Ocean and Coastal Management 220 (2022) 106091

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

Scuba divers' behavior and satisfaction in a new marine protected area: Lessons from the implementation of a best practices program☆

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ARTICLE INFO

Keywords:
Environmental sustainability
Recreational diving
Marine wildlife tourism
Adaptive management
Marine reserve

ABSTRACT

Subtropical reefs have suffered from increasing threats and impacts mainly from anthropogenic activities. These reefs also have socioeconomic relevance being in many locations an important income source through recreational activities. This study aimed to assess the potentially damaging behaviors of scuba divers on benthic reefs organisms in the first year of a new Brazilian diving destination, the Alcatrazes Archipelago Wildlife Refuge. We also assessed diver satisfaction to verify the effects of management measures on diver experience. Management measures were implemented through a best practices program aiming to improve low-impact diver behavior. Scuba divers caused the lowest contact rate with the reef described in the literature, maintaining low rates of potentially damaging behaviors over the year. Overall, each diver made an average of 0.63 contacts with the reef and 0.06 with the reef biota per 45 min of dive. Most of the contacts were unintentional and occurred in the first 10 min of the dive. The overall satisfaction of divers was high in all seasons. However, regarding specific attributes, experienced divers were more sensitive to increased underwater supervision. Our results highlight the effectiveness of continued initiatives like best practices program to improve low-impact diver behavior. Visitation monitoring programs are essential to understand the behavior of scuba divers and how the restrictions may affect diver enjoyment in reef environments.

1. Introduction

Subtropical rocky reefs have been increasingly impacted by multiple anthropogenic stressors, from local to global levels, such as overfishing, habitat destruction, and climate change (Beger et al., 2014; Halpern et al., 2015; Magris et al., 2021). Such a scenario has resulted in biodiversity loss (McCauley et al., 2015), altering ecosystem functioning and services (Gamfeldt et al., 2015). Among the strategies for the sustainable use of marine resources, wildlife tourism has emerged as an alternative to extractive activities like fishing, reconciling non-extractive use of natural resources, and generating income for local communities (Steenbergen, 2013; Trave et al., 2017).

Scuba diving is one of the most popular marine wildlife tourism activities worldwide, supporting regional economies by creating revenue and employment (Pascoe et al., 2014; De Brauwer et al., 2017; Spalding et al., 2017). The most popular diving destinations are inside marine protected areas - MPAs, acknowledged for providing high-quality diving experiences due to preserved biodiversity attributes (Green and Donnelly 2003). However, poor management allied to high visitation rates may make scuba diving tourism unsustainable (Zakai and Chadwick-Furman 2002; De et al., 2020). For instance, mechanical damage from diving activities on benthic reef sessile organisms may cause shifts in reef seascape (Casoli et al., 2017; Giglio et al., 2020). Dive sites may receive tens of thousands of divers per year who usually dive in predetermined reef trails. In this context, the cumulative impacts of a few damage events per diver can be a matter of concern. In a degraded reef, lower ecological and aesthetic appeal decreases the attractiveness for divers, reducing the socioeconomic incomes (Tapsuwan and Asafu-Adjaye 2008; Tribot et al., 2019). While poor management may collapse diving tourism, best practices aiming to mitigate potential impacts may transform it into a useful tool for education and environmental awareness, constituting an important path to disseminating

☆ Vinicius J. Giglio reports financial support was provided by The São Paulo Research Foundation.
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https://doi.org/10.1016/j.ocecoaman.2022.106091
Received 4 June 2021; Received in revised form 13 January 2022; Accepted 7 February 2022
Available online 20 February 2022

socioecological information (Hunt et al., 2013; Rangel et al., 2015).

Diving tourism may provide substantial financial resources to MPAs management through user fees (e.g., Tongson and Dygico 2004; Roberts et al., 2017). Thus, the development of management frameworks for diving tourism and other recreational activities has been increasing demand (Rouphael 2020). A noteworthy characteristic of scuba diving is that behavior is site-specific, influenced by diver profile and dive site characteristics (Lucrezi et al., 2020). Management interventions should be planned considering the local context on how divers contact with sensitive benthic organisms. Studies have tested different management approaches to reduce damaging behaviors by divers to reef benthos mainly through education (Medio et al., 1997; Worachananant et al., 2008) and in-water assistance by dive guides (Barker and Roberts 2004; Hammerton and Bucher 2015). Such initiatives have shown effectiveness in reducing damaging behaviors; however, most of them are experimental studies (but see Hunt et al., 2013), not continuous, and usually fail to integrate the multiple views of stakeholders. This occurs in part due to a lack of incentive structure and resources necessary for long-term compliance (Lin 2021).

