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TITOLO TESI

VOLUNTEER-BASED CORAL REEF MONITORING: RELIABILITY OF DATA, ENVIRONMENTAL EDUCATION AND IMPLICATIONS FOR CONSERVATION

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“How inappropriate to call this planet *Earth*

when it is quite clearly *Ocean*."

Arthur C. Clarke

“The sea, once it casts its spell, holds one in its net

of wonder forever”

Jacques Y. Cousteau

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Abstract

Coral reefs are the most biodiverse ecosystems of the ocean and they provide notable ecosystem services. Nowadays, they are facing a number of local anthropogenic threats and environmental change is threatening their survivorship on a global scale. Large-scale monitoring is necessary to understand environmental changes and to perform useful conservation measurements. Governmental agencies are often underfunded and are not able of sustain the necessary spatial and temporal large-scale monitoring. To overcome the economic constrains, in some cases scientists can engage volunteers in environmental monitoring. Citizen Science enables the collection and analysis of scientific data at larger spatial and temporal scales than otherwise possible, addressing issues that are otherwise logistically or financially unfeasible. "STE: Scuba Tourism for the Environment" was a volunteer-based Red Sea coral reef biodiversity monitoring program. SCUBA divers and snorkelers were involved in the collection of data for 72 taxa, by completing survey questionnaires after their dives. In my thesis, I evaluated the reliability of the data collected by volunteers, comparing their questionnaires with those completed by professional scientists. Validation trials showed a sufficient level of reliability, indicating that non-specialists performed similarly to conservation volunteer divers on accurate transects. Using the data collected by volunteers, I developed a biodiversity index that revealed spatial trends across surveyed areas. The project results provided important feedbacks to the local authorities on the current health status of Red Sea coral reefs and on the effectiveness of the environmental management. I also analysed the spatial and temporal distribution of each surveyed taxa, identifying abundance trends related with anthropogenic impacts. Finally, I evaluated the effectiveness of the project to increase the environmental education of volunteers and showed that the participation in STEproject significantly increased both the knowledge on coral reef biology and ecology and the awareness of human behavioural impacts on the environment.

Keywords: Biodiversity; Biodiversity monitoring; Citizen science; Eco-tourism; Environmental awareness; Environmental education; Environmental monitoring; Red Sea; SCUBA divers; Volunteers in research.

Chapter 1.

GENERAL INTRODUCTION

1.1 The biodiversity and the importance of its monitoring

Biodiversity is a multifaceted concept that often eludes simple operational definitions. The concept of biodiversity cannot be reduced to a numerical value and a variety of definitions have been proposed each with different levels of complexity and scope. For these reasons, biodiversity is presently a minor consideration in environmental policy since it has been regarded as too broad and vague a concept to be applied to real-world regulatory and management problems. In biological terms, diversity is a property of any biological system: there is a diversity among genes, populations, species, communities, and then a diversity in ecosystems. While different definitions of biodiversity exist, the basic unit of measurement for the vast majority of studies is conducted at the species level (Duro 2007). This definition, used mainly in the ecological field, is based on a set of populations of species that persist in the same area. The meaning of this type of diversity is the concept of species richness (Colwell 2009), defined as the number of species living in a particular habitat, region or ecosystem. Ecologists usually measure the diversity through a series of indices that, more or less directly, relate the number of species with their abundance and/or numerical dominance. The connection between biodiversity, ecosystem functions and services has been widely described over the past 20 years, as pointed out in Cardinale et al. (2012). Costanza et al. (1997) estimated that the economic value of ecosystem services of the entire biosphere ranges, with a conservative estimation, between 16 and 54 trillion dollars per year. Coral reefs, 'rainforests of the sea', are among the richest and most diverse ecosystems of the world, they are also among the most threatened. Each year reefs provide nearly US$ 30 billion in net benefits of goods and services to world economies, including tourism, fisheries and coastal protection. An estimated 30 million people worldwide depend entirely on reef services, and about 500 million depend in part on reef services (Hoegh-Guldberg et al. 2009). The growing interest in biological diversity therefore derives from the belief that loss of biodiversity would result in the loss of ecosystem functions and a consequent loss of "services" for humanity. These services encompass a number of functions dependent on both chemical and physical interactions of organisms with the environment, and the value that these organizations have as their source of food or raw material (Duarte 2000).

Biodiversity monitoring is critically important for forewarning of impending species declines and/or extinctions, creating triggers for management intervention, quantifying the effectiveness of management practices designed to conserve biodiversity, and accumulating the data to underpin metrics reflecting the status of biodiversity. These roles of biodiversity monitoring are, in turn, essential for sustaining ecosystems and ultimately underpinning the well-being of humanity (Lindenmayer 2012). Biodiversity monitoring allows to determine the status of biological diversity of one or more ecological levels and to record any change in space and time. The obtained information can be used to create useful guidelines to orient decisions concerning the management of biological diversity in terms of production and conservation (Niemelä 2000). Unfortunately, governmental agencies, which are responsible for the conservation of biodiversity, are often severely underfunded and are not able of sustain the necessary spatial and temporal large-scale monitoring, that requires a large number of operators (Sharpe and Conrad 2006). To overcome the economic constrains, in some cases we can implement a workaround that involves volunteers in environmental monitoring, namely "*Citizen Science*". Volunteers can be an important resource for monitoring schemes requiring many observers, such as those designed to estimate the status of local resources, establish basic ecological measures or identify the impacts of human activities on environmental quality (Goffredo 2004, 2010, Dickinson 2010, Conrad and Hilckey 2011).

1.2 Citizen science: engage people in the scientific process

Citizen science, the practice of involving the public in the scientific process, from collecting, categorizing and transcribing to analysing and interpreting scientific data, has been growing rapidly across numerous disciplines in the last two decades. The term '*Citizen Science*' was coined by the social scientist Alan Irwin in his 1995 book *Citizen Science*, in which he describes how people accumulate knowledge in order to learn about and respond to environmental threats. Irwin was concerned with the uncertainty of scientific knowledge and contended that alternative forms of knowledge – such as those constructed by 'lay publics' – can and should be considered as complementary (Irvin 1995). Nevertheless, the roots of *Citizen Science* go back to the very beginning of modern science itself. Charles Darwin, who is probably considered one of the greatest scientists of the modern age, was not a professional naturalist, he sailed on the Beagle as an unpaid companion with Captain Robert FitzRoy, who was himself a pioneer of the modern meteorology. As historians pointed out, before the rise of scientific professionalization in the late Nineteenth century, the amateurs, particularly the gentlemen amateurs, led the scientific knowledge advancement because of their independence of interests due to the fact that they did not have to work for living (Porter 1978). For centuries "lay" people flourished in different fields of science, especially in disciplines such as astronomy, archaeology and geology (Stebbin 1979, 1980; Ferris 2002). The earliest *Citizen Science* project dates back to the beginning of XX century. The Christmas Bird Count (CBC) was begun by Frank Chapman in December 1900 as an alternative to the traditional Christmas hunt. The CBC, run every year by the National Audubon Society, has involved, in the most recent count, tens of thousands of volunteer observers who counted a total of over 63 million birds and has become a major source of scientific data on trends in the status of bird species in North America. Nearly 350 scientific papers and reports using CBC data have been published, including studies of population dynamics, community ecology, biogeography and census methods (Silvertown 2009). In the UK, the British Trust for Ornithology was founded in 1932 with the express purpose of harnessing the efforts of amateur birdwatchers for the benefit of science and nature conservation. These data now contribute to the database held by the National Biodiversity Network that contains over 31 million records of over 27 000 UK species of animals and plants, the majority collected by amateur naturalists (Silvertown 2009).

Similar schemes now exist in many other countries where citizen scientists are the bedrock of biological recording. The characteristic that clearly differentiates modern *Citizen Science* from its historical form is that it is now an activity that is potentially available to everyone, not just a privileged few. Advances in technology are leading to new web-based applications that use crowd-sourcing to invite large numbers of people to participate in *Citizen Science* programs over broad geographic regions, and allow volunteers to access and interpret the data they collect (Tulloch 2013). New technologies, such as mobile applications (apps), wireless sensor networks, and online computer/video gaming, show great potential for advancing *Citizen Science*. Mobile apps include software developed for use on portable devices such as smartphones and other mobile, web-enabled equipment. Wireless sensor networks consist of spatially distributed, autonomous or semi-autonomous sensors that monitor physical and/or environmental conditions, such as temperature, sound, vibration, pressure, motion, or pollutants. The internet and geographic information system (GIS) enabled web applications allow participants to collect large volumes of location-based ecological data and submit them electronically to centralized databases. Gaming genres include alternate- and augmented-reality games, context-aware games, and games that involve social networking (Newman 2012). Alternate-reality games permit multiple players to combine information and form coherent stories, and rely on peer-rated performance and feedback tied to location or place to solve real-world challenges (Kim et al. 2009). The ubiquity of smartphones, the potential for digital photo validation of questionable observations, and the development of infrastructure for creating simple online data-entry systems provide added potential for initiating projects quickly, inexpensively, and with stringent criteria to ensure data accuracy. These same web-based tools are democratizing project development, allowing the creation of data-entry systems for community-based projects that arise out of local, practical issues or needs (Dickinson 2012). Collectively, these and other emerging technologies have the potential to engage broad audiences (Clery 2011), motivate volunteers (Cooper et al. 2010), improve data collection (Willett et al. 2010), control data quality (Kelling et al. 2009), corroborate model results (Darg et al. 2011), and increase the speed with which decisions can be made (Danielsen et al. 2010).

To date, *Citizen Science* projects cover a breadth of topics from microbiomes to native bees to water quality to galaxies. Most projects obtain or manage scientific information at scales or resolutions unattainable by individual researchers or research teams, enrolling thousands of individuals collecting data across several continents, enlisting small armies of participants in categorizing vast quantities of online data, or organizing small groups of volunteers to tackle local problems (Bonney et al. 2014). Ornithology is an area, as in the past, that widely and successfully uses the *Citizen Science* (Bhattacharjee 2005). The Cornell University, in particular the Cornell Lab of Ornithology, has welcomed public participation in its research for decades. Today, the Cornell Lab of Ornithology operates numerous *Citizen Science* projects of various sizes, each designed to answer scientific questions while helping the public learn about birds and the process of science. In the past two decades, the Cornell Lab of Ornithology projects have engaged thousands of individuals in collecting and submitting data on bird observations, reading about project findings, visualizing data through web-based graphs and maps, and even analysing data themselves. Collectively, the projects gather tens of millions of observations each year. Recent publications using data collected by the Cornell Lab of Ornithology projects have examined how bird populations change in distribution over time and space; how breeding success is affected by environmental change; how emerging infectious diseases spread through wild animal populations; how acid rain affects bird populations; how seasonal clutch-size variation is affected by latitude; and how databases can be mined and models constructed to discover patterns and processes in ecological systems (Bonney et al. 2009b). Some projects have been able to cross the boundaries of a specific research field, engaging volunteers in broad environmental monitoring programs. OPAL (OPen Air Laboratories) is a large programme of environmental *Citizen Science* activities funded by a £12 million grant over 5 years that has been awarded by the Big Lottery Fund for England to a consortium of 16 institutions led by Imperial College London. The overall aim is to increase public engagement with, and understanding of, the environment, particularly among the socially disadvantaged. Community scientists from universities are working with local people to develop projects on local environmental issues. Together they will record local wildlife and the quality of air, soil and water and analyse and interpret these data to understand how local conditions can affect species diversity, distribution and population size. A suite of new, interactive resources is being developed to help simplify complex issues such as climate change and to demonstrate how they can directly affect local biodiversity and environmental quality. The aim is to inspire a new generation of environmentalists to protect our natural heritage. Five national surveys of different bio-indicators are being used to engage with the public and iSpot, a social networking website for natural history, will help people develop a sustained interest in biodiversity. Data from all activities will contribute toward a 'State of the Environment Report' at the end of the project. Another very successful example in the *Citizen Science* field is the Zooniverse (zooniverse.org). It began in 2007, with the launch of Galaxy Zoo, a project in which more than 175,000 people provided shape analyses of more than 1 million galaxy images sourced from an international astronomic survey. These galaxy 'classifications', some 60 million in total, have subsequently been used to produce more than 50 peer-reviewed publications based not only on the original research goals of the project but also because of serendipitous discoveries made by the volunteer community (Smith et al. 2013). Based upon the success of Galaxy Zoo the team have gone on to develop more than 25 web-based *Citizen Science* projects, all with a strong research focus in a range of subjects from astronomy to zoology where human-based analysis still exceeds that of machine intelligence. Over the past years *Zooniverse* projects have collected more than 300 million data analyses from over 1 million volunteers providing fantastically rich datasets for not only the individuals working to produce research from their projects but also the machine learning and computer vision research communities.

As suggested by Bonney et al. (2009) and reinforced by Haklay (2014), volunteer engagement in *Citizen Science* occurs at different levels of the scientific process. To date, in most *Citizen Science* projects, volunteers have been asked to act as data collectors: making and reporting observations. Volunteers have also been successfully involved in labour-intensive analytical tasks that require human expertise in pattern recognition - so-called crowd-sourcing of data interpretation. Increasingly, scientists are making use of data that are generated automatically (or with minimal management) from sensors used by volunteers. According to the different methods through which the project is developed, scholars have defined a classification of *Citizen Science* projects. Three main approaches are recognised: 1) *contributory* projects are designed entirely by scientists. Participants primarily collect, or in the case of crowd-sourcing, analyse data. 2) *collaborative* project are also designed by scientists, but participants are involved in more than one stage of the scientific process (perhaps contributing or analysing data, helping to inform the way in which the questions are addressed or communicating findings). 3) *co-created* (or *participative*) projects are designed collaboratively. Scientists and participants or communities work together in partnership. At least some of the volunteer participants are involved in most or all steps of the scientific process. Often, some projects use a combination of approaches, perhaps including a core group of highly involved participants who help to develop new research questions and methods, alongside a wider group of participants who contribute their observations. Contributory citizen science features a top-down approach. Scientists and/or policy makers set the questions, design the survey protocols, process and analyse the data, then communicate the results. Participants are generally invited to collect and submit data according to clearly defined guidelines, but that's the limit of their involvement. Crowd sourcing projects in which participants help interpret existing datasets can also fall into this category. Most *Citizen Science* projects to date have followed this approach. Contributory citizen science is well suited to engaging different participants, raising awareness of an issue and gathering lots of data over a wide geographic area. At the opposite end of the spectrum from contributory citizen science is the completely open, collaborative approach called co-created citizen science. The project team may be established by a community approaching a group of scientists with a question or issue they would like to resolve, or vice versa (e.g. it could be several members of a natural history group approaching their committee with an idea). The project team includes individuals from the voluntary community working alongside scientists (and/or policy makers) in partnership. The project team members work together to define goals, set the experimental approach, and analyse, interpret and communicate the findings. This approach requires willingness from all parties to listen and adapt, and an ongoing commitment to the project (Tweddle et al. 2012).

There are three fundamental steps for designing an effective *Citizen Science* project: i) participant recruitment, ii) participant training, and iii) data acceptance (Bonney 2009).

Participant recruitment. Different ways to engage volunteers in *Citizen Science* projects have been adopted. In some cases, volunteers were recruited through environmental or ecological societies' newsletters and electronic mailing lists or personal communications of the project staff (McCaffrey 2005). Often, a website was designed to facilitate participants' involvement in the projects (Worthington et al. 2011, Lee et al. 2011, Goffredo et al. 2010). In some cases, to increase the number of volunteers, the project information was disseminated by print media, features on network television and interviews on radio (Trumbull et al. 2000, Goffredo et al. 2010, Worthington et al. 2011). Integration of different approaches ensured that the greatest diversity of people was reached because it addressed user needs across generations and did not restrict participation to people with access to a computer. Call-in phone services and personal interviews could be useful to engage old generations (Lee et al. 2011). Finally, referrals from existing volunteers surely contribute to recruit new volunteers. Some projects are restricted to citizens who stand evaluation tests. In the Tucson Birds Count (McCaffrey 2005), volunteers had to meet the project's definition of a skilled observer proving their ability to identify the most common Tucson-area species quickly by sight or sound. To determine if participants met this criteria, volunteers were required to take a self-test at the project website prior to adding information in the database. This strategy could limit the data validation process after the programs, but reduces the educative potential of *Citizen Science*.

Participant training. The training stage is fundamental to achieve reliable scientific results and different approaches were used. Some researchers introduced the volunteers to the project goals and methodologies in face to face training sessions, that could vary form an hour-long briefings (Galloway et al. 2006) to week-long workshops (Hodgson and Lieber 2002). Other researchers sent kits to volunteers containing field guides and instruction booklets, providing also the survey materials (Trumbull et al. 2000). Most projects ensured volunteer training by information and materials provided in the project websites or by web-based quiz, games and tutorials (Worthington et al. 2012, Lee et al. 2011).

Data acceptance. Data validation is required to turn the collected data into an effective scientific or management tool. The reliability of data collected by volunteers can be assessed by comparison with that collected by professional surveyors (Galloway et al. 2006, Goffredo et al. 2010), or when the amount of data was limited by a double check provided by researchers (McCaffrey 2005). In many cases, web-based systems were developed to ensure the data quality, such as rejection of incorrect data (Hodgson and Liebler 2002) or measures designed to identify errors and, where necessary, remove, erroneous data (Worthington et al. 2012). In other cases, the system provided warning signals relating specific data and researchers could contact participants to verify any unusual or unexpected observation (McCaffrey 2005).

The growing importance of *Citizen Science,* as well as the professionalization process, is evidenced by the fact that national and European governments are now utilizing it and also newly organized societies are being established, such as the European Citizen Science Association (ECSA), funded in 2013. The first attempt to define *Citizen Science* in a policy view was the Aarhus convention (1998) that emphasised public participation in decision-making. The Aarhus Convention, promoted by the United Nations Economic Commission for Europe (UNECE), has established a number of rights for the public regarding the environment. In particular, the Convention declared the right of everyone to receive environmental information that is held by public authorities and that public authorities should actively disseminate environmental information in their possession. Moreover, the Convention stated the right to participate in environmental decision-making, asking public authorities to enable the public to comment on environment related issues and to take these comments into account in decision-making. The Aarhus Convention was translated into a European Commission Directive in 2003 (Directive 2003/35/EC). Lately the European Commission (EC) has dedicated a lot of effort in promoting *Citizen Science* development. With the 7th Framework Programme for Research, the EC promoted five Citizens' Observatories projects, funded under the topic: "*Developing community-based environmental monitoring and information systems using innovative and novel earth observation applications*". The expected impact of these projects is the empowerment of citizens allowing them to influence the environmental governance processes, providing models for decision-makers that facilitate connections between environmental governance, global policy objectives and citizens' needs. The following EC Framework Programme, *Horizon 2020*, launched in 2014, refers to *Citizen Science* in different topics, such as "*Demonstrating the concept of 'Citizen Observatories*'" prompts researchers to scale up, demonstrate, deploy, test and validate in real-life conditions the concept of Citizen Observatories. The EU goal is to generate new and original methods and applications to reduce investment and running costs of in-situ observations and monitoring. It also calls for a strong involvement of citizens and citizens' associations together with the private sector and public bodies to facilitate knowledge transfer, assessment, valuation, uptake and exploitation of data and results for policy, industry and society at large. Connections with *Citizen Science* are present also in other topics, such as "Ocean literacy – Engaging with society – Social Innovation" and "Pan-European public outreach: exhibitions and science cafés engaging citizens in science". The European Environmental Agency devoted many efforts in promoting *Citizen Science*. EEA contributed to develop Eye on Earth, a web-based platform that allows citizens to visualize water or air quality from the Member Countries. It is also running *Marine LitterWatch*, which aims to collect data on marine litter on beaches, with the help of interested citizens and communities and to organize community-based initiatives such as clean-ups. Due to the great interest at the European level, national governments have started to focus on *Citizen Science*. This is the case of the UK Government that published several communications on this topic, such as the step-by-step "Guide to Citizen Science", resulted from a project, carried out in the UK

Environmental Observation Framework, looking at the role of volunteers in environmental monitoring. The project looked at lessons learnt from past *Citizen Science* projects; the best ways to encourage more researchers and volunteers to get involved; and the potential for using available and emerging technologies for data recording. The Parliamentary Office of Science and Technology (POST) published a note on "Environmental Citizen Science", analysing the advantages of volunteer-based monitoring programs and how they can contribute to inform policy (such as for environmental impact assessment, monitoring environmental indicators and invasive species outbreak or the designation of protected areas) and what stakeholders should do to implement Citizen Science projects.

