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Voluntary scuba diving as a method for monitoring invasive exotic marine species

Tárcio S. Mangelli[1]; Cleverson Zapelini[1,2,*]; Wesley Duarte da Rocha[3] and Alexandre Schiavetti[4]

ABSTRACT

Monitoring surveys provide data needed to assess ecosystem conditions in places where bioinvasion occurs. The collection of data by volunteer researchers (citizen science) is an alternative for scientists and research agencies that lack information but do not have sufficient financial resources. The objective of the study was to evaluate the potential of volunteer divers with different diving experiences and the use (or not) of an invasive marine species identification guide at eight diving sites distributed between the north of Ilha Grande and the municipality of Angra dos Reis in the Central Channel of Ilha Grande Bay, Rio de Janeiro state. During the three months of study, 207 questionnaires were evaluated. The results showed that the group of volunteer divers with more experience identified a greater number of invasive exotic species compared to the group of divers with less experience. No statistical difference was found in the number of species identified between the groups of volunteer divers with and without a species identification chart. As a recommendation for the use of citizen science, it is necessary to use divers with greater diving experience. Developing stricter protocols for the identification of invasive exotic marine species is essential for the collection of quality data. The improvement of monitoring programs based on citizen science can provide useful information for research on biodiversity in marine environments, significantly reducing financial costs and time in the field, in addition to contributing to the ecological knowledge, awareness and environmental education of participants.

Keywords: Bioinvasion; Citizen Science; Marine Ecosystem; Sun Coral.

1 Ethnoconservation and Protected Areas Lab (LECAP), Universidade Estadual de Santa Cruz, Rodovia Jorge Amado, Km 16, Salobrinho, 45662-900, Ilhéus, BA, Brazil.

2 Collaborator researcher of Programa de Pós-Graduação em Sistemas Aquáticos Tropicais, Universidade Estadual de Santa Cruz, Rodovia Jorge Amado, Km 16, Salobrinho, 45662-900, Ilhéus, BA, Brazil.

3 Laboratório de Mirmecologia, Centro de Pesquisa do Cacau, CEPLAC, C.P. 7, 45600-900, Itabuna, BA, Brazil.

4 Departamento de Ciências Agrárias e Ambientais (DCAA), Universidade Estadual de Santa Cruz, BA, Brazil. Research associate CESIMAR, CENPAT, Chubut, Argentina.

* Corresponding author. E-mail address: TSM (tarciosm@gmail.com), CZ (clever.zapelini@gmail.com), WDR (wd.darocha@gmail.com), AS (aleschi@uesc.br)

SIGNIFICANCE STATEMENT

This study was carried out in an area of great ecological relevance around the Tamoios Ecological Station (RJ). We use volunteer divers with different diving experiences and the use (or not) of an invasive marine species identification guide at eight diving sites. The results show that the guide was not a relevant factor to help in the identification of invasive exotic marine species, while the diving experience was. As a recommendation for the use of citizen science, it is necessary to use divers with greater diving experience. The use of citizen science can provide useful information for research on biodiversity in marine environments, significantly reducing financial costs and time in the field.

INTRODUCTION

The introduction of invasive exotic species by human activities can cause major changes not only to native biodiversity, but also lead to new forms of balance in the impacted ecosystem (Beisner et al. 2003, Petraitis 2013). This can occur regardless of whether their origin is accidental or unintentional (e.g. ballast water, bio-encrustations etc.), or intentional, such as by fishkeeping (Occhipinti-Ambrogi and Savini 2003, Padilla and Williams 2004, Olenin et al. 2011, Ferreira et al. 2015; Soares et al., 2020).

Monitoring surveys provide important data on ecosystem conditions in places where bioinvasion occurs (Lee II et al. 2008). In addition to predicting possible impacts and providing data on the environment, monitoring programs encourage more research to be carried out, thereby expanding the share of scientific information on management and prevention (McKenzie et al. 2016). In this way, studies on bioinvasion can help to improve prevention strategies and management of essential environmental policies to address aspects of change in impacted environments, including species extinctions, evolutionary processes and ecosystem functioning (Sax et al. 2007).

There is a growing expansion in the use of information from volunteer researchers who can contribute to the detection of new bioinvaders and provide additional data on the distribution of introduced marine species (Delaney et al. 2008, Crall et al. 2011, 2012). Citizen science is the term used when ordinary citizens, who work as volunteer researchers, contribute to the collection and/or processing of data, as part of scientific research (Cooper 2016, Gouraguine et al. 2019). Citizen science is made up of people who care about the environment, feel in touch with nature and/or have some degree of scientific knowledge (Freiwald et al. 2018, Gouraguine et al. 2019). However, a recurring concern in relation to the data collected by citizen science is its quality: the greater potential to introduce bias in the data due to the lack of training in scientific research when compared to professional researchers (e.g. Krasny and Bonney 2005, Bonter and Cooper, 2012). The literature points to some examples where a lack of scientific training and the difficulties in identifying some species can lead to a greater error or bias in the sampling (Dickinson et al. 2010). One way to assess the accuracy of the data is to compare it with the data obtained by scientists, and from this point on, develop methods and protocols that assist in detecting errors in the data provided by citizen science (Schmeller et al. 2009, Dickinson et al. 2010, Crall et al. 2011).

