Conservation in Practice

Volunteers in Marine Conservation Monitoring: a Study of the Distribution of Seahorses Carried Out in Collaboration with Recreational Scuba Divers

STEFANO GOFFREDO,*‡ CORRADO PICCINETTI,† AND FRANCESCO ZACCANTI*

*Department of Evolutionary and Experimental Biology, University of Bologna, Via F. Selmi 3 I-40126, Bologna, Italy

†Laboratory of Fisheries and Marine Biology at Fano University of Bologna, Viale Adriatico 1/N I-61032, Fano (Ps), Italy

Abstract: *Seahorses (*Hippocampus*) live in tropical and temperate waters. Habitat degradation and fishery overexploitation have led to drastic population declines on a global scale. Population monitoring is therefore essential to determine current status and manage conservation. In this first study in Italian waters on the geographic and ecological distribution of the two Mediterranean species,* Hippocampus hippocampus *and* Hippocampus ramulosus*, recreational scuba divers were recruited and trained to report sightings. A specially formulated questionnaire was produced and distributed to scuba diving schools and centers. In the 3-year study, 2536 divers spent 6077 diving hours gathering data and completed 8827 questionnaires. Eight percent of the questionnaires showed seahorse sightings, for a total of 3061 sighted specimens, 68% of which referred to* Hippocampus ramulosus*. The two species had overlapping geographic distributions. Seahorse abundance varied, with the northern Adriatic Sea showing greatest abundance, followed by the central-southern Tyrrhenian Sea. Seahorses were rare in the Ligurian and northern Tyrrhenian seas. Preferred habitats were shallow areas with either sandy bottoms or* Posidonia oceanica *(L.) Delile meadows. Seahorse distribution may be correlated with the degree of degradation of* P. oceanica *meadows. Resource users (the divers) were willing to take part in biological monitoring and contributed in scientific terms by collecting considerable amounts of data over short time periods and in economic terms by decreasing costs. The greatest limitation with volunteers was the difficulty in obtaining a uniformly distributed sample across time and space. We conclude that recreational divers and other resource users can play an active part in monitoring the marine environment and that the Mediterranean* Hippocampus *Mission may be used as a model for biodiversity monitoring.*

Key Words: *Hippocampus* monitoring, Mediterranean *Hippocampus* Mission, scuba, seahorse monitoring, volunteers in research

Voluntarios en el Monitoreo de Conservación Marina: un Estudio de Distribución de Caballitos de Mar Llevado a Cabo con Buzos Scuba Recreativos

Resumen: *Los caballitos de mar (*Hippocampus*) viven en aguas tropicales y templadas. La degradación del hábitat y la sobreexplotación pesquera han conducido a declinaciones poblacionales drásticas en una escala global. Por lo tanto, el monitoreo de poblaciones es esencial para determinar el estatus actual y gestionar su conservación. En este primer estudio en aguas italianas sobre la distribución geográfica y ecológica de dos especies Mediterráneas,* Hippocampus hippocampus *e* Hippocampus ramulosus*, se reclutó y entrenó a buzos scuba recreativos para reportar avistamientos. Un cuestionario especialmente formulado fue producido y distribuido en escuelas y centros de buceo scuba. En el estudio de 3 años, 2536 buzos pasaron 6077 horas reuniendo datos y completaron 8827 cuestionarios. Ocho por ciento de los cuestionarios mostraban avistamientos de caballitos de mar, para un total de 3061 individuos avistados, de los cuales 68% se referían a* Hippocampus ramulosus*. Las dos especies tuvieron distribuciones geográficas traslapadas. La abundancia de caballitos de mar varió, el Mar Adriático norte mostró la mayor abundancia seguido por el centro-sur del Mar Tirreno. Los caballitos*

‡*email stefano.goffredo@marinesciencegroup.org*

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de mar fueron raros en en los Mares de Ligurian y norte del Tirreno. Los hábitats preferidos fueron áreas someras con fondo arenoso o con praderas de Posidonia oceanica *(L.) Delile. La distribución de caballitos de mar puede correlacionarse con el nivel de degradación de las praderas de* P. oceanica*. Usuarios del recurso (los buzos) estuvieron dispuestos a participar en el monitoreo biológico y contribuyeron en términos científicos al colectar cantidades considerables de datos en períodos de tiempo cortos y en términos económicos al reducir los costos. La mayor limitación con los voluntarios fue la dificultad para obtener una muestra distribuida uniformemente en el tiempo y espacio. Concluimos que los buzos recreativos y otros usuarios del recurso pueden jugar un papel activo en el monitoreo del ambiente marino y que la Misión* Hippocampus Mediterránea *puede ser utilzada como un modelo para el monitoreo de biodiversidad.*

Palabras Clave: Misión *Hippocampus* Mediterránea, monitoreo de caballitos de mar, monitoreo de *Hippocampus*, scuba, voluntarios en investigación

Introduction

Seahorses (*Hippocampus*, Syngnathidae, Syngnathiformes) have an evolutionary history dating back at least 40 million years. Thirty-two species are distributed throughout tropical and temperate regions (Lourie et al. 1999). Their habitats include coral reefs, mangroves and seagrass meadows. Maximum adult size varies between 10 and 300 mm according to species. It is the life-history traits of seahorses—low reproductive rate, monogamy, sedentary behavior, and fragmented distributions—that enhance the vulnerability of these creatures (Vincent 1994*a*, 1994*b*, 1995; Kvarnemo et al. 2000).

Seahorses have been featured in myths and legends since ancient times and are still used as ingredients in traditional medicines (supposedly healing respiratory problems and male impotence), especially in Southeast Asia and China (Vincent 1995, 1996). They are also fished for the aquarium and curio trades. In some areas seahorse populations have been reduced by 50% over a 5-year period (Vincent 1995, 1996; Lockyear et al. 1997). Their decline is also associated with habitat degradation caused by marine dredging, waste dumping, chemical pollution, and land reclamation (Vincent 1995). Around the mid-1990s, widespread decline of *Hippocampus* populations was brought to the attention of the international community, leading to their classification as threatened species, inclusion in the World Conservation Union Red List of Threatened Species (Vincent & Hall 1996; World Conservation Union 2002) and, in 2002, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2002). This strengthened the case for the need to monitor and sustainably manage seahorse populations.

In 1999 the Biology Department of the University of Bologna began work on a 3-year research project called Mediterranean *Hippocampus* Mission to (1) test the effectiveness of volunteers for monitoring marine environments to save time and money and (2) collect data on the distribution of the two Mediterranean seahorse species, *H. hippocampus* and *H. ramulosus* (= *H. guttulatus*). Requirements for volunteers included an interest in marine conservation consistent with the objectives of the project, a willingness to raise project awareness and be trained to suit the project's needs, and scuba qualifications.

Recreational scuba diving is an increasingly popular sport worldwide. The Recreational Scuba Training Council (RSTC 1997) estimates that there are 6 million certified European divers, 330,000 of which are in Italy. Importantly, the overwhelming majority of divers do not, as it is still widely thought, dive to hunt or collect marine organisms; instead, they observe and take photographs or videos of marine life. Most certified divers subsequently use facilities and services of accredited diving centers, which provide experienced dive guides and instructors who typically brief divers on important aspects of dives such as depth, duration, and safety and on the plant and animal life they might encounter.

Given the above, recreational scuba diving could be considered an activity with minimal impacts on the environment (Tilmant 1987). Studies have shown, however, that scuba divers can have negative impacts on marine environments through direct physical contact and stirring of sediments (Hawkins & Roberts 1992; Medio et al. 1997; Zakai & Chadwick-Furman 2002). Potential environmental impacts are therefore an important consideration in marine areas that attract significant tourism. However, scuba diving, as an important part of local economies, also provides a strong incentive for conservation efforts (Dixon et al. 1993; Medio 1996; Hawkins et al. 1999; Tratalos & Austin 2001). The importance of educating divers in environmental awareness is evident (Brylske 2002), especially to limit impacts while still supporting local economies (Medio et al. 1997; Tratalos & Austin 2001). Medio et al. (1997), for example, showed that environmental awareness programs and tools such as pre-dive briefings can positively influence divers' behavior, reducing both the rate and type of impact to coral reefs and other marine habitats.

Increasing environmental awareness goes beyond theorizing or regulatory actions and should extend to the practical involvement of the general public in conservation efforts. By participating in environmental projects, individuals have the opportunity to contribute to the environmental cause in a practical way (Newman et al. 2003; Pattengill-Semmens & Semmens 2003). Mediterranean *Hippocampus* Mission offered Italian recreational divers precisely this opportunity: participation in the first study on the geographical and ecological distribution of seahorses in the Mediterranean.

Methods

The mission began in 1999 and lasted to the end of 2001. After each dive the recreational divers reported the distribution of seahorses they saw on a specially formulated questionnaire (Fig. 1; for other marine conservation monitoring programs involving recreational divers, see Schmitt & Sullivan 1996; Pattengill-Semmens & Semmnes 2003). To maximize the number of volunteers, we contacted two of the largest educational scuba diving agencies in Italy: Scuba Schools International and Scuba Nitrox Safety International. These agencies produced the questionnaires and distributed them to diving schools and swimming pools where divers undertook instruction, diving centers, and dive shops. The educational scuba diving agencies, in collaboration with the university, also organized thematic workshops for instructors, divemasters, and private divers to train them in the required research methods so they could instruct other volunteers at the dive sites. The workshops, called *Hippocampus* Day, took place over weekends at various tourist localities and at the annual European Eu.Di. scuba diving show in Italy and included general ecological awareness and environmental education as well as conservation of marine biodiversity. These workshops were a time- and cost-effective method for volunteer training (Newman et al. 2003). In a relatively brief period of time, a considerable number of motivated volunteers were trained in the collection of data and in the recruitment of other divers. The environmental association Underwater Life Project also contributed to the recruitment and training of volunteer scuba divers by asking its own staff to participate. During the project, the University of Bologna's Press Office contacted the media, resulting in the dissemination of information regarding the project through regional and national television, radio and newspapers. The project's aims and methods were reported and recreational divers were invited to participate in data collection. The efficiency of our volunteer recruitment training program was estimated to be between 8.5% and 10.1% (in 3 years, of the 25,000–30,000 divers committed to the program, 2536 filled out questionnaires). The project had the patronage of the Italian Ministry of the Environment.

Recorded information included the diver's name, address, and dive site (site, date, depth, time) and details of seahorse sightings (depth, habitat, number of individuals sighted, species). Seahorse species were identified based on the presence (*Hippocampus ramulosus*) or absence (*H. hippocampus*) of dorsal dermal flaps (Figs. 1 & 2), a distinguishing trait between the two species (Whitehead et al. 1986; Riedl 1991; Garrick-Maidment 1998). If uncertain, divers recorded *Hippocampus* spp.

Completed questionnaires were sent to Underwater Life Project headquarters, where a database for project results had been set up. These data were sent to the Department of Biology of the University of Bologna twice yearly, checked, and processed, and reports were prepared with an update on the project and its main results. The reports were mailed to divers who had contributed the most questionnaires. This direct feedback from the university to divers was a way of thanking them for their contribution to the project, probably enhancing their commitment to the study (as was the case in other monitoring programs; Newman et al. 2003; Pattengill-Semmens & Semmens 2003).

To sustain the project, the Department of Evolutionary and Experimental Biology supplied both a fellow, who committed anywhere from 2200 to 2500 hours to the program over the 3-year period, and a graduate student. The diving agency Scuba Schools International Italy granted the department US$55,000 over the 3-year period. This sum paid for the fellowship, computer hardware, software, and participation at conservation conferences and workshops related to the project. The diving agency also invested US$25,000 to pay for printing costs and general publicity (posters, stickers, video cassettes, and page spreads in newspapers and popular magazines).

Results

Number of Sightings

During the 3-year study, 2536 volunteers dove for 6077 hours and completed 8827 questionnaires (Table 1). Completed questionnaires varied from 1 per diver to as many as 140. Eight percent of questionnaires reported seahorse sightings, for a total of 3061 observed individuals. Sighting frequency was 0.504 (SE = 0.034) seahorses per diving hour (Table 1). The majority of sightings (68.4%) were of *Hippocampus ramulosus* individuals. During the period of study, the frequency of seahorse sightings varied significantly (one-way analysis of variance, $p = 0.003$). In particular, seahorse sightings were less frequent during the second year of observation (0.357, SE = 0.053) than during the first (1.235, SE = 0.093; Scheffé's test, $p < 0.05$), whereas sightings during the second and third years did not differ (Scheffé's test, $p > 0.05$).

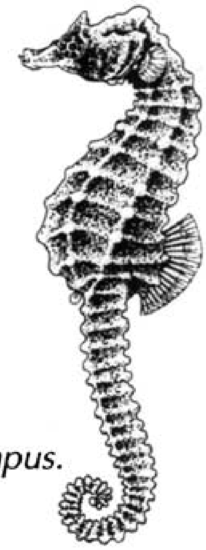
University of Bologna
Department of Biology

Italian Ministry of the Environment

UNDERWATER LIFE PROJECT

Name	Address
Surname	Diving License (educational agency and level)

Diving point	
Closest populated area	
Province	
School-Diving Center	
Date of the dive	
Maximum depth	
Actual bottom time	
Time the dive began	



Watch out for my "mane"! I am *Hippocampus ramulosus*.

I don't have a " mane"! I am *Hippocampus hippocampus*.

YES — DID YOU SEE ANY SEAHORSES? — NO

YES

Congratulations! Please answer the following questions:

At which depth were they sighted?	

In which habitat? (Only one answer)
- ☐ meadow of *Posidonia*
- ☐ sandy bottom
- ☐ rocky bottom
- ☐ wall
- ☐ other

How many minutes did you spend in this habitat?	

How many seahorses did you see? (number)

Did the seahorses have a "mane"?
- ☐ YES (you saw Hippocampus ramulosus)
- ☐ NO (you saw Hippocampus hippocampus)
- ☐ I DON'T KNOW (you saw Hippocampus)

NO

Better luck next time! Please answer the following questions:

At which depth did you spend most of your dive?	

In which habitat did you spend most of your dive? (only one answer)
- ☐ meadow of *Posidonia*
- ☐ sandy bottom
- ☐ rocky bottom
- ☐ wall
- ☐ other

How many minutes did you spend in this habitat?	

Thank you for your cooperation, you have helped us take the first step towards saving the seahorse.
The results of our study will soon be published.

Please send this questionnaire to:

SSI Scuba Schools International
via Bergami 4, I-40133 Bologna, Italy
Tel. +39-051-383082
Fax +39-051-383554

MARINE SCIENCE RESEARCH GROUP

SSI SCUBA SCHOOLS INTERNATIONAL

SNSI SCUBA NITROX SAFETY INTERNATIONAL

Figure 1. Questionnaire distributed to diving schools, swimming pools where divers undertook instruction, diving centers, and dive shops. Volunteer divers completed the questionnaire after each dive regardless of whether or not they had sighted seahorses.

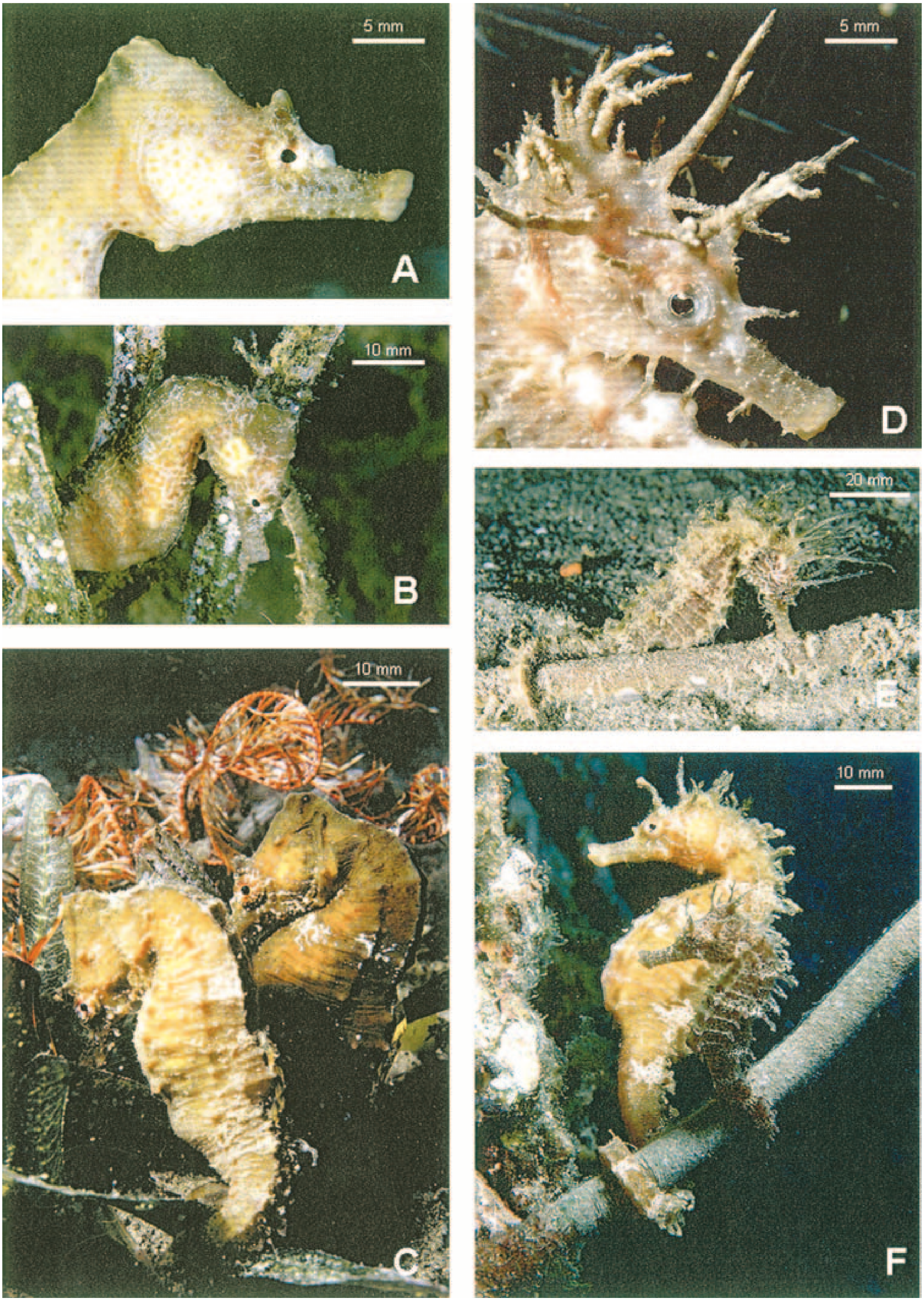

5 mm
A
10 mm
B
10 mm
C
5 mm
D
20 mm
E
10 mm
F

Table 1. Data collected by volunteer divers during the 3-year survey project on *Hippocampus*.*

Year	*No. questionnaires*	*Diving hours*	*Questionnaires reporting* Hippocampus *(%)*	Hippocampus hippocampus	Hippocampus ramulosus	Hippocampus *spp.*	*Total*
1999	1813	1320	20.79	0.393 (0.064)	0.677 (0.060)	0.165 (0.039)	1.235 (0.093)
2000	3139	2098	6.56	0.014 (0.004)	0.317 (0.052)	0.025 (0.008)	0.357 (0.053)
2001	3875	2659	4.03	0.028 (0.006)	0.201 (0.044)	0.027 (0.013)	0.257 (0.046)
All three years	8827	6077	8.37	0.103 (0.014)	0.344 (0.029)	0.056 (0.011)	0.504 (0.034)

**Frequency of seahorse sightings is number of individuals per diving hour. Standard errors are given in parentheses.*

Geographic Distribution

The areas surveyed included parts of the Ligurian, Tyrrhenian, and Adriatic seas off 18 coastal regions (Fig. 3). The regions on the Ligurian and Tyrrhenian seas included the islands of Corse, Sardegna, and Sicilia, and the mainland regions of Provence in France and the regions of Liguria, Toscana, Lazio, Campania, Basilicata, and Calabria in Italy. The Adriatic coastal regions were Puglia, Molise, Abruzzo, Marche, Emilia-Romagna, Veneto, and Friuli–Venezia Giulia in Italy and Istra in Croatia.

Data collected by recreational divers was not homogeneously distributed across regions (Fig. 4a & 4b). More questionnaires were collected for the Ligurian and Tyrrhenian coasts (86%) than for the Adriatic (14%). The most questionnaires (71%) were collected for Toscana and Liguria, whereas no questionnaires were collected for Basilicata and Abruzzo.

