Biological Conservation 197 (2016) 223–228

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention

Thomas Webler [a], Karin Jakubowski [b]

[a] Social and Environmental Research Institute, P. O. Box 1487, Northampton, MA 01060, United States
[b] Department of Biology and Environmental Science, University of New Haven, 300 Boston Post Road, New Haven, CT 06516, United States

ARTICLE INFO

Article history:
Received 18 September 2015
Received in revised form 6 March 2016
Accepted 13 March 2016
Available online xxxx

Keywords:
Coral
Diving
Ecotourism
Messaging
Recreation
Snorkeling

ABSTRACT

There is widespread consensus that recreational snorkelers are damaging coral reefs, but the magnitude of the issue is unknown. Loss of reefs jeopardizes tourism, which is a significant economic driver. Recreational snorkeling is a popular activity and yet there has been little research about the behavior of snorkelers at reefs. The authors carried out observations at several reef locations in Puerto Rico to determine the baseline level of snorkeler behavior that threatens coral reefs. From August of 2010 until June 2012, they observed 328 different recreational snorkelers in-water at various reef locations and recorded number and types of potentially damaging behaviors. Snorkelers exhibited 0.26 potentially damaging behaviors per minute. Most were fin kicks (39%) and the next most frequent behavior was sitting, standing or kneeling on the reef (22%). The authors asked a subset of the people who were observed to make self-reports of their behavior, evaluated the accuracy of self-reports, and found that people underreported their potentially harmful behaviors. The authors experimented with a video message and signed pledge to promote proper snorkeling etiquette. From March 2012 until June 2012, snorkelers watched the video and signed the pledge before they boarded a tour operator led excursion. The pledge expressed commitment to specific pro-reef behaviors. Post-treatment in-water observations of 79 different snorkelers found a five-fold reduction in the rate of potentially damaging behaviors. Furthermore, the percentage of snorkelers who never harmed the reef shot up from 65% to 89%. The research suggests the pre-trip messaging together with a written pledge can change behaviors, thus improving the ability of ecotourism operators to help sustain reefs as well as the economic livelihoods of their employees.

1. Introduction

The biodiversity, complexity, and beauty of coral reefs make them an important ecological and economic resource. One estimate places the total global value of coral reef recreation and tourism at $9.6 billion (Cesar et al., 2003). Unfortunately, approximately 20% of the world's reefs have been destroyed, 24% are under imminent risk of collapse, and another 26% are in grave danger of irreparable damage (Riegl et al., 2009). Scleractinians, the corals responsible for building the primary foundation of the reef, are particularly vulnerable and are at elevated risk of extinction as a combined effect of global climate change and local anthropogenic impacts.

Several human-mediated stresses are of concern, including increasing sea surface temperatures, ocean acidification, and sea level rise (Doney, 2006). Localized threats include overfishing, which disrupts the ecological balance of the reef and can lead to algal infestations that impend the recovery of coral communities (Fenner, 2012) and pollution from sediments, chemicals, and sewage which decrease the growth, reproduction, and survival rates of corals (Nemeth and Nowlis, 2001; Negri et al., 2002). The main sources of these contaminants are agriculture, coastal construction, and wastewater outfalls. Corals also suffer physical damage by vessels transiting the reefs and poor navigation and anchoring practices (Tilmant, 1987).

People also degrade coral reefs through direct contact. Snorkelers and scuba divers break coral via fin kicks, body or equipment brushes, grasping, standing, sitting, or kneeling on coral polyps (Rouphael and Inglis, 2001; Medio et al., 1997; Prior et al., 1995). Brittle scleractinians are most vulnerable to direct human contact since they can be easily broken or crushed (Tratalos and Austin, 2001), however, even minor human contact can damage the protective layer of tissue that covers the corals leaving them susceptible to algae colonization, which then collects sediment and ultimately smothers the coral (Hall, 2001a, 2001b; Walker and Ormond, 1982). Abrasions also make corals susceptible to predation and disease (Rosenberg et al., 2007; Guzner et al., 2010; Hawkins and Roberts, 1997). Divers and snorkelers physically break the skeletons of hard corals through contacts (Kay and Liddle, 1989; Woodland and Hooper, 1977). Fins kicking near sandy bottoms can re-suspend sediment and expose coral polyps to additional sedimentation loads, which reduces coral growth and reproduction (Hawkins and Roberts, 1994; Neil, 1990).