The participation of volunteer researchers in underwater monitoring projects presents different challenges. In addition to the scuba diving course, there is a need for skills while submerged. Projects like The Reef Fish Survey evaluate volunteer researchers with the skills to identify fish species through courses that involve identification techniques and diving skills (Goffredo et al. 2010). These authors found that the accuracy and consistency of the volunteer divers was between 50 and 80%, results comparable to other similar projects. In addition, there was a large collection of data in a short period of time at a low cost. Thus, the objective of this study was to evaluate the recognition of eight invasive exotic marine species: *Caulerpa scalpelliformis* (R. Brown Ex Turner) *C. Agardh*, 1817, *Charybdis hellerii* (A. Milne-Edwards, 1867), *Isognomon bicolor* (C. B. Adams, 1845), *Myoforceps aristatus* (Dillwyn 1817), *Ophiothela mirabilis* (Verrill, 1867), *Styela plicata* (Lesueur, 1823), *Tubastraea coccinea* (Lesson 1829) and *Tubastraea tagusensis* (Wells 1982) (Add File 1), by groups of voluntary divers with and without a clipboard to aid in identification in eight dive sites in Ilha Grande Bay, Rio de Janeiro state.

Despite the ecological relevance of the region and the growing potential that citizen science has to aid scientific research, there is still no study evaluating the participation of volunteer divers in the identification of invasive exotic marine species. In this way, we evaluate the potential of volunteer divers with different experiences in identifying invasive exotic species in locations around a marine protected area, the Tamoios Ecological Station. It was expected that divers with more experience and who use a clipboard as an aid would be more accurate/efficient in the identification of invasive species.

MATERIAL AND METHODS

Study area

The study was carried out in Ilha Grande Bay (IGB), situated in the south of the state of Rio de Janeiro (23°06'S 44°00'W–23°18'S 44°30'W) covering the municipalities of Angra dos Reis, Paraty and a small portion of the municipality of Mangaratiba. It has a total area of 1,124 km2, being subdivided into three physiographic units, named: Western Portion (located between the mainland/Paraty and the west of Ilha Grande), Central Channel (located between Ilha Grande and the mainland/Angra dos Reis) and Eastern Portion (located east of Ilha Grande) (Mahiques and Furtado 1989, Lodi and Hetzel 1998).

The Tamoios Ecological Station (ESEC) is located around IGB, a federally protected marine area (AMP) with full protection (a category that does not allow any type of extraction of natural resources, only public visitation and scientific research are allowed). This MPA was created in 1990 (Brasil 1990), as a counterpart to the implantation of the Angra Nuclear Power Plants 1, 2 and 3, with the objective of protecting, preserving and monitoring the island and marine ecosystem of IGB.

IGB has a great diversity of marine ecosystems. Environments of rocky shores, beaches and 365 islands are found in its greatest extension. It is considered to be a relatively well-preserved area, in which remnants of insular Atlantic forest occur (Belo 2003, Pires et al. 2007). Its waters are characterized as oligotrophic, however, close to urban areas locations with domestic sewage discharges culminating in a eutrophic environment close to the coast can be observed (Mayer-Pinto and Junqueira 2003, Ignacio et al. 2010).

It is a bay little influenced by the tide and local winds. Within IGB, not only winds but also ocean currents are of low incidence and have low hydrodynamics (Signorini 1980, Fragoso 1999). It presents calm waters and temperatures that vary between 20○ and 28○C, in the summertime the water visibility can reach the maximum depth depending on the location (Skinner et al. 2016). The waters surrounding the islands do not have depths greater than eight meters (Ignacio et al. 2010). These characteristics make IGB an excellent location for recreational scuba diving and freediving activities.

Currently, two nuclear power plants are found in IGB, the Port of Angra dos Reis, the Naval Shipyard (Brasfels, former Verolme shipyard) and a Transpetro/Petrobras oil terminal (Ilha Grande Bay Terminal - TEBIG). Thus, the presence of port areas, marine oil terminals and the large number of vessels are potential vectors that facilitate bioinvasion (Ignacio et al. 2010, Castro et al. 2016).

Data collection

After the registration of the bioinvader *Tubastraea* spp. (sun coral; Figure 1) in 2004 on IGB islands, and studies proving the impact on native benthic communities and the hypothesis that these organisms propagated within ESEC Tamoios (Paula and Creed 2004, Lages et al. 2010), the "Eclipse Project" was implemented. This project aimed to manage (remove) the colonies of sun coral on the ESEC Tamoios islands and monitor these areas in order to prevent new occurrences (Brasil 2016). To maximize monitoring outside the AMP, ESEC created the "Identification Guide for Invasive Exotic Marine Species of Ilha Grande Bay, RJ", to be distributed mainly to divers and recreational diving operators in the region, so that they could report the location of these organisms outside the AMP (ICMBio, 2016). Thus, a partnership was built between the Ethnoconservation and Protected Areas Laboratory (LECAP) of the State University of Santa Cruz (UESC) and ESEC Tamoios to use the guide as support material for this work.