There was no correlation between the number of seahorses sighted and the number of diving hours performed by region over the 3-year period ($r = 0.032, p > 0.05$; Fig. 4b & 4c). There were high numbers of sightings in some regions with only moderate survey effort (number of diving hours). Two examples of this were Friuli–Venezia Giulia, where just 2.5% of the total survey effort yielded 39.0% of all seahorse sightings, and Campania, where similarly low effort (3.2%) yielded 18.3% of individuals sighted (Fig. 4b & 4c).

Given the geographic heterogeneity in survey effort, the abundance of seahorses per region was expressed as the mean number of individuals sighted per diving hour (Fig. 5). The highest frequency of sightings was reported off the coasts of Friuli–Venezia Giulia (7.808, SE = 0.926) and Veneto (5.654, SE = 1.575), on the northern Adriatic Sea, followed by the central and southern Tyrrhenian Sea, off the coasts of Campania (2.197, SE = 0.395), Calabria (1.571, SE = 0.206), and Sardegna (1.356, SE = 0.148) (Fig. 5a). Data from Provence (0.000, SE = 0.000), Liguria (0.119, SE = 0.019), Corse (0.000, SE = 0.000), and Toscana (0.076, SE = 0.011) revealed low frequencies of sightings in the Ligurian and northern Tyrrhenian Seas. The geographic distribution of the two seahorse species was generally overlapping except in areas with the highest frequency of sightings (i.e., the Friuli–Venezia Giulia coast had the highest abundance of *H. ramulosus* [6.745, SE = 0.194] and the Veneto coast had the highest abundance of *H. hippocampus* [2.737, SE = 1.234]). The former species was also significantly well represented off the Sardegna coast (1.297, SE = 0.147), whereas there were few sightings of *H. hippocampus* in this area (0.027, SE = 0.020) (Fig. 5b & 5c).

Habitat Distribution

The distribution of survey effort by habitats was not homogeneous: most dives took place in habitats with pebbly-rocky seabeds and vertical walls (69% of questionnaires reported dives in these two habitats; Table 2). There was no correlation between the number of individuals sighted and the number of diving hours by habitat ($r = 0.245, p > 0.05$). The number of sightings was low in habitats where the most diving hours were spent. In

Figure 2. Some morphological and ecological aspects of the two Mediterranean seahorse species, Hippocampus hippocampus *(a–c) and* Hippocampus ramulosus *(d–f). (a) Close-up of the head of* H. hippocampus*. The snout is relatively short; note the absence of dermal flaps.* (*b*) A *H. hippocampus* hidden among seagrass leaves. (*c*) Two *H. hippocampus* partially hidden by seagrass leaves. Note the tail of one of the individuals wrapped around a leaf. Also note the arms of a sea lily (Crinoidea, *Antedon mediterranea*) in the background. (*d*) Close-up of the head of *H. ramulosus*. Its snout is relatively long; also note the presence of dermal flaps. (*e*) An individual of *H. ramulosus* on a sandy bottom. Its tail is wrapped around a small wood branch. (*f*) Two individuals of the species *H. ramulosus* cling to the tube of a polychaete worm (*Sabella spallanzanii*)

Figure 3. Eighteen coastal regions of the Ligurian, Tyrrhenian, and Adriatic Seas.

contrast, sandy-bottomed areas, although accounting for only 12.4% of the total diving effort, had the highest number of seahorse sightings (49.2% of sightings over the course of 3 years).

The preferred habitats of seahorses are areas with sandy bottoms and meadows of *Posidonia oceanica* (L.) Delile (frequency of sightings can be found in Table 2). Although the frequency of *H. hippocampus* sightings appeared relatively high in both these environments, *H. ramulosus* showed a marked preference for habitats with sandy bottoms.

Bathymetric Distribution

The distribution of survey effort across the four depth bands (1–10, 11–20, 21–30, 31–40 m) appeared to be unimodal. Divers spent the most time (57.0% of the total diving effort) between the depths of 11 and 20 m. There was no correlation between the number of diving hours and the number of seahorses sighted by depth ($r = 0.578$, $p > 0.05$). Seahorse abundance decreased exponentially with increasing depth. The equation matching depth to abundance of seahorses was $y = 10.498x^{-1.228}$, where y is number of total *Hippocampus* per diving hour, x is depth (m) ($r = 0.997$, $p < 0.01$; total data [i.e., 1999 + 2000 + 2001, were used to calculate the coefficients]).

Discussion

Use of Volunteers for Environmental Monitoring

Volunteers and amateurs have contributed to scientific knowledge for centuries. Some scientific fields such as astronomy and ornithology have always encouraged volunteers to collect data (Root & Alpert 1994; Mims 1999). Only recently have international academic and scientific communities become aware of the contribution that can be made by volunteers in environmental monitoring. For example, a U.S. intergovernmental task force of experts found that more than 500 volunteer groups in the United States are involved in monitoring water quality and recommended that the efforts of these groups be integrated into government programs (U.S. Geological Survey 1995). Furthermore, the U.S. Environmental Protection Agency (EPA) supports surveillance performed by volunteers by sponsoring conferences to promote the exchange of information among volunteer groups, governmental agencies, industry, and educators and by granting funds for the training of volunteers and for financing data collection (EPA 1997). During the 1990s, the explosion of interest in scuba diving (RSTC 1997) led several programs in marine environmental monitoring to include volunteer divers (Fish Survey Project, Florida and Caribbean Sea, http://www.reef.org; Reef Check, global, http://www.reefcheck.org; Reef Watch, South Australia, http://www.reefwatch.asn.au; Project Seahorse, Philippines, http://www.seahorse.fisheries.ubc.ca; Mediterranean *Hippocampus* Mission, Mediterranean Sea, http://www.marinesciencegroup.org).

It seems evident that volunteers could be used to collect data that are intrinsically difficult to obtain and thus could fill holes in our knowledge in such areas. Difficulties arise, however, when administrators and researchers must guarantee the quality and validity of the data collected by volunteers. Results of some studies have shown that under conditions of appropriate recruitment and training, volunteer-collected data are qualitatively equivalent to those collected by professionals (Greenwood 1994; Schmitt & Sullivan 1996; Fore et al. 2001; Newman et al. 2003; Pattengill-Semmens & Semmens 2003). A number of features in our study lead us to conclude that the volunteer-collected data presented here are reliable. (1) Volunteers were assisted during data collection in the field by dive guides and instructors who had previously attended workshops and received training on project objectives and methodology. (2) Seahorse identification was not difficult because there are clear morphological differences between the two species. (3) Information requested on the questionnaire such as dive location, depth, dive time, and habitat are details most divers routinely record in their personal divelogs, whether the purpose of the dive is recreation or data collection. (4) Finally, data were markedly consistent across years, indicating a strong degree of reliability. Because no professional surveys of seahorse abundance and distribution could be found in the literature, however, no data were available with which to compare our results, so reliability cannot be quantitatively assessed.

The participation of volunteer scuba divers in the Mediterranean *Hippocampus* Mission exceeded our expectations. We calculated that it would have taken a professional researcher 20 years and would have cost more

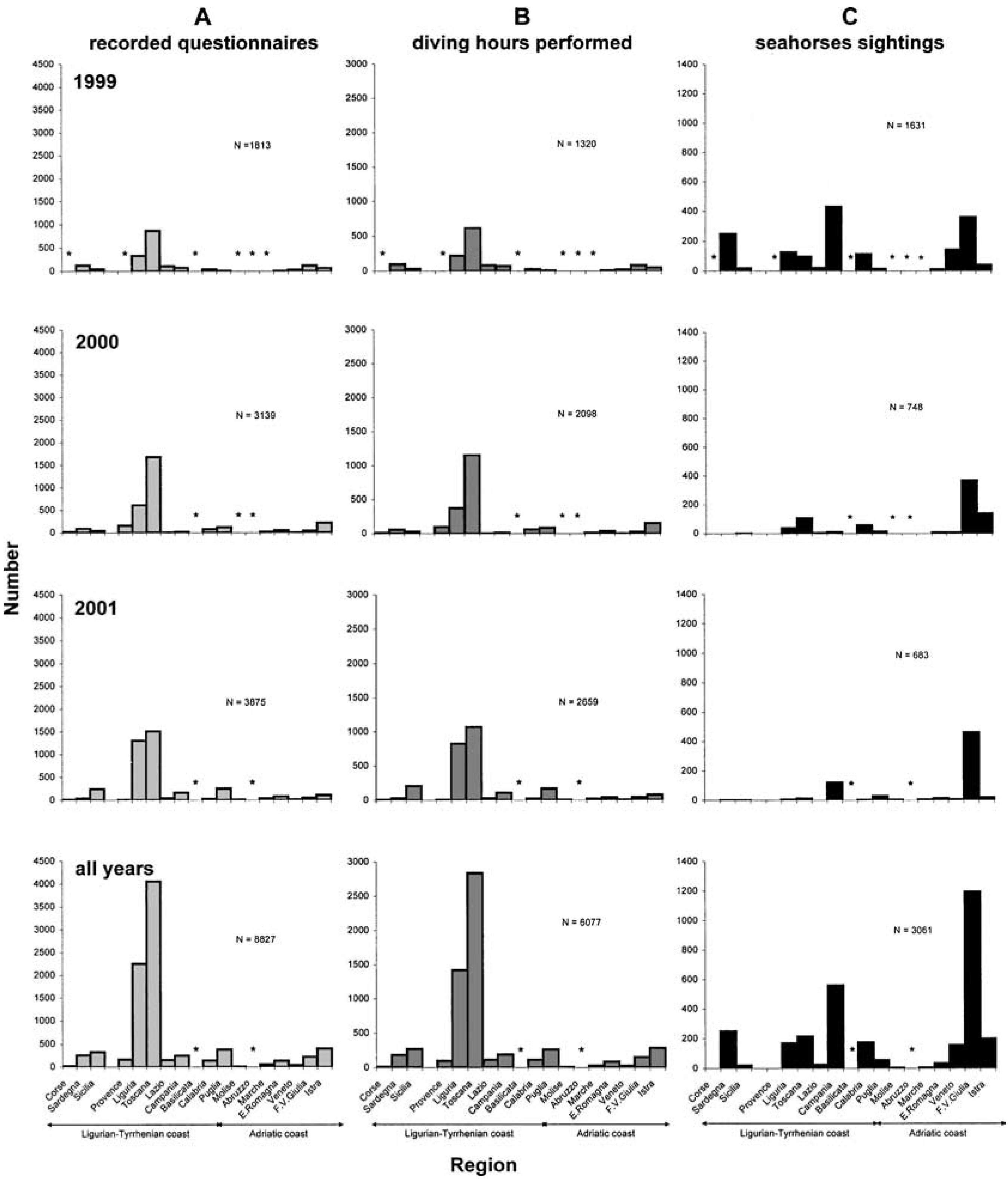


Figure 4. Number of (a) questionnaires collected, (b) diving hours performed, and (c) seahorses sighted per region over the 3-year study of Hippocampus. *Horizontal arrows at the bottom of the graphs indicate whether the regions border the Ligurian-Tyrrhenian or Adriatic seas. Asterisk indicates that no questionnaires were collected.*

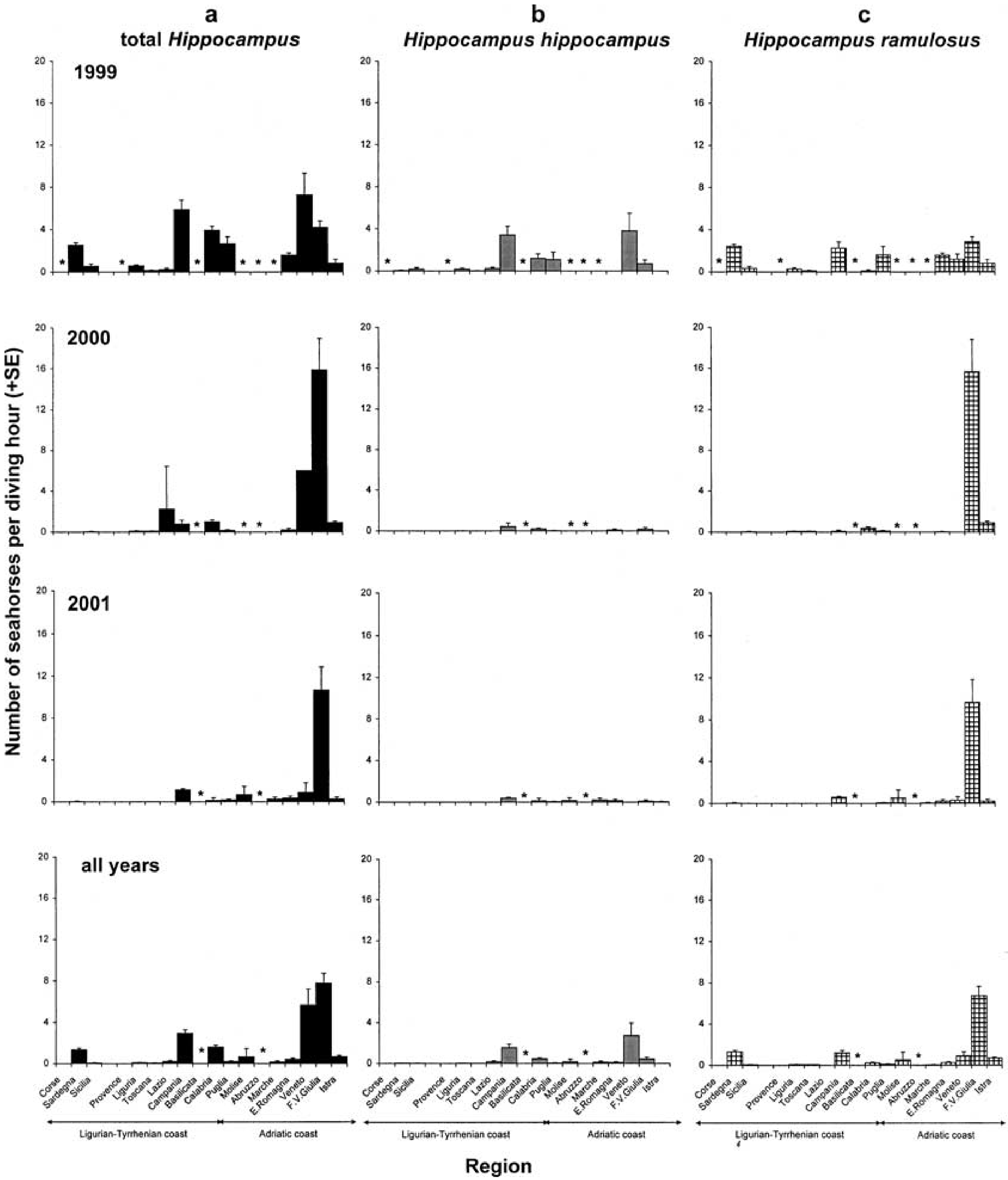


Figure 5. Frequency of seahorse sightings per region over the 3-year period of study. Horizontal arrows at the bottom of the graphs indicate whether the regions border the Ligurian-Tyrrhenian or Adriatic seas. Asterisk indicates that no questionnaires were recorded.

Table 2. Habitat distribution based on the total number (i.e., 1999 + 2000 + 2001) of questionnaires, diving hours, number of seahorses sighted, and frequency of seahorse sightings.*

Habitat	*Questionnaires*	*Diving hours*	*Seahorses sighted*	Hippocampus hippocampus	Hippocampus ramulosus	*Total* Hippocampus
All three years (1999, 2000, 2001)	8827	6077	3061	0.103 (0.014)	0.344 (0.029)	0.504 (0.034)
Posidonia oceanica meadow	1187	844	460	0.327 (0.084)	0.191 (0.038)	0.546 (0.092)
Sandy bottom	1131	751	1505	0.191 (0.045)	1.557 (0.213)	2.004 (0.226)
Pebbly-rocky bottom	3347	2340	552	0.052 (0.014)	0.150 (0.021)	0.236 (0.027)
Wall	2726	1858	472	0.038 (0.009)	0.192 (0.021)	0.254 (0.024)
Other	226	141	34	0.021 (0.025)	0.222 (0.080)	0.243 (0.083)
Not specified	210	144	38	0.062 (0.031)	0.166 (0.050)	0.263 (0.062)

**Frequency is the number of individuals per diving hour. Standard errors are given in parentheses.*

than US$1,365,000 to collect the same amount of data our volunteers collected in just 3 years. This is further evidence that (1) the public at large wants to take part in biological monitoring, and there is considerable potential for people practicing other recreational activities to be recruited by the scientific community to assist with environmental monitoring programs and (2) volunteers can collect a considerable amount of information over a relatively short amount of time and save the public and scientific community precious financial resources because they directly incur part of the costs needed for research projects (see also the recently published results of other monitoring projects involving volunteers, such as Newman et al. [2003] for terrestrial environments and Pattengill-Semmens and Semmens [2003] for marine environments).

A major limitation in the recruitment of volunteers for this kind of work is the absence of guarantees that the data set they acquire will be uniformly distributed across time and space. Clearly, the distribution of survey effort was not homogeneous across regions, depths, or habitats. But because recreational divers reported from most regions, habitats, and depths during each year of the study, it can be considered adequate for our purposes. In particular, with regard to the geographic distribution of the survey effort, and notwithstanding the lack of homogeneity, 13 of the 15 Italian coastal regions were surveyed (Basilicata and Abruzzo being the exceptions), as were three regions bordering Italy, Corse, Provence, and Istra. There are several reasons for the more significant diving effort along the Liguria and Toscana coasts. A behavioral reason is that recreational divers dive for pleasure and so choose stretches of coastline that are more enjoyable (the waters of the Ligurian and Tyrrhenian Seas are more limpid than the Adriatic). Logistically, there is a high density of diving centers along the Ligurian and northern Tyrrhenian coasts (21.4 diving centers/100 km of coastline vs. a national average of 6.7; data from http://www.diveitaly.com). Politically, Italy's national diving agencies supporting the project are located in the north, as are most of their affiliated diving schools, because of the diving quality and logistics, and divers from northern Italy prefer the Liguria and Toscana coasts. The following actions were taken to increase the homogeneity of the distribution of diving effort. First, incentives were granted to divers who dove in less popular areas; for example, we listed their names on the project's Web site and in our periodic reports on works in progress, thank-you letters were sent to individual divers, prizes were granted by our partners including subscriptions to recreational scuba diving and travel magazines, popular scientific journals, and all-expense paid diving trips (these kinds of incentives have been used in other environmental monitoring programs such as the Fish Survey Project, http://www.reef.org). Second, the university, in collaboration with the diving centers and tourist agencies located in the less-popular diving areas, endorsed the organization of promotional campaigns to inform local governments, the coast guard, tourist information bureaus, and local and national newspapers and television about the project. As part of the campaign, divers taking part in the training workshops were given discounts on room and board and diving costs. Our own experience and that of Brylske (2002) shows that these types of incentives greatly improve communication between the tourism community and those responsible for the conservation and management of marine resources, benefiting research efforts and improving local economies.

Individual diver effort was also not evenly distributed. The number of questionnaires turned in by the individual divers ranged from 1 to 140. This substantial difference in quantity is closely related to the fundamental role that the diving schools and centers played in promoting the project. Evidently, some divers took part regularly in the activities promoted by the centers and schools, whereas others were more sporadic in their attendance. In recognition of their efforts, the diving schools and centers that were most successful in promoting the project received the Silver Seahorse, a plaque donated by the university and by the diving agencies. These centers could easily become the promoters of future environmental monitoring initiatives.

Recreational divers are the base of a complex pyramidal organization with the educational scuba diving agencies at the apex. By targeting educational diving agencies we were able to trigger a cascade effect and thereby secure the participation of thousands of people. From the experience gained during this project, we conclude that recreational scuba divers can be useful for marine environmental monitoring activities and that our project, Mediterranean *Hippocampus* Mission, may be taken as a model for monitoring marine biodiversity.

Abundance and Distribution of Seahorses along Italian Coasts

The total number of individuals observed (3061) and the frequency of sighting (0.504 individuals per diving hour) indicate a discrete presence of seahorses in Italy's coastal waters. The decrease in the frequency of sightings recorded from year 1 to year 2 could be attributable to the fact that volunteers involved in the first year were more skilled (most were professional dive masters and instructors who had attended specific training workshops) than those in the second and third years (most were newly recruited private divers). This fact supports the reduction in the frequency of sighting between the first and second year of study and the leveling out of sighting frequency between the second and third years of study.

