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RESEARCH ARTICLE

Behaviour of recreational spearfishers and its impacts on corals

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Abstract

1. Recreational diving is a concern regarding its effects on benthic assemblages, especially on heavily dived coral reefs. However, spearfisher behaviour and the scale of damage they cause to corals remains unknown.
2. The behaviour of recreational spearfishers was observed to determine their rate of physical contacts with corals. The experience level and fishes captured by spearfishers were assessed to establish their relationship with the number of contacts with corals.
3. All spearfishers made contact with corals, at an average rate of 1.25 ± 0.1 SE touches per minute and caused physical damage at a rate 0.51 ± 0.04 per minute. Massive corals were most frequently touched and branching corals were most frequently damaged. Touches and damage occurred mainly through fin kicks, spearfisher bodies and spearguns. Contact rates varied according to spearfisher experience level and the fish they were targeting. Novice spearfishers showed no preference for specific targets while experienced spearfishers target mesopredator fishes.
4. Spearfishing caused the highest known rates of touches and damage to corals among all the activities involving recreational diving. The activity may add to local stressors on corals, especially at sites with high visitation rates. Understanding how the factors that affect spearfisher behaviour and their effects on corals may help managers to develop strategies to mitigate the incidence of damaging behaviour.

KEYWORDS

Abrolhos Bank, benthic assemblages, coastal management, coral reef fisheries, fisheries management, recreational diving, recreational fishing

1 | INTRODUCTION

Coral reefs have suffered impacts from a range of human activities varying from local to global scales, resulting in an accelerated coral loss. Thus, the need to understand the underlying causes of coral declines have been widely recognized (Bellwood, Hughes, Folke, & Nyström, 2004; Hoegh-Guldberg et al., 2007). Among the recreational activities that are practised on coral reefs, the impacts caused by scuba diving on corals have been of particular concern at sites with high visitation rates (Lamb, True, Piromvaragorn, & Willis, 2014; Zakai & Chadwick-Furman, 2002). Divers can damage corals through direct (physical) or indirect (sediment re-suspension and deposition) contact with their hands, body, scuba gear, and mainly fin kicks (Giglio, Luiz, & Schiavetti, 2016; Rouphael & Inglis, 1997). Owing to the fragile structure of hard-corals, divers' contact can result in abrasion, breakage, or tissue removal. Damaged corals become more susceptible to predation, competition interference, and disease, which can result in the death of the individual or even of the colony (Guzner, Novplansky, Shalit, & Chadwick, 2010).

Besides scuba diving, other recreational activities that also involve immersion in the sea include snorkelling and spearfishing. The latter is a sport widely practised in tropical and temperate seas (Bulleri & Benedetti-Cecchi, 2014). Nevertheless, spearfishing is largely unreported, and when available, data are lumped into a broad 'recreational fishing' category that includes other types of fishing gear but mostly line fishing. Despite being highly target-selective, spearfishing can have a considerable impact on fish populations, specifically those with life-history attributes than make them vulnerable to overfishing, such as large body size, high longevity, and late maturity (Coll, Linde, García-Rubies, Riera, & Grau, 2004; Young, Foale, & Bellwood, 2014).

The adverse effects of spearfishing on reef fishes have been widely described (Frisch, Cole, Hobbs, Rizzari, & Munkres, 2012; Godoy, Gelcich, Vásquez, & Castilla, 2010; Lloret et al., 2008; Nunes, Medeiros, Reis-Filho, Sampaio, & Barros, 2012). Moreover, as widely reported for recreational scuba diving (Au, Zhang, Chung, & Qiu, 2014; Hasler & Ott, 2008; Lamb et al., 2014), spearfishing can cause damage to corals. To capture reef-associated prey, spearfishers intentionally swim near the bottom and may hold themselves to the reef to remain still while waiting for fish to approach within range.

Nevertheless, the behaviour of spearfishers and the damage they cause to corals have not been properly quantified. Identifying the factors that describe spearfisher behaviour and the potential stresses on benthic organisms may help managers to develop strategies such as training procedures, educational approaches, use of zoning and carrying capacity to mitigate spearfishing impacts. The aim of this study was to examine the behaviour of spearfishers in the largest coral reef complex of the South Atlantic, Abrolhos Bank, by quantifying how contact rates with corals vary among spearfishers' profile and fishes captured.

2 | METHODS

2.1 | Study area

Situated on the eastern Brazilian coast, the Abrolhos Bank (16°40′ to 19°30′S and 37°25′ to 39°45′W) is the largest and richest coral reef complex in the South Atlantic (Leão & Kikuchi, 2001; Moura et al., 2013). Eighteen coral species are described from the region and of these, eight are endemic to the South Atlantic (Leão & Kikuchi, 2001). Abrolhos Bank is a popular destination for recreational diving in Brazil (Giglio, Luiz, & Schiavetti, 2015). Recreational spearfishing has been practised in Abrolhos Bank since the 1980s (Francini-Filho & Moura, 2008), however, the numbers involved and captures remain unassessed. The coral reefs sampled are located in shallow reefs of Abrolhos Bank, at Parcel das Paredes (17°48′47″, 39°0′40″) and Popa Verde reefs (18°0′40.4″, 39°1′6.2″).

