Perspectives in Ecology and Conservation 18 (2020) 51–59

ABECO ASSOCIAÇÃO BRASILEIRA DE CIÊNCIA ECOLÓGICA E CONSERVAÇÃO

Perspectives in ecology and conservation

Supported by Boticário Group Foundation for Nature Protection

www.perspectecolconserv.com

Research Letters

Diving into science and conservation: recreational divers can monitor reef assemblages

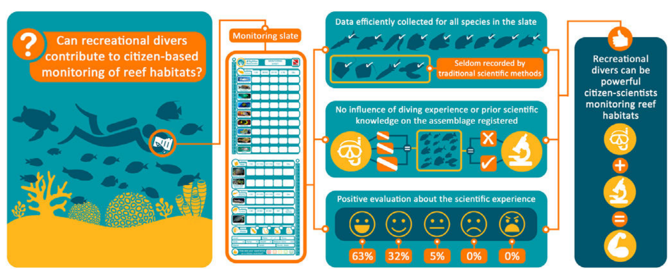
Edson Aparecido Vieira[1], Leonardo Rodrigues de Souza[1], Guilherme Ortigara Longo*

Marine Ecology Laboratory, Department of Oceanography and Limnology, Universidade Federal do Rio Grande do Norte, RN, Brazil

HIGHLIGHTS

- Volunteer divers recorded data for all species selected for the monitoring protocol.
- Diving experience did not affect data collection.
- Volunteer divers estimated abundance and size similarly to trained scientific divers.
- Volunteer divers recorded flagship species, complementing traditional surveys.
- Recreational divers enjoyed the citizen-science experience, attesting its potential.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 August 2019
Accepted 3 December 2019
Available online 27 January 2020

Keywords:
Citizen-science
Monitoring protocol
Reef fish
Sea turtle
Tourism

ABSTRACT

Overfishing, pollution and global changes threaten reef ecosystems all over the world and several conservation actions emerged to reduce and mitigate such impacts. Citizen-based programs with hands-on conservation experience and voluntarily data collection are a successful way of involving society in the conservation process. We developed and tested a citizen-based monitoring protocol to monitor reef fish and sea turtles during regular recreational diving operations, with minimum impact on the routine of the diving company. We compared data collected by volunteer divers and by trained scientists using this protocol, and assessed the influence of the volunteers'diving experience in data collection. We found that recreational divers were able to record all the species included in the monitoring slate, providing estimates of species abundance and composition that did not differ from those obtained by trained scientific divers using the same protocol. This method also recorded large reef species, such as rays, sharks and turtles more effectively in comparison to traditional scientific surveys conducted in the same area. Such difference indicates complementarity between the citizen-based monitoring protocol and traditional scientific monitoring methods. The diving experience of recreational divers did not affect their ability to characterize reef assemblages and most volunteers provided a positive feedback of their experience as citizen-scientists. Therefore, recreational divers can be powerful citizen-scientists and implementing similar monitoring protocols in reef areas, particularly in marine protected areas where diving activities are allowed and regulated, seems feasible and a good way to engage divers in data collection and marine conservation.

© 2019 Associação Brasileira de Ciência Ecológica e Conservação. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

* Corresponding author.
E-mail address: guilherme.o.longo@gmail.com (G.O. Longo).

[1] Both authors contributed equally to this manuscript.

https://doi.org/10.1016/j.pecon.2019.12.001

2530-0644/© 2019 Associação Brasileira de Ciência Ecológica e Conservação. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Reefs are among the most diverse and productive environments on the planet (Odum and Odum, 1995), providing important ecosystem services such as coastal protection, maintenance of high biodiversity, tourism and fishing (Moberg and Folke, 1999). Despite their importance, reefs are under severe risk and threatened by anthropogenic actions (Hodgson, 1999; Hughes et al., 2017; Magris et al., 2018). In addition to the gradual reduction of fish stocks, overfishing and species extinction (Jackson et al., 2001), eutrophication (Fabricius, 2011) and the emission of pollutants into the atmosphere causing global changes are impacting reef ecosystems drastically (Hughes et al., 2018). Such increasing anthropogenic impacts has gained worldwide attention, leading to a growing concern about the conservation of reef systems (Magris et al., 2018). However, there is still a mismatch between social commitment and conservation actions (Kollmuss and Agyeman, 2010).

Involving the society in the conservation process is critical for its success. One way to promote such engagement is through citizen-based monitoring programs, in which people collect data on a voluntary basis, contributing to scientific research and taking action in conservation practices (Trumbull et al., 2000; Cohn, 2008; Bonney et al., 2009; Goffredo et al., 2010; Earp and Liconti, 2019). Such practice of voluntary enrolment of the public to collect scientific data and monitoring habitats is acknowledged as citizen-science (Cohn, 2008; Bonney et al., 2009). Beyond disseminating scientific knowledge, citizen-science includes the society in the scientific process and recognizes its contribution (Cohn, 2008; Nov et al., 2011), promoting engagement in environmental causes, curiosity, interest and responsibility in the subject, which may change behaviors and translate into conservation actions (Trumbull et al., 2000, 2005; Evely et al., 2011). Integrating volunteers in data collection allows the formation of large networks that take part of multiregional efforts, including different habitats and organisms (Costello et al., 2010; Teleki, 2012), which often improve the spatial and temporal scope of scientific monitoring (Cohn, 2008; Cerrano et al., 2017).

Despite the broad potential and applicability, and the rise of citizen-science initiatives in several fields all over the world (Cohn, 2008), the credibility and quality of data generated by citizen scientists have been questioned due to the non-scientific nature of people engaged on such programs (Cohn, 2008; Burgess et al., 2017; Freitag et al., 2016; Lukyanenko et al., 2016). Some citizen-based programs can generate data that are vague, variable and difficult to properly be included and published in traditional research (Cohn, 2008; Burgess et al., 2017), as a result of issues related to lack of accuracy and precision, small sample size and poor standardization of protocols (Lewandowski and Specht, 2015). A number of practices can be incorporated to citizen-based programs to ensure that the data will comply with the standards required by the scientific community. First, it is necessary to create an easy-to-follow protocol for data collection that demands realistic tasks and accounts for the volunteerś prior experiences (Cohn, 2008; Freitag et al., 2016; Lukyanenko et al., 2016). Such protocol should also be flexible so the citizen-scientist may contribute to information other than the ones requested, which may help in evaluating the quality of the data provided (Lukyanenko et al., 2016). Volunteers can also be trained on data collection, including training in how to manipulate scientific equipment, to process and send the data if necessary (Cohn, 2008; Freitag et al., 2016). Leaders of citizen-based science should also establish communication channels with volunteers throughout the entire process, facilitating *in situ* staff guidance and data curation (Cohn, 2008; Freitag et al., 2016). Another powerful tool to ensure the quality of citizen-based data is to compare it to data generated by trained scientists using the same collection protocol (Cohn, 2008; Freitag et al., 2016; Lukyanenko et al., 2016). The implementation and association of these methods increase the chances of citizen-science data to be trusted by academic scientists, and consequently to be integrated to their researches and published, bringing more visibility to citizen-science (Burgess et al., 2017).

