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Using an educational video-briefing to mitigate the ecological impacts of scuba diving

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ABSTRACT

Recreational scuba diving is rapidly increasing, and the negative impacts to marine reef biota are of conservation concern. Educational approaches have been tested to mitigate diver damage to benthic organisms, but logistical constraints impede their implementation in many locations. We investigated the behaviors of scuba divers in terms of their contacts with benthic organisms, and assessed how an educational video-briefing caused changes in diver behavior. The video provided environmental information to divers, and enhanced their use of low-impact diving techniques. Divers who received the video-briefing exhibited significantly lower rates of contact with and damage to the benthos, than did divers who did not receive a briefing. The level of diving experience did not correlate with the rate of benthic contact in either group of divers. Male divers and photographers both contacted the benthos significantly less, and female divers and photographers both caused significantly less damage when they viewed the video-briefing prior to diving. Our findings highlight the importance of easily implemented, standardized educational approaches such as the use of video-briefings to mitigate the impacts of scuba diving. This study adds to the framework of tested strategies available to support the sustainable use of marine areas by the diving tourism industry.

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Recreational diving; marine protected area; marginal reef; environmental education; coral damage; tourism management

Introduction

During the past few decades, diving tourism has become increasingly popular in the world's oceans at both temperate and tropical destinations, and especially on tropical coral reefs. Recreational diving is one of the world's fastest growing recreational sports, and has developed rapidly to become a multi-billion dollar industry (Cope, 2003; Spalding et al., 2017). In the 1990s, approximately 10–14 million people each year engaged in scuba diving (Viders, 1997). Currently, this number is estimated to be much larger, with ~1 million new recreational divers being trained each year (Davenport & Davenport, 2006).

Recreational diving can function as a non-extractive use of the aquatic environment, because it often involves no-take appreciation of wildlife biodiversity. This type of activity has become an important income alternative to water-based extractive activities, such as fishing and collection of organisms for the aquarium trade. Ecotourism-based scuba diving represents one of the main income sources for coastal populations in many developing countries, especially at tropical coral reef

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destinations such as Palau (Vianna, Meekan, Pannell, Marsh, & Meeuwig, 2012), Indonesia, the Philippines (De Brauwer et al., 2017) and Bonaire (Thur, 2010). Scuba diving is generally considered to be a low-impact activity with high educative potential. Recreational divers have become increasingly involved in marine conservation through their activism, citizen science, monetary donations, and participation in conservation initiatives (Hammerton, Dimmock, Han, Dalton, & Smith, 2012; Holt, Rioja-Nieto, MacNeil, Lupton, & Rahbek, 2013).

As an ecotourism activity, diving is highly dependent on a conserved and biodiverse underwater environment. Preferred diving destinations are generally located inside marine protected areas (MPAs), especially those that are renowned for high coral reef biodiversity (Giglio, Luiz, & Schiavetti, 2015; Williams & Polunin, 2000). MPAs protect marine species diversity and conserve ecosystems, making these areas attractive to diving tourists. Divers can contribute significantly to marine conservation efforts by paying user fees to access MPAs, and generally are willing to pay more to visit sites with enhanced conservation (Casey, Brown, & Schuhmann, 2010) and biodiversity (Emang, Lundhede, & Thorsen, 2016; Wielgus, Chadwick-Furman, Zeitouni, & Shechter, 2003).

Paradoxically, the increasing popularity of MPAs with scuba divers has led to high levels of diver-caused ecological damage, especially in intensively visited tropical regions such as the Red Sea (Hasler & Ott, 2008; Zakai & Chadwick-Furman, 2002) and Florida, USA (Krieger & Chadwick, 2013). Negative impacts of diving tourism therefore have become a conservation concern on many tropical coral reefs. Studies have examined various approaches to mitigate the damaging effects of recreational diving on reefs, such as the use of pre-dive educational briefings and close underwater supervision by dive leaders (reviewed in Renfro & Chadwick, 2017). However, the effectiveness of these approaches necessarily varies with the local characteristics of each diving operation, such as time constraints and the level of dive staff training and motivation.

We contribute here the findings of an empirical study that was designed to provide critical insights into the effectiveness of a standardized pre-dive video briefing to mitigate the negative impacts of recreational divers on marine reefs. Our specific objectives were to develop an educational video that explained low-impact techniques for diving on reef biota, quantify changes in underwater behavior by divers who viewed the video, and evaluate diver perceptions about the effectiveness of the video as a standardized approach to mitigate their negative impacts on reef systems.

Reefs, scuba diving and sustainable tourism

Many marine reefs currently are in a degraded ecological state. Especially coral reefs have declined markedly over the past several decades, with ~50% of living coral cover lost worldwide (Birkeland, 2015). This decline in ecosystem condition has included major losses of fish biomass, and shifts to alternate ecological states of dominance by marine algae or other non-reef-building organisms (Birkeland, 2015; Norstrom, Nystrom, Lokrantz, & Folke, 2009). The major anthropogenic threats to reefs include localized stressors such as overfishing, coastal development and nutrient pollution (Halpern et al., 2008). Ecotourism impacts including tour boat anchor scars and infliction of damage directly by scuba divers also have altered reef communities (reviewed in Krieger & Chadwick, 2013). These localized impacts may act in synergy with the major global stressor of climate change to damage benthic reef organisms, through ocean acidification and temperature extremes (Hughes et al., 2003). Climate change has become an existential threat to coral reefs, as evidenced by the dramatic and widespread coral bleaching events recently on Australia's Great Barrier Reef (Hughes et al., 2017). Studies have estimated that unless we advance rapidly toward meeting the goals of the Paris Climate Change Agreement to reduce greenhouse gas emissions, coral reefs are expected to cease to exist as functional ecosystems within <50 years (Hoegh-Guldberg, Poloczanska, Skirving, & Dove, 2017; Sheppard, Davy, & Pilling, 2009). Local, regional and global actions need to be implemented to enhance reef resilience and limit reef degradation in the face of climate change (Norström et al., 2016).

