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Intentional and Accidental Diver's Contact to Reefs at Popular Locations in the Dutch Caribbean

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Abstract

The Bonaire National Marine Park, in the Dutch Caribbean, is considered a model park for coral reef conservation and management, and strategies employed here have been modeled around the world. Despite these efforts, its reef, like many reefs in the Caribbean, has shown signs of degradation and decreased resilience over the last decade. SCUBA diving is an ever-growing tourism activity, but divers can damage the very resource this tourism depends on. In this study, the impact of recreational divers was evaluated by counting the frequency at which divers (n=296) touched the substratum. Field sampling revealed that the majority of contacts were made with fins (74%), while few divers touched the substrate with their hands, other parts of the body (knees, elbows, etc.) or instruments. Overall, the divers made statistically more accidental (1.07 ± 2.30) than intentional contacts (0.23 ± 0.77). Variables significantly affecting divers' behavior were found to be the level of certification and the use of an underwater camera. In light of the results, direct and indirect management measures are proposed to reduce user pressure on natural reefs and improve the balance between conservation and use of Bonaire's reefs and avoid further damage on the local environment due to divers.

Keywords: carrying capacity, diver's behavior, SCUBA diver impact, underwater photographer

Introduction

The economic opportunities generated by the tourism industry are obvious but depend on environmental integrity of dive sites (Townsend, 2000). Divers spend time and money to dive in better-preserved dive sites, enhancing the importance of preserving these areas. Tourism, however, can also damage these areas by increasing the need for infrastructure (e.g. hotels, sewage treatment plants), as well as from direct tourist traffic; in this case, boats and divers (Hawkins and Roberts, 2000).

Recreational SCUBA diving is one of the main public activities in Marine Protected Areas (MPAs) and one of the major forms of commercial use (Di Franco et al., 2009, Luna et al., 2009). SCUBA diving allows individuals to have a direct relationship with the natural environment (Augustowski and Francine Jr., 2002). However, several studies have shown that through direct contact with the reef (with body parts or equipment), divers are damaging the environment (Talge, 1990, 1992; Rouphael and Inglis, 1995, Poonian et al., 2010; Chung et al. 2013; Hammerton and Bucher, 2015). Even though one single individual generates limited damage, cumulative effects can cause significant

disturbance, particularly when the resilience of the system is already degraded due to other stressors (e.g. increased sediment load, climate change, etc.) (Garrabou et al., 1998; Hawkins et al.1999; Plathong et al., 2000, Hayes et al., 2015, Titus et al. 2015).

The small Caribbean island of Bonaire created the Bonaire National Marine Park (BNMP) in 1979, one of the first MPAs established worldwide. The park covers an area of 6,672 acres (27 km^2). BNMP is a United Nations Environment Programme (UNEP) demonstration site used as a marine park model. The marine park hosts 70,000 tourists each year, with about 50% of those being divers (BNMP, 2007). Hawkins and Roberts (1997) reported that dive sites in Bonaire have similar fish and coral communities when compared with sites closed to diving only when a maximum of 6,000 dives/year/dive site is respected. However, Scura and van't Hof (1993) calculated the maximum number at between 4,500 and 5,000 dives/year/dive site for maintenance of aquatic communities. Divers impact the reef's fauna and flora in various ways including anchoring, organic waste, sound produced by boats or their mere presence (Hawkins and Roberts, 1992, Edney, 2006, Poonian et al., 2010; Chung et al. 2013; Hammerton and Bucher, 2015). The number of contact events with the substrate is often used as a proxy to study divers' impact on a reef (Poonian et al., 2010; Hammerton and Bucher, 2015; Krieger and Chadwick, 2015). In addition, a recent study showed that heavily trafficked dive sites in Bonaire had 10% less structural complexity than areas with light traffic (Lyons et al., 2015).