Citizen-science in marine systems is increasing in number of initiatives, scale and diversity of habitats and target taxa (Thiel et al., 2014; Earp and Liconti, 2019). In reef ecosystems, the participation of voluntary divers has already promoted important advances in data collection, generating a broader monitoring of coral and sponge biodiversity (Bell, 2007), abundance of several species of fish (Hodgson, 1999; Goffredo et al., 2006), distribution range of some species (Heard et al., 2019), occurrence of invasive species (Delaney et al., 2007), and large biodiversity assessment at continental scales (Stuart-Smith et al., 2017). The "Reef Life Survey" initiative, for instance, have assembled an impressive global database on reef biodiversity collected by SCUBA divers engaged in the citizen-science program (Edgar & Smith, 2014), which have been rigorously analyzed and published by scientists in high-impact journals (*e.g.* Duffy et al., 2016; Strain et al., 2019). A drawback of some of these initiatives is that they often require some level of previous training and/or a complex dive logistics that allows the use of transects or similar method (Stuart-Smith et al., 2017), usually meaning that the dive company has to change their routine operation. Despite resulting in good quality data, these approaches also restrict the reach and applicability of monitoring protocols in regular diving operations, both because not all recreational divers are experienced or willing to engage in previous training and not all diving companies are able to change their operations. Simplifying these protocols and adapting them to the routine of diving companies would likely expand its application, which is particularly important for monitoring multiple areas through time when research budget may be a constraint. We developed and tested a citizen-based monitoring protocol to monitor reef fish and sea turtlesábundance during regular recreational diving operations at a tropical reef in Northeast Brazil. The effectiveness of the protocol was assessed by comparing data collected by volunteer divers and by trained scientists in the same area and season. We also assessed the influence of the volunteer diving experience in data collection and their level of satisfaction with the proposed protocol.

Material e methods

Study area

This study was conducted at a popular dive site in Northeastern Brazil, known as "*Batente das Agulhas*" (05 ° 33′52′′S 35 ° 04′21′′W), approximately 25 km off the coast in the state of Rio Grande do Norte (Fig. 1). This reef was considered one of the three best dive sites in Brazil (Brasil Mergulho, 2016) and is visited by an average of 250 divers during the diving season between November and May, according to the only dive company that works in this area. Reefs consist of sandstone consolidated by calcium carbonate, with depths varying from 13 m at the top to 22 m on the reef base (Morais, 1969), covered by seaweeds, sponges and corals, harboring high reef fish diversity and biomass (Morais et al., 2017; Pinheiro et al., 2018; Roos et al., 2019).

Field procedures

The dive trips occurred between December 2017 and April 2018 in partnership with a local diving company (Natal Divers - http://www.nataldivers.com.br/). From 190 individuals diving in the area during this period, 40 were having their first diving experience (*i.e.* courses or guided dives) and 150 were certified and able to use the protocol. Thirty-seven divers volunteered to participate

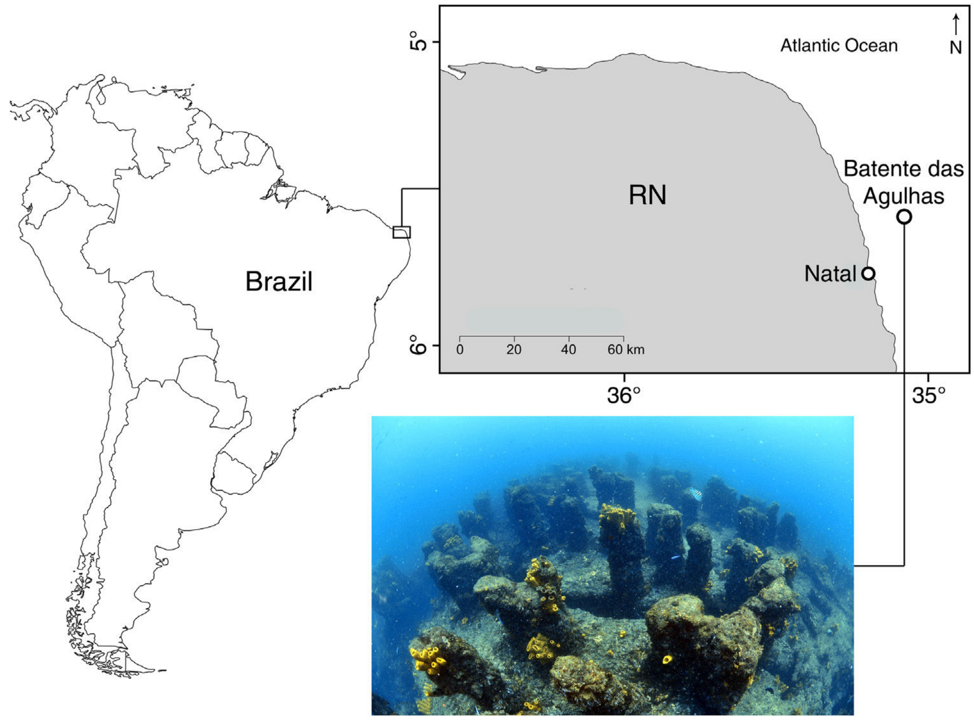


Fig. 1. Location of the study area "*Batente das Agulhas*". The reef is located 25 km distant from the coast of Rio Grande do Norte state, Northeastern Brazil (05°33′52″S 35°04′21″W).

in the monitoring activity (25%), an average of two volunteers per dive trip (see Acknowledgements section for a recognition of the volunteer divers that contributed to this research and agreed to be acknowledged).

We designed a simplified protocol containing a set of reef fish and sea turtle species indicated by pictures of each animal and a size scale on the borders of an acrylic slate (Fig. S1). Instead of an open register protocol, which could generate problems with data quality and also impair volunteer enrollment (Cohn, 2008; Lukyanenko et al., 2016), we selected species/groups with high ecological and economical relevance, which are common in the area and that divers would be able to identify based on the picture on the slate (Table 1). Including common reef organisms ensures that all volunteers will have the experience to collect data, as opposed to a slate where only rare species are included. Similarly, species with clear traits, such as bright color, naturally calls the attention of divers, increasing the effectiveness of the protocol (Bonney et al., 2009). As some species may be difficult to be properly identified by non-trained divers, parrotfishes, jackfishes and turtles were grouped into categories to facilitate the records. During the navigation from the pier to the dive site, we explained the monitoring activities and instructed the volunteers with clear guidelines on how to fill the monitoring slate underwater, ensuring an efficient and standardized data collection (Cohn, 2008; Bonney et al., 2009; Freitag et al., 2016). Volunteers were instructed to count the number of individuals of each species/group observed during the dive and to assign each observed individual to a predetermined size class (<25, 26–50, 51–75, >76 cm). A ruler was included on the side of the slate to facilitate this estimate (Fig. S1).

Recreational divers received the monitoring slates underwater at the initial diving depth and started the monitoring while following the dive guide around the reef in a predetermined course. We calculated the area surveyed by the recreational divers by inflating buoys on the corners of the underwater trail and marking the coordinates of each buoy on the surface. The coordinates were loaded into Google Earth software and resulted in a polygon of approximately 200 m of perimeter and 2,356 m^2 of area. Therefore, considering that the recreational diver swam along the 200 m perimeter collecting data and had an estimated visual field of 4 m (2 m in each side), we estimated that the total sampled area consisted of 800 m^2. At the end of the dive, we collected the monitoring slates so that everyone could safely return to the surface without having to carry the slate.