Still underapplied to marine wildlife tourism (Trave et al., 2017), adaptive comanagement has been considered a key strategy to guiding socioecological systems (Ban et al., 2012; Weeks and Jupiter 2013). Adaptive comanagement is a comprehensive and iterative process of changing practices based on new experiences and insights, continually testing and refining policies and actions (Norton and Steinemann 2001). Higham et al. (2008) proposed a multilevel framework for the adaptive management of wildlife tourism activities. The framework is divided into two phases, pre-tourism and tourism, integrating stakeholders in a research-informed and adaptive way. Implementation of adaptive comanagement frameworks for diving tourism is still incipient; current knowledge is more theoretical than the description of study cases (Dimmock and Musa 2015; Giglio et al., 2020; Lucrezi et al., 2020).

Here, we assessed the behavior of scuba divers and their interactions with reef benthic organisms over a year in a new destination in Brazil, the Alcatrazes Archipelago Wildlife Refuge (Alcatrazes Refuge). The archipelago was closed to visitation for 30 years due to the existence of a small no-take MPA (Tupinambás Ecological Station) around part of the islands and reef environments. This protection ensured conserved marine biodiversity, especially regarding commercially important fish species (Rolim et al., 2019; Motta et al., 2021). The Alcatrazes Refuge was established in 2016, allowing recreational visitation through diving and nautical activities. An adaptive comanagement framework to visitation was implemented during the pre-MPA planning, including a best practices program for diving tourism to improve low-impact diver behavior. Besides investigating the behavior of scuba divers, we also evaluated the satisfaction of scuba divers after the visit. We predicted that rates of diver-reef contact would remain low compared to other sites due to the management measures implemented to reduce damaging behaviors. We also predicted that the diver's overall satisfaction would remain high despite management restrictions since they are aware of their potential impact on reefs after watching the pre-dive briefing, being more willing to accept management measures. Finally, we discuss the perspectives of the adaptive comanagement framework implemented in Alcatrazes Refuge.

2. Material and methods

2.1. Study area

Alcatrazes Refuge is a no-take MPA (674.09 km^2) comprising islands, islets, and submerged rock reefs located in southeastern Brazil, 35 km off the mainland. It corresponds to IUCN category III (Dudley, 2008), where scuba diving began in December 2018. Notwithstanding, Alcatrazes Refuge has been considered to harbor relevant biodiversity, including one of the highest reef fish biomass from the Brazilian province (Morais et al., 2017), being considered a climate refuge due to the remarkable tolerance to intense bleaching (Banha et al., 2020). The reef morphology primarily comprises rocks, varying from low to high complexity with large boulders (Fig. 1). Regarding the benthic cover, the shallow reefs (<15 m depth) are covered mainly by filamentous algae (i.e., turfs, ~51%), macroalgae (~39%), corals (i.e., *Mussismilia hispida* and *Madracis decactis,* ~3%), encrusting coralline algae, sponge and

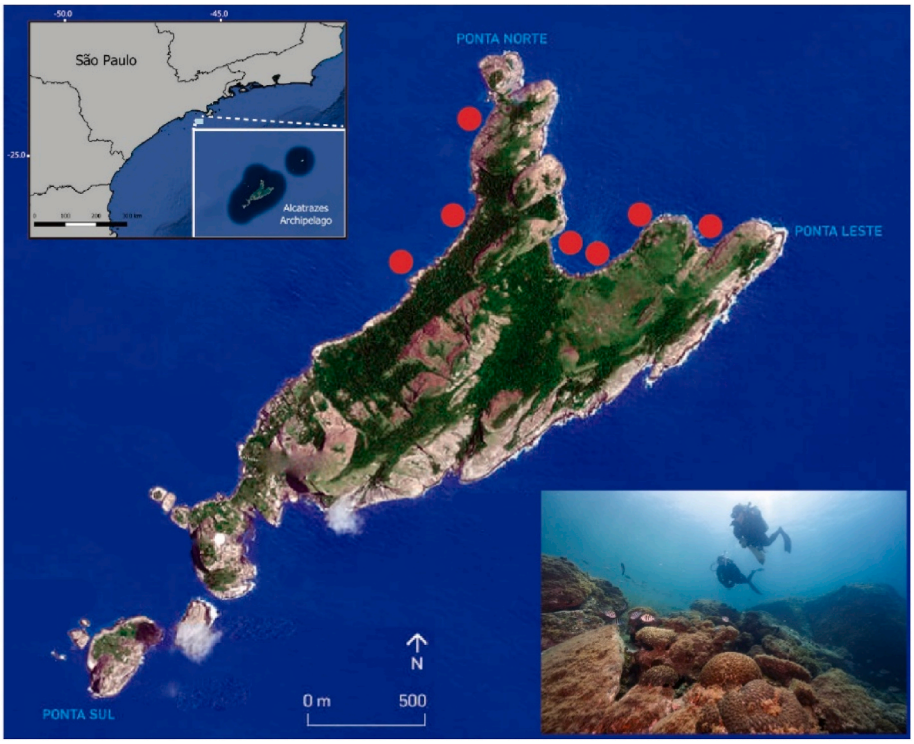

Fig. 1. Map of the studied area. Red dots indicate the dive sites surveyed. Photo: Leo Francini.

Table 1
Management measures implement in the best practices programs to improve low-impact diver behavior in Alcatrazes Archipelago Wildlife Refuge, Brazil.