To assess marine monitoring outside the AMP, eight dive sites were selected within IGB, located between Ilha Grande and the municipality of Angra dos Reis: Enseada do Sítio Forte (*Naufrágio pinguino*) (23°07'04" S, 44°17'01" W), *Lagoa Azul* (23°05'08" S, 44°14'39" W), Lagoa Verde (23°08'23" S, 44°19'36" W), *Laje Branca* (23°08'14" S, 44°20'48" W), *Laje do Matariz* (Naufrágio Helicóptero) (23°06'34" S, 44°15'58" W), *Ponta do Bananal* (23°05'57" S, 44°15'35" W), *Ponta Grossa de Sítio Forte (Ponta Grossa)* (23°06'59" S, 44°17'51" W) and *Laje Preta Redonda* (23°03'00" S, 44°18'32" W) (Figure 2).

The study was carried out in partnership with the managing body of ESEC Tamoios and with the diving operator Sotto Mare Diving Center. Waterproof clipboards made of PVC, containing photos, popular and scientific names of the eight invasive exotic species (Add File 2, 3) were used by divers as support material for identification of species in the field. The eight sampling points (located outside the ESEC Tamoios marine area) were selected because they were the most visited points by the diving operator during the study. It was recognized that the sample points do not cover all the structural complexity that exists in IGB. However, the sampled locations allowed a baseline for future research in the region to be designed. The information was collected through questionnaires distributed to the dive operator and divers at the end of each dive. The study was carried out between March and May 2017, between the hours of 9 am to 4 pm.

The entire process was carried out and monitored by the diver responsible for the study (MANGELLI, T.S.). Initially, a quick presentation was made to the

Figure 1. Photo taken by Juliana da Costa Gomes (IBAMA/MMA) of invasive exotic marine species, *Tubastraea coccínea* (orange) and *Tubastraea tagusensis* (yellow). Source: IBAMA.

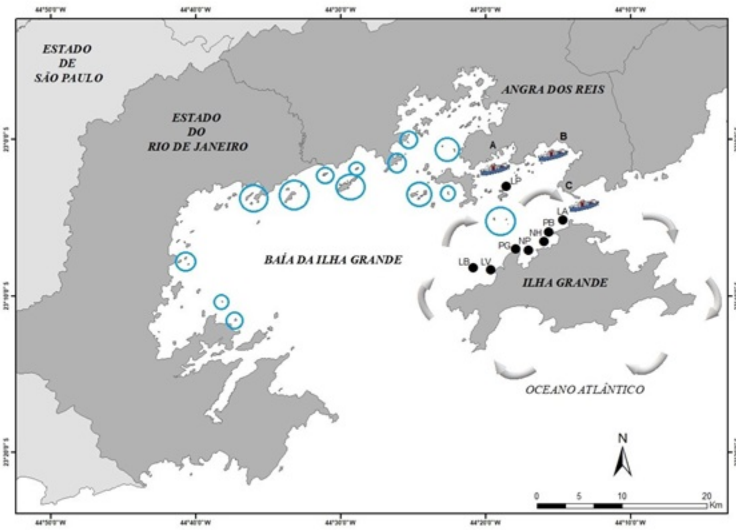

Figure 2. Study area located in Ilha Grande Bay, Rio de Janeiro state. Sample points (black): (LB) *Laje Branca*, (LV) *Lagoa Verde*, (PG) *Ponta Grossa*, (NP) *Naufrágio Pinguino*, (NH) *Naufrágio Helicóptero*, (PB) *Ponta do Bananal*, (LA) *Lagoa Azul*, and (LP) *Laje Preta*. Marine environment belonging to ESEC Tamoios (area outlined in blue). Port area (A: Angra dos Reis Port Terminal, B: Brasfels Shipyard and C: Ilha Grande Bay Terminal - TEBIG) and the arrows representing the direction of circulation of ocean currents (west-east) in the Central Channel (between the north of Ilha Grande and the municipality of Angra dos Reis).

recreational divers who were on the vessel about the purpose of the study and how it would be carried out. After the presentation, divers who agreed to participate in the study were classified as volunteer divers. Two groups of volunteer divers were formed (each group varied between 10 and 13 divers). Both groups received no prior training and the divers were randomly assigned to each group. The first group was classified as "voluntary divers without a clipboard", this group performed the dive without the aid of the identification clipboard and could consult it only after the end of the dive, with the questionnaire in hand. The second group was classified as "volunteer divers with clipboard", this group used the clipboard throughout the dive to facilitate the identification of the organisms. At each site ($n = 8$), only one dive was performed by each group of volunteer divers (with and without a clipboard). Also, for each site, each group was composed of new divers (that is, there was no repetition of divers). Thus, at each site, only one dive was evaluated for each group of divers (with and without a clipboard).

