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Using a citizen science program to monitor coral reef biodiversity through space and time

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Abstract Coral reefs are the most biodiverse ecosystems of the ocean and they provide notable ecosystem services. Large-scale monitoring is necessary to understand the effects of anthropogenic threats and environmental change on coral reef habitats and citizen science programs can support this effort. Seventy-two marine taxa found in the Red Sea were surveyed by non-specialist volunteers during their regular recreational dives, using SCUBA Tourism for the Environment (STE) questionnaires. Over a period of 4-years, 7,125 divers completed 17,905 questionnaires (14,487 diving hours). Validation trials were carried out to assess the data reliability (Cronbach's alpha >50 % in 83.6 % of validation trials), showing that non-specialists performed similarly to conservation volunteer divers on accurate transect. The resulting sightings-based index showed that the biodiversity status did not change significantly within the project time scale, but revealed spatial trends across areas subjected to different protection strategies. Higher biodiversity values were found in Sharm el-Sheikh, within protected Ras Mohammed National Park and Tiran Island, than in the less-regulated Hurghada area. Citizen science programs like STEproject represent novel, reliable, cost-effective models for biodiversity monitoring, which can be sustained and embedded within long-term monitoring programmes, and extended to include a wider geographical scale, while increasing the environmental education of the public.

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Introduction

Although coral reefs only spatially represent 0.2 % of the marine environment, they are the most biodiverse ecosystems of the ocean and are estimated to harbour around one third of all described marine species (Reaka-Kudla 1997; 2001). Moreover, coral reefs have a key role for human activities. Coral reefs provide critically important goods and services to over 500 million people worldwide (Hoegh-Guldberg et al. 2009), such as: (1) recreational opportunities, thus supporting the industry of tourism which is the main economic source for many third-world countries; (2) coastal protection and habitat/nursery functions for commercial and recreational fisheries; and (3) welfare associated with the diverse natural ecosystems.

Despite the provision of multiple valuable services, coral reefs are facing a number of direct anthropogenic threats (Cesar 2000). Environmental change is threatening the survivorship of coral reefs on a global scale. The consequences of coral reef degradation would not be limited to the loss of the goods and services they provide, but would also result in the extinction of a major component of the Earth's total biodiversity.

Broad conservation efforts and large-scale monitoring are needed for effective management to prevent biodiversity loss and the impacts of climate change, yet governmental agencies are often under-funded (Sharpe and Conrad 2006). In some cases, citizen science can overcome economic constraints on data collection, by using the skills of non-specialist volunteer researchers, collecting reliable data and, in addition, increasing the environmental awareness and public education (Goffredo et al. 2004, 2010; Schmeller et al. 2008; Dickinson et al. 2010; Conrad and Hilchey 2011).

The last two decades have seen a rapid increase in recreational diving activity that prompted researchers to involve recreational divers as volunteers, making use of their interest in marine diversity (Evans et al. 2000; Goffredo et al. 2004, 2010; Huveneers et al. 2009; Biggs and Olden 2011). Many works (e.g., Fish Survey Project, Pattengill-Semmens and Semmens 2003; or Reef Check, Hodgson 1999) use formal methods of data collection, requiring intensive training and asking volunteers to perform surveys on specific sites according to strict protocols may ensure uniform data collection. This method can reduce project appeal, thus reducing the number of volunteers (Marshall et al. 2012), and also it can affect the data accuracy (Dickinson et al. 2012).

The project "SCUBA Tourism for the Environment" (STE) replicated the standardized methodology used in Goffredo et al. (2004, 2010; Recreational Citizen Science) to collect data on the status of the Red Sea coral reef biodiversity. Our study used a survey protocol based on casual diver observations. This method allowed divers to carry out normal recreational activities during their reef visits and ensured the reliability of collected data through standardized data collection.

The present work aimed to:

(1) verify the implementation of the method used in Goffredo et al. (2010) in a coral reef habitat, evaluating the quality of the data collected by volunteers;
(2) analyse the health status of coral reefs in the Northern Red Sea, with particular attention to Egyptian coastlines, to contribute to local environmental management.

The Egyptian Ministry of Tourism was a partner in the project and it annually requested a report on the data analysis, looking for feedback on the effectiveness of the conservation management plans.

Materials and methods

Survey questionnaires

Questionnaires distributed to volunteer recreational divers over a 4-year period were used to gather key information on coral reef ecosystem health. Each questionnaire contained an initial section providing guidance for limiting anthropogenic impacts on the reef and throughout the vacation period, a second section with photographs to be used in species identification, and a third section for recording data obtained by the volunteers on animal taxa, negative environmental conditions, and recreational divers' behaviour (Online Resource 2).

A total of seventy-two animal taxa were included on the survey questionnaire, which enabled assessment of environmental quality based on biodiversity (i.e., a single species by itself was not considered as an environmental quality indicator; Grime 1997; Therriault and Kolasa 2000; Goffredo et al. 2010). The detailed species list was likely to increase the number of recreational divers involved, as volunteer interest is known to increase when familiar species are included (Goffredo et al. 2010). All of the different ecosystem trophic levels, from primary producers to predators, were represented among the 72 chosen taxa. Furthermore, each taxon was easily recognizable by volunteer recreational divers and expected to be common and abundant throughout the Red Sea (after Goffredo et al. 2010), thereby increasing accuracy of surveys by volunteers. The relevance of each taxon in revealing variations in diversity among sites was quantified using the "global BEST test" (Bio-Env + STepwise; PRIMER-E version 6 software, PRIMER-E, Ltd., Ivybridge, UK; Clarke et al. 2008), to determine the minimum subset of taxa which would generate the same multivariate sample pattern as the full assemblage (Goffredo et al. 2010). These characteristics assured that: (1) the method was suitable for amateurs and tasks were realistically achievable (Pearson 1994; Goffredo et al. 2004, 2010; Bell 2007); (2) the variation in biodiversity composition detected among sites was not solely attributable to natural variation (Pearson 1994; Goffredo et al. 2004); (3) the estimated level of biodiversity was related to local conditions.