Measure	Justification	Source
Pre-dive briefing	Promote low-impact diver behavior through reduction of diver-reef contacts	Camp and Fraser (2012), Webler and Jakubowski (2016), Giglio et al. (2018)
Ban of extension pole use	Divers using extension poles attached to cameras may cause behavioral disruption to cryptobenthic fish and sea turtles.	Giglio et al. (2019)
Dive guides intervention	Intervention is the most effective approach to reduce diver-reef interactions.	Barker and Roberts (2004); Hammerton and Bucher (2015)
Continued dive guides training	Increase the skills of dive guides to promote low-impact diver behavior and share environmental and technical information.	Camp and Fraser (2012); Hunt et al. (2013)
A lower number of guided divers	The ability of dive guides to intervene when observing damaging behaviors decrease with larger group sizes.	Barker and Roberts (2004); Roche et al. (2016)

zoanthids (~4.5%) (Aued et al., 2018).

2.2. Implementation of the best practices program for scuba diving

A series of best practices management measures described as effective to improve low-impact diver behavior were implemented (see Table 1 for details). Such measures integrate the adaptive comanagement framework implemented in Alcatrazes Refuge. The framework was designed experimentally to be updated according to real-time data from monitoring. Management measures involve the use of educational approaches, banning potentially damaging practices, and increasing divers' in-water assistance by dive guides who participate of a continuous training program. Other initiatives aiming to spatial management of recreational diving implemented include reef zoning to avoid high diving pressure on sensitive sites and the installation of mooring buoys.

2.3. Monitoring of scuba divers behavior

Scuba divers were followed discretely during dive parties between December 2018 and December 2019. The behavior of divers was sampled through direct observations during the entire dive since they submerged in the water until they moved away from the reef to finish the dive. Trained researchers described all diver-reef contacts according to the diving time phase, the part of the diver that contacted with the reef, the type of contact, the part of the reef or organism touched, if the interaction was intentional or not, and if the dive guide intervenes when witnessing a damaging behavior (see Table 2 for details). Contact was described as all physical contact with the reef. Damage was reported when a contact results in physical damage to the benthic organisms (e.g., abrasion or compression). At the end of each dive, we asked the observed diver about their certification and diving experience (no. of dives performed). The monitoring sampled scuba divers in 36% of the diving operations in Alcatrazes Refuge during the analyzed period.

2.4. Monitoring of scuba diver profile and satisfaction

The monitoring was carried out based on interviews using self-filled semi-structured questionnaires. The interviews aimed to describe the profile and verify perceptions of divers about the scuba diving experience in Alcatrazes Refuge. Data was collected between December 2018 and December 2019. The detailed profile of scuba divers is described in Marconi et al. (2020), where divers were predominantly male (71%), aged between 25 and 45 years (66%) and education level university graduates and postgraduates (89%). The overall satisfaction of divers was measured through a 10-point scale where 1 = very dissatisfied and 10 = extremely satisfied. We also verified satisfaction regarding three specific attributes during the diving experience: water visibility, other divers' behavior techniques, and the briefing/additional guide information. The satisfaction for the specific attributes was described through a 5-point Likert-Type scale where 1 = not satisfied at all, to 5 = extremely satisfied.

2.5. Data analysis

The relationships between the dive timing on diver rates of contacts on the reef according to i) gender; ii) status as a photographer or not; and iii) season were analyzed using generalized linear models with a negative binomial distribution. The best model distribution was checked using Zeileis et al. (2008) protocol for regression models for data count. Cross-validation procedures were conducted to assess better model performance. Spearman Rank correlation was fitted to check the relationship between the rate of contacts and diver experience. Kruskal-Wallis test was conducted to test differences in diver-reef contacts and diver satisfaction attributes among seasons. Statistical analyses were performed using the software R v.3.5.1. (R Core Development Team, 2018), with a significance level set at $p < 0.05$.

3. Results

3.1. Diver and diving characteristics

We observed the behavior of 309 scuba divers (i.e., 23% of scuba divers who visited the Alcatrazes Refuge in the period). Sixty-four percent of divers were male and 28% carried photographic equipment. Most of the divers were advanced open water (44%) followed by open water divers (31%) and the divers' experience ranged from 1 to 5,000 (mean ± s.e. = 149 ± 26.4 dives; Table 3). Diving timing ranged from 20 to 72 min (49 ± 2.3 min). Concerning season, 113 divers were sampled in Summer, 59 in Autumn, 70 in Winter and 67 in Spring. Such discrepancy in the sample size is because summer is the peak of visitation. We sampled a higher number of divers in summer to ensure our sample universe would be comparable with the other seasons.