For validation and control of the data collected by the groups of volunteer divers (Finn et al. 2010), a third group was formed, consisting of three divers. One of the divers was the diver responsible for the study, the other two were diving instructors from the dive operator itself who have been working in the region for more than 10 years and have knowledge of both the sites and the organisms. For this group, training was carried out, and they were classified as "specialist divers". The members of the group of specialist divers used the clipboard during all dives, performed only one sampling per site and dove simultaneously with the group of volunteer divers without interfering with their observations (Goffredo et al. 2010).

At the end of each dive, the three groups received identical questionnaires to assess what was identified, which also included a brief profile of the diver and information about the dive (Add File 4). The variable diving experience was categorized according to Giglio et al. (2015) and analyzed through the frequency of dives performed annually, as follows: 1 to 30 dives (beginner diver), 31 to 60 dives (intermediate diver), 61 to 100 dives (advanced diver) and ¿100 dives (experienced diver).

The diving operator's personnel responsible for the operation received a questionnaire with different questions (Add File 5).

The anonymity of participants and the confidentiality of the information provided by them were guaranteed under the conditions established in the informed consent statement (TCLE; Authorization No. 2.593.218 of the Research Ethics Committee of the Universidade Estadual de Santa Cruz)

Statistical analyses

For data analysis, a generalized linear model - GLM (Crawley 2013) was constructed to estimate the effect of the explanatory variables, i.e. use of identification material, groups of volunteer divers (with and without a clipboard), gender, age, diving experience, dive time, dive sites and whether or not they have diving experience at the site on the number of identified exotic species (response variable). We used GLM with Poisson distribution, however, due to overdispersion, it was necessary to correct standard errors using a Quasi-Poisson model.

For the construction of the GLM, complete models were created and submitted to residue analysis to test the ideal adequacy of the error distribution (Crawley 2013). Subsequently, non-significant explanatory variables ($p > 0.05$) were excluded from the model until the adequate minimum model was obtained. When differences ($p < 0.05$) were observed in the categories of groups of volunteer divers, level of diving certification and dive sites, the data were subjected to contrast analysis for aggregation of non-significant levels (Crawley 2013). All analyses were performed using the R program (R Core Team, 2019).

RESULTS

207 questionnaires were applied during the three months of study. Volunteer divers with a clipboard answered 91 questionnaires and volunteer divers without a clipboard answered 92 questionnaires. The specialist divers answered 24 questionnaires. Among the group of volunteer divers, only 21.3% of respondents were female.

The dives took place between the depths of 6 and 13 meters, the average dive time at the sites was 47 minutes, varying between 26 and 60 minutes, totaling 10,435 minutes of diving. The type of seabed observed in most places presented 50% unconsolidated substrate (sandy environment) and 50% consolidated substrate (rocky environment).

The age of volunteer divers ranged between 20 and 61 years. When asked what an invasive exotic marine species was, 21.3% answered correctly, 23% answered that they knew but the answer was not correct and 55.7% said they did not know. The invasive exotic species with the highest relative abundance found by the group of volunteer divers among the eight sites were *T. coccinea* (35.8%) and *T. tagusensis* (40.9%). With the exception of the genus *Tubastraea* and the crab *C. hellerii*, the rest of the organisms obtained a low identification index.

The number of exotic species recorded by volunteer divers did not differ between groups with and without a clipboard ($p = 0.58$), gender ($p = 0.38$), age of the diver ($p = 0.43$), or having previously dived at the site ($p = 0.26$; Table 1).

However, the number of registered species differs in relation to diving experience ($p < 0.0001$) but did not differ between the beginner and intermediate categories, nor between the advanced and experienced categories. However, the beginner and intermediate categories differed from the advanced and experienced categories (Quasi-poisson, $gl = 1, Deviance = 6.27, p = 0.0003$; Table 1; Figure 3).

The number of exotic species recorded was positively correlated with dive time ($p = 0.0003$, Table 1, Figure 4).

The dive sites differ in the number of registered exotic species ($p = 0.0003$). The average number of exotic species at the LA, LB, LP and LV sites were higher and differed significantly from the NH, NP, PB and PG sites which were also equal among themselves (Quasi-poisson, $gl = 1, Deviance = 11.99, p < 0.0001$, Table 1, Figure 5).

The number of species did not differ between diving experience and dive sites ($p = 0.4$), just as there is no difference between the group of volunteer divers,

Table 1. Results of generalized linear models, explanatory variables used and distribution of errors for each model. * Significant difference.