The surveyor was asked to provide general information about himself (name, address, e-mail and diving licence—level and agency) technical information about the dive (place, date, time, depth, dive time), type of habitat explored (coral reef, sandy bottom, or other habitat) and estimated abundance for each sighted taxon. Using databases (http://www.gbif.org; http://www.marinespecies.org), literature (Wielgus et al. 2004) and personal observation, abundance for each taxon was categorized as "rare", "frequent" or "abundant" based on the expected natural occurrence during a typical dive. For example, 1–5 groupers (Epinephelinae, *Perciformes*) were classed as rare, 6–10 as frequent, and more than 15 as abundant. The presence of dead, bleached, broken, and sediment covered corals and the presence of litter were considered negative environmental conditions. The number of divers present on the dive site and the number of contacts with the reef were recorded as diver behaviour features. Participation in the project was open to snorkelers and all SCUBA diving levels, from open water diver (at least 4–6 recorded dives) to instructor (at least 100 recorded dives). Diving certification level was ranked based on the international standards (World Recreational Scuba Training Council; WRSTC or World Confederation of Underwater Activities; CMAS): open water diver (level 1), advanced diver (level 2), rescue diver (level 3), divemaster (level 4), and instructor (level 5).

During the study periods from 2007 to 2010, recreational volunteer divers and snorkelers completed questionnaires immediately following a dive, with each recreational diver recording one questionnaire per dive (i.e., number of recorded questionnaires = number of performed dives). Completion of questionnaires shortly after the dive with the assistance of trained professional divers assures the quality control of collected data (Goffredo et al. 2004, 2010). Volunteer divers were not assigned survey sites and times, rather they performed survey dives when and where they preferred, resulting in an unassigned sample design. Also the recreational dive profile (dive depth, time, path, and safe diving practices) was not modified for surveys: divers performed each dive as they normally would during recreational diving (after Goffredo et al. 2004, 2010). The area of reef surveyed by divers at each site typically amounts to 10.000 m^2 (Medio et al. 1997).

The surveyed area consisted of Egypt, including the Sinai Peninsula and the African coasts to the border with Sudan, and a small portion of Saudi Arabia, including Yanbu al Bahr and Rabigh coasts (Fig. 1).

Training activities

Divemasters and SCUBA instructors who worked with volunteers in the field, all attended the same training courses on project goals and methods. The research team held training courses for professional divers before the beginning of the project (five 2-hours courses were organized in diving centers in the Sharm el Sheik area from July to November 2006) and during hobby fairs every year (2 or 3 courses in February during Eu.Di.—European Dive Show). The research team trained professional divers on the project objectives and methods, including taxa identification and data recording (the training program comprised lectures, video, slideshows, and field identification). Topics such as biodiversity and its application in assessing environmental change caused by natural and anthropogenic pressures were covered. The training courses were efficient because they reached a large number of diving professionals, who in turn involved recreational divers (an example of this cascade effect were the annual SSI or PADI scuba instructor conference meetings, during which a 2-hour training seminar was held by one scientist and attended by more than one thousand professional divers).

On field, divemasters and SCUBA instructors briefed the divers, providing information about the habitat features, the species that may be encountered, and tips on how to minimize the impact of diving activities on coral reefs. They then assisted the volunteers during data collection and were available for consultation in case of difficulties with species identification, but without suggesting to the volunteers what sightings had to be recorded. A single trained dive master or SCUBA instructor subsequently involved several snorkelers and divers, thus generating a cascade effect that was able to involve several thousands of volunteers.

Volunteer-marine biodiversity index (V.MBI)

Incomplete or illegible questionnaires were discarded, as were those that showed a misunderstanding of the methods (for example, multiple dives recorded on the same questionnaire), amounting to 9.8 % of submitted questionnaires.

