Fernandes, 1995), to US$682 million gained in 1991–1992 from tourists to the Great Barrier Reef, Australia (Driml, 1994). However, diving, once thought to be benign (Tilmant and Schmahl, 1981; Talge, 1992; Hawkins and Roberts, 1992, 1993) is not necessarily so. Signs of diver damage such as broken coral fragments and dead, re-attached and abraded corals have been reported at heavily used dive sites throughout the Caribbean, Red Sea and Australia (Muthiga and McClanahan, 1997; Hawkins et al., 1999;

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Tratalos and Austin, 2001; Zakai and Chadwick-Furman, 2002). Diver damage varies depending on the types of corals present. Branching corals appear to sustain most of the breaks (Rouphael and Inglis, 1997; Garrabou et al., 1998) although Hawkins et al. (1999) found that due to their faster growth, the percentage cover of branching corals in Bonaire increased by 8.2% in heavily dived areas, at the expense of slower growing corals.

Certain dive and diver characteristics have also been linked to diver damage. Inexperienced divers, those with less than 100 dives, may be more likely to damage the reef than experienced divers (Roberts and Harriott, 1994), although some studies found no such trend (Harriott et al., 1997; Rouphael, 1997). Although a large proportion (70–90% depending on the study) of divers contact the reef during their dive, a minority cause most of the damage (Talge, 1991; Rouphael and Inglis, 1995; Harriott et al., 1997). Male divers, camera use and the initial phase of the dive are also associated with increased levels of reef damage (Rouphael and Inglis, 2001). Fins cause most damage to the reef, followed by hands, knees and equipment gauges (Rouphael, 1997). Apart from contacts with living substrate, fin kicks can also re-suspend sediment, which then settles on whatever substrate is in the vicinity, including corals (Rouphael and Inglis, 1995; Zakai and Chadwick-Furman, 2002).

One way of reducing damage is by diver education. Medio et al. (1997) showed that divers did less damage after they were given a 45-min illustrated dive briefing covering reef biology, contacts caused by divers and the concept of a protected area, followed by an in-water demonstration lasting a few minutes. Divers were shown the different forms of live reef cover and non-living substrate, such as rock and dead coral, to illustrate areas of the reef that could be touched safely. However, dive companies often give briefings that last only a few minutes and in many instances those briefings do not include how to avoid damaging the reef. Even if visitors are briefed about avoiding touching the reef, it is not known whether such briefings are sufficient to control their behaviour.

A positive aspect of diving tourism is the economic gain from user fees which help pay towards reef management. Marine parks such as Saba and Bonaire in the Caribbean have, through a fee system, become self-financing (Dixon et al., 1993; D. Kooistra, 2002 pers. comm.). Though divers may be willing to pay park fees such a system is pointless if, in the process, they destroy what they have come to see.

It is clear that coral reefs are a valuable but vulnerable asset to the dive tourism industry, but that with the growth of reef tourism, damage from reef users must be addressed. This study quantifies diver damage in St. Lucia, one of the Windward Islands of the Eastern Caribbean (Fig. 1) and seeks ways to reduce it. Tourism is one of St. Lucia's main industries (CIA, 2002) accounting in 2001 for an estimated 53% of GDP (WTTC, 2002). An estimated 137,000 dives are done yearly throughout the island (Barker, 2003).

In this study, we determined the influence of certain characteristics of divers, dives and dive sites on levels of damage caused by divers visiting St. Lucia. We tested the effect on diver behaviour of a one-sentence inclusion in the usual dive briefing given by dive leaders, asking divers to avoid all contact with the reef. We also tested the effect of intervention by dive leaders if and when they saw a diver contacting the reef. In contrast to Medio et al. (1997), where Medio carried out all brief-