E-mail address: twebler@seri-us.org (T. Webler).

http://dx.doi.org/10.1016/j.biocon.2016.03.012
0006-3207/

Studies of snorkelers found correlations between heavily used snorkeling areas and the number of broken and damaged corals (Gill et al., 2015; Plathong et al., 2000; Allison, 1996). Anecdotally, Allison remarked that more damage was done by less competent snorkelers, when partners stopped together, and when standing snorkelers were jostled by waves. Studies have also found correlations between scuba diver activity and coral damage (Riegl and Velimirov, 1991; Tratalos and Austin, 2001; Krieger and Chadwick, 2013). *In situ* observations of scuba divers have found that most direct contacts with the reef resulted from fin kicks and divers intentionally grasping onto coral — usually to steady themselves as they take photographs (Prior et al., 1995; Harriott et al., 1997; Zakai and Chadwick-Furman, 2002; Chung et al., 2013).

Snorkelers and scuba divers damage and stress coral reefs, leading to degraded or dead reefs. For example, the daily use by thousands of visitors has left the near shore reefs in Hanauma Bay Hawaii mostly dead (Wells and Hanna, 1992). Many other reefs have suffered this same fate. However, not all reefs are equally affected and the permanence of the impacts is unknown. It is difficult to estimate how many tourists a reef can support. Reef management would be empowered with knowledge of the level of human impacts and the critical thresholds that must be avoided.

There are no published studies of attempts to modify snorkeler behavior, and only four published studies on divers. Three studies examined effects of brief verbal interventions and found a weak effect on behavior (Medio et al., 1997; Barker, 2003; Krieger and Chadwick, 2013) while two studies found that in-water policing by dive leaders significantly reduced contacts (Barker and Roberts, 2004; Hammerton and Bucher, 2015).

We conducted our research in Puerto Rico because its reefs are vital to its economy, under stresses that are poorly understood, and there is support among managers for taking action. Puerto Rico's coral reefs add 1.8 billion dollars to the local economy of Eastern Puerto Rico (Estudios Técnicos Inc., 2007). Their amenity value for tourism is reflected in the demand for dive and snorkel services and the number of people employed by the industry. The island has a population of 3.5 million residents, but receives 4.9 million visitors per year (Turner, 2014). Tourism-related employment increased by 81% between 1985 and 2010 (Hernández-Delgado et al., 2012).

Despite their value, coral reefs in the Caribbean have been declining for at least the last forty years (Appeldoorn et al., 2009). Early warning signs were documented in the 1970s with the loss of elkhorn coral (*Acropora palmata*) and the long-spined black sea urchin (*Diadema antillarum*) in the 1980s (Lessios et al., 1984). In the 1990's steep catch declines in several commercial reef species served as more evidence (Appeldoorn et al., 1992). However, during this time, most of the coral reef research taking place in Puerto Rico focused on coral community characterization, monitoring programs, and coral diseases, often as part of environmental impact assessments (Garcia-Sais et al., 2005). Little communication took place between scientists, coral reef managers, and policymakers.

To date, no research has been done on tourism activities, even though Puerto Rico's Coral Reef Management Plan prioritizes the study of recreational use at reefs as one of its top goals (The Commonwealth of Puerto Rico and NOAA Coral Reef Conservation Program, 2010). No data on snorkelers have been collected, yet resource managers acknowledge that such data would be valuable.

2. Methods

2.1. Specific reefs where data were collected

We collected data at eight reefs around the island of Puerto Rico, five in La Cordillera Reserve, and others on the Isle of Culebra, near Caja de Muertos off the southern coast, and at Tres Palmas Marine Reserve. Reefs in the La Cordillera Reserve have the highest tourist exposure and, because we required the collaboration of tourism companies, most of the baseline observations and all the treatments were made there. There are at least seven large catamarans that leave from the port of Fajardo daily during the high season, bringing hundreds of visitors to reefs such as Icacos, Lobos, Tortugas, and Palomino Island.

2.2. Collaboration with tour operators

We approached vessel owners with information about our project and requested permission to attend a snorkel trip free of charge. We explained that we would observe people in the water without their consent or knowledge. We also asked permission to survey tourists on the return sail. Most owners were strongly supportive and allowed us to attend whenever we wanted. In return, they received reports of our findings for their vessel. A few owners were not supportive, but allowed us to attend if we paid. On those trips we made observations, but were unable to survey tourists.

2.3. Study design

We made baseline measurements (control group) in Year 1 and conducted treatments in Year 2. Because we were not always able to implement the treatment as planned, we also gathered baseline data in Year 2.

Our dependent variable was number of potentially damaging behaviors (or "contacts") made by a snorkeler to coral or other living organisms during a measured observation period. We made counts of the following behaviors: silting the reef; fin kicks; sitting, standing or kneeling (SSK); touching the reef with a finger or hand; brushing up against the reef; harassing marine organisms; picking up marine life; and collecting. The independent variables were gender, personal flotation device (PFD) use, and camera use.