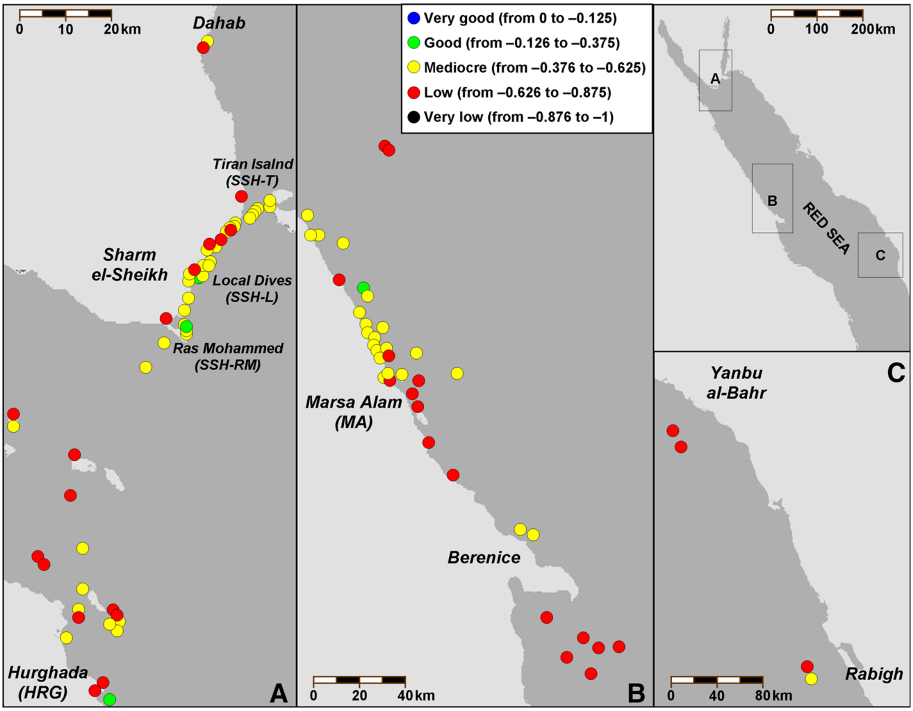

Fig. 1 Volunteer-Marine biodiversity index (V.MBI). The figure shows the marine biodiversity in index in the 100 stations surveyed calculated from the data collected by volunteers in the 4 years of research (2007–2010). In *parenthesis* are the abbreviations of five areas that presented a sufficient number of stations to allow a spatial analysis of the biodiversity index. The detailed maps of the single areas are available on the Online Resource 7

Data were aggregated according to the habitat explored: coral reef, sandy bottom or other. The V.MBI was calculated only for coral reef sites, because this environment was recorded in the vast majority of survey questionnaires, enabling spatiotemporal comparison of results. The questionnaires from coral reef habitats were then aggregated by dive site. The term "survey station" defined a dive site that produced at least 10 valid questionnaires in 1 year of the project, which were defined as "useful questionnaires" and were statistically analysed (Goffredo et al. 2010).

Following the protocol used in Goffredo et al. (2010) several parameters was be calculated for each survey station and a biodiversity index was developed. The parameters for each station and those calculated for a virtual "reference station", were compared to evaluate the biodiversity level at each survey station (see the exact procedure in Online Resource 1). The index was reduced to five classes: very good, good, mediocre, low, and very low.

Validation trials

As in Goffredo et al. (2010), records from volunteers were compared to independent records from a marine biologist (800 h of marine surveying experience), hereafter referred to as the "control diver". Following the protocols of Mumby et al. (1995), Darwall and Dulvy (1996) and Goffredo et al. (2010) for comparing volunteers to the control diver, we have maintained the following characteristics:

(1) The volunteer group was composed of at least three divers;
(2) The control diver dived simultaneously with trained volunteers without interacting with them;
(3) Validation dive sites were not selected in advance by the control diver; the control diver dived where the diving center officer planned the dive for that day, accordingly to safety conditions (weather, currents, divers experience);
(4) At the end of the dive the control diver completed the questionnaire independently and apart from the volunteers without any interference with their data recording;
(6) For each trial an inventory of taxa (with abundance rating) was generated by the control diver, and compared with the inventory generated by each volunteer surveyor to assess accuracy.

Correlation analyses between the records of the control diver and the records of the volunteers were performed to assess agreement between the independent records (Darwall and Dulvy 1996; Evans et al. 2000; Goffredo et al. 2010). A variety of nonparametric statistical tests were used to analyse the survey data:

(1) Spearman's rank correlation coefficient (ρ_s) was calculated, for accuracy and consistency parameters. Other terms were used to describe sources of inaccuracy, error and variation in survey data (Table 1).
(2) Cronbach's alpha (α) correlation was used to analyse the reliability of survey data (Hughey et al. 2004; Goffredo et al. 2010). The α coefficient ranges between 0 and 1 and was expressed as a percentage in the text. Values above 0.5 are considered acceptable as evidence of a relationship (Nunnally 1967; Hair et al. 1995; Goffredo et al. 2010). An α value above 0.6 is considered an effective reliability level (Flynn et al. 1994; Goffredo et al. 2010), while values above 0.7 are more definitive (Peterson 1994; Goffredo et al. 2010). The α coefficient was calculated for each volunteer taxa inventory against the control diver inventory.
(3) Czekanowski's proportional similarity index SI was used to obtain a measure of similarity between each volunteer and the control diver ratings (as for Sale and Douglas 1981; Darwall and Dulvy 1996 and Goffredo et al. 2010). The index ranges from 0 when two censuses have no taxa in common to 1 when the distribution of abundance ratings across species is identical. Values above 0.5 are considered as an indication of sufficient levels of precision, while values above 0.75 are considered as high levels of precision (Darwall and Dulvy 1996; Goffredo et al. 2010).

The results of each parameter were displayed in terms of mean value and 95 % confidence limit. To develop eligibility criteria for future surveys, independent variables (diving certification level and group size of participants) were identified and their effect on the precision of volunteers was examined. The possible influence of dive time and depth on volunteer precision was also assessed. For all of these analyses the Spearman's rank correlation was tested.

Statistical analyses were conducted using SPSS 12.0 for Windows (SPSS, Chicago, Illinois, USA).

Dissemination activities

Project news have been periodically published and communicated to the public in order to disseminate information and give updates to participating volunteers about the study progress (Goffredo et al. 2004, 2010; Novacek 2008).