Rates of recreational diving have increased rapidly on some marine reefs, leading to upwards of 30,000 dives year^{-1} at intensively visited reef sites in the Israeli Red Sea (Zakai & Chadwick-Furman,

2002) and >100,000 dives year^{-1} site^{-1} in the Mexican Caribbean (Renfro & Chadwick, 2017). Benthic reef organisms at intensively visited sites exhibit several types of diver-caused damage that impair their resilience in the face of climate change and other environmental stressors. On tropical reefs, repeated skeletal fracture and tissue abrasion by divers had led to loss of live coral cover and reduced habitat complexity (Hawkins et al., 1999; Lyons et al., 2015), diminished coral growth (Guzner, Novplansky, Shalit, & Chadwick, 2010), shifts in reef assemblage composition (Hawkins et al., 1999; Riegl & Velimirov, 1991; Renfro & Chadwick, 2017), and increases in coral disease prevalence (Lamb, True, Piromvaragorn, & Willis, 2014). Documentation of diver damage to subtropical and temperate reefs has received less attention and has focused mainly on coralligenous reefs of the Mediterranean Sea (Lloret, Marín, Marín-Guirao, & Carreño, 2006; Luna, Pérez, & Sánchez-Lizaso, 2009; Sala, Garrabou, & Zabala, 1996). The relative dearth of diver damage studies at subtropical and temperate reef destinations may be due in part to their generally lower visitation rates than in tropical areas, and perceptions that they may be less vulnerable to diving impacts than the tropical reefs which are dominated by branching corals. However, corals on subtropical reefs may be equally vulnerable to impacts from divers, or even more so, than are those in tropical locations. Some subtropical corals exhibit slower rates of recovery and regrowth after repeated damage than do tropical species, because the former have slow overall grow rates due to living near their environmental tolerance limits (Ballesteros, 2006; Harriott, 1999). On subtropical reefs, intensive recreational diving has led to reduced abundance and cover of bryozoans (Nuez-Hernandéz, Valle, Forcada, Correa, & Torquemada, 2014; Sala et al., 1996), decreased ascidian body sizes (Luna-Pérez, Valle, Fernández, Sánchez-Lizaso, & Ramos-Esplá, 2010), and detachment of coral colonies (Terrón-Sigler, León-Muez, Peñalver-Duque, & Torre, 2016).

Diver-related factors that contribute to their rates of damage on marine reefs appear to include poor diving proficiency, such as inadequate swimming skills and buoyancy control. Divers who use underwater photographic equipment also tend to contact the reef more frequently than do non-photographers (Luna et al., 2009). Regardless of their skill level, most divers contact benthic reef organisms by unintentionally kicking the reef with their foot fins (Chung, Au, & Qiu, 2013; Uyarra & Côté, 2007). Each fin kick potentially results in the instantaneous skeletal breakage of branching stony corals, or abrasion of the surface tissues of massive corals (Zakai & Chadwick-Furman, 2002).

Management responses to mitigate these negative ecological impacts have focused in part on limiting the numbers and/or types of divers at selected reef areas. Some reefs have been zoned according to diver profile, in which inexperienced divers have been excluded from the most delicate reef areas (Worachananant, Carter, Hockings, & Reopanichkul, 2008). At other locations, limits have been set on the total number of recreational dives per year based on the level of reef fragility (Lloret et al., 2006), the estimated carrying capacity of the reef for visitation, and calculated limits of acceptable change to the reef ecosystem (Rouphael & Hanafi, 2007; Zang, Chung, & Qui, 2016).

Additional approaches have involved educational initiatives to improve diver behaviors underwater. These types of approaches contribute to reef conservation by reducing rates of per-diver reef contact (Medio, Ormond, & Pearson, 1997), rather than by limiting the total number of dives in each reef area. They have been implemented mainly through pre-dive briefings which stimulate divers to apply low-impact diving techniques. The information provided to divers via conservation-oriented briefings has varied from simple sentences (Barker & Roberts, 2004; Luna et al., 2009; Worachananant et al., 2008) to more elaborate ones, including descriptions of the biological characteristics of corals, the threats they face, and their vulnerability to diving impacts (Camp & Fraser, 2012; Krieger & Chadwick, 2013; Medio et al., 1997; Toyoshima & Nadaoka, 2015). The addition of one or two simple sentences such as “do not touch the corals” to a general dive safety briefing does not appear to cause a significant reduction in diver damage (Barker & Roberts, 2004). Dive companies generally give short pre-dive briefings that last only a few minutes, and in many cases, include mostly safety information rather than discussion of environmentally responsible diver behavior. This limitation may occur in part because dive company staff often do not have enough expertise or interest to provide effective briefings about environmental awareness and low-impact diving techniques (Barker & Roberts, 2004; Hammerton, 2016). Other management techniques such as direct underwater intervention by dive leaders also may reduce per-diver rates of reef contact (Barker & Roberts, 2004; Hammerton & Bucher, 2015). However, the size of the dive group impacts the frequency with which a dive leader can participate in interventions underwater (Roche et al., 2016).