2.2 | Data collection

Sampling was conducted between December 2012 and February 2013. The observer was introduced as a member of the charter boat crew to avoid influencing spearfishers' behaviour. The behaviour of each recreational spearfisher was assessed over 10 minutes through direct observation. Spearfishers were observed just once and to a maximum depth of 8 m. The observer remained as inconspicuous as possible between 3 and 6 m behind their subjects within visual contact. Physical contact between the spearfishers and corals was quantified according to the parts of the spearfisher's body or equipment (fin, body, hand, speargun or spear line) contacting the coral. Each contact was classified either as a touch or damage depending on whether the physical contact caused visible damage to the coral. Coral type was grouped into one of three categories: (i) branching (e.g. *Millepora alcicornis*); (ii) massive (e.g. *Mussismilia braziliensis* and *M. hartii*); and (iii) octocorals (e.g. *Phyllogorgia dilatata*, *Muriceopsis sulphurea* and *Plexaurella* sp.). The number of fish captured during the sample period was recorded. After dives, spearfishers were questioned as to their fishing targets and experience level. To determine the experience, spearfishers were asked about the number of dives conducted per year and number of years they had been spearfishing. For a spearfisher who conducts 50 dives per year and has 10 years of practice, the experience was 500 dives. Experience level was categorized as novice (≤ 150 dives), intermediate (151–400 dives) and experienced spearfishers (> 400 dives). After the data had been collected, the survey aims were explained to subjects and authorization to use data was requested.

The spearfisher contact rates with corals obtained in this study were compared with data from scuba divers elsewhere, compiled from peer-reviewed publications using Scopus and Google scholar search engines. The keywords used were 'recreational diver behaviour' and 'scuba diving impact'. In this analysis, only studies conducted on coral reefs and which discriminated diver contacts either as touch or damage was included. Scuba divers using a camera (hereafter underwater photographers) were grouped separately from scuba divers without cameras.

2.3 | Data analysis

The relationship between the spearfisher-coral contacts and their experience and number of fish captured were modelled using generalized additive models using the package mgcv (Wood, 2017) of R (R Core Team, 2016), assuming a Gaussian distribution, identity link function and cubic regression splines (Hastie & Tibshirani, 1990). As data do not have the assumptions of normality and homoscedasticity, results were compared with data from literature using the non-parametric ANOVA (Kruskal–Wallis test). A post hoc test was conducted to verify differences among groups using the Dunn's test. All tests were performed at a significance level of $P < 0.05$.

3 | RESULTS

Fifty-seven spearfishers were observed, totalling 570 minutes. They were all male ranging in age from 17 to 53 years old (mean = 38 years ±6.2 SE). The experience level ranging from 10 to 750 dives, comprising novice (n = 16), intermediate (n = 26) and experienced spearfishers (n = 15). All spearfishers made contact with the corals, with an average of 1.25 ± 0.1 touches min^{-1}, with damage occurring at a rate of 0.51 ± 0.04 times min^{-1}. Novice spearfishers generated the highest rate of touches (1.57 ± 0.11 min^{-1}) and damage (0.64 ± 0.08 min^{-1}), followed by those with intermediate experience (1.22 ± 0.09 touches min^{-1} and 0.49 ± 0.03 incidences of damage min^{-1}). Experienced spearfishers had the lowest rate of touches (0.96 ± 0.12 min^{-1}) and lowest rates of damage (0.40 ± 0.03 min^{-1}). Massive corals were the most frequently touched (0.79 ± 0.2 min^{-1}) and branching corals the most often damaged (0.39 ± 0.1 min^{-1}). Touches and damage were mostly caused by fin kicks (0.39 ± 0.1 and 0.23 ± 0.03 min^{-1}, respectively). The rates of contacts according to spearfisher body part or equipment and organisms are described in Table 1.

Touches and damage rates showed a significant relationship with spearfisher experience (Table 2), both decreasing as experience

TABLE 1 Rates of touches and damage per minute caused to different corals by spearfishers and their equipment. Deviations are standard errors. The higher rates are in bold

	Touch				Damage			
	Massive	Branching	Octocoral	Total	Massive	Branching	Octocoral	Total
Body	0.16 ± 0.04	0.02 ± 0.001	**0.08 ± 0.01**	0.26 ± 0.05	0.02 ± 0.001	0.07 ± 0.02	**0.01 ± 0.003**	0.1 ± 0.02
Hand	0.14 ± 0.002	0.01 ± 0.001	0.05 ± 0.07	0.2 ± 0.07	0	0.05 ± 0.03	0.009 ± 0.004	0.06 ± 0.03
Fin kick	**0.27 ± 0.1**	0.02 ± 0.005	0.1 ± 0.02	**0.39 ± 0.1**	**0.05 ± 0.01**	**0.18 ± 0.02**	0	**0.23 ± 0.03**
Spear gun	0.09 ± 0.05	0.007 ± 0.002	0.06 ± 0.01	0.16 ± 0.06	0.02 ± 0.01	0.07 ± 0.04	0.01 ± 0.002	0.01 ± 0.05
Line	0.13 ± 0.02	**0.05 ± 0.003**	0.06 ± 0.003	0.24 ± 0.03	0	0.02 ± 0.01	0.001 ± 0.001	0.01
Total	**0.79 ± 0.2**	0.11 ± 0.1	0.35 ± 0.1	1.25 ± 0.34	0.09 ± 0.02	**0.39 ± 0.1**	0.03 ± 0.01	0.51 ± 0.2