3.2. The behavior of scuba divers

A total of 225 scuba diver-reef contacts were observed (mean = 0.014 ± 0.003 contacts min^{-1}). Most of the subjects (i.e., 74%) did not contact the reef, and a small fraction of divers were responsible for higher contact rates (Fig. 2a). Scuba diver-reef contacts were caused mainly through fins (90%), followed by hands (5%) and dive gear (3%). The reef part more contacted by divers were turf algae (72%) and bare rock (23%; Fig. 2b). Only 1.8% of contacts resulted in physical damage to benthic organisms, three events to turf algae and one in stony coral. Ninety-five percent of contacts were unintentional, the intentional contacts were through hands (n = 6) and knees (n = 1) on bare rock and turf algae. Dive guides intervened when observing a damaging diver behavior 77 times, avoiding further contact with the reef. Divers who contacted benthic reef organisms (corals, sponges and zoanthids) represented only 2.9% (n = 9) of the sampled individuals.

Male divers caused significantly more contact with the reef than females (0.02 ± 0.02 *vs.* 0.007 ± 0.002 contacts min^{-1}, respectively; see Table 4). For both male and female divers, the rate of contacts decreased in the first 20 min of diving and remained stable in the rest of the dive (Fig. 2c). The scale of decreased rates of contacts along the diving time was different because some male divers caused a high number of contacts in the first 10 min. No relationship was verified between the rate of contacts and diver experience ($r = -0.03$, $p = 0.28$). Regarding certifications, open water and advanced open water divers caused the highest rates of contacts and instructors the lowest (Table 3). No significant

Table 2
Data collected on scuba diver behavior monitoring and their interactions with benthic reef organisms.

	Variable	Data type	Units/levels
Diver profile	Gender	Categorical	Male or female
	Certification	Categorical	*OWD, AOWD, RESCUE, DM or Instructor
	Experience	Continuous	Number of previous dives
	Use of camera	Binomial	Yes or No
Diver behavior	Timing	Categorical	10-min segments (0–10, 11–20, 21–30 …)
	Type of contact	Categorical	Contact or damage
	Context of contact	Categorical	Intentional or unintentional
	Part of diver body	Categorical	Fin, hand, knee or scuba gear
	Part of the reef/organism contacted	Categorical	Massive coral (*Mussismilia hispida* and *Madracis decactis*), zoanthid (*Palythoa caribaeorum*), bare rock, turf algae and macroalgae, or sponge
	Intervention	Binomial	Yes or No

*Certification categories: OWD: open water diver; AOWD: advanced open water diver; RESCUE: rescue diver; DM: divemaster or similar.

Table 3
Experience (no. of dives performed) and contacts with the reef according to scuba diving certification. The deviations are standard errors.

Certification	N	Mean experience	Contacts min^{-1}	Total no. of contacts
Open Water Diver	97	18 ± 2	0.02 ± 0.006	90
Advanced OWD	137	66 ± 8	0.01 ± 0.004	107
Rescue Diver	22	169 ± 39	0.002 ± 0.001	3
Divemaster	35	183 ± 34	0.009 ± 0.004	18
Instructor	18	1390 ± 328	0.001 ± 0.006	7

differences were found in the rates of contact with the reef among those divers using a camera (0.016 ± 0.014 min^{-1}) *vs.* non-users (0.015 ± 0.012 min^{-1}; Table 4). Photographers caused more contacts at the beginning of the dive, but the rate decreased over the dive timing for both photographers and non-photographers (Fig. 2d; Table 4).

The rate of diver-reef contacts along seasons varied significantly (KW test, H = 8.4, p = 0.03) where winter accounted the highest value (0.02 ± 0.02 min^{-1}; Fig. 3a). A decrease in the rate of contacts over diving time was verified along seasons, except in autumn that differed significantly from the descent trend over dive timing (Fig. 3b; Table 4).

3.3. Scuba divers satisfaction

A total of 257 scuba divers were interviewed. Alcatrazes Refuge had a high overall satisfaction (8.27 ± 1.73 from a maximum of 10) throughout the year, with little difference among seasons (Table 5). Regarding the specific attributes' performance, the perception of water visibility differed among seasons, summer and autumn were higher than from winter and spring (Table 5). The perception about low-impact diver behavior skills of other divers and the briefing information by diving guides obtained high satisfaction throughout the seasons.

4. Discussion

4.1. Do the scuba divers have the potential to cause cumulative detrimental effects to reef benthic organisms?

Our results revealed that scuba divers in Alcatrazes Refuge caused the lowest rate of potentially damaging behaviors to the reef described in the literature, 0.014 contacts with the reef per min^{-1} and 0.0013 contacts min^{-1} with the reef benthic organisms. In other words, during a 45 min dive, each diver makes 0.63 contacts with the reef and 0.06 contacts with the reef biota. In contrast, on subtropical reefs of Australia,