Video messaging provides several important advantages over orally delivered pre-dive briefings, in educating divers to reduce their negative impacts on marine reefs. Videos can be created with high-quality visual messaging that is standardized and appealing to divers, and easy to deliver by dive providers. Snorkelers have been shown to significantly reduce their rates of reef contact after viewing a pre-dive briefing provided through a standardized video, in this case allied to a signed pledge to promote responsible behavior (Webler & Jakubowski, 2016). The pre-dive video was created based on the Theory of Planned Behavior (TPB), which assumes that the performance of a given behavior is a function of the knowledge and beliefs of the person performing that particular behavior, and that these beliefs and information serve as the base which determines a person's attitudes, intentions, and behaviors (Ajzen, 1991). The TPB helps to explain why humans behave as they do during outdoor recreational and wildlife experiences (Apps, Dimmock, Lloyd, & Huveneers, 2016; Apps, Lloyd, & Dimmock, 2014; Ong & Musa, 2011). Video messages based on the TPB also have caused people to alter their behaviors in ways that reduce their rates of sexually transmitted disease (Warner et al., 2008) and tobacco use (Mahabee-Gittens, Vaughn, & Gordon, 2010). Educational videos have been employed to brief divers before they observe charismatic marine megafauna such as manatees in Florida (U.S. Fish & Wildlife Service, 2013), but the impact of the videos was not tested. To date, no research has examined the effects of video-briefings on diver behavior throughout the entire dive, or among scuba divers. The present study represents the first investigation of the effectiveness of an educational video-briefing based on the TPB, to mitigate the negative effects of scuba divers on benthic reef organisms.

Methods

Study area

The present study was conducted during the austral summer (January to March) in 2015 and 2016, at the Arraial do Cabo Marine Extractive Reserve (ACMER), Brazil (22°57′57″S, 42°1′40″W). In this MPA, fishing and tourism were allowed according to management guidelines. Assemblages of sessile reef organisms within the reserve were dominated by zoanthids *Palythoa caribaeorum*, which covered up to 40% of the hard substratum, followed by stony corals (~13% cover) comprised mostly of branching hydrocorals *Millepora alcicornis* and the massive scleractinian corals *Siderastrea stellata* and *Mussismilia hispida* (Lima & Coutinho, 2015; Rogers et al., 2014). Anecdotal evidence indicated that coral cover in the ACMER had decreased markedly since the 1960s (Rogers et al., 2014), when these reefs were described qualitatively as biological oases with high cover of both *M. alcicornis* and *S. stellata* (Laborel, 1967). Both the reserve and the surrounding region had been negatively impacted previously by overfishing (Bender et al., 2014; Giglio, Bender, Zapelini, & Ferreira, 2017), unregulated tourism (Giglio, Ternes, Mendes, Cordeiro, & Ferreira, 2017), the introduction of invasive species (Batista et al., 2017; Ferreira, Gonçaves, & Coutinho, 2006), and collection of reef organisms for the aquarium trade during the 1980s (Gasparini, Floeter, Ferreira, & Sazima, 2005; Rogers et al., 2014).

The ACMER is the most popular scuba diving destination in Brazilian coast, with 13 dive companies serving recreational divers inside the reserve. The annual diver visitation rate recently was estimated at ~25,000 dives per year (Giglio, Ternes, et al., 2017). These high levels of visitation caused concern among scientists and managers regarding potentially negative effects on benthic reef organisms, leading to the motivation for the present study. We investigated four major dive sites within the reserve: Ilha dos Porcos, Anequim, Cardeiros, and Abobrinha, which each ranged 3–11 m depth below sea level and exhibited underwater visibility of 5–15 m. The composition of benthic assemblages was similar among the four examined sites (Rogers et al., 2014).

Creation and use of the educational video-briefing

We conducted preliminary observations by participating in group scuba dives led by five local dive companies. These observations revealed that the divers in these groups were not being informed in a standardized way regarding low-impact techniques; this type of information was being communicated to divers only occasionally and in a minimal way. The pre-dive briefings usually were given orally by dive company staff while divers were on the boat, and they mostly addressed dive planning and general marine biota features. Occasionally, the dive staff mentioned in a single sentence that divers should avoid contacts with the reef, using phrases such as "do not touch anything."

We then engaged in informal conversations with staff members of the five selected dive companies, in which they indicated that lack of training, time, and interest were the main impediments to their performing environmentally friendly pre-dive briefings. In this context, we proposed to the local dive company association to produce and test an educational video-briefing, to be shown to recreational divers before they entered the water, either in the dive company office or on the dive boat. Based on the dive company association's interest in this type of video, we proceeded to develop information concerning reef etiquette to present in the video, based on the TPB (Ajzen, 1991). For the video development, we also utilized information contained in teaching guides produced by two international scuba diving certifiers (Professional Association of Diving Instructors [PADI], 2014; Scuba Schools International [SSI], 2010). The resulting video contained five major messages to divers concerning proper reef etiquette, which in order of appearance were: (1) Do not collect anything; (2) Do not touch the animals; (3) Make your descent over a sandy bottom; (4) Establish neutral buoyancy and maintain a horizontal swimming posture; and (5) Photographers especially should focus on not touching the reef. The video also incorporated other aspects related to the TPB, as detailed in Figure 1.

We then presented a draft version of the video to members of the local dive company association, and incorporated their suggestions about which messages should be shown to divers concerning reef etiquette. Their suggestions were to not change the five main driver messages, but to add material promoting the reserve as a dive destination, which we did. The final video was 4 min and 44 s in duration, with the audio in Portuguese and captions in Portuguese, Spanish and English (available at www.youtube.com/watch?v=GrGT7fvnqaw or from the authors upon request).