TABLE 2 Generalized additive model results showing the effects of different factors on spearfisher rates of contact with corals. Significant effects ($P < 0.05$) are in bold

	Estimate	SE	*t*	P
Touch				
(intercept)	1.411	0.121	11.695	**< 0.001**
Experience	−0.001	0.0003	−5.015	**< 0.001**
No. of fishes caught	0.254	0.074	3.421	**< 0.01**
Damage				
(intercept)	0.694	0.062	11.114	**< 0.001**
Experience	−0.0005	0.0001	−3.236	**< 0.01**
No. of fishes caught	−0.010	0.042	−0.239	0.81

increased (Figure 1a). Although not statistically significant, there was a slight tendency for an increase in the number of touches as the number of fish captured increased, while damage did not increase (Figure 1b). The relationship between experience level and number of fish captured was not significant. With respect to the targets, about half of novice spearfishers did not specify a target species or family, while most intermediate and experienced spearfishers targeted mainly mesopredators (Table 3).

Nine studies were found that provided data on touch rates and eight on damage by scuba divers on corals (Table 4). Spearfishers made significantly more touches and damage than scuba divers and photographers in the Abrolhos Bank (Kruskal–Wallis test for touches, $x^2 = 114.01$, $P < 0.001$ and damage $x^2 = 132.6$, $P < 0.001$; Figure 2a and b). At this site, average touch rate of spearfishers was 5.7-fold higher than that of scuba divers (1.25 ± 0.1 vs 0.22 ± 0.02) and damage rate was 24-fold higher than scuba divers (0.51 ± 0.04 vs 0.02 ± 0.003). When compared with data from other sites (Table 4), the touch rates of spearfishers were ~4.5-fold higher than those of scuba divers and photographers, and damage caused by spearfishers was 9-fold higher than that of scuba divers and ~12-fold higher than that of underwater photographers (Figure 3).

4 | DISCUSSION

Spearfishers caused the highest known rates of touch and damage to corals among all the recreational activities involving diving in coral reefs. Spearfishing may add to local stressors on corals and other fragile benthic organisms, especially at sites with high visitation rates. Although the potential damage produced by individuals is minor, there is evidence that cumulative effects of disturbances caused by divers can have adverse effects on corals, such as loss of cover (Fava, Ponti, Scinto, Calcinai, & Cerrano, 2009; Hawkins et al., 1999) and consequently loss of structural complexity (Lyons et al., 2015). Injured corals are more susceptible to diseases, predation and competition interference from algae and other organisms (Guzner et al., 2010; Lamb et al., 2014). In the long term, this can result in the death of the colony. The loss of coral reef structural complexity caused by physical disturbances adversely affects ecosystem functioning and decreases the recovery potential after disturbances (Mellin, MacNeil, Cheal, Emslie, & Caley, 2016). In addition, the loss of reef complexity can have negative consequences for reef fish growth and survival, because complex reefs provide more refuges mediating predator–prey interactions (Graham & Nash, 2013). This has has resulted in significant declines in fisheries (Rogers, Blanchard, & Mumby, 2014).

Similar to scuba divers, more experienced spearfishers made fewer contacts with the reef. Experienced practitioners generally have better swimming technique and buoyancy control and thus can better avoid collisions with reefs (Barker & Roberts, 2004). Also, experienced spearfishers tend to shoot less frequently than novice divers, as they are more selective in their targets. This means that experienced spearfishers cause fewer collisions with the reef through their gear. For instance, when a shot is missed, the spearhead may hit and often damage the reef. In addition, a fish may survive the shot and in an attempt to take shelter, it may lead to the speargun, line or spearfisher coming into contact with the coral in the ensuing battle. Thirdly, experienced spearfishers were more patient, avoiding colliding with the reef and waiting for the best moment to shoot. When questioned about this behaviour, they mentioned that unnecessary noise from collisions with the reef and unsuccessful shots usually scare the fish away. Experienced spearfishers also avoided making long distance shots because of the greater chance of missing the target and the increased likelihood of spears damaging the reef.

Novice spearfishers had no specific targets, they were simply motivated to catch the greatest number of fish. Fish captures have been described as a measure of success by demonstrating ability and masculinity among fishers (Dumont, 1992). Young and inexperienced practitioners are generally very competitive in order to gain the respect and admiration of their peers (Young, Foale, & Belwood, 2016). In the same way, Pinheiro and Joyeux (2015)