Previous research has demonstrated that frequency of contact and breakage of fragile marine organisms depend on (1) technical competence, (2) activities executed underwater, (3) extent and content of the pre-dive briefing (guidelines given by a guide before the dive), (4) physical environmental conditions (i.e., waves and currents), (5) biological characteristics of the dive site and (6) gender (Medio et al., 1997; Harriot et al., 1997; Rouphael and Inglis, 1997; Townsend, 2000; Worachananant et al., 2008; Meyer and Holland, 2009; Luna et al. 2009; Poonian et al., 2010; Chung et al. 2013; Edney, 2015; Hammerton and Bucher, 2015; Krieger and Chadwick, 2015). Recent studies show that even if branching and faster growing corals (such as *Millepora spp.* and *Madracis mirabillis*) might benefit from a slightly increased dive pressure because they naturally spread due to breakage, this comes at the expense of large massive coral (Hawkins et al., 1999; Guzner et al. 2010; Lamb et al., 2014). In addition, increased susceptibility to disease can be linked to coral tissue lesions attributed to diver contact (reviewed in Peters, 1997).

This present research evaluates the risks posed by divers to reefs in BNMP, looking more specifically at the most used and possibly more damaged dive sites, comparing behaviors between guided (boat dive) and unguided (shore dive) divers, photographers and non-photographers, and experienced and non-experienced divers. Strategic actions for the BNMP management following this research are proposed here and may be helpful to other marine parks in the creation of a Visitor Impact Management System. The suggested management strategies can be easily implemented, monitored and can minimize the impacts on the reef.

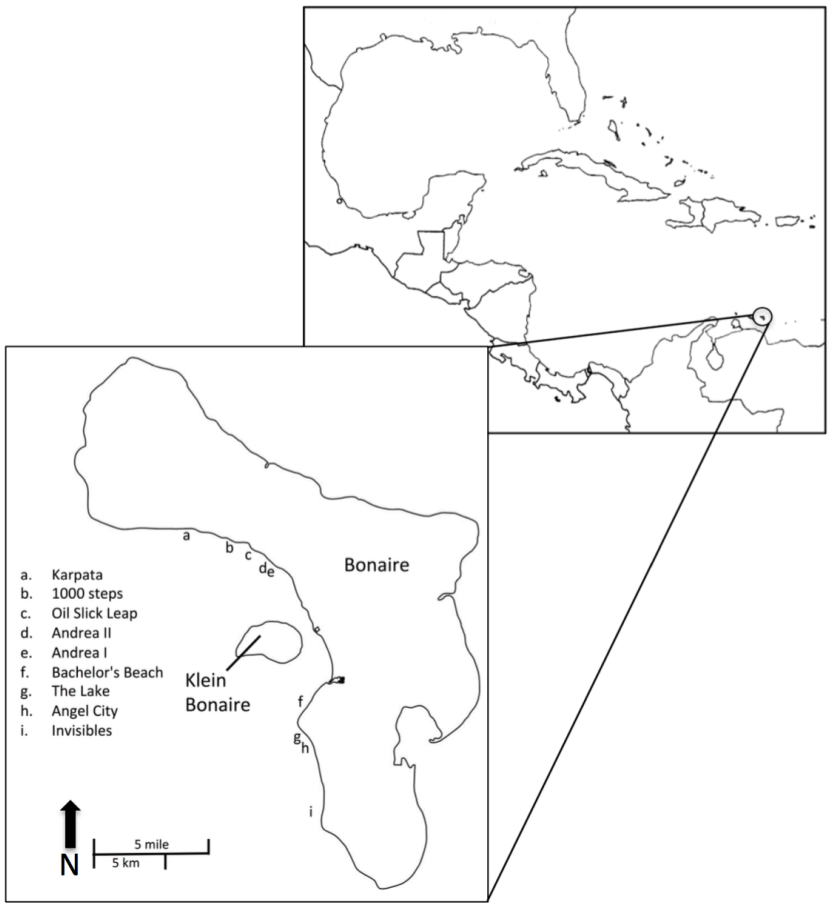

Figure 1. Map of Bonaire in the Dutch Caribbean with nine of the most frequently visited dives sites.