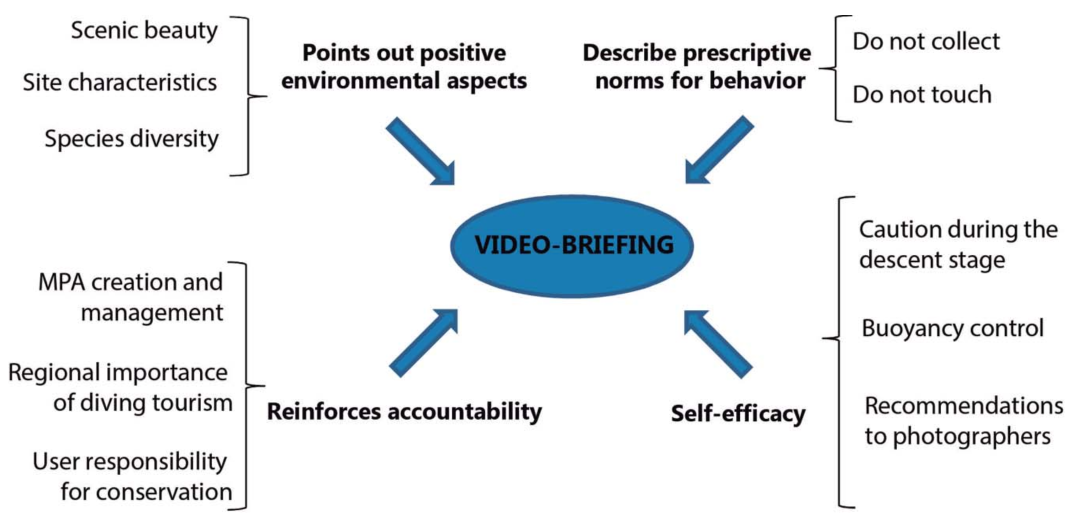

Figure 1. Messages provided in the video-briefing that are relevant to divers performing a particular behavior: (1) information on positive environmental characteristics worth preserving at the dive site, (2) description of prescriptive behavioral norms at the dive site, (3) presentation of issues that may motivate diver accountability for their behaviors, and (4) directions on self-efficacy techniques for conducting low-impact diver behavior.

Observations of diver behavior

We also observed the behaviors of scuba divers on boat trips made by the five selected dive companies. Divers were assigned to one of two experimental groups: control divers (n = 94) not exposed to the video-briefing, and treatment divers (n = 86) who viewed the video-briefing in the dive company head office before they boarded the dive boat. All divers in the control group were observed during 2015, before the video was created, to obtain baseline information about the behaviors of divers in the reserve before video creation and use (Webler & Jakubowski, 2016).

We then created the video (see below), and observed the behaviors of divers in the treatment group, who all viewed the video prior to diving during 2016. The video was shown to divers on about half (~45%) of the dive boat trips run by each of the five companies during summer 2016, with each boat trip selected based on the availability of the researchers, and the presence of enough divers per boat trip (at least five) for efficient data collection. The dive staff was informed of the experiment, but did not disclose to their diver customers that they were being observed to avoid bias in diver behavior.

The behaviors of divers belonging to both groups were sampled through direct observations underwater. One observer (V.J. Giglio, accompanied by a dive buddy) followed and recorded the behaviors of a pair of divers throughout each dive (after Giglio, Luiz, & Schiavetti, 2016), within a visual distance (2–4 m behind the divers) that allowed clear observation of any diver contacts with benthic organisms. It was possible for the observer to record all reef interactions by both members of each pair of observed divers, because the divers in each pair swam close together. In both the control and treatment groups, divers were sampled randomly during each boat trip. Data from subjects who were obviously aware of the presence of the observer were not used. Other information also was collected about each observed diver, to create a diver profile as detailed in Table 1. During the dive, interactions between divers and benthic organisms were recorded for each 10-min period throughout the dive, and classified in terms of the region of the diver's body involved, the types of benthic organisms contacted (see below), and impacts of contact (either no observed damage to benthic organisms, or damage observed in the form of breakage or injury to organismal tissues). Because it was not possible in most cases to verify whether any sediment clouds that were raised by divers actually reached or damaged benthic reef organisms, we did not include data about this type of potential impact in the present study. Contacted benthic organisms were identified (Table 1) as belonging to six major categories of organisms that were abundant at the study sites (Rogers et al., 2014), and were known to be susceptible to diving impacts (Lloret et al., 2006). We also recorded whether each interaction appeared to be intentional (i.e. divers focused visually on their hands or other limbs while contacting the benthos, such as when photographers reached toward and held

Table 1. Data collected on diver profiles and behaviors during interactions with benthic reef organisms.

	Variable	Data type	Units/levels
Diver profile	Gender	Categorical	Male/female
	Experience	Continuous	Number of previous dives
	Use of camera	Binary	Yes/no
	Dive duration	Continuous	Time in minutes
Diver behavior	Timing∗	Categorical	10-min segments (0–10, 11–20, 21–30, 31–40, 41–50, 51–60)
	Type of contact	Categorical	Contact, damage
	Context of contact	Categorical	Intentional, unintentional
	Part of diver body	Categorical	Fin, hand, knee, scuba gear
	Organism contacted	Categorical	Massive coral (*Siderastrea stellata* and *Mussismilia hispida*), branching coral (*Millepora alcicornis*), zoanthid (*Palythoa caribaeorum*), gorgonian (*Phylogorgia dillatata*) and sponge (*Aplysina* sp.)

Note: ∗ = time in minutes since the start of each dive.

onto reef organisms to maintain stability), or unintentional (i.e. divers did not observe themselves to contact the reef, and appeared oblivious to contact, such as when they hit reef organisms with their dive fins).