Table 1 Definition and derivation of terms used to describe the components of accuracy and consistency of volunteer data

Parameter	Definition and derivation of parameter
Accuracy	Similarity of volunteer-generated data to reference values from a control diver measured as rank correlation coefficient and expressed as a percentage in the text. This measure of accuracy is assumed to encompass all component sources of error
Consistency	Similarity of data collected by separate volunteers during the same dive. This was measured as rank correlation coefficient and expressed as percentage in the text. This measure of consistency is assumed to encompass all component source of error
Percent identified	The percentage of the total number of taxa present that were recorded by the volunteer diver. The total number of taxa present was derived from the control diver data (i.e., we assumed the taxa recorded by the control diver to be all the taxa present)
Correct identification	The percentage of volunteers that correctly identified individual taxa when the taxon was present
Correctness of abundance ratings (CAR)	This analysis quantified the correctness in abundance ratings made by the volunteer. It has been expressed as the percentage of the 62 surveyed taxa whose abundance has been correctly ratedby the volunteer (i.e., the value of the rating indicated by the volunteer was equal to the reference value recorded by the control diver)

Major international and Italian local media were contacted to raise awareness and involve a wide number of volunteers. Press releases were sent to various editorial desks, the information was sent by e-mail, and then journalists were contacted by telephone, explaining the main issues, goals and methods of the research. Specific agreements were defined with the magazine Tuttoturismo and the airline Neos, which provided information on project in their journal or on-board magazine. A real-time update to volunteers was provided by website (www.STEproject.org) and by page on the social network Facebook. Participation in fairs was also a crucial dissemination activity. Every year a project booth was set at BIT (International Tourism Exchange) and Eu.Di. Show (European Dive Show). These activities promoted contact with a large number of people interested in the research. During these events many diving schools and individual tourists were involved, who then actively participated in the monitoring project by completing many questionnaires each year and regularly asking for updates about the research progress. In order to actively contribute to Red Sea coral reef conservation, partial results on the biodiversity state of coral reefs in the Egyptian Red Sea were presented to the Director of the Tourism Agency and to the Egyptian Minister of Tourism during BIT, suggesting possible future actions of conservation.

Results

Validation trials

Sixty-one validation trials were performed (Online Resource 3). A total of 383 different volunteers were tested (about 5 % of all the volunteers that participated in the monitoring program), with a mean of 6 volunteers per validation team (95 % CI 5–7). The mean diving certification level of volunteers was 2.9 (95 % CI 2.7–3.1; Online Resource 3).

The mean accuracy of each team ranged from 40.4 to 77.9 %, with the majority of teams (43; 70.5 %) with mean accuracy between 45 and 60 % (52.9 % on average; Online Resource 3). Intra-group variation was approximately 45 % (coefficient of variation, CV) per team. Accuracy was not correlated with volunteer diving certification level ($\rho_s = 0.110$, N = 61, $P = 0.398$), number of participants in the trial group ($\rho_s = 0.067$, N = 61, $P = 0.611$), depth of the trial ($\rho_s = 0.092$, N = 61, $P = 0.483$), dive time of the trial ($\rho_s = 0.032$, N = 61, $P = 0.805$), or time from the beginning of the trials ($\rho_s = -0.069$, N = 61, $P = 0.599$). Accuracy was higher in the Marsa Alam area (MA) compared to the Tiran Island area (SSH-T; ANOVA; F = 2.808, *df* = 4, $P = 0.025$; Tuckey Post-hoc; $P = 0.34$) and on horizontal bottom dives compared to vertical wall dives (F = 9.276, *df* = 1, $P = 0.002$).

The mean consistency of each team ranged from 33.5 to 77.2 %, with the majority of teams (41; 67.2 %) having a mean consistency between 40 and 55 % (47.6 % on average; Online Resource 3). Intra-group variation was approximately 24 % (CV) per team. Consistency was not correlated with volunteer diving certification level ($\rho_s = 0.014$, N = 61, $P = 0.915$), number of participants in the trial group ($\rho_s = -0.050$, N = 61, $P = 0.701$), depth of the trial ($\rho_s = -0.099$, N = 61, $P = 0.446$), dive time of the trial ($\rho_s = -0.008$, N = 61, $P = 0.950$, or time from the beginning of the trials ($\rho_s = -0.148$, N = 61, $P = 0.254$). Consistency was higher in the MA compared to the SSH-T (ANOVA; F = 5.531, *df* = 4, $P < 0.001$; Tuckey Post-hoc; $P = 0.04$) and on horizontal bottom dives compared to vertical wall dives (F = 14.839, $P < 0.001$).

Most survey teams correctly identified approximately 65 % of the taxa present in the survey trials (68.9 % of teams correctly identify a mean percentage of taxa between 55 and 80 %; Online Resource 3). Intra-group variation was approximately 24 % (CV) per team. The percent identified was not correlated with the diving certification level of the team members ($\rho_s = 0.091$, N = 61, $P = 0.487$), the group size of participants ($\rho_s = 0.072$, N = 61, $P = 0.580$), depth ($\rho_s = 0.056$, N = 61, $P = 0.668$) or dive time of the trial ($\rho_s = 0.058$, N = 61, $P = 0.656$). Percent identified was higher on horizontal bottom dives compared to vertical wall dives (F = 5.573, *df* = 1, $P = 0.019$).

A positive correlation between the number of validation trials in which the taxon was present and the level of correct identification by volunteers was detected (Online Resource 4; $\rho_s = 0.711$, N = 71, $P < 0.001$; correct identification (%) = 0.600 × [presence frequency] − 1.222). Eight taxa were not present (i.e., were not recorded by the control diver) in any of the 61 validation trials, thus the assessment of their correct identification was not possible.