2.4. Observation protocol

With the knowledge and permission of the captain and the tour vessel owner, we boarded the vessel with tourists in Fajardo and sailed to the first snorkel site. On the voyage to the reefs, we disguised our purpose and intent to avoid influencing snorkeler behavior. At their own accord, all tour operators gave a briefing onboard the vessel before snorkelers went into the water. To prevent the staff from changing their behavior with guests or their briefings, we kept the details of the research limited from the crew, although the captain knew. We told tourists who inquired about our clipboards that we were scientists, counting fish for Reef Check. Our data collection and experimental protocols were approved by a Human Subjects Review Committee.

At the reef, dozens of people depart the catamaran for the reef. At some sites, tourists disembark to shore and wade into the reef. At other locations the vessel anchors in deep water and tourists approach the reef from the deep water. We made sure we were among the first in the water and the last to leave. We developed the following observation protocol. When the first individual arrived at the reef, we started a timer and followed about 2 m behind and counted potentially damaging behaviors. We also recorded personal identifying traits so that the individual could be approached to fill out a survey afterwards. Observations of the individual ended when he or she left the area of the reef or 5 min passed. This meant that the observation period varied. At the end of each observation period, the researcher would turn right and immediately begin observing the next person in view over the reef. If that individual had already been observed, the researcher would continue swinging to the right until a new visitor was identified. Only adult individuals wearing fins, mask, and snorkel were observed.

2.5. Survey

With prior consent of the owner and the captain, we surveyed visitors during the return trip. We approached each individual and explained we were collecting data on snorkeling experiences and that the information provided would be used to manage coral reef resources. We interviewed as many snorkelers as possible during the 40-minute cruise. When we recognized an individual whom we had observed in the water, we recorded their observation number on the survey. This allowed us to compare self-reports of behavior with in-water observations. For shore-based snorkelers, we approached the individual after he or she exited the water. If a group of snorkelers exited the water at the same time, we began with the first to reach dry sand. Surveys were available in English or Spanish. The survey asked snorkelers to estimate the time spent snorkeling, the type of potentially damaging behaviors made with the reef, and number that occurred.

2.6. The treatment

We developed a coral reef etiquette message for snorkelers to view before boarding a vessel. Puerto Rico's Coral Reef Conservation Local Action Strategies (DNER, Department of Natural and Environmental Resources, 2011) emphasize messaging to discourage negative behaviors. We evaluated existing messages and found them to be inconsistent with social science theories of behavior and behavior change. For example, none of the messages referred to self-efficacy — the ability of snorkelers to avoid doing harm. They also gave contradictory messages about descriptive social norms by showing images associated with improper behavior (*e.g.* garbage on the reef, motor boats scarring the reef) while verbally urging the opposite. In response we designed and developed new coral reef etiquette video messaging based on the Value-Belief-Norms (VBN) theory (Stern et al., 1999; Stern, 2000) and the Theory of Planned Behavior (Ajzen, 1991) (Table 1). Since we were not testing one of these theories, we sought to influence as many variables as we could in both theories. The video can be found at http://vimeo.com/38726976.

Snorkelers were also asked to sign a pledge stating commitment to specific behaviors while recreating around coral reefs. Commitment techniques have been shown to be effective in promoting a diverse variety of behaviors (McKenzie-Mohr and Smith, 1999). Written commitments have been found to be more effective then verbal commitments (Pardini and Katzev, 1983-84). By signing the pledge, a snorkeler committed to carry through with the intention to be responsible near the reef.

Table 1
Snorkel video messages and corresponding behavioral variables.

Message	Behavioral variable
Snorkelers come to Puerto Rico to experience its remarkable coral reefs.	Asserts positive environmental attitude toward reefs
Of course, we would never deliberately do anything to hurt marine life. And we all want to practice responsible behaviors underwater.	Reinforcement of benevolence, Appeal to benevolence
However, even experienced snorkelers can accidentally impact the reef. Here are a few things you need to know about how snorkelers can affect coral reefs and suggestions for practicing good reef etiquette.	Awareness of consequences
Corals build a strong skeleton but their "skin" is fragile. Even the lightest touch with your hands or fins can damage sensitive coral.	Awareness of consequences
Keeping a little distance from coral reefs and sea life helps ensure your safety and protects the reef!	Self-efficacy
Some corals can burn. Keep your distance. Some animals that live in the reef can bite or sting. Waves and currents can push you into reefs resulting in scrapes, bruises, and cuts.	Awareness of consequences (to value of security)
For all these reasons, it's a good idea to keep a little space between you and the reef.	Prescriptive norm to protect oneself
Coral is not like grass, it will die if you stand on it.	Awareness of consequences
If you need to adjust your mask, swim away from the reef first.	Self-efficacy
If you want to talk with your friends, swim away from the reef first.	Self-efficacy
When treading water, be aware of where your fins are, so you don't accidently kick the coral.	Ascription of responsibility
Any silt your fins kick up can land on coral, smothering it over time.	Awareness of consequences
When you are near the reef, it's a good idea to float horizontally at all times.	Prescriptive norm
Leave sand, empty shells or bits of dead coral. Coral reefs need these non-living resources to remain vibrant.	Prescriptive norm
Remember: there are no policemen here. If you choose to break, collect, or stand on the coral, it will harm the reef and people who come after you will not be able to enjoy what is here for you today.	Affirm widely held values of self-direction and self-efficacy.
We have the choice to make a positive impact on the underwater world. Be aware of your movement in the water and keep a safe distance!	Ascription of responsibility, Prescriptive social norm