Back on the boat following each dive, we explained the aims of the study to the observed divers, asked for their verbal consent to use the observational data (consent was granted by all observed divers), and enquired about their level of experience with scuba diving, in terms of their number of dives completed. For all divers who had viewed the video prior to entering the water (treatment group), we requested their verbal ranking of the video content on a scale of 1–10 (1 = low value, 10 = high value content). To verify whether the treatment divers had memorized aspects of the video content, we also posed an open-ended question asking each of them to describe as completely as possible the five low-impact diving techniques that were mentioned in the video (see above). Responses to this question were considered correct for each of the five low-impact diving techniques, if the driver was able to describe clearly the basic idea that the video conveyed concerning each technique.

We assumed that the two groups (96 control divers observed in 2015 and 86 treatment divers observed in 2016) sampled a homogenous set of divers, because: (1) both groups were sampled during the same period each year (austral summer) which coincided with the high-visitation season, to reduce any potential bias from changes in the behaviors of divers and dive staff (such as the amount of time that dive staff devoted to oral briefings) between the low and high visitation seasons, and (2) none of the four major characteristics examined for the diver profiles (level of dive experience, dive duration, proportion of male vs. female divers, and proportion carrying cameras; Table 1) differed significantly between the two groups (see the Results section), and so were unlikely to have altered the results, and (3) only one observer (see above) was used for both groups, so observer effects did not vary between the two groups.

Data analysis

Comparisons of the four major types of diver characteristics between the control and treatment groups were made using *t*-tests (for dive duration and diver experience level) and Chi-squared tests (for the proportion of males vs. females, and the proportion of divers carrying cameras). Comparisons of the underwater behaviors of divers with different characteristics between the control and treatment groups were made using Kruskal–Wallis one-way analyses of variance, because the data were nonparametric. To examine the relationship between the level of diver experience (number of previous dives) and their contact rates with benthic organisms, we conducted a separate Spearman-rank correlation test for each diver gender, followed by a two-sided *t*-test to determine variation with gender. Effects of the experimental manipulation (treatment vs. control) and of time segment during each dive on diver rates of contact and damage to benthic organisms were analyzed using a generalized linear model, with a zero-inflated negative binomial distribution. The assumptions and best-fit model for the count data on contact and damage rates were verified according to Zeileis, Kleiber, and Jackman (2008). Statistical analysis were performed using the software R (R Core Team, 2016), with a significance level set at $p < 0.05$. Results are reported as means $\pm$ one standard error.

Results

Behavior of divers in the control group

We observed 94 control divers for a total of 4084 min (time observed per dive = 43.2 $\pm$ 0.8 min), with males comprising 61% and females 39% of the divers observed. The experience levels of these divers ranged widely between 3 and 500 dives (98.4 $\pm$ 16.2 dives), and ~one-third of them (35%) carried photographic cameras.

Table 2. Summary of results from Kruskal–Wallis tests comparing diver rates of benthic organismal contact and damage, between groups of divers with different characteristics in the control and treatment groups. Rates are shown as means ± standard error. Significant differences are in bold.

	Control	Treatment	x^2	*p* Value
Contacts min^{-1}				
Female	0.28 ± 0.07	0.05 ± 0.01	3.09	0.07
Male	0.22 ± 0.07	0.07 ± 0.14	3.90	**0.04**
Photographer	0.29 ± 0.05	0.06 ± 0.02	6.97	**0.008**
Non-photographer	0.21 ± 0.05	0.07 ± 0.01	1.36	0.2
Overall	0.24 ± 0.05	0.07 ± 0.01	7.22	**0.007**
Damage min^{-1}				
Female	0.02 ± 0.009	0	5.08	**0.02**
Male	0.01 ± 0.005	0.004 ± 0.001	1.35	0.2
Photographer	0.02 ± 0.008	0	4.33	**0.03**
Non-photographer	0.01 ± 0.005	0.004 ± 0.001	1.41	0.2
Overall	0.02 ± 0.004	0.003 ± 0.001	4.50	**0.03**

Most of the control divers (70% of $N = 94$) were observed to contact benthic reef organisms, for a total of 946 contacts at a rate of 0.24 ± 0.05 contacts min^{-1}. Also, they caused a total of 66 instances of damage to benthic organisms, at a 10-fold lower rate than that of contact (0.02 ± 0.004 instances of damage min^{-1}). Thus, during a typical dive extending ~43 min, each control diver caused ~10 contacts and 1 instance of damage to benthic organisms. Almost all contacts appeared to be unintentional (94%), and were caused by the divers' fins (89%). The few observed instances of intentional contact were caused by photographers who contacted the substrate with their hands to stabilize themselves while taking pictures. The organisms most frequently contacted were gorgonians (0.11 ± 0.02 min^{-1}) and zoanthids (0.10 ± 0.02 min^{-1}), followed by sponges (0.02 ± 0.008 min^{-1}). In contrast, damage was caused most frequently to zoanthids (0.11 ± 0.003 min^{-1}), followed by branching corals (0.004 ± 0.002 min^{-1}), and gorgonians (0.002 ± 0.001 min^{-1}).

The level of diving experience did not correlate with the frequency of benthic contact by either male ($r = -0.07$, $p = 0.2$) or female divers ($r = 0.2$, $p = 0.05$). In addition, the rate of contact did not vary significantly with diver gender (Kruskal-Wallis test: contact $x^2 = 1.77$, $p = 0.18$; damage: $x^2 = 0.34$, $p = 0.5$). Photographers engaged in apparently high rates of both contact and damage to benthic organisms relative to non-photographers (Table 2), but the difference was significant only for contacts ($x^2 = 6.34$, $p = 0.01$).