Hippocampus ramulosus was the more abundant of the two species, with a ratio of *H. ramulosus* to *H. hippocampus* of 3.4:1.0. For British seahorse populations, Garrick-Maidment (1998) reported a significant difference in the reproduction potential of the two species, with maximum numbers of offspring per brood at 100 and 300 young for *H. hippocampus* and *H. ramulosus*, respectively. This difference in reproduction could cause the difference in abundance between the two species seen in this study. The difference could also be influenced by the greater or lesser visibility of the species. *H. ramulosus* is perhaps more easily observed by divers because of its preference for sandy-bottom habitats, where seahorses cannot easily hide. Therefore, its presence may be more accurately recorded. By contrast, *H. hippocampus*, which was also common in *Posidonia oceanica* meadows, is likely to be less easily observed by divers, a factor that may have led to underestimation of this species.

The main characteristics of habitats preferred by seahorses around Italian coasts were shallow areas with either sandy bottoms or *P. oceanica* meadows. As noted above, however, seahorses may have been underestimated in *P. oceanica* meadows, and the actual presence of seahorses in this habitat may be considerably higher than reported. Data from the literature on the habitat characteristics of Mediterranean seahorses agree with the observations made by the divers in our study (Whitehead et al. 1986; Riedl 1991; Renones & Massuti 1995; Garrick-Maidment 1998).

The greatest abundance of seahorses was reported in the northern Adriatic and central-southern Tyrrhenian seas. Seahorses are rare in the northwestern Mediterranean (Ligurian and northern Tyrrhenian seas). This distribution may be related to the degree of habitat degradation. *P. oceanica* meadows, the climax community of soft substratum infralittoral zones in the Mediterranean, have declined significantly in the Ligurian and northern Tyrrhenian seas as a result of human disturbance along the coasts (Pérès & Picard 1975; Gabrielides 1995; Marbà et al. 1996) and the introduction of an invasive tropical seaweed (Meinesz & Hesse 1991; Verlaque & Fritayre 1994; DeVillèle & Verlaque 1995). This habitat loss could explain the rarity of seahorse sightings in this area.

Implications for Conservation

To obtain a real indication of the decline of *H. hippocampus* and *H. ramulosus* and to determine whether or not they need to be protected through priority conservation interventions, it is necessary for their populations to be monitored effectively. An objective assessment of the vulnerability of Italian seahorse populations requires further studies into demographic, genetic, reproductive, behavioral and dispersive aspects of seahorse biology.

In light of the positive results of the Mediterranean *Hippocampus* Mission, we suggest that the seahorse could become a banner species for the conservation of marine biodiversity. A focus on seahorses could allow us to engage professional colleagues, policy makers, and the public in interdisciplinary conservation ventures (see also the results of Project Seahorses, http://www.seahorse.fisheries.ubc.ca). Seahorses are charismatic and regarded fondly by interest groups in diverse cultures. Seahorse conservation could hitherto be very cooperative, providing a new opportunity for constructive action toward conservation of other marine species and systems. Due to the success of the *Hippocampus* project, we have begun a new venture called Diving for the Environment: Mediterranean Underwater Biodiversity Project. In addition to monitoring seahorses, volunteer divers are also reporting the presence of 59 other taxa, including both plant and animal species (for details go to http://www.marinesciencegroup.org).

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Unite research with what citizens do for fun: "recreational monitoring" of marine biodiversity

Stefano Goffredo,[1,3] Francesco Pensa,[1] Patrizia Neri,[1] Antonio Orlandi,[1] Maria Scola Gagliardi,[1] Angela Velardi,[1] Corrado Piccinetti,[1,2] and Francesco Zaccanti[1]

[1]*Marine Science Group, Citizen Science Lab, Department of Evolutionary and Experimental Biology, Alma Mater Studiorum, University of Bologna, Via F. Selmi 3, I-40126 Bologna, Italy*
[2]*Laboratory of Fisheries and Marine Biology at Fano, Alma Mater Studiorum, University of Bologna, Viale Adriatico 1/N, I-61032 Fano (PU), Italy*

Abstract. Institutes often lack funds and manpower to perform large-scale biodiversity monitoring. Citizens can be involved, contributing to the collection of data, thus decreasing costs. Underwater research requires specialist skills and SCUBA certification, and it can be difficult to involve volunteers. The aim of this study was to involve large numbers of recreational divers in marine biodiversity monitoring for increasing the environmental education of the public and collecting data on the status of marine biodiversity. Here we show that thousands of recreational divers can be enrolled in a short time. Using specially formulated questionnaires, nonspecialist volunteers reported the presence of 61 marine taxa encountered during recreational dives, performed as regular sport dives. Validation trials were carried out to assess the accuracy and consistency of volunteer-recorded data, and these were compared to reference data collected by an experienced researcher. In the majority of trials (76%) volunteers performed with an accuracy and consistency of 50–80%, comparable to the performance of conservation volunteer divers on precise transects in other projects. The recruitment of recreational divers involved the main diving and tour operators in Italy, a popular scientific magazine, and mass media. During the four-year study, 3825 divers completed 18 757 questionnaires, corresponding to 13 539 diving hours. The volunteer-sightings-based index showed that in the monitored area the biodiversity status did not change significantly within the project time scale, but there was a significant negative correlation with latitude, suggesting improved quality in the southernmost areas. This trend could be related to the presence of stressors in the northern areas and has been supported by investigations performed by the Italian Ministry of the Environment. The greatest limitation with using volunteers to collect data was the uneven spatial distribution of samples. The benefits were the considerable amounts of data collected over short time periods and at low costs. The successful development of citizen-based monitoring programs requires open-mindedness in the academic community; advantages of citizen involvement in research are not only adding large data sets to the ecological knowledge base but also aiding in the environmental education of the public.

Key words: biodiversity; citizen science; education; environmental monitoring; Mediterranean Sea; SCUBA divers; volunteers in research.

Introduction

Preserving biodiversity and the benefits it provides to society is a basic need for mankind (Balmford et al. 2005). The identification and quantification of threats enable managers to take effective measures. While broad conservation efforts require the implementation of global monitoring programs to build up-to-date databases, government agencies are often under-funded, and many cannot afford large-scale monitoring (Sharpe and Conrad 2006). Paradoxically, this decline in ecological monitoring over the second half of the 20th century has coincided with the huge increase in concern for biodiversity and the environment (Secord 1996). Economic constraints on data collection in some cases can be overcome by using the skills of nonspecialist volunteer researchers: the "citizen scientists" (Darwall and Dulvy 1996, Fore et al. 2001, Bhattacharjee 2005, Bell 2007, Greenwood 2007, Cohn 2008).

Citizen scientists are typically people who care about the wild, feel at home in nature, want to feel like they are making a difference while exploring new places, seek an experience where they help solve environmental problems, and have some awareness of the scientific process learning new things about nature (Gilmour and Saunders 1995, Ryan et al. 2001, Bruyere and Rappe 2007, Cohn 2008). They are attracted by the opportunity for cultural immersion, the chance to gain research

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[3] E-mail: stefano.goffredo@marinesciencegroup.org

experience, and the camaraderie that occurs on volunteer projects (Campbell and Smith 2006).

Citizen science contributed to the conservation of various organisms, adding information about their population structure, distribution, and behavior, and resource managers have taken advantage of volunteer networks (Darwall and Dulvy 1996, Fore et al. 2001, Goffredo et al. 2004, Bell 2007, Delaney et al. 2008). The United Nations Environment Program now emphasizes public involvement in environmental monitoring and management (Sharpe and Conrad 2006). The advantages of using such nonspecialist volunteers include the provision of manpower sufficient to conduct extensive surveys, providing simultaneous spatial coverage and placing the investigation in its local context; large financial savings through the provision of free labor and fund raising; an increase in the level of public awareness of ecological problems through active participation in ecological survey work; and the provision of a simple, low-cost survey program that can be continued in the long term using local expertise and financing (Stokes et al. 1990, Darwall and Dulvy 1996, Goffredo et al. 2004, Sheil and Lawrence 2004, Greenwood 2007). This is especially important since permanent monitoring increases the chance of early detection of biological invasions, and offers the greatest likelihood for their eradication (Myers et al. 2000, Lodge et al. 2006, Delaney et al. 2008).

The reliability and relevance of data generated by nonspecialist volunteers are held with some skepticism by the scientific community (Darwall and Dulvy 1996, Foster-Smith and Evans 2003), and despite the advantages raised above some seem reluctant to accept citizen science. The use of nonspecialist volunteers is often criticized on the grounds that the information collected will be unreliable as a result of either insufficient training or lack of consistency from using large numbers of observers (Darwall and Dulvy 1996). The potential of citizen science needs evaluation and its challenges need to be addressed since outright disregard means that valuable opportunities are being missed (Douglas and Lawrence 2004). Acceptance of citizen science by the scientific community would allow widespread nonspecialist participation in monitoring, and thereby greatly increase our ecological understanding by creating large spatial and temporal data sets.

For terrestrial environments, a range of successful ecological projects are based on the active involvement of the public (U.S. Environmental Protection Agency 1997, Bhattacharjee 2005, Cohn 2008). Important examples come from ornithological studies (Greenwood 2007, Kovács et al. 2008). Birds are good indicators of biodiversity generally, and they are easy to monitor because they are easy to identify and observe, and because there are many potential observers (National Audubon Society 2006, Greenwood 2007). Over the past decade, Cornell University has harnessed the enthusiasm of nonspecialist volunteers to explore questions such as the dynamics of infectious disease in bird populations and the impact of acid rain on their reproductive success. Those efforts have resulted in a list of peer-reviewed publications, clearly demonstrating the value of citizen science as a research tool (Hames et al. 2002, Altizer et al. 2004, Cohn 2008). Several other examples of published research confirm that nonspecialist volunteers can collect valid data (see, for instance, Evans et al. 2000, Fore et al. 2001, Lambert et al. 2005, Oberhauser et al. 2007, Delaney et al. 2008).

Volunteer participation in underwater monitoring presents unique challenges. Both terrestrial and marine projects require volunteer training but marine projects have the additional requirement of SCUBA diving skills. The last 20 years have seen a rapid increase in the numbers of recreational divers (Garrod and Gössling 2008), and research programs have begun to solicit divers as volunteers, making use of their natural interest in marine life. Among the research projects that developed the use of nonspecialist volunteers in marine monitoring, Coral Cay Conservation in Belize (Mumby et al. 1995), Fish Survey Project, conducted in Florida and the Caribbean (Pattengill-Semmens and Semmens 2003), and Reef Check, on a global scale (Hodgson 1999) are three significant examples. Coral Cay Conservation volunteers undergo an intensive eight-day training program in marine life identification and survey techniques. The training program incorporates lectures, practical exercises, individual tutoring, video, slides, and frequent testing. The course syllabus includes the identification of key species of macroalgae, seagrass, coral, and other marine invertebrates, as well as topographical features, species interaction, taxonomy, physiology, and consideration of coastal zone management issues and practices. After the training, volunteer divers conduct detailed survey transects for assessing marine resources for management initiatives. The Fish Survey Project assesses volunteers on fish species identification skills and classifies recruits as "beginners" or "experts" according to test results. Reef Check enrolls volunteers who pass a training course involving surveying techniques and diving skills. Participants perform successive surveys (fish, invertebrates, and substratum) at specific reef sites, transects and depths, following a strict protocol, and collect biophysical and socioeconomic data on that site under the guidance of professional scientists. Collectively these projects are able to involve few hundreds of recreational divers every year.

Asking volunteers to travel at their own expense to specific sites to perform surveys according to overbearing regimentation of the survey methods and strict protocols, may ensure uniform data collection, but carries the risk of making participation in the research project less attractive and so reducing the number of volunteers willing to participate. For detailed surveys, the use of volunteers would even be unsuitable. Detailed surveys require greater expertise in, for example, taxa identification, and an ability to maintain interest and accuracy. If demands are too great, people will not take part: the British Trust for Ornithology's Nest Sanitation project recruited very few participants, and thus reached no conclusions, because it required people to conduct such intensive work (Greenwood 2007). Darwall and Dulvy (1996) argue that the survey of "unknown" areas is sufficiently exciting for volunteers to maintain a high level of interest, but detailed studies repeated at a site lead to a significant drop in the level of interest, which is likely to lead to a loss in the quality of data collected. Striking the balance between work that is challenging enough to be satisfying but not so demanding as to off-put potential participants is not easy, especially because this balance varies for different people (Greenwood 2007). In an ideal world, all surveys would be conducted by a small team of highly experienced individuals but this is seldom possible due to lack of finance and time. Time is particularly important given the restricted physical limitations of diving surveys. For example, subtidal baseline surveys over large geographical scales require thousands of dives by hundreds of individuals, and this is most easily facilitated through the participation of a large number of volunteers (Darwall and Dulvy 1996).

There are also major educational and social benefits from the involvement of citizen volunteers in scientific projects. Participation in citizen-science projects provides a forum in which participants engage in thought processes similar to those that are part of science investigations, and increase their knowledge of ecology and environmental issues (Trumbull et al. 2000, Evans and Birchenough 2001, Brossard et al. 2005). The "self-education" of those collecting data, "the raising of a conservation force for change," and the pride that citizen scientists take in helping advance scientific knowledge and protecting the environment are also recognized benefits (Cohn 2008).

Since 1999, in an effort to maximize recreational diver participation, we have been testing a method of volunteer involvement that ensures reliability but does not diminish the diver enjoyment (i.e., without changing the normal recreational dive profile: depth, time, path; Goffredo et al. 2004). We wanted to give people an opportunity to become involved in environmental conservation in a novel way, balancing the need to collect good quality data with public education. This effort has therefore been to unite research with recreation, putting citizens at the forefront of the conservation drive. We first designed the "Mediterranean *Hippocampus* Mission," that focused on only one taxon: seahorses (Goffredo et al. 2004). Approximately 2500 recreational divers took part in the search for seahorses, and reported sightings via a user-friendly questionnaire. Volunteers enabled us to map the distribution of seahorses in the Italian Mediterranean Sea. This achievement prompted us to design a more ambitious project, named "Divers for the Environment: Mediterranean Underwater Biodiversity Project," the subject of this paper. The aims of Divers for the Environment were:

1) Involving as many people as possible in biodiversity monitoring;

2) Validating this new volunteer based monitoring approach, where volunteers perform recreational dives (i.e., pre-oriented precise transects are not carried out), and comparing results with those from professional investigations;

3) Developing a volunteer sightings-based index model for evaluating the status of the marine environment;

4) Making information available to the whole community by wide dissemination of the results.

The dissemination of information from citizen science projects can go far beyond the participants themselves. The mass media are keen to report findings of studies involving citizen-volunteers (Evans et al. 2000, Foster-Smith and Evans 2003, Goffredo et al. 2004). Evans et al. (2000) suggested that, because of media attention, the results of volunteer surveys may have wider impacts than other "purely scientific" studies. Wider implications are far-reaching because there can be little doubt that the public's failure to comprehend scientific issues is a root cause of the under-funding of science (Foster-Smith and Evans 2003). Citizen volunteers may also bring attributes of scientific studies, such as special skills (Foster-Smith 2000), specialist knowledge (Harrison et al. 1998) and new insights (Kendall and Lewis 1986), so that they contribute significantly more than a workforce that collects data (Foster-Smith and Evans 2003).

Materials and Methods

Survey questionnaires

From 2002 to 2005, we asked recreational divers to complete a questionnaire recording the presence of animal and plant taxa and refuse (litter). The questionnaire had two sections: one with photographs to identify the surveyed taxa (Appendix A: Fig. A1), the other with a form to record data (Appendix B: Fig. B1).

Sixty-one organismal taxa were surveyed (four vegetal taxa and 57 animal taxa; Appendix B: Fig. B1). It was necessary to have a long taxa list to address the overarching aim of assessing the quality of the environment from its biodiversity status (i.e., a single species by itself was not considered as an environmental quality indicator; Grime 1997, Therriault and Kolasa 2000). In a census of a comparable number of taxa (56 reef taxa), Darwall and Dulvy (1996) show that nonspecialist volunteer divers were able to reach a level of precision equivalent to an experienced researcher. Surveyed taxa had to be previously well known by volunteer recreational divers or easily recognizable (see Appendix C for volunteer training methods), benthic (highly mobile pelagic species were not censused; after Darwall and Dulvy 1996), historically expected to be found throughout the entire Mediterranean Sea (based on Riedl 1991 and the databases Global Biodiversity Information Facility, Ocean Biogeographic Information System, and MarineSpecies) and representative of each of the major trophic levels (databases available online).[4,5,6] These characteristics were necessary in order that the method is suitable for amateurs and tasks are realistic and achievable (Oliver and Beattie 1993, Pearson 1994, Therriault and Kolasa 2000, Foster-Smith and Evans 2003, Greenwood 2003, Newman et al. 2003, Goffredo et al. 2004, Bell 2007, Cohn 2008), the variation in biodiversity composition detected among geographic areas is not solely attributable to natural variation (Pearson 1994), and the estimated level of biodiversity is related to local conditions. The relevance of each taxon in revealing variation 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), in order to determine the minimum subset of taxa which would generate the same multivariate sample pattern as the full assemblage.

As in previous works (Schmitt and Sullivan 1996, Pattengill-Semmens and Semmens 2003, Goffredo et al. 2004), the required data were general information about the surveyor, level of diving qualification, diving agency that issued the license, technical information about the dive (place, date, time of day, depth, length of time), type of habitat explored (rocky bottom, sandy bottom, or other habitat), and an estimate of the abundance of surveyed organisms (Appendix B: Fig. B1). For each taxon we defined the scale of abundance as "rare," "frequent," or "abundant" based on the frequency at which the taxon is normally encountered. This frequency was estimated using scientific databases, literature, and personal observations. As an example, 1–4 rainbow wrasse was classed as rare, 5–10 as frequent, and more than 10 as abundant. Litter (fish pots, nets, or general refuse) was also recorded.

The diving certification level of volunteers ranged from open water divers (at least six recorded dives), to instructors (at least 100 recorded dives). The diving certification level was ranked on an ordinal scale, 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), instructor (level 5).

Simple random sampling design was used (i.e., volunteer divers were not forced; they performed survey dives when and where it was convenient for them). Also the recreational dive profile (dive depth, time, path, and safe diving practices) was not modified for the surveys: divers performed the dive as they normally do during sport diving (after Goffredo et al. 2004). This was because the aim of the study was to test the validity of using data from recreational dives for marine monitoring. During the survey dive each diver was responsible for observing plants, invertebrates and fishes, as well as litter. Soon after the dive, each participant completed a recording questionnaire (i.e., number of recorded questionnaires = number of dives performed). The completion of data questionnaire shortly after the dive, and the assistance of trained professional divers during data recording were key elements of the survey protocol to control data quality (Goffredo et al. 2004). Divemasters and other trainers that worked with the volunteers all attended the training courses for professional divers (see Appendix C). Their similar backgrounds and training assured limited influence on the accuracy of the volunteers under their supervision.

Assessing characteristics of sites: the survey station parameters

Incomplete or illegible questionnaires were discarded, as were those that demonstrated misunderstanding of methods (for example, multiple dives recorded on the same questionnaire), amounting to 16.6% of questionnaires submitted.

Data were aggregated according to type of habitat explored: rocky bottom, sandy bottom or other. We calculated the marine biodiversity index (V.MBI) for rocky bottom sites, since this environment was recorded in the highest number of survey questionnaires, enabling spatiotemporal comparison of results. Data from sites that did not have rocky bottoms were not used for any of the analyses in this paper. The questionnaires from rocky habitats were aggregated by dive site. We used the term "survey station" to define a dive site that produced at least 10 valid questionnaires in one year. Questionnaires from the survey stations were defined as "useful questionnaires" and were statistically analyzed. Dive sites that failed to reach the quorum of ten valid questionnaires over one year were defined as "sparse sites" and their questionnaires, defined as "sparse questionnaires," were not elaborated.

As in previous studies (Schmitt and Sullivan 1996, Pattengill-Semmens and Semmens 2003, Goffredo et al. 2004), we performed a statistical analysis for each survey station by calculating the following parameters: number of useful questionnaires recorded in one year; mean date, time of day, and depth of survey; number of vegetal (S_V) and animal (S_A) sighted taxa (aggregated over all questionnaires); sighting frequency of each taxon (%SF; expressed as percentage of dives in which the taxon was sighted); relative abundance of each taxon (abundance score, calculation follows); biodiversity values, vegetal (V) and animal (A) biodiversity, calculated by the Shannon-Wiener index (observed biodiversity H_{SH}, maximum biodiversity $L(S)$, equipartition index E_{SH}; Magurran 1988) using the relative abundance of each taxon (abundance score) to calculate the parameter p_i of the Shannon-Wiener index (p_i =

[4] ⟨http://www.gbif.org/⟩
[5] ⟨http://iobis.marine.rutgers.edu/⟩
[6] ⟨http://www.marinespecies.org/⟩

proportion of individuals of the taxon *i*; Magurran 1988); litter sighting frequency (%LF) expressed as percentage of dives where litter was observed.