After returning to the boat, the volunteers filled out the fields related to personal information (name, number of dives, level of certification) and diving information and conditions (dive time, visibility, depth and water temperature). The number of dives was used as an estimate of the diver's experience, following diving certification criteria. Divers with up to 20 dives were considered beginners, between 21 and 60 dives intermediate divers, and above 61 dives experienced divers. At the end of the survey, the recreational diver also classified her/his experience in acting as a citizen-scientist (terrible, bad, neutral, good or excellent). Simultaneously to the monitoring by recreational divers, seven trained scientists from the Marine Ecology Laboratory of Federal University of Rio Grande do Norte (UFRN) (https://longolab.weebly.com) conducted the same survey using the monitoring slate in the same area and season. This procedure allowed us to assess how the lack of scientific knowledge would impact the data generated by the proposed monitoring protocol, enabling us to evaluate the credibility and quality of the citizen-based data (Cohn, 2008; Burgess et al., 2017; Freitag et al., 2016; Lukyanenko et al., 2016).

Data analysis

The total and per species abundance and size distribution recorded by recreational divers were qualitatively described by visual analysis. To assess whether the level of diving experience (beginner, intermediate and experienced) influenced the assemblages recorded, we used a multivariate approach using diving experience as the predictor factor. From the 37 divers we randomly selected a subset of 33 divers, 11 of each level of experience, in order

Table 1
Species selected for the monitoring protocol. Scientific and common names, its relevance (AQ: Aquarism; CI: Commercially Important; FI: Functionally Important, FS: Flagship Species; PR: Predator), conservation status (BR: Ordinance MMA 445/2014; RL: Red List IUCN; NE: Not Evaluated; DD: Data Deficient; LC: Least Concern; VU: Vulnerable; EN: Endangered; CR: Critically Endangered) and size variation based on literature (Humann, 2008).

Scientific name	Common name	Relevance	Status (BR/RL)	Size (cm)
Anisotremus virginicus	Porkfish	AQ	NE/LC	15–35
Holacanthus ciliaris	Queen angelfish	AQ	NE/LC	20–35
Holacanthus tricolor	Rock beauty	AQ	NE/LC	12–30
Pomacanthus paru	French angelfish	AQ	NE/LC	25–45
Caranx lugubris	Black jack	PR,CI	NE/LC	30–90
Caranx hippos	Crevalle jack	PR, CI	NE/LC	*75–124*
Caranx bartholomei	Yellow jack	PR,CI	NE/LC	*30–32*
Ginglymostoma cirratum	Nurse shark	PR, CI	VU/DD	152–426
Gymnothorax funebris	Green Moray	PR, CI	NE/LC	90–243
Hypanus americanus	Southern stingray	PR, CI	NE/DD	90–160
Hypanus marianae	Brazilian large-eyed stingray	PR, CI	NE/DD	20–30
Lutjanus jocu	Dog snapper	PR, CI	NE/DD	45–91
Sphyraena barracuda	Great barracuda	PR, CI	NE/LC	45–182
Scarus trispinosus	Greenbeak Parrotfish	FI, CI	EN/EN	30–91
Scarus zelindae	Zelinda's Parrotfish	FI, CI	VU/DD	17–25
Sparisoma amplum	Reef Parrotfish	FI, CI	NE/LC	30–60
Sparisoma axillare	Gray Parrotfish	FI, CI	VU/DD	35–43
Sparisoma frondosum	Agassiz's Parrotfish	FI, CI	VU/DD	30–40
Sparisoma radians	Buck Tooth Parrotfish	FI	NE/LC	7–17
Chelonia mydas	Green turtle	FS	EN/EN	91–121
Eretmochelys imbricata	Hawksbill turtle	FS	CR/CR	76–91

to conduct a balanced analysis. A similarity matrix was built using Bray-Curtis distance on abundance data (squared-root transformed to achieve a better dispersion) and generated a nMDS plot (Clarke, 1993). Differences among the three groups were tested through a PERMANOVA with 999 permutations (Anderson, 2001).

In order to assess the influence of lack of scientific experience in data collection by recreational divers using the proposed protocol, we compared the data generated by them with data collected by seven scientific divers using the same protocol. As we had 37 volunteer divers and only seven scientific divers, we selected a subset of seven recreational divers that conducted the survey in the same dates of the scientific divers, or as close as possible, avoiding temporal variability. We then assessed the effect of diver type (recreational or scientific) in total abundance using a t-test and tested for interactive effects of diver type and size class distribution on total abundance using a two-way ANOVA. For both sets of comparisons, normality and homoscedasticity were checked using Shapiro-Wilk and Levene test, respectively. Although variances were not homogeneous for the test of the interactive effects of diver type and size class distribution, we decided to keep the two-way ANOVA test because it is a more powerful test and not sensitive for departures of assumptions when replicate number is high and balanced (Underwood, 1997). We also used species abundance data to compare assemblage structure registered by volunteer and scientific divers using the same multivariate approach explained above and diver type as the predictor variable.

Results

Volunteer divers were able to record all the species/groups present in the slate, counting on average 26.1 (±3.2) individuals of 7.8 (±0.4) species/groups per dive. From the 1,139 organisms recorded, around 9% were out of the size range published in the literature and all cases corresponded to underestimates (Fig. 2). Diving experience was well distributed among classes, with 40% of the 37 recreational divers rated as experienced divers, 30% being rated as beginners and 30% intermediate. The composition of the assemblage recorded by a subset of 33 recreational divers (11 in each category) was consistent regardless of diving experience level (PERMDISP: $P = 0.317$/PERMANOVA: Pseudo-$F_{2,30} = 1.61$; $P = 0.108$; Fig. 3).

Among the 37 recreational divers, 77% recorded anthropogenic debris on the reef, mostly represented by ship debris (54%) or fishing gear (35%), while only 4% and 7% were plastic and other types of waste, respectively. Most recreational divers rated their experience as citizen-scientists as excellent (63%), 32% ranked as good, 5% as neutral, and none of the participants rated their experience as bad or terrible.

The lack of scientific experience did not affect the data collected by recreational divers, with no difference observed in total abundance (Shapiro-Wilk: $P = 0.132$ / Levene: $P = 0.257$/T-test: $t = 0.24$, $df = 12$, $p = 0.813$; Fig. 4A), size distribution (Shapiro-Wilk: $P = 0.182$/Levene: $P = 0.001$/ANOVA: Diver Type – $F_{1,48} = 0.08$, $p = 0.784$; Size Distribution – $F_{3,48} = 20.92$, $p < 0.001$, DT × SD – $F_{3,48} = 0.64$, $p = 0.596$; Fig. 4B) and assemblage composition (PERMDISP: $P = 0.123$ / PERMANOVA: Pseudo-$F_{1,12} = 1.91$, $p = 0.141$; Fig. 4C) observed when compared to data collected by scientific divers.