Behavior of divers in the treatment group

We observed 86 treatment divers for a total of 3757 min (time observed per dive = 44.3 ± 0.6 min), with male divers comprising 66% and female 34% of the divers observed. Similar to the control divers, the experience level of treatment divers ranged widely between 2 and 450 dives (72.7 ± 14.8 dives), and about one-third (29%) carried photographic cameras. None of the four major characteristics of the treatment divers observed in 2016 differed significantly from those of the control divers observed in 2015 (dive duration, proportion of male vs. female divers, experience level, or proportion who were photographers; *t*-tests: $t = 1.6$ and 0.5 for duration and experience level, $p = 0.1$ and 0.6, respectively; Chi-square tests: $x^2 = 0.5$ and 4.1 for proportion of male vs. female and proportion of photographers, $p = 0.5$ and 0.07, respectively). In contrast to the control divers, only 58% of the treatment divers ($N = 86$) contacted benthic reef organisms, for a total of 245 contacts observed, at a rate of only 0.07 ± 0.001 contacts min^{-1}. They caused a total of nine instances of damage to benthic organisms, which was 20-fold less frequent than their rate of contact (only 0.003 ± 0.001 instances of damage min^{-1}). As such, treatment divers engaged in significantly lower rates of both contact and damage than did control divers (Figure 2; Table 1). During a typical dive extending ~44 min, each treatment diver caused only ~3 contacts and ~0.1 instances of damage to benthic organisms (= one-third the contact rate and one-tenth the damage rate of control divers who had not viewed the video briefing). Almost all contacts by treatment divers

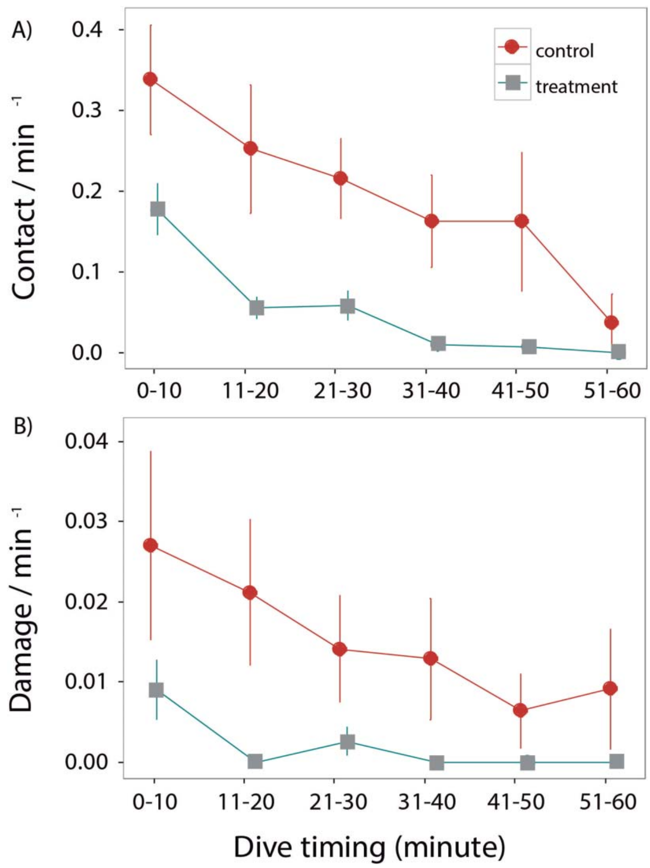

Figure 2. Variation in rates of (a) contact and (b) damage by divers interacting with benthic reef organisms, with time since the start of each dive. Data are shown as means ± standard error.

appeared to be unintentional (97%) and were caused by the divers' fins (92%), as in the control group. The five observed instances of intentional contact in the treatment group were caused by photographers who contacted the substrate with their hands apparently to stabilize themselves while taking pictures. Treatment divers most frequently contacted zoanthids (0.04 ± 0.007 min^{-1}) and gorgonians (0.03 ± 0.007 min^{-1}), and of the seven instances of damage caused by treatment divers, all were to zoanthids (0.002 ± 0.001 min^{-1}); these divers completely avoided damaging stony corals and gorgonians, unlike the control divers.

As in the control group, the level of diving experience did not correlate with the frequency of benthic contact by either male ($r = -0.04$, $p = 0.2$) or female treatment divers ($r = -0.2$, $p = 0.06$). Also, female divers did not cause significantly higher rates of contact than did males, although their means were higher (Table 2). Finally, in a reversal of the pattern in the control group, the treatment photographers engaged in significantly lower rates of both contact and damage than did the non-photographer divers (Table 2).

The observed declines in reef-damaging behaviors by the treatment vs. control divers were significant for rates of contact to zoanthids, gorgonians and sponges, and for rates of damage to zoanthids and branching corals (Figure 3). The mean rates of both contact and damage by treatment divers decreased with elapsed time since the start of the dive, with a significant decline occurring for rates of contact ($p = 0.04$; Table 3).