2.7. Delivery of treatment condition

We delivered our treatment condition to tourists boarding large catamarans in Fajardo. As small groups of guests arrived at the dock, they would check in with the vessel crew. We would then approach them and explain that before boarding the vessel they needed to watch a short video on how to behave around coral reefs while snorkeling. Two portable DVD players were used to reach as many people as possible. After watching the video, we asked people to read and sign the pledge stating commitment to specific behaviors. The pledge said: "Most visitors to coral reefs never touch, kick, or stand on the coral. They are careful not to stir up the sand near the coral with their fins. Corals are fragile and, if injured, are slow to recover. Keeping a safe distance from the reef is the best way to ensure these beautiful reefs are here for future generations. If you need to fix your mask or snorkel, it is best to swim away from the reef first. **I pledge to be a responsible visitor** to the reef by:

- Being aware of where my fins are at so I don't kick the coral
- Treading water instead of standing on the reef
- Not stirring up silt near the reef
- Keeping a safe distance from all marine organisms."

We approached as many people as possible before it was time to board the vessel.[1] Only nine people did not sign the pledge and these were removed from the treatment group. These nine did sign because there was not time for the researcher to get to them before the captain had started his safety briefing. At the reef, we employed the same observation procedure as with controls. Mostly, people swim with their friends, therefore finding another individual from our vessel who received the treatment was not difficult. We attempted to observe all snorkelers who watched the video and signed the pledge. We used excess time to observe non-treatment snorkelers from other tour operators. These data were added to Year 2 baseline data.

2.8. In water data collection time period

We collected data on 32 different days between January 2011 and June 2012. Observations were made during both the high tourist season

[1] We did not count the number of people who viewed the video, but we estimate the number to be about 200. Almost everyone on the vessel viewed the video, but not all went snorkeling. We observed 79 different people in the water.

(November through April) and the low tourism season (May through October). Baseline observations of 325 unique individuals were completed on 25 different days between January 2011 and June 2012. We observed 79 unique individuals in the treatment group on seven different days between March 2012 and June 2012. Observation time varied per individual. For the control group the average observation period was 5.26 min (s.d. = 3.46), while for the treatment group it was 4.63 min (s.d. = 0.85).

3. Results

3.1. Behaviors of control group

We observed 216 unique snorkelers in 2011 and 109 in 2012. To ensure there were no significant changes over the two-year period of data collection, we compared these two years of baseline data. They had identical non-normal distributions and similar (Mann–Whitney U test, $p = 0.269$) overall rates of 0.27 and 0.23 potentially damaging behaviors per minute, respectfully. Therefore data for the two control groups were combined, yielding a total of 325 observations for 1710 min. Males comprised 58% of the observations while 42% of those observed were female. Only 29% wore personal flotation devices (PFD) and 13% carried or used a camera while snorkeling.

Sixty-five percent of the control group had no potentially damaging reef behaviors. A total of 445 potentially damaging behaviors were observed in the control group (Table 2). Most were fin kicks (39%), followed by sitting, standing or kneeling (22%), siltation (14%), touching the reef (13%), picking up marine life (5%), harassing organisms (4%), collecting (2%) and brushing up against the reef (2%).

Overall, the frequency of potentially damaging behaviors was 0.26 per snorkeler-minute for the control group. Because the observation period per subject varied, we do not present averages and standard deviations of contact rates per snorkeler. Instead, we report and compare group averages. To indicate the variation in rates of potentially damaging behaviors across snorkelers in the control and treatment groups, we have included Fig. 1.

Linear regression found no statistically significant difference between the rates of potentially damaging behavior and the following independent variables: wearing personal flotation device ($p = 0.42$), using cameras ($p = 0.29$), which researcher made the observations ($p = 0.55$), the tour operator ($p = 0.27$), or the reef visited ($p = 0.81$). Women were less likely than men to contact the reef ($B = -0.12$, $p = 0.028$).

3.2. Effect of video and pledge

We observed 79 unique individuals in the treatment group for a total of 366 min. Females comprised 62% of the observations. Only 18% wore a PFD and 9% carried or used a camera while snorkeling.

Table 2
Potentially damaging behaviors for the control (N = 325) and the treatment groups (N = 79).