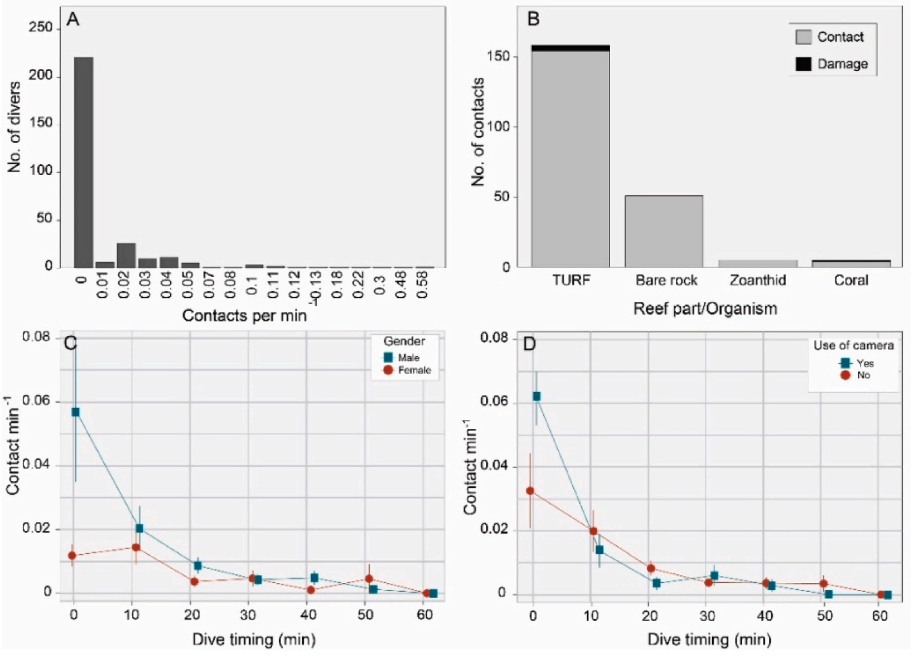

Fig. 2. Frequency of a) scuba diver-reef contacts and b) the organism or part of the reef contacted. Variation in rates of scuba diver-reef contacts along the entire dive timing comparing c) gender, and d) use of camera or not. Data are shown as mean ± standard error.

Table 4
Summary of the generalized linear model results on the effects of gender and use of camera or not on rates of scuba diver contacts with the reef. Significant differences are in bold. The reference season was set as of summer.

Variable/Factor	Estimate	Std. Error	Z value	p-value
Gender				
(intercept)	−1.97	0.33	−6.04	**< 0.001**
Gender	1.28	0.39	3.29	**0.001**
Timing	−0.03	0.01	−2.70	**0.006**
Gender*Timing	−0.03	0.02	−1.88	0.06
Use of camera or not				
(intercept)	−1.12	0.21	−5.33	**< 0.001**
Use of camera	0.40	0.39	1.00	0.3
Timing	−0.06	0.009	−5.84	**< 0.001**
Use of camera*timing	−0.03	0.02	−1.25	0.2
Season				
(intercept)	−0.85	0.22	−3.75	**< 0.001**
Autumn	−0.94	0.37	−2.56	**0.01**
Winter	0.22	0.30	0.72	0.4
Spring	−0.57	0.33	−1.70	0.09
Timing	−0.06	0.008	−7.39	**< 0.001**

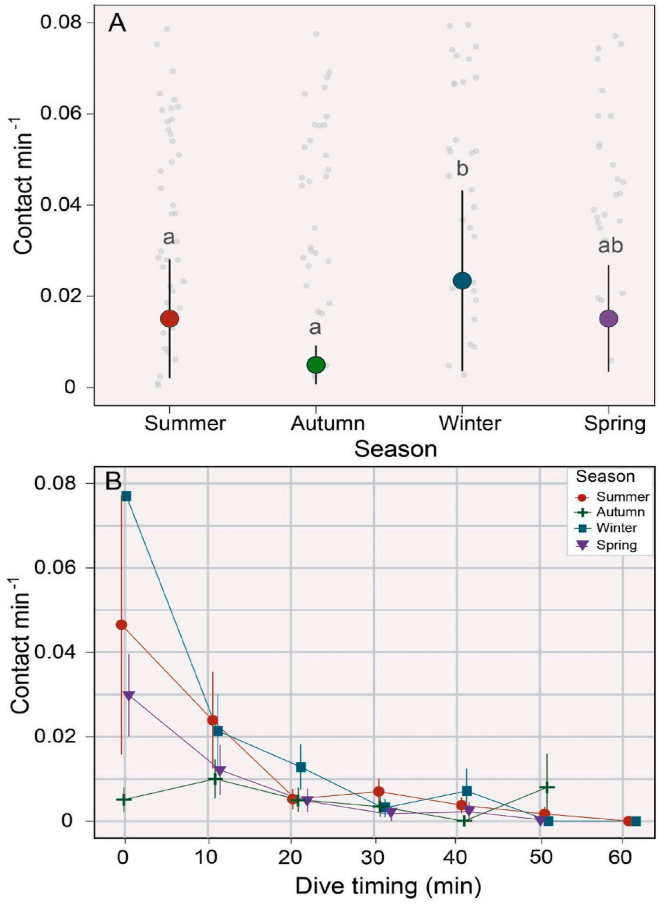

Fig. 3. a) Scuba diver-reef contacts per season. b). Rate of contacts along the diving time and seasons. Data from diver-reef contacts are shown as mean ± standard error.