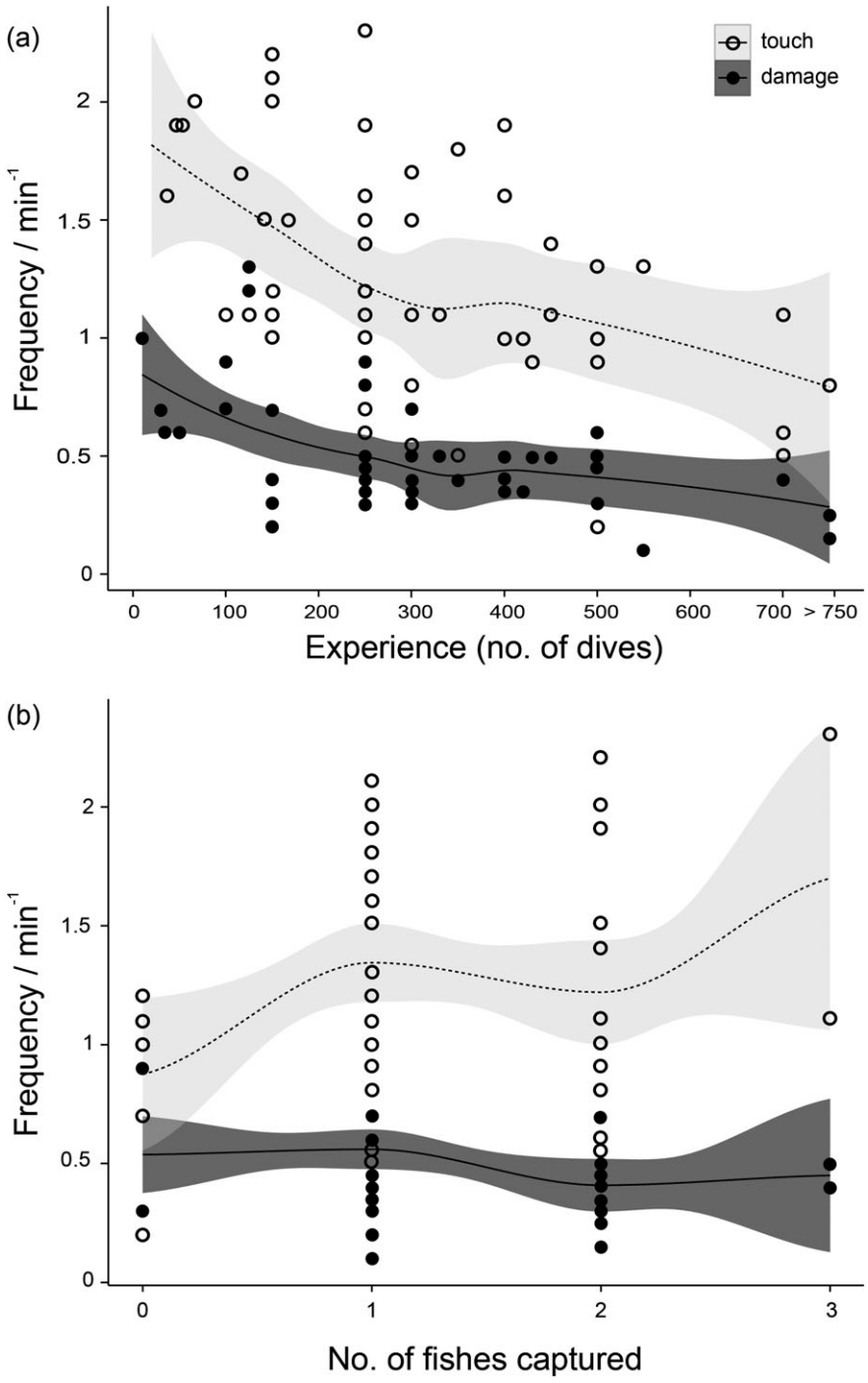

FIGURE 1 Relationships between contacts (touches and damage) of spearfishers with corals and (a) experience, and (b) number of fishes caught as defined by generalized additive models. 95% confidence limits are shown in grey

TABLE 3 Fish species targeted by spearfishers according to their experience level. Values are categorized according to experience level as: Novice (< 150 dives; *n* = 16), intermediate (151–400 dives; *n* = 26) and experienced (> 400 dives; *n* = 15). Species: Black grouper: *Mycteroperca bonaci*, dog snapper: *Lutjanus jocu*, great barracuda: *Sphyraena barracuda*, and yellow jack: *Carangoides bartholomei*

Target	Novice	Intermediate	Experienced
Black grouper	26	43	62.5
Dog snapper	13	29	25
Great barracuda	7	7	0
Yellow jack	0	7	12.5
Parrotfishes	7	0	0
Not specified	47	14	0

and Diogo, Pereira, and Schmiing (2017) verified that novice spearfishers were less selective in their fish targets. Thus, as novice spearfishers shoot with higher frequency than experienced ones, the number of contacts with corals increases. It is important to note also that the behaviour of divers can be influenced by the characteristics of the site, such as reef complexity and topography, depth, currents and visibility (Barker & Roberts, 2004; Giglio et al., 2016).

The fins of spearfishers caused most touches and damage to the corals. Among scuba divers, fin kicks are the main cause of damage to benthic organisms, generally indicating a lack of proficiency at swimming and buoyancy control (Hammerton, 2017). However, among spearfishers, the frequency of fin kicks was related to the fish targets

TABLE 4 Summary of compiled surveys of recreational diver behaviour on coral reefs. NI = not informed

Site	Type of diver	Touch rate	Damage rate	Source
Australia	Scuba	0.49 ± 0.05	0.04 ± 0.008	Harriott, Davis, & Banks (1997)
Australia	Scuba	NI	0.18 ± 0.08	Rouphael & Inglis (1997)
Australia	Scuba	0.54	0.04 ± 0.01	Rouphael & Inglis (2001)
Hong Kong	Scuba	0.23	NI	Chung, Au, & Qiu (2013)
Palau	Scuba	0.18 ± 0.03	NI	Poonian, Davis, & McNaughton (2010)
Eilat (Red Sea)	Scuba	NI	0.03 ± 0.005	Zakai & Chadwick-Furman (2002)
Florida (USA)	Scuba	0.23 ± 0.002	0.07 ± 0.001	Krieger & Chadwick (2013)
Florida (USA)	Scuba	0.09 ± 0.03	NI	Camp & Fraser (2012)
St Lucia (Caribbean)	Scuba	NI	0.006	Barker & Roberts (2004)
Brazil	Scuba	0.19 ± 0.02	0.03 ± 0.003	Giglio et al. (2016)
Palau	Photographer	0.31 ± 0.07	NI	Poonian et al. (2010)
St Lucia (Caribbean)	Photographer	NI	0.03	Barker & Roberts (2004)
Brazil	Photographer	0.26 ± 0.06	0.05 ± 0.01	Giglio et al. (2016)
Brazil	Spearfisher	1.25 ± 0.1	0.51 ± 0.04	This study