1.3 The marine environment and the "Recreational Citizen Science"

The implementation of *Citizen Science* in the underwater marine environment needs an additional mention. In fact, the engagement of significant numbers of volunteers in marine environment monitoring programs is more difficult, due to the special diving skills required (a license is needed to dive underwater). Since the Nineties, with the explosion of people's interest for diving as a recreational activity, it was possible to implement research programs in the marine environment which attempted the engagement of recreational divers as volunteers, by using their natural interest in marine diversity (Evans et al., 2005; Goffredo et al. 2004 2010). Among the research projects developing the use of non-specialist volunteers in marine monitoring, Fish Survey Project, conducted in Florida and the Caribbean (Pattengill-Semmens and Semmens, 2003), and Reef Check, on a global scale (Hodgson, 1999) are two significant examples. The Fish Survey Project assessed volunteers on fish species identification skills and classifies recruits as "beginners" or "experts" according to test results. Reef Check has enrolled volunteers who pass a training course involving survey 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. This method provides certain guarantees about the quality of collected data, but limits the attractiveness of the research projects and the number of volunteers willing to participate. Since 1999, the Marine Science Group (MSG), where I performed my PhD research, has been testing a novel biodiversity monitoring method based on citizens' involvement, which ensures the reliability of collected data and citizens education, while not diminishing their recreational enjoyment (Recreational Citizen Science; Goffredo et al., 2004, 2010). MSG's goal has been to unite research and recreation, placing citizens at the forefront of the conservation drive. In this approach, the diving features (such as: dive site, depth, explored habitat) were not modified and the volunteers performed their dive as they normally would during their recreational activity. The recruitment of the volunteers followed pyramidal scheme where research team members trained professional divers on the overarching project objectives and methods, including taxa identification and data recording (the training program comprised of lectures, video, and slideshows). Topics such as biodiversity and its application in assessing environmental change caused by natural and anthropogenic pressures were covered. The training courses were very efficient because they allowed to reach and empower a large number of diving professionals, who in turn involved recreational divers. During the pre-diving briefing, the trained professionals informed and involved recreational divers, distributing questionnaires, which served as teaching tools, and informed the volunteer divers on project goals, methods, taxa to be surveyed, and data recording methodology and needs. After the dive, the trained professionals assisted volunteers with data questionnaire recording, providing consultations in the event of difficulties with recording or taxa identification. This "friendly" approach has resulted in the participation of several thousands of volunteers in marine conservation monitoring. MSG first designed the "Mediterranean Hippocampus Mission", focused on seahorses (Goffredo et al., 2004). Recreational divers took part in the first census of the two species of seahorses living in Italian coastal waters, by reporting sightings in a user-friendly questionnaire, mapping their distribution in the Italian Mediterranean. The project highlighted the interest of recreational divers to take part in biological monitoring. The "Mediterranean Hippocampus Mission" achievement prompted to design a more ambitious project, called "Divers for the Environment: Mediterranean Underwater Biodiversity Project" (www.progettosubambiente.org; Goffredo et al., 2010). This second project described the environmental status of the Italian coastlines.

In 2006, this approach was exported to the Red Sea with the support of the Egyptian Ministry of Tourism. My PhD research focused on this monitoring program, called "STE: Scuba Tourism for the Environment – Red Sea Biodiversity Monitoring Program". My first goal was to quantify the reliability of the data collected by volunteers, through this recreational approach, for environmental monitoring purposes (Branchini et al. 2014; Chapter 2). Subsequently, I analysed the potential of this method to detect environmental status health (Branchini et al. 2014; Chapter 2) and species distribution (*manuscript in preparation*; Chapter 3) changes, evaluating how this information could contribute to Red Sea environmental management and conservation. During my Ph.D., each year, I presented the project results to the staff of the Egyptian Tourism Ministry (partner of the research), with the aim of integrating the projects finding in future environmental management actions and contribute to the development of wide conservation plans. Finally I evaluated the influence of "*STE project*" on volunteers' environmental education (*manuscript submitted to Bioscience*; Chapter 4). Citizen science projects could increase the volunteers' environmental awareness, modifying the volunteers' behaviour, and lead to a more sustainable approach toward the natural resources.

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Chapter 2.

USING CITIZEN SCIENCE PROGRAM TO MONITOR CORAL REEF BIODIVERSITY THROUGHT SPACE AND TIME

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ORIGINAL PAPER

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

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

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Introduction

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

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

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

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

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

The present work aimed to:

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

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

Materials and methods

Survey questionnaires

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

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

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

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

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

Training activities

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

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

Volunteer-marine biodiversity index (V.MBI)

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

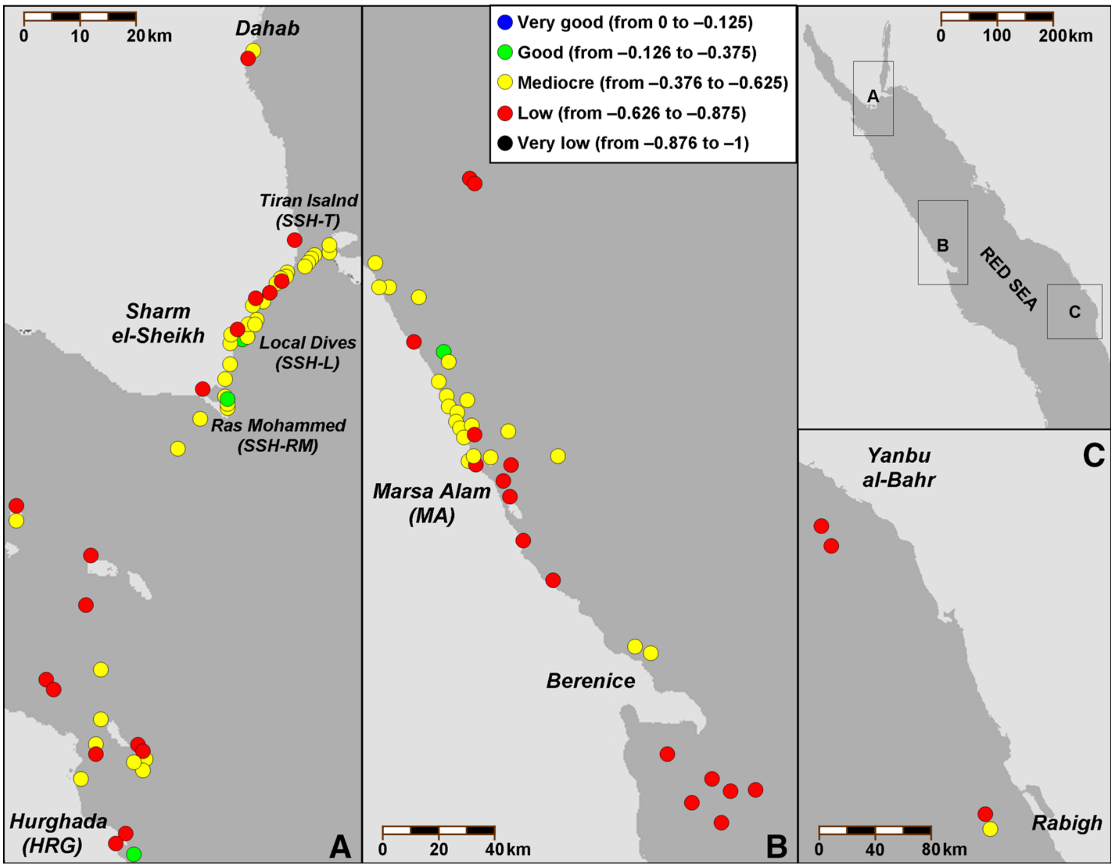

Fig. 1 Volunteer-Marine biodiversity index (V.MBI). The figure shows the marine biodiversity in index in the 100 stations surveyed calculated from the data collected by volunteers in the 4 years of research (2007–2010). In *parenthesis* are the abbreviations of five areas that presented a sufficient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

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

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

Validation trials

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

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

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

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

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

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

Dissemination activities

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

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

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

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

Results

Validation trials

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

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

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

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

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

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

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

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

Marine biodiversity monitoring

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

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

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

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

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

[a] Expressed in percentage

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

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

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

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

Dissemination activities

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

Discussion

Validation trials

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

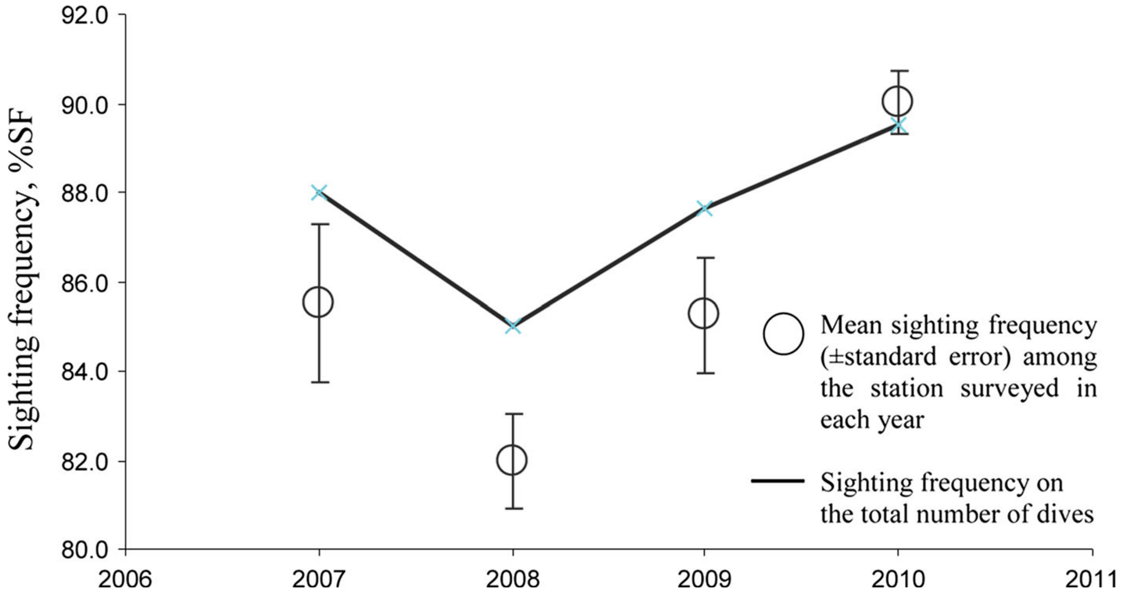

Fig. 2 Sighting frequency of fire coral (*Millepora sp.*). The sighting frequency of fire coral (%SF), which was not homogenous among years, is represented over the four year period

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

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

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

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

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

Volunteer participation

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

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

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

Assessed biodiversity and environmental conditions

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

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

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

Dissemination activities

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

Contribution to the conservation management field

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

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

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

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Biodiversity and Conservation

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

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Online resource 1: Exact procedure to calculate the Volunteer-Marine Biodiversity Index (V.MBI)

Assessing site characteristics: the survey station parameters

Similarly in Goffredo et al. (2010), a statistical analysis was performed for each survey station by calculating the following parameters: number of useful questionnaires recorded each year; mean date, time of day, and depth of survey; number of sighted taxa (S; 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, calculated by the Shannon-Wiener index (observed biodiversity H_{SH}, maximum biodiversity L(S), equipartition index E_{SH}; Magurran 1988) using the abundance score to calculate the parameter p_i of the Shannon-Wiener index (p_i = proportion of individuals of the taxon *i*; Magurran 1988); sighting frequencies of negative environmental conditions (dead corals, %DCF; bleached corals, %BlCF; broken corals , %BrCF; corals covered by sediments, %CCF; and litter, %LF) and of diver behaviour features (number of divers presents on the dive site, %DiF; and contacts with the reef, %ImF). Sighting frequencies were expressed as the percentage of questionnaires where negative environmental conditions or negative diver behaviour features were recorded.

To calculate the abundance score, first the density score was calculated:

$$\frac{(R \times X_1) + (F \times X_2) + (A \times X_3)}{n}$$

where R, F, and A are the number of times the taxon was recorded as "rare," "frequent," or "abundant," respectively; X_1, X_2, and X_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 Goffredo et al.(2010), Pattengill-Semmens and Semmens (2003), Schmitt and Sullivan (1996). Then abundance score = density score x %SF, for statistical characteristics and rationale please see Goffredo et al.(2010), Pattengill-Semmens and Semmens (2003), Schmitt and Sullivan (1996).

Construction of the biodiversity evaluation model

Preliminary remarks. — In the present model, the measure of biodiversity at a single survey station was derived from the overall recorded information on surveyed taxa, negative environmental conditions and divers behavioural features. Single taxa by themselves are not indicators of general patterns (Goffredo et al.2010,Grime 1997, Therriault and Kolasa 2000). The observed marine biodiversity was synthesized into components of the Shannon-Wiener index (Goffredo et al.2010, Magurran 1988, Loher et al.2004).

The parameters for each station and those calculated for a virtual "reference station" were compared to evaluate the biodiversity level at each survey station. The parameters were S, H_{SH}, E_{SH}, %LF, %DCF, %BlCF, %BrCF, %CCF, %DiF and %ImF, defined as "main parameters," and sighting frequencies of individual taxa (%SF), defined as "special parameters." There was a single 'virtual reference station' for the entire study. The assumption was that the virtual reference station represented the best current condition for a station in a coral reef habitat (i.e., its parameters were calculated from the actual stations having the best parameter conditions: highest biodiversity, lowest presence of environmental negative conditions and sustainable diver's behaviour features). 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.

Parameters of the virtual reference station and V.MBI (volunteer marine biodiversity index) We adapted the protocol used in Goffredo et al.(2010) in relation to the parameters described above.

The virtual reference station parameters were calculated as follows:

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

2) The mean value among the stations and the lower 95% confidence limit was calculated for the special parameters and for SA, HSH, ESH, %LF and %ImF; and the upper 95% confidence limit for %DCF, %BlCF, %BrCF, %CCF and %DiF.

3) The parameters of each station were compared with the confidence limits obtained above. If a value was below (for the special parameters, SA, HSH, ESH) or above (for %LF, %DCF, %BlCF, %BrCF, %CCF, %DiF and %ImF), this counted as a "non-matching point" for the station. The number of "non-matching points" for the station was summed.

4) The mean number of "non-matching points" per station and the 95% upper confidence limit were calculated. The stations with a number of non-matching points higher than the confidence limit were rejected.

5) For the stations remaining after the rejection, steps 2, 3, and 4 were repeated until all the remaining stations had a number of "non-matching points" less than or equal to the upper confidence limit.

6) The lower 95% confidence limits (for the special parameters and SA, HSH, ESH, %LF and %ImF) or upper 95% limits (for %DCF, %BlCF, %BrCF, %CCF and %DiF) of the means for the remaining stations were assumed as the critical values for the virtual reference station.

For each year, the parameters of each station were compared with those of the virtual reference station. The parameters that did not reach the critical value of the virtual reference station were considered as penalties (for SA, HSH, ESH and %ImF and the special parameters, the value had to be equal or higher; for the %LF, %DCF, %BlCF, %BrCF, %CCF and %DiF, the value had to be equal or lower). 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 (two sums were obtained). Each sum was normalized on a scale from 0 to -1, where 0 indicated the absence of penalties and -1 indicated all penalties. The V.MBI for each individual station was calculated as the mean of the two normalized sums. The index was reduced to five classes: very good (for V.MBI 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).

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Biodiversity and Conservation

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

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Online Resource 2 Survey questionnaire

Fig. 1 Survey questionnaire cover and back

www.STEproject.org

HOW YOU CAN HELP TO DEFEND CORAL REEFS

Once upon a time only a fortunate few had the opportunity of exploring the wonders of a coral reef. Times have surely changed and, thanks to quick and efficient means of travel, many now have the chance of enjoying the beauty and pleasure of diving into and exploring these fascinating ecosystems. Corals and the life forms they host are extremely delicate. So, in order to make sure that the impact and the potential harm that could be done is reduced to a minimum, please follow the instructions in this pamphlet. Let them be of value to you in making your dive even more exciting and in helping you to preserve the beauty of your diving experience for future generations.
We wish you an enjoyable vacation.

Alma Mater Studiorum
University of Bologna
Italian Ministry of the Environment and Land and Sea Protection
Ministry of Tourism of the Arab Republic of Egypt
Egyptian Tourist Authority
ASTOI (Association of Italian Tour Operators)
PROJECT AWARE FOUNDATION
SNSI (Scuba Nitrox Safety International)
SSI (Scuba Schools International Italy)
ULP (Underwater Life Project)
EULF (Egyptian Underwater & Lifesaving Federation)
TUTTOTURISMO
MSG (Marine Science Group Association)

BEFORE LEAVING HOME

- Choose tour operators and diving schools that honor the environment and that teach respect and safety for human life and nature: refer to associations and agencies that vouch for their affiliated members (www.astoi.com, www.projectaware.org, www.snsi.it, www.ssi-italy.org, www.underwaterlifeproject.it, www.msgassociation.net).

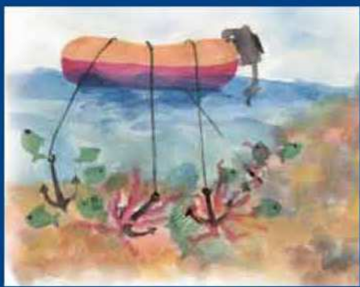
LOOK FOR QUALIFIED TOUR OPERATORS ONLY
READ UP ON THE CULTURE AND ECOLOGY OF THE PLACE YOU PLAN TO VISIT

- Get informed by reading books and magazines on scuba diving and tourism: read up on geography, culture, and customs of the country you'll be visiting so you'll be more sensitive to the local population; read up on the most important ecological features of the place to heighten your awareness about the nature there.
- Be prepared to be very careful when diving in coral reefs: a single coral is the result of the long and hard construction efforts of the "polyps", very small and delicate animal organisms.