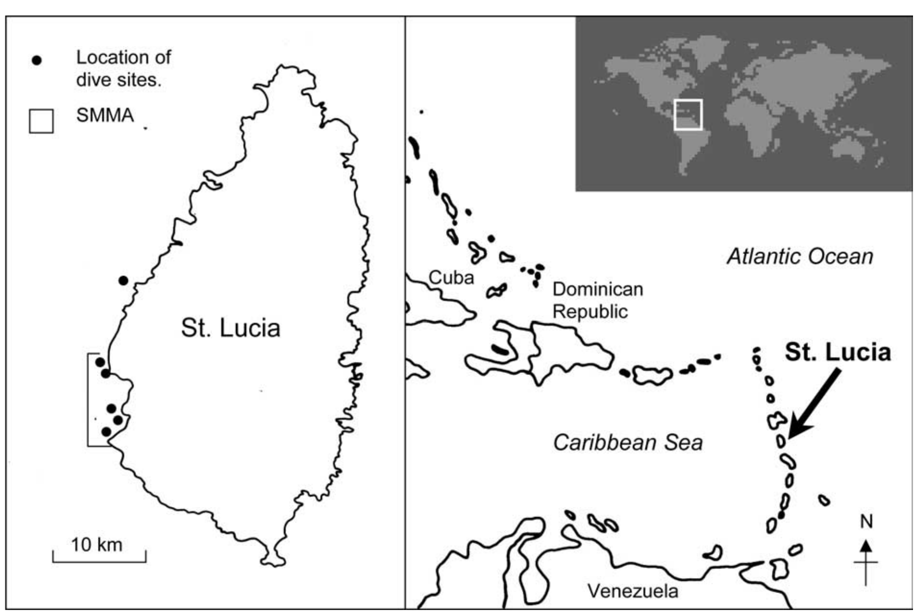

Fig. 1. Location of study area. Boxed area on west coast of St. Lucia shows the boundaries of the Soufrière Marine Management Area (SMMA). Dots show approximate locations of dive sites.

ings and demonstrations himself, we used non-scientifically trained dive staff to give the briefings and carry out interventions.

2. Methods

2.1. Study site and diver samples

We collected data on scuba divers in St. Lucia for 26 weeks spread over two periods. The first (12 weeks between 13 December 2000 and 11 March 2001) coincided with the high tourist season and the second (14 weeks between 28 June and 7 October 2001) with the low season. One of us (N. Barker) accompanied guests diving with a dive company based within the Soufrière Marine Management Area (SMMA) a marine protected area on the south–west coast. Dive staff were asked to treat the observer as any other guest so that the observer remained anonymous and to prevent any change in behaviour by the divers due to the observer's presence. Dive sites were all, with the exception of one, within 5 to 10 min transport time away. On arrival at a dive site, a briefing was given to divers.

Stratified random selection was used to decide which divers were to be observed before they entered the water in order to fill chosen sub-groups. These included: photographers or non-photographers, first day divers or divers on their second or more day of diving, men or women, cruiseship visitors or visitors staying in hotels on the island, visitors diving from the shore or from the boat. On each dive, between one and three divers were discretely observed from a distance of 3–4 m underwater. Observations started from the time divers entered the water and ended at the point when they began their ascent to the surface.

After each dive, divers that had been observed were asked about their diving experience using two questionnaires, constructed to elicit diver perceptions of the reef and their expenditure patterns, both of which were for separate studies (Barker, 2003). Embedded within those questionnaires were questions pertaining to personal dive history and dive holiday. Divers were asked how many dives they had done so far on their trip to St. Lucia and in total since becoming certified as divers, what was their highest diving qualification, whether they were members of an environmental group or read articles on marine life and their age. Visitors that enquired about the observer's note taking underwater were told that information was being collected on the fish and corals for the marine park.

2.2. Dive sites

The operator used 10 dive sites inside and two sites outside of the SMMA (Fig. 1). All 12 sites used for observations of divers were classed according to topography: plateau, sloping, wall and varied, the last being for sites that had some combination of the three topographies. The dive company used sites in rotation, but weather or client needs sometimes required certain sites to be used more than others. For all recreational scuba divers diving with the operator (whether their dive qualification was at the Basic, Advanced or Instructor level), the first dive was a checkout dive, and done from the shore on Anse Chastanet reef (the only site accessible from shore). Divers were required to enter the water from the shore to a depth of about 2 m and perform two tasks: mask clearing and regulator recovery. Observations during Anse Chastanet dives began after those performance requirements had been met. Night dives were also conducted only from the shore, on Anse Chastanet reef. This facilitated our research comparing diver behaviour during day and night dives, as it minimised variation that may have resulted from using different sites. All day dives at the remaining dive sites were accessed only by boat.