Response variable	Explanatory variable	Error distribution	gl	Deviance/F	P
Number of exotic species	Volunteer divers	Quasi-poisson	1	0.1290	0.58
	Sex	Quasi-poisson	1	0.3301	0.38
	Age	Quasi-poisson	1	0.2630	0.43
	Previous dive	Quasi-poisson	1	0.5509	0.26
	Dive experience	Quasi-poisson	3	8.1278	<0.0001*
	Dive time	Quasi-poisson	1	5.5321	0.0003*
	Dive site	Quasi-poisson	7	13.1326	0.0003*
	Experience/Site	Quasi-poisson	18	8.6606	0.4
	Volunteers/Experience/Site	Quasi-poisson	9	5.4118	0.2

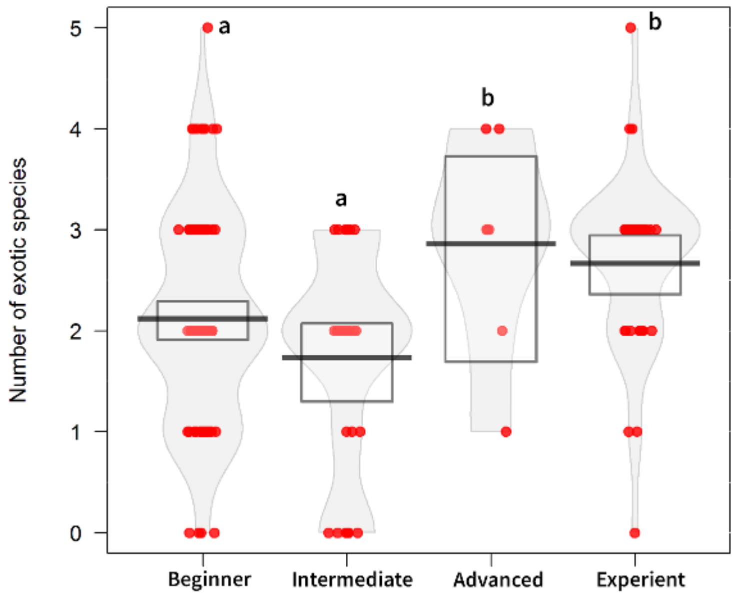

Figure 3. Number of exotic species according to diver's experience. Points are the raw data, black line represents the average, bean is the inference interval. Different letters above plots indicate significant differences.

their diving experience and the study sites ($p = 0.2$, Table 1).

The validation carried out between the group of volunteer divers and specialists demonstrated variation, mainly for the species *S. plicata* (Table 2).

DISCUSSION

Divers with more diving time (more experience) showed better potential in identifying invasive exotic species. This occurred regardless of the use of a clipboard as an auxiliary material in the dives. In addition, the effective diving time was also relevant, with more species being noted in longer dives.

Our results indicated that the number of species recorded is related to the diver's level of experience, corroborating the situation where less experienced divers are still in the learning process (Ward-Waige & Lotze 2011). One possible explanation is related to buoyancy control: less experienced divers have less control and this can compromise the observation of organisms. On the other hand, more experienced divers have greater buoyancy control, which allows a greater perception of the organisms around them (Thapa et al. 2005, Giglio et al. 2015, Anderson et al. 2017). Thus, our results suggest that citizen science projects that intend to use the partnership of volunteer divers to observe invasive exotic species should prioritize the selection of divers who already have a certain level of diving experience. The positive relationship between the number of species identified according to the highest level of experience of divers has also been observed

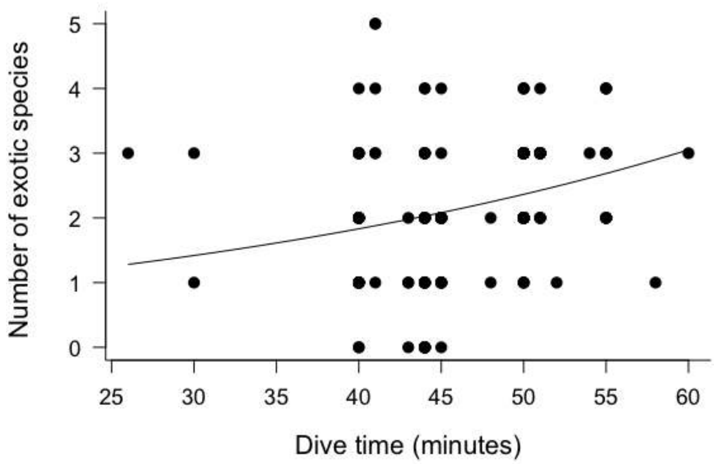

Figure 4. Number of exotic species recorded as a function of dive time (in minutes).