Methods

Field work

From May 12th to June 29th 2008, 296 divers visiting Bonaire (12°10' N 68°17' W, Figure 1) were monitored at 9 of the most frequently visited dives sites (Karpata, 1000 steps, Oil Slick Leap, Andrea II, Andrea I, Bachelor's Beach, The Lake, Angel City and Invisibles). The observer followed the diver for 30 minutes; observations were divided in 3 periods of 10 minutes. For shore dives, the observer entered the water quickly after the diver and made every effort possible to follow the dive party inconspicuously in order to not modify the diver's behavior. In cases where divers noticed that they were being followed, the data were discarded. After the diver(s) exited the water, he or she was informed about the on-going research and after their agreement to participate in the study, the observer interviewed the diver to collect information on the diver's certification level, age, gender, number of dives, years of experience, country, and, in the case of photographers, if they had formal training for underwater videography or photography. Underwater observation of boat dives followed the same methodology as for shore dives. Boat staff were informed about the research only after the surveys were executed.

Dive profile
Direct contacts of divers with the substratum were recorded and classified as intentional (IC) or accidental (AC). Contacts were also classified according to the part of the body or instrument responsible for it (hands, fin, knee, console or others). In addition, the use of underwater video or photo camera was recorded, as was the influence of this equipment on the amount of contacts. Besides certification level and years since initial certification, experience was also measured by the number of dives.

Statistical analysis
Data were tested for normality by the Kolmogorov-Smirnov tests (Sall et al., 2001). Student's T-test was used to evaluate whether diver experience, activity (photography) or the presence of a guide influenced rate of contact. One-way ANOVAs were used to evaluate the difference in contact rate between the 0-10, 10-20 and 20-30 minutes periods and the intentional and accidental contact among the different certification levels. All statistical calculations were performed using the package Statistica 6.0. Normality was tested using Shapiro-Wilks test. When data were not normally distributed, Kruskall-Wallis was used to test for significance (age, number of dives, levels of certification).

Results

Demographics
The interviews conducted after the dives (n=296, 112 guided vs. 184 non-guided) drew a snapshot of divers using Bonaire's reefs at the time of the survey. Divers from the United States of America represented 76% of the monitored divers, followed by Dutch and Brazilian divers with 9% and 6% respectively. Men represented 59% and women 41% of the 296 interviewed divers.

Effects of the level of experience
Open Water Divers (or first course or one star) and Advanced Open Water Divers (or second level or two stars) represented more than 70% of all divers. Rescue Divers (or third level or three stars), Divemasters and Recreational Diving Instructors represented 27%. The divers' experience varied from a few days to 37 years. Divers with more than 11 years of experience were the most representative group and comprised 33.5% of the total. Only 4% started practicing in 2008, the same year of the survey. The least number of dives from a monitored diver was 6 and the most 5,000. Only 12% of the divers were considered novices with less than 20 dives.

Divers with the most experience had the highest level of IC among all certification levels (2.0 ± 0.03, mean ± SE) (one way ANOVA, $p=0.0158$). The Open Water Divers presented the lowest average (0.34±0.05, S.E.), and all the other levels had similar averages with less than one intentional contact during the whole 30 minutes (Table 1).

On the other hand, AC were higher among the Open Water Divers (3.86±0.56, SE) and, unexpectedly, did not significantly differ from the professional levels (Course Director, Instructors, Divemasters) where the average was also higher than three (3.0±0.3, 4.1±0.1 and 3.2±0.2 respectively) (one Way-ANOVA, $p>0.05$). Advanced and Rescue Divers had the lowest average accidental contacts (2.46±0.46 and 2.16±0.54, respectively) during the 30-minute observation time.

Types of contacts
While sixty-three per cent (187) of the observed divers made an accidental and/or intentional contact, only 36 divers (12%) were responsible for 52.2% of the 1,136 contacts made on the substratum. The majority of contacts were made with the fins (74%), while few divers touched the substrate with their

hands (about 14%) or with another parts of the body (knees, elbows, etc.) (9%) and fewer contacts (3%) were made with instruments (Table 1). Interestingly, 100% of the contacts made with instruments (consoles, octopus) were in situations where they were not correctly placed on the diver's Buoyancy Control Device.