To calculate the abundance score, we first calculated density score $= [(R \times 1) + (F \times 2) + (A \times 3)]/n$ where R, F, and A are the number of times the taxon was recorded as "rare," "frequent," or "abundant," respectively; 1, 2, and 3 are normalized abundance values assigned to the classes "rare," "frequent," and "abundant"; and $n = (R + F + A)$ (for statistical characteristics and rationale please see Schmitt and Sullivan 1996, Pattengill-Semmens and Semmens 2003). Then abundance score = density score × %SF (for statistical characteristics and rationale please see Schmitt and Sullivan 1996, Pattengill-Semmens and Semmens 2003).

Construction of the biodiversity evaluation model

Preliminary remarks.—In our model, the measure of biodiversity at a single survey station derives from the overall recorded information on censused taxa; single taxa by themselves are not considered indicators of general patterns (Grime 1997, Therriault and Kolasa 2000). The observed marine biodiversity has been synthesized into components of the Shannon-Wiener index (Magurran 1988, Lohrer et al. 2004).

To evaluate the biodiversity level at each survey station, we made a comparison between the values of parameters for each station and those calculated for a virtual "reference station." The parameters were S_V, H_{SHV}, E_{SHV}, S_A, H_{SHA}, E_{SHA} and %LF, defined as "main parameters," and sighting frequencies of individual taxa, defined as "special parameters." The virtual reference station was only one for the entire study. The assumption was that the virtual reference station represented the best current condition for a station in a rocky bottom habitat (i.e., its parameters were calculated from the actual stations having the best parameter conditions: higher biodiversity, lowest presence of litter). The parameter values of each individual station were expected to match those of the virtual reference station; otherwise they were considered as "penalties." The number of penalties resulting in the individual station determined the biodiversity index value.

Parameter calculation of the virtual reference station.—We calculated the virtual reference station parameter values as follows:

1) We calculated the "main" and "special" parameters of each survey station from the total number of useful questionnaires obtained during the four years.

2) For each of the parameters (main and special) we calculated the mean value among the stations and lower 95% confidence limit (upper 95% confidence limit for %LF).

3) We compared the parameter values of each station with the confidence limits obtained. If a value was below (above, for %LF), this counted as a "non-matching point" for the station. We summed the number of non-matching points for the station.

4) We calculated the mean number of non-matching points per station and the 95% upper confidence limit. We rejected the stations with more non-matching points than the confidence limit.

5) For the stations remaining after the rejection we returned to step 2. The 2, 3, and 4 cycle was repeated until all the remaining stations had a number of non-matching points less than or equal to the upper confidence limit.

6) We assumed as the critical values for the virtual reference station the lower 95% confidence limits of the means for the remaining stations (upper 95% limit for %LF).

Index (V.MBI [volunteers marine biodiversity index]).—For each year, we compared the values of the parameters for each station with the values of the virtual reference station. The parameters that did not reach the minimum requirements were considered as penalties (for S_V, H_{SHV}, E_{SHV}, S_A, H_{SHA}, and E_{SHA} and the special parameters, the value had to be equal or higher than that of the virtual reference station; for the %LF, the value had to be equal or lower than that of the virtual reference station). Each penalty was assigned a value calculated according to the frequency with which the penalty itself occurred in the totality of the stations: penalty value = 100 − penalty frequency (i.e., the percentage of stations in which the penalty was present). The sum of the penalty values was calculated for the main parameters and for the special parameters (we got two sums). Each sum was normalized on a scale from 0 to −1, where 0 indicated the absence of penalties and −1 indicated all penalties. We calculated marine biodiversity index for each individual station as the mean of the two normalized sums. The index was reduced to five classes: very good (for values between 0 and −0.125), good (−0.126 to −0.375), mediocre (−0.376 to −0.625), low (−0.626 to −0.875), and very low (−0.876 to −1).

Assessment of the validity of data collected by nonspecialist volunteers

Validation trials.—Comparisons were made between records from trained volunteers and independent records from a marine biologist (over 2000 hours of marine surveying experience), hereafter referred to as the "control diver." The explanations for the experimental design comparing volunteers to the control diver are after Mumby et al. (1995) and Darwall and Dulvy (1996):

1) The control diver was the same individual for all validations; in each validation the volunteer divers were different from previous ones (i.e., each volunteer was tested only once);

2) The control diver dived simultaneously with trained volunteers without interfering with them;

3) Validation dive sites were not selected prior to the assessment; the control diver dived where the diving

Table 1. Definition and derivation of terms used to describe components of the accuracy and consistency of volunteers 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 rated by the volunteer (i.e., the value of the rating indicated by the volunteer was equal to the reference value recorded by the control diver).

Note: Modified from Mumby et al. (1995).

center officer planned the dive for that day, accordingly to safe conditions (weather, currents, divers experience);

4) All trials were conducted in between 09:00 and 16:00 to avoid changes in activity between nocturnal and diurnal taxa populations;

5) At the end of the dive the control diver filled the questionnaire independently and apart from the volunteers without any interference with volunteer data recording;

6) For each trial an inventory of taxa (with abundance rating) was generated by the control diver, and this was compared with the inventory generated by each volunteer surveyor to identify data accuracy.

Data validation statistics.—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). This comparison was performed each year at different survey stations with different volunteers, to constantly monitor the validity of the data collected and the effectiveness and consistency of the annual training workshops. A variety of nonparametric statistical tests were used to analyze the survey data:

1) Spearman rank correlation coefficients (ρ_s) were calculated and results displayed in terms of mean value and 95% confidence limit. Several 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 analyze the reliability of survey data (Hughey et al. 2004). The α coefficient is a calculated value (ranging between 0 and 1, and expressed as a percentage in the text) based on the average correlation of items within a test if the response categories are standardized (Coakes and Steed 1997). Values above 0.5 are considered acceptable as evidence of a relationship (Nunnally 1967, Hair et al. 1995), an α above 0.6 is considered an effective reliability level (Flynn et al. 1994), while values above 0.7 are more definitive (Peterson 1994). The α coefficient was calculated for each volunteer taxa inventory against the control diver inventory. The results were displayed in terms of mean value and 95% confidence limit.

3) Czekanowki'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] and Darwall and Dulvy [1996]):

$$\mathrm{SI}_{ij} = 1 - \frac{1}{2}\sum_{n=1}^{s}[p_{in} - p_{jn}]$$

where there are s taxa, and p_{in} and p_{jn} represent the proportions of individuals in census i and j respectively that belong to the nth species. The value $p_{in} - p_{jn}$ is taken as the absolute difference between the two proportions. 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 indication of sufficient levels of precision, while values above 0.75 are considered as high levels of precision (Darwall and Dulvy 1996). The results were displayed in terms of mean value and 95% confidence limit.

To develop eligibility criteria for future surveys, we identified independent variables (diving certification level and group size of participants) to examine their effect on the precision of volunteers. The possible influence of dive time and depth on volunteer precision was also assessed. For all of these analyses the Spearman rank correlation was tested.

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

Results

Quality of recreational volunteer-generated data: the validation trials

The overall trends of accuracy, consistency, reliability, and similarity are described, including an inspection of the individual components of accuracy (defined in Table 1) and species-level analysis.

TABLE 2. Quality of volunteer-generated data; results of the 38 validation trials performed during the four-year research project (2002–2005).

Station name	Code	Date	Team size†	Cert. level‡	Depth (m)	Dive time (minutes)
2002						
Gorgonie	gr-14	25 Apr	9	3.0 (2.1–3.9)	21 (19–22)	42 (41–43)
Punta della Madonna	pm-16	2 Jun	7	2.4 (1.6–3.3)	26 (20–32)	37 (32–42)
Scogliera Parco Marino	spm-31	15 Jun	7	2.3 (1.3–3.3)	4 (4–5)	63 (58–69)
Tato Point	tp-14	22 Jun	10	1.7 (1.3–2.1)	28 (26–30)	43 (40–47)
Calafuria	c-14	23 Jun	10	1.8 (1.0–2.6)	13 (11–16)	58 (54–62)
Ancorone	a-14	24 Aug	6	1.5 (0.8–2.2)	17 (15–19)	46 (43–49)
Gorgonie	gr-14	25 Aug	9	1.4 (0.9–2.0)	17 (15–18)	40 (40–41)
Tato Point	tp-14	25 Aug	10	1.4 (1.0–1.8)	18 (16–19)	43 (42–44)
Scoglione	s-15	4 Oct	4	2.7 (1.6–3.8)	16 (14–17)	49 (42–56)
Secca Turco	st-15	4 Oct	5	3.0 (2.4–3.6)	23 (20–25)	44 (40–48)
Scoglione	s-15	5 Oct	7	1.6 (0.8–2.3)	14 (13–15)	56 (52–59)
Secca Turco	st-15	5 Oct	7	2.7 (2.2–3.3)	25 (22–27)	37 (35–39)
2003						
Cartellino	ct-14	11 May	4	2.3 (1.3–3.2)	22 (21–22)	49 (46–51)
Calafuria	c-14	18 May	6	2.0 (1.1–2.9)	10 (7–13)	45 (44–46)
Cala Fetente	cf-24	23 May	6	2.3 (1.5–3.2)	8 (6–9)	33 (30–36)
C.po Spartivento	cs-24	24 May	6	3.0 (2.0–4.0)	22 (16–27)	43 (41–44)
Grotta Azzurra	ga-24	24 May	11	2.5 (1.6–3.3)	16 (13–19)	47 (43–52)
Civitata	cv-15	7 Jun	7	1.4 (0.8–2.0)	11 (11–12)	50 (50–51)
Formiche	f-15	8 Jun	5	1.4 (0.6–2.2)	13 (12–15)	50 (46–54)
Forbici	fr-16	4 Jul	15	2.1 (1.4–2.7)	17 (15–19)	49 (44–53)
Picchi Pablo	pp-16	5 Jul	9	2.7 (1.9–3.4)	18 (15–22)	44 (35–52)
Sc. Remaiolo	sr-16	26 Jul	6	1.0	17 (15–18)	42 (40–43)
Secca di Fonza	sdf-16	26 Jul	6	1.0	17 (16–19)	39 (39–40)
Spiaggia di Portoazzurro	spa-16	7 Nov	11	1.5 (0.8–2.1)	7 (6–8)	30 (29–31)
2004						
P.ta della Fica	pf-15	28 May	6	2.3 (1.7–3.0)	16 (12–20)	42 (41–42)
Formiche	f-15	30 May	10	1.5 (0.9–2.1)	13 (12–14)	47 (45–49)
Calafuria	c-14	13 Jun	14	1.5 (0.9–2.0)	7 (6–8)	38 (38–39)
Sc. Remaiolo	sr-16	23 Jul	12	1.8 (1.0–2.5)	12 (11–13)	44 (42–47)
Corbelli	cri-16	24 Jul	19	1.5 (1.0–2.0)	12 (11–13)	47 (45–48)
Sc. Remaiolo	sr-16	24 Jul	18	1.5 (1.0–2.0)	12 (11–12)	51 (50–52)
C.po Focardo	cf-16	27 Jul	10	1.6 (0.8–2.4)	7 (6–8)	43 (42–43)
Cannelle	cn-16	27 Nov	8	1.8 (0.8–2.7)	10 (7–13)	40 (37–43)
Picchi Pablo	pp-16	28 Nov	13	1.5 (0.9–2.1)	10 (9–11)	47 (42–53)
2005						
Cala Turchi	ct-30	27 Oct	3	4.2 (3.3–5.0)	23 (20–27)	46 (43–48)
Punta Secca di Caprara	psc-30	27 Oct	3	3.5 (2.0–5.0)	27 (20–33)	46 (43–50)
Spiaggia di Portoazzurro	spa-16	29 Oct	9	1.7 (0.8–2.5)	8 (7–9)	45 (43–47)
Sc. Remaiolo	sr-16	30 Oct	10	1.6 (0.8–2.4)	13 (11–15)	46 (39–52)
Cala Caffè	cc-30	31 Oct	5	3.5 (2.3–4.7)	21 (18–23)	45 (45–46)

Notes: Parameter definitions are in Table 1 and in *Materials and methods*. Values in parentheses are 95% CIs. Volunteers tested in 2002 had <1 year of survey experience, those tested in 2003 had <2 years of survey experience, those tested in 2004 had <3 years of survey experience, and those tested in 2005 had <4 years of survey experience.

† Number of volunteers.

‡ Diving certification level of volunteers.

Thirty-eight validation trials were performed (Table 2). A total of 324 different volunteers were tested, with a mean number of volunteers per validation team of 9 (95% CI = 7–10). Mean diving certification level of volunteers varied significantly among teams from 1.0 to 4.2 (Table 2).

There was significant variability in the accuracy of validation trials. The mean accuracy of each team ranged from 38% to greater than 90%, with the majority of teams (76%) performed with mean accuracy of between 50% and 80% (Table 2). Intra-group variation was approximately 21% (coefficient of variation, CV) per team. Accuracy was not correlated with volunteers diving certification level ($\rho_s = -0.262$, $N = 38$, $P = 0.112$), number of participants in the trial group ($\rho_s = -0.110$, $N = 38$, $P = 0.511$), depth of the trial ($\rho_s = -0.281$, $N = 38$, $P = 0.087$), or dive time of the trial ($\rho_s = -0.025$, $N = 38$, $P = 0.882$). A consistent trend emerged from the regression analysis between time from the beginning of the trials and accuracy, which indicated an increase in accuracy of 7 points each year ($\rho_s = 0.702$, $N = 38$, $P < 0.001$; Accuracy (%) = 7.013time (in years) + 57.465).

Consistency showed a similar pattern to that of accuracy; the mean consistency of each team ranged from 39% to 91%, with the majority of teams (76%) performing with a mean consistency of between 50% and 80% (Table 2). Intra-group variation was at approximately 26% (CV) per team. Consistency was not

TABLE 2. Extended.

Accuracy	Consistency	Percent identified	CAR	Reliability (α)	Similarity index
62.5 (53.3–71.7)	43.4 (38.5–48.4)	67.5 (60.5–74.5)	81.7 (78.4–85.0)	75.7 (66.6–84.8)	59.7 (52.2–67.1)
42.7 (34.6–50.8)	44.3 (36.3–52.2)	64.8 (47.8–81.9)	72.8 (69.3–76.4)	55.1 (47.2–63.0)	44.1 (37.2–51.0)
57.6 (50.0–65.2)	52.3 (47.8–56.7)	63.8 (49.0–78.6)	80.6 (78.7–82.6)	68.8 (58.1–79.5)	55.1 (43.4–66.7)
54.2 (48.7–59.6)	61.9 (58.3–65.4)	58.5 (53.3–63.6)	79.5 (77.7–81.3)	77.3 (73.5–81.1)	57.8 (54.4–61.2)
54.8 (50.6–58.9)	49.5 (44.2–54.8)	65.3 (58.6–72.0)	76.0 (73.6–78.3)	64.0 (55.7–72.3)	52.4 (46.6–58.3)
70.4 (54.2–86.5)	65.4 (56.3–74.5)	79.5 (72.0–86.9)	84.1 (76.3–92.0)	78.2 (62.8–93.7)	67.4 (49.6–85.1)
69.8 (58.1–81.4)	58.2 (51.8–64.6)	83.3 (76.3–90.4)	85.3 (78.9–91.7)	82.7 (75.0–90.4)	65.7 (53.0–78.4)
66.1 (56.8–75.5)	60.5 (56.0–65.0)	78.0 (68.0–88.0)	82.4 (76.4–88.5)	81.6 (76.3–87.0)	63.0 (54.8–71.1)
57.6 (40.7–74.4)	48.5 (43.7–53.3)	75.0 (58.7–91.3)	82.3 (70.0–94.5)	77.4 (62.6–92.2)	51.3 (28.9–73.8)
49.0 (39.8–58.1)	49.3 (42.4–56.2)	60.0 (46.1–73.9)	80.6 (78.9–82.4)	69.9 (60.0–79.7)	50.4 (40.3–60.6)
38.4 (26.4–50.4)	39.0 (28.5–49.5)	57.1 (39.9–74.4)	73.3 (68.9–77.6)	52.2 (35.3–69.1)	39.0 (29.5–48.4)
53.8 (47.0–60.6)	50.6 (43.9–57.4)	54.0 (45.2–62.8)	85.7 (83.2–88.2)	77.4 (67.2–87.5)	56.3 (46.7–66.0)
68.5 (53.0–84.0)	60.8 (50.0–71.5)	77.3 (58.0–96.5)	67.7 (59.1–76.4)	79.7 (66.7–92.8)	67.6 (54.7–80.6)
80.7 (63.6–97.9)	56.1 (45.1–67.1)	85.2 (71.8–98.6)	89.0 (80.3–97.7)	79.5 (64.0–95.0)	66.8 (46.3–87.2)
68.0 (57.4–78.6)	49.5 (41.3–57.7)	70.8 (55.8–85.9)	94.1 (92.1–96.0)	84.5 (73.2–95.8)	63.1 (50.7–75.5)
67.0 (55.2–78.8)	61.1 (56.5–65.7)	72.0 (60.4–83.6)	74.7 (68.2–81.2)	82.9 (76.1–89.7)	70.5 (60.9–80.1)
52.3 (44.9–59.7)	57.0 (53.4–60.6)	73.9 (67.9–79.8)	68.3 (63.9–72.8)	66.9 (60.6–73.1)	54.1 (48.9–59.3)
90.1 (87.2–93.1)	90.5 (88.5–92.5)	93.2 (91.3–95.1)	92.6 (88.9–96.4)	94.7 (92.3–97.0)	88.9 (84.3–93.4)
67.7 (65.2–70.2)	74.9 (69.7–80.2)	77.9 (72.8–82.9)	73.5 (70.3–76.8)	79.5 (77.3–81.6)	66.5 (63.6–69.5)
61.5 (55.8–67.1)	55.0 (52.7–57.4)	67.4 (60.1–74.6)	73.1 (70.4–75.8)	72.7 (67.2–78.1)	58.6 (53.9–63.3)
59.0 (52.3–65.6)	51.5 (46.1–56.8)	71.4 (61.3–81.6)	73.8 (70.0–77.7)	73.0 (66.7–79.3)	56.7 (50.4–62.9)
80.1 (70.1–90.1)	76.4 (70.0–82.8)	86.1 (78.3–93.9)	84.1 (76.4–91.9)	86.7 (78.7–94.7)	76.8 (66.9–86.8)
74.3 (54.6–94.1)	57.9 (47.9–68.0)	76.4 (55.8–97.0)	84.7 (73.8–95.6)	83.3 (68.4–98.3)	74.0 (53.8–94.2)
72.7 (59.3–86.0)	54.2 (47.6–60.8)	64.8 (47.7–81.9)	90.8 (86.9–94.7)	80.6 (68.6–92.6)	65.2 (49.2–81.2)
68.1 (59.7–76.4)	62.8 (56.9–68.7)	64.6 (56.4–72.7)	81.7 (77.3–86.2)	83.2 (75.9–90.4)	65.5 (57.7–73.3)
69.4 (64.8–74.0)	65.8 (61.1–70.4)	75.6 (68.3–82.9)	73.9 (72.3–75.5)	81.5 (78.4–84.7)	66.5 (62.5–70.5)
63.1 (55.8–70.5)	72.0 (69.0–74.9)	62.2 (55.6–68.9)	84.2 (81.6–86.8)	82.6 (77.5–87.6)	64.9 (57.9–71.8)
68.6 (62.3–74.9)	63.3 (59.8–66.8)	80.8 (73.0–88.5)	77.0 (70.7–83.3)	81.5 (76.7–86.4)	64.7 (57.2–72.3)
71.2 (63.3–79.1)	61.3 (58.9–63.7)	74.6 (68.3–80.8)	80.6 (75.4–85.9)	83.1 (77.9–88.4)	70.0 (62.6–77.4)
76.0 (70.3–81.8)	65.9 (63.7–68.1)	85.8 (81.2–90.3)	80.8 (76.7–85.0)	85.7 (81.3–90.1)	73.7 (67.9–79.4)
84.7 (78.9–90.6)	81.2 (77.9–84.6)	85.2 (80.5–89.9)	87.3 (82.2–92.3)	90.9 (87.2–94.6)	81.5 (75.6–87.5)
78.6 (62.7–94.4)	64.6 (56.0–73.2)	84.2 (74.3–94.0)	86.7 (78.2–95.2)	84.4 (69.7–99.2)	77.7 (61.8–93.5)
73.4 (61.6–85.2)	64.4 (60.2–68.7)	74.8 (60.8–88.9)	75.7 (68.0–83.3)	82.6 (74.7–90.5)	68.3 (56.1–80.5)
80.6 (63.6–97.6)	67.5 (55.4–79.7)	79.6 (59.3–100.0)	85.5 (77.5–93.4)	92.6 (87.1–98.2)	80.8 (68.4–93.1)
88.5 (77.9–99.1)	74.6 (66.2–82.9)	84.1 (68.3–100.0)	88.2 (82.6–93.7)	94.9 (89.9–100.0)	85.0 (73.6–96.4)
75.3 (66.0–84.6)	71.4 (66.6–76.1)	76.3 (69.4–83.2)	87.1 (83.0–91.1)	85.2 (76.5–93.9)	73.2 (65.3–81.1)
74.4 (64.0–84.8)	71.7 (67.7–75.6)	77.9 (69.6–86.1)	94.6 (90.8–98.4)	83.8 (76.3–91.3)	71.5 (61.3–81.6)
82.0 (69.8–94.2)	68.3 (60.3–76.4)	85.7 (73.5–97.9)	86.5 (77.7–95.2)	91.1 (83.2–99.0)	83.3 (71.7–94.8)

correlated with depth of the trial ($\rho_s = -0.209$, $N = 38$, $P = 0.209$), the dive time of the trial ($\rho_s = 0.094$, $N = 38$, $P = 0.574$), or number of participants in the group ($\rho_s = 0.021$, $N = 38$, $P = 0.899$). Interestingly, there was an inverse correlation between volunteers diving certification level and consistency ($\rho_s = -0.372$, $N = 38$, $P = 0.022$). The regression analysis between time from the beginning of the trials and consistency showed a consistent trend with an increase of 6 points in consistency each year ($\rho_s = 0.680$, $N = 38$, $P < 0.001$; consistency (%) = 5.798[time (in years)] + 52.657).