the lowest rates of diver-reef biota contacts were 0.26 times min^{-1} (Hammerton and Bucher 2015), while in Mediterranean temperate coralligenous reefs, contacts occurred at 0.13 times min^{-1} in Portofino MPA (Lucrezi et al., 2020) and 0.36 times min^{-1} the Capo Gallo-Isola delle Femmine MPA (Di Franco et al., 2009). The lowest rates of contacts at tropical destinations were 0.03 min^{-1} on Red Sea coral reefs (Medio et al., 1997). It is important to note the rate of contact over different studies may be influenced by reef cover, topography and the morphological composition of benthic assemblages (Rouphael and Inglis 1997; Lucrezi et al., 2020). Divers are more likely to damage benthic organisms in tropical reefs, where the coral cover and reef complexity are higher than in subtropical rocky reefs (Aued et al., 2018).

Table 5
Variations in responses about satisfaction attributes related to the scuba diving experience in Alcatrazes Refuge. Significant differences are in bold. Data are shown as average ± standard error.

	Summer	Autumn	Winter	Spring	Kruskal-Wallis test	Post-hoc
Overall Satisfaction (0–10)	8.2 ± 1.8	8.6 ± 1.7	8.0 ± 1.6	8.0 ± 1.7	H = 5.1; p = 0.2	Sum = Aut = Win = Spr
Water visibility (0–5)	3.9 ± 1.1	3.8 ± 1.3	2.8 ± 1.5	3.5 ± 0.8	**H = 0.7; p = 0.02**	Sum = Aut ≠ Win ≠ Spr
Low-impact diver behavior techniques of other divers (0–5)	4.2 ± 0.1	4.2 ± 1.1	4.1 ± 1.1	4.5 ± 0.7	H = 1.5; p = 0.6	Sum = Aut = Win = Spr
Briefing/ additional guidance (0–5)	4.4 ± 0.1	4.4 ± 1	4.7 ± 0.6	4.3 ± 1	H = 1.3; p = 0.7	Sum = Aut = Win = Spr

In Alcatrazes Refuge, the 309 scuba divers were observed contacting reefs 225 times; however, only ten contacts were on benthic organisms susceptible to diving impacts. The management measures implemented through a best practices program to improve low-impact diver behavior in Alcatrazes Refuge contributed to decreasing the potentially damaging behavior to reef benthos. For instance, after watching the video briefing, divers were more aware of maintaining a safe distance from the reef and following the instructions. In addition, dive guides made interventions when observing divers with poor swimming skills or fins close to the reef. Of the 79 divers that contacted the reef, 34% received dive guide intervention avoiding further contacts.

Extrapolating our results to the current diver visitation levels (~2600 annual dives), scuba divers contacted the reef biota of Alcatrazes Refuge 165.6 times a year. Such an amount is low and is likely not to cause detrimental effects on reef biota. The cover of fragile organisms (i.e., corals, gorgonians and sponges) in Alcatrazes Refuge is low (~7.5%), and the corals are more resilient to stressors than tropical reef systems (Banha et al., 2020). Among divers that caused more than two consecutive contacts with the reef, the frequency of dive guide interventions increased to 53%. As dive guides intervene after observing damaging behavior, the likelihood is expected to increase after the first contact with the reef. In some occasions, dive guides also made early interventions avoiding contact with the reef. Such results support the role of dive guide interventions to reduce damaging behaviors (Barker and Roberts 2004; Hammerton and Bucher 2015). During the management council meetings of Alcatrazes Refuge, the posture of dive guides was extensively discussed, supported by data from diver behavior and satisfaction. One of the main aspects discussed was the threshold between improving low-impact diver behavior and not decreasing visitor