Reef-threatening behaviors	Control		Treatment	
	Nr (%)	Nr per min	Nr (%)	Nr per min
Fin kicks	173 (39%)	0.100	10 (53%)	0.028
Sit stand kneel	96 (22%)	0.056	3 (16%)	0.008
Silting	64 (14%)	0.037	4 (21%)	0.010
Hand touch	58 (13%)	0.034	2 (10%)	0.006
Pick up marine life	20 (5%)	0.012		
Harass marine life	17 (4%)	0.010		
Collect objects or animals	9 (2%)	0.005		
Body brush	8 (2%)	0.005		
All behaviors	445 (100%)	0.257	19 (100%)	0.052

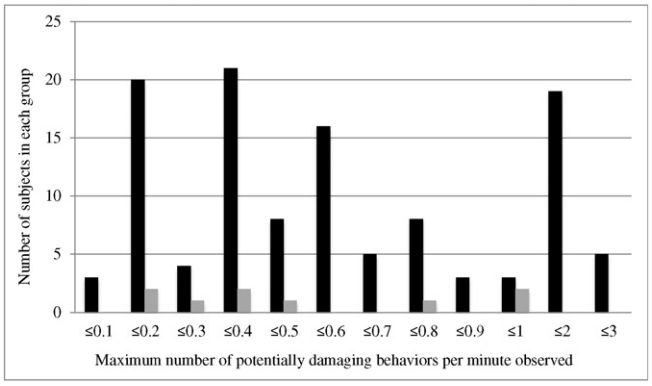

Fig. 1. Count of snorkelers for each rate of potentially damaging behaviors for control (black) and treatment (gray) groups. Data are binned and the number on the x-axis indicates the inclusive top end of the bin. The zero group was omitted due to its large size. The first bar represents the number of snorkelers whose contact rate was less than 0.1 contact per minute. We present data as rates because not all snorkelers were observed for the same amount of time.

Only 19 potentially damaging behaviors were observed. Most were fin kicks (53%); followed by silting (21%); sitting, standing or kneeling (16%); and touching the reef (11%). No snorkelers in the treatment group were observed touching other organisms, picking up marine life, brushing up against the reef, or collecting (see Table 2). No one in the treatment group had more than four contacts. 89% of people in the treatment group had no reef contacts. The variability in the rate of potentially damaging behaviors for the other 11% is shown in Fig. 1.

Multiple regression analysis confirmed that watching the video and signing the pledge had a significant effect on potentially damaging behaviors ($p = 0.011$), as did gender ($p = 0.03$). To examine the effect of gender, we analyzed our data for males and females separately. The rate of potentially damaging behaviors for men decreased from 0.3/min in the control group to 0.06/min for the treatment group (Mann–Whitney U = 3595, $p = 0.0047$) and for women it decreased from 0.16/min to 0.04/min (Mann–Whitney U = 3741, $p = 0.0178$). The use of a personal flotation device ($p = 0.32$), and camera ($p = 0.36$) had no significant effect on rate of potentially damaging behaviors. The average frequency of potentially damaging contacts for all snorkelers in the treatment group was 0.052 contacts per minute (Mann–Whitney U = 13,794, $p = <0.001$), a five-fold reduction from the baseline.

3.3. Snorkel surveys

For the snorkelers in the control group who completed surveys, in-water observational data was available for 57 of them. These individuals reported 67 potentially damaging behaviors on the reef in 3060 reef-visit minutes or an average of 0.022 contacts per minute. For these same individuals, we observed 43 behaviors in only 277 min, for a rate of 0.155 contacts per minute. Our observed contact rate exceeded the self-reported rate by a factor of seven, however there was high inconsistency in the reported rates among subjects and we emphasize that we only observed people for a short period of their snorkeling time.

4. Discussion

The literature is slim when it comes to testing the effect of videos or briefings on recreationalist snorkeler behavior at coral reefs. This is surprising, since Hanauma Bay State Park in Hawaii has been requiring visitors to watch a coral reef etiquette video for years. There are no other published studies of the effect of briefings or videos or pledges on snorkelers.

The baseline frequency of potentially damaging behaviors in Puerto Rico was higher than that measured by Barker (2003), the only other

published study of snorkeler behavior. Further study is required to determine the reason behind this difference. It could be that tour operators in Puerto Rico take visitors to reefs where there are more opportunities for contact (shallow coral, tight spaces, strong currents). The difference could also lie in the methods used by the researchers to count potentially damaging behaviors. For instance, we counted each fin kick (as opposed to a sequence of fin kicks as one kick). It is unclear how Barker counted fin kicks.