Most survey teams managed to correctly identify approximately 75% of the taxa present in each survey trial (87% of the teams correctly identified a mean percentage of between 60% and 90%; Table 2). Intra-group variation was approximately 20% (CV) per team. The ability to correctly identify taxa was not correlated with the diving certification level of the team members ($\rho_s = -0.275$, $N = 38$, $P = 0.095$), the group size of participants ($\rho_s = -0.157$, $N = 38$, $P = 0.348$), depth ($\rho_s = -0.132$, $N = 38$, $P = 0.430$) or dive time of the trial ($\rho_s = 0.143$, $N = 38$, $P = 0.392$).

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 (Table 3; $\rho_s = 0.448$, $N = 46$, $P < 0.01$; correct identification (%) = 1.057[presence frequency] + 53.952). Sixteen rare taxa were not present (i.e., were not recorded by the control diver) in any of the 38 validation trials, thus assessment of correct identification was not possible.

Most survey teams managed to correctly rate the abundance of approximately 82% of the surveyed taxa (95% of the teams produced a mean correctness of abundance ratings, CAR, of between 70% and 100%; Table 2). Intra-group variation was approximately 9%

TABLE 3. Taxon-level analyses.

Taxon		Correct identification (%)			
Common name	Scientific name	Mean	95% CI	*N*	Best taxon
Mermaid's wine glass	*Acetabularia acetabulum*	94.5	89.7, 99.4	12	
Damselfish	*Chromis chromis*	94.1	90.7, 97.6	35	×
Mediterranean tapeweed	*Posidonia oceanica*	93.6	87.2, 100.0	19	×
Sea anemone	*Anemonia viridis*	91.8	86.0, 97.6	10	
Salema	*Sarpa salpa*	91.0	85.1, 96.9	20	
Yellow cluster anemone	*Parazoanthus axinellae*	89.2	84.1, 94.3	18	
Precious red coral	*Corallium rubrum*	87.5	75.0, 100.0	6	
Red gorgonian	*Paramuricea clavata*	87.0	74.1, 100.0	3	×
Other fishes		86.5	79.5, 93.4	27	
Dusky grouper	*Epinephelus guaza*	84.0	74.6, 93.3	7	×
Fin shell	*Pinna nobilis*	83.3	66.7, 100.0	4	
Other bivalves		83.3	66.7, 100.0	2	×
Moray eel	*Muraena helena*	83.3	71.5, 95.0	9	
Other sponges		82.2	75.2, 89.2	31	
Fan tube worm	*Sabella spallanzanii*	81.4	71.4, 91.4	17	
Other sea stars		78.4	66.9, 89.9	16	×
Dotted sea slug	*Peltodoris atromaculata*	78.2	56.4, 100.0	8	
Petrosia	*Petrosia ficiformis*	77.5	67.7, 87.4	15	
Other echinoids		77.2	69.2, 85.4	27	
Sea lace	*Sertella septentrionalis*	76.3	66.7, 86.0	15	×
Sea rose	*Peyssonnelia squamaria*	76.3	67.5, 85.1	25	
Common spiny lobster	*Palinurus elephas*	75.8	51.6, 100.0	3	
Rainbow wrasse	*Coris julis*	75.6	66.9, 84.2	31	
False coral	*Myriapora truncata*	75.2	65.5, 84.9	26	×
Other octocorals		74.2	62.8, 85.5	15	
Sea raven	*Sciaena umbra*	74.1	51.4, 96.9	2	
Sea red potato	*Halocinthya papillosa*	72.9	63.2, 82.7	23	×
Other vegetals		68.8	58.4, 79.3	28	×
Litter		67.5	56.5, 78.5	17	
Sea lily	*Antedon mediterranea*	66.7		1	
Other sedentary worms		65.4	51.9, 78.9	23	×
Brain sponge	*Chondrilla nucula*	59.3	31.1, 87.5	5	×
Common octopus	*Octopus vulgaris*	59.2	41.2, 77.3	2	
Other holoturians		59.1	47.0, 71.2	17	×
Cuttlefish	*Sepia officinalis*	57.1		1	
Spider crab	*Maja squinado*	57.1		1	
Other gastropods		56.0	37.5, 74.5	10	×
Other ascidians		53.5	31.0, 76.0	5	×
Other hexacorals		46.2	32.3, 60.1	21	
Other bryozoans		34.3	11.9, 56.6	9	×
Pencil sea urchin	*Stylocidaris affinis*	33.3		1	
Cerianthid anemone	*Cerianthus membranaceus*	32.6	9.2, 56.1	4	
Other decapods		21.4	−20.6, 63.4	2	
Sea cucumber	*Stichopus regalis*	14.3		1	
Other ophiuroids		14.3		1	
Pentagon sea star	*Ceramaster placenta*	0.0		1	
Eyed electric ray	*Torpedo torpedo*			0	
Smooth brittlestar	*Ophioderma longicaudum*			0	×
Thornback ray	*Raja clavata*			0	×
Anglerfish	*Lophius piscatorius*			0	
John dory	*Zeus faber*			0	
Flying gurnard	*Dactylopterus volitans*			0	×
Winged oyster	*Pteria hirundo*			0	×
Purple dye murex	*Bolinus brandaris*			0	×
Red dead man's fingers	*Alcyonium palmatum*			0	×
Box crab	*Calappa granulata*			0	×
Giant tun	*Tonna galea*			0	×
Long-snouted branched seahorse	*Hippocampus ramulosus*			0	×
Short-snouted seahorse	*Hippocampus hippocampus*			0	
European lobster	*Homarus gammarus*			0	
Other crinoids				0	×
Other cephalopods				0	×

Notes: Correct identifications were generated from a maximum sample size of 38 validation trials performed at the stations listed in Table 2, from 25 April 2002 to 31 October 2005. *N* is the actual sample size for each taxon (i.e., presence frequency, the number of validation trials in which the taxon was present). Refer to Table 1 for definition of "correct identification." Best taxon refers to a subset of 27 taxa. The BEST test (Bio-Env + STepwise; PRIMER-E version 6 software) was performed on the total sample size of 16 533 questionnaires collected over the four years of research. These 27 taxa constituted the minimum subset that generated the same multivariate sample pattern derived from the full taxa assemblage and represented in Fig. 4 (BEST test, $\rho_s = 0.951$, $P < 0.01$).

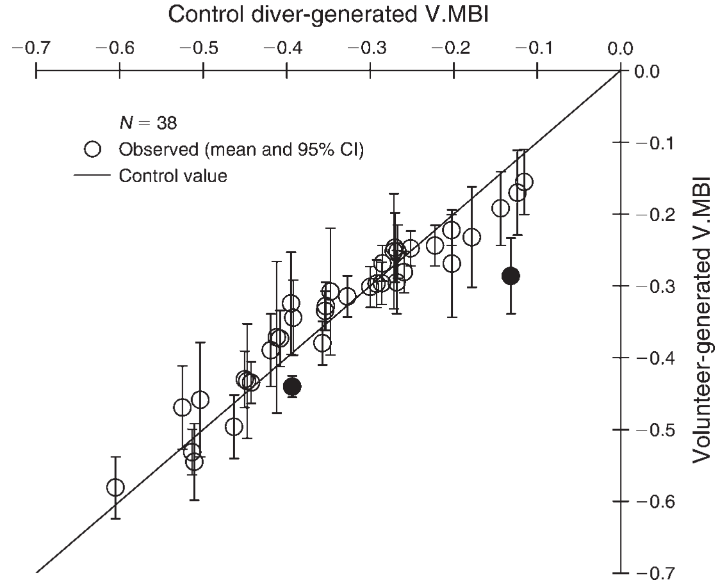

FIG. 1. Validation trials: comparison of the volunteer results with those of the control diver. The marine biodiversity index results (V.MBI) calculated from volunteers' data are compared with those calculated from the scientist control diver's data. The validation trials were performed during the four years of research from April 2002 to October 2005. Black points indicate volunteer-generated values that are significantly different from the control diver-generated values. *N* is the number of validation trials.

(CV) per team. While there was no trend in the correctness of abundance ratings with diving certification level of team members ($\rho_s = -0.097$, $N = 38$, $P = 0.562$), group size of participants ($\rho_s = -0.161$, $N = 38$, $P = 0.334$), or depth of the trial ($\rho_s = -0.302$, $N = 38$, $P = 0.065$), a negative correlation was detected with dive time of the trial ($\rho_s = -0.385$, $N = 38$, $P = 0.017$). The regression analyses, CAR (%) = −0.414[time (in minutes)] + 100.184, indicated a decrease of 4 points in CAR for every 10 minutes of dive time.

According to the α correlation test (Table 2), only two teams (5.3%) performed with an insufficient level of reliability (α, 95% CL lower bound ≤ 50%); three teams (7.9%) scored acceptable relationship with the control diver census (α, 95% CL lower bound > 50% ≤ 60%), 12 teams (31.6%) scored an effective reliability level (α, 95% CL lower bound > 60% ≤ 70%), and 21 teams (55.3%) performed from definitive to very high levels of reliability (α, 95% CL lower bound > 70% ≤ 100%). Intra-group variation was approximately 15% (CV) per team. α correlation coefficient was not correlated with diving certification level ($\rho_s = -0.264$, $N = 38$, $P = 0.110$), group size of participants ($\rho_s = 0.070$, $N = 38$, $P = 0.675$), depth ($\rho_s = -0.131$, $N = 38$, $P = 0.433$), or dive time of the trial ($\rho_s = -0.046$, $N = 38$, $P = 0.783$), but it showed a positive trend from the first to the last year of the trials ($\rho_s = 0.711$, $N = 38$, $P < 0.001$). The regression analyses (α(%) = 6.394[time (in years)] + 62.036) indicated a 6-point increase in reliability each year.

According to the Czekanowki's proportional similarity index, SI (Table 2), 11 teams (28.9%) performed with levels of precision below the sufficiency threshold (SI, 95% CL lower bound ≤ 50%); 25 teams (65.8%) scored a sufficient level of precision (SI, 95% CL lower bound > 50% ≤ 75%), and 2 teams (5.3%) scored high levels of precision (SI, 95% CL lower bound > 75% ≤ 100%). Intra-group variation was approximately 22% (CV) per team. The similarity index was not correlated with diving certification level ($\rho_s = -0.222$, $N = 38$, $P = 0.181$), number of participants in the trial group ($\rho_s = 0.042$, $N = 38$, $P = 0.802$), depth ($\rho_s = -0.108$, $N = 38$, $P = 0.518$), or dive time of the trial ($\rho_s = 0.051$, $N = 38$, $P = 0.763$), but it showed a positive trend from the first to the last year of the trials ($\rho_s = 0.734$, $N = 38$, $P < 0.001$). The regression analyses (SI(%) = 6.923[time (in years)] + 45.687) indicated a 7-point increase in precision each year.

A comparison of V.MBI values calculated from volunteers' data with those calculated from the control diver indicated that in 36 out of 38 trials (94.7%) the volunteer generated index was not significantly different from the control diver index (Fig. 1).

Marine biodiversity monitoring

Over four years, a total of 3825 volunteer recreational divers participated in the monitoring program (Table 4). They spent a total of 13 539 hours underwater and completed 18 757 valid survey questionnaires, with a mean dive time effort per questionnaire of 43.3 minutes (95% CI 43.1–43.5; Table 4). The great majority of questionnaires (88.1%) involved rocky habitats (Table 4). The low number of useful questionnaires from sandy habitats did not allow spatiotemporal analyses of results. Conversely, for rocky habitats, most questionnaires were useful (73.8–81.2% per year).

The geographic distribution of rocky habitat surveys was homogenous over the four years (α = 0.976; $\rho_s = 0.868$; Fig. 2). Most surveys were made in the northern Tyrrhenian and Ligurian Seas, accounting for 61.9% of the total number of valid recorded questionnaires for rocky habitats. The total number of survey stations for rocky habitats was 209, of which 113 (54.1%) were surveyed for >1 year (47 stations for two years, 34 for three years, 32 for four years; detailed results from each

TABLE 4. Distribution of survey effort performed by volunteer recreational divers in the four years of research; only useful questionnaires were elaborated.

Year	No. volunteer divers	Hours of diving	Total valid questionnaires	Rocky bottom valid questionnaires		Sandy bottom valid questionnaires		Other habitat valid questionnaires	
				Recorded	Useful (%)	Recorded	Useful (%)	Recorded	Useful (%)
2002	936	2446	3342	2847	73.8	387	34.9	108	21.3
2003	1615	4459	6230	5544	79.3	428	19.2	258	46.5
2004	1214	3830	5313	4699	80.3	452	26.1	162	29.6
2005	803	2805	3872	3443	81.2	352	42.3	77	0.0
All years	3825	13 539	18 757	16 533	79.0	1619	29.9	605	31.6

Note: See *Materials and methods: Construction of the biodiversity evaluation model* for details.

survey station are available on Appendix D: Table D1). Mean depth of the surveys performed at the stations was homogeneous among years ($\alpha = 0.958$; $\rho_s = 0.898$); the most commonly surveyed depth range was between 11 and 30 m (90.0% of the stations). Also the mean time (date and hour) of the surveys performed at the stations was homogeneous among years (for the date, $\alpha = 0.851$, $\rho_s = 0.720$; for the hour, $\alpha = 0.907$, $\rho_s = 0.767$); the surveys were concentrated around the spring–summer period (83.3% of the stations had mean sampling date between May and August) and between late morning and early afternoon (84.7% of the stations had a mean sampling time between 10.00 and 15.00).

Of the 61 organismal taxa surveyed, 49.2% (30 taxa) were not common, with a sighting frequency (%SF, calculated on the total number of surveys over the four years) of $\leq$20%, 45.9% (28 taxa) were common (20% $<$ %SF $<$ 70%), and only 4.9% (3 taxa) were very common (%SF $\geq$ 70%; detailed data about each taxon are available on Appendix E: Table E1; taxa ranking according to sighting frequency is after Schmitt and Sullivan 1996, Darwall and Dulvy 1996). Most of the organismal taxa (54, 88.5%) had homogeneous sighting frequencies throughout the years ($\alpha = 0.925$, SE = 0.005; $\rho_s = 0.790$, SE = 0.012). Only seven taxa (11.5%) had significant annual sighting frequency differences (Fig. 3). In six cases, box crab (*Calappa granulata*), thornback ray (*Raja clavata*), John dory (*Zeus faber*), long-snouted branched seahorse (*Hippocampus ramulosus*), short-snouted seahorse (*Hippocampus hippocampus*), and flying gurnard (*Dactylopterus volitans*), the sighting frequencies had a negative trend over time (Jonckheere-Terpstra test, $P = 0.001$–0.014) and in one case, the pentagonal sea star (*Ceramaster placenta*), there were wide variations throughout the years without a trend (Jonckheere-Terpstra test, $P = 0.079$). Vegetal (H_{SHV}) and animal (H_{SHA}) biodiversity, sighting frequency of litter (%LF) and the marine biodiversity index (V.MBI) were homogeneous among years (for H_{SHV}, $\alpha = 0.868$, $\rho_s = 0.716$; for H_{SHA}, $\alpha = 0.869$, $\rho_s = 0.716$; for %LF, $\alpha = 0.939$, $\rho_s = 0.841$; for V.MBI, $\alpha = 0.826$, $\rho_s = 0.653$; Appendix E: Table E1).

The V.MBI calculated for the 209 stations did not change significantly over the project time scale, but it had a highly significant negative correlation with latitude ($\rho_s = -0.228$, $P < 0.001$; Fig. 4). The correlation analysis performed by aggregating stations into two macro-geographic areas showed the same trend: for the western sector, stations in the Ligurian, Tyrrhenian, and Sardinian Seas, and in the Sicilian Channel gave $\rho_s = -0.231$, $P < 0.01$, N stations = 172 (the ds-10 station was excluded from the correlation analysis because it was isolated and the only one in the Gulf of Lions); for the eastern sector, stations in the Adriatic and Northern Ionian Seas gave $\rho_s = -0.294$, $P < 0.05$, N stations = 35 (the sbv-6 station was excluded from the correlation analysis because it was isolated, and the only one in the Southern Ionian Sea).

With the intention to critically evaluate the rationalization of survey effort requested to volunteers divers, the "best" match between the multivariate among-sample pattern depicted in Fig. 4, which was derived from the full assemblage of variables listed in the survey questionnaire (62: 61 organismal taxa plus litter), 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, turned out to be the subset of 27 organismal taxa listed in Table 3, representing the 43.5% of the original list of variables.

DISCUSSION

Validation trials: quality of recreational volunteer-generated data

The levels of accuracy performed during validation trials were encouraging given the number of species surveyed and the recreational dive profile (i.e., the divers did not follow pre-oriented transects, but they dived following the normal recreational dive path for a given dive site). Accuracy was comparable to that performed by conservation volunteer divers on precise transects in other projects (Mumby et al. 1995, Darwall and Dulvy 1996), or in community-based terrestrial monitoring (Evans et al. 2000). At greater than the high level of accuracy of 80% (categorized high by Delaney et al. 2008), the accuracy reached by volunteers in some trials was particularly impressive, as impressive was the results that only in two trials out of 38 (5.3%), the V.MBI

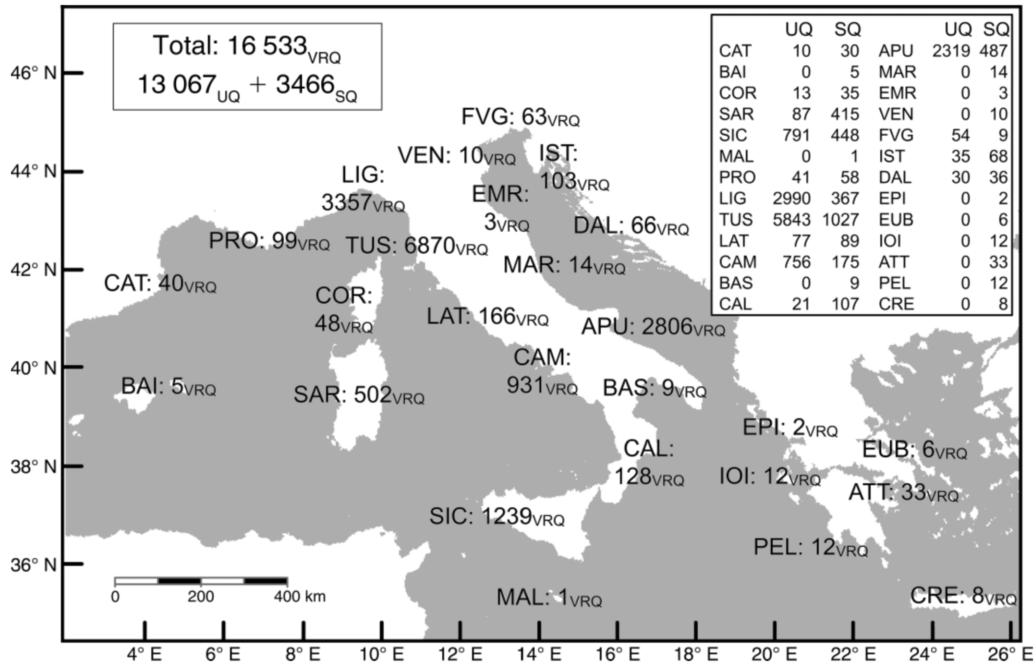

FIG. 2. Geographic distribution of the survey effort performed on rocky bottom habitats over the four years of research (2002–2005). The total number of valid recorded questionnaires (VRQ) was divided into useful questionnaires (UQ), those coming from survey stations, and sparse questionnaires (SQ), those coming from diving sites that failed to reach an annual quorum of 10 recorded questionnaires. Key to site abbreviations: APU, Apulia; ATT, Attica; BAI, Balearic Islands; BAS, Basilicata; CAL, Calabria; CAM, Campania; CAT, Catalonia; COR, Corsica; CRE, Crete; DAL, Dalmatia; EMR, Emilia-Romagna; EPI, Epirus; EUB, Euboea; FVG, Friuli-Venezia Giulia; IOI, Ionian Islands; IST, Istria; LAT, Latium; LIG, Liguria; MAL, Malta; MAR, Marches; PEL, Peloponnesus; PRO, Provence; SAR, Sardinia; SIC, Sicily; TUS, Tuscany; VEN, Veneto.

generated by the volunteers was significantly different from the control value generated by the scientist diver.