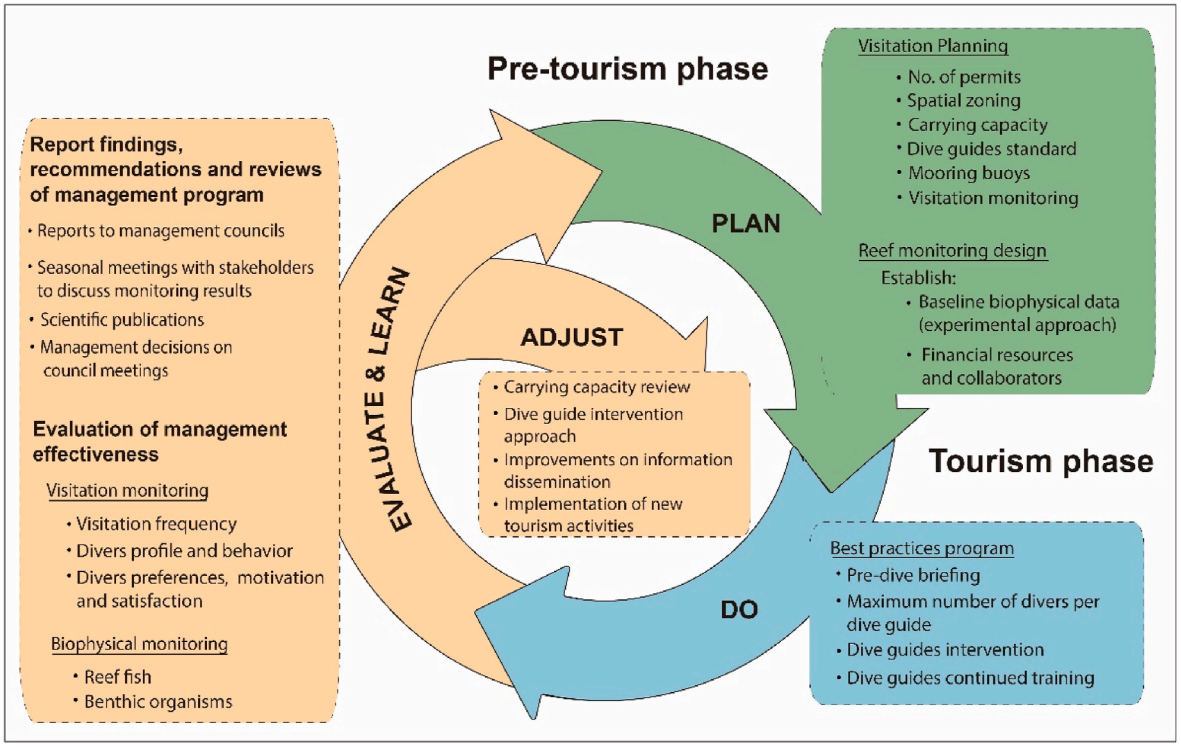

Fig. 4. The adaptive comanagement framework for scuba diving tourism implemented in Alcatrazes Archipelago Wildlife Refuge. Initiatives are centered on a extensive visitation planning, biophysical and visitation monitoring, and the best practices program to improve low-impact diver behavior. The framework was based on Higham et al. (2008) where the planning is divided in the pre-tourism and tourism phase. In the pre-tourism phase, early planning and biophysical monitoring using the before-after control-impact approach was implemented (Underwood 1994). Real-time data from visitation and biophysical monitoring are shared with stakeholders in the tourism phase that conduct adjustments when necessary.

satisfaction due to management measures.

Despite diver-reef contacts varying throughout the year, the rate of interactions remained low compared to other subtropical sites. Winter accounted for the highest rate of diver-reef contacts (Fig. 4) and also the lower satisfaction on the water visibility attribute (Table 5). In fact, the poorest conditions of water visibility in Alcatrazes Refuge occur in winter. In poor visibility conditions, the spatial awareness of divers can be reduced, and they usually swim closer to the reef for navigation and observing associated biota (Hammerton 2017).

4.2. The effect of diver profile in diver-reef interactions

Certain diver and dive characteristics have been linked to increased diver damage. Regarding the diving time, the beginning of each dive is the most critical phase (Camp and Fraser 2012; Giglio et al., 2020). During this stage, divers were adjusting their gear and becoming familiar with the aquatic environment, increasing the likelihood of performing damaging behaviors. After the presentation of the first monitoring data from scuba diver's behavior, the management council discussed how to reduce this increased rate of diver-reef contacts. The core strategy was to intensify dive guide interventions in this phase to divers who are likely to contact the reef (i.e., those divers showing inadequate swimming or close to the reef less than 1 m). Despite the increase of surveillance in the initial stage of diving, the pattern did not change throughout the year. However, it is important to note that contacts were caused primarily on bare rock, macroalgae and algae turf, representing a minimal potential impact on the reef biota of Alcatrazes Refuge.

Other common characteristics linked to increased diver-reef contacts also were verified in this study. Less experienced divers caused more contacts and fin kicks were the primary source of contacts, caused unintentionally and a minority of divers represented most of the contacts. These characteristics are usually from divers with poor swimming technique and incorrect weighting (Toyoshima and Nadaoka 2015; Hammerton 2016). Photographers and male divers are also associated with higher diver-reef contact rates on some destinations (Barker and Roberts 2004). In fact, male divers from Alcatrazes Refuge caused more contact to the reef than female divers. The difference was higher at the beginning of the dive, when few divers with poor swimming skills contacted the reef often. However, we did not observe differences between contacts with the reef by photographers and non-photographers. Such similarity can be explained by the higher awareness of photographers after the pre-dive briefing who provided particular instructions for photographers on avoiding touch the reef while getting images. Specific instructions among photographers may improve the low-impact diver behavior (Giglio et al., 2018). In addition, the attractions preferred by photographers and non-photographers are the organisms from the megafauna like large and colorful fishes (Marconi et al., 2020). Divers did not need to stay close to the bottom as they needed to observe small and cryptic species, increasing the damaging behavior incidence.