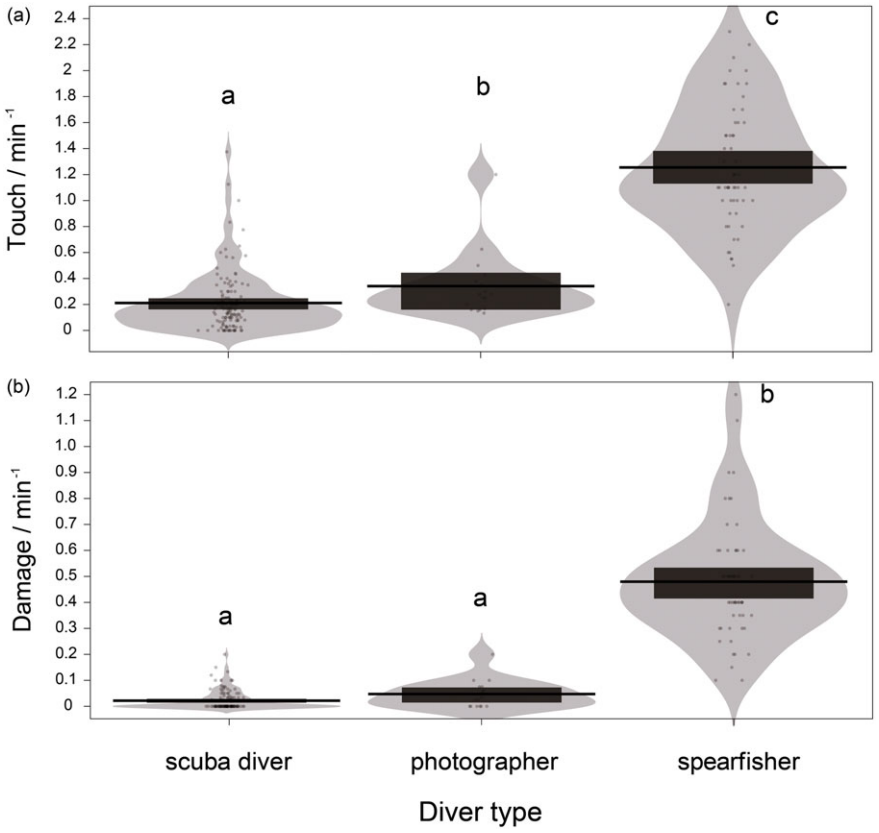

FIGURE 2 Rates of contact with corals caused by recreational scuba divers, specialist photographers (scuba diver using professional camera with external flash greater bulk than compact camera), in the Abrolhos Bank (extracted from Giglio et al., 2016) and recreational spearfishers (this study): (a) touch contacts and (b) damaging contacts. Points are the raw data, black line represents the average, bean is the density and band is the inference interval. Different letters above bars indicate significant differences

and fishing strategy. Spearfishers were largely oblivious of the damage that they caused to corals and their main reason to avoid touching the corals was to reduce noise and optimize fish captures. Clearly, spearfishing needs initiatives to educate and improve practitioners' awareness of the ecological role of corals, the threats they face, and the importance of these organisms in improving fisheries sustainability.

In Abrolhos Bank, spearfishing has contributed to the current over-exploitation of several reef fishes, mainly groupers, snappers and parrotfishes (Ferreira, 2005; Francini-Filho & Moura, 2008; Giglio, Luiz, & Gerhardinger, 2015; Zapelini, Giglio, Carvalho, Bender, & Gerhardinger, in press). With respect to corals, despite the marked increase in diseases (Francini-Filho et al., 2008), short-term monitoring (2003–2008) has not revealed a decline in coral cover (Francini-Filho et al., 2012). However, the sites most frequented by spearfishers were not sampled and remain poorly assessed. A better understanding of the effects of spearfishing allied to multiple local stressors in Abrolhos Bank benthic organisms is necessary to manage the impacts and assess the recovery potential of cumulative anthropogenic physical disturbances, such as anchoring, boat strikes, destructive fishing practices, nautical and diving tourism.