Since temporal and spatial comparisons of sites are based upon the survey data obtained by volunteers, attaining high consistency is, therefore, essential for comparative data analyses. The level of consistency reached by volunteers during validation trials is comparable to that performed by conservation volunteer divers on precise transects (Mumby et al. 1995), and in some trials consistency resulted greater than 70%.

One trend related to both data accuracy and consistency emerged, with the presence of a clear improvement in data quality from the first through to the last year of validation trials. This result was not surprising, considering the key presence of positive feedback during the survey program. Feedback, corrections and learning were given by trained professional divers (trained divemasters and instructors that guided the volunteers during the dive) under normal survey conditions. After each dive, trained professional divers debriefed volunteer divers to highlight areas of weakness, source of inaccuracy, and taxa misidentification. Among the several potential sources of group variation, diligence may explain the negative correlation between the level of consistency reached in the validation trial and the diving certification level of group members. First level divers tend to stay in pairs, close to each other, and to follow the divemaster along the dive path with attention; in contrast more highly qualified divers are less diligent, and tend to diversify from the path, consequently recording different sightings and leading to decreased correlation among recorded data.

Similarly to conservation volunteers on precise transects (Mumby et al. 1995, Bell 2007), the positive correlation between correct identification and the taxa presence 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 rare/cryptic taxa, even if the identification of these of taxa was specifically addressed in the training program. The intercept of the regression analyses between correct identification and taxa presence frequency suggested that even the rarest taxa tend to be correctly identified by more than 50% of volunteers, which represents sufficient correct identification.

The negative regression between dive time and the capability of volunteers to assign precise ordinal abundance ratings indicates that after 45 minutes of dive, which represent a mean recreational dive time in temperate water, the correctness of abundance ratings is still above 80%, and that after 60 minutes (long recreational dive time in temperate water) the correctness of abundance ratings is still 75%. These data

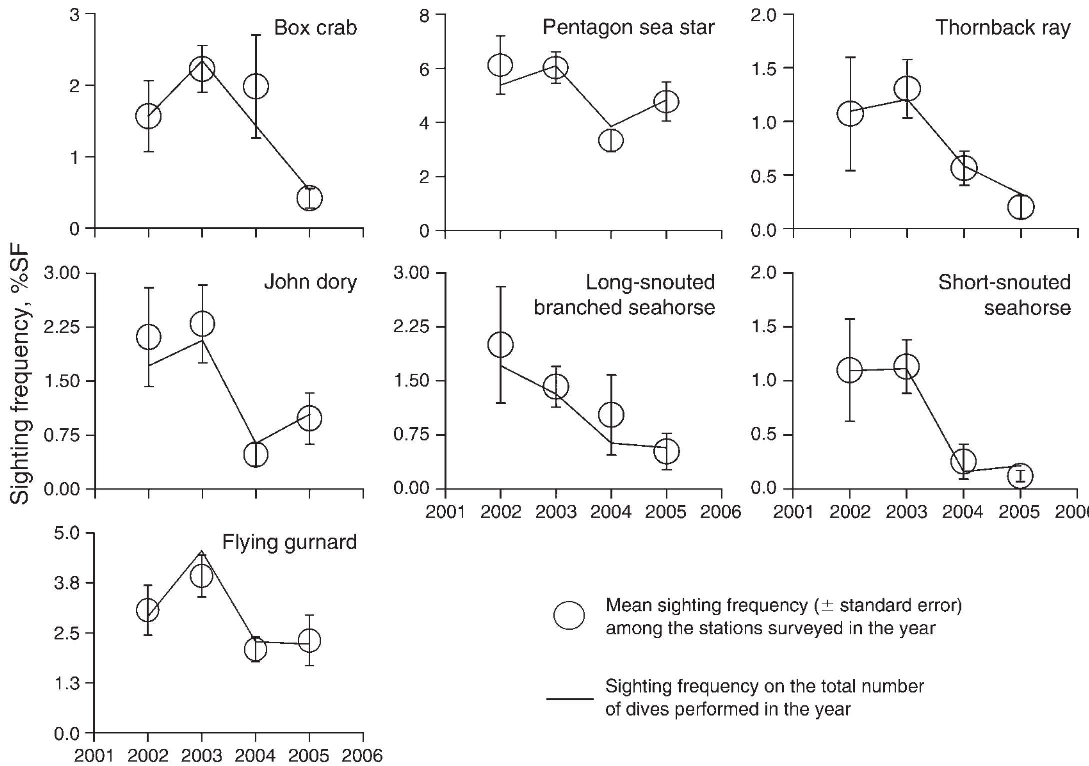

FIG. 3. Taxa with non-homogeneous sighting frequencies among the years: box crab (*Calappa granulata*), pentagon sea star (*Ceramaster placenta*), thornback ray (*Raja clavata*), John dory (*Zeus faber*), long-snouted branched seahorse (*Hippocampus ramulosus*), short-snouted seahorse (*Hippocampus hippocampus*), flying gurnard (*Dactylopterus volitans*). For these taxa the sighting frequency (%SF, percentage of dives where the taxon was sighted) is represented over the four-year study.

suggest that only after very long dive times (which are highly improbable for recreational dives in temperate waters) physical, physiological, and psychological factors (tiredness, chilling, possible nitrogen narcosis effects, anxiety, memory recall, fatigue) can significantly reduce survey performance at the depths were recreational volunteers performed (4–28 m) and with a normal recreational SCUBA gear.

Problems and limitations

Some studies show that under conditions of appropriate recruitment and training, volunteer-collected data are qualitatively equivalent to those collected by professional researchers and useful for resource management (Darwall and Dulvy 1996, Schmitt and Sullivan 1996, Fore et al. 2001, Greenwood 2003, Newman et al. 2003, Pattengill-Semmens and Semmens 2003, Boudreau and Yan 2004, Bell 2007, Tobias and Brightsmith 2007). There were a number of features of this study that indicated reliability of the volunteer-collected data presented here. The points that showed that acceptable level of reliability was achieved are outlined below:

1) The data were markedly consistent across years, indicating a strong degree of reliability, as in our previous volunteer-based marine conservation monitoring project (Goffredo et al. 2004);

2) Trends in this data set were corroborated by data in scientific literature and databases;

3) The results of the validation trials indicated that volunteers performed with levels of accuracy and consistency comparable to those of conservation volunteers on precise transects in other projects (Mumby et al. 1995, Darwall and Dulvy 1996, Evans et al. 2000).

The reasons why reliability was achieved are:

1) Volunteers were trained and assisted during data collection in the field by dive guides and instructors who had previously attended workshops and received training on project objectives and methodology by professional researchers;

2) The method was designed to be suitable for amateurs (i.e., user-friendly questionnaire and taxa that are easily recognizable by recreational divers);

3) Information requested on the questionnaire such as dive location, depth, dive time, and habitat are details that most divers routinely record in their personal dive logs, whether the purpose of the dive is recreational or for data collection; selection of appropriate tasks for volunteers at the research planning stage of the project is fundamental, since volunteer skills and abilities vary, and we only wanted volunteers collect data for which they could be trained quickly and reliably.

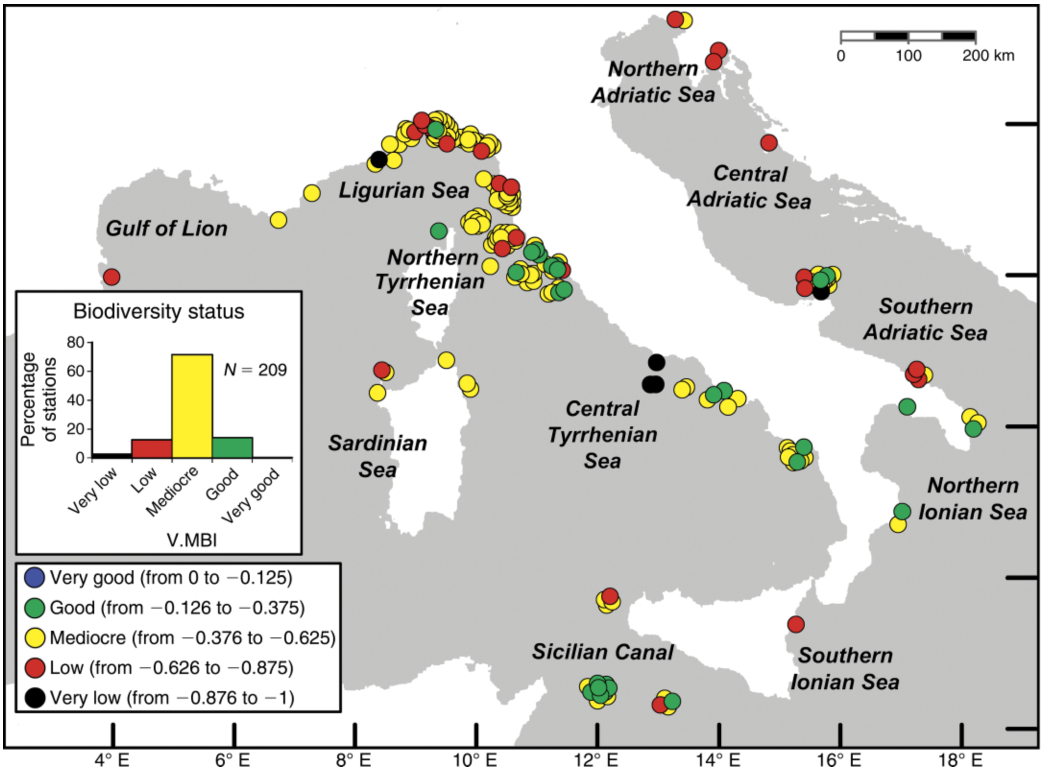

FIG. 4. Marine biodiversity index (V.MBI) in the 209 stations surveyed in the four years of research (2002–2005). Marine biodiversity measured by the index in the 209 stations gave a Gaussian distribution, with most stations (71.3%) being of mediocre status. The index did not show maximum status class (very good) in any of the stations. Summary measures by region are presented in Appendix F: Figs. F1–F3.

The primary limiting factor in involving citizen-volunteers was the difficulty in obtaining data homogeneously spatially distributed. In fact, most questionnaires came from rocky habitats along Ligurian and northern Tyrrhenian sea coasts. This biased sampling effort may be explained by recreational divers' preference for rocky habitats, which tend to be more biodiverse and are therefore more interesting to visit than sedimentary habitats (Goffredo et al. 2004). Attempts made to encourage data collection on sandy bottoms (in the form of prizes; as in Goffredo et al. 2004) were not successful in increasing surveys in this habitat. The northwestern coast was surveyed more because: (1) the Tyrrhenian and Ligurian Seas are more attractive to divers because of water clarity compared to the central northern Adriatic Sea; (2) there are proportionately more diving centers along the Northern Tyrrhenian and Ligurian sea coasts providing logistical appeal (21.4 centers per 100 km of coast vs. a national average of 6.7); (3) the national headquarters of some of the diving agencies that officially supported the project are located in northern Italy.

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 (World Recreational Scuba Training Council 2006) and the preferred period for diving is the warm season during the daytime (only advanced divers perform night dives).

Volunteer participation

Participation reached its peak in the second year when the popular national scientific magazine, Quark, and the Italian Tour Operators Association became official partners. They helped to promote the project and offered prizes to reward volunteers. After the second year, there was a drop in the number of participants, especially in the fourth year (–33.9% in 2005 compared to the previous year). This drop may have been due to the departure of one of the partner diving agencies from the project, poor weather during the summer of 2005 and, according to interviews with tour operators, the economic crisis that limited general public expenditure on recreation. Unfortunately we did not collect data on the "enjoyment" of the survey dives compared to non-survey dives as experienced by the divers. However, the mean annual survey effort per individual volunteer constantly increased over the four-year period (mean number of questionnaires recorded /hours of diving a year per volunteer: first year 3.6/2.6, second year 3.9/2.8, third year 4.4/3.2, fourth year 4.8/3.5). This positive trend may reflect the growing interest and loyalty of volunteer divers to the project.

Assessed biodiversity and environmental conditions

Given that our study lasted only four years, it is not surprising that sighting frequencies of most taxa were consistent over the years. Of the seven exceptions, six showed significant declines. It is known that four of these have declined in the long term in the Mediterranean sea due to over-fishing or habitat damage (thornback ray, John Dory, and the two seahorses: Garofalo et al. 2003, Boudouresque 2004, Vrgoč et al. 2006).

The fact that the presence of litter in the environment did not substantially change over a four-year period is also expected, unless clean-up operations are performed (Davenport and Davenport 2006).

Our findings regarding increasing of the V.MBI with decreasing latitude can be interpreted as an improvement in environmental conditions at coastal stations going from north to south. An alternative explanation is that the detected variation is just a latitudinal variation, given the geographic scale. The first interpretation is supported by the data from the Italian Ministry of the Environment. Concurrent with this study, the Ministry conducted sea water quality surveys, including parameters reflecting hygiene/health risks (CAM index, sea water classification; Italian Ministry of the Environment and Land and Sea Protection 2006). For areas overlapping with those monitored by our study, data from the Italian Ministry corroborate negative correlations between latitude and environmental quality: for the western region $\rho_s = -0.277$, $P < 0.01$, 114 stations; for the eastern region $\rho_s = -0.543$, $P < 0.001$, 46 stations. In the seas surrounding Italy stressors (overexploitation of fisheries, eutrophication, domestic waste, hydrocarbons and oil, heavy metals,) are more prominent in the northern areas than in southern ones with some northern locations extremely degraded (Caddy 1998, Danovaro 2003, Thibaut et al. 2005). In the northern parts of the Western Mediterranean, a marked reduction in overall marine biodiversity has also resulted from both biological invasions of alien species and the largest mass mortality event of benthic invertebrates ever recorded in the Mediterranean basin, which was most probably caused by climatic anomalies (Boudouresque and Verlaque 2005, Linares et al. 2005).

According to the BEST test of searching over subsets of variables for a combination that optimizes the survey effort, 27 out of 62 taxa (43.5% of the original assemblage) were sufficient to generate the same multivariate sample pattern. For future monitoring research, limitation of items to the most necessary could, one hand lead to a reduction in effort during both volunteer training and field work, but on the other hand, it could limit the appeal of the project to potential volunteers. Removing attractive species from the questionnaire (for example red coral, yellow cluster anemone, dotted sea slug, common octopus, lobster, spider crab, moray eel, sea raven, rainbow wrasse, anglerfish) is likely to have decreased volunteers' enjoinment and loyalty, and also the educational potential of the project. Adding charismatic organisms that citizen volunteers are likely to see to the survey in order to give them something to report with satisfaction is an approach successfully experimented in ornithological studies (Greenwood 2007).

Conclusions

This project successfully involved citizens that use the sea for recreational purposes (such as tourist divers and snorkelers) in the collection of data recording the presence of biological taxa and litter. The conclusions that can be drawn from this work are:

1) Trained recreational divers achieve an acceptable level of accuracy and consistency.

2) Recreational diver-based surveys can provide useful information in marine biodiversity surveys, significantly reducing financial and time costs. With the participation of recreational divers we were able to amass a large data set, covering a wide geographic area, over a relatively short period of time. We estimated that in order to collect the same amount of data obtained by the volunteers in this study a single professional would have needed 45 years and more than US$4 758 000.

3) Recreational divers tend to concentrate on rocky bottoms, in a scheme where they were not forced to cover any habitats in particular.

4) The quality of data improved with time, as the survey organizers and instructors gained experience of how to brief volunteers.

5) The consistency of the records of high level divers was less than the consistency of low-level divers.

6) A subset of the taxa would have been adequate for the survey purposes, though it was probably useful to include at least some of the "unnecessary" taxa in order to maintain the interest of the volunteers.

In our experience, and of other institutes (Darwall and Dulvy 1996, U.S. Environmental Protection Agency 1997, Evans et al. 2000, Foster-Smith and Evans 2003, Bhattacharjee 2005, Sharpe and Conrad 2006, Bell 2007), "citizen science" can complement and augment conventional methods, and it can be a key solution to personnel needed to carry out research. Given the scarce government resources, the role of citizens and the civil community in monitoring is especially important, even when volunteers need special skills, as those necessary for exploring the underwater environment.

Citizen involvement as ecological research operators improves scientific literacy and environmental awareness and education amongst all age groups in the community (Evans et al. 2005), and determines a more sustainable approach to the environment (Medio et al. 1997). Environmental education provides the long-term solution to sustainable management of the environment. However, formal education operates under severe curriculum constraints and has been at best only partially successful in achieving this goal (Holdren and Ehrlich 1971, Evans 1988). There is a need therefore for new educational initiatives. "Divers for the Environment: Mediterranean Underwater Biodiversity Project" was one of such initiative. Education, the "citizen science" approach, the development of an interdisciplinary mentality in researchers, and the realization of research projects that take into account the needs and motivations of people are practical efforts necessary to complete the mission of modern conservation biology (Meffe et al. 2006). This report may inspire other researchers to incorporate citizen scientists in their projects.

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APPENDIX A

Survey questionnaires: section with photographs to identify the surveyed taxa (*Ecological Archives* A020-081-A1).

APPENDIX B

Survey questionnaires: section with a form to record data (*Ecological Archives* A020-081-A2).

APPENDIX C

Volunteer divers training and involvement (*Ecological Archives* A020-081-A3).

APPENDIX D

Geographic coordinates, number of useful questionnaires, bathymetry of survey, and moment of survey in the survey stations on rocky bottom (*Ecological Archives* A020-081-A4).

APPENDIX E

Taxa sighting frequency, observed biodiversity, vegetal and animal litter sighting frequency, and marine biodiversity index in the survey stations on rocky bottom (*Ecological Archives* A020-081-A5).

APPENDIX F

Summary measures by region of marine biodiversity index (V.MBI) in the four years of research (2002–2005) (*Ecological Archives* A020-081-A6).

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ORIGINAL PAPER

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

Simone Branchini · Francesco Pensa · Patrizia Neri · Bianca Maria Tonucci · Lisa Mattielli · Anna Collavo · Maria Elena Sillingardi · Corrado Piccinetti · Francesco Zaccanti · Stefano Goffredo

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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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S. Branchini · F. Pensa · P. Neri · B. M. Tonucci · L. Mattielli · A. Collavo · M. E. Sillingardi · F. Zaccanti · S. Goffredo (✉)
Marine Science Group, Citizen Science Lab, Department of Biological, Geological and Environmental Sciences, Section of Biology, University of Bologna, Via F. Selmi 3, 40126 Bologna, Italy
e-mail: s.goffredo@unibo.it

C. Piccinetti
Laboratory of Fisheries and Marine Biology at Fano, University of Bologna, Viale Adriatico 1/N, 61032 Fano, PU, Italy

Keywords Biodiversity · Environmental monitoring · Citizen science · Red Sea · SCUBA divers · Volunteers in research

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.