Most survey teams correctly rated the abundance of approximately 58.6 % of the surveyed taxa (72.1 % of the teams produced a mean correctness of abundance ratings, CAR, between 50 and 65 %; Online Resource 3). Intra-group variation was approximately 10 % (CV) per team. The CAR was not correlated with the diving certification level of the team members ($\rho_s = -0.015$, N = 61, $P = 0.907$), the number of participants in the team ($\rho_s = -0.021$, N = 61, $P = 0.872$), depth ($\rho_s = \_0.085$, N = 61, $P = 0.515$) or dive time of the trial ($\rho_s = 0.022$, N = 61, $P = 0.865$), but it showed a negative trend from the first to the last years of the trials ($\rho_s = -0.313$, N = 61, $P = 0.014$) The regression analyses, (CAR (%) = 0.005 × [time (in years)] + 64.647), indicated a decrease of 0.005 points per year. CAR was higher in the MA compared to the SSH-T and to Ras Mohammed area (ANOVA; F = 5.473, *df* = 4, $P < 0.001$, Tuckey Post-hoc; $P = 0.034$ and $P = 0.002$, respectively) and in Local reefs area compared to Ras Mohammed area (Tuckey Post-hoc; $P = 0.008$), and on horizontal bottom dives compared to vertical wall dives (F = 19.804, *df* = 1, $P < 0.001$).

According to the α correlation test (Online Resource 3), 8 teams (13.1 %) scored acceptable relationships with the control diver census (α, 50 < 95 % CI lower bound ≤ 60 %), 36 teams (59.0 %) scored an effective reliability level (α, 60 < 95 % CI lower bound ≤ 70 %), and 17 teams (27.9 %) performed from definitive to very high levels of reliability (α, 95 % CI lower bound >70 %). Intra-group variation was approximately 13.6 % (CV) per team. The reliability was not correlated with diving certification level ($\rho_s = 0.095$, N = 61, $P = 0.465$), group size of participants ($\rho_s = 0.142$, N = 61, $P = 0.274$), depth ($\rho_s = 0.164$, N = 61, $P = 0.205$), dive time of the trial ($\rho_s = 0.074$, N = 61, $P = 0.572$), or time from the beginnings of the trials ($\rho_s = -0.090$, N = 61, $P = 0.490$). Reliability was higher in the MA compared to the SSH-T (ANOVA; F = 3.393, *df* = 4, $P = 0.010$; Tuckey Post-hoc; $P = 0.007$) and on horizontal bottom dives compared to vertical wall dives (F = 8.798, *df* = 1, $P = 0.003$).

According to the Czekanowski's proportional similarity index, SI (Online Resource 3), 7 teams (11.5 %) performed with levels of precision below the sufficiency threshold (SI, 95 % CI lower bound ≤ 50 %); 53 teams (86.9 %) scored a sufficient level of precision (SI, 50 < 95 % CI lower bound ≤ 75 %), and one team (1.6 %) scored high levels of precision (SI, 95 % CI lower bound >75 %). Intra-group variation was approximately 16.7 % (CV) per team. The similarity index was not correlated with diving certification level ($\rho_s = 0.155$, N = 61, $P = 0.232$), number of participants in the trial group ($\rho_s = 0.100$, N = 61, $P = 0.443$), depth ($\rho_s = 0.101$, N = 61, $P = 0.439$), dive time of the trial ($\rho_S = 0.039$, N = 61, $P = 0.764$), or time from the beginnings of the trials ($\rho_s = -0.033$, N = 61, $P = 0.801$). SI was higher in the MA compared to the SSH-T (ANOVA; F = 3.746, df = 4, $P = 0.005$; Tuckey Post-hoc; $P = 0.008$) and on horizontal bottom dives compared to vertical wall dives (F = 5.040, *df* = 1, $P = 0.025$).

Marine biodiversity monitoring

Over 4 years, a total of 7,125 volunteer recreational divers participated to the monitoring program (Table 2). A total of 6827 volunteers participated for only 1 year, 236 for two, 45 for three and 17 participated for all 4 years. Volunteers spent a total of 14,487 h underwater and completed 17,905 valid survey questionnaires, with a mean dive time per questionnaire of 48.6 min (95 % CI 48.5–48.7; Table 2). The majority of questionnaires (88.2 %) came from coral reef habitats (Table 2), the majority of which were useful (92.5–96.9 % per year). The few recorded questionnaires from others habitats did not allow spatiotemporal analyses of results.

The geographic distribution of reef habitat surveys was homogenous among the 4 years (α = 0.885, SE = 0.022; $\rho_s = 9.951$, SE = 0.019). Most surveys were made in the Sharm el-Sheikh area, accounting for 63.6 % of the total number of valid recorded questionnaires for reef habitats. The total number of survey stations for reef habitats was 100 (57 were surveyed for 1 year, 17 for 2 years, 7 for 3 years, 19 for 4 years; see Online Resource 5). Mean depth ($\rho_s = 0.958$, SE = 0.013) and mean time (date: $\rho_s = 0.882$, SE = 0.028; and hour: $\rho_s = 0.912$, SE = 0.032) of the survey were homogenous among years.

The V.MBI calculated for the 100 stations did not change significantly over the project time scale, but it showed spatial variations. In particular, five areas presented a sufficient number of stations to allow a spatial analysis of biodiversity index: Marsa Alam (MA), Hurghada (HRG) and the three principal areas in Sharm el-Sheikh, Ras Mohamed peninsula (SSH-RM), Tiran Island (SSH-T) and the Local reefs (SSH-L; Fig. 1 and see Online Resources 6 and 7). These areas were significantly different (ANOVA; $F = 4.638$, $df = 4$, $P = 0.002$). A pairwise analysis of variance between the individual areas showed that

Table 2 Distribution of survey effort performed by volunteer recreational divers; only coral reef useful questionnaires were elaborated

Year	Volunteer divers	Total recorded questionnaires	Coral reef questionnaires		Sandy bottom questionnaires		Wreck questionnaires		Blue questionnaires	
			Recorded	Useful[a]	Recorded	Useful[a]	Recorded	Useful[a]	Recorded	Useful[a]
2007	1,154	3,248	2,975	91.6	129	4.0	113	3.5	31	1.0
2008	1,760	4,870	4,656	95.6	109	2.2	83	1.7	22	0.5
2009	1,926	4,120	3,031	73.6	928	22.5	120	2.9	41	1.0
2010	2,598	5,667	5,133	90.6	358	6.3	123	2.2	53	0.9
Total	7,125	17,905	1,5795	88.2	1524	8.5	439	2.5	147	0.8

[a] Expressed in percentage

HRG was different from SSH-RM (Tukey Post-hoc; $P = 0.039$) and from SSH-T (Tukey Post-hoc; $P = 0.007$; see Online Resource 7).