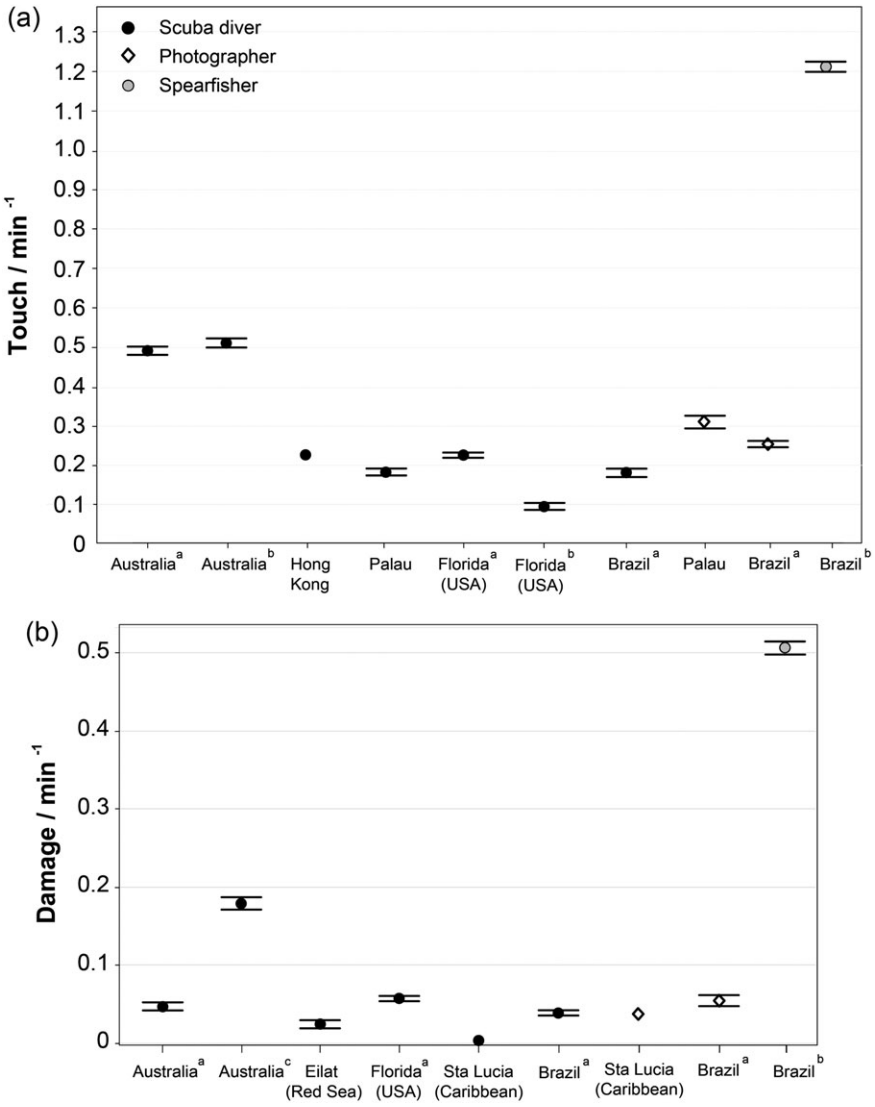

FIGURE 3 Comparison of the average rates of contact with corals by recreational divers in a number of sites throughout the world. The data are presented as (a) touch rates and (b) damage rates. The deviations are standard errors. Note y-scales are different for the two plots. Sites: Australia a: Harriott et al. (1997); Australia b: Rouphael and Inglis (1997); Australia c: Rouphael and Inglis (2001); Florida (USA) a: Krieger and Chadwick (2013); Florida (USA) b: Camp and Fraser (2012); Brazil a: Giglio et al. (2016); Brazil b: This study

Managers and scientists are concerned about the potential of spearfishing for reducing abundance of fishes (Frisch et al., 2012; Godoy et al., 2010). This study adds another important consequence of spearfishing: the potential to cause damage to corals. Extrapolating results of this survey to a typical 60-minute dive, each spearfisher could generate up to 75 touches resulting in 30.6 incidences of damage, while scuba divers have significantly fewer contacts (16 touches and 3.9 occurrences of damage) and photographers have 17 touches and 4.1 incidences of damage to corals. Management strategies need to consider the potential of spearfishing to cause breakage of corals and consequently reduced reef complexity. As proposed for scuba divers (Zhang, Chung, & Qiu, 2016), we suggest that managers establish use zoning and carrying capacity limits for spearfishing, aimed at reducing the pressure on sites with a high abundance of complex and fragile corals, such as the branching form (e.g. milleporines).

In Brazil, recreational spearfishers must renew their licence to fish on an annual basis. We strongly recommend that the licence be accompanied by educational material through videos and booklets, addressing the ecology and conservation of corals, and including the potential adverse effects of spearfishing on them. This material can also include advice to divers on how to avoid damaging coral, such as, for example, avoid shooting near corals and refrain from using coral colonies as anchors to secure them. Diving practitioners (mainly novices) are usually not aware of their impacts on reef biota (Dearden, Bennett, & Rollins, 2007; Leujak & Ormond, 2007), therefore educational initiatives are important to help mitigate the effects of spearfishers on benthic organisms. Scuba diving tourism has many successful initiatives that could serve as a model to encourage environmentally responsible practices within the spearfishers, such as low impact diver training (Hammerton, 2017) and a 'green fins' approach (Roche et al., 2016). The diversity and abundance of reef fishes, and consequently fishery yields, are largely dependent on structurally complex coral reefs (Graham, 2014). Therefore, by adopting environmentally responsible practices that contribute to keep the reef healthy and its associated ecological processes unspoilt, spearfishers would eventually benefit with higher and more sustainable catches.

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REFERENCES

Au, A. C., Zhang, L. Z., Chung, S. S., & Qiu, J. W. (2014). Diving associated coral breakage in Hong Kong: Differential susceptibility to damage. *Marine Pollution Bulletin*, *85*, 789–796.