2.3. Factors recorded

On each dive, all contacts made by divers were noted as was the number of minutes into the dive, what part of the diver was involved in the contact, whether it was intentional or unintentional, and what part of the reef was affected. The consequence of contact was also noted, whether minor (touch or scrape), major (breakage), and whether or not it resulted in re-suspension of sediment.

During day dives, a method was devised to make approximate measurements of underwater current speed by using a 1 m length of ribbon attached to a pencil. The time in seconds was estimated for the ribbon to unthread and lie straight. Estimates of current rate ranged from 0.08 to 0.94 $m\,s^{-1}$.

To compare our results with previous research on underwater photographers by Rouphael and Inglis (2001), we used similar photographer classes. Divers using single-use and point-and-shoot cameras were classed as non-specialist photographers (e.g., Sea and Sea MX5 and MX10, Bonica Handy Snapper, Aquion Splashshot and Oceanic Aqua Snap cameras). Divers using bulkier and more expensive camera equipment were classed as specialist photographers (e.g., Sea and Sea MMII-EX and cameras in housings).

2.4. Statistical analyses

Non-parametric statistical analyses were used to examine relationships between diver and dive site characteristics and diver contact rates. To obtain predicted contact rates for divers, we used multiple regression using the program SPSS (Norušis, 1990; see also Kinnear and Gray, 2000; and Pallant, 2001) to explore the relationships between twelve independent variables: (1) whether dive leaders were 'on-call' to intervene with divers seen to damage the reef or not, (2) male diver or not, (3) whether diver's lowest diving qualification was basic or not (basic was taken to be any diving course not including rescue training; above basic included courses with rescue training), (4) whether diver was using a camera or not, (5) whether noticeable current was present or not (up to 0.08 m s^{-1}), (6) whether a briefing was given or not, (7) whether the dive was from shore or not, (8) number of dives completed by diver in St. Lucia at point of observation, (9) total number of dives complete by diver in whole dive history, (10) cruiseship visitor or not, (11) whether diver belonged to an environmental group or not and (12) whether diver read articles on marine life or not; and the number of contacts min^{-1} and coral breakages min^{-1}.

3. Results

3.1. Diver characteristics

353 divers were observed underwater throughout their dives, and interviewed immediately afterwards. Slightly more men than women were observed (58.4%) and age ranged from 15 to over 60 years. The mean and median age class for both sexes from the first sample was the same age class of 40–49 years. Age was noted only in the first survey and dropped in the second to compress the questionnaire but our qualitative impression was that the age distribution was similar for both surveys. Proportions of men and women sampled within each age category were similar.

54 (15.3%) of the 353 observed divers were photographers, 33 (9.3%) non-specialist and 21 (5.9%) specialist. 74.1% of photographers were male ($n = 40$) and both sexes had individuals in the non-specialist and specialist categories.

3.2. Diver behaviour underwater

Overall, 261 of the 353 observed divers (73.9%) made at least one contact with the reef during their dive, with a mean contact rate of 0.25 ± 0.04 (95% CI) and a median of 0.09 contacts min^{-1}.

Contact rates of divers were significantly different between sites with different topographies (Kruskal–Wallis Test: both sample periods combined $p < 0.001$). Sites typified by plateaus had a higher rate of diver contact than other sites. Only Turtle Reef and Anse Chastanet belonged to this category. Both were equally close to shore, but only Anse Chastanet was dived from the shore. To determine whether the shore dive caused the significant difference seen, calculations were re-run excluding Anse Chastanet. Contact rates at remaining sites with different topographies were not found to differ significantly from one another (Kruskal–Wallis test, $p = 0.464$). Further analyses therefore consider boat dives and the shore dive separately, and unless mentioned otherwise, analyses only include boat dives.

Many more divers (97.9%) contacted the reef on the shore dive compared to boat dives (65.0%). Divers also had significantly higher contact rates (mean of 0.51 ± 0.12 (95% CI) and median of 0.35 contacts min^{-1}) when diving from the shore than from a boat (mean of 0.2 ± 0.03 (95% CI) and median of 0.05 contacts min^{-1}; Mann–Whitney U test, $p < 0.001$).

Time from start of the dive had a significant effect on contact rates. There were significant differences among the time intervals for both boat dives and the shore dive (Friedman test, $p < 0.001$ in both cases) with the greatest number of contacts occurring in the first 10 min and decreasing thereafter.