Discussion

We found that recreational divers could successfully identify, estimate abundance and size class of fish and turtles to characterize the reef assemblage, despite their lack of prior scientific experience. In addition to effectively recording all the species presented in the monitoring slate, volunteer divers were able to record data of large species such as rays, sharks and turtles, that are important for both reef ecosystem functioning and conservation. More traditional scientific survey methods, such as transects or stationary censuses, commonly underestimate these large-sized species as discussed in a previous study in the area (Morais et al., 2017). These results indicate that the citizen-based approach proposed here can complement traditional scientific monitoring (Cohn, 2008), corroborating our hypothesis that recreational divers can be powerful citizen-scientists. The use of different methodologies provides a more comprehensive view of reef assemblages optimizes data collection and, combined, generate more refined monitoring data (Schmitt et al., 2002; Baker et al., 2017; Bosch et al., 2017). Additionally, recreational divers characterized fish assemblages successfully regardless of their diving experience and provided a positive feedback of their experience as scientists. Therefore, there is a great potential for implementing similar monitoring protocols in other reef areas with recreational diving activities, particularly in marine

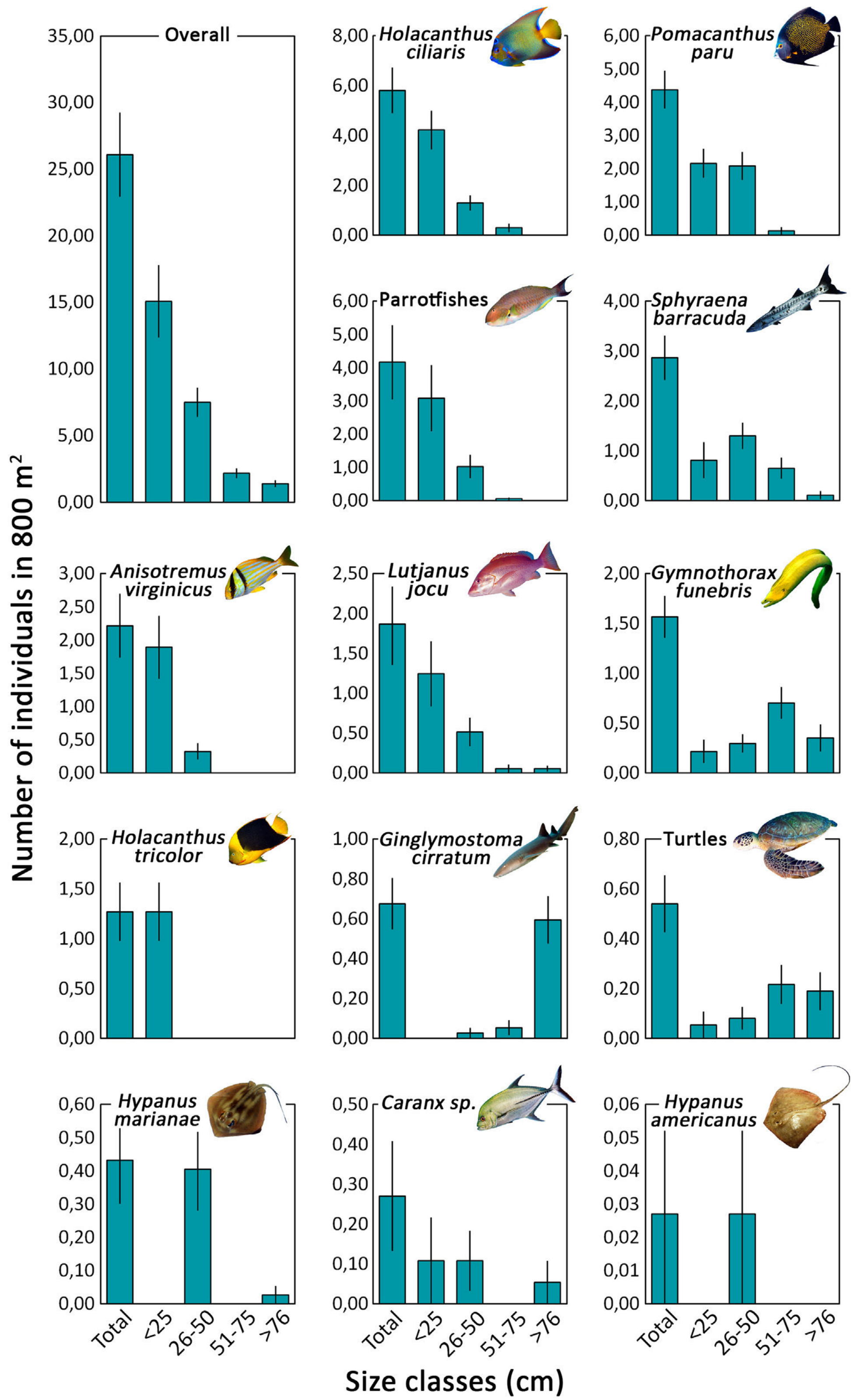


Fig. 2. Data collected by recreational divers using the monitoring slate. Total and per size class abundance (mean ± SE) recorded for the species/groups present in the monitoring slate.

protected areas where this activity is allowed and regulated, contributing to the popularization of citizen-science initiatives as a good tool to biodiversity monitoring (Burgess et al., 2017).

Our results showed no difference between recreational and scientific divers conducting the proposed protocol, but some departures arise when we contrast them with previous traditional surveys conducted by scientists in the same area (Morais et al., 2017). We are aware that different methods are not always comparable as diversity and abundance are related to sampling area effort (Schmitt et al., 2002), however a previous study in the area using

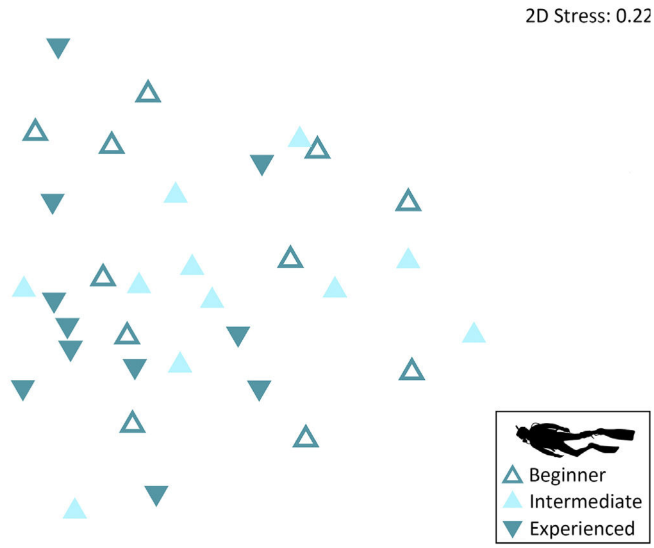


Fig. 3. Effects of diving experience on data collection. nMDS plot comparing the assemblages recorded by recreational divers with different diving experience: beginner (white), intermediate (light blue) and experienced (dark blue).