BEFORE DIVING

Boats

- Ask your tour operator, diving school, tour leader, and/or dive master which is the best boat available and rent that one: avoid boats that pollute the waters because they have engines that leak oil, diesel, or gasoline; remember that the cheapest package deal does not usually correspond to safety for you or for the environment.

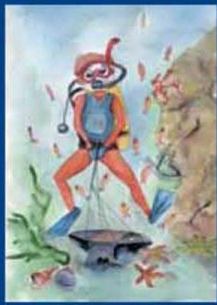


DO NOT CAST ANCHORS

- Do not cast anchors – stop this destructive habit that causes harm to coral reefs by mooring the boat to buoys.
- Give your support locally to having buoys placed in diving areas: it is a custom that defends nature and supports ecological sustainability and that is not practiced nearly enough in tourist localities.

The Weather

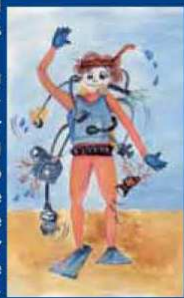
- Find out about the local weather conditions, currents and underwater visibility where you are planning your dive: for your own safety, seek advice from local certified diving instructors.
- Do not go out to sea until you have become acquainted with the safety precautions specifically related to where you are planning to dive.



KEEP YOUR BELT AS LIGHT AS POSSIBLE

Equipment

- Never dive alone and never push yourself beyond safety limits: prepare all your diving equipment and go through the safety checklist with your diving partner before the diving.
- Do not put too much weight in your belt, extra pounds require more exertion and this increases air consumption during the dive, thus reducing safety levels and causing more harm to the environment: when they are on the sea bottom, overly weighted divers tend to fall onto the corals causing breakages.
- Attach all extra equipment (manometer, alternative air supply, torch, etc.) to clasps that keep objects close to the body: if you leave them dangling they could catch on the corals causing damage and/or breakages.



KEEP EQUIPMENT CLOSE TO YOUR BODY

- Always begin with a check-dive to get familiar with the equipment and with the area.

Land Access

- If your dive starts on land, it is best to enter the water from a platform or gangway: the better hotels and diving centers provide these platforms so that tourists and divers do not step on and harm the coral reefs.
- Support this and do not enter the water directly from the shore trampling on corals but use gangways.

Illustration Maura Marinozzi

USE GANGWAYS WHEN ENTERING THE WATER FROM LAND

PROJECT DEVELOPED BY
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Fig. 2 Section with guidance for limiting impacts on the reef during a recreational dive and throughout the vacation period. Part A

Fig. 3 Section with guidance for limiting impacts on the reef during a recreational dive and throughout the vacation period. Part B

Fig. 4 Section with photographs to be used in species identification.

Please, send this questionnaire to: STE project, Marine Science Group - Department of Evolutionary and Experimental Biology, University of Bologna, Via F. Selmi 3, I-40126 Bologna Italy
www.STEproject.org

Surname	Name
Complete address	
E-mail	Dive Certification (level and training organization)
Dive site	Nearest town
Diving Center	
Dive date	Maximum depth (m)
Depth where yuo spent most of your dive (m)	Water temperature (°C)
Actual bottom time (minutes)	Dive starting time (0-24)

Environment where yuo spent most of your dive (choose one) ❒ **coral reef** ❒ **sandy bottom** ❒ **other**__________

Please select the organisms you have seen in the checklist below estimating the frequency of their occurrence. Your instructor can help you!

	RARE	FREQUENT	VERY FREQUENT
SPONGES			
1 - tube sponge (*Siphonochalina* sp., Demospongiae)	❒ 1-2	❒ 3-10	❒ more than 10
Other sponges	❒ 1-2	❒ 3-10	❒ more than 10
COELENTERATES, CORALS			
2 - fire coral (*Millepora* sp., Milleporina, Hydrozoa)	❒ 1-10	❒ 11-100	❒ more than 100
3 - leather coral (*Sarcophyton* sp., Alcyonacea, Anthozoa)	❒ 1-5	❒ 6-15	❒ more than 15
4 - soft tree coral (*Dendronephthya* sp., Alcyonacea, Anthozoa)	❒ 1-10	❒ 11-100	❒ more than 100
5 - sea fan (*Subergorgia hicksoni,* Gorgonacea, Anthozoa)	❒ 1-3	❒ 4-10	❒ more than 10
6 - red sea fans (Melithaeidae, Gorgonacea, Anthozoa)	❒ 1-5	❒ 6-15	❒ more than 15
7 - sea whips (Ellisellidae, Gorgonacea, Anthozoa)	❒ 1-2	❒ 3-6	❒ more than 6
8 - sea carpet host anemones (Stichodactylidae, Actiniaria, Anthozoa)	❒ 1-3	❒ 4-10	❒ more than 10
9 - plating acropora (*Acropora* sp., Scleractinia, Anthozoa)	❒ 1-2	❒ 3-6	❒ more than 6
10 - porcupine coral (*Seriatopora hystrix,* Scleractinia, Anthozoa)	❒ 1-5	❒ 6-15	❒ more than 15
11 - bubble coral (*Plerogyra* sp., Scleractinia, Anthozoa)	❒ 1-5	❒ 6-15	❒ more than 15
12 - mushroom corals (Fungiidae, Scleractinia, Anthozoa)	❒ 1-5	❒ 6-15	❒ more than 15
13 - lettuce coral (*Turbinaria* sp., Scleractinia, Anthozoa)	❒ 1-5	❒ 6-15	❒ more than 15
14 - pineapple corals (Faviidae, Scleractinia, Anthozoa)	❒ 1-2	❒ 3-6	❒ more than 6
15 - black coral (*Antipathes* sp., Antipatharia, Anthozoa)	❒ 1-2	❒ 3-6	❒ more than 6
Other corals	❒ 1-5	❒ 6-25	❒ more than 25
ANELLIDA, SEDENTARY WORMS			
16 - Christmas tree worm (*Spirobranchus* sp., Polychaeta)	❒ 1-5	❒ 6-15	❒ more than 15
Other sedentary worms	❒ 1-5	❒ 6-15	❒ more than 15
MOLLUSCS, GASTROPODS (SEA SLUGS)			
17 - cowries (Cypraeidae, Prosobranchia)	❒ 1	❒ 2-3	❒ more than 3
18 - spanish dancer (*Hexabranchus sanguineus,* Opisthobranchia)	❒ 1	❒ 2-3	❒ more than 3
19 - coriacea (*Chromodoris quadricolor,* Opisthobranchia)	❒ 1-2	❒ 3-4	❒ more than 4
Other sea slugs	❒ 1	❒ 2-3	❒ more than 3
MOLLUSCS, BIVALVES			
20 - tridacnae (*Tridacna* sp.)	❒ 1-2	❒ 3-6	❒ more than 6
21 - wing oyster (*Pteria* sp.)	❒ 1-5	❒ 6-15	❒ more than 15
Other bivalves	❒ 1-4	❒ 5-10	❒ more than 10
MOLLUSCS, CEPHALOPODS			
22 - squids (Sepiidae)	❒ 1-2	❒ 3-4	❒ more than 4
23 - bigfin reef squid (*Sepioteuthis* sp.)	❒ 1	❒ 2-3	❒ more than 3
Other cephalopods	❒ 1-2	❒ 3-4	❒ more than 4
ARTHROPODS, CRUSTACEANS, DECAPODS			
24 - banded boxer shrimp (*Stenopus hispidus*)	❒ 1	❒ 2-3	❒ more than 3
25 - hermit crabs (Diogenidae)	❒ 1	❒ 2-3	❒ more than 3
Other decapods	❒ 1	❒ 2-3	❒ more than 3

Fig. 5 Section for recording data obtained by volunteers on animal taxa, negative environmental conditions, and recreational diver's behaviour. Part A

	RARE	FREQUENT	VERY FREQUENT
ECHINODERMS, CRINOIDS (SEA LILIES)			
26 - sea lilies (Crinoidea)	❒ 1-5	❒ 6-15	❒ more than 15
ECHINODERMS, HOLOTHURIANS (SEA CUCUMBERS)			
27 - sea cucumbers (Holothuroidea)	❒ 1-2	❒ 3-10	❒ more than 10
ECHINODERMS, ASTEROIDS (STARFISHES)			
28 - pearl red star (*Fromia* sp.)	❒ 1	❒ 2-3	❒ more than 3
29 - spiny starfish (*Acanthaster planci*)	❒ 1-2	❒ 3-6	❒ more than 6
Other starfishes	❒ 1-2	❒ 3-5	❒ more than 5
ECHINODERMS, ECHINOIDS (SEA URCHINS)			
30 - fire urchin (*Asthenosoma* sp.)	❒ 1-2	❒ 3-4	❒ more than 4
31 - pencil urchin (*Phyllacanthus* sp.)	❒ 1-3	❒ 4-10	❒ more than 10
Other sea urchins	❒ 1-3	❒ 4-7	❒ more than 7
VERTEBRATES, BONY FISHES			
32 - giant moray (*Gymnothorax javanicus*, Anguilliformes)	❒ 1	❒ 2-3	❒ more than 3
33 - needlefishes (Syngnathidae, Syngnathiformes)	❒ 1-2	❒ 3-4	❒ more than 4
34 - squirrelfish (*Sargocentron* sp., Beryciformes)	❒ 1-5	❒ 6-15	❒ more than 15
35 - groupers (Epinephelinae, Perciformes)	❒ 1-5	❒ 6-15	❒ more than 15
36 - blackspotted rubberlip (*Plectorhinchus gaterinus*, Perciformes)	❒ 1-3	❒ 4-10	❒ more than 10
37 - humpback batfish (*Platax* sp., Perciformes)	❒ 1-10	❒ 11-100	❒ more than 100
38 - red bass (*Lutjanus bohar*, Perciformes)	❒ 1-10	❒ 11-100	❒ more than 100
39 - glassfishes (Pempheridae, Perciformes)	❒ 1-100	❒ 101-1000	❒ more than 1000
40 - goatfishes (Mullidae, Perciformes)	❒ 1-10	❒ 11-100	❒ more than 100
41 - map angel (*Pomacanthus maculosus*, Perciformes)	❒ 1	❒ 2-3	❒ more than 3
42 - butterflyfishes (Chaetodontidae, Perciformes)	❒ 1-5	❒ 6-15	❒ more than 15
43 - longnose hawkfish (*Oxycirrhites typus*, Perciformes)	❒ 1	❒ 2-3	❒ more than 3
44 - Red Sea clownfish (*Amphiprion bicinctus*, Perciformes)	❒ 1-3	❒ 4-15	❒ more than 15
45 - humphead wrasse - Napoleon fish (*Cheilinus undulatus*, Perciformes)	❒ 1	❒ 2-3	❒ more than 3
46 - parrotfishes (Scaridae, Perciformes)	❒ 1-5	❒ 6-25	❒ more than 25
47 - barracuda (*Sphyraena* sp., Perciformes)	❒ 1-5	❒ 6-25	❒ more than 25
48 - Sohal surgeonfish (*Acanthurus sohal*, Perciformes)	❒ 1-5	❒ 6-15	❒ more than 15
49 - caranxes (Carangidae, Perciformes)	❒ 1-5	❒ 6-15	❒ more than 15
50 - lionfish (*Pterois* sp., Scorpaeniformes)	❒ 1-5	❒ 6-15	❒ more than 15
51 - spotted flatheads (Platycephalidae, Scorpaeniformes)	❒ 1-2	❒ 3-4	❒ more than 4
52 - titan triggerfish (*Balistoides viridescens*, Tetraodontiformes)	❒ 1-2	❒ 3-4	❒ more than 4
53 - boxfishes (Ostraciidae, Tetraodontiformes)	❒ 1-2	❒ 3-4	❒ more than 4
54 - blowfishes (Tetraodontidae, Tetraodontiformes)	❒ 1-3	❒ 4-10	❒ more than 10
55 - porcupinefishes (Diodontidae, Tetraodontiformes)	❒ 1	❒ 2-3	❒ more than 3
Other bony fishes	❒ 1-10	❒ 11-65	❒ more than 65
VERTEBRATES, CARTILAGE FISHES, SHARKS			
56 - sharks (Squaliformes)	❒ 1	❒ 2-3	❒ more than 3
VERTEBRATES, CARTILAGE FISHES, RAYS AND TORPEDOS			
57 - blue-spotted stingray (*Taeniura lymma*)	❒ 1-2	❒ 3-6	❒ more than 6
58 - manta (*Manta* sp.)	❒ 1	❒ 2-3	❒ more than 3
59 - torpedo (*Torpedo* sp.)	❒ 1	❒ 2	❒ more than 2
Other rays and torpedos	❒ 1	❒ 2-4	❒ more than 4
VERTEBRATES, REPTILES, TURTLES			
60 - turtles (Cheloniidae)	❒ 1	❒ 2-3	❒ more than 3
VERTEBRATES, MAMMALS, CETACEANS			
61 - dolphins (Delphinidae)	❒ 1-2	❒ 3-6	❒ more than 6

Attention: please indicate the possible presence of the following negative conditions

62 - PARTIALLY OR TOTALLY DEAD CORALS	❒ 1-10	❒ 11-100	❒ more than 100
63 - BLEACHED CORALS	❒ 1-10	❒ 11-100	❒ more than 100
• - BROKEN CORALS	❒ 1-10	❒ 11-100	❒ more than 100
• - SEDIMENT COVERED CORALS	❒ 1-10	❒ 11-100	❒ more than 100
• - LITTER	❒ 1	❒ 2-10	❒ more than 10

Attention: please give information about snorkelers and scuba divers behaviour

How many snorkelers and scuba divers were present on the dive site?	❒ 1-25	❒ 26-50	❒ more than 50
How many snorkelers and scuba divers contacts with the reef did you see during your dive? (both voluntary or involuntary contacts)	❒ 1-5	❒ 6-10	❒ more than 10

Fig. 6 Section for recording data obtained by volunteers on animal taxa, negative environmental conditions, and recreational diver's behaviour. Part B

Biodiversity and Conservation

Using 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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Online Resource 3 Quality of volunteer-generated data