3.3. Effect of dive leader briefing and intervention on diver behaviour underwater

Giving a one-sentence environmental briefing had no effect on contact rates of divers on boat and shore dives (Mann–Whitney U test, $p = 0.194$). Excluding the shore dive, no significant difference was found between contact rates of divers given a briefing and those not given one (median of 0.04 compared to 0.05 contacts min^{-1}, Mann–Whitney U test, $p = 0.248$, Fig. 2). However,

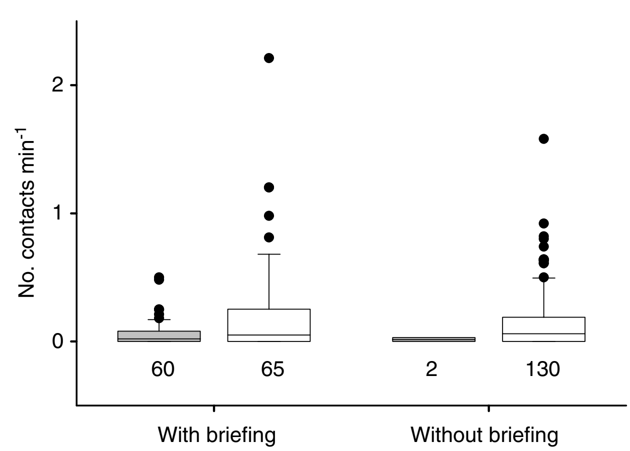

Fig. 2. The effect of briefing and intervention by dive leaders on diver contact rate (boat dives only). Shaded boxes represent dives with dive leader intervention, non-shaded boxes represent dives without dive leader intervention. Boxes represent the interquartile range which contain 50% of the values. A line across the box indicates the median. The whiskers extend to the 5th and 95th percentiles and filled circles are the outliers. Numbers directly below each box represent sample size. Only two instances occurred where divers were not given a briefing but where the dive leader intervened. Both divers had low contact rates and the sample size was not large enough to draw confidence intervals.

there was a significant effect of dive leader intervention on contact rates of divers, reducing mean contact rates from 0.3 to 0.1 contacts min^{-1} on boat and shore dives. On boat dives only, divers whose contact with the reef was brought to their attention by dive-leaders had a median contact rate of 0.02, less than half the median contact rate of 0.05 of divers who were not notified (Mann–Whitney U test, $p = 0.002$). For a 40-min dive with intervention, the mean and median number of times that divers contacted the reef were 2.4 and 1. Without intervention, divers contacted the reef a mean of 7.5 times with a median of 2 times. Similar results were found when shore and boat dives were combined.

3.4. Diver behaviour and influencing characteristics

The distribution of contacts among the various parts of the diver was similar for the shore and boat dives. Taking the mean values from both the shore and boat dives, kicking and touching the reef substrate with fins was by far the most common form of contact (81.4%), followed by touching and holding with hands (10.1%). Most contacts (79.8%) caused minor damage (touch or scrape), almost half (49.0%) resulted in the re-suspension of sediment, and a small proportion (4.1%) caused major damage, i.e. caused breakage. Fin kicks accounted for the greatest proportion of each type of contact: 95.2% ($n = 138$) of major damage, 78.5% ($n = 2228$) of minor damage, and 90.8% ($n = 1581$) of re-suspended sediment. Divers holding onto the substrate with their hands and resting against the substrate with their knees were the next most problematic actions, followed by loose, dangling equipment (gauges and alternative air sources 'octopuses') which brushed against and knocked into the reef.

Considering the type of damage resulting from contacts, shore dives had a small proportion of major damage (1.5%) and roughly equal amounts of minor and sediment damage (51.5% and 47.1%, respectively). Boat dives however showed a higher percentage of major and minor damage (5.6% and 73.4%, respectively), but a lower percentage of sediment damage (21.0%). All contacts resulting in major damage involved direct contact with living organisms for both shore and boat dives. However, contacts with living substrate varied between shore and boat dives. On the shore dive, 35% of contacts that resulted in minor damage and 19.5% of contacts that resulted in the re-suspension of sediment were with living substrate. By contrast, on boat dives, these figures were 84.5% and 73.6% of contacts, respectively.