Of the 72 organismal taxa surveyed, 38.9 % (28 taxa) were classified as not common, with a sighting frequency (%SF, calculated on the total number of surveys over the four years) $\leq$ 20 %, 52.8 % (38 taxa) were common (20 % < %SF < 70 %), and only 8.3 % (6 taxa) were very common (%SF $\geq$ 70 %; detailed data about each taxon are available on Online Resource 5; taxa ranking according to sighting frequency is after Darwall and Dulvy 1996; Therriault and Kolasa 2000).

Most of the organismal taxa (66, 91.7 %) had homogeneous sighting frequencies among years ($\alpha = 0.927$, SE = 0.003; $\rho_s = 0.817$, SE = 0.007). Only six taxa (5.0 %) had significant sighting frequency differences among years. Only in one case, the fire coral (*Millepora sp.*), the sighting frequency had a positive trend in time (Jonckheere-Terpstra test; $P = 0.005$; Fig. 2). The homogeneity of fire coral sighting frequency among years was tested in the five areas described above to better understand the trend. The fire coral sighting frequency showed a positive trend only in the Ras Mohammed peninsula (Sharm el-Sheikh—Jonckheere-Terpstra test; $P = 0.016$). The other five taxa, the Spanish dancer (*Hexabranchus sanguineus*), Hermit crabs (Diogenidae), sharks (Squaliformes), other corals (Coelenterates) and other starfishes (Asteroides) showed wide variations among years without a defined trend (Jonckheere-Terpstra test; $P = 0.063$–0.671). Sighting frequency of main parameters and V.MBI were homogeneous among years ($\alpha = 0.837$, SE = 0.023; $\rho_s = 0.698$, SE = 0.040).

To evaluate the possibility of rationalization of the survey effort requested to volunteers divers, the “best” match between the multivariate among-samples pattern depicted in Fig. 1, which was derived from the full assemblage of variables listed in the survey questionnaire (79: 72 organismal taxa plus 5 negative conditions and 2 behaviour aspects), and that from random subsets of the variables was determined. The best explanatory variables, which generated the same multivariate sample pattern as the full list, were the subset of 22 organismal taxa listed in Online Resource 4, representing the 27.8 % of the original list of variables.

Dissemination activities

During the period 2007–2010 a total of 62,378,500 people were reached by STEproject dissemination activity. The total audience was been 48,507,500 people, as readers of newspapers and magazines and 13,871,000 as radio-listeners (see Online Resource 8). The project Facebook page counted 788 likes.

Discussion

Validation trials

The level of accuracy, reliability and similarity supported the findings of Goffredo et al. (2010). The results showed a sufficient level of the quality of the data collected by non-specialist volunteers, taking into account the high number of species surveyed and the recreational dive profile (i.e. the divers did not follow a pre-determined transect, but they dived following the normal recreational dive path for a given dive site). Moreover, the results showed that non-specialist volunteers performed similarly to conservation volunteer divers on accurate transects (e.g. we detected a median accuracy ranged from 39 to 76 %,

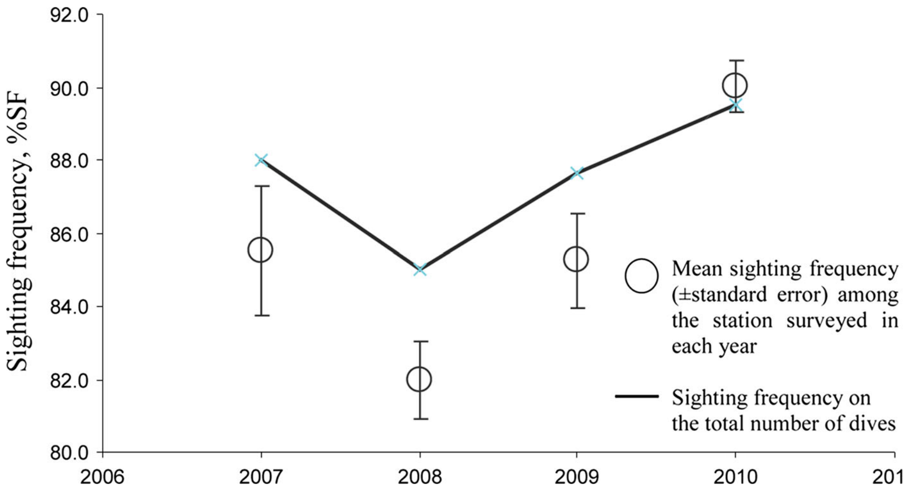

Fig. 2 Sighting frequency of fire coral (*Millepora sp*.). The sighting frequency of fire coral (%SF), which was not homogenous among years, is represented over the four year period

which was comparable with the median accuracy detected in Mumby et al. (1995), that varies from 52 to 70 %). Using a scheme in which the divers were free to behave as they normally do during recreational diving allows the involvement of a great number of volunteers, covering a wide spatial and temporal scale. Given the overall findings on the quality of data collected by the volunteers, the methodology proposed in Goffredo et al. (2010) can be successfully implemented in different geographic areas and habitats.