Table 1 Number, average and Standard Deviation of contact made by the different demographic sectors with different body parts during the first 30 minutes of the dive.

		Fins		*Hands*		*Other body parts*		*Instruments*		*Intentional touches*		*Accidental touches*	
	n	*Average*	*S.D.*	*Average*	*S.D.*	*Average*	*S.D.*	*Average*	*S.D.*	*Average*	*S.D.*	*Average*	*S.D.*
Female	*120*	2.85	0.29	0.36	0.05	0.17	0.03	0.06	0.02	0.38	0.06	3.07	0.30
Male	*176*	2.88	0.26	0.65	0.11	0.44	0.07	0.13	0.03	0.88	0.13	3.22	0.29
Open water	110	3.59	0.32	0.28	0.04	0.22	0.04	0.08	0.02	0.34	0.05	3.84	0.34
Advanced Open Water	103	2.26	0.25	0.55	0.11	0.34	0.07	0.08	0.02	0.78	0.13	2.47	0.27
Rescue	26	1.85	0.17	0.69	0.09	0.19	0.02	0.15	0.03	0.69	0.08	2.19	0.18
Dive Master	36	2.94	0.22	0.53	0.07	0.36	0.04	0.11	0.02	0.72	0.09	3.25	0.24
Instructor	19	3.26	0.08	1.63	0.04	1.05	0.04	0.21	0.04	2.00	0.03	4.11	0.08
Course director	2	2.00	0.26	0.50	0.19	0.50	0.13	0.50	0.05	0.50	0.19	3.00	0.34
Non-Photographer	93	2.51	0.28	0.35	0.09	0.12	0.03	0.08	0.03	0.40	0.09	2.67	0.29
Photographer	210	3.45	0.25	0.91	0.10	0.77	0.09	0.15	0.03	1.25	0.13	4.03	0.28

Effects of cameras on diver behavior

Photographers/videographers represented 31% (n=93) of the 296 interviewed divers. The photographers had a total of 491 contacts with the substratum, 38% of which were made while taking a photo, 65% were made with fins and 17% were made with hands.

When studying the relationship of photographers and non-photographers and their types of contacts on the substrate it was found that IC was significantly higher (t-test, df=131, p=0.001) among divers with a camera than divers without one. The average of IC during 30 minutes of diving was 1.25±0.13 (S.E.) for photographers and 0.4±0.09 (S.E.) for the non-photographers. AC were also significantly higher (4.03±0.28 vs. 2.67±0.29 t-test, df=180, p=0.029) (Figure 2).

Photographers/videographers with underwater video or photo training represented only 26% of the interviewed photographers. However, it is interesting to note that no significant difference was observed among photographers that had or did not have a formal underwater photography course.