Most potentially damaging behaviors with the reef in both the baseline and experimental groups were fin kicks. Fins add length to a snorkeler's legs, bringing the snorkeler closer to the reef. Presumably, these fin contacts were unintentional, because they do not involve standing on the reef, but are likely caused my poor snorkeling technique. When maneuvering around the water, snorkelers (especially beginners) were often unaware that their fin had made contact with the reef. We also noted that snorkelers tend to engage in more potentially damaging behaviors with the reef when in a group, because they pause to take their heads out of the water and discuss what they are seeing. During this time, they usually become vertical in the water and their fins are often contacting the coral, or they are standing on it. Standing on the reef was another common behavior. Unskilled snorkelers stand on the reef to fix their equipment, rest, or find their friends.

While there were minor differences in the style and content of the briefing given by the tour operators before tourists disembarked for the reef, all gave instructions for proper reef etiquette. On several instances, we observed crew intervening when snorkelers stood on the reef by blowing a whistle or shouting and waving to snorkelers who were standing on the reef. We did not interfere with the crew's briefings, but anecdotally we noticed that people preparing to snorkel are occupied with donning their gear and do not always listen to briefings.

One can get a rough estimate of the magnitude of the threat of snorkeler behavior by estimating the daily number of visitors in La Cordillera Reserve. There are seven catamarans that carry approximately 45 people and visit two different reefs on each trip. If most people snorkel for 15 min at each of the two reefs, at our baseline rate, that would result in over 2000 potentially damaging behaviors per day, in La Cordillera Reserve alone. There are many other reefs also under tourism pressure in Puerto Rico.

It is unclear to what extent we can generalize to all coral reefs from our study sites. The depth, size, topography, and location of the reef surely shape the reef's vulnerability to tourist contacts. For our baseline data, we gathered data at reefs all around Puerto Rico. Our treatment observations were made at four different reefs in La Cordillera. These reefs ranged in depth and topography quite extensively, however all included shallow areas and we found no difference in contact rates across reefs.

It is also unclear to what extent we can generalize to all snorkelers. We sampled at different times of year, but local Puerto Ricans were infrequent guests on the Fajardo tour vessels. In some locales, snorkelers approached the reef from the beach while at others they approached from deep anchor. Some snorkelers were on their own, but mostly we studied people on tourist vessels.

Most of the tourists who snorkel in Puerto Rico access reefs through the catamarans out of Fajardo. Since these vessels are licensed, there is an opportunity to add a condition to the license that every tourist be required to watch a short video about tourism etiquette and sign a pledge before boarding the vessel. Given our results, such an action could significantly reduce tourism-induced damage to sensitive coral reefs and ecosystems.

We note that, at shore-based sites used by independent snorkelers, there is a need to educate people about the best way to enter and exit the water. At Tres Palmas on Rincón and at Tamarindo Grande on Culebra there is only a small sand alley that allows safe access to the deep water. Snorkelers who do not know about this pathway often enter by walking over the reef. Signs or coral reef stewards on the beach could help.

5. Conclusion

This study reported on in-water observations of tourist snorkelers at coral reefs in Puerto Rico. We counted the number of potentially damaging behaviors associated with snorkeling at reefs. We investigated the effectiveness of pre-trip messaging and a written pledge at reducing the frequency of potentially damaging behaviors. Our video and pledge were designed to reinforce social norms, self-efficacy, and personal values. The treatment group showed a five-fold reduction in the rate of potentially damaging behaviors, as well as a dramatic increase in the number of people who never touched the reef from 65% to almost 90%. The effect was similar for men and women, although overall women contacted the reef much less than men did. We did not document the ecological significance of potentially damaging behaviors, but other research has shown a strong correlation between snorkeler activity and coral reef damage. Our messaging and pledge dramatically reduced the frequency of potentially damaging behaviors. Tourists did not find the five-minute video burdensome. To the contrary, most were grateful to be educated and were eager to minimize their impact on the reef. Implementing a well-designed mandatory video message and pledge is one way to reduce tourist pressure on coral reefs.

Role of the funding source

This project was made possibly by funding from NOAA's Coral Reef Conservation Program Grant Number NA10NMF4630072. Matching funds were contributed by snorkel tour operators including Casa del Mar, East Wind, Sea Ventures, Spread Eagle, Traveler, and the Social and Environmental Research Institute (SERI), an independent 501(c)(3) research institute located in Massachusetts.

Acknowledgments

We are grateful for the hospitality and advice of Dr. Richard Appeldoorn at the University of Puerto Rico at Mayaguez, and the conversations we had with Aileen Velasco of the Department of Natural and Environmental Resources. Additionally we would like to recognize the input and advice we gained from Alida Ortiz-Sotomayor at Universidad Metropolitana, Yilmalia Suarez and Luis Rijos at Sea Ventures Dive Center, Lucho Sa'ez at Catamaran Spread Eagle II, Roberto Colon at Casa del Mar., and Ruperto Chaparro and staff at Puerto Rico Sea Grant. We are especially grateful to the tour operators, captains, crew, and staff for their hospitality and collaboration.

References

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50, 179–211.