Most contacts (81.2%, $n = 2888$) were unintentional. However, the distribution of major and minor damage and raised sediment between intentional and unintentional contacts were similar. The frequency of major damage ranged from 2.8% to 4.4%, minor damage ranged from 76.4% to 94.3%, and re-suspension of sediment ranged from 46.6% to 49.5%. The total number of contacts was less than the sum of frequencies of major, minor and sediment damage. This is because some individual contacts resulted in two forms of effect. One fin kick for example, may have resulted in breakage of a coral plus re-suspension of sediment. This one contact therefore scored as both major and sediment damage.

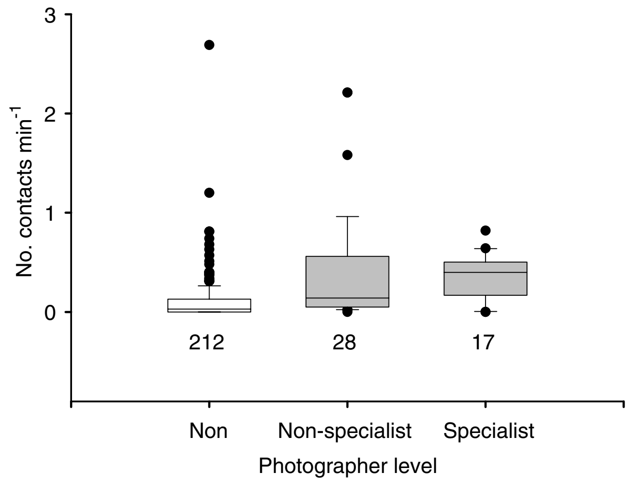

Fig. 3. Contact rate of divers taking photographs (shaded boxes) compared to divers without cameras (non-shaded box) on boat dives. 'Non-specialist' photographers were those using point-and-shoot or disposable cameras and 'Specialist' photographers were those using cameras that required a higher technical capability. Numbers directly below boxes show sample size. See legend to Fig. 2 for explanation of box plot.

Divers using a camera contacted the reef significantly more frequently than non-camera users (Kruskal–Wallis test, $p < 0.001$, Fig. 3), but there was no significant effect of whether or not a diver was a non-specialist or specialist photographer (Mann–Whitney U test, $p = 0.631$).

Contact rate did not vary significantly with the level of dive qualification (Kruskal–Wallis test, $p = 0.137$), possibly due to low sample sizes in the Advanced, Leader and Instructor categories compared to Basic.

Although there was a negative correlation between contact rate and number of dives completed so far on the trip (Spearman's rank correlation, $r = -0.399$, $p < 0.001$, $n = 352$), this was probably biased by the first dive of the holiday which resulted in more than twice as many contacts as subsequent dives. As mentioned previously, the first dive was always at Anse Chastanet, the sole site that was dived from the shore. Once the first dive was removed, the correlation between contact rate and number of dives completed was non-significant ($r = -0.084$, $p = 0.091$, $n = 256$). This result indicated that the site and method of entry (shore dive) were probably the greater influencing variable rather than dive number of holiday. However, experience, as measured by total dives in whole dive history did give a significant positive correlation with contact rate (Spearman's rank correlation: $r = 0.117$, $p = 0.031$).

Rates of contact were compared between night and day dives at the same site for 33 divers. Night dives had more than double the contact rate compared to day dives (mean of 0.45 versus 0.26, Wilcoxon's signed ranks test, $p < 0.001$).

Contact rates did not vary significantly with current speed (Kruskal–Wallis test, $p = 0.923$).

3.5. Predicting rates of contact and coral breakage

Multiple regression analysis using the twelve independent variables confirmed that dive type, photography and intervention status made the strongest contributions to explaining contact rate, so these three variables were used to re-run the regression (Multiple regression, Table 1, $F = 45.786$, $P < 0.001$, $R^2 = 0.282$). Predicted contact rates for any one dive according to the whether the dive was from the shore or boat, whether the diver was using a camera or not and whether the dive leader was on call to intervene or not, ranged from 0.02 to 0.67 contacts min^{-1} (Table 2).