Survey Station	Code	Date	Team Size	Certification Level	95% CI		CV	Depth (m)	95% CI		CV	Dive Time (minutes)	95% CI		CV	Accuracy	95% CI		CV	Consistency	95% CI		CV	Percent Identified	95% CI		CV	CAR	95% CI		CV	Reliability (α)	95% CI		CV	Similarity index	95% CI		CV
Ras Nasrani	RNS	3-Jul-07	3	3.0	1.0	5.0	57.7	26.7	23.4	29.9	10.8	48.3	35.3	61.4	23.9	45.0	42.8	47.2	4.3	35.4	30.6	40.1	11.8	59.7	36.0	83.5	35.1	65.0	57.6	72.3	10.0	65.0	60.2	69.8	4.6	48.7	41.8	55.6	12.5
Ras Katy	RKT	3-Sep-07	5	2.0	1.4	2.6	35.4	14.0	14.0	14.0	0.0	53.0	53.0	53.0	0.0	77.9	70.6	85.1	10.6	76.2	71.3	81.1	10.4	78.7	67.3	90.1	16.5	77.7	74.3	81.1	5.0	88.3	83.3	93.3	4.5	75.6	69.6	81.6	9.0
Ras Nasrani	RNS	11-Sep-07	5	2.0	1.1	2.9	50.0	10.5	8.0	12.9	26.7	49.3	47.9	50.7	3.2	62.1	59.0	65.2	5.7	62.6	54.0	71.2	22.1	73.2	67.9	78.4	8.2	65.3	63.5	67.2	3.2	76.2	74.2	78.1	2.0	65.8	62.8	68.9	5.3
Shark & Yolanda Reef	SYR	12-Sep-07	5	2.6	1.6	3.6	43.9	14.3	12.4	16.3	15.8	45.2	39.1	51.3	15.4	43.2	40.1	46.3	8.2	47.8	44.0	51.5	12.6	53.6	39.5	67.7	30.0	48.6	44.8	52.4	8.9	61.3	55.8	66.7	7.1	50.3	40.3	60.3	22.7
Ras Ghozlani	RGZ	20-Sep-07	3	1.3	0.7	2.0	43.3	18.2	14.5	21.8	17.6	50.0	50.0	50.0	0.0	59.1	49.3	69.0	14.7	55.0	40.8	69.2	22.8	74.2	66.8	81.7	8.8	57.4	55.7	59.0	2.5	73.8	61.3	86.3	10.4	66.6	63.3	69.9	4.4
Ras Katy	RKT	24-Sep-07	5	2.2	0.8	3.6	74.7	9.5	8.6	10.4	10.8	43.2	36.9	49.5	16.6	52.1	44.5	59.6	16.5	45.5	41.3	49.7	15.0	61.9	41.1	82.7	38.4	60.8	57.9	63.6	5.3	64.7	50.4	78.9	17.5	52.1	42.1	62.2	22.0
Ras Umm Sid	RUS	24-Sep-07	3	2.7	0.3	5.0	78.1	19.1	15.3	23.0	17.7	42.7	39.0	46.3	7.5	53.5	37.9	69.0	25.8	54.5	50.3	58.8	6.9	73.0	49.8	96.2	28.1	54.9	49.1	60.6	9.3	67.7	46.1	89.2	19.6	62.3	49.5	75.2	18.2
Jackson Reef	JKR	16-Oct-07	5	3.2	1.8	4.6	51.3	14.0	12.0	16.0	16.0	44.2	41.4	47.0	7.2	62.3	53.6	70.9	15.8	64.8	53.2	76.5	29.1	80.8	67.3	94.3	19.0	71.4	69.5	73.2	3.0	69.4	57.4	81.4	13.7	58.6	52.6	64.6	11.7
Ras Za' Atar	RZA	18-Jun-08	7	3.3	3.3	3.3	0.0	12.7	8.5	17.0	45.1	49.1	45.9	52.3	8.8	45.6	41.9	49.3	10.8	43.9	36.9	50.9	37.3	53.2	43.4	62.9	24.8	58.6	54.8	62.3	8.6	61.1	54.6	67.7	10.1	49.8	45.2	54.4	12.5
Shark & Yolanda Reef	SYR	18-Jun-08	5	3.1	2.5	3.6	19.4	17.8	16.2	19.4	10.0	44.8	43.2	46.4	4.0	50.3	42.1	58.5	18.7	35.1	29.4	40.9	26.4	52.7	34.5	70.9	39.4	55.7	51.2	60.2	9.2	63.6	53.7	73.5	12.4	50.9	37.5	64.4	30.2
Shark & Yolanda Reef	SYR	9-Jul-08	8	2.4	1.6	3.2	48.5	17.4	14.7	20.1	22.6	48.6	45.6	51.7	9.0	54.4	49.8	59.0	12.3	43.3	38.1	48.5	32.4	72.5	62.2	82.8	20.5	68.0	62.7	73.4	11.3	71.3	64.8	77.9	9.2	54.6	50.6	58.6	10.5
Shark Observatory	SOB	25-Jul-08	6	4.2	3.2	5.1	28.1	17.5	13.9	21.1	25.5	53.3	46.9	59.7	15.0	59.8	47.7	71.9	25.2	59.1	53.6	64.5	18.2	76.8	66.9	86.6	16.0	55.9	47.7	64.1	18.2	72.9	58.6	87.1	17.1	66.2	59.7	72.7	12.3
Shark & Yolanda Reef	SYR	30-Jul-08	10	2.5	1.8	3.3	47.3	16.3	14.4	18.1	18.2	52.2	48.9	55.5	10.2	52.2	47.6	56.8	14.2	52.2	48.9	55.4	21.5	75.1	67.2	83.1	17.0	53.3	49.1	57.4	12.5	67.5	64.3	70.7	7.6	60.5	56.7	64.3	10.1
Temple	TMP	11-Aug-08	6	3.7	2.5	4.9	41.1	14.1	12.9	15.3	10.8	53.2	47.9	58.4	12.3	49.4	47.4	51.5	5.2	48.9	43.5	54.2	21.6	65.4	60.6	70.2	9.1	65.8	63.3	68.4	4.9	63.9	57.4	70.5	8.9	54.4	51.3	57.5	7.1
Jackson Reef	JKR	14-Aug-08	11	2.8	2.2	3.5	38.3	15.6	12.6	18.5	31.7	57.8	52.9	62.7	14.3	50.9	46.1	55.7	15.9	45.7	42.5	48.8	26.3	68.2	58.7	77.7	23.6	57.9	53.8	62.0	11.9	65.8	60.4	71.1	9.6	56.7	52.6	60.9	12.4
Jackson Reef	JKR	16-Aug-08	6	2.5	1.8	3.2	33.5	20.3	15.8	24.8	27.6	61.0	58.0	64.0	6.2	53.7	48.0	59.4	13.3	52.8	49.1	56.6	14.0	74.1	63.5	84.7	17.9	62.0	58.5	65.5	7.1	70.9	63.2	78.6	9.5	57.2	54.0	60.5	7.1
Ras Katy	RKT	12-Sep-08	6	3.0	1.7	4.3	55.8	14.6	12.9	16.3	14.6	59.7	57.8	61.5	3.9	49.2	44.0	54.3	13.1	54.6	47.1	62.0	27.1	68.1	60.6	75.6	13.8	67.7	63.6	71.8	7.5	61.5	54.3	68.8	10.3	51.5	47.2	55.8	10.4
Shark & Yolanda Reef	SYR	12-Sep-08	12	2.8	1.9	3.6	54.0	16.9	14.7	19.0	22.7	42.0	41.0	43.0	4.3	70.5	64.5	76.6	15.2	65.4	62.5	68.2	18.0	78.9	74.8	83.0	9.3	68.0	62.9	73.2	13.3	84.0	77.6	90.5	9.4	72.7	68.4	76.9	10.3
Temple	TMP	6-Oct-08	5	3.0	1.4	4.6	62.4	14.6	14.1	15.1	3.8	45.9	42.8	49.0	7.8	50.1	44.1	56.1	13.6	57.8	51.8	63.8	16.8	58.6	45.0	72.1	26.4	64.1	57.8	70.3	11.1	67.1	58.8	75.4	9.8	51.8	44.4	59.1	16.2
Shark & Yolanda Reef	SYR	9-Oct-08	5	3.2	1.8	4.6	51.3	16.8	14.1	19.5	18.1	45.0	43.2	46.8	4.4	56.5	42.9	70.0	27.4	57.1	47.0	67.2	28.6	67.8	53.5	82.0	24.0	61.3	55.7	66.8	10.4	71.1	55.2	87.0	17.9	60.9	50.0	71.9	20.5
Shark Observatory	SOB	9-Oct-08	9	3.3	2.4	4.3	42.4	18.8	15.8	21.8	24.4	48.9	45.3	52.4	11.2	53.4	47.0	59.8	18.4	43.1	38.4	47.8	33.3	61.1	52.0	70.2	22.8	64.4	61.9	67.0	6.1	67.2	57.9	76.5	14.8	55.9	49.3	62.5	18.0
Marsa Abu Dabab	MAD	28-Jul-09	9	2.0	1.4	2.6	43.3	15.4	14.8	16.1	6.5	53.0	50.2	55.8	8.2	67.8	61.8	73.7	13.5	65.5	62.5	68.4	13.6	79.4	74.4	84.4	9.6	76.7	70.7	82.6	12.0	83.7	76.9	90.5	8.7	70.1	64.3	75.9	12.7
Shark & Yolanda Reef	SYR	19-Aug-09	7	2.7	1.6	3.7	51.5	16.1	13.7	18.5	20.2	46.1	39.8	52.4	18.6	52.8	44.7	60.9	20.7	42.0	37.1	46.9	27.5	69.9	62.3	77.5	14.7	54.6	51.1	58.1	8.7	65.2	55.0	75.4	14.8	61.6	57.8	65.4	8.2
Jackfish Alley	JAL	27-Aug-09	9	2.9	2.0	3.8	47.2	17.0	15.3	18.6	15.0	54.2	51.8	56.5	6.6	50.0	43.9	56.2	18.8	43.4	39.3	47.5	28.9	59.8	49.0	70.7	27.8	57.1	55.8	58.4	3.4	67.1	60.1	74.1	11.2	56.0	49.0	63.0	19.1
Shark & Yolanda Reef	SYR	27-Aug-09	8	3.1	2.2	4.1	43.4	17.2	14.8	19.6	19.9	54.3	51.8	56.9	6.7	49.1	40.4	57.7	25.6	50.6	44.7	56.5	31.3	60.2	50.2	70.2	24.0	58.1	55.1	61.1	7.4	64.8	51.4	78.1	20.7	55.4	48.7	62.1	17.4
Eel Garden	EGR	3-Sep-09	5	2.4	1.6	3.2	38.2	14.9	8.3	21.6	51.0	51.2	46.6	55.8	10.2	40.4	36.6	44.1	10.6	37.7	30.8	44.5	29.2	46.5	34.3	58.8	30.0	49.6	46.7	52.5	6.6	56.6	50.6	62.5	8.4	48.1	37.9	58.4	24.3
Shark & Yolanda Reef	SYR	3-Sep-09	6	3.1	1.9	4.4	48.8	14.2	10.9	17.4	28.6	53.3	48.5	58.2	11.4	46.0	39.4	52.6	18.0	39.4	33.1	45.7	31.5	54.8	45.0	64.6	22.3	54.0	50.5	57.5	8.1	59.6	50.8	68.4	12.9	51.2	44.3	58.1	16.8
Woodhouse Reef	WDR	28-Sep-09	6	2.3	1.2	3.4	58.6	20.1	16.6	23.6	21.8	47.1	43.9	50.3	8.5	53.4	43.4	63.3	23.2	48.8	43.5	54.1	21.4	58.6	41.0	76.2	37.5	63.9	61.2	66.7	5.4	67.4	56.5	78.3	14.1	53.0	41.2	64.9	27.9
Jackson Reef	JKR	29-Sep-09	13	2.9	2.1	3.8	52.8	18.0	16.0	20.1	20.6	49.1	45.9	52.3	12.0	48.3	44.0	52.7	16.7	39.7	36.8	42.6	32.5	54.4	46.0	62.7	28.2	55.6	53.1	58.1	8.4	62.7	56.0	69.4	13.8	52.8	46.0	59.6	23.7
Shark Observatory	SOB	4-Nov-09	18	3.8	3.2	4.4	36.5	17.6	16.2	18.9	16.4	47.6	45.7	49.4	8.4	55.6	49.4	61.7	24.0	51.4	49.1	53.8	28.6	66.9	58.5	75.2	27.1	64.3	61.8	66.8	8.5	68.3	59.7	76.9	19.0	57.7	52.1	63.4	21.1
Jackson Reef	JKR	12-Nov-09	3	4.0	2.0	6.0	43.3	17.0	15.0	18.9	10.0	58.3	49.5	67.0	13.3	58.7	41.1	76.4	26.5	42.6	21.5	63.6	43.8	64.8	34.2	95.3	41.7	63.3	54.7	71.9	12.0	71.7	50.0	93.4	18.7	58.3	36.7	80.0	32.8
Torfa Mikky	TMK	17-Apr-10	3	3.0	1.0	5.0	57.7	13.3	10.7	15.9	17.3	48.0	48.0	48.0	0.0	49.9	20.1	79.8	52.8	51.5	44.9	58.1	11.3	71.3	57.1	85.5	17.6	59.9	54.0	65.9	8.8	67.5	54.9	80.0	11.5	62.1	55.7	68.4	9.0
Dolphin House	DLH	15-May-10	5	2.5	1.7	3.3	34.6	10.2	7.9	12.4	25.1	44.0	36.7	51.2	18.8	58.3	46.7	69.9	22.7	49.9	41.6	58.3	27.1	82.0	73.6	90.4	11.7	55.9	45.0	66.9	22.2	71.2	53.2	89.1	20.1	63.2	55.5	70.9	13.8
Marsa Samadai	MSA	24-May-10	4	2.0	2.0	2.0	0.0	13.8	11.2	16.4	19.3	48.7	44.5	52.8	8.7	55.7	43.9	67.4	21.5	54.8	43.6	66.0	25.5	63.8	52.9	74.6	17.4	58.2	54.7	61.7	6.1	69.5	53.8	85.2	16.1	59.1	48.8	69.3	17.7
Abu Ghusun (relitto Hamata)	AGH	28-May-10	3	4.0	4.0	4.0	0.0	16.3	14.6	18.1	9.4	46.7	44.3	49.0	4.5	51.1	45.7	56.5	9.3	48.1	39.7	56.5	15.4	61.0	48.7	73.2	17.7	59.1	55.8	62.4	4.9	60.4	49.7	71.2	11.0	56.6	46.8	66.3	15.2
Elphinstone Reef	ELR	16-Jun-10	3	3.0	1.0	5.0	57.7	18.8	12.6	25.0	29.1	48.7	43.6	53.8	9.3	59.1	27.4	90.8	47.4	43.5	35.5	51.6	16.3	61.8	31.3	92.3	43.6	67.9	48.7	87.2	25.0	66.3	25.2	107.3	38.2	60.0	29.9	90.1	44.4
Marsa Shagra	MSG	16-Jun-10	4	3.3	1.8	4.7	46.2	13.9	10.1	17.7	27.9	51.0	44.9	57.1	12.2	54.7	42.2	67.1	23.3	49.4	44.8	54.0	11.5	57.1	38.2	75.9	33.7	58.9	52.3	65.4	11.3	66.2	46.5	85.9	21.2	57.3	42.3	72.3	26.8
Temple	TMP	5-Jul-10	4	1.8	1.3	2.2	28.6	14.6	11.1	18.2	25.0	52.5	44.6	60.4	15.3	57.5	35.3	79.6	39.3	45.2	27.6	62.7	48.5	60.0	30.3	89.7	50.6	58.9	55.9	61.8	5.1	68.8	39.3	98.2	30.5	55.3	33.2	77.4	40.8
Woodhouse Reef	WDR	8-Jul-10	5	2.6	1.7	3.4	37.3	16.1	14.2	18.0	13.5	56.0	50.6	61.4	11.0	54.9	46.9	62.9	16.6	54.5	47.5	61.6	20.9	72.4	57.6	87.2	23.3	57.0	50.4	63.5	13.1	69.5	59.0	80.0	12.0	56.3	50.8	61.9	11.3
Ras Umm Sid	RUS	19-Jul-10	5	5.0	5.0	5.0	0.0	18.2	11.6	24.8	41.2	45.7	42.4	49.1	8.4	51.6	46.3	57.0	11.8	51.4	47.3	55.6	13.0	72.2	62.3	82.1	15.6	53.6	47.6	59.6	9.8	66.5	56.3	76.8	12.2	58.8	53.4	64.3	10.7
Shark & Yolanda Reef	SYR	21-Jul-10	9	4.0	3.2	4.8	30.6	15.8	13.9	17.7	18.7	46.4	42.7	50.1	12.2	63.3	54.0	72.5	22.3	50.6	46.8	54.4	22.9	74.6	64.0	85.3	21.8	59.5	55.8	63.2	7.1	76.0	63.8	88.2	17.1	66.6	59.5	73.7	16.3
Ras Za' Atar	RZA	28-Jul-10	7	3.0	1.8	4.2	54.4	16.2	15.0	17.5	10.7	52.9	50.6	55.1	5.7	51.0	40.7	61.4	27.3	42.8	37.3	48.3	25.3	60.2	45.8	74.7	32.3	60.2	55.4	65.0	10.8	62.3	50.2	74.4	18.3	55.8	47.1	64.5	21.1
Jackson Reef	JKR	5-Aug-10	5	2.8	1.5	4.0	53.8	15.4	12.7	18.1	20.3	46.4	42.8	49.9	8.7	47.0	43.7	50.2	7.9	36.2	28.0	44.4	36.5	55.7	44.7	66.6	22.4	57.7	53.8	61.7	7.8	65.9	61.2	70.6	5.7	52.3	49.2	55.3	6.6
Gordon Reef	GRR	10-Aug-10	5	3.0	1.6	4.4	52.7	12.4	8.7	16.2	34.6	50.2	47.1	53.3	7.1	57.0	46.4	67.5	21.2	46.6	41.2	52.0	18.6	75.0	65.7	84.3	14.1	62.3	55.2	69.4	13.0	68.1	53.6	82.5	16.9	60.6	54.5	66.6	11.3
Ras Ghozlani	RGZ	11-Aug-10	4	2.0	0.6	3.4	70.7	10.8	4.1	17.5	63.1	50.7	43.1	58.2	15.2	46.1	39.5	52.7	14.6	41.2	35.7	46.8	16.7	54.8	47.1	62.5	14.3	46.2	42.0	50.4	9.4	59.5	42.6	76.4	20.2	55.4	49.6	61.1	10.6
Ras Za' Atar	RZA	15-Aug-10	6	4.2	3.2	5.1	28.1	12.2	8.7	15.7	35.9	55.7	49.2	62.1	14.4	52.8	46.4	59.2	15.2	48.6	43.4	53.8	21.1	62.5	51.5	73.5	22.1	59.5	49.2	69.8	21.6	67.5	58.8	76.3	11.3	56.6	51.0	62.2	12.5
Ras Umm Sid	RUS	23-Aug-10	3	2.7	0.9	4.4	57.3	14.9	11.5	18.3	20.2	39.0	37.0	41.0	4.4	43.4	40.0	46.8	694.3	33.5	26.6	40.4	18.2	49.2	32.1	66.3	30.7	57.0	53.2	60.8	5.9	59.2	47.0	71.5	12.8	47.7	33.5	61.8	26.3
Woodhouse Reef	WDR	26-Aug-10	3	1.5	0.9	2.1	33.3	15.6	12.6	18.6	17.1	50.3	46.5	54.0	7.7	42.1	34.6	49.5	15.7	40.4	33.7	47.2	14.8	54.7	27.3	82.1	44.3	57.0	47.6	66.4	14.6	52.6	41.3	63.9	13.3	45.5	30.6	60.4	28.9
Shark & Yolanda Reef	SYR	27-Aug-10	4	1.3	0.7	2.0	43.3	14.5	8.9	20.0	39.4	41.5	34.6	48.4	16.9	44.9	40.6	49.2	979.1	41.6	33.8	49.4	23.5	51.6	37.8	65.4	27.3	60.8	55.3	66.2	9.2	58.2	51.3	65.2	8.5	47.6	40.3	55.0	15.7
Gordon Reef	GRR	28-Aug-10	3	1.5	0.5	2.5	47.1	13.9	11.8	16.0	13.4	46.7	40.1	53.2	12.4	40.8	35.2	46.4	12.1	62.8	41.5	84.1	30.0	39.0	27.0	51.1	27.2	54.9	52.7	57.0	3.5	53.3	41.4	65.1	13.7	40.9	29.9	51.9	23.8
Jackson Reef	JKR	28-Aug-10	4	3.0	2.2	3.8	27.2	15.0	6.5	23.4	57.5	48.8	46.3	51.2	5.1	42.9	33.0	52.9	23.7	40.0	26.2	53.8	43.1	69.1	48.8	89.4	30.0	51.3	40.4	62.1	21.6	54.5	33.7	75.3	27.2	50.9	43.1	58.7	15.7
Gordon Reef	GRR	31-Aug-10	11	3.4	2.5	4.3	43.9	13.5	10.9	16.0	32.3	45.5	44.8	46.2	2.6	47.9	38.2	57.7	34.5	45.3	40.9	49.6	36.0	56.1	50.0	62.3	18.6	66.4	56.7	76.1	24.7	62.8	58.2	67.5	8.8	52.5	48.8	56.2	11.9
Temple	TMP	3-Oct-10	4	2.8	1.1	4.4	62.1	12.9	10.4	15.3	19.3	49.0	47.9	50.1	2.4	64.0	55.9	72.2	13.1	65.8	53.3	78.3	23.8	65.0	50.4	79.6	22.9	65.5	57.7	73.3	12.2	72.6	60.5	84.7	11.9	61.8	50.6	72.9	18.4
Blue Hole - El Bells	BHL	8-Oct-10	3	3.7	1.9	5.4	41.7	17.2	16.0	18.5	6.3	43.7	37.4	49.9	12.6	60.6	59.8	61.4	1.2	77.2	60.5	94.0	19.2	79.4	72.8	86.1	7.4	59.1	54.5	63.7	6.9	72.7	70.6	74.8	1.8	64.7	64.3	65.1	0.6
Canyon	CNY	8-Oct-10	3	3.7	1.9	5.4	41.7	16.5	11.1	22.0	29.2	47.7	40.1	55.2	14.0	63.3	49.2	77.4	19.7	73.7	49.5	97.9	29.0	81.8	72.7	90.9	9.8	62.0	57.1	67.0	7.1	73.0	58.1	88.0	12.6	64.3	56.7	71.9	10.4
Ras Umm Sid	RUS	1-Nov-10	7	3.7	2.7	4.7	37.2	20.1	17.4	22.7	18.0	46.3	40.7	51.8	16.2	44.1	40.2	47.9	11.8	42.1	37.9	46.4	23.7	57.5	43.4	71.6	33.1	49.7	44.9	54.6	13.1	62.9	56.9	69.0	9.1	52.7	47.5	57.9	13.4
Ras Za' Atar	RZA	5-Nov-10	15	3.5	2.7	4.2	43.4	16.5	14.5	18.5	23.8	49.1	46.1	52.0	12.1	55.6	47.9	63.4	27.6	43.4	41.1	45.6	27.4	62.4	52.4	72.4	31.6	56.3	53.3	59.3	10.4	69.3	60.0	78.6	18.5	58.3	51.1	65.5	24.5
Shark & Yolanda Reef	SYR	5-Nov-10	10	3.2	2.4	4.0	40.8	15.7	12.7	18.7	31.1	50.2	45.9	54.5	13.7	55.8	49.0	62.7	19.8	51.1	47.9	54.2	21.2	74.4	65.9	82.9	18.5	49.5	44.0	55.0	18.0	69.4	60.0	78.8	15.3	63.7	60.0	67.4	9.3
Jackson Reef	JKR	11-Nov-10	11	3.5	2.8	4.1	32.7	17.5	15.8	19.3	17.0	48.4	45.5	51.3	10.2	58.8	51.3	66.3	21.6	45.3	41.5	49.0	31.6	62.3	51.7	72.9	28.8	56.0	52.0	60.1	12.2	72.6	63.9	81.4	14.2	60.8	52.8	68.8	22.3
Thomas Reef	TMR	11-Nov-10	9	3.4	2.6	4.3	38.7	17.1	11.4	22.8	50.8	61.9	56.1	67.7	14.3	52.6	45.1	60.1	21.8	47.0	43.4	50.7	24.0	55.8	47.1	64.5	23.9	54.0	49.7	58.4	12.3	71.1	61.1	81.1	15.0	58.6	50.9	66.2	20.1
Shark & Yolanda Reef	SYR	12-Nov-10	7	3.7	2.7	4.6	34.0	17.0	13.7	20.4	26.5	44.6	37.7	51.5	20.8	52.4	45.1	59.7	18.8	50.4	45.1	55.7	24.8	57.1	45.3	68.9	27.9	47.4	45.0	49.7	6.6	68.0	58.3	77.7	13.5	57.1	49.0	65.2	19.2