Barker, N. H. L., & Roberts, C. M. (2004). Scuba diver behaviour and the management of diving impacts on coral reefs. *Biological Conservation*, *120*, 481–489.

Bellwood, D. R., Hughes, T. P., Folke, C., & Nyström, M. (2004). Confronting the coral reef crisis. *Nature*, *429*, 827–833.

Bulleri, F., & Benedetti-Cecchi, L. (2014). Chasing fish and catching data: Recreational spearfishing videos as a tool for assessing the structure of fish assemblages on shallow rocky reefs. *Marine Ecology Progress Series*, *506*, 255–265.

Camp, E., & Fraser, D. (2012). Influence of conservation education dive briefings as a management tool on the timing and nature of recreational SCUBA diving impacts on coral reefs. *Ocean & Coastal Management*, *61*, 30–37.

Chung, S., Au, A., & Qiu, J. W. (2013). Understanding the underwater behaviour of scuba divers in Hong Kong. *Environmental Management*, *51*, 824–837.

Coll, J., Linde, M., García-Rubies, A., Riera, F., & Grau, A. (2004). Spear fishing in the Balearic Islands (west central Mediterranean): Species affected and catch evolution during the period 1975-2001. *Fisheries Research*, *70*, 97–111.

Dearden, P., Bennett, M., & Rollins, M. (2007). Perceptions of diving impacts and implications for reef conservation. *Coastal Mangement*, *35*, 305–317.

Diogo, H., Pereira, J. J., & Schmiing, M. (2017). Experience counts: Integrating spearfishers' skills and knowledge in the evaluation of biological and ecological impacts. *Fisheries Management and Ecology*, *24*, 95–102. https://doi.org/10.1111/fme.12206

Dumont, J.-P. (1992). *Visayan vignettes: Ethnographic traces of a Philippine island*. Chicago, USA: University of Chicago Press.

Fava, F., Ponti, M., Scinto, A., Calcinai, B., & Cerrano, C. (2009). Possible effects of human impacts on epibenthic communities and coral rubble features in the marine Park of Bunaken (Indonesia). *Estuarine, Coastal and Shelf Science*, *85*, 151–156.

Ferreira, C. E. L. (2005). The status of target reef fishes. In G. F. Dutra, A. T. Werner, & S. A. McKenna (Eds.), *Rapid marine biodiversity assessment of the Abrolhos Bank, Bahia, Brazil* (pp. 56–66). Washington, DC: Conservation International.

Francini-Filho, R. B., Coni, E. O. C., Meirelles, P. M., Amado-Filho, G. M., Thompson, F. L., Pereira-Filho, G. H., … Moura, R. L. (2012). Dynamics of coral reef benthic assemblages of the Abrolhos Bank, eastern Brazil: Inferences on natural and anthropogenic drivers. *PLoS ONE*, *8*, e54260.

Francini-Filho, R. B., & Moura, R. L. (2008). Dynamics of fish assemblages on coral reefs subjected to different management regimes in the Abrolhos Bank, eastern Brazil. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *18*, 1166–1179.

Francini-Filho, R. B., Moura, R. L., Thompson, F. L., Reis, R. M., Kaufman, L., Kikuchi, R. K. P., & Leão, Z. M. A. N. (2008). Diseases leading to accelerated decline of reef corals in the largest South Atlantic reef complex (Abrolhos Bank, eastern Brazil). *Marine Pollution Bulletin*, *56*, 1008–1014.

Frisch, A. J., Cole, A. J., Hobbs, J. P. A., Rizzari, J. R., & Munkres, K. P. (2012). Effects of spearfishing on reef fish populations in a multi-use conservation area. *PLoS ONE*, *7*, e51938.

Giglio, V. J., Luiz, O. J., & Gerhardinger, L. C. (2015). Depletion of marine megafauna and shifting baselines among artisanal fishers in eastern Brazil. *Animal Conservation*, *18*, 348–358.

Giglio, V. J., Luiz, O. J., & Schiavetti, A. (2015). Marine life preferences and perceptions among recreational divers in Brazilian coral reefs. *Tourism Management*, *51*, 49–57.

Giglio, V. J., Luiz, O. J., & Schiavetti, A. (2016). Recreational diver behavior and contacts with benthic organisms in the Abrolhos National Marine Park, Brazil. *Environmental Management*, *57*, 637–648.

Godoy, N., Gelcich, S., Vásquez, J. A., & Castilla, J. C. (2010). Spearfishing to depletion: Evidence from temperate reef fishes in Chile. *Ecological Applications*, *20*, 1504–1511.

Graham, N. A. J. (2014). Habitat complexity: Coral structural loss leads to fisheries declines. *Current Biology*, *24*, 359–361.

Graham, N. A. J., & Nash, K. L. (2013). The importance of structural complexity in coral reef ecosystems. *Coral Reefs*, *32*, 315–326.

Guzner, B., Novplansky, A., Shalit, O., & Chadwick, N. E. (2010). Indirect impacts of recreational scuba diving: Patterns of growth and predation in branching stony corals. *Bulletin of Marine Science*, *86*, 727–742.

Hammerton, Z. (2017). Low-impact diver training in management of SCUBA diver impacts. *Journal of Ecotourism*, *16*, 69–94. https://doi.org/10.1080/14724049.2016.1194849

Harriott, V. J., Davis, D., & Banks, S. A. (1997). Recreational diving and its impact in marine protected areas in eastern Australia. *Ambio*, *26*, 173–179.