Photographer status was the only significant predictor of breakage rate among the independent variables for boat and shore dives, although the regression was weak. The regression was run again using photographer status as the single predictor variable against breakage rate (Table 3, Multiple regression, $F = 20.873$, $P < 0.001$, $R^2 = 0.056$). Coral breaks by divers were few, but it appears that when they did occur, being a photographer had some, albeit small, influence. Predicted number of breaks min^{-1} for any one dive for photographers was 0.032 and for non-photographers 0.006.

Table 2
Predicted contact rates for any one dive calculated from the multiple regression analysis

Multiple regression equation	
Predicted contact rate (no. contacts min^{-1}) = [0.348 (shore dive) + 0.211 (photographer) − 0.114 (with intervention) + 0.260]^2	
Predicted contact rates (no. contacts min^{-1}) for any one dive:	
Shore dive, photographer, without intervention	0.67
Shore dive, photographer, with intervention	0.50
Shore dive, non-photographer, without intervention	0.37
Shore dive, non-photographer, with intervention	0.24
Boat dive, photographer, without intervention	0.22
Boat dive, photographer, with intervention	0.13
Boat dive, non-photographer, without intervention	0.07
Boat dive, non-photographer, with intervention	0.02

4. Discussion

In St. Lucia, contacts by divers with the reef were common with most occurring during the first 10 min of the dive, when divers were adjusting their equipment and becoming familiar with the underwater environment. Most contacts with the reef (81.4%) were caused by fin kicks, confirming findings in the Red Sea (Prior et al., 1995; Zakai and Chadwick-Furman, 2002) and Australia (Roberts and Harriott, 1994; Harriott et al., 1997; Rouphael and Inglis, 2001), and over half resulted in the raising of sediment. Most contacts (81.2%) appeared unintentional and to be caused by poor swimming technique, incorrect weighting and ignorance.

Camera users were far more likely to contact the reef and to cause a coral breakage than non-camera users, often whilst holding onto or kneeling on the reef when steadying themselves to take a picture. Medio et al. (1997) and Rouphael and Inglis (2001) also found this, the latter study noting that specialist underwater photographers caused on average more damage (1.6 breaks per 10 min) compared to divers without cameras (0.3 breaks per 10 min). In our study, specialist and non-specialist photographers were equally as damaging and in combination caused on average 3.8 contacts and 0.4 breaks per 10 min, respectively. By comparison, divers without cameras averaged 1.1 contacts and 0.04 breaks per 10 min. In Prior et al.'s (1995) study the difference in damage done to corals between camera users and non-camera users was thought to be a function of a greater proportion of the men using cameras compared to women, however our study found no such trend.

Table 1
Multiple regression analysis results showing variables with significant influence on diver contact rate with the reef

	Unstandardised coefficients		Standardised coefficients	t	P-value
	β	Standard error	β		
Shore dive	0.348	0.037	0.448	9.405	<0.001
Photographer	0.211	0.044	0.220	4.790	<0.001
With intervention	−0.114	0.043	−0.126	−2.636	0.009
Constant	0.260	0.023		11.332	<0.001

Table 3
Multiple regression analysis results showing the significant influencing variable on the rate of breakage by divers

	Unstandardised coefficients		Standardised coefficients	t	P-value
	β	Standard error	β		
Photographer	0.026	0.006	0.237	4.569	<0.001
Constant	0.006	0.002		2.851	0.005

The only factor that reduced diver damage in St. Lucia was dive-leader intervention underwater. Contrary to Medio et al.'s (1997) work, we found that if the briefing was short and given by local staff it did not reduce diver contact rate with the reef or the probability of a diver breaking living substrate. By contrast, dive leader intervention was highly effective, reducing average contact rates from 11.6 to 2.4 per 40-min dive (including the shore dive), and from 7.5 to 2.4 contacts for boat dives.

Differences in the type of briefing may in part account for the non-significant effect of a briefing alone on contact rates found in this study and for the difference between our results and those of Medio et al. (1997). However, the short briefing given by dive leaders during our study probably represents a more realistic commitment for a dive company with time and other constraints. Our results indicate that dive companies need to ensure dive leaders brief divers, and more importantly, should intervene when they see divers damaging the reef. For this to be practical, dive group size needs to be small enough so that dive leaders can supervise all members of the group adequately. Our interviews in St. Lucia revealed that many divers appreciated the intervention of dive guides and wanted to avoid damaging the reef.