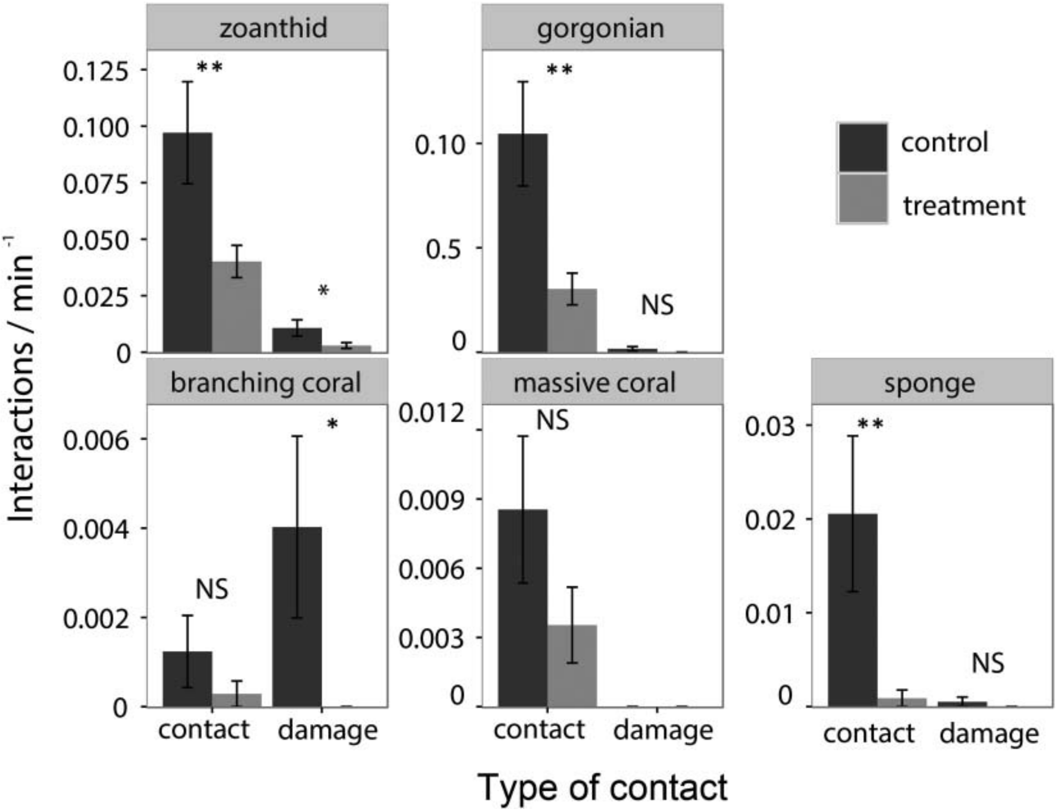

Figure 3. Variation in rates of contact by divers to benthic organisms, with diver group (control vs. treatment), type of contact (contact vs. damage), and type of benthic organism contacted. Levels of significance: $*p < 0.05$; $**p < 0.01$; $***p < 0.001$; NS: not significant. Data are shown as means ± standard error.

Memorization and evaluation of the video-briefing

After their dives, the treatment divers remembered most of the five tips on low-impact techniques from the pre-dive video-briefings (see the "Methods" section; 3.2 ± 0.8 tips remembered per diver). The most-remembered tips were: do not touch the animals (remembered by 76% of respondents), establish neutral buoyancy and correct swimming by maintaining a horizontal swimming posture (69%), and do not collect anything (60%). Divers evaluated the content of the video-briefing positively, providing a ranking of 9.3 ± 0.2 on a scale of 1–10.

Table 3. Summary of generalized linear model results on the effect of a video-briefing on rates of diver contact and damage to benthic reef organisms. Significant differences are in bold.

	Estimate	S.E.	*Z* value	*p* Value
Contact				
(Intercept)	1.33	0.23	5.81	**<0.001**
Group	−0.67	0.30	−2.23	**0.01**
Timing	0.001	0.01	0.18	0.85
Group*Timing	−0.03	0.02	−2.00	**0.04**
Damage				
(Intercept)	0.90	0.43	2.07	**0.03**
Group	−2.64	1.13	−2.33	**0.01**
Timing	−0.02	0.02	−1.27	0.20
Group*Timing	−0.08	0.11	0.25	0.42

Note: Group = treatment versus control group. Timing = time since start of dive.

Discussion

The present study reveals that viewing an educational video-briefing significantly enhances the use of low-impact behaviors by scuba divers, in that it appears to substantially reduce their rates of contact with and damage to benthic reef organisms. In the control group which did not view the video-briefing, photographers caused more damage and contacts to benthic organisms than did non-photographers, as has been verified at other reef destinations (Barker & Roberts, 2004; Giglio, Ternes, et al., 2016). Interestingly, in the treatment group the pattern reversed, with the photographers altering their behavior to cause relatively fewer contacts and less damage to the benthos than did the divers without cameras. This result may have occurred because a portion of the video message was designed specifically for photographers, in which they were reminded to not touch the reef, to establish neutral buoyancy, and to slowly approach live photographic subjects to avoid scaring them away. This type of messaging was based on the TPB in that it targeted the motivations and attitudes of photographers in wanting to not scare away their subjects, and may thus have especially motivated photographers to behave in a more ecologically responsible manner. This finding is of universal value in terms of applying the TPB to alter diver behavior, particularly in marine areas which receive frequent visits by underwater photographers.