4.3. Are the management initiatives decreasing scuba diver satisfaction?

The high overall satisfaction among scuba divers over the year revealed that best practice program initiatives implemented did not decrease the quality of visitation. After divers watch the video briefing, they can be more careful about reef conservation and aware of their potentially detrimental effects to reef biota. Aware divers usually prefer more restrictive regulatory management scenarios over the status quo (Sorice et al., 2007). In this win-win scenario, management measures to reduce damaging reef contacts are aligned with the conservation and economic aspects of diving tourism. However, we also observed that experienced divers were more complainant about management initiatives, especially dive guides interventions. More specialized divers

tended to be more sensitive to increased levels of underwater supervision and guided dives (Sorice et al., 2007). As experienced divers have improved diving skills, they claim to be less likely to harm the reef than novice ones and are less satisfied with close supervision (Dearden et al., 2006). In fact, more experienced divers caused less potentially damaging behaviors than novice (Table 3). The profile of divers should be considered in the planning of management measures (Marconi et al., 2020).

Among specific attributes, the lowest satisfaction rates were water visibility. Scuba diver satisfaction is positively related to water visibility (Shokri and Mohammadi 2021), but we did not verify the influence of this attribute on overall satisfaction which remained high in all seasons. The lowest rates for water visibility may be explained because most of divers were first-time visitors in Alcatrazes Refuge. Thus, visibility expectation was based on the nearest dive site with similar characteristics, the Laje de Santos Marine State Park. In such a dive site, water visibility can reach up to 35 m due to South Atlantic Central Water and environmental characteristics (Braga et al., 2017). Alcatrazes Refuge is subject to a higher variation in water visibility conditions due to island geomorphology, ocean currents, and higher sedimentation than Laje de Santos (ICMBio 2017).

4.4. Perspectives for the adaptive comanagement in Alcatrazes Refuge

The implementation of recreational activities in MPAs previously free of human harvesting or recreational activities is uncommon; thus, there are rare opportunities to launch insights concerning adaptive comanagement using experimental designs (Rouphael 2020; Lucrezi et al., 2020). Understanding the effects of diving tourism on reef systems using robust experimental approaches is an important gap in this segment of marine wildlife tourism (Hammerton 2017). Historically, management concerns for diving tourism begin when impacts are already perceived. However, in Alcatrazes Refuge, stakeholders were able to plan and implement an adaptive comanagement framework involving diving stakeholders and addressing these issues since the pre-tourism phase. In this phase, biophysical monitoring was implemented as well as the continued planning and implementation of management initiatives to manage diving tourism (see the detailed framework in Fig. 4).

Such a context allows the implementation of a best practices program using a precautionary approach for routine management practices to be tested during the visitation phase. For instance, the number of four guided divers in Alcatrazes Refuge is not typical; most destinations allow dive guides to guide six or more divers. However, stakeholders agreed to use this number. It has been revisited after checking monitoring data on scuba diver behavior and satisfaction. After the COVID-19 pandemic, the number of divers per dive guide was increased to six to reduce the number of people in the boat and avoid agglomeration. The behavior and satisfaction of scuba divers continue to be monitored to support adaptive comanagement, although adjustments are needed to define the appropriate frequency aiming at its long-term maintenance. The adaptive comanagement framework is expected to achieve multiple goals involving diving stakeholders to act together in planning and support the development and improvement of existing norms, anticipating potential damage sources and creating a culture of precaution and sustainability for public use in Alcatrazes Refuge.

5. Conclusion

Results of the present study in Alcatrazes Refuge revealed the lowest rate of diver-reef contacts described in the literature through a continued sampling over a year. The first 10 min of the diving was the critical phase where most of the diver-reef contacts occurred. As observed in many sites, damaging behavior is usually unintentional, and the intervention of dive guides was determinant to reduce such contacts with the reef. The sensitiveness on the management measures was influenced by diver profile, where those experienced who cause less impact were less likely to dive guide interventions measure. We provide evidence that continued use of management measures to reduce the damaging behavior of scuba divers were effective while overall satisfaction remained high in a more restrictive dive destination. The adaptive comanagement framework implemented should be the focus of further study to determine if the cumulative effects of diving tourism are causing changes in reef biota and the effectiveness of management interventions to mitigate impacts. If continuous and well implemented, best practice programs can reduce the negative effects of diving tourism, aligned with the core objective of no-take MPAs, the conservation of biodiversity.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Acknowledgements

We thank the diving companies and dive guides for support. Managers and volunteers of Alcatrazes Archipelago Wildlife Refuge, the ICMBio team, to provide research permits and support (SISBIO 62932-1). The Questionnaire's application with divers was approved by the Research Ethics Committee of the Federal University of São Paulo (CEP: 0450/2018) and by the Brazil Platform (Nº 890074718.9.0000.5505). We also thank SOS Mata Atlântica Foundation (Grant 01/2018/05) and Linha D'água Institute for essential funding support. VJG received a post-doctoral grant #2017/22273-0, from São Paulo Research Foundation (FAPESP). FSM acknowledge individual grant #2019/19423-5 from FAPESP. GHPF acknowledge individual grant from the Brazilian Research Council (CNPq).

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