In our study, shore diving appeared to be more damaging than diving from boats, largely because divers swam across a shallow sandy area at the beginning and end of the dive. Floating buoys could mark where divers should begin their descent and ascent to avoid this problem. Since divers tend to mimic the behaviour of their dive leaders, much good can come from example. Leaders should stay far enough from the reef so that their fins do not stir up sediment or contact coral and avoid touching or holding on to any part of the reef.

Dive leader vigilance is even more important during night dives. Night dives resulted in >2 times as many diver contacts with the reef than during the day, likely in part to reduced visibility at night, causing divers to stay closer to the reef. Reduced visibility also limited our ability to observe divers so our estimate of night-time contact rate is conservative. Encouraging divers to stay well away from the reef at night and making them aware of their increased likelihood of contacting the reef could help reduce the impacts of night diving.

Although diver impacts can be reduced by education and dive leader intervention underwater, high levels of damaged coral may be unavoidable if large numbers of divers use a reef. In St. Lucia, minor damage and the raising of sediment were widespread (79.8% and 49.0% of contacts, respectively), but corals were only broken in 4.1% of contacts. These results are similar to those of Talge (1991) from the Florida Keys, where 90% of divers had one or more physical interactions with the reef but only 2% damaged corals. Minor damage and re-suspension of sediment by most divers may seem trivial, but by compounding other reef stresses, they could undermine the resilience of reef ecosystems (Nyström et al., 2000). St. Lucia's reefs have received substantial amounts of sediment following storms (Sladek Nowlis et al., 1997; Schelten, 2002) and construction work (Schelten, 2002). Sediment is highly damaging to corals (Visser, 1992; Hodgson, 1993; Hawkins and Roberts, 1994; Carias, 1998; Cox et al., 2000; Nemeth and Sladek Nowlis, 2001) and some of St. Lucia's dive sites now have substantial mud deposits. Diving at these sites means sediment is continually being re-suspended into the water column and deposited on coral colonies. Corals subjected to such pollution divert energy from growth and reproduction to rid themselves of sediment (Rogers, 1990; Richmond, 1996; Dodge and Vaisnys, 1997).

When divers have direct contact with corals and other reef organisms they can abrade the protective layer of tissue covering these organisms but the implications of this are unclear. A laboratory study in Florida (Talge, 1992) for example, detected no lasting influence of touching corals on eleven of twelve species. However, popular sites in St. Lucia and elsewhere receive upwards of 10,000 dives per year, where corals are likely to be touched more often than in Talge's experiments. Damaged corals are also more likely to be infected by pathogens or other invading organisms and have a higher risk of mortality than undamaged colonies (Hall, 2001). Hawkins et al. (1999) implicate coral disease, facilitated by diver-inflicted lesions on massive corals, in effecting the shift from massive to branching coral dominance at dive sites at Bonaire.

At sites that are heavily used, diver impacts may render the reef ecosystem less able to recover from bigger stressors such as hurricanes, storms and disease (Hawkins and Roberts, 1992). Above a certain threshold of use, estimated at between 4000–6000 dives per year, coral cover loss and coral colony damage levels may increase rapidly (Riegl and Velimirov, 1991; Dixon et al., 1993; Prior et al., 1995; Hawkins and Roberts, 1997). In Israel for example, the percentage of diver-damaged coral colonies at sites with 4000 dives per year was 8%, compared to 66% at sites with more than 30,000 dives per year (Zakai and Chadwick-Furman, 2002). In St. Lucia 137,000 dives are carried out per annum and approximately 84,800 of those are done in the SMMA (Barker, 2003). One site in particular, Anse Chastanet receives around 28,000 dives per year, well above the suggested threshold.

We conclude that scuba divers can substantially damage coral reefs. While user fees levied on divers can help pay for reef management, more active management is needed to reduce diver damage. Simple measures implemented by dive companies through their dive guides could greatly reduce impacts. They include underwater intervention when divers contact the reef, leading by example in keeping fins and equipment clear of the reef, and extra vigilance toward camera users, on night dives and at the beginning of dives. The size of the dive group will influence the ability of dive leaders to perform their supervisory role, so smaller groups are better for the reef, and are preferred by divers in any case (Barker, 2003).

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