The treatment divers who watched the video-briefing exhibited one of the lowest known rates of diver contacts with benthic organisms, among worldwide diving destinations: only 0.03 contacts min^{-1} (Table 2). This value is higher only than that reported for divers on reefs in the Egyptian Red Sea, with 0.02 contacts min^{-1} (Medio et al., 1997), in which both an elaborate pre-dive educational briefing and *in situ* instruction concerning the traits of benthic organisms were used to improve diver behavior and mitigate diving impacts. However, this more extensive approach likely is not feasible in the framework of most dive operations due to limitations of dive staff training, interest, and time. Our study site comprised rocky reefs with less structural complexity and coral cover than at many coral reef dive destinations, which probably also contributed to the relatively low damage rates observed here. Reefs with high coral cover and structural complexity are particularly vulnerable to diver damage (Hawkins & Roberts, 1993; Lyons et al., 2015). In ACMER, 49% of the observed contacts were with the zoanthid *P. caribaeorum* which is abundant on Brazilian reefs, and is relatively resistant to the effects of anthropogenic stressors (Silva et al., 2015). The rates reported here of diver contact with each type of benthic organism appeared to be influenced by the relative percent cover of each type on the reefs, in which the most abundant organisms received more contacts. For example, branching corals occurred at low rates of cover (<5%) and accounted for only 1.7% of contacts in the control group, which reduced to zero in the treatment group. In contrast, the gorgonian *Phylogorgia dillatata* also occurred at low cover, but received a relatively high frequency of contacts (40%), possibly explained by its patchy distribution and high vertical relief compared to *P. caribaeorum*. We also observed that divers often swam slowly in the vicinity of gorgonians to observe the organisms associated with them, potentially causing them to contact gorgonians more frequently than they contacted other benthic organisms. Gorgonians have suffered from tissue loss and death in the region (Cassola, Pacheco, Barbosa, Hansen, & Ferreira, 2016), and our results indicate that scuba diving may be one of the contributing stressors. This issue needs to be further investigated through field experimentation to simulate the effects of diver contacts on gorgonians. Because divers may know that fire coral can sting them, potentially they could avoid contact with this organism. However, many of the divers in the present study did not appear able to identify fire coral, and most of their reef contacts were unintentional via their fin kicks, so they did not seem to intentionally avoid fire coral contacts.

In our study, we observed that divers reacted in a highly favorable manner to the video-briefing, and appeared willing to participate in educational initiatives. Messages provided in pre-dive briefings potentially can be forgotten by divers after they enter the water (Hammerton & Bucher, 2015). However, in our study, divers remembered most of the low-impact behavior tips from the video after they had finished diving, indicating their high retention of the video content. These patterns may have occurred in part because the level of diver commitment to the messages of a pre-dive video-briefing are influenced by their affinity and attachment to a given dive site, as suggested by place attachment theory (Halpenny, 2010). Most of the sampled divers in the present study lived in nearby metropolitan cities, and thus may have been especially site-attached to ACMER; they expressed a positive attitude toward local reef conservation, in terms of the need to reduce damaging behaviors. This finding also links with our use of the TPB to design our video, in that our message to avoid contacting reef organisms was framed in the context of the known motivation of recreational divers to enhance reef conservation.

A limitation of the present study was that divers from the control and treatment groups were segregated temporally. This occurred because of the time required to create the video-briefing and to engage the participation of dive industry stakeholders in the video-showing process, after the control group had already been observed. However, both groups were sampled during the same period each year which coincides with the high visitation season, to reduce any potential bias from changes in divers and dive staff behavior among the low and high visitation seasons (Barker & Roberts, 2004; Roche et al., 2016). We also found that levels of diver experience and other diver traits did not differ significantly between the two groups, so these variables were unlikely to have impacted the results. An improvement in future studies would be to temporally integrate the treatment and control diver groups, to ensure that timing alone does not impact these types of results.

Despite these methodological limitations, it appears that the use of a pre-dive video was mainly responsible for the changes observed in diver behavior in the present study, especially as the treatment divers remembered most of the low-impact behavior tips from the video even after dive was over. They also were highly receptive to the implementation of this educational approach, at a local dive destination which previously did not provide consistent information to visitors about reef conservation and responsible behavior. We recommend further research to investigate the effectiveness of video briefings in reducing diver–benthos interactions, especially at destinations which are highly susceptible to the impacts of scuba diving such as on structurally complex coral reefs.

Conclusion

We report here aspects of scuba diver behavior at a popular dive destination on a subtropical reef in Brazil, and test an educational video-briefing as a tool to mitigate potentially damaging diver behaviors toward benthic reef organisms. Divers in the treatment group caused one of the lowest known rates of benthic contact, only ~3 contacts and ~0.1 instances of damage to benthic organisms during a typical dive of ~44 min. The video-briefing was produced in partnership with local diving stakeholders, and proved to be an efficient tool to mitigate the impacts of scuba diving. Divers at all experience levels reduced their reef contact rates after viewing the video, especially if they were underwater photographers. Divers who watched the video enhanced their use of low-impact diving techniques, leading to ~3-fold reduction in their rates of contact and an even larger, ~10-fold reduction in their rates of damage to benthic organisms, over divers who did not receive the video-briefing.

We show here that the use of a video-briefing can be valuable at dive sites where the commitments of dive companies, in terms of their time limitations and other constraints, impede the administration of consistent oral pre-dive briefings by dive staff to encourage responsible diver behavior. This advantage occurs in part because the content of video-briefings does not depend on the training level of dive company staff, and videos can deliver a uniform, high-quality message to divers. They also are easy to implement because they may be effective even when short in duration (<5 min in the present study), inexpensive to produce (potentially <US$ 4000), made available online at no cost to dive operators and divers, and can be viewed in a flexible format depending on the local site conditions.

The conceptual contribution of this research to the field is that it demonstrates the efficacy of video-briefings as an educational tool to mitigate the negative impacts of tourism in natural ecosystems, especially among recreational divers on rocky reefs. We also demonstrate that working with local tourism providers in developing the content of educational videos can enhance their content and render a final video product that is acceptable to members of the industry, and therefore likely to be used voluntarily by tour operators. Finally, we show that application of the TPB can be used to inform the development of video-based educational messages to underwater ecotourists. Our results provide evidence that video-briefing by informing divers about environmentally responsible practices can reduce negative impacts of the scuba diving on benthic marine organisms, as well satisfying divers by presenting educational messages in an entertaining and motivational context. However, it is important to note that the video was tested at a subtropical reef area which had lower coral cover and less structural complexity than a tropical coral reef. An important next step in research on this topic would be to verify if this type of video can provide similarly positive results on highly complex tropical coral reefs. This study adds to the framework of tested strategies available to support the sustainable use of MPAs by the diving tourism industry.

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