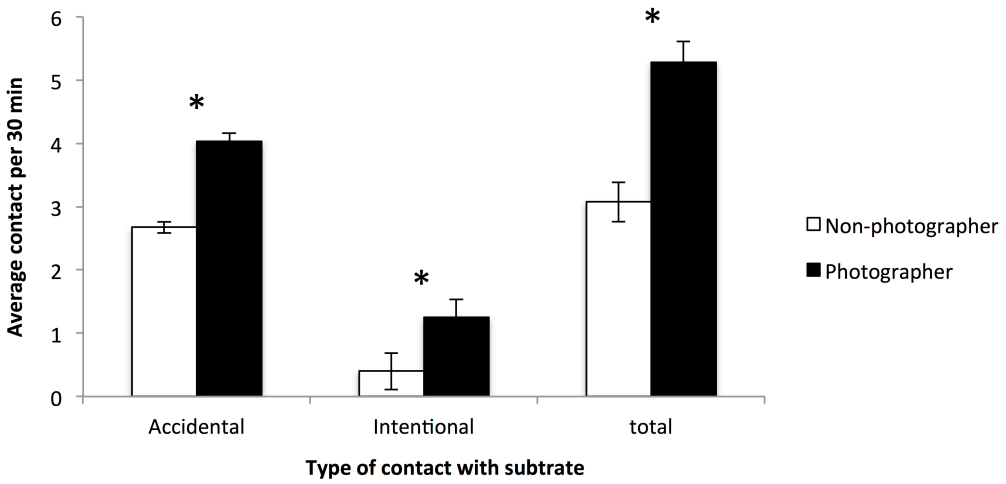

Figure 2. Average number of accidental and intentional contacts by photographers and non-photographers during 30-minute dives. Bars represent standard errors, * statistical significance.

Discussion

Since the establishment of the BNMP in 1979, awareness campaigns for divers in Bonaire's waters have been established. Bonaire's divers spending time in the island marine park touch the substrate less often than other divers around the world (Rouphael and Inglis, 1995; Harriot et al., 1997; Medio et al., 1997; Townsend, 2000; Rouphael and Inglis, 2001; Walters and Samways, 2001; Luiz-Júnior, 2003; Barker and Roberts 2004) (Table 2), this could be attributed to the awareness campaigns but also to other factors such as the topographical relief, diver nationalities or experience, etc.

Similarly to research in other locations, more AC than IC were made (Table 2). AC may be easily reduced with an increase in diver training and peak performance buoyancy clinics for novice divers. Briefings and environmental education have also shown to help lower the number of AC and IC (Medio et al., 1997; Townsend 2000).

First-level divers (PADI open water, CMAS*, etc.) had lower numbers of IC than any other level. Several authors propose the hypothesis that inexperienced divers are more afraid to get close to the reef and consequently less at risk to intentionally touch the substrate (Harriot et al. 1997; Walters and Samways, 2001; Rouphael and Inglis, 2001; Bertuol, 2005). On the other hand, instructors had the highest number of IC. Despite the fact that several contacts were made on dead parts of the corals, it was expected that a lower number of any type of contact would be made by the instructors, since they are the most experienced and, in theory, more conscious about the environment than other divers. While these professionals may be making a conscious decision to touch only dead parts of the reef, they are nonetheless setting a bad example for the less experienced divers under their charge, who may not have the experience to make the distinction between live and dead substrate. This is an important finding of this study and should be taken into consideration when designing materials for sustainable diving tourism plans, which should include specific briefings for dive professionals.

Table 2. Comparison among scientific papers about contact rate around the world with mean and maximum number of contacts, duration of the monitoring, author of the study, status of the area surveyed and country.

Author	Contacts (Mean)	Max. number of contacts by diver	Duration of monitoring (min)	Status area	Location	Comments
Roberts & Harriot, 1994	35	121	NA	Marine Reserve	Julian Rocks Aquatic Reserve Southeastern Australia	
Harriot, et al., 1997	121.2	304	30	Marine Reserve	Solitary Islands, Eastern Australia	
Harriot, et al., 1997	52.2	192	30	Not Protected	Gneering Shoals, Eastern Australia	
Harriot, et al., 1997	44.5	296	30	Marine Park	Lady Elliot Island, Great Barrier. Australia	
Harriot, et al., 1997	31.3	296	30	Marine Park	Heron Island, Great Barrier. Australia	
Luiz-Júnior, 2002	4.6	14	30	Marine Park	Laje de Santos, SP, Brazil	
Luiz, 2008**	5.0	27	30	Marine Park	Fernando de Noronha, PE, Brazil	
Present work	**3.75**	**33**	**30**	**Marine Park**	**Bonaire, Dutch Caribbean**	
Rouphael & Inglis, 1997	5.4 ± 0.63	30	10	Marine Park	Agincourt Reef, Great Barrier. Australia	The authors count the "damage interactions"
Townsend, 2000	6.56 ± 8.48 1.95 ± 2.98	40 14	10	Marine Park	British Virgin Islands	The second set of numbers are after environmental education
Walters & Samways, 2001	0.15 to 2.49 0.21 to 0.75	NA	10	Not Protected	Two mile Reef, South Africa	First set of number are for accidental touches, second for intentional touches Range depending on diver's experience
Zakai, & Chadwick- Furmen, 2002	2.5 ± 2.6 to 5.5 ± 4.6	NA	10	10 of 12 sites in a Coral Beach Nature Reserve	Eilat, Israel	Range depending on topography
Bertuol, 2005	9.67 ± 1.08	47	10	Buffer zone of Marine Reserve	Arvoredo Island, SC, Brazil	
Barker & Roberts, 2004	0.25 ± 0.04	NA	Entire dive	Marine Protected Area	St. Lucia	
Medio, 1997	1.4	NA	7	Boundaries of Marine Park, and Marine Park	Ras Mohamed, Egypt	prior briefings