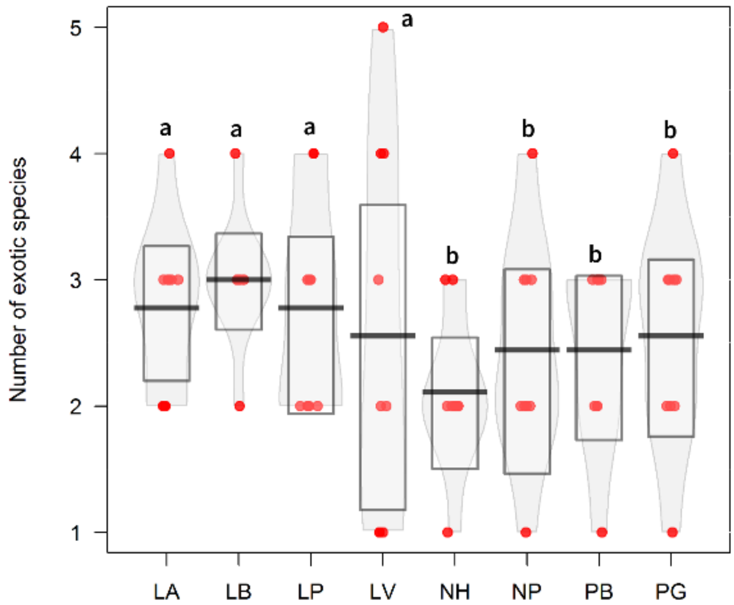

Figure 5. Number of exotic species according to dive site. Points are the raw data, black line represents the average, bean is the inference interval. Different letters above plots indicate significant differences. (LA: *Lagoa Azul*, LB: *Laje Branca*, LP: *Laje Preta*, LV: *Lagoa Verde*, NH: *Naufrágio Helicóptero*, NP: *Naufrágio Pinguino*, PB: *Ponta do Bananal* and PG: *Ponta Grossa*).

in other studies (Savage et al. 2016).

Some authors suggest that long dives (> 60 minutes) may impair the identification of species, as factors such as cold, anxiety, stress and fatigue, for example, are related to the significant reduction in the diver's performance (Goffredo et al. 2010). However, the results of the current study contrast with those of Goffredo et al. (2010), since the positive relationship between the dive time and the number of species identified can be related to two aspects: I) divers are less likely to present the factors reported by Goffredo et al. (2010), since the region has calm waters and temperatures that vary between 20° and 28° C (Skinner et al. 2016); and, II) due to the fact that the duration of the dive did not exceed 60 minutes (average of 47 minutes), it cannot be confirmed that above

Table 2. Presence (+) or absence (-) of invasive exotic marine species recorded at the eight study sites in Ilha Grande Bay (VD: volunteer diver; SD: specialist diver).

Espécie	Mergulhador	Ponta do Bananal	Lagoa Verde	Laje Branca	Lagoa Azul	Ponta Grossa	Naufrágio Pinguino	Naufrágio Helicóptero	Laje Preta
Tubastraea coccinea	VD	+	+	+	+	+	+	+	+
	SD	+	+	+	+	+	+	+	+
Tubastraea tagusensis	VD	+	+	+	+	+	+	+	+
	SD	+	+	+	+	+	+	+	+
Ophiothela mirabilis	VD	-	+	+	-	-	-	-	-
	SD	-	+	-	+	-	-	-	-
Styela plicata	VD	-	+	+	+	+	-	-	+
	SD	-	+	-	-	-	+	+	+
Isognomon bicolor	VD	-	+	+	+	-	-	-	-
	SD	-	-	-	-	-	-	-	-
Myoforceps aristatus	VD	-	-	+	-	+	-	+	-
	SD	-	-	-	-	-	-	-	-
Charybdis hellerii	VD	+	+	+	+	+	+	+	+
	SD	+	+	+	+	+	+	-	+
Caulerpa scalpelliformis	VD	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-

that time there would be a decrease in the number of species identified.

The correlation between the variables diving experience and dive sites was not relevant, this may be related to the proximity of areas called bioinvader dispersion center (port areas with intense vessel traffic; Ignacio et al. 2010, Castro et al. 2016, Magaletti et al. 2017). The main hypothesis considered is the way in which ocean currents move in the IGB region close to these areas, as these organisms can be introduced via ballast water and bio-encrustation and, soon after, transported by ocean currents (Tavares and Mendonça 1996; Castro et al. 2016).

Tubastraea coccinea and *T. tubastraea* were the only species present in all sampled sites. The register of these species had already been noted in the places studied by other authors (Silva et al. 2014, Creed et al. 2017a). These bioinvaders can be considered organisms that stand out from the other exotic species analyzed in this study. Their intense and striking colors facilitate their identification and perhaps explain the higher indices of records made in relation to other invading organisms, a situation similar to that observed in other places where 82% of the volunteer researchers correctly identified invasive plant species, entitled "easy recognition", while 62% correctly identified those entitled "difficult recognition" (Crall et al., 2011). However, Mantellato et al. (2011) recommend caution in the identification of the genus Tubastraea, as the species can be confused among themselves.

The use of field guides as a scientific tool for the identification of species should be used with caution (Aguiar et al. 2017). Nerbonne and Vondracek (2003) found that inexperienced volunteers are biased and ineffective in correctly identifying most organisms, even with the help of a clipboard with their image. In addition, inexperienced divers are more likely to mistakenly identify cryptic species or even pass them by without noticing their presence (Cox et al. 2012, Giglio et al. 2015).