Biodiversity and Conservation

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

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Online Resource 4 Taxon-level analyses

Taxon			Correct Identification (%)			
Common name	Scientific Name	N	Mean	%95 CI		Best taxon
2 - fire coral	*Millepora sp.*	60	91.7	87.5	95.8	
5 - sea fan	*Subergorgia hicksoni*	50	91.0	86.2	95.7	
46 - parrotfishes	Scaridae	53	87.6	83.9	91.4	
42 - butterflyfishes	Chaetodontidae	59	87.0	82.4	91.7	
44 - Red Sea clownfish	*Amphiprion bicinctus*	49	85.2	80.3	90.2	
How many snorkelers and scuba divers were present?		60	83.2	78.8	87.5	
4 - soft tree corals	*Dendronephythya sp.*	59	82.3	76.5	88.0	
9 - planting acropora	*Acropora sp.*	49	81.8	75.9	87.7	X
35 - groupers	Ephinephelinae	58	80.9	76.1	85.6	
1 - tube sponges	*Siphonochalina sp.*	54	78.4	72.3	84.5	
20 - tridacnae	*Tridacna sp.*	55	76.0	70.3	81.7	
3 - leather coral	*Sarcophyton sp.*	59	75.2	68.9	81.4	
• - broken corals		55	75.1	68.3	81.9	
37 - humpback batfish	*Platax sp.*	19	74.6	62.2	87.1	
12 - mushroom corla	Fungiidae	59	73.4	67.1	79.8	
32 - giant moray	*Gymnothorax javanicus*	25	72.6	60.8	84.5	X
13 - lettuce coral	*Turbinaria sp.*	33	72.3	66.1	78.5	
57 - blue-spotted stingray	*Taeniura lymma*	34	71.0	61.3	80.8	
45 - humphead wrasse - Napoleon fish	*Chelinus undulatus*	21	68.5	59.1	77.9	
62 - partially or totally dead corals		50	68.5	61.0	76.0	X
8 - sea carpet host anemones	Stichodactylidae	55	68.1	62.4	73.8	
63 - bleached corals		33	67.8	59.2	76.4	X
50 - lionfish	*Pterois sp.*	45	66.9	59.2	74.6	
10 - porcupine coral	*Seriatopora hystrix*	48	66.0	58.4	73.5	
49 - caranxes	Carangidae	54	65.7	56.8	74.6	
54 - blowfishes	Tetradontidae	54	63.7	57.1	70.3	X
Other sponges		51	63.6	56.9	70.2	X
Other cephalopods		2	63.3	56.8	69.9	
7 - sea whips	Ellisellidae	39	63.3	54.5	72.2	
14 - pineapple corals	Faviidae	39	62.7	54.8	70.6	
Other rays and torpedo		2	62.5	25.8	99.2	
11 - bubble coral	*Plerogyra sp.*	39	62.2	54.6	69.9	
47 - barracuda	*Sphyraena sp.*	14	61.6	41.8	81.4	
39 - glassfishes	Pempheridae	18	59.8	44.0	75.6	X
51 - spotted flatheads	Platycephalidae	11	57.6	39.7	75.5	
40 - goatfishes	Mullidae	40	57.3	48.8	65.7	
41 - map angel	*Pomacanthus maculosus*	32	56.2	46.3	66.2	
52 - titan triggerfish	*Balistroides viridiscens*	18	54.2	42.1	66.3	

Online Resource 4 Continued

Taxon		N	Correct Identification (%)			Best taxon
Common name	Scientific Name	N	Mean	%95 CI		Best taxon
60 - turtles	Cheloniidae	10	53.8	34.9	72.8	
How many contacts did you see?		41	53.8	46.2	61.4	
6 - red sea fans	Melithaeidae	32	53.2	44.5	61.9	
48 - Sohal surgeonfish	*Acanthurus sohal*	22	51.8	38.6	65.0	
38 - red bass	*Lutjanus bohar*	31	51.3	42.1	60.4	
• - litter		34	50.0	39.2	60.8	
34 - squirrelfish	*Sargocentron sp.*	45	48.6	42.5	54.8	
19 - coriacea	*Chromodoris quadricolor*	4	48.6	30.3	66.9	X
27 - sea cucumbers	Holothuroidea	10	48.2	28.6	67.7	
• - sediment covered corals		40	47.7	38.9	56.4	
Other corals		56	46.1	38.8	53.4	
36 - blackspotted rubberlip	*Plectorhinchus gaterinus*	11	45.4	31.5	59.4	
15 - black coral	*Antipathes sp.*	31	44.8	35.4	54.2	X
33 - needlefishes	Syngnathidae	12	44.6	27.7	61.5	
53 -boxfishes	Ostraciidae	19	43.2	29.0	57.3	
Other bony fishes		53	42.4	35.0	49.7	
56 - sharks	Squaliformes	1	40.0	-	-	
18 - spanish dancer	*Hexabranchus sanguineus*	1	33.3	-	-	X
21 - wing oyster	*Pteria sp.*	24	30.0	20.8	39.2	
28 - pearl red star	*Fromia sp.*	2	28.6	0.0	84.6	X
26 - sea lilies	Crinoidea	31	27.6	18.7	36.4	X
16 - Christmas tree worm	*Spirobranchus sp.*	30	26.1	17.1	35.2	
55 - porcupinefishes	Diodontidae	8	22.9	7.0	38.9	
43 - longnose hawfish	*Oxycirrhites typus*	5	21.3	0.8	41.8	X
Other sea hurchins		37	20.9	13.5	28.2	
Other sea slugs		11	20.7	8.9	32.5	X
61 - dolphins	Delphinidae	1	20.0	-	-	X
Other seastarfish		7	15.1	3.8	26.4	X
Other sedentary worms		10	14.9	1.7	28.1	
Other bivalves		23	14.5	8.0	20.9	
Other decapods		8	9.7	0.0	21.8	
24 - banded boxer shrimp	*Stenopus hispidus*	2	5.6	0.0	16.4	X
31 - pencil urchin	*Phyllacanthus sp.*	1	0.0	-	-	
17 - cowries	Cypraedae	0	-	-	-	
22 - squids	Seepidae	0	-	-	-	X
23 - bigfin reef squid	*Sepioteuthis sp.*	0	-	-	-	X
25 - hermit crabs	Diogenidae	0	-	-	-	X
29 - spiny starfish	*Acanthaster planci*	0	-	-	-	X
30 - fire urchin	*Asthenosoma sp.*	0	-	-	-	X
58 - manta	*Manta sp.*	0	-	-	-	
59 - torpedo	*Torpedo sp.*	0	-	-	-	

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Online Resource 5 List of the 100 survey stations analyzed on coral reef

Name	N° of useful questionnaires					Bathymetry of survey		Moment of survey			
	2007	2008	2009	2010	Total	Mean Depth (m)	SE	Mean date (yearly fraction)	SE	Mean Hour (Daily fraction)	SE
Abili Gafar (BE)	-	-	-	14	14	20.3	0.7	0.84	0.00	0.29	0.00
Sha'ab Aid (BE)	-	-	-	10	10	16.4	0.9	0.84	0.00	0.65	0.00
Sha'ab Aiman (BE)	-	-	-	15	15	17.9	1.0	0.84	0.00	0.50	0.00
Sha'ab Mahrous (BE)	-	-	-	22	22	21.1	0.9	0.84	0.00	0.41	0.02
Blue Hole - El Bells (DA)	57	34	16	22	129	16.8	0.4	0.71	0.01	0.47	0.00
Canyon (DA)	51	35	26	34	146	17.4	0.4	0.69	0.02	0.53	0.00
Abu Galawi Soraya (HA)	-	-	-	14	14	10.7	1.0	0.69	0.05	0.46	0.02
Sataya reef (HA)	-	-	10	-	10	10.5	1.3	0.32	0.00	0.60	0.05
Abu Ramada Cave (HRG)	21	-	-	-	21	13.0	0.7	0.60	0.04	0.47	0.01
Abu Ramada Sud (HRG)	13	-	-	-	13	12.8	0.7	0.49	0.03	0.45	0.02
Aida - Big Brother (HRG)	-	-	12	-	12	19.3	1.3	0.84	0.00	0.49	0.00
El Aruk Broken (HRG)	-	-	15	-	15	9.8	0.2	0.84	0.00	0.58	0.00
El Aruk Gigi (HRG)	18	-	-	-	18	8.2	0.5	0.46	0.00	0.58	0.01
Erg Somaya (HRG)	-	-	15	-	15	17.3	0.4	0.85	0.00	0.44	0.00
Fanadir (HRG)	13	-	-	-	13	13.2	1.3	0.47	0.00	0.43	0.01
Fanus (HRG)	16	-	-	-	16	12.1	0.6	0.46	0.01	0.53	0.01
Gota Abu Ramada (HRG)	31	-	14	-	45	9.3	0.3	0.66	0.02	0.51	0.01
Halg Disha (HRG)	18	-	-	-	18	13.7	1.2	0.47	0.00	0.45	0.01
House Reef Makadi Bay (HRG)	-	29	-	-	29	12.5	0.9	0.38	0.01	0.52	0.02
Numidia - Big Brother (HRG)	-	-	14	-	14	18.8	1.4	0.84	0.00	0.39	0.02
Ras Disha - Ergs (HRG)	16	-	-	-	16	9.2	1.0	0.46	0.01	0.54	0.01
Sha'ab El Erg (HRG)	-	-	-	12	12	8.8	1.2	0.78	0.00	0.48	0.01
Sha'ab Sabina (HRG)	-	-	15	-	15	9.6	0.1	0.85	0.00	0.56	0.00
Small Giftun - Giftun Soraya (HRG)	-	-	25	-	25	11.7	0.4	0.84	0.00	0.58	0.03
Umm Gamar (HRG)	-	10	-	17	27	13.9	1.8	0.71	0.02	0.46	0.04
Yellowfish Reef (HRG)	-	-	-	12	12	13.0	1.2	0.79	0.00	0.67	0.00
Abu Dabbab (MA)	15	330	-	-	345	1.5	0.1	0.72	0.00	0.41	0.00
Abu Ghusun (MA)	-	-	-	10	10	9.6	0.8	0.52	0.02	0.46	0.01
Aquarius (MA)	-	-	-	10	10	5.2	0.5	0.48	0.03	0.51	0.02
Turtle Bay (MA)	-	146	-	-	146	1.0	0.0	0.66	0.01	0.62	0.00
Check Point (MA)	-	-	-	11	11	12.3	1.1	0.50	0.04	0.49	0.04
Daedalus (MA)	-	11	-	-	11	23.7	2.3	0.64	0.00	0.50	0.05
Dolphin House (MA)	-	-	29	12	41	6.4	0.4	0.57	0.01	0.49	0.00
El Qulan (MA)	-	-	-	14	14	1.0	0.0	0.58	0.03	0.48	0.01
Elphinstone Reef (MA)	15	10	-	16	41	20.9	0.7	0.62	0.02	0.43	0.01
Erg Torfa (MA)	-	-	-	18	18	14.3	0.5	0.46	0.02	0.49	0.02
Erg Tunduba (MA)	-	-	-	19	19	14.9	1.0	0.44	0.03	0.47	0.01
Gota el Sharm (MA)	-	-	-	21	21	21.1	1.2	0.85	0.00	0.32	0.00
Habili Marsa Alam (MA)	-	-	-	23	23	15.4	0.7	0.48	0.02	0.57	0.02
House Reef BL (MA)	-	-	-	26	26	12.1	1.1	0.47	0.06	0.48	0.03
Lagoon (MA)	-	-	59	27	86	1.2	0.0	0.55	0.01	0.55	0.00
Marsa Abu Dabab (MA)	9	-	66	29	95	4.7	0.3	0.66	0.01	0.44	0.00
Marsa Asalaya (MA)	12	-	-	34	46	12.6	0.8	0.51	0.03	0.53	0.02
Marsa Ghamal (MA)	15	-	-	39	54	14.1	0.6	0.43	0.02	0.48	0.01
Marsa Mikky (MA)	1	-	-	45	45	15.2	0.9	0.50	0.04	0.46	0.02
Marsa Naizak (MA)	24	-	-	50	74	15.6	0.8	0.46	0.05	0.49	0.02
Marsa Samadai (MA)	-	-	-	83	83	11.8	0.3	0.50	0.01	0.61	0.01
Marsa Shona (MA)	-	-	97	-	97	14.4	0.7	0.84	0.00	0.53	0.01
Sha'ab Claudia (MA)	-	-	-	119	119	9.9	0.5	0.81	0.04	0.48	0.00
Sha'ab Marsa Alam (MA)	-	15	332	141	488	9.0	0.6	0.63	0.01	0.48	0.00

Online Resource 5 Continued

Name	N° of useful questionnaires					Bathymetry of survey		Moment of survey			
	2007	2008	2009	2010	Total	Mean Depth (m)	SE	Mean date (yearly fraction)	SE	Mean Hour (Daily fraction)	SE
Sha'ab Nakary (MA)	-	-	-	145	145	17.6	0.9	0.47	0.03	0.44	0.02
Sharm el-Luli (MA)	-	156	9	144	300	1.1	0.0	0.60	0.01	0.43	0.00
Torfa Mikky (MA)	-	-	-	204	204	12.3	0.6	0.33	0.01	0.41	0.01
Torfa Tunduba (MA)	-	-	-	441	441	15.0	0.4	0.46	0.02	0.51	0.01
Erg Wadi Gimal (MA)	-	-	-	11	11	14.9	0.4	0.84	0.00	0.64	0.00
Big Brother (Q)	-	10	47	-	57	19.6	0.9	0.81	0.82	0.47	0.02
Small Brother (Q)	-	12	53	-	65	18.8	0.7	0.81	0.01	0.43	0.02
Maria's Reef (RBG)	-	11	-	-	11	24.9	3.5	0.75	0.00	0.46	0.05
Noura Reef - Mary Joy (RBG)	-	12	-	-	12	16.4	1.9	0.75	0.00	0.65	0.03
Abili Ali (SHL)	-	-	-	21	21	18.4	0.7	0.84	0.00	0.39	0.02
Dangerous Reef (SHL)	-	-	-	30	30	13.9	0.5	0.84	0.00	0.72	0.02
Alternatives (SSH - G)	-	31	-	11	42	6.5	0.7	0.57	0.02	0.50	0.01
Bluff Point ((SSH - G)	-	-	-	11	11	20.0	2.3	0.79	0.00	0.30	0.00
Dunraven - Sha'ab Mahmoud (SSH - G)	-	40	19	14	73	16.4	0.4	0.67	0.02	0.52	0.01
Kingston (SSH - G)	-	-	-	16	16	9.8	1.6	0.78	0.00	0.68	0.00
Ulysses (SSH - G)	-	-	-	13	13	11.1	2.9	0.79	0.00	0.49	0.00
Club Reef house reef (SSH - L)	104	63	-	-	167	1.4	0.2	0.59	0.02	0.51	0.01
Far Garden (SSH - L)	-	35	-	-	35	16.6	0.7	0.60	0.03	0.55	0.01
Middle Garden (SSH - L)	-	14	-	-	14	14.4	0.9	0.45	0.02	0.51	0.01
Near Garden (SSH - L)	41	47	10	10	108	15.7	0.4	0.58	0.02	0.53	0.01
Paradise (SSH - L)	-	39	-	-	39	17.5	0.6	0.69	0.02	0.57	0.01
Ras Bob (SSH - L)	18	39	12	20	89	9.1	0.6	0.63	0.02	0.46	0.01
Ras Ghamila (SSH - L)	88	35	-	-	123	16.1	0.4	0.57	0.02	0.57	0.01
Ras Katy (SSH - L)	109	110	16	27	262	12.4	0.4	0.65	0.01	0.49	0.01
Ras Nasrani (SSH - L)	127	115	1	10	252	11.7	0.4	0.66	0.01	0.47	0.00
Ras Umm Sid (SSH - L)	175	249	41	68	533	16.3	0.2	0.64	0.01	0.54	0.00
Sinai Grand Resort House Reef (SSH - L)	-	-	-	72	72	14.6	2.2	0.59	0.01	0.78	0.07
Sodfa (SSH - L)	-	11	-	-	11	17.7	1.3	0.75	0.01	0.61	0.02
Spiaggia Naama Bay (SSH - L)	21	14	66	128	229	7.3	0.6	0.36	0.04	0.63	0.02
Temple (SSH - L)	55	202	136	186	579	14.1	0.2	0.65	0.01	0.49	0.00
Torfa El Karuf - Pinky Wall (SSH - L)	122	69	156	-	347	14.2	0.2	0.53	0.01	0.51	0.01
Tower (SSH - L)	-	13	-	243	256	18.1	0.9	0.36	0.04	0.55	0.01
White Knight (SSH - L)	-	17	-	-	17	17.9	1.7	0.64	0.03	0.47	0.01
Laguna Reef (SSH - NBQ)	13	21	36	76	146	9.0	0.6	0.62	0.01	0.53	0.00
Radisson Hotel House Reef (SSH - NBQ)	10	19	-	-	29	2.4	0.4	0.65	0.01	0.54	0.02
Marsa Bareika (SSH - RM)	-	-	-	15	15	12.4	1.2	0.53	0.02	0.60	0.06
Eel Garden (SSH - RM)	-	78	21	25	124	14.5	0.6	0.57	0.01	0.46	0.00
Jackfish Alley (SSH - RM)	120	222	78	110	530	11.8	0.3	0.62	0.01	0.48	0.00
Marsa Ghozlani (SSH - RM)	75	69	-	-	144	1.6	0.2	0.64	0.01	0.57	0.01
Ras Ghozlani (SSH - RM)	119	192	116	114	541	13.8	0.3	0.65	0.01	0.51	0.00
Ras Za' Atar (SSH - RM)	151	133	147	159	590	15.0	0.3	0.58	0.01	0.48	0.00
Shark & Yolanda Reef (SSH - RM)	422	582	152	227	1383	16.3	0.1	0.61	0.00	0.48	0.00
Shark Observatory (SSH - RM)	48	170	268	374	860	9.8	0.4	0.62	0.01	0.46	0.00
Gordon Reef (SSH - T)	83	199	70	13	365	9.8	0.3	0.64	0.00	0.48	0.00
Jackson Reef (SSH - T)	318	483	99	126	1026	15.7	0.2	0.64	0.00	0.48	0.00
Kormoran (SSH - T)	-	-	-	232	232	6.1	0.1	0.66	0.01	0.57	0.01
Thomas Reef (SSH - T)	106	124	232	272	734	16.8	0.3	0.60	0.01	0.51	0.00
Woodhouse Reef (SSH - T)	218	224	253	399	1094	16.5	0.2	0.62	0.01	0.49	0.00
Abu Galawa (YNB)	-	13	-	-	13	25.1	3.6	0.74	0.00	0.59	0.05
Sha'ab Suflani - marker 44 (YNB)	-	18	-	-	18	33.6	2.6	0.75	0.00	0.55	0.03