** Unpublished report to IBAMA – Brazilian Environmental Authority

As expected, AC were high among the first level divers having less buoyancy control. Because a higher portion of these contacts are made in the first 10 minutes of the dive, this could be mitigated by beginning dives over sandy substrate when novice divers are present, to allow some buoyancy acclimation time before proceeding to the reef. Surprisingly, however, instructors and divemasters also showed high average number of AC, almost as high as the first level divers (despite smaller sample size and higher variability). Professional divers (instructors and divemasters) should serve as models of conduct to others divers. Attention must be paid to these diver levels when applying management measures.

Several studies have shown that, when it comes to contacts on the substrate, underwater photographers are the most problematic group (Medio et al. 1997; Rouphael and Inglis, 2001; Barker and Roberts, 2004). Consistent with other research (Medio et al., 1997; Barker and Roberts, 2004), the present study determined that both AC and IC were statistically higher among photographers than non-photographers, implying that they tend to cause more damage to coral reefs.

It is interesting to note that photographers with formal underwater video or photo training were not statistically different from photographers without training in their number of contacts. This indicates that formal underwater video or photo courses are not effective in transmitting the importance of environmental protection. Indeed, environmental protection is poorly discussed in most of underwater photography handbooks, which do not mention that the use of underwater photography equipment may damage the underwater ecosystem or teach special buoyancy control techniques. This is something that can be easily rectified through diligent outreach within the underwater photography community and discussion with diver education organizations.

During this study, only a very small percentage of contacts were intentional (17.6% IC vs. 82.4% AC). However, these IC did not necessarily involve damaging the substrate. Many were made on a dead coral or sandy patch to provide support while taking pictures. It is therefore recommended to include, in any sustainable diving briefing, the notion that a careful IC is far better for the environment than a devastating AC. These are potentially more harmful to the reef since AC are mostly made with fins or instruments when divers cannot see where they are touching and don't realize how strong this contact is. On the other hand, most IC are usually less damaging as they are mainly made with the hands. The strict prohibition on the use of gloves inside the BNMP probably plays a major role in the lower IC numbers observed in this study.

During the year 2008, a total of 36,219 divers purchased the dive tag allowing them to dive in the BNMP (STINAPA, 2008). According to the manager of the park (Ramon de Leon, pers. comm.) an estimated 40% of these divers returned to dive during the same year. The carrying capacity values presented by Dixon et al. (1993) and Hawkins and Roberts (1997) for Caribbean coral reef environments range from 4,500 to 6,000 dives per site per year. Assuming that each person dives for 6 days and averages 2-3 dives per day, at the end of the year a total of 608,479 - 912,618 dives were done in the BNMP during 2008. Assuming dives are equally distributed among all the 89 dive sites presented by informative maps of the BNMP, an average of 6,837 - 10,254 dives/site/year are made, which is already above estimates for sustainable carrying capacity. However, Bonaire's divers seem to have a preference for a few sites for various reasons, e.g., ease of access from shore, easy entry and exit, presence of dive shops or other facilities. Thus the most frequented sites would have a number of divers much higher than 10,000 per year, well above the recommended dive carrying capacity and would therefore be the most at risk. The same authors emphasize that environmental education and suitable management measurements (rotation of dive sites as an example) could increase the carrying capacity and help devote more money to the conservation of Bonaire's reefs.