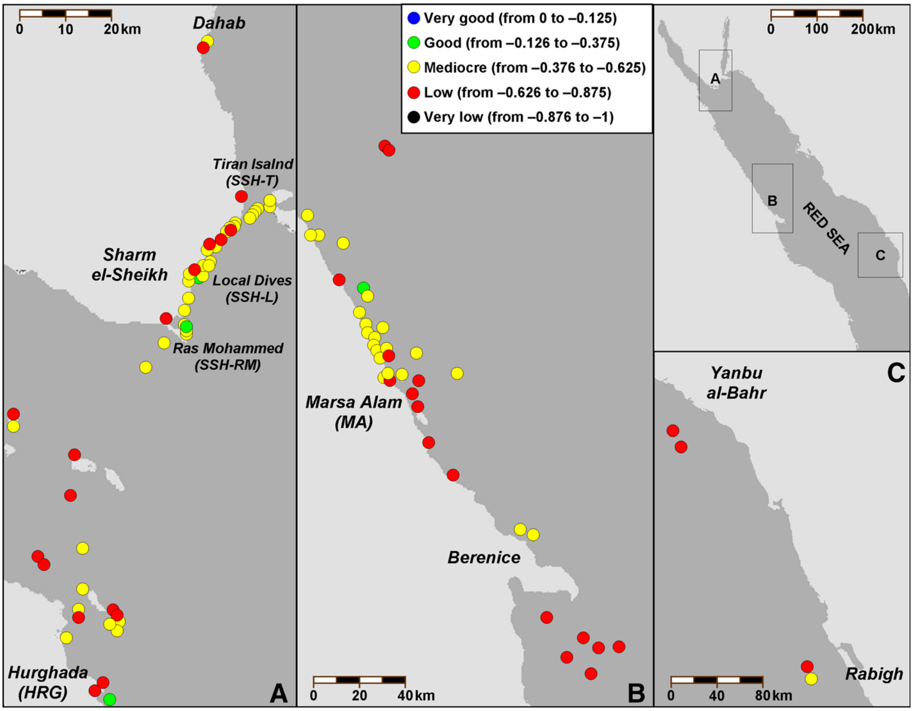

Fig. 1 Volunteer-Marine biodiversity index (V.MBI). The figure shows the marine biodiversity in index in the 100 stations surveyed calculated from the data collected by volunteers in the 4 years of research (2007–2010). In *parenthesis* are the abbreviations of five areas that presented a sufficient 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 $\leq$ 60 %), 36 teams (59.0 %) scored an effective reliability level (α, 60 < 95 % CI lower bound $\leq$ 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 $\leq$ 50 %); 53 teams (86.9 %) scored a sufficient level of precision (SI, 50 < 95 % CI lower bound $\leq$ 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 ($\alpha = 0.885$, 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 %,

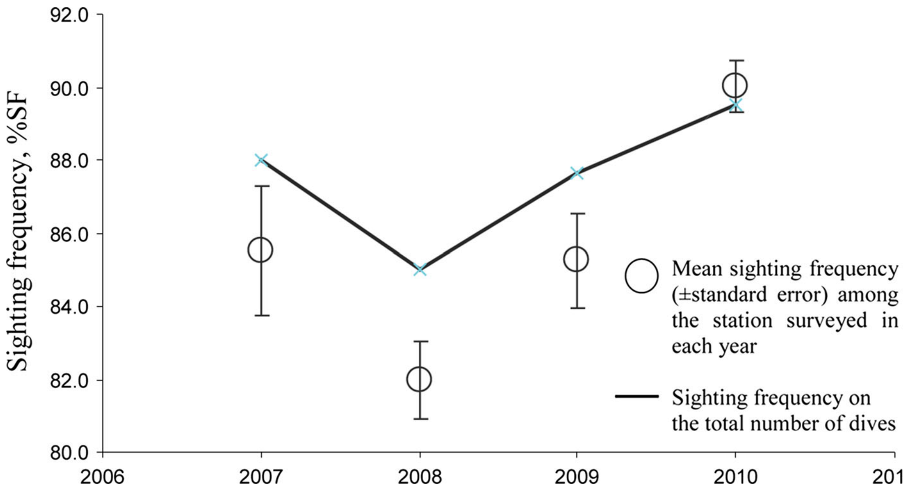

Fig. 2 Sighting frequency of fire coral (*Millepora sp*.). The sighting frequency of fire coral (%SF), which was not homogenous among years, is represented over the four year period

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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RESEARCH ARTICLE

Participating in a Citizen Science Monitoring Program: Implications for Environmental Education

Simone Branchini[1], Marta Meschini[1], Claudia Covi[1], Corrado Piccinetti[2], Francesco Zaccanti[1], Stefano Goffredo[1]*

1 Marine Science Group, Citizen Science Lab, Department of Biological, Geological and Environmental Sciences, Section of Biology, University of Bologna, Via F. Selmi 3, I-40126, Bologna, Italy, European Union, **2** Laboratory of Fisheries and Marine Biology at Fano, University of Bologna, Viale Adriatico 1/N, I-61032, Fano (PU), Italy, European Union

* s.goffredo@unibo.it

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Abstract

Tourism is of growing economical importance to many nations, in particular for developing countries. Although tourism is an important economic vehicle for the host country, its continued growth has led to on-going concerns about its environmental sustainability. Coastal and marine tourism can directly affect the environment through direct and indirect tourist activities. For these reasons tourism sector needs practical actions of sustainability. Several studies have shown how education minimizes the impact on and is proactive for, preserving the natural resources. This paper evaluates the effectiveness of a citizen science program to improve the environmental education of the volunteers, by means of questionnaires provided to participants to a volunteer-based Red Sea coral reef monitoring program (STEproject). Fifteen multiple-choice questions evaluated the level of knowledge on the basic coral reef biology and ecology and the awareness on the impact of human behaviour on the environment. Volunteers filled in questionnaires twice, once at the beginning, before being involved in the project and again at the end of their stay, after several days participation in the program. We found that the participation in STEproject significantly increased both the knowledge of coral reef biology and ecology and the awareness of human behavioural impacts on the environment, but was more effective on the former. We also detected that tourists with a higher education level have a higher initial level of environmental education than less educated people and that the project was more effective on divers than snorkelers. This study has emphasized that citizen science projects have an important and effective educational value and has suggested that tourism and diving stakeholders should increase their commitment and efforts to these programs

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Introduction

Tourism is a cross-cutting sector, involving a large diversity of services and professions, linked to many other economic activities and policy areas. For this reason, tourism is one of the most important forces shaping our world, which makes it worth devoting attention to [1; 2]. Tourism is of growing economical importance to many nations and is recognized as the largest export earner in the world and as an important provider of foreign exchange and employment [2; 3]. To date, the tourism industry represents 9% of global GDP, which corresponds to USD 1.4 trillion in international exports [4]. According to the United Nations World Tourism Organization, despite occasional shocks, such as the global economical crisis, international tourist arrivals have shown virtually uninterrupted growth (from 528 million in 1995 to 703 million in 2002 and 1085 million in 2013) and they are expected to increase by 3.3% per year from 2010 to 2030, reaching 1.8 billions by 2030. In particular, visitors in emerging destinations (+ 4.4% per year) are expected to increase at twice the rate of those in advanced economies (+ 2.2% per year) [4; 5].

For these reasons, developing countries are encouraged to use tourism as a means of economic development that wreaks less damage than extractive industries [6] and can be used to create many employment opportunities for the local population and to generate revenue for other developmental activities [7]. In Egypt, tourism generates an estimated USD 7.8 billion annually (equivalent to 11.3% of the national gross domestic product) and represents 47.8% of international exports, providing employment for 12.6% of the national work force [8; Egyptian Tourist Authority, personal communication]. Although the Great Pyramids of Giza and The Nile River are some of the world's most iconic touristic attractions, the Red Sea coastal zone attracts great numbers of tourists. In the period 2010–2013, more than 30 million people arrived from all over the world to visit the coral reefs of the Egyptian Red Sea, providing growing demand for touristic infrastructures and delivering important foreign revenue to the regional and national economy (according to CAPMAS–Egyptian Central Agency for Public Mobilization and Statistics; www.capmas.gov.eg).

Although tourism is an important economic vehicle for the host country, its continued growth has led to on-going concerns about its environmental sustainability and the increasing criticism on the negative impacts of tourism began in the 1980s [9–15]. In particular, coastal and marine tourism can directly affect the environment through localized pollution, resource depletion, habitat loss, conversion and habitat and wildlife disturbance. In addition, these impacts have been shown to reduce recreational enjoyment, decreasing tourism business [16; 17]. Physical development of resorts, consumption of fuel by buildings, aircraft, trains, buses, taxis and cars, overuse of water resources, oil-spills, pollution by vehicle emissions, sewage, litter and boat anchors and groundings have caused ecosystem degradation. Several studies have shown how the direct presence and activities of the tourists along the shores have a negative impact on the environment [18–21].

Although all coastal habitats are affected by tourism [22], coral reef habitats seem more susceptible to an uncontrolled and unplanned tourist flow. Recreational marine activities affect corals in many ways, such as trampling, breakages, physical contact with organisms, sediment resuspension, behavioural changes among marine life due to food offerings, animal harassment, trash and debris production. For example, snorkelers and SCUBA divers can inadvertently damage corals by clambering over them, by kicking them accidentally with their fins, or by stirring up silt that suffocates them (e.g. [18; 19]). They may unintentionally damage stony corals and other benthic reef organisms by breaking their skeletons and abrading their tissues. Also other activities, not properly related with snorkelling or SCUBA diving, are reasonably considered dangerous for the environment, such as shell collecting, feeding fish and buying or collecting "marine" souvenirs.

The tourism sector needs practical actions to ensure sustainability. These actions must be integrated into all steps of tourism planning and coordinated at community or regional level, and applied to all forms of tourism in all types of destinations. The importance of raising environmental awareness and education among tourists is emphasized by Lansing and De Vries [2]. Education minimizes the impact on and is proactive for preserving the natural resources [18, 23–26]. Medio et al. [27] showed that divers did less damage after a 45-minute illustrated dive briefing covering reef biology, contacts caused by divers and the concept of a protected area. Divers were shown the different forms of live reef cover and non-living substrate, such as rock and dead coral, to illustrate areas of the reef that could be touched without damage it. Also, Rouphael and Inglis [28] suggested that the probability of divers coming into contact with corals is determined also by their awareness of the environmental consequences of their actions. Barradas et al. [29] state that no sustainable actions (such as: limitation of water consumption, wasting and pollution reduction, environmental limitations) are effective without a good educational program. Nevertheless, dive companies often give briefings that last only a few minutes and in many instances they do not include sustainability tips [16].

This paper evaluates the effectiveness of a citizen science program to improve the environmental education of the volunteers, by involving them in a practical biodiversity monitoring program. Through a specific questionnaire, the level of environmental education of volunteers was assessed before the participation in a coral reef biodiversity monitoring program and after several participations to it.

Methods

STE project

"STE: Scuba Tourism for the Environment" (STE) is a volunteer-based coral reef biodiversity monitoring program based, which is being implemented in three countries facing the Red Sea: Egypt, Sudan and Saudi Arabia. The main project goals have been to: 1) collect information on the presence and abundance of key coral reef taxa, by using the skills of non-specialist volunteers, and 2) improve their environmental awareness, by engaging them in a practical conservation program. The "recreational monitoring" approach [30; 31] used in STEproject allowed volunteers to carry out normal recreational activities during their reef visits and ensured the reliability of gathered data through standardized data collection. Without forcing volunteers to follow pre-selected transects or strict survey protocols, this approach guaranteed the enjoyment of the volunteer in project participation and allowed the engagement of a relevant number of volunteers.

Since 2007, user-friendly questionnaires distributed to volunteer recreational divers and snorkelers were used to gather key information on coral reef ecosystem health. During seven years of data collection (2007–2013), 14,502 volunteers were involved in the project resulting in 29,312 completed questionnaires. The data collected was useful to detect environmental status trends and inform the local environmental managers on the effectiveness of current management actions and how to direct future efforts [32].

The research team held training courses for professional divers before the beginning of the project and yearly throughout the project. The research team trained professional divers about the project's objectives and methods, including taxa identification and data recording (the training program consisted of 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. Subsequently in the field, divemasters and SCUBA instructors, with the help of students of the research team, briefed the divers, providing information on 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, providing more information about environmental and ecological issues (see [32], for detailed training procedure).

The questionnaire contained an initial section providing guidance for limiting anthropogenic impacts on the reef and throughout the vacation period (see [32], for the questionnaire). This section could be torn off and conserved by volunteers after their participation in the project.

Environmental education: evaluation questionnaire

To verify the effectiveness of the project in increasing the environmental education of the volunteers, an additional questionnaire was created and provided in Egypt to a subset of volunteers during the years 2012 and 2013. This questionnaire consisted of two sections. The first section aimed to collect personal and demographic data of the volunteer to identify factors that could influence the initial level of environmental education and its improvement after the project (Table 1): 1) gender (male, female); age (five age categories); level of education (five categories, according to Italian level of education); diving qualification (six categories, according to World Recreational Scuba Training Council–WRSTC). An additional question assessed if the volunteer already participated in the project: "How many questionnaires of the STEproject did you fill out until today?". A statement declared that the survey was used for research purpose. The second section evaluated the level of environmental education. It contained 15 multiple-choice questions. These questions contained two different kinds of issues. The first set of questions (9 questions, from number 1 to number 9; Fig 1) covered the knowledge on the basic coral reef biology and ecology, hereafter called reef biology questions. The second set of questions (6 questions, from number 10 to number 15; Fig 1) dealt with the awareness on the impact of human behaviour on the environment, hereafter called human impact questions.

Table 1. Volunteers' personal and demographic data collected to identify factors that could influence the initial level of environmental awareness and its improvement after the project.

Factor	Categories
Gender	1: Female
	2: Male
Age	1: < 15 years old
	2: 16–30 years old
	3: 31–45 years old
	4: 46–60 years old
	5: > 61 years old
Level of education	1: Compulsory School
	2: High School
	3: Bachelor Degree (B.Sc.)
	4: Master Degree (M.Sc.)
	5: Doctorate of Philosophy (Ph.D.)
Diving qualification	1: None
	2: Open Water Diver (O.W.D.)
	3: Advanced Open Water Diver (A.O.W.D.)
	4: Rescue Diver
	5: Divemaster
	6: Instructor

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Choose the correct answers:

1) Corals are sturdy organisms.
☐ true. ☐ FALSE ☐ Don't know.

2) Corals are:
☐ Plants. ☐ ANIMALS. ☐ Minerals. ☐ Other. ☐ Don't know.

3) Stony corals get most of their nutrition from the:
☐ SYMBIOTIC ALGAE. ☐ They don't feed, are plants. ☐ Sand.
☐ Plankton floating in the water. ☐ Don't know.

4) The shark is a:
☐ FISH. ☐ Mammal. ☐ Other. ☐ Don't know.

5) The turtle is a:
☐ Fish. ☐ REPTILE. ☐ Amphibious ☐ Don't know.

6) The spiny starfish is dangerous for coral reefs.
☐ No, never. ☐ YES, BUT ONLY IF IT IS VERY NUMEROUS.
☐ Yes, it releases a toxic substance. ☐ Don't know

7) Coral reefs are threatened by: Choose all correct answers.
☐ SEA WATER ACIDIFICATION. ☐ SEA WATER WARMING. ☐ Strong marine currents.
☐ Big marine predators (such as sharks). ☐ FREE BOATS ANCHORING.
☐ POLLUTION. ☐ HURRICANES. ☐ Don't know.

8) Today, the coral reefs condition is:
☐ Excellent, practically in virgin condition. ☐ Very good, just few areas are suffering.
☐ Getting better. ☐ IN DANGER, LARGE AREAS ARE THREATENED BY CLIMATE CHANGE AND LOCAL ANTHROPOGENIC STRESSES.
☐ In danger, surely they will disappear in few years. ☐ Don't know.

9) The parrot fish feeds on:
☐ Coral polyps. ☐ Little invertebrates that live in the sand .
☐ ALGAE. ☐ Don't know.

10) Snorkelers and divers can damage coral reef organisms by: Choose all correct answers.
☐ TOUCHING A MORAY EEL. ☐ FEEDING THEM TO SEE THEM CLOSER.
☐ MOVING SAND DURING FINNING. ☐ TOUCHING CORALS. ☐ Don't know.

11) Divers and snorkelers, by touching corals, damage them.
☐ No, in fact they scare off their natural predators. ☐ No, they don't interfere in any way.
☐ YES, THEY MAKE THEM MORE SUSCEPTIBLE TO DISEASES. ☐ Yes, but only if they collect them.
☐ Don't know.

12) Your position in the water, during snorkelling or diving, could severely damage corals.
☐ TRUE. ☐ False. ☐ Don't know.

13) Feeding fishes is wrong. Choose all correct answers.
☐ No, it allows weak organisms survival.
☐ YES, IT CHANGES THEIR BEHAVIOUR AND DIET.
☐ No, it lets to see fishes closer.
☐ YES, THEY CAN'T DIGEST SOME FOODS.
☐ Don't know.

14) It is wrong touching big marine organisms (moray eels, turtles, dolphins). Choose all correct answers.
☐ No, they enjoy. ☐ YES, IT REMOVES THEIR PROCTECTIVE MUCUS ☐ YES, THEY ARE SCARED
☐ No, if the are big. ☐ Don't know.

15) To buy souvenirs or collect organisms coming from the coral reefs (shells, star-fishes, etc.) is dangerous for the coral reefs.
☐ TRUE. ☐ False. ☐ Don't know.

Fig 1. Environmental education evaluation questionnaire. The figure show the section dedicated to the evaluation of the level of environmental education. The answers in capital letters show the correct answer. *STE project-Citixen Science Lab,Marine Science Group, Dipartimento di Biologia E.S., Universita di Bologna, Via Selmi 3,40126 Bologno, italy* www.marinesciencegroup.org

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There was only one correct answer, except when explicitly stated with the sentence "Choose all answers that you consider correct". We developed the questions tailored to a tropical marine environment and based on the content that the STEproject was expected to cover. Members of the STEproject research group working in the field provided the questionnaire to the volunteers twice, once at the beginning, before being involved in the project and again at the end of their stay, after several days participation in the program, so that every volunteer filled out the same questionnaire twice.

Participants (or parents/guardians in case of minors) gave their consent by signing a declaration inserted in the questionnaires. STEproject and its consent acquisition procedure have received the approval of Bioethics Committee of the University of Bologna.

The data were anonymously analysed. The second section was analysed giving a score for each answer. The score was negative if the answer was wrong, positive if it was correct and zero if it was "*I don't know*". The value of the score of each question was calculated so that the sum of all correct answers would be +1 and the sum of all the wrong answers -1. During the elaboration, we analysed and compared the overall questionnaire score (15 questions), the score of the reef biology questions (9 questions) and the score of the human impact questions (6 questions). For this reason we standardized all the scores ranging from 0 (all answers wrong) to 10 (all answers correct). We performed a volunteer-level analysis by comparing, for each volunteer, the total scores of the pre-questionnaire with those of the post-questionnaire, for all volunteers together and then splitting the volunteers according to their personal and demographic data (gender, age, level of education, diving qualification; Table 1).

Differences in the mean score of questionnaires were examined either by T-student test or by one-way analysis of variances (ANOVA), when the factors that could influence the initial level of environmental education and its improvement after the project were defined by more than two groups or categories.

Results

In two years a total of 212 volunteers completed 424 questionnaires. Most of the volunteers were men (129, 60.8%), but there was a considerable participation of women (83, 39.2%). The most frequent age group comprised 31 to 45-year-olds (84, 39.6%), followed by 46 to 60-year-olds (66, 31.1%) and 16 to 30-year-olds (44, 20.8%). The groups under 15 years-old (10, 4.7%) and over 60 years-old (8, 3.8%) had low numbers and were less surveyed. The level of education of the majority of volunteers was high school (95, 44.8%), 45 volunteers (21.2%) were master graduated, 42 (19.8%) completed the compulsory school, 27 (12.7%) had a bachelor degree and 3 were Doctors of Philosophy. A hundred and thirty-five (63.7%) volunteers were snorkelers, 60 (28.3%) were recreational divers (20 open water divers, 9.4%; 32 advanced open water divers, 15.1%; and 8 rescue diver, 3.8%) and 17 (8.0%) were professional divers (5 divemasters, 2.4%; 12 instructors, 5.7%). No volunteers had already participated in the STE project before filling the first environmental awareness evaluation questionnaire.