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Online Resource 7 V.MBI: Focus by areas

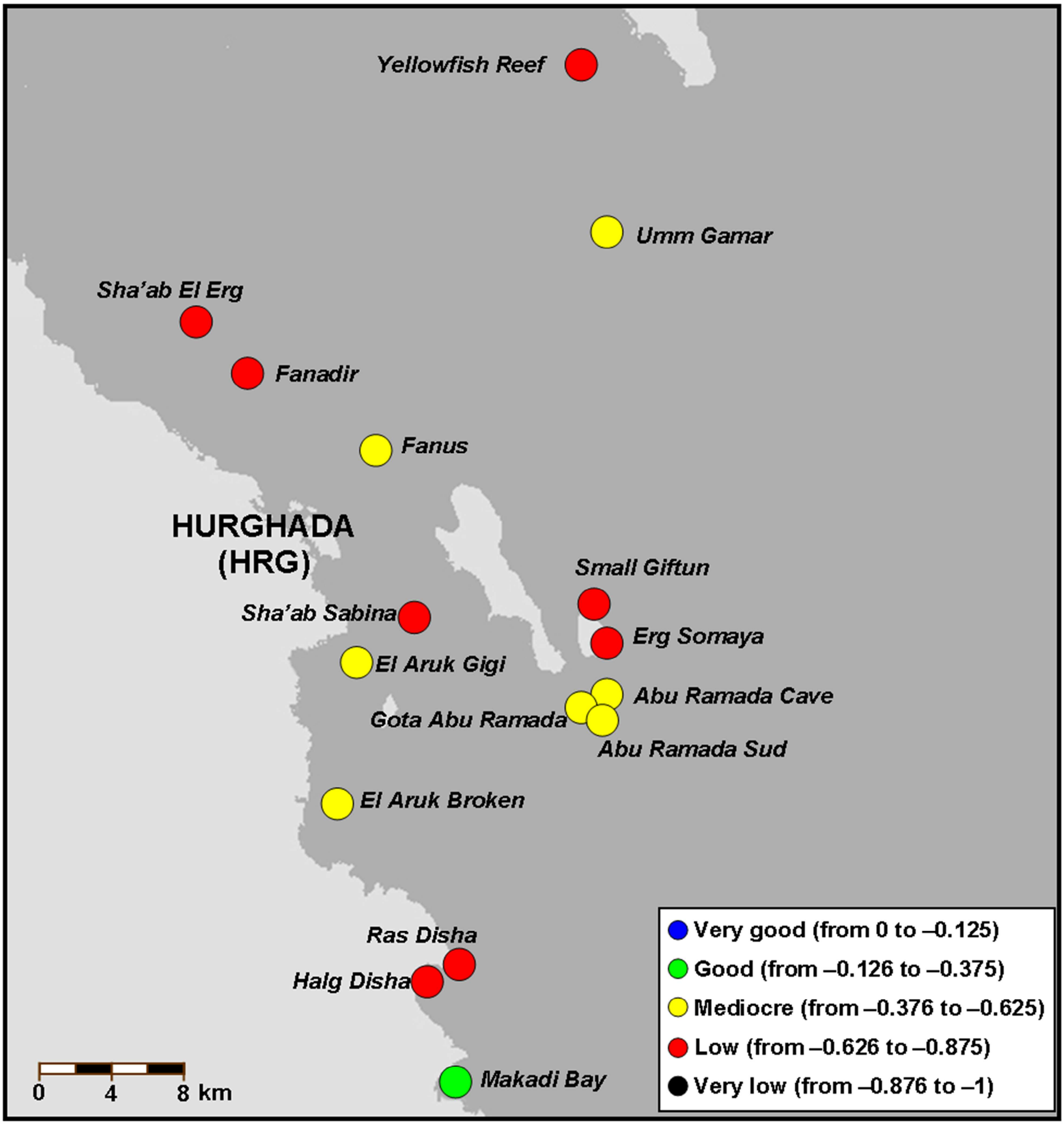

Fig. 1 V.MBI in Hurghada area. The figure shows the focus of marine biodiversity index in the Hurghada stations calculated from the data collected by volunteers in the four years of research (2007 – 2010)

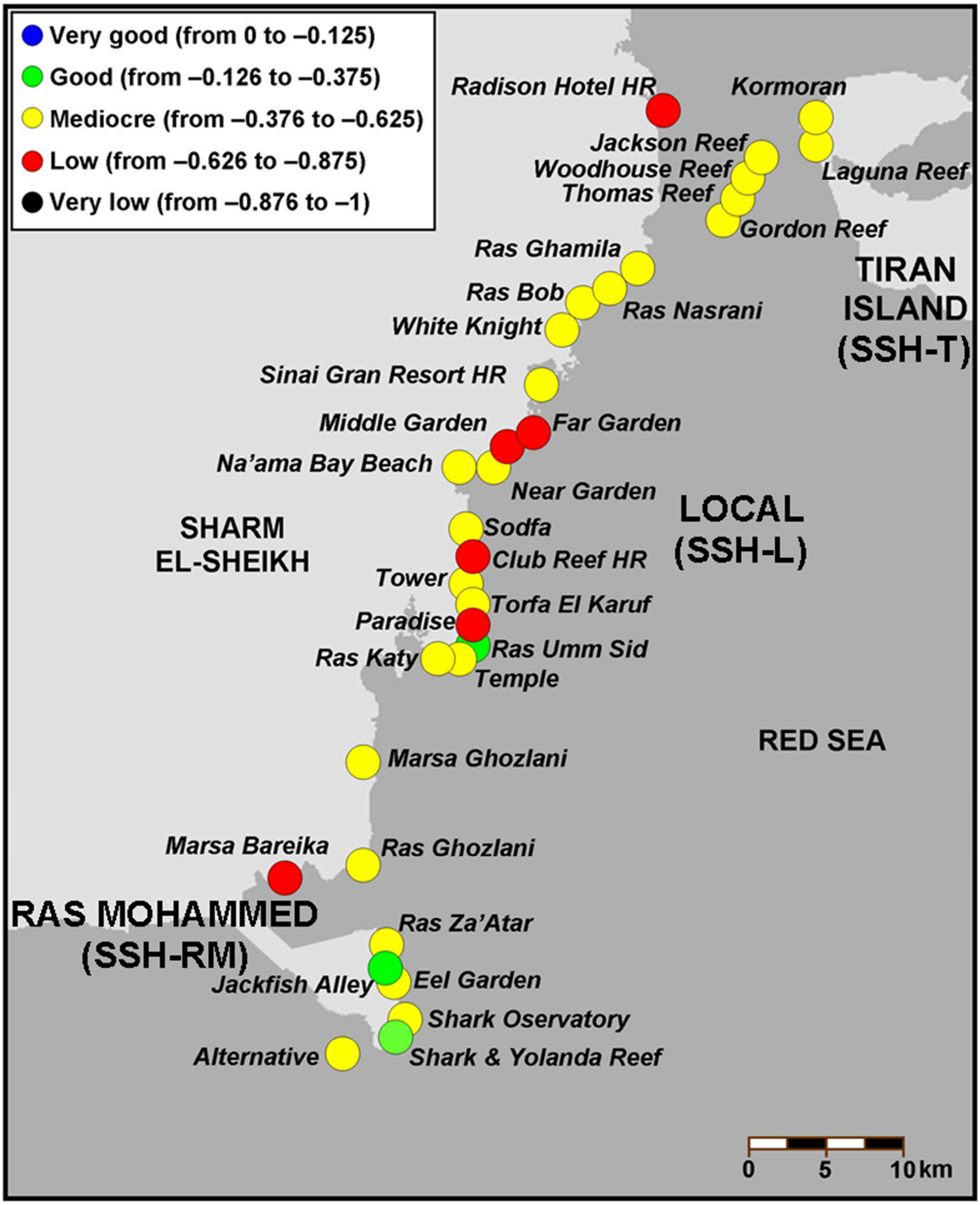

Fig. 2 V.MBI in Sharm el-Sheikh area. The figure shows the marine biodiversity index in the Sharm el-Sheikh stations calculated from the data collected by volunteers in the four years of research (2007 – 2010). In parentheses are shown the three different areas of Sharm el-Sheik included in the spatial analysis of biodiversity index: Tiran Island (SSH-T), Local reefs (SSH-L) and Ras Mohammed peninsula (SSH-RM)

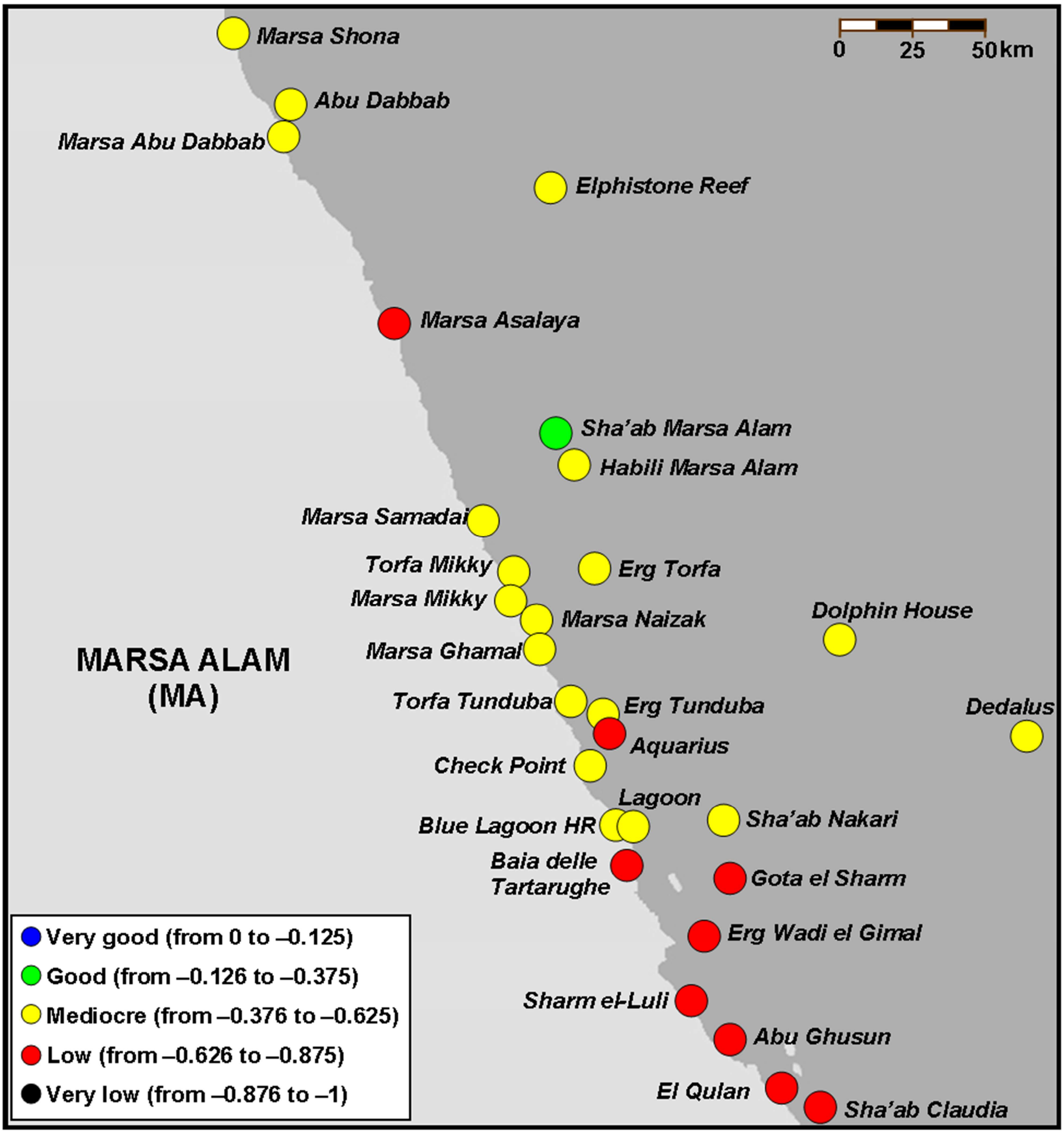

Fig. 3 V.MBI in Marsa Alam area. The figure shows the marine biodiversity index in the Marsa Alam stations calculated from the data collected by volunteers in the four years of research (2007 – 2010).

Biodiversity and Conservation

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

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Online Resource 8 Public dissemination data, number of contact.

Date	News paper, magazine, broadcast	Contatcs
7 December 2010	QN - Il Resto del Carlino, La Nazione, Il Giorno	2,372,000
9 September 2010	Sette - Corriere della Sera	3,056,000
21 August 2010	Radio 24 - Moebius, by Federico Pedrocchi	2,371,000
9 August 2010	Il Corriere dell'Umbria	380,000
28 July 2010	Radio Studio Più - La Carovana On the road	222,000
14 July 2010	RTL 102.5 - Protagonisti, by Francesca Cheyenne and Roberto Uggeri	5,533,000
10 June 2010	Metro	1,776,000
10 June 2010	City	2,036,000
10 June 2010	Leggo	2,212,000
13 April 2010	Switerland Radio and Televisione in italian language - Lo sciamano ìn bicicletta - Rete Uno	300,000
19 March 2010	Trend	24,000
September 2009	Mete	105,000
September 2009	Corriere della Sera	2,906,000
September 2009	Dove	388,000
8 August 2009	Il Sole 24 Ore	1,122,000
31 July 2009	Il Venerdì di Repubblica	2,252,000
16 July 2009	Radio Montecarlo - Anteprima News, by Maurizio Di Maggio	1,653,000
6 July 2009	Il Bologna	90,000
June 2009	Natura	25,000
June 2009	Mondo Sommerso	
June 2009	Subaqva	60,000
June 2009	Ambiente Europa	90,000
1 May 2009	Trend	24,000
May 2009	Mondo Sommerso	144,000
23 April 2009	Leggo	81,000

Online Resource 8 Continued

Date	News paper, magazine, broadcast	Contatcs
September 2008	Tuttoturismo	
August 2008	Mondo Sommerso	
22 July 2008	Switerland Radio and Televisione in italian language - Lo sciamano ìn bicicletta - Rete Uno	300,000
20 July 2008	Corriere della Sera	2,615,000
17 July 2008	Panorama	2,829,000
09 July 2008	Oggi	3,209,000
July 2008	Ambiente Europa	90,000
19 June 2008	Il Resto del Carlino	1,197,000
18 June 2008	La Repubblica	
10 June 2008	MF/Milano Finanza	383,000
7 June 2008	Gioia	545,000
30 May 2008	Italia Oggi	188,000
15 May 2008	Neos In-Flight Magazine	400,000
2 May 2008	Trend	24,000
23 April 2008	Radio Capital	1,671,000
23 April 2008	L'Espresso	2,287,000
23 April 2008	La Repubblica	2,944,000
23 April 2008	La Stampa	1,378,000
23 April 2008	AGI	250,000
March 2008	Tuttoturismo	
March 2008	Mondo Sommerso	144,000
January 2008	Tuttoturismo	236,000
September 2007	SubAqva	60,000
August 2007	Tuttoturismo	
June 2007	Parchi e Riserve	36,000
22 June 2007	Il Resto del Carlino	
19 June 2007	Il Resto del Carlino	
May 2007	Neos in-flight magazine	400,000
22 February 2007	Il Giornale del Turismo	31,500
18 February 2007	RadioRai - Radio2 Strada facendo	1,032,000
February 2007	Tuttoturismo	233,000
12 January 2007	MF/Milano Finanza	456,000
January 2007	Speciale Qui Touring	
January 2007	Qui Touring	626,000
January 2007	Mondo Sommerso	144,000
29 December 2006	Il Resto del Carlino - La Nazione - Il Giorno	
December 2006	Sub	
November 2006	Studenti Magazine	90,000
11 October 2006	L'Agenzia di Viaggi	
September 2006	Mythos	90,000
September 2006	Mix	27,000
September 2006	Il Subacqueo	111,000
September 2006	Sub	
9 August 2006	Il Resto del Carlino - La Nazione - Il Giorno	2,379,000
5 August 2006	La Repubblica - Bologna	390,000
4 August 2006	Leggo	150,000
July 2006	Deep	6,000
July 2006	Tempo Libero	30,000
29 July 2006	Il Venerdì di Repubblica	2,713,000
June 2006	Sub	75,000
May 2006	Quark	
April 2006	TuttoTurismo	219,000
April 2006	Quark	800,000
2 March 2006	Il Resto del Carlino	1,579,000
8 January 2006	Rete 4 - Pianeta Mare	789,000
	project's total contacts	**62,378,500**

Chapter 3.

RED SEA CORAL REEF SPECIES DISTRIBUTION ANALYSES THROUGH DATA COLLECTED BY CITIZEN SCIENTISTS

Manuscript in preparation

Red Sea coral reef species distribution analyses through data collected by citizen scientists

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ABSTRACT:

Coral reefs are the most biodiverse ecosystems of the ocean, and they have a key role for human activities. Despite the provision of multiple valuable services, coral reefs are facing a number of direct anthropogenic threats, including destructive fishing practices, pollution and waste, mining and dredging and non-sustainable tourism practices. Knowing where a species occurs and recording changes in its distribution has major implications in ecology, species management, and conservation planning. Large scale monitoring of targeted species distribution is essential to understand current ecosystem changes and allow decision and policy-makers to enhance the protection and restoration of coastal resources. Using the data collected by an eight-year coral reef volunteer based monitoring program, the present study aimed at detecting the spatial and temporal distribution of 72 key coral reef taxa.