40 m^2 belt transect surveys (Morais et al., 2017) counted ~9.5 times more individuals of all the species selected for this study (standardizing by area and effort). Such contrasting pattern may have resulted from volunteers underestimating parrotfishes due to their diverse colors and juveniles that are quite different from adults, making it difficult for volunteers to recognize and count them. These results reflect the long training process of scientific divers, which improve their ability to properly identify, count and estimate size of all organisms during underwater surveys (Thompson and Mapstone, 1997). In some cases, recreational divers in our study also underestimated the size of individuals (9% of the 1,139 individuals recorded; Humann, 2008). This occurred for more cryptic species such as the green moray, *Gymnothorax funebris*, which stays in burrows during the day and may exhibit nocturnal behavior (Carvalho-Filho, 1999) impairing the size estimates. This was also the case for large-sized species such as *Caranx* spp., *Lutjanus jocu* and *Sphyraena barracuda*, which generally avoid divers, possibly because they are targeted by fishing activities (Floeter et al., 2006; Lindenmayer and Likens, 2009; Lindfield et al., 2014). Because recreational divers are not trained to estimate sizes underwater, the distance from the fish can make it difficult to properly estimate size, commonly resulting in underestimation (Bozec et al., 2011). Despite the ruler on the monitoring slate and the previous instructions, recreational divers show calibration errors. The support of scientific divers to recreational divers during and after the monitoring activity, allied to the use of novel technological tools, photography websites, social media profiles and applications (Newman et al., 2012; Mazumdar et al., 2018) may decrease the distance between the expertise of scientists and volunteers, improving estimates and increasing the reliability of the method (Cohn, 2008; Jiguet, 2009; Bonter and Cooper, 2012; Freitag et al., 2016; Lukyanenko et al., 2016). Also, a longer training to make recreational divers more familiar with the method may also be a good strategy to provide more accurate counts and size estimates (Thiel et al., 2014), ensuring data quality and suitability to scientific standard requirements (Burgess et al., 2017).

Despite the difficulties in counting and estimating sizes, recreational divers were efficient in recording species, particularly larger-sized and high-mobility ones, which are commonly not recorded by traditional surveys in the area (Morais et al., 2017). This possibly reflects the spatial limitation from the underwater visual census methodology (Williams et al., 2006; Lindfield et al., 2014). Larger species that have greater mobility and those targeted by fishing tend to fall out of the visual field surveyed by the scientific diver and are not recorded (Schmitt et al., 2002; Bozec et al., 2011; Dickens et al., 2011; Lindfield et al., 2014). This limitation makes traditional methods more efficient in the detection of species with low mobility (Bosch et al., 2017) as opposed to those with higher mobility, in the case of this stydy: the nurse shark *Ginglymostoma cirratum*, jacks *Caranx* spp. and rays *Hypanus americanus* and *Hypanus marianae*. Recreational divers in our study recorded these highly mobile species that are critical to the reef system functioning, in contrast to other studies in the area that used the transect survey method (Morais et al., 2017). Sharks, rays and turtles are considered charismatic (Frazier, 2005; Gallagher and Hammerschlag, 2011) and of interest to recreational divers, that tend to actively search for these species (Gallagher and Hammerschlag, 2011). This highlights important benefits from combining scientific and citizen-based approaches for monitoring reef communities, and from including flagship species to stimulate citizen engagement (Schmitt et al., 2002; Walpole and Leader-Williams, 2002; Cohn, 2008; Smith and Sutton, 2008).

Occurrence data generated by recreational divers may be important to identify population changes because the frequency of records may be directly related to changes in the number of individuals of a given species (Bender et al., 2014), as already observed by citizen-scientists monitoring monarch butterflies (Cohn, 2008). This becomes even more important for endangered and flagship species, which were efficiently recorded by recreational divers in our study (*e.g.* sea turtles and sharks). The colors and shapes of reef fishes, as well as the large sizes of sharks and sea turtles facilitate its identification to the species level, particularly when compared to other taxa with less evident traits such as some insects (Bonney et al., 2009; van Strien et al., 2013). In the largest citizen-based database on reef biodiversity, for example, nearly all of the 1,400 fish recorded were identified to the species level, largely because unique species traits enabled citizen-scientists to identify species using field guides and digital photographs that could also be sent to specialists to confirm it (Edgar and Smith, 2014). Proper species identification of fishes is a key advantage for the development of citizen-based monitoring programs in reef environments. Also, because recreational diving activities are well-stablished in several reefs worldwide and occur on a daily basis, they can be important allies to supplement the scientific data

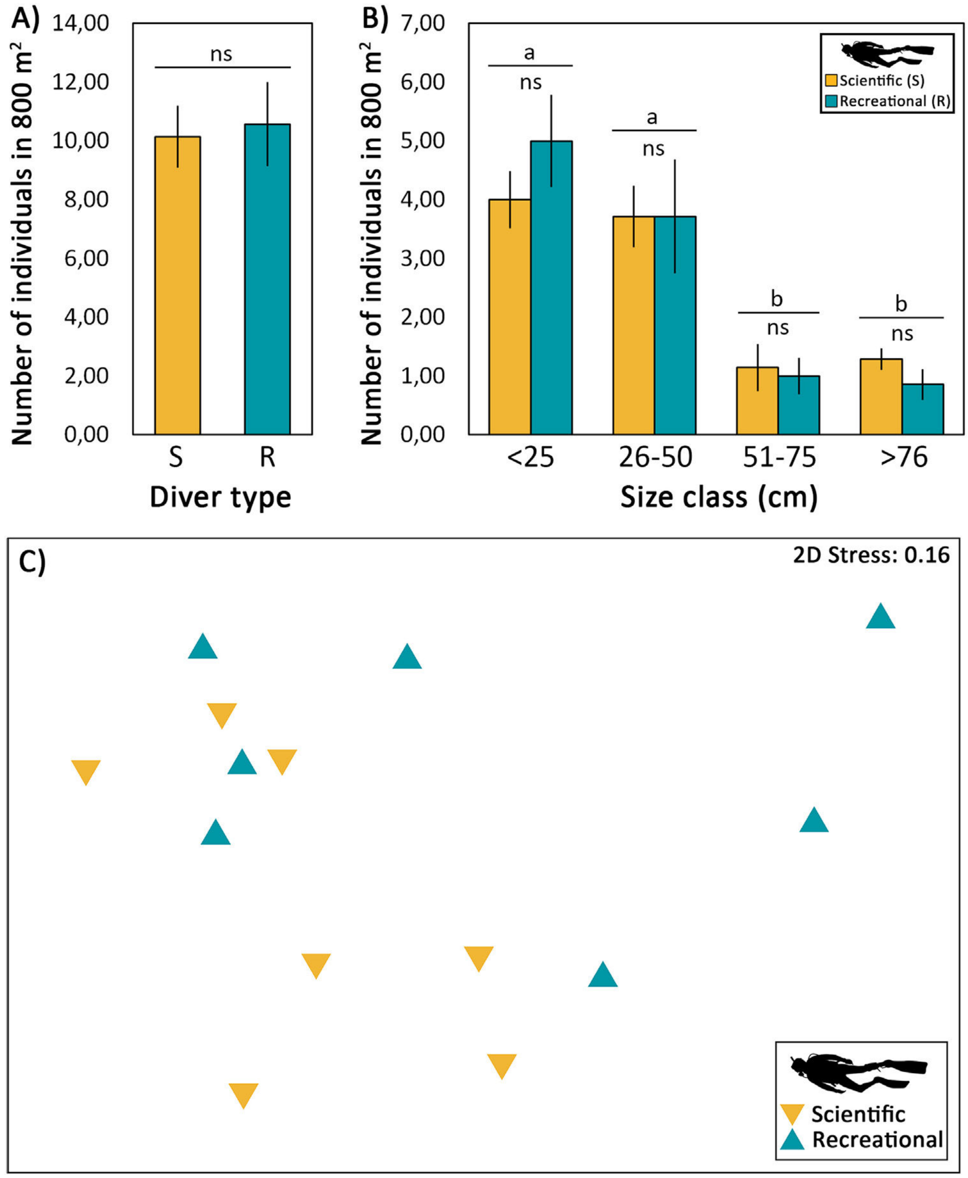


Fig. 4. Effects of previous scientific training on data collection. Total (A) and per size class (B) abundance (mean ± SE), and the nMDS plot for assemblage structure (C), comparing assemblage data recorded by scientific (orange) and recreational (blue) divers. For comparisons between types of divers, 'ns' stands for non-significant effects. For comparisons among size classes, groups sharing the same letter are not statistically different.