The quality of the images and the characteristics of the environment are factors that influence the identification of the organisms, the use of high-quality images and relevant knowledge about the organism in question increase precision in identification (Mantellato et al. 2013, Gibbon et al. 2015). In addition to a training appropriate for the group of volunteer divers. Crall et al. (2012) realized that the index of correct answers increases after training and emphasize the need for training for more efficient and accurate data collection (Nerbonne and Vondracek 2003, Dickinson et al. 2010, Finn et al. 2010, Williams et al. 2015).

With continuous and personalized training, it is possible that the performance of volunteer researchers is compared to that of specialist researchers. (Nerbonne and Vondracek, 2003, Dickinson et al. 2010, Gibbon et al. 2015).

The use of the identification clipboard was not a relevant factor in this study, but diving experience was. More experienced divers have demonstrated greater ease in identifying organisms and can provide more accurate information about the study site (Ward-Paige and Lotze 2011). As a recommendation for the use of citizen science, it is necessary to use divers with greater diving experience.

The absence of a record of *C. scalpelliformis* is related to the environments in which it is found, as well as to the depth of the dives. In addition, doubts and difficulties are common among voluntary divers, especially when identifying organisms considered cryptic or very small, as is the case of *S. plicata* and *O. mirabilis*, respectively (Nerbonne and Vondracek 2003, Cox et al. 2012).

The difficulty in recognizing certain species increases the error at the time of identification. In this case, the creation of protocols can be a way to decrease this error rate, or the use of underwater photography for future screening in the laboratory may be an option. However, accuracy in taxonomic identification requires years of specialized training, this can be a major barrier to the quality of data acquired by volunteer researchers (Crall et al. 2011).

The results of the present study point to the high susceptibility to bioinvasion in IGB and corroborate results of previous studies (Ignacio et al. 2010; Castro et al. 2016), highlighting the urgent need to implement monitoring programs and greater control of vessel traffic. In addition, the high index of records obtained for *Tubastraea* spp. indicates that this genus is a bioinvader that requires greater attention on the part of the responsible bodies in the IGB region, mainly for its highly competitive capacity.

CONCLUSION

For less experienced divers (beginner and intermediate), the use of the identification clipboard in the field proved to be ineffective when compared to more experienced divers (advanced and experient). More experienced divers showed greater ease in identifying organisms. As a recommendation for the management in the use of citizen science it is necessary to use divers with greater diving experience.

The methodology applied in this study made it possible to collect a considerable amount of data in a short period of time and at a low cost. Developing stricter protocols for the identification of invasive exotic marine species is essential for the collection of quality data. The improvement of monitoring programs based on citizen science can provide useful information for research on biodiversity in marine environments, significantly reducing financial costs and time in the field, in addition to contributing to the ecological knowledge, awareness and environmental education of participants.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTION STATEMENT

Conceived of the presented idea: T.S.M., A.S.
Carried out the experiment: T.S.M.
Carried out the data analysis: T.S.M., C.Z., W.D.R.
Wrote the first draft of the manuscript: T.S.M.
Review and final write of the manuscript: T.S.M., C.Z., W.D.R.
Supervision: A.S.

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Additional Files

Add File 1. Description of the invasive exotic marine species that were used in the study in Ilha Grande Bay.