In the BNMP, each diver must attend an orientation briefing before the first dive. This orientation briefing and the subsequent changes in the diver's behaviour may be effective as this study presents one of the lowest observed levels of substrate contact (Table 2). However, based on the findings of this study, park managers could implement changes in the briefings in order to lower contact rates, for example by emphasizing the negative impact of even small intentional contacts by photographers and dive professionals; a group shown to have one of the highest rate of contact with the reef in this study.

Some management measures are suggested in order to minimize the effects of the divers in the region:

- Divers' behavior is influenced by the use of educational tools (Medio et al., 1997). We recommend dive professionals (divemasters and instructors) of local operators should be required or strongly encouraged attend environmentally aware diver-education programs to increase their ability to deal with guests touching the substrate. A superficial pre-dive briefing does not decrease the number of contacts (Baker and Roberts 2004).
- Peak performance buoyancy programs, offered by most dive agencies, should be promoted and offered at low cost by local operators in order to decrease the number of AC.
- Photographers are a risk group and cause more damage than other divers. Since no difference was found among photographers with or without a formal underwater photo or video course, it is important for dive agencies such as PADI and CMAS to re-evaluate their course materials in order to emphasize the need of being more environmentally conscious while taking underwater photos or videos. Underwater photo/videographer divers course should include special buoyancy, body control techniques and a special dive gear configuration.
- Marine Park briefings should pay particular attention to the potential damage that can be caused by careless body motions while photographing, and suggest sustainable photography techniques.
- Manufacturers of underwater cameras and housings could include materials on environmental stewardship with their products and recommended techniques to avoid damage.
- Instructor training should include the need for a responsible environmental conduct of the dive professional and consequently of their students. This study shows instructors are not leading by example, since they had the high levels of contact.
- Educational leaflets and booklets in MPAs and popular dive sites, like those used by the BNMP, should include information about the importance of buoyancy acclimation of novice divers during the first minutes of the dive. In addition, dive operators could lead novice divers to a safe area in the beginning of the dive before proceeding to the reef.
- The most used dive sites are also chosen inter alia due to their ease of entrance and exit from the water (presence of stairs and platforms). By improving access to similar facilities at different dive sites, diver pressure could be more evenly distributed, reducing negative impacts at the most pristine sites.
- The number of dive sites available could be increased by adding artificial reefs and diverting divers to these sites in order to decrease dive pressure on natural reefs. This technique has been effectively employed elsewhere in the Caribbean, the Red Sea and the Gulf of Thailand (Leeworthy, 2006, Polak and Shashar, 2012; Nichols, 2013; Kirkbride-Smith et al., 2013; Edney and Spennemann 2015). Divers in training could be required to conduct checkout dives on these sites to gain control of their buoyancy before diving on the natural reef.
- Monitoring needs to be continued. Volunteers and the BNMP staff should be trained in order to reproduce the methodology used here to monitor the evolution of Bonaire diver behavior and evaluate the success and failure of the management strategies put in place. A measurement of damage should also be included to further studies.

Proper management measures and a continuous monitoring program may improve the balance between conservation and use of Bonaire's reefs. However, it is important to remember that visitors not only cause direct damage, but also have indirect impacts that affect the reef environment and need to be considered -such as an increased use of freshwater, an increase in the production of wastewater and garbage, more boating, and more hotels and other facilities necessary for tourism. All these impacts should be taken into consideration with a holistic approach in order to preserve Bonaire's reef.

Bonaire is the diver's Mecca of the Caribbean and the island relies heavily on tourism. Despite AC and IC rates lower than other regions around the world, the reef is showing signs of degradation and decreased resilience. Both direct and indirect management strategies suggested in this paper will help reduce user pressure on natural reef and improve the balance between conservation and use of Bonaire's reefs.

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