collection allowing a broader spatial and temporal monitoring of reef environments (Mason et al., 2018), often constrained by funding, particularly in developing countries that harbor great marine diversity. Recreational divers enjoyed their experience as citizen-scientists, collecting useful data regardless of their diving experience, reinforcing the great potential to implement similar protocol in other diving areas.

We demonstrated that recreational divers are efficient and committed when included in the scientific process. They can not only contribute to increase sampling effort, but also to supplement the scientific monitoring of reef environments when conducting standardized monitoring protocols, as the one we developed and implemented. More than turning citizens into scientific partners for reef monitoring, citizen-science activities are able to transform simple recreational interest into responsibility, bringing society closer to reef environments and promoting interest to preserve these ecosystems and their associated species (Trumbull et al., 2005; Cohn, 2008; Evely et al., 2011; Roy et al., 2012). Despite being developed for reef monitoring, our protocol has the potential to be adapted and applied in other systems and for other taxonomic groups as it has achieved the two mandatory issues that ensures the credibility of a citizen-based monitoring: (I) volunteer interest and enrollment by using an attractive design and considering charismatic and common species; (II) data quality by volunteer training, *in situ* scientific support and validation by comparison with data generated by scientific experts. We believe that the protocol presented in this paper can inspire data collection during recreational activities in other habitats and with other organisms, contributing to increase the credibility and popularity of citizen-science initiatives and reinforcing how powerful this tool can be to increase the scale and scope of scientific research.

Conflict of interest

We acknowledge that this work is original; has not been published or accepted for publication, nor is being considered for publication elsewhere; all the authors have read and approved the submitted version of the manuscript; all listed authors are entitled to authorship and agreed to be listed; all funding agencies have been properly acknowledged, had no role in the study conception, design, or results, and do not have a direct or indirect financial interest in the subject matter discussed in this manuscript. We have no conflicts of interests to declare.

Funding

This work was supported by the Serrapilheira Institute (Grant numbers :Serra-1708-15364 and R-1805-24275 awarded to GOL). Also, this study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, with a post-doctoral scholarship awarded to EAV.

Acknowledgements

The authors thank the 37 recreational divers and citizen-scientists that collected the data presented in this manuscript voluntarily: A. Melo, B. Oliveira, B. David, C. Wessen, E. Lima, E. Aroira, E. Matos, E. Funk, F. Costa, F. Gabriel, J. Silva, J. Borges, J. Alves, J. Sobral, J. Nissin, J. Silveira, L. Meneses, L. Lima, L. Bezerra, L. Silva, L. Oliveira, L. Guerra, M. Gilda, M. Cavalcanti, M. Schwengber, N. Utescher, R. Campelo, R. Valentina, R. Guerra, S. Simões, S. Glabote, S. Rocha, T. Santos, V. Hajek, V. Casemiro, V. Pederneschi and V. Bouth; the diving company staff, Eduardo Lima, Leonardo Bezerra, Leonardo Lemos, Leandro Lima, Francisco Santos and Cleberson Silva, for providing field support during the dive trips (Natal Divers); Bruno Lonzetti, Daniel Rovira, Gabriel Garcia, Jéssica Bleuel and Kelly Inagaki, for helping with the scientific data collection; Zaira Matheus (All Angle) for providing some of the photos used in the monitoring slate; and Rafael Laia and Adriana Carvalho for providing valuable suggestions in earlier versions of this manuscript. This study is a result of #DeOlhoNosCorais, a Brazilian citizen-based monitoring and science outreach program (https://www.instagram.com/deolhonoscorais/) supported by the Serrapilheira Institute (Grant numbers: Serra-1708-15364 and Camp Serrapilheira R-1805-24275).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2019.12.001.