Phylum	Chlorophyta	Arthropod	Mollusca	Mollusca	Echinodermata	Chordata	Cnidaria
Species	***Caulerpa scalpelliformis***	***Charybdis hellerii***	***Isognomon bicolor***	***Myoforceps aristatus***	***Ophiothela mirabilis***	***Styela plicata***	***Tubastraea* spp.**
Place of origin	Indo-Pacific Ocean.	Indo-Pacific Ocean.	Caribbean Region.	Caribbean Region.	Pacific Ocean.	Unknown origin but may have arisen in the northern region of the Hemisphere.	Indo-Pacific Ocean.
First record in Brazil.	In 1965, in the tropical region of the Brazilian coast.	In 1995, in Guanabara Bay, state of Rio de Janeiro.	In 2002, in the region of São Sebastião, state of São Paulo, the entire southeast region and part of the southern region.	In 2006, in the states of Rio de Janeiro and São Paulo.	In 2000, on Ilha do Pai, state of Rio de Janeiro.	In 1883, in the state of Rio de Janeiro.	In 2004 in Ilha Grande Bay, Rio de Janeiro state.
Vectors responsible for introduction	Navigation (embedded on ship hulls and floating objects) and fishkeeping.	Navigation (ballast water) and marine currents.	Navigation (embedded on oil and ballast water platforms) and marine currents.	Navigation (embedded on ship hulls and ballast water) and aquaculture.	Navigation (embedded on ship hulls and ballast water).	Navigation (embedded on ship hulls), aquaculture and marine currents.	Navigation (embedded on oil platforms and ship hulls).
Geographic distribution in Brazil	States from Piauí to Rio de Janeiro.	States of Maranhão, Ceará, Rio Grande do Norte, Pernambuco, Alagoas, Bahia, Espírito Santo, Rio de Janeiro, São Paulo and Paraná.	States of Rio Grande do Norte, Pernambuco, Bahia, Rio de Janeiro, São Paulo, Santa Catarina and Rio Grande do Sul.	States of Ceará, Bahia, Rio de Janeiro, São Paulo and Santa Catarina.	States of Pernambuco, Bahia, Espírito Santo, Rio de Janeiro, São Paulo, Paraná and Santa Catarina.	States of Pernambuco, Bahia, Rio de Janeiro, São Paulo, Paraná and Santa Catarina.	States of Ceará, Sergipe, Bahia, Espírito Santo, Rio de Janeiro, São Paulo and Santa Catarina.
References	JOLY et. al., 1965; MITCHELL et. al.,1990; NUNES, 1998; FALCÃO; SZÉCHY, 2005; VASCONCELOS; SCHUBART; SZÉCHY,2011.	TAVARES; MENDONGA JR, 1996; MANTELATTO; DIAS, 1999; MANTELATTO; GARCIA, 2001, FERREIRA et. al., 2001; BEZERRA; ALMEIDA, 2005; FRIGOTTO; SERAFIM-JUNIOR, 2007; SILVA; BARROS, 2011; MUSIELLO-FERNANDES; VILAR; ROSA, 2011; SANT'ANNA et. al., 2012; PEREIRA, 2016.	DOMANESCHI; MARTINS, 2002; OLIVEIRA; CREED, 2008; HENRIQUES; CASARINI, 2009; BREVES-RAMOS et. al., 2010; ZAMPROGNO; FERNANDES; FERNANDES, 2010.	SIMONE; GONÇALVES, 2006; AGUDO-PADRÓN, 2011; CAVALLARI; GONÇALVES; AMARAL, 2012; BREVES-RAMOS et. al.,2016.	HENDLER et. al.,2012; MANTELATTO et. al.,2016; RIBEIRO; GAMA; PEREIRA, 2017.	MILLAR, 1958; MAYER-PINTO; JUNQUEIRA, 2003; LAMBERT, 2005; ROCHA; COSTA, 2005; ROCHA; KREMER, 2005; FARRAPEIRA et. al., 2007; BARROS; ROCHA; PIE, 2009; ROCHA et. al., 2009; MARINS et. al.,2010; ROCHA; DIAS; LOTUFO, 2011; BOUZON; BRANDINI; ROCHA, 2012; SKINNER et al., 2016a	CASTRO; PIRES, 2001; PAULA; CREED, 2004, 2005; MANTELATTO et. al, 2011; SILVA et. al., 2011; SAMPAIO et. al., 2012; COSTA et. al., 2014; MIRANDA et. al., 2016; SOARES; DAVIS; CARNEIRO, 2018; CREED et. al., 2017b; LUZ; KITAHARA, 2017.

Add File 2. Clipboard (front) used by divers to identify invasive exotic marine species in the field.

Add File 3. Clipboard (back) used by divers to identify invasive exotic marine species in the field.

Add File 4. Questionnaire distributed to divers to assess their profile and the exotic invasive species sighted.

OPERATOR NAME:
____.

DIVER PROFILE:

Sex: ( ) male; ( ) female.
Age: ( ) years.
How long have you been diving?____.
Dive frequency:
( ) times per month; ( ) times per year.
What diving course(s) have you done?
( ) basic; ( ) advanced; ( ) other courses.

ABOUT THE DIVE:

Length of dive:________________(min.)
Dive Location (name of dive site):____.
How deep was the dive:____________________(meters).

Type of bottom (mark on the straight line how the bottom was at the dive site):

sand rock

What species were seen?

Sun coral (orange):
( ) not seen; ( ) seen.
Sun coral (yellow):
( ) not seen; ( ) seen.
Yellow ophiuroid:
( ) not seen; ( ) seen.
Pleated sea squirt:
( ) not seen; ( ) seen.
Invasive oyster:
( ) not seen; ( ) seen.
Scissor date mussel:
( ) not seen; ( ) seen.
Spiny hands crab:
( ) not seen; ( ) seen.
Invasive alga:
( ) not seen; ( ) seen.

Have you already dived in this area?
( ) yes: ( ) no.
When? (month /year)

If yes: Have you already seen any of these species here before?
( ) yes; ( ) no; ( ) I don't remember.

Do you know what an invasive exotic marine species is?
( ) yes; ( ) no.
What is it?____.

Add File 5. Questionnaire used by the dive operator with information about the dive and its location.

QUESTIONNAIRE FOR THE DIVER OPERATOR

Operator name:____.
Person responsible for the operation:____.
Number of people per trip:____.
Date of dive trip:____.

INFORMATION ABOUT THE DIVES (please fill out a site for each dive location of the same day):

SITE 1:

Name of dive site:____.
Latitude and longitude:____.
Dive time:____.

SITE 2:

Name of dive site:____.
Latitude and longitude:____.
Dive time:____.

SITE 3:

Name of dive site:____.
Latitude and longitude:____.
Dive time:____.

SITE 4:

Name of dive site:____.
Latitude and longitude:____.
Dive time:____.

SITE 5:

Name of dive site:____.
Latitude and longitude:____.
Dive time:____.