INTRODUCTION

Coral reefs are the most biodiverse ecosystem of the ocean, estimated to harbour around one third of all described marine species (Reaka-Kudla, 1997, 2001), and they have a key role for human activities. They provide critically important goods and services to over 500 million people worldwide (Hoegh-Guldberg et al., 2009), such as: 1) recreational opportunities for diving, snorkelling, and viewing, 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, including destructive fishing practices, pollution and waste, mining and dredging and non-sustainable tourism practices (Cesar, 2000). Additionally, environmental change (such as ocean warming and acidification) is also threatening the survivorship of coral reefs on a global scale.

Knowing where a species occurs and recording changes in its distribution has major implications in ecology, species management, and conservation planning (Brotons et al 2007). Target species can define a trait or characteristic of the environment. A species may delineate an eco-region or indicate an environmental condition such as a disease outbreak, pollution, species competition, anthropogenic pressure or climate change. Indicator species can be among the most sensitive species in a region or have particular features that permit their survivorship in particular environmental conditions and sometimes act as an early warning for monitoring biologists. The use of bioindicators can provides a number of significant advantages over direct measurements of environmental quality. For example, a direct measurement of water quality provides information about the condition of the water column at that particular point in time. Moreover, if the frequency of sampling is limited, or is weather-dependant and constrained by safety considerations, then important information on the effects of acute episodic events that can strongly influence the structure of coral communities may not be quantified (e.g. terrestrial discharges during floods or the resuspension of sediments during strong winds). These issues are addressed with the use of appropriate bioindicators that provide a time-integrated measure (from time periods of minutes to years) of the effects of changes in environmental quality on coral reefs (Cooper et al. 2009).

Species distribution monitoring has a precious value directly for their conservation. Effective detection of population trends is important, for example, for managing threatened species (Joseph et al 2006). Detection of trends can provide compelling evidence for making listing decisions under the IUCN Red List system (IUCN 2001). Thus, large scale monitoring of targeted species distribution is essential to understand current changes in the ecosystem and allow decision and policy-makers to enhance the protection and restoration of coastal resources. Collaborations between scientists and volunteers have enabled the collection and analysis of scientific data at larger spatial and temporal scales than otherwise possible. If well designed, Citizen Science projects have allowed scientists to address issues that are otherwise logistically or financially unfeasible.

The present study aimed to detect the spatial and temporal distribution of 72 key coral reef taxa that were monitored during an eight-year volunteer based monitoring program.

METHODS

Ste project

"STE: Scuba Tourism for the Environment" (STE) is a volunteer-based coral reef biodiversity monitoring program. The main project goal has been to detect spatial and temporal trends of Red Sea coral reef biodiversity, in order to analyse the health status of coral reefs and contribute to local environmental management and conservation planning. The Egyptian Ministry of Tourism was a project partner and it annually requested a report on the data analysis, to get feedback on the effectiveness of the conservation management plans. To achieve this purpose, user-friendly questionnaires distributed to volunteer recreational divers were used to gather information on the presence and abundance of 72 taxa (Figs 1 and 2). The chosen taxa were easily recognizable by volunteer recreational divers, to assure its correct identification and make the survey achievable by recreational divers, as well as common and abundant throughout the Red Sea, to correlate variation with local stressors. All of the different ecosystem trophic levels, from primary producers to predators, were represented among the 72 chosen taxa, in order to assess the environmental quality based on biodiversity (Branchini et al. 2015; Figs 1 e 2). Using databases (http://www. gbif.org; http://www.marinespecies.org), literature (Wielgus et al. 2004) and personal observations, abundance for each surveyed taxon was categorized as ''rare'', ''frequent'' or ''abundant'' based on the expected natural occurrence during a typical coral reef dive. During seven years of data collection (2007-2014), 19,502 volunteers were involved in the project resulting in 32,191 completed questionnaires. The "recreational monitoring" approach (Goffredo et al. 2004; 2010) 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 significant number of volunteers. The research team held training courses for professional divers before the beginning of the project and yearly throughout the project. The professional divers were trained on the project objectives and methods, including taxa identification and data recording (the training program consisted of lectures, videos, 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 Branchini et al. 2015, for detailed training procedure).

Species ecological value

The main criterions adopted for choosing the taxa followed the Citizen Science principles for an effective project. 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 (Branchini et al. 2015). Furthermore, each taxon was easily recognizable by volunteer recreational divers and expected to be common and abundant throughout the Red Sea (Branchini et al. 2015), thereby increasing accuracy of surveys by volunteers. These characteristics assured that the method was suitable for amateurs and tasks were realistically achievable. Likewise, a specific ecological value can be detected for several taxon or group of taxa, as showed in Table 1.

Detection of species distribution trends

Following the procedure used in Branchini et al. (2015), data were aggregated according to the habitat explored: coral reef, sandy bottom or other (such as wreck or blue dives). The species distribution analysis was performed only for coral reef sites, because this environment was recorded in the vast majority of survey questionnaires, enabling spatial and temporal comparison of results. The questionnaires from coral reef habitats were then aggregated by dive site. A dive site was used in the analysis and defined as “survey station” only when it produced at least 10 valid questionnaires (defined as “useful questionnaires”) in 1 year of the project.

For each survey station, the sighting frequency of each taxon, expressed as percentage of dives in which the taxon was sighted (%SF), and the relative abundance of each taxon (abundance score; AS), were calculated.

To determine the abundance score, the density score was calculated as follows:

$$\frac{(R \times X_1) + (F \times X_2) + (A \times X_3)}{n}$$

where R, F, and A are the number of times the taxon was recorded as “rare,” “frequent,” or “abundant,” respectively; X_1, X_2, and X_3 are normalized abundance values assigned to the classes “rare,” “frequent,” and “abundant”; and $n = (R + F + A)$. The abundance score is given by the product of density score and the sighted frequency.

Sighting frequency and the abundance score values were calculated for each survey station using, on one hand, the overall questionnaires collected during the project period and, on the other, the questionnaires collected during each single year.

To determine temporal variations of %SF and AS throughout the project period (2007-2014), the total %SF and AS values of each taxon were correlated with the values of each single year using Cronbach's α and Spearman's ρ. When %SF and/or AS showed at least a value of Cronbach's α lower than 0.5 or when a value Spearman's ρ was not significant ($p > 0.05$) the taxon was defined as not homogeneous. The spatial homogeneity of each taxon was tested using PERMANOVA (PRIMER-E version 6 software, PRIMER-E, Ltd., Ivybridge, UK; Clarke et al. 2008). We performed PERMANOVA using %SF and density score, that was chosen rather than AS, since the latter strongly correlated with the %SF. Only six areas were used for the spatial analyses, as they comprised a sufficient number of survey stations to allow the detection of significant variations (three areas in Sharm el – Sheik: Tiran Island, SSH-T; local dive sites, SSH-L; Ras Mohammed National Park, SSH-RM and the areas of Hurghada, HRG; Marsa Alam, MA and Berenice, BE).

Firstly we tested the temporal homogeneity. For the taxa that were homogeneous among years, we performed the PERMANOVA analyses using the %SF and density score values calculated from the overall questionnaires collected during the project period. For the taxa that were not homogenous among years, we recalculated %SF and density score values using only the questionnaires from the years that correlated with the value calculated from the questionnaires collected during the overall project period. Then, we performed the PERMANOVA analyses using the %SF and density score values calculated from questionnaires of homogeneous years and other tests were performed using the %SF and density score values calculated from questionnaires of non homogeneous years.

For the taxa that resulted temporally not homogeneous, we also evaluated the temporal trend over the years performing the Jonckheere-Terpstra test. Finally, we correlated the AS values with the biodiversity index calculated for each survey station during the period 2007 - 2014 (following the procedure used in Branchini et al. 2015).

RESULTS

Most of the taxa (46, 63.9 %) had homogeneous sighting frequencies and abundant score among years ($\alpha = 0.866$, SE = 0.003; $\rho = 0.758$, SE = 0.004). Twenty-six taxa (36.1 %) showed at least a value of %SF or AS calculated for a single year that was not correlated with that calculated for the overall project period (Table 2). Only 11 cases showed a significant trend in time. In particular, cowries and other sea urchins showed a significant trend only for AS (respectively positive and negative). Lettuce corals and fire urchins showed a significant negative trend in time for both

%SF and AS. Goatfishes, puffer fishes, sharks, other rays and torpedos, other corals, other decapods and other bony fishes showed a significant negative trend in time for both %SF and AS (Figs 3 – 12).

Most of the taxa (55, 76.4%) didn't show spatial variation. Among the 17 taxa that showed significant differences among areas, 8 were temporally homogeneous. Nine taxa, that were not temporal homogeneous, showed significant differences among areas only related to the %SF and density score values calculated from questionnaires of homogeneous years (see Appendix A).

Most of the taxa (51; 70.9%) showed the AS positive correlated with the biodiversity index. Only a taxa, the squirrel fish showed the AS negative correlated with the biodiversity index (Table 3).

DISCUSSION

The results showing taxa with non homogenous sighting frequencies and abundance scores among years are difficult to interpret. The data is still in the process of being analysed so I will discuss only the results of a few species. The negative trend of the lettuce coral (*Turbinaria spp.*) could be interpreted as a positive signal on the environmental quality status of this region. Previous studies show that corals of the genus *Turbinaria* are the most tolerant to high turbidity and sedimentation (Erftemeijer 2012) as they present active sediment rejecting systems (Stafford-Smith and Ormond 1992). In a study on the detection of bio-indicators for water quality, Fabricius et al. (2012) shows that coral communities exposed to high turbidity shift from highly dominant *Acropora* and other predominantly phototrophic taxa, to taxa with increasing trophic plasticity, such as *Turbinaria*. Previous studies (Moufaddal 2005, Branchini et al. 2015) show that sedimentation from dredging and land infilling activities have seriously damaged Egyptian coral reefs. However, in the past few years the Egyptian government has taken measures to reduce this anthropogenic impact on the reefs (Moufaddal 2005).The decreasing trend of the lettuce coral observed in this study could indicate that these measures are working and are improving the environmental quality of this region. Also the negative temporal trends observed for the fire urchin (*Asthenosoma spp.*) could have the same explanation, since sea urchins feed mainly on algae, which are the major competitors of corals in high-turbidity and sedimentation environments (Fabricius et al. 2005).

The results on the spatial homogeneity agreed with a premise of the project methods. Each taxon was expected to be common and abundant throughout the Red Sea to assure that the variation in biodiversity composition detected among sites was not solely attributable to natural variation (Branchini et al. 2015). This premise could explain why most of the organisms didn't showed spatial variation. Seventeen taxa showed significant differences among survey stations, but these differences were not correlated with any latitudinal or longitudinal gradients or different environmental management regimes. Following the above premise the non-homogeneity could be related to local conditions, resulting in the differences detected in the calculated biodiversity index.

Also the correlation with the biodiversity index seemed to support the method premises, since the significant positive correlation between the Abundant Score (AS) values and the biodiversity index of most taxa indicated that all taxa contribute to assess the environmental quality based on biodiversity and no single species by itself acted as a good environmental quality indicator (Grime 1997; Therriault and Kolasa 2000). The negative correlation observed for the squirrel fish (*Sargocentron sp.*) is difficult to interpret, also due to the lack of literature on this organism. These data could, therefore, provide a starting point to begin a specific studying program for squirrelfish.

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, otherwise logistically or financially unfeasible. The data collected by citizen science programs can be used to inform marine management, researchers and private institutions devoted to marine conservation.

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Tables

Table 1. Ecological values of census taxa

Taxa or group of taxa	Taxa surveyed by STE project	Ecological value	References
Sponges	1 - tube sponge (*Siphonochalina* sp., Demospongiae) Other sponges	High-turbidity and sedimentation tolerant	Fabricius et al. (2012)
Soft corals	3 - leather coral (*Sarcophyton* sp., Alcyonacea, Anthozoa) 4 - soft tree coral (*Dendronephthya* sp., Alcyonacea, Anthozoa) 5 - sea fan (*Subergorgia hicksoni*, Gorgonacea, Anthozoa) 6 - red sea fans (Melithaeidae, Gorgonacea, Anthozoa) 7 - sea whips (Ellisellidae, Gorgonacea, Anthozoa) 15 - black coral (*Antipathes* sp., Antipatharia, Anthozoa)	Sensor for diving impact	Hawkins and Roberts (1992) Allison 1996 Bellani and Bellani Santini (2001) Barker and Roberts (2004)
Hard corals	2 - fire coral (*Millepora* sp., Milleporina, Hydrozoa) 9 - plating acropora (*Acropora* sp., Scleractinia, Anthozoa) 10 - porcupine coral (*Seriatopora hystrix*, Scleractinia, Anthozoa) 11 - bubble coral (*Plerogyra* sp., Scleractinia, Anthozoa) 12 - mushroom corals (Fungiidae, Scleractinia, Anthozoa) 13 - lettuce coral (*Turbinaria* sp., Scleractinia, Anthozoa) 14 - pineapple corals (Faviidae, Scleractinia, Anthozoa)	Sensor for diving impact	Hawkins and Roberts (1992) Allison 1996 Bellani and Bellani Santini (2001) Barker and Roberts (2004)
Anemones	8 - sea carpet host anemones (Stichodactylidae, Actiniaria, Anthozoa)	Habitat disturbance tolerant	Haussermann and Forsterra (2001)
Lettuce coral	13 - lettuce coral (*Turbinaria sp*., Scleractinia, Anthozoa)	High-turbidity and sedimentation tolerant	Fabricius et. al 2012
Polychaeta	16 - Christmas tree worm (*Spirobranchus* sp., Polychaeta) Other sedentary worms	Pollution tolerant	Dean (2008)
Sea slugs	17 - cowries (Cypraeidae, Prosobranchia) 18 - spanish dancer (*Hexabranchus sanguineus*, Opisthobranchia) 19 - coriacea (*Chromodoris quadricolor*, Opisthobranchia) Other sea slugs	Habitat alteration and fragmentation	Clark 1994 Roberts and Hawkins (1999)
Threatened organisms	56 – sharks 57 - blue-spotted stingray (*Taeniura lymma*) 58 - manta (*Manta* sp.) 59 - torpedo (*Torpedo* sp.) Other rays and torpedos 60 - turtles (Cheloniidae) 61 - dolphins (Delphinidae)	Threatened organisms	IUCN List (http://www.iucn redlist.org)

Table 2. Results of the correlation analyses (Cronbach's α and Spearman's ρ, indicated respectively as *α* and *ρ*, in the *Test* column) between the sighting frequency (%SF) and the abundant score (AS) values calculated for a single year and those calculated for the overall project. In bold are shown the value that show a non-significant correlation.

Surveyed Taxa	Test	%SF								AS							
		2007	2008	2009	2010	2011	2012	2013	2014	2007	2008	2009	2010	2011	2012	2013	2014
1 - tube sponge	α	.725	.699	.737	.83	.822	.695	.704	.646	.702	.744	.708	.854	.85	.695	.768	.561
	ρ	.78	.866	.866	.914	.913	.714	.875	.79	.844	.887	.879	.921	.947	.759	.840	.832
2 - fire coral	α	.719	.753	.788	.672	.739	.712	.694	.464	.764	.892	.863	.708	.8	.448	.561	.818
	ρ	.915	.896	.837	.796	.876	.909	.692	.737	.901	.952	.929	.867	.926	.577	.665	.914
3 - leather coral	α	.627	.771	.609	.887	.883	.735	.649	.71	.747	.703	.75	.884	.88	.765	.695	.835
	ρ	.904	.898	.754	.945	.897	.771	.753	.844	.878	.858	.826	.958	.937	.831	.790	.918
4 - soft tree coral	α	.717	.685	.636	.901	.917	.77	.846	.891	.845	.815	.822	.845	.928	.789	.822	.936
	ρ	.942	.892	.790	.927	.957	.853	.863	.947	.936	.925	.899	.913	.969	.896	.890	.962
5 - sea fan	α	.945	.811	.882	.928	.905	.738	.821	.897	.967	.847	.906	.926	.907	.759	.874	.907
	ρ	.976	.924	.903	.964	.946	.868	.907	.957	.982	.919	.947	.970	.945	.903	.933	.944
6 - red sea fans	α	.934	.844	.747	.942	.858	.692	.834	.859	.93	.886	.871	.929	.852	.716	.829	.81
	ρ	.959	.927	.891	.977	.936	.839	.903	.894	.964	.923	.965	.973	.934	.869	.879	.859
7 - sea whips	α	.738	.859	.783	.815	.944	.624	.801	.86	.806	.87	.773	.858	.946	.643	.825	.897
	ρ	.897	.913	.910	.895	.974	.741	.896	.942	.930	.899	.952	.885	.980	.770	.863	.946
8 - sea carpet host anemones	α	.748	.809	.875	.804	.894	.684	.445	.549	.739	.798	.939	.841	.874	.65	.445	.613
	ρ	.874	.923	.937	.910	.920	.786	.692	.794	.827	.931	.972	.913	.922	.792	.688	.826
9 - plating acropora	α	.737	.772	.76	.891	.909	.613	.633	.674	.819	.808	.797	.887	.889	.695	.592	.707
	ρ	.863	.873	.882	.933	.960	.718	.863	.813	.893	.892	.918	.950	.967	.714	.847	.857
10 - porcupine coral	α	.76	.755	.731	.716	.806	.601	.69	.607	.805	.728	.73	.766	.76	.585	.671	.757
	ρ	.937	.879	.852	.850	.879	.669	.795	.741	.907	.848	.893	.901	.906	.679	.775	.861
11 - bubble coral	α	.727	.773	.842	.881	.921	.744	.861	.841	.78	.81	.834	.831	.913	.74	.866	.85
	ρ	.881	.849	.898	.943	.953	.891	.898	.886	.892	.841	.876	.919	.964	.874	.891	.886
12 - mushroom corals	α	.551	.621	.598	.836	.768	.78	.639	.496	.588	.613	.549	.894	.849	.749	.74	.685
	ρ	.863	.736	.669	.917	.863	.828	.770	.702	.822	.684	.804	.961	.920	.844	.829	.830
13 - lettuce coral	α	.812	.894	.899	.924	.873	**.291**	.766	.851	.812	.883	.841	.901	.832	**.167**	.678	.746
	ρ	.913	.912	.952	.954	.939	**.430**	.859	.908	.845	.905	.950	.939	.909	**.204**	.787	.837
14 - pineapple corals	α	.65	.777	.729	.754	.793	.777	.408	.597	.544	.71	.789	.789	.784	.704	.586	.688
	ρ	.855	.881	.855	.901	.885	.622	.715	.801	.819	.870	.923	.942	.866	.658	.698	.802
15 - black coral	α	.818	.804	.794	.818	.934	.754	.748	.921	.842	.803	.794	.815	.936	.663	.717	.904
	ρ	.914	.876	.893	.918	.974	.848	.857	.944	.925	.864	.896	.910	.972	.854	.887	.952
16 - Christmas tree worm	α	.789	.706	.751	.859	.575	.611	.49	.659	.741	.635	.717	.815	.555	.703	.535	.74
	ρ	.896	.865	.954	.928	.860	.769	.723	.812	.830	.859	.914	.910	.942	.832	.802	.870
17 - cowries	α	.853	.567	.418	.733	.687	**.277**	.451	.702	.902	.603	.461	.733	.669	.401	.405	.703
	ρ	.740	.887	.909	.942	.721	**.316**	.536	.791	.728	.862	.769	.918	.700	**.458**	.614	.715
18 - spanish dancer	α	.768	.683	.439	.78	.601	.6	.375	.762	.802	.677	.42	.774	.616	.452	**.276**	.802
	ρ	.592	.950	.631	.931	.679	.595	.562	.900	.521	.936	.536	.930	.647	.697	.596	.905
19 - coriacea	α	.688	.745	.797	.897	.728	.364	.473	.619	.715	.751	.723	.878	.71	**.356**	.472	.637
	ρ	.900	.860	.940	.916	.770	**.243**	.923	.849	.908	.892	.916	.925	.640	**.172**	.957	.942
20 - tridacnae	α	.715	.846	.843	.895	.868	.717	.613	.465	.789	.799	.902	.929	.92	.788	.791	.704
	ρ	.890	.861	.971	.922	.906	.775	.815	.822	.881	.867	.969	.954	.954	.861	.864	.884
21 - wing oyster	α	.783	.802	.784	.928	.911	.732	.797	.842	.837	.828	.848	.92	.885	.763	.834	.854
	ρ	.887	.847	.932	.957	.948	.871	.836	.904	.882	.836	.940	.946	.919	.896	.837	.912
22 - squids	α	.838	.684	.664	.771	.78	.448	.613	.715	.859	.69	.645	.751	.672	.398	.581	.682
	ρ	.859	.961	.925	.958	.856	.611	.851	.772	.872	.975	.952	.959	.738	.692	.817	.726
23 - bigfin reef squid	α	.846	.538	.405	.755	.542	.499	.688	.482	.84	.549	.424	.777	.556	.515	.688	.495
	ρ	.764	.883	.943	.943	.612	.868	.829	.534	.761	.905	.965	.928	.805	.849	.834	**.439**
24 - banded boxer shrimp	α	.749	.752	.757	.797	.744	.526	**.268**	.756	.73	.76	.749	.814	.753	.527	.415	.771
	ρ	.832	.816	.627	.966	.938	.637	**.258**	.841	.836	.796	**.423**	.971	.956	.611	**.387**	.859