The comparison between the score of the pre-questionnaire with those of the post-questionnaire showed 192 cases (90.6%) where the post-questionnaire had a higher score than the first one, 12 cases (5.7%) where the score of the two questionnaires were equal and 8 cases (3.8%) where the post-questionnaire had a lower score than the first one. For the overall questionnaire, the reef biology and the human impact questions, the mean score of the post-questionnaire resulted significantly higher than that of the pre-questionnaire (respectively T = -18.959, $p < 0.01$; T = -17.385 $p < 0.01$; and T = -10.132, $p < 0.01$; Fig 2)

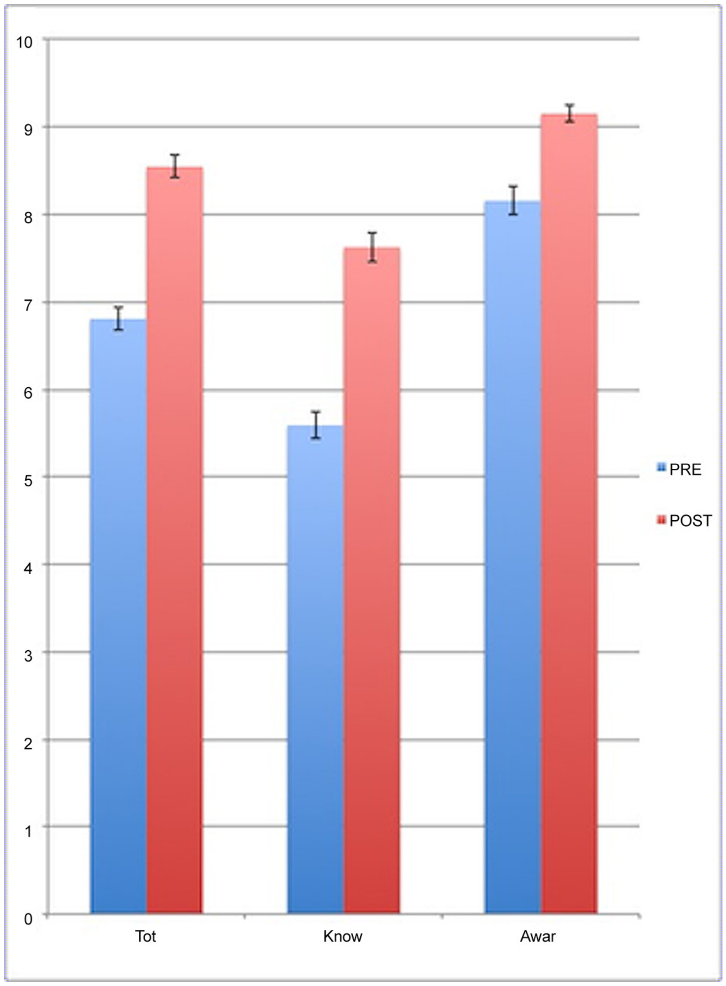

Fig 2. Mean score of the environmental education evaluation questionnaire. *Tot* represents the mean score of the overall questionnaires, *Know* represents the mean score of the reef biology questions and *Awar* represents the mean score of the human impact questions. Error bars are 95% confidence intervals (CI), N = 212.

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Both males and females showed the mean score of the post-questionnaire significantly higher than that of the pre-questionnaire for the overall questionnaire, the reef biology and the human impact questions (Table 2), without significant differences between genders (Table 3).

According to age, all categories showed the mean score of the post-questionnaire significantly higher than that of the pre-questionnaire for the overall questionnaire, the reef biology and the human impact questions (Table 2), without significant differences among the categories (Table 3).

According to the level of education, all categories showed the mean score of the post-questionnaire significantly higher than that of the pre-questionnaire for the overall questionnaire, the reef biology and the human impact questions (with the only exception of the category "*Doctor of Philosophy*" for the reef biology and the human impact questions; Table 2), without significant differences among education categories (Table 3). The categories were pooled into the two different groups: under-graduate (Compulsory School, High School and Bachelor Degree) and post-graduate (Master Degree and Doctorate of Philosophy). Both under-graduate and post-graduate showed the mean score of the post-questionnaire significantly higher than that

Table 2. Results of T-student test and the percent increase between the score of the post-questionnaire and the score of the pre-questionnaire for the overall questionnaire, the reef biology and the human impact questions.

			Overall questionnaire			*Knowledge questions*			*Awareness questions*		
		df	T	*p*	%	T	*p*	%	T	*p*	%
Gender	Female	166	-12.500	< 0.001	20.6	-11.129	< 0.001	26.1	-6.237	< 0.001	10.5
	Male	254	-14.300	< 0.001	19.1	-13.331	< 0.001	27.	-8.025	< 0.001	11.5
Age	< 15 y.o.	18	-3.813	0.001	16.1	-2.722	0.014	20.4	-3.500	0.003	11.1
	16–30 y.o.	86	-7.374	< 0.001	18.9	-7.365	< 0.001	28.2	-3.428	0.001	7.3
	31–45 y.o.	166	-13.171	< 0.001	20.7	-11.957	< 0.001	28.6	-6.093	< 0.001	10.8
	46–60 y.o.	130	-10.743	< 0.001	19.6	-10.493	< 0.001	25.0	-9.707	< 0.001	13.0
	> 61 y.o.	14	-3.086	0.011	17.9	-3.111	0.008	21.5	-3.874	0.002	13.3
Level of education	Compulsory School	82	-8.435	< 0.001	19.1	-7.078	< 0.001	24.3	-4.912	< 0.001	12.8
	High School	186	-13.746	< 0.001	19.6	-11.733	< 0.001	27.1	-7.119	< 0.001	10.1
	B.Sc.	52	-5.610	< 0.001	21.6	-6.263	< 0.001	28.9	-3.151	0.003	12.2
	M.Sc.	90	-8.022	< 0.001	19.2	-8.421	< 0.001	26.1	-4.614	< 0.001	10.5
	Ph.D.	4	-15.76	< 0.001	22.8	**-2.226**	**0.086**	37.1	**-1.131**	**0.321**	5.5
	Under-grad.	324	-8.825	< 0.001	19.8	-15.010	< 0.001	26.7	-8.938	< 0.001	11.1
	Post-grad.	96	-2.311	0.022	19.4	-8.735	< 0.001	26.8	-4.727	< 0.001	10.2
Diving qualification	None	270	-14.080	< 0.001	19.7	-14.055	< 0.001	27.2	-7.716	< 0.001	10.3
	O.W.D.	38	-6.068	< 0.001	21.6	-5.911	< 0.001	29.1	-3.371	0.002	11.6
	A.O.W.D.	60	-9.722	< 0.001	20.1	-6.028	< 0.001	25.3	-5.871	< 0.001	13.7
	RD	14	-3.685	0.003	15.3	**-2.090**	**0.055**	22.6	**-1.118**	**0.282**	6.5
	Divemaster	8	-4.470	0.004	31.2	-6.094	< 0.001	32.7	-2.708	0.027	29.1
	Instructor	22	-4.533	< 0.001	13.3	-4.462	< 0.001	20.9	**-0.811**	**0.426**	3.4
	Snorkelers	270	-14.08	< 0.001	19.7	-14.055	< 0.001	27.2	-7.716	< 0.001	10.3
	Divers	150	-13.421	< 0.001	19.7	-10.181	< 0.001	25.9	-6.589	< 0.001	11.9

The *Overall questionnaire* column represents the analyses performed on the 15 questions, the *Knowledge questions* column represents the analyses performed on the 9 questions on the knowledge on the basic coral reef biology and ecology and the *Awareness questions* column represents the analyses performed on the 6 questions on the awareness on the impact of human behaviour on the environment. In the table are represented the value of the T-student Test (*T*) and the level of significance (*p*). The non-significant differences of the T-student test are in bold. % represents the percent increase between the score of the post-questionnaire and the score of the pre-questionnaire for the overall questionnaire.

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of the pre-questionnaire for the overall questionnaire, the reef biology and the human impact questions (Table 2). Considering the overall questionnaire, the mean score of the pre-questionnaire was significantly higher in post-graduate than in under-graduate volunteers (Table 3). However, the mean score of the post-questionnaire and the increase of the mean score between pre- and post-questionnaire didn't show significant differences between under-graduates and post-graduates (Table 3). Considering the reef biology and the human impact questions, the mean score of the pre-questionnaire, the mean score of the post-questionnaire and the increase of the mean score between pre- and post-questionnaire didn't show significant differences between under-graduates and post-graduates (Table 3).

According to the diving experience, all categories showed the mean score of the post-questionnaire significantly higher than that of the pre-questionnaire for the overall questionnaire, the reef biology and the human impact questions (except for the category "*Rescue*" for the mean score of the reef biology and the human impact questions and for the category "*Instructor*" for the mean score of the human impact questions; Table 2). Considering the overall questionnaire, the mean score of the post-questionnaire showed significant difference among the categories, the post-hoc tests showed significant difference between the category *Snorkelers* and

Table 3. Results of T student test or ANOVA test among the categories and groups for the mean score of the overall questionnaire, for the reef biology and the human impact questions, in the pre-, in the post-questionnaire and the its increase between the pre- and the post-questionnaire.

					Pre questionnaire		Post questionnaire		Increase	
			Test	*df*	value	*p*	value	*p*	value	*p*
Gender		Overall	T-student	210	0.400	0.680	0.968	0.334	0.454	0.650
		Know	T-student	210	0.477	0.634	-0.374	0.709	-0.673	0.502
		Awar	T-student	210	0.980	0.328	0.793	0.429	-0.508	0.612
Age		Overall	ANOVA (F)	4	0.720	0.579	0.831	0.507	1.138	0.340
		Know	ANOVA (F)	4	0.997	0.410	0.584	0.675	0.893	0.469
		Awar	ANOVA (F)	4	0.642	0.633	0.413	0.799	1.316	0.265
Level of education	*all categories*	Overall	ANOVA (F)	4	1.636	0.166	1.429	0.225	1.240	0.295
		Know	ANOVA (F)	4	0.816	0.517	1.340	0.256	0.639	0.636
		Awar	ANOVA (F)	4	1.583	0.180	1.750	0.140	0.418	0.796
	under-graduate	Overall	T-student	210	**-2.311**	**0.022**	-1.104	0.271	1.175	0.243
	vs. post-graduate	Know	T-student	210	-0.036	0.971	-0.62	0.951	-0.026	0.979
		Awar	T-student	210	-0.276	0.783	0.282	0.778	0.440	0.660
Diving qualification	*all categories*	Overall	ANOVA (F)	5	0.685	0.635	**2.283***	**0.048***	0.648	0.663
		Know	ANOVA (F)	5	0.748	0.588	0.993	0.423	0.689	0.633
		Awar	ANOVA (F)	5	**2.44†**	**0.036†**	1.000	0.419	**3.553‡**	**0.004‡**
	snorkelers vs.	Overall	T-student	210	-1.251	0.212	**-2.906**	**0.004**	-1.294	0.199
	divers	Know	T-student	210	-0.721	0.472	-0.157	0.875	0.417	0.677
		Awar	T-student	210	0.973	0.332	0.358	0.721	-0.768	0.443

* LSD post-hoc tests showed a significant difference between the category *Snorkelers* and the categories *Open Water Divers and Instructors* (*p* = 0.008; 0045).

† LSD post-hoc tests showed a significant difference between the category *Open Water Divers* and the category *Instructors* (*p* = 0.044) and between the category *Divemasters* and the categories *Snorkelers*, *Advanced Open Water Divers*, *Rescue Divers and Instructors* (*p* = 0.010; 0.042; 0.014; 0.002).

‡ LSD post-hoc tests showed a significant difference between the category *Advanced Open Water Divers* and the category *Instructors* (*p* = 0.019) and between the category *Divemasters* and *Snorkelers*, *Open Water Divers*, *Advanced Open Water Divers*, *Rescue Divers and Instructors* (*p* = 0.001; 0.004; 0.010; 0.002; < 0.001). The significant differences are in bold.

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the categories *Open Water Divers and Instructors* (*p* = 0.008; 0045; Table 3). The mean score of the pre-questionnaire and the increase of the mean score between pre- and post-questionnaire didn't show significant differences among diving experience categories (Table 3). Considering the reef biology questions, the mean score of the pre-questionnaire, the mean score of the post-questionnaire and the increase of the mean score between pre- and post-questionnaire didn't show significant differences among the categories (Table 3). Considering the human impact questions, the mean score of the pre-questionnaire and the increase of the mean score between pre- and post-questionnaire showed significant differences among the categories. For the mean score of the pre-questionnaire, the post-hoc tests showed a significant difference between the category *Open Water Divers* and the category *Instructors* (Table 3) and between the category *Divemasters* and the categories *Snorkelers*, *Advanced Open Water Divers*, *Rescue Divers and Instructors* (Table 3). For the increase of the mean score between pre- and post-questionnaire, the post-hoc tests showed a significant difference between the category *Advanced Open Water Divers* and the category *Instructors* (Table 3) and between the category *Divemasters* and *Snorkelers*, *Open Water Divers*, *Advanced Open Water Divers*, *Rescue Divers and Instructors*

(Table 3). The mean score of the post-questionnaire didn't show significant differences among the categories (Table 3). The categories were pooled into two different groups: snorkelers and divers. Both snorkelers and divers showed the mean score of the post-questionnaire significantly higher than that of the pre-questionnaire for the overall questionnaire, the reef biology and human impact questions (Table 2). Considering the overall questionnaire the mean score of the post-questionnaire was significantly higher in divers than in snorkelers (Table 3). The mean score of the pre-questionnaire and the increase of the mean score between pre- and post-questionnaire didn't show significant differences between the groups (Table 3). Considering the reef biology and the human impact questions, the mean score of the pre-questionnaire, the mean score of the post-questionnaire and the increase of the mean score between pre- and post-questionnaire didn't show significant differences between the groups (Table 3).

Significant differences between the score of the reef biology questions and that of the human impact questions were detected. All categories and pooled groups (i.e. under-graduate, post-graduate, snorkelers and divers) showed that the mean score of the reef biology questions was significantly lower than that of the human impact questions, both in pre-and post-questionnaire (with the exception of the score of the pre-questionnaire in the category "*Divemaster*" for certification level, and in the post-questionnaire in the category "*Doctor of Philosophy*" see Table 4).

Discussion

We found that the participation in a citizen-science monitoring project significantly increased both the knowledge of coral reef biology and ecology and the awareness of human behavioural impacts on the environment. The overall number of correct answers after participation in the project was 25.6% higher than before. According to the reef biology knowledge and the human impact awareness questions, the increase was respectively 36.5% and 12.2%. Our results showed that the level of environmental education of tourists who reach the Red Sea is quite low, (only 32.1% scored more than 7 in the pre-questionnaire, but 86.8% scored more than 7 in the post-questionnaire). From an environmental conservation perspective, this means that tourists represent a serious potential threat for coral reefs, as several previous studies have shown [26, 33–36]. Environmental education is important because it can be determinant of more specific attitudes that, in turn, can help to change human intentions and behaviour toward natural resources such as coral reefs [37; 38]. If people know about organism ecological features or how their own behaviour impacts the reefs, they may be more concerned about the health of the natural resources and also more careful to avoid erroneous behaviours such as touching or interfering with coral reef species.

The analyses to detect differences between categories showed that tourists with a higher education level have a higher initial environmental knowledge and awareness than less educated people, which is in line with normal expectations. The higher mean score of the post-questionnaire for divers compared to that of snorkelers is remarkable, which seems to indicate that the project was more effective on divers than snorkelers. Two motivations could explain this result. The first could be the higher interest and motivation of divers to protect the marine environment. Previous studies have shown that the biocentric orientation of divers is related to the degree of learning and to the fact that divers are well-disposed towards environmental education programs [39; 40]. Future citizen science projects aiming to influence volunteers' environmental education should focus on this aspect during the design process, to tackle the different citizens' motivation to participate and their value orientations. A complementary explanation for the higher mean score of the post-questionnaire for divers compared to that of snorkelers is related to the long-term effectiveness of environmental education projects. Divers

Table 4. Results of T student test between the mean score of the reef biology and the human impact questions, in the pre- and in the post-questionnaire.

			Pre-questionnaire		*Post-questionnaire*	
		df	**T**	***p***	**T**	***p***
Gender	Female	166	-12.929	< 0.001	-8.737	< 0.001
	Male	254	-17.993	< 0.001	-12.714	< 0.001
Age	< 15 years old	18	-6.508	< 0.001	-4.256	< 0.001
	16–30 years old	86	-12.208	< 0.001	-6.275	< 0.001
	31–45 years old	166	-14.107	< 0.001	-8.792	< 0.001
	46–60 years old	130	-10.493	< 0.001	-9.707	< 0.001
	> 61 years old	14	-3.111	0.008	-3.874	0.002
Level of education	Compulsory School	82	-9.681	< 0.001	-7.946	< 0.001
	High School	186	-15.300	< 0.001	-10.979	< 0.001
	Bachelor Degree	52	-5.995	< 0.001	-3.767	< 0.001
	Master Degree	90	-11.174	< 0.001	-6.657	< 0.001
	Doctorate of Philosophy	4	-4.285	0.013	**-2.115**	**0.102**
	Under-graduate	324	-18.734	< 0.001	-13621	< 0.001
	Post-graduate	96	-11.851	< 0.001	-7.037	< 0.001
Diving qualification	None	270	-18.490	< 0.001	-12.288	< 0.001
	Open Water Diver	38	-6.671	< 0.001	-2.877	0.007
	Advanced Open Water Diver	60	-8.456	< 0.001	-7.746	< 0.001
	Rescue Diver	14	-3.828	0.002	-3.010	0.009
	Divemaster	8	**-1.040**	**0.329**	-2.732	0.026
	Instructor	22	-6.177	< 0.001	-3.711	0.001
	Non-diver	270	-18.490	< 0.001	-12.288	< 0.001
	Diver	150	-12.122	< 0.001	-9.160	< 0.001

In the table are represented the value of the T-student Test (*T*) and the level of significance (*p*). The non-significant differences of the T-student test are in bold.

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could have acquired knowledge similar to that provided by the project during their diving training and have lost it before the participation in the project. In this case, the project just reminded them issues they already knew about. This aspect is also discussed in the following "*Limitation*" paragraph.

Another consideration could be made by taking into account the score of the reef biology questions and that for the human impact questions. All categories and pooled groups showed a significantly lower mean score of the reef biology questions than that of the human impact questions (with the exception of the category of "*Divemaster*" and "*Doctor of Philosophy*", that could also be an artefact, given the very low number of volunteer in this category, respectively N = 5 and N = 3). This could mean that volunteers know that specific behaviours are wrong, but they don't know exactly how these behaviours affect the environment and the organisms. This result confirms previous findings. Barker and Roberts [21] have shown that if the briefing is short and given by local staff it does not reduce diver contact rate with the reef or the probability of a diver breaking living substrate. Camp and Fraser [41] found that only more detailed briefings (that included legal requirements of the area, scientific evidences and generational equity) significantly reduced the number of diver interactions with the substrate. Several studies have shown that briefings decreased the diving impact on the natural environments but several other studies have shown that divers continue to have an impact. These findings seem to show that very short briefings, that probably represent the more realistic commitment for a dive company with time-wise and other constraints, is not enough to affect the diver behaviour. To use briefings as effective education programs they should be more detailed and last longer than what is normally proposed by dive leaders.

Limitations

First of all, we must consider that people voluntarily decided to participate in the project. This could mean that involved volunteers were potentially more likely to learn about environmental issues and this could affect the results of this study, preventing a generalization to the broad public of the very promising results obtained here.

The present study didn't evaluate the long-term effectiveness of the participation in the monitoring program, since the post-questionnaire was filled in during the last day of the volunteers' holiday. Unfortunately, none of the surveyed volunteers had already participated in the project in the previous years. Further studies should be necessary to examine if the acquired knowledge and awareness remain several months after the participation in the project and if citizen science programs prompt long-term environmentally responsible attitudes and behaviour in participants. Further studies could also explain the better performance of divers than snorkelers, in terms of a long-term effectiveness of environmental education projects. Further studies should also take into account the different role of coral reef biology and ecology knowledge and human behaviour impact awareness. Understanding how behaviour affects the organisms and the environments they live in could play a key role in determining a change in the attitude and behaviour of people towards the environment.

Conclusion

As emphasized in this study, citizen science projects have an important and effective educational value. Thanks to the recreational approach, STE project has engage a relevant number of volunteers and increased the environmental education of the participants of all ages, gender, education level or diving experience. The results of this study have also suggested that tourism and diving stakeholders should increase their commitment and efforts to these programs for different reasons.

First of all, more educated and, consequentially, more sustainable tourists are of central interest for stakeholders to preserve the environment that primarily supports their business. In addition, the environmental education of tourists, which leads to a decrease in the frequency of environmental impacting activities, raises the carrying capacity of the environment [19], boosting the economical business.

Barker and Roberts [21] have argued that, often, diving companies are unable to provide a briefing that guarantees a sufficient number of environmental education information. Implementing citizen science programs could enhance the possibility for the dive leaders to create moments to talk about the environment and how to approach it or provide scientific figures (research volunteers, students) to assure these educational activities are carried out.

Third, as suggested by Orams and Hill [23], citizen science and educational programs could represent a marketing tool, which increases the acceptance of tourism involving a sustainable exploitation of the environment, fostering a green reputation for the company.

Supporting Information

S1 Table. Dataset.
(HTM)

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Author Contributions

Conceived and designed the experiments: SB SG CP FZ. Performed the experiments: SB MM CC. Analyzed the data: SB MM CC. Wrote the paper: SG SB CP FZ.

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