Allison, W.R., 1996. Snorkeler damage to reef corals in the Maldive Islands. Coral Reefs 15 (4), 215–218.

Appeldoorn, R., Beets, J., Bohnsack, J., Bolden, S., Matos, D., Meyers, S., Rosario, A., Sadovy, Y., Tobias, W., 1992. Shallow water reef fish stock assessment for the U.S. Caribbean. NOAA Tech. Mem. 1–70 NMFS-SEFSC-304.

Appeldoorn, R., Yoshioka, P., Ballantine, D., 2009. Coral reef ecosystem studies: integrating science and management in the Caribbean. Caribb. J. Sci. 45 (2–3), 134–137.

Barker, N.H.L., 2003. Ecological and Socio-Economic Impacts of Dive and Snorkel Tourism in St. Lucia, West Indies (Doctoral dissertation). University of York, United Kingdom.

Barker, N.H.L., Roberts, C., 2004. Scuba diver behavior and the management of diving impacts on coral reefs. Biol. Conserv. 120 (4), 481–489.

Cesar, H.J.S., Burke, L., Pet-Soede, L., 2003. The economics of worldwide coral reef degradation. Cesar Environmental Economics Consulting, Arnhem, and WWF-Netherlands, Zeist, The Netherlands.

Chung, S., Au, A., Qui, J., 2013. Understanding the underwater behaviors of scuba divers in Hong Kong. Environ. Manag. 51 (4), 824–837.

DNER (Department of Natural and Environmental Resources), 2011. Local action strategies for coral reef conservation. San Juan, Puerto Rico. Accessed on 14 February 2016 from http://coralreef.noaa.gov/aboutcrcp/resources/pdfs/lasreport2012.pdf.

Doney, S., 2006. Oceanography: plankton in a warmer world. Nature 444 (7120), 695–696.

Estudios Técnicos Inc., 2007. Economic valuation of coral reefs and associated environments in eastern Puerto Rico: Fajardo, reefs of La Cordillera, Vieques, and Culebra. Final Report. Accessed on 14 February 2016 from http://clmeims.gcfi.org/valuation-bibliography/