Levels of consistency higher than 50 % were found only in 42.6 % of the validation trials. This result indicates a lack of homogeneity between the observations of volunteers during the same dive. Different interests or activities of volunteers during the dive could explain this aspect. For example, some divers interested in macro photography may have focused their attention on the benthic environment, while others interested in megafauna (such as sharks) may have focused on the pelagic environment. Another consideration on the level of consistency comes out from the comparison between our results and those obtained by Goffredo et al. (2010), where most of the teams scored a level of consistency greater than 50 %. This result can be attributed to the different conditions of the diving sites in the Red Sea compared to those of the Mediterranean Sea. The waters of the Red Sea are clearer than in the Mediterranean, allowing divers to be farther apart from each other. Red Sea dives are usually drift dives conducted on vertical walls in the outer-reef. This feature may diversify the dive path of each diver, resulting in different areas surveyed by each volunteer.

In respect to the validation trials realized in Goffredo et al. (2010), in the present work we performed analysis of the data quality in relation to the different features of the survey areas to corroborate the possibility of implementing this method in different habitats. All parameters, except the percent identified, were significantly different among geographic areas. These findings may be attributed to the dive site topography, as supposed above. The dive sites located in Ras Mohammed and Tiran Island are mainly characterized by a drop off and the divers typically prefer diving on the external vertical walls. On the contrary, the dive sites located in Marsa Alam and in the Local reefs of Sharm el-Sheikh present horizontal bottom reefs. The comparison between validation trials performed on horizontal bottom dives with those on vertical wall indicated significant higher values for the former for all tested parameters. These differences reflect the behaviour of the recreational divers that on horizontal bottom dives are obliged to strictly follow the dive path of the dive-master while on vertical wall dives can be more dispersive. The lower values detected for the vertical wall dives still remained above the threshold that is described in the literature (Nunnally 1967; Flynn et al. 1994; Peterson 1994; Hair et al. 1995; Darwall and Dulvy 1996; Goffredo et al. 2010) as an acceptable level of precision. The findings of these trials, performed to deeply explore the robustness of the data collected by the volunteers, confirmed that the methodology used in Goffredo et al. (2010) can be successfully applied in different habitats, as the quality of the gathered information revealed a sufficient level of precision in different survey conditions.

Similarly to monitoring programs on precise transects (Bell 2007; Goffredo et al. 2010), the positive correlation between correct identification and taxa frequency in the validation trials indicated that recreational volunteers were more accurate in recording the most frequent/straightforward taxa, while they were less accurate with cryptic taxa, even if the identification of these taxa was specifically addressed in the training program.

The CAR fell by 10 percentage points from the beginning to the end of the project (Online Resource 3). Even if this reduction can be considered minimal because it does not affect the other main parameters (such as accuracy, reliability and similarity), it provides a feedback on volunteer participation and loyalty to the project. In fact, the number of questionnaires recorded per volunteer per year decreased from 2.8 to 2.2 (ANOVA, $F = 7.919$, $df = 3$, $P < 0.001$). This decline in loyalty of volunteers to the project, if exacerbated, may lower volunteer's attention affecting the precision in taxa abundance evaluation.

Volunteer participation

The number of volunteers involved per year was positively correlated with the time from the beginning of the project, probably as a consequence of the networking with local diving centers. Moreover, there was an increase in questionnaires collected in Marsa Alam area during the last 2 years (+97.7 % in 2009 and +82.2 % in 2010, relative to the previous year) due to the collaboration with Settemari Tour Operator. This tour operator hosted some researchers to recruit volunteers in its resort in Marsa Alam.

A reduction in the mean annual survey effort per individual volunteer was noted in the last 2 years (mean number questionnaires recorded/hours of diving per year per volunteer: first 2.81/2.18, second year 2.77/2.25, third year 2.14/1.80 and fourth year 2.18/1.75). This finding could be attributed to a decrease of loyalty to the project. In the future some actions should be taken to counteract this trend. Prizes could be awarded to volunteers that complete the largest number of questionnaires per year or promotional events could be organized, giving discounts on room, board and diving costs, thanks to the partnership with project partners. An alternative explanation for the negative trend observed in the survey effort could be given by the greater amount of snorkelers involved compared to divers in the last years. Snorkelers are less devoted to the underwater excursions, and are involved in many other recreational activities during the holiday.

The primary limiting factor of this method was the difficulty in obtaining data with a homogeneous spatial distribution. As expected, most questionnaires came from coral reef habitats close to the principal areas, without covering remote areas and sandy bottoms. This biased sampling effort may be explained by recreational divers' preference for coral reef habitats, which are more biodiverse and therefore more interesting to visit than sandy bottoms, and reflected the distribution of tourist facilities along the Red Sea coast. Bathymetric and temporal survey distribution reflected the typical pattern of recreational diver activity. Normally, international diving school agencies recommend 30 m as the maximum depth (WRSTC 2006) and the preferred period for diving is the warm season during the daytime (only Advanced Divers perform night dives).