References

Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance. Austral. Ecol. 26, 32–46, http://dx.doi.org/10.1111/j.1442-9993.2001.tb00081.x.
Baker, D.G.L., Eddy, T.D., McIver, R., Schmidt, A.L., Thériault, M.H., Boudreau, M., Courtenay, S.C., Lotze, H.K., 2017. Comparative analysis of different survey methods for monitoring fish assemblages in coastal habitats. PeerJ 4, e1832, http://dx.doi.org/10.7717/peerj.1832.
Bell, J.J., 2007. The use of volunteers for conducting sponge biodiversity assessments and monitoring using a morphological approach on Indo-Pacific coral reefs. Aquat. Conserv. 17, 133–145, http://dx.doi.org/10.1002/aqc.789.
Bender, M.G., Machado, G.R., De Azevedo Silva, P.J., Floeter, S.R., Monteiro-Netto, C., Luiz, O.J., Ferreira, C.E.L., 2014. Local ecological knowledge and scientific data reveal overexploitation by multigear artisanal fisheries in the Southwestern Atlantic. PLoS One 9, e110332, http://dx.doi.org/10.1371/journal.pone.0110332.
Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., Shirk, J., 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy. BioScience 59, 977–984, http://dx.doi.org/10.1525/bio.2009.59.11.9.
Bonter, D.N., Cooper, C.B., 2012. Data validation in citizen science: a case study from Project FeederWatch. Front. Ecol. Environ. 10, 305–307, http://dx.doi.org/10.1890/110273.
Bosch, N.E., Gonçalves, J.M.S., Erzini, K., Tuya, F., 2017. "How" and "what" matters: sampling method affects biodiversity estimates of reef fishes. Ecol. Evol. 7, 4891–4906, http://dx.doi.org/10.1002/ece3.2979.
Bozec, Y.M., Kulbicki, M., Laloë, F., Mou-Tham, G., Gascuel, D., 2011. Factors affecting the detection distances of reef fish: implications for visual counts. Mar. Biol. 158, 969–981, http://dx.doi.org/10.1007/s00227-011-1623-9.
Burgess, H.K., DeBey, L.B., Schmidt, N., Theobald, E.J., Ettinger, A.K., HilleRisLambert, J., Tewksbury, J., Parrish, J.K., 2017. The science of citizen science: Exploring barriers to use as a primary research tool. Biol. Conserv. 208, 113–120, http://dx.doi.org/10.1016/j.biocon.2016.05.014.
Carvalho-Filho, A., 1999. Editora melro, São Paulo. In: Peixes: Costa Brasileira, 3rd ed.
Cerrano, C., Milanese, M., Ponti, M., 2017. Diving for science – science for diving: volunteer scuba divers support science and conservation in the Mediterranean Sea. Aquat. Conserv. 27, 303–323, http://dx.doi.org/10.1002/aqc.2663.
Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18, 117–143, http://dx.doi.org/10.1111/j.1442-9993.1993.tb00438.x.
Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., Miloslavich, P., 2010. A census of marine biodiversity knowledge, resources, and future challenges. PLoS One 5, e12110, http://dx.doi.org/10.1371/journal.pone.0012110.
Cohn, J.P., 2008. Citizen science: can volunteers do real research? BioScience 58, 192–197, http://dx.doi.org/10.1641/B580303.
Delaney, D.G., Sperling, C.D., Adams, C.S., Leung, B., 2007. Marine invasive species: validation of citizen science and implications for national monitoring networks. Biol. Invasions 10, 117–128, http://dx.doi.org/10.1007/s10530-007-9114-0.
Dickens, L.C., Goatley, C.H.R., Tanner, J.K., Bellwood, D.R., 2011. Quantifying relative diver effects in underwater visual censuses. PLoS One 6, 6–8, http://dx.doi.org/10.1371/journal.pone.0018965.
Duffy, J.E., Lefcheck, J.S., Stuart-Smith, R.D., Navarrete, S.A., Edgar, G.J., 2016. Biodiversity enhances reef fish biomass and resistance to climate change. Proc. Natl. Acad. Sci. USA 113, 6230–6235 https://doi.org/10.1073/pnas.1524465113.
Earp, H.S., Liconti, A., 2019. Science for the future: the use of citizen science in marine research and conservation. In: Jungblut, S., Liebich, V., Bode-Dalby, M. (Eds.), YOUMARES 9 – The Oceans: Our Research, Our Future. Springer, Cham, http://dx.doi.org/10.1007/978-3-030-20389-4_1.
Edgar, G.J., Stuart-Smith, R.D., 2014. Systematic global assessment of reef fish communities by the Reef Life Survey program. Sci. Data 1, 140007, http://dx.doi.org/10.1038/sdata.2014.7.
Evely, A.C., Pinard, M., Reed, M.S., Fazey, I., 2011. High levels of participation in conservation projects enhance learning. Conserv. Lett. 4, 116–126, http://dx.doi.org/10.1111/j.1755-263X.2010.00152.x.
Fabricius, K.E., 2011. Factors determining the resilience of Coral reefs to eutrophication: a review and conceptual model. In: Dubinsky, Z., Stambler, N. (Eds.), Coral Reefs: An Ecosystem in Transition. Springer, Dordrecht, pp. 493–505.
Floeter, S.R., Halpern, B.S., Ferreira, C.E.L., 2006. Effects of fishing and protection on Brazilian reef fishes. Biol. Conserv. 128, 391–402, http://dx.doi.org/10.1016/j.biocon.2005.10.005.
Frazier, J., 2005. Marine turtles: the role of flagship species in interactions between people and the sea. MAST 3, 5–38, http://dx.doi.org/10.1111/j.1523-1739.2005.00158.x.
Freitag, A., Meyer, R., Whiteman, L., 2016. Strategies employed by citizen science programs to increase the credibility of their data. Citiz. Sci. Theory Pract. 1, 1–11, http://dx.doi.org/10.5334/cstp.6.
Gallagher, A.J., Hammerschlag, N., 2011. Global shark currency: the distribution frequency and economic value of shark ecotourism. Curr. Issues Tourism 14, 797–812 https://10.1080/13683500.2011.585227.
Goffredo, S., Pensa, F., Neri, P., Orlandi, A., Scola, M., Velardi, A., Piccinetti, C., Zaccanti, F., Goffredo, S., Pensa, F., Neri, P., Orlandi, A., Gagliardi, M.S., Velardi, A., Piccinetti, C., Zaccanti, F., 2010. Unite research with what citizens do for fun: ṙecreational monitoringö̈f marine biodiversity. Ecol. Appl. 20, 2170–2187, http://dx.doi.org/10.1890/09-1546.
Goffredo, S., Piccinetti, C., Zaccanti, F., 2006. Volunteers in marine conservation monitoring: a study of the distribution of seahorses carried out in collaboration with recreational scuba divers. Conserv. Biol. 18, 1492–1503, http://dx.doi.org/10.1111/j.1523-1739.2004.00015.x.
Heard, J., Chen, J., Wen, C.K.C., 2019. Citizen science yields first records of *Hippocampus japapigu* and *Hippocampus denise* (Syngnathidae) from Taiwan: a hotspot for pygmy seahorse diversity. ZooKeys 883, 83–90, http://dx.doi.org/10.3897/zookeys.883.39662.
Hodgson, G., 1999. A global assessment of human effects on coral reefs. Mar. Pollut. Bull. 38, 2–8, http://dx.doi.org/10.1016/S0025-326X(99)00002-8.
Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B.C., Kleypas, J., van de Leemput, I.A., Lough, J.M., Morrison, T.H., Palumbi, D.R., van Nes, E.H., Scheffer, M., 2017. Coral reefs in the anthropocene. Nature 546, 82–90, http://dx.doi.org/10.1038/nature22901.
Hughes, T.P., Anderson, K.D., Connolly, S.R., Heron, S.F., Kerry, J.T., Lough, J.M., Baird, A.H., Baum, J.K., Berumen, M.L., Bridge, T.C., Claar, D.C., Eakin, C.M., Gilmour, J.P., Graham, N.A.J., Harrison, H., Hobbs, J.P.A., Hoey, A.S., Hoogenboom, M., Lowe, R.J., McCulloch, M.T., Pandolfi, J.M., Pratchett, M., Schoepf, V., Torda, G., Wilson, S.K., 2018. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science 359, 80–83, http://dx.doi.org/10.1126/science.aan8048.
Humann, P., 2008. Reef Fish Identification. New World Publications, Jacksonville, Florida, Caribbean, Bahamas.
Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, M., Peterson, C.H., Steneck, R.S., Tegner, M.J.,