Hasler, H., & Ott, J. A. (2008). Diving down the reefs? Intensive diving tourism threatens the reefs of the northern Red Sea. *Marine Pollution Bulletin*, *56*, 1788–1794.

Hastie, T. J., & Tibshirani, R. J. (1990). *Generalized additive models. Monographs on statistics and applied probability, vol. 43*. Boca Ratan, FL: CRC Press.

Hawkins, J. P., Roberts, C. M., Hof, T. V., De Meyer, K., Tratalos, J., & Aldam, C. (1999). Effects of recreational scuba diving on Caribbean coral and fish communities. *Conservation Biology*, *13*, 888–897.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., … Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, *318*, 1737–1742.

Krieger, J. R., & Chadwick, N. E. (2013). Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida Coral reefs. *Journal of Coastal Conservation*, *17*, 179–189.

Lamb, J. B., True, J. D., Piromvaragorn, S., & Willis, B. L. (2014). Scuba diving damage and intensity of tourist activities increases coral disease prevalence. *Biological Conservation*, *178*, 88–96.

Leão, Z. M. A. N., & Kikuchi, R. K. P. (2001). The Abrolhos Reefs of Brazil. In U. Seeliger, & B. Kjerfve (Eds.), *Coastal marine ecosystems of Latin America* (pp. 83–96). Berlin, Germany: Springer.

Leujak, V., & Ormond, R. F. G. (2007). Visitor perceptions and the shifting social carrying capacity of South Sinai's coral reefs. *Environmental Management*, *39*, 472–489.

Lloret, J., Zaragoza, N., Caballero, D., Font, T., Casadevall, M., & Riera, V. (2008). Spearfishing pressure on fish communities in rocky coastal habitats in a Mediterranean marine protected area. *Fisheries Research*, *94*, 84–91.

Lyons, P. J., Arboleda, E., Benkwitt, C. E., Davis, B., Gleason, M., Howe, C., … Vilalobos, S. (2015). The effect of recreational SCUBA divers on the structural complexity and benthic assemblage of a Caribbean coral reef. *Biodiversity and Conservation*, *24*, 3491–3504.

Mellin, C., MacNeil, M. A., Cheal, A. J., Emslie, M. J., & Caley, M. J. (2016). Marine protected areas increase resilience among coral reef communities. *Ecology Letters*, *19*, 629–637.

Moura, R. L., Secchin, N. A., Amado-Filho, G. M., Francini-Filho, R. B., Freitas, M. O., Minte-Vera, C. V., … Bastos, A. C. (2013). Spatial patterns of benthic megahabitats and conservation planning in the Abrolhos Bank. *Continental Shelf Research*, *70*, 109–117.

Nunes, J. A. C. C., Medeiros, D. V., Reis-Filho, J. A., Sampaio, C. L. S., & Barros, F. (2012). Reef fishes captured by recreational spearfishing on reefs of Bahia state, northeast Brazil. *Biota Neotropica*, *12*, 179–185.

Pinheiro, H. T., & Joyeux, J. C. (2015). The role of recreational fishermen in the removal of target reef fishes. *Ocean & Coastal Management*, *112*, 12–17.

Poonian, C., Davis, P. Z. R., & McNaughton, C. K. (2010). Impacts of recreational divers on Palauan coral reefs and options for management. *Pacific Science*, *64*, 557–565.

R Core Team. (2016). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Roche, R. C., Harvey, C. V., Harvey, J. J., Kavanagh, A. P., McDonald, M., Stein-Rostaing, V. R., & Turner, J. R. (2016). Recreational diving impacts on coral reefs and the adoption of environmentally responsible practices within the SCUBA diving industry. *Environmental Management*, *58*, 107–116.

Rogers, A., Blanchard, J. L., & Mumby, P. J. (2014). Vulnerability of coral reef fisheries to a loss of structural complexity. *Current Biology*, *24*, 1000–1005.

Rouphael, A. B., & Inglis, G. J. (1997). Impacts of recreational scuba diving at sites with different reef topographies. *Biological Conservation*, *82*, 329–336.

Rouphael, A. B., & 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. *Biological Conservation*, *100*, 281–287.

Wood, S. (2017). Mgcv: Mixed GAM computation vehicle with GCV/AIC/REML smoothness estimation. R package version 1.8-17. Vienna, Austria: R Foundation for Statistical Computing.

Young, M. A. L., Foale, S., & Bellwood, D. R. (2014). Impacts of recreational fishing in Australia: Historical declines, self-regulation and evidence of an early warning system. *Environmental Conservation*, *41*, 350–356.

Young, M. A. L., Foale, S., & Belwood, D. R. (2016). Why do fishers fish? A cross-cultural examination of the motivations for fishing. *Marine Policy*, *66*, 114–123.

Zakai, D., & Chadwick-Furman, N. E. (2002). Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. *Biological Conservation*, *105*, 179–187.

Zapelini, C., Giglio, V. J., Carvalho, R. C., Bender, M. G., & Gehardinger, L. C. (2017). Assessing fishing experts' knowledge to improve conservation strategies for an endangered grouper in southwestern Atlantic. *Journal of Ethnobiology*.

Zhang, L. I., Chung, S. S., & Qiu, J. W. (2016). Ecological carrying capacity assessment of diving site: A case study of Mabul Island, Malaysia. *Journal of Environmental Management*, *183*, 253–259.

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