Assessed biodiversity and environmental conditions

The lower V.MBI in Hurghada (HRG) than in Sharm el Sheikh (SSH-T and SSH-RM, see Online Resource 7) may be interpreted in terms of the different management of these areas. Sharm el-Sheikh area is located in Ras Mohammed National Park, established in 1983, simultaneously with the construction of the first touristic resorts (Hawkins and Roberts 1994). The Park regulations forbid commercial and sport fishery and introduced a system of mooring buoys for diving boats, to prevent damage caused by anchors. This kind of damage has proved to be one of the main causes of the coral reef deterioration (Jameson et al. 1999, 2007). A complementary explanation could be the absence of buildings in the Ras Mohammed peninsula and Tiran Island, respectively, due to park regulations and the presence of a military post on the island. Dredging and land infilling of the backshore and fringing reef areas are one of the most devastating activities to the coastal environment, and, unfortunately, these activities have always been widespread along the coastal zone of the Hurghada sector (Moufaddal 2005). Marsa Alam (MA) and Local reefs of Sharm el-Sheikh (SSH-L) didn't show significant differences compared to Ras Mohammed peninsula (SSH-RM) and Tiran Island (SSH-T), in spite of their anthropogenic use, which is similar to that of Hurghada area. In Hurghada, like in Marsa Alam and in Local reefs of Sharm el-Sheikh, several resorts were built close to the coast. Regarding Marsa Alam reefs, this situation could be explained by the fact that tourist activities in the area began only few years ago. A possible explanation for the relatively good conditions of the Local reefs could be that they are located between Ras Mohammed and Tiran Island, which may act as biodiversity reservoirs, providing a larval flow on local reefs (Neubert 2003; Botsford et al. 2009). Besides a few environmental assessments in restricted areas (e.g. Sharm el-Sheikh; Borhan et al. 2003; Hurghada and Safaga; Moufaddal 2005; Jameson et al. 2007 and Dahab; Hasler and Ott 2008) or specific sites (e.g. Sharm el-Loli and Tobia Kebir in Marsa Alam; Ammar and Mahmoud 2006), the present study represents the first large-scale and long-term environmental monitoring performed in the Red Sea. The relevant dataset collected during the 4-year period could also be useful for both public and private institutions and organizations interested in the conservation and management of the Egyptian Red Sea and create the baseline for future environmental health evaluations of the area. Thanks to our proactive collaboration with the Egyptian Ministry of Tourism, the results of the project shall be integrated in an overall perspective of the Egyptian coastlines management, as discussed in the following paragraph "*Contribution to the conservation management field*".

Since the duration of our study was relatively short (4 years), it is not surprising that sighting frequencies of most taxa were consistent over the period. Of the six exceptions, five presented wide variations throughout the years without a trend. Only the fire coral was statistically significant in Jonckheere-Terpstra test, however, this trend was only weakly explained (Fig. 2). Fire coral is a fragile branching taxa (Riegl and Cook 1995; Harriott 2002) and it is possible that yearly variations can be influenced by colony breakage due to diver carelessness. These data could, therefore, provide a starting point to begin a specific monitoring program for fire coral.

According to the BEST test of searching over subsets of variables for a combination that optimizes the survey effort, 22 out of 79 taxa (27.8 % of the original assemblage) would have been sufficient to generate the same multivariate sample pattern as the whole variables dataset. For future, the limitation of surveyed taxa to the least necessary could lower the effort during both volunteer training and field-work. However, this reduction could limit the appeal of the project to potential volunteers. Removing attractive species from the questionnaire would likely decrease volunteers' enjoyment and loyalty, as well as the educational potential of the project. Including in the survey charismatic organisms that citizen volunteers normally look for, in order to give them something to report with satisfaction, is an approach successfully experimented in ornithological studies as well as in underwater biodiversity monitoring projects (Greenwood 2007; Goffredo et al. 2010). The relevance of the BEST test, which indicated a possible reduction of survey effort, could become valuable only if a survey performed by professionals, in order to reduce survey time and consequentially survey costs.

Dissemination activities

Traditional and web-based dissemination activities first allowed the enrolment of a large number of volunteers. The wide media dissemination of the project has enabled high citizen awareness and participation. Media have also helped to maintain the loyalty of volunteers. Sharing project results may help to increase the public interest in environment and biodiversity issues (Novacek 2008). Dissemination activities were also useful for fund-raising, as media exposure offered opportunities for project sponsors to earn an eco-friendly reputation and marketing benefits.

Contribution to the conservation management field

This study reinforced the validity of the method used in Goffredo et al. (2004, 2010). This recreational monitoring method has assured a significant amount of data with an acceptable level of reliability because: (1) volunteers are trained and assisted during data collection in the field by dive guides and instructors who had previously been trained by professional researchers; (2) the method is suitable for amateurs (i.e., user-friendly questionnaire and taxa that are easily recognizable by recreational divers); (3) the tasks selected for volunteers during project planning are appropriate, since volunteer skills and abilities vary, and we only wanted volunteers to collect data for which they could be trained quickly and reliably. This project has confirmed that "recreational" (Goffredo et al. 2004, 2010) and "easy and fun" (Dickinson et al. 2012) citizen science is an efficient and effective method to recruit a large number of volunteers and can be reliable if well designed.

The present study described the status of biodiversity of the Egyptian coral reefs and its spatial variations, providing important indications to the local authorities on the current health status of the Egyptian coastlines and on the effectiveness of the environmental management. Each year the project results were presented to the Egyptian Tourism Minister and his staff, with the aim of integrating the projects finding in future environmental management actions and contribute to the development of wide conservation plans. For instance, the encouraging findings for the Sharm el-Sheikh area are an example of effective management in that area, which may serve as a model to establish new marine protected areas in other Egyptian regions.

This paper has shown a successful case study of collaboration among researchers, local authorities and the public, showing that with appropriate recruitment and training, volunteer-collected data are qualitatively equivalent to those collected by professional researchers and useful for resource management. This work has confirmed the effectiveness of citizen science projects as fundamental tools to provide robust, objective and repeatable data for large-scale and long term monitoring, which can be used to inform marine management. The method, showed in the present work, could be applied in different countries by local governments and marine managers to achieve large-scale and long-term conservation and management actions, required in a fast-changing world where climate change and anthropogenic uses of natural resources are determining fast environmental changes worldwide.

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