Warner, R.R., Pandolfi, J.M., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629–638, http://dx.doi.org/10.1126/science.1059199.
Jiguet, F., 2009. Method learning caused a first-time observer effect in a newly started breeding bird survey. Bird Study 56, 253–258, http://dx.doi.org/10.1080/00063650902791991.
Kollmuss, A., Agyeman, J., 2010. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? Environ. Educ. Res. 8, 239–260, http://dx.doi.org/10.1080/13504620220145401.
Lewandowski, E., Specht, H., 2015. Influence of volunteer and project characteristics on data quality of biological surveys: Data Quality of Volunteer Surveys. Conserv. Biol. 29, 1–11 https://doi.org/10.1111/cobi.12481.
Lindenmayer, D.B., Likens, G.E., 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends Ecol. Evol. 24, 482–486 https://foi.org/10.1016/j.tree.2009.03.005.
Lindfield, S.J., Harvey, E.S., Mcilwain, J.L., Halford, A.R., 2014. Silent fish surveys: bubble-free diving highlights inaccuracies associated with SCUBA-based surveys in heavily fished areas. Methods Ecol. Evol. 5, 1061–1069, http://dx.doi.org/10.1111/2041-210X.12262.
Lukyanenko, R., Parson, J., Wiersman, Y.F., 2016. Emerging problems of data quality in citizen science. Conserv. Biol. 30, 447–449, http://dx.doi.org/10.1111/cobi.12706.
Magris, R.A., Grech, A., Pressey, R.L., 2018. Cumulative human impacts on coral reefs: assessing risk and management implications for brazilian coral reefs. Diversity 10, 26, http://dx.doi.org/10.3390/d10020026.
Mason, S.C., Hill, J.K., Thomas, C.D., Powney, G.D., Fox, R., Brereton, T., Oliver, T.H., 2018. Population variability in species can be deduced from opportunistic citizen science records: a case study using British butterflies. Insect Conserv. Diver. 11, 131–142, http://dx.doi.org/10.1111/icad.12242.
Mazumdar, S., Ceccaroni, L., Piera, J., Hölker, F., Berre, A.J., Arlinghaus, R., Bowser, A., 2018. Citizen science technologies and new opportunities for participation. In: Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J., Bonn, A. (Eds.), Citizen Science: Innovation in Open Science, Society and Policy. UCL Press, London, http://dx.doi.org/10.14324/111.9781787352339.
Moberg, F., Folke, C., 1999. Ecological goods and services of coral reef ecosystems. Ecol. Econ. 29, 215–233, http://dx.doi.org/10.1016/S0921-8009(99)00009-9.
Morais, J.O., 1969. Contribuição ao estudo dos “beach-rocks” do nordeste do Brasil. Trabalhos do Instituto Oceanográfico da Universidade Federal de Pernambuco 11, 79–89.
Morais, R.A., Ferreira, C.E.L., Floeter, S.R., 2017. Spatial patterns of fish standing biomass across Brazilian reefs. J. Fish Biol. 91, 1642–1667, http://dx.doi.org/10.1111/jfb.13482.
Newman, G., Wiggnis, A., Crall, A., Graham, E., Newman, S., Crowston, K., 2012. The future of citizen science: emerging technologies and shifting paradigms. Front. Ecol. Environ. 10, 298–304, http://dx.doi.org/10.1890/110294.
Nov, O., Arazy, O., Anderson, D., 2011. Technology-mediated citizen science participation: a motivational model. In: Proceedings of the Fifth International AAAI Conference on Weblogs and Social Media, pp. 249–256.
Odum, H.T., Odum, E.P., 1995. Trophic structure and productivity of a windward coral reef community on eniwetok atoll. Ecol. Monogr. 25, 291–320, http://dx.doi.org/10.2307/1943285.
Pinheiro, H.T., Rocha, L.A., Macieira, R.M., Carvalho-Filho, A., Anderson, A.B., Bender, M.G., DiDario, F., Ferreira, C.E.L., Francini-Filho, R.B., Gasparini, J.L., Joyeux, J.C., Luiz, O.J., Mincarone, M., Moura, R.L., Nunes, J.A.C.C., Quimbayo, J.P., Rosa, R.S., Sampaio, C.L.S.S., Sazima, I., Simon, T., Vila-Nova, D.A., Floeter, S.R., 2018. Southwestern Atlantic reef fishes: zoogeographic patterns and ecological drivers reveal a secondary biodiversity center in the Atlantic Ocean. Diver. Distrib. 1, 20, http://dx.doi.org/10.1111/ddi.12729.
Roos, N.C., Pennino, M.G., Carvalho, A.R., Longo, G.O., 2019. Drivers of abundance and biomass of Brazilian parrotfishes. Mar. Ecol. Progr. Series 623, 117–130, http://dx.doi.org/10.3354/meps13005.
Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C., Robinson, L.D., 2012. Understanding citizen science and environmental monitoring. In: Final Report on Behalf of UK-EOF. NERC Centre for Ecology & Hydrology and Natural History Museum.
Schmitt, E.F., Sluka, R.D., Sullivan, K.M., 2002. Evaluating the use of roving diver and transect surveys to assess the coral reef fish assemblage off southeastern Hispaniola. Coral Reefs 21, 216–223, http://dx.doi.org/10.1007/s00338-002-0216-y.
Strain, E.M., Edgar, G.J., Ceccarelli, D., Stuart-Smith, R.D., Hosack, G.R., Thomson, R.J., 2019. A global assessment of the direct and indirect benefits of marine protected areas for coral reef conservation. Divers. Distrib. 25, 9–20, http://dx.doi.org/10.1111/ddi.12838.
van Strien, A.J., van Swaay, C.A., Termaat, T., 2013. Opportunistic citizen science data of animal species produce reliable estimates of distribution trends if analysed with occupancy models. J. Appl. Ecol. 50, 1450–1458, http://dx.doi.org/10.1111/1365-2664.12158.
Smith, A.M., Sutton, S.G., 2008. The role of a flagship species in the formation of conservation intentions. Hum. Dimens. Wildl. 13, 127–140, http://dx.doi.org/10.1080/10871200701883408.
Stuart-Smith, R.D., Edgar, G.J., Barrett, N.S., Bates, A.E., Ker, S.C., Bax, N.J., Becerro, M.A., Berkhout, J., Blanchard, J.L., Brock, D.J., Clark, G.F., Cooper, A.T., Davis, T.R., Day, P.B., Duffy, E.J., Holmes, T.H., Howe, S.A., Jordan, A., Kininmonth, S., Knott, N.A., Jonathan, L.S., Ling, S.D., Parr, A., Strain, E., Hugh, S., Russell, T., 2017. Assessing national biodiversity trends for rocky and coral reefs through the integration of citizen science and scientific monitoring programs. Bioscience 67, 134–146, http://dx.doi.org/10.1093/biosci/biw180.
Teleki, K.A., 2012. Power of the people? Aquat. Conserv. 22, 1–6, http://dx.doi.org/10.1002/aqc.2219.
Thiel, M., Penna Díaz, M., Luna Jorquera, G., Salas, S., Sellanes, J., Stotz, W., 2014. Citizen scientists and marine research: volunteer participants, their contributions, and projection for the future. Oceanogr. Mar. Biol. 52, 257–314, http://dx.doi.org/10.1201/b17143-6.
Thompson, A.A., Mapstone, B.D., 1997. Observer effects and training in underwater visual surveys of reef fishes. Mar. Ecol. Progr. Series 154, 53–63, http://dx.doi.org/10.3354/meps154053.
Trumbull, D.J., Bonney, R., Grudens-Schuck, N., 2005. Developing materials to promote inquiry: lessons learned. Sci. Educ. 89, 879–900 https://10.1002/sce.20081.
Trumbull, D.J., Bonney, R., Bascom, D., Cabral, A., 2000. Thinking scientifically during participation in a citizen-science project. Informal Sci. 84, 265–275, http://dx.doi.org/10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5.
Underwood, A.J., 1997. Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance. Cambridge University Press, Cambridge.
Walpole, M.J., Leader-Williams, N., 2002. Tourism and flagship species in conservation. Biodivers. Conserv. 11, 543–547, http://dx.doi.org/10.1023/A:1014864708777.
Williams, I.D., Walsh, W.J., Tissot, B.N., Hallacher, L.E., 2006. Impact of observers' experience level on counts of fishes in underwater visual surveys. Mar. Ecol. Progr. Series 310, 185–191, http://dx.doi.org/10.3354/meps310185.