estudios-técnicos-inc-2007-valoración-económica-de-los-arrecifes-de-coral-y?language=en.
Fenner, D., 2012. Challenges for managing fisheries on diverse coral reefs. Diversity 4 (1), 105–160.
Garcia-Sais, J., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., Carrubba, L., Corredor, J., Diaz, E., Lilyestrom, C., Garcia-Moliner, G., Hernandez-Delgado, E., Menza, C., Morell, J., Pait, A., Sabater, J., Weil, E., Williams, E., Williams, S., 2005. The state of coral reef ecosystems of Puerto Rico. In: Waddell, J. (Ed.), *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States*. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. *silver* Spring, MD, pp. 91–134.
Gill, M., Renfro, B., Figueroa-Zavala, B., Penie', I., Dunton, K., 2015. Rapid tourism growth and declining coral reefs in Akumal, Mexico. Mar. Biol. 162 (11), 2225–2233.
Guzner, B., Novplansky, A., Chadwick, N.E., 2010. Indirect impacts of recreational scuba diving: patterns of growth and predation in branching stony corals. Bull. Mar. Sci. 86 (3), 727–742.
Hall, C.M., 2001a. Trends in ocean and coastal tourism: the end of the last frontier. Ocean Coast. Manag. 44 (9), 601–618.
Hall, V.R., 2001b. The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: scraping injury, tissue mortality and breakage. J. Exp. Mar. Biol. Ecol. 264 (2), 209–223.
Hammerton, Z., Bucher, D., 2015. Levels of intervention: reducing SCUBA-diver impact within subtropical marine protected areas. J. Ecotour. 14 (1), 3–20.
Harriott, V., Davis, D., Banks, S., 1997. Recreating diving and its impact in marine protected areas in Eastern Australia. Ambio 26 (3), 173–179.
Hawkins, J.P., Roberts, C.M., 1994. The growth of coastal tourism in the Red Sea: present and future effects on coral reefs. Ambio 23 (8), 503–508.
Hawkins, J.P., Roberts, C.M., 1997. Estimating the carrying capacity of coral reefs for SCUBA diving. In: Lessios, H.A., Macintyre, I.G., McGee, M. (Eds.), Proceedings of the Eighth International Coral Reef Symposium. Smithsonian Tropical Research Institute, Balboa, Panama, pp. 1923–1926.
Hernández-Delgado, E.A., Ramos-Scharrón, C.E., Guerrero, C., Lucking, M.A., Laureano, R., Méndez-Lázaro, P.A., Meléndez-Díaz, J.O., 2012. Long-term impacts of tourism and urban development in tropical coastal habitats in a changing climate: lessons learned from Puerto Rico. In: Kasimoglu, M. (Ed.), Visions from Global Tourism Industry-Creating and Sustaining Competitive Strategies. InTech Publications, pp. 357–398.
Kay, A.M., Liddle, M.J., 1989. Impact of human trampling in different zones of a coral reef flat. Environ. Manag. 13 (4), 509–520.
Krieger, J., Chadwick, N., 2013. Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida coral reefs. J. Coast. Conserv. 17 (1), 179–189.
Lessios, H.A., Robertson, D.R., Cobit, J.D., 1984. Spread of *Diadema* mass mortality through the Caribbean. Science 226 (4672), 335–337.
McKenzie-Mohr, D., Smith, W., 1999. *Fostering Sustainable Behavior*: *An Introduction to Community-Based Social Marketing*. second ed. New Society, Gabriola Island, British Columbia, Canada.
Medio, D., Ormond, R.F.G., Pearson, M., 1997. Effect of briefings on rates of damage to corals by divers. Biol. Conserv. 79 (1), 91–95.
Negri, A., Smith, L.D., Webster, N., Heyward, A., 2002. Understanding ship-grounding impacts on a coral reef: potential effects of anti-foulant paint contamination on coral recruitment. Mar. Pollut. Bull. 44 (2), 111–117.
Neil, D., 1990. Potential for coral stress due to sediment resuspension and deposition by reef walkers. Biol. Conserv. 52 (3), 221–227.
Nemeth, R.S., Nowlis, J.S., 2001. Monitoring the effects of land development on the near-shore reef environment of St. Thomas, USVI. Bull. Mar. Sci. 69 (2), 759–775.
Pardini, A.U., Katzev, R.D., 1983-84. The effect of strength of commitment on newspaper recycling. J. Environ. Syst. 13 (3), 245–254.
Plathong, S., Inglis, G.J., Huber, M.E., 2000. Effects of self-guided snorkeling trails on corals in a tropical marine park. Conserv. Biol. 14 (6), 1821–1830.
Prior, M., Ormond, R., Hitchen, R., Wormald, C., 1995. The impacts on natural resources of activity tourism: a case study of diving in Egypt. Int. J. Environ. Stud. 48 (3–4), 201–209.
Riegl, B., Velimirov, B., 1991. How many damaged corals in Red Sea reef systems? A quantitative survey. Hydrobiologia *216/217*, 249–256.
Riegl, B., Bruckner, A., Coles, S.L., Renaud, P., Dodge, R.E., 2009. Coral reefs: threats and conservation in an era of global change. Ann. N. Y. Acad. Sci. 1162, 136–186.
Rosenberg, E., Koren, O., Reshef, L., Efrony, R., Zilber-Rosenberg, I., 2007. The role of micro-organisms in coral health, disease, and evolution. Nat. Rev. Microbiol. 5, 355–362.
Rouphael, A., Inglis, G.J., 2001. "Take only photographs and leave only footprints?": an experimental study of the impacts of underwater photographers on coral reef dive sites. Biol. Conserv. 100, 281–287.
Stern, P., 2000. Toward a coherent theory of environmentally significant behavior. J. Soc. Issues 56 (3), 407–424.
Stern, P., Dietz, T., Abel, T., Guagnano, A., Kalof, L., 1999. A value-belief-norm theory of support for social movements: the case of environmentalism. Hum. Ecol. Rev. 6 (2), 81–97.
The Commonwealth of Puerto Rico and NOAA Coral Reef Conservation Program, 2010a. *Puerto Rico's coral reef management priorities*. Silver Spring, MD: NOAA. Accessed on 14 February 2016 from http://coralreef.noaa.gov/aboutcrcp/strategy/reprioritization/managementpriorities/resources/prico_mngmnt_clr.pdf.
Tilmant, J.T., 1987. Impacts of recreational activities on coral reefs. In: Salvat, B. (Ed.), *Human Impacts on Coral Reefs*: *Facts and Recommendations*. Antenne Museum EPHE, French Polynesia, pp. 195–214.
Tratalos, J., Austin, T., 2001. Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. Biol. Conserv. 102 (1), 67–75.
Turner, R., 2014. Travel & tourism: economic impact. Puerto Rico. Accessed on 14 February 2016 from http://www.wttc.org//media/files/reports/economic%20impact%20research/country%20reports/puerto_rico2014.pdf.
Walker, D.I., Ormond, R.F.G., 1982. Coral death from sewage and phosphate pollution at Aqaba, Red Sea. Mar. Pollut. Bull. 13 (1), 21–25.
Wells, S., Hanna, N., 1992. The Greenpeace book of coral reefs. Blandford Press, London.
Woodland, D.J., Hooper, J.N.A., 1977. The effect of trampling on coral reefs. Biol. Conserv. 11 (1), 1–4.
Zakai, D., Chadwick-Furman, N.E., 2002. Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. Biol. Conserv. 105 (2), 179–187.