Table 2. Continued

Surveyed Taxa	Test	%SF								AS							
		2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
25 - hermit crabs	α	.702	.783	.381	.824	.671	.571	.622	.613	.723	.82	.336	.808	.639	.539	.725	.674
	ρ	.743	.940	**.382**	.982	.843	.767	.809	.891	.715	.958	**.343**	.984	.831	.796	.849	.894
26 - sea lilies	α	.776	.898	.84	.905	.881	.804	.789	.842	.787	.84	.87	.888	.861	.828	.797	.812
	ρ	.908	.917	.897	.939	.955	.838	.820	.822	.911	.837	.843	.904	.949	.852	.822	.838
27 - sea cucumbers	α	.791	.836	.858	.901	.828	.606	.51	.839	.814	.836	.815	.913	.816	.602	.553	.82
	ρ	.904	.935	.902	.942	.927	.816	.721	.921	.935	.922	.894	.935	.910	.850	.709	.856
28 - pearl red star	α	.669	.822	.835	.871	.705	**.169**	.404	.732	.618	.761	.914	.839	.722	**.087**	.378	.689
	ρ	.689	.939	.893	.956	.716	**.138**	**.460**	.844	.644	.926	.914	.973	.664	**0.02**	.570	.833
29 - spiny starfish	α	.755	.552	.626	.596	.577	.384	.452	.767	.666	.543	.56	.592	.555	**.330**	.473	.766
	ρ	.736	.748	.669	.855	.918	**.274**	**.347**	.834	.706	.750	.623	.822	.918	**.275**	**.339**	.836
30 - fire urchin	α	.685	.685	.733	.899	.811	.417	.436	.634	.752	.648	.807	.916	.813	.454	.378	.621
	ρ	.808	.902	.947	.950	.880	.803	**.252**	.790	.926	.921	.932	.946	.864	.831	**.149**	.732
31 - pencil urchin	α	.573	.75	.784	.839	.71	.461	.47	.785	.532	.753	.791	.858	.71	.51	.501	.686
	ρ	.838	.843	.940	.970	.923	.684	.593	.537	.800	.805	.928	.970	.912	.603	.519	.610
32 - giant moray	α	.777	.796	.838	.833	.845	.406	.644	.754	.828	.816	.832	.841	.884	.483	.681	.759
	ρ	.910	.903	.951	.925	.908	.625	.789	.859	.954	.887	.960	.957	.940	.763	.836	.857
33 - needlefishes	α	.755	.688	.822	.885	.856	.668	**.247**	.813	.803	.805	.781	.874	.84	.603	**.314**	.817
	ρ	.838	.842	.915	.942	.938	.847	.752	.934	.850	.861	.941	.937	.947	.855	.833	.954
34 - squirrelfish	α	.77	.77	.663	.911	.87	.7	.703	.63	.718	.742	.847	.909	.884	.806	.556	.701
	ρ	.925	.836	.827	.956	.948	.870	.736	.767	.871	.867	.924	.967	.949	.829	.707	.832
35 - groupers	α	.69	.806	.569	.793	.801	.755	.871	.677	.817	.793	.712	.85	.882	.761	.89	.826
	ρ	.877	.897	.813	.920	.900	.868	.851	.866	.930	.880	.905	.920	.947	.899	.868	.920
36 - blackspotted rubberlip	α	.761	.845	.834	.83	.809	.509	**.228**	.763	.828	.814	.85	.85	.829	.522	**.239**	.702
	ρ	.944	.926	.916	.935	.859	.585	**.383**	.897	.969	.892	.950	.942	.893	.632	**.399**	.947
37 - humpback batfish	α	.783	.741	.75	.86	.82	.657	.738	.845	.774	.713	.788	.847	.866	.699	.771	.819
	ρ	.955	.894	.902	.950	.953	.879	.825	.940	.932	.903	.911	.943	.963	.914	.892	.932
38 - red bass	α	.741	.706	.826	.829	.776	.781	.673	.796	.769	.737	.828	.828	.829	.767	.647	.79
	ρ	.857	.891	.908	.928	.858	.875	.845	.898	.835	.905	.935	.945	.910	.874	.877	.904
39 - glassfishes	α	.766	.835	.85	.911	.868	.657	.703	.824	.773	.828	.812	.924	.889	.661	.624	.818
	ρ	.885	.863	.946	.964	.952	.851	.780	.856	.938	.849	.907	.969	.962	.869	.744	.806
40 - goatfishes	α	.736	.87	.891	.843	.828	.799	**.348**	.59	.807	.851	.909	.891	.823	.768	.559	.595
	ρ	.856	.924	.962	.911	.917	.911	.503	.758	.808	.901	.928	.929	.929	.897	.714	.768
41 - map angel	α	.628	.853	.818	.908	.888	.681	.712	.847	.617	.854	.704	.886	.884	.541	.596	.836
	ρ	.863	.872	.901	.953	.907	.756	.789	.900	.869	.888	.928	.944	.886	.693	.734	.882
42 - butterflyfishes	α	.857	.85	.739	.805	.815	.723	.457	.687	.869	.776	.763	.857	.838	.75	.393	.735
	ρ	.872	.982	.874	.884	.851	.675	.608	.890	.921	.950	.942	.938	.906	.777	.570	.886
43 - longnose hawkfish	α	.584	.648	.828	.866	.752	**.193**	.599	.753	.599	.602	.766	.869	.827	**.109**	.527	.757
	ρ	.877	.666	.870	.822	.890	**.277**	.591	.725	.908	.554	.939	.854	.916	**.227**	.726	.726
44 - Red Sea clownfish	α	.809	.806	.822	.876	.908	.677	.722	.66	.803	.823	.906	.862	.869	.609	.754	.773
	ρ	.952	.940	.959	.925	.942	.734	.857	.891	.913	.929	.972	.929	.941	.782	.874	.894
45 - humphead wrasse - Napoleon fish	α	.794	.888	.784	.873	.794	.718	.715	.811	.818	.869	.877	.907	.827	.683	.637	.731
	ρ	.893	.940	.861	.939	.866	.855	.800	.901	.904	.928	.872	.947	.866	.819	.772	.858
46 - parrotfishes	α	.764	.678	.399	.711	.715	.552	.575	.59	.594	.633	.691	.826	.709	.471	.704	.678
	ρ	.756	.906	.755	.939	.894	.632	.630	.772	.770	.887	.911	.906	.810	.661	.708	.784
47 - barracuda	α	.835	.821	.775	.887	.773	.452	.734	.865	.822	.826	.762	.874	.766	.48	.717	.844
	ρ	.954	.938	.933	.921	.914	.634	.923	.935	.961	.882	.886	.836	.956	.694	.911	.916
48 - Sohal surgeon fish	α	.839	.74	.839	.906	.783	.707	.821	.716	.853	.737	.844	.909	.802	.703	.835	.64
	ρ	.936	.893	.926	.942	.871	.807	.896	.814	.952	.932	.932	.947	.900	.839	.909	.832

Table 2. Continued

Surveyed Taxa	Test	%SF								AS							
		2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
49 - caranxes	α	.753	.772	.717	.925	.854	.833	.888	.889	.746	.847	.785	.945	.881	.834	.906	.893
	ρ	.851	.869	.835	.964	.938	.891	.902	.938	.850	.903	.914	.971	.960	.899	.921	.952
50 - lionfish	α	.697	.844	.774	.906	.865	.617	.682	.861	.717	.864	.773	.922	.862	.627	.692	.846
	ρ	.823	.924	.909	.944	.923	.805	.790	.934	.860	.954	.927	.958	.929	.801	.745	.882
51 - spotted flatheads	α	.753	.902	.874	.758	.822	.647	.718	.784	.763	.895	.878	.745	.816	.709	.742	.77
	ρ	.911	.862	.865	.803	.945	.918	.897	.847	.917	.872	.881	.827	.951	.939	.893	.812
52 - titan triggerfish	α	.824	.715	.573	.886	.937	.817	.567	.731	.857	.779	.607	.923	.918	.849	.619	.741
	ρ	.852	.850	.740	.934	.961	.913	.758	.844	.833	.918	.810	.948	.953	.922	.763	.867
53 - boxfishes	α	.728	.814	.75	.905	.641	.799	**.244**	.782	.717	.847	.772	.896	.592	.761	**.222**	.729
	ρ	.875	.876	.913	.951	.819	.913	**.402**	.822	.851	.881	.883	.934	.764	.891	**.311**	.773
54 - blowfishes	α	.655	.759	.857	.826	.837	.754	**.123**	.825	.753	.737	.752	.845	.813	.51	**.261**	.844
	ρ	.859	.869	.930	.935	.928	.821	**.196**	.904	.830	.836	.893	.900	.895	.659	**.339**	.917
55 - porcupinefishes	α	.676	.882	.758	.732	.753	.512	.623	.706	.694	.887	.734	.805	.701	.421	.676	.648
	ρ	.767	.946	.945	.886	.826	.589	.821	.771	.683	.929	.873	.883	.744	.571	.869	.718
56 - sharks	α	.701	.829	.761	.716	.888	.853	.477	.768	.663	.845	.769	.715	.88	.84	.474	.754
	ρ	**.413**	.977	.960	.929	.966	.801	.792	.942	**.394**	.980	.974	.924	.988	.835	.784	.949
57 - blue-spotted stingray	α	.94	.946	.88	.894	.872	.89	.861	.759	.886	.951	.875	.879	.868	.882	.875	.707
	ρ	.955	.940	.938	.937	.918	.928	.913	.877	.889	.900	.915	.928	.925	.908	.912	.838
58 - manta	α	.83	.646	.675	.644	.776	.496	.84	.57	.841	.654	.667	.641	.793	.489	.824	.582
	ρ	.789	.888	.811	.924	.752	.824	.828	.503	.665	.918	.852	.891	.691	.793	.898	.636
59 - torpedo	α	.615	.755	.754	.634	.667	.649	.678	.541	.64	.747	.708	.632	.662	.709	.677	.579
	ρ	.808	.900	.694	.779	.642	.554	.622	.597	.794	.880	.706	.714	.557	.681	.542	.644
60 - turtles	α	.882	.785	.852	.83	.894	.797	.546	.867	.857	.784	.854	.845	.902	.812	.54	.906
	ρ	.944	.938	.974	.936	.930	.964	.764	.897	.972	.975	.988	.962	.937	.985	.920	.942
61 - dolphins	α	.762	.721	.817	.826	.771	.8	**.363**	.481	.728	.733	.813	.808	.733	.767	**.369**	.553
	ρ	.889	.798	.896	.971	.859	.908	.880	.624	.799	.853	.867	.981	.899	.943	.894	.725
Other sea slugs	α	.715	.689	.472	.773	.786	.556	.402	.778	.675	.639	.434	.709	.715	.75	.421	.743
	ρ	.946	.821	.956	.952	.884	.795	.916	.908	.946	.743	.970	.963	.831	.859	.940	.915
Other rays and torpedos	α	.617	.809	.547	.697	.798	**.296**	.565	.681	.583	.788	.509	.698	.779	**.239**	.567	.701
	ρ	.804	.742	.911	.914	.856	.780	.703	.777	.822	.721	.925	.850	.842	.816	.734	.792
Other sponges	α	.739	.528	.527	.779	.895	.562	.741	.645	.661	.649	.575	.797	.919	.515	.779	.727
	ρ	.889	.659	.910	.899	.945	.547	.764	.828	.874	.776	.939	.879	.959	.551	.831	.889
Other starfishes	α	.682	.758	.583	.754	.591	**.337**	.415	.604	.782	.719	.558	.713	.631	**.355**	.407	.596
	ρ	.953	.945	.531	.957	.910	.545	**.368**	.819	.938	.947	.569	.965	.923	.538	.592	.691
Other bivalves	α	.638	.597	.709	.604	.677	.554	.78	.658	.66	.568	.688	.687	.644	.649	.724	.609
	ρ	.825	.690	.971	.937	.911	.535	.627	.801	.841	.641	.987	.937	.897	.554	.546	.850
Other cephalopods	α	.724	.779	.568	.796	.734	.592	.483	.465	.715	.75	.538	.811	.736	.614	.466	.511
	ρ	.983	.852	.691	.976	.814	.568	.533	**.443**	.991	.848	.730	.969	.836	.598	.690	**.460**
Other corals	α	.454	.623	.752	.565	.76	.621	**.228**	.636	.367	.607	.787	.535	.781	.564	**.166**	.674
	ρ	.546	.766	.825	.845	.890	.732	**.344**	.815	.506	.776	.827	.828	.906	.716	**.360**	.884
Other decapods	α	.685	.738	.555	.773	.768	.663	**.267**	.672	.645	.737	.543	.8	.773	.681	**.343**	.773
	ρ	.915	.673	.545	.973	.929	.795	.655	.941	.939	.668	**.121**	.976	.910	.781	.613	.951
Other bony fishes	α	.739	.632	.707	.639	.703	.674	**.154**	.643	.737	.55	.725	.533	.715	.652	**.206**	.698
	ρ	.823	.799	.863	.809	.897	.815	**.185**	.822	.836	.796	.828	.776	.924	.755	**.330**	.852
Other sea urchins	α	.732	.779	.874	.88	.742	.618	.457	.545	.791	.8	.87	.88	.759	.628	.561	.682
	ρ	.899	.814	.937	.918	.953	.690	**.475**	.678	.949	.859	.974	.942	.951	.754	.669	.662
Other sedentary worms	α	.625	.749	.604	.732	.854	.508	**.271**	.596	.587	.726	.611	.759	.766	.572	**.311**	.656
	ρ	.946	.918	.980	.963	.932	.528	**.392**	.812	.923	.931	.986	.944	.869	.533	**.457**	.735

Table 3. Results of Spearman correlation between Abundant score and biodiversity index. For the temporal homogeneous taxa, the column *Tot* refers to the overall years (2007-2014). For the temporal non – homogeneous taxa the column *Tot* refers only to the homogenous years, correlation value of non homogeneous years are displayed in the single year columns.

Surveyed Organisms	Tot	2007	2008	2012	2013	2014
1 - tube sponge (*Siphonochalina* sp., Demospongiae)	0.239**					
2 - fire coral (*Millepora* sp., Milleporina, Hydrozoa)	-0.054					
3 - leather coral (*Sarcophyton* sp., Alcyonacea, Anthozoa)	-0.04					
4 - soft tree coral (*Dendronephthya* sp., Alcyonacea, Anthozoa)	-0.149					
5 - sea fan (*Subergorgia hicksoni*, Gorgonacea, Anthozoa)	0.115					
6 - red sea fans (Melithaeidae, Gorgonacea, Anthozoa)	0.252**					
7 - sea whips (Ellisellidae, Gorgonacea, Anthozoa)	-0.079					
8 - sea carpet host anemones (Stichodactylidae, Actiniaria, Anthozoa)	0.185*					
9 - plating acropora (*Acropora* sp., Scleractinia, Anthozoa)	0.009					
10 - porcupine coral (*Seriatopora hystrix*, Scleractinia, Anthozoa)	0.08					
11 - bubble coral (*Plerogyra* sp., Scleractinia, Anthozoa)	0.339**					
12 - mushroom corals (Fungiidae, Scleractinia, Anthozoa)	0.179*					
13 - lettuce coral (*Turbinaria* sp., Scleractinia, Anthozoa)	0.365**			0.030		
14 - pineapple corals (Faviidae, Scleractinia, Anthozoa)	0.167					
15 - black coral (*Antipathes* sp., Antipatharia, Anthozoa)	0.096					
16 - Christmas tree worm (*Spirobranchus* sp., Polychaeta)	0.275**					
17 - cowries (Cypraeidae, Prosobranchia)	0.413**			-0.187		
18 - spanish dancer (*Hexabranchus sanguineus*, Opisthobranchia)	0.426**				-0.054	
19 - coriacea (*Chromodoris quadricolor*, Opisthobranchia)	0.368**			-0.154		
20 - tridacnae (*Tridacna* sp.)	0.303**					
21 - wing oyster (*Pteria* sp.)	0.533**					
22 - squids (Sepiidae)	0.562**					
23 - bigfin reef squid (*Sepioteuthis* sp.)	0.369**					0.594**
24 - banded boxer shrimp (*Stenopus hispidus*)	0.415**		0.169		0.208	
25 - hermit crabs (Diogenidae)	0.425		0.227			
26 - sea lilies (Crinoidea)	0.313**					
27 - sea cucumbers (Holothuroidea)	0.390**					
28 - pearl red star (*Fromia* sp.)	0.243**				-0.236	
29 - spiny starfish (*Acanthaster planci*)	0.457**			-0.258	-0.103	
30 - fire urchin (*Asthenosoma* sp.)	0.386**				-0.009	
31 - pencil urchin (*Phyllacanthus* sp.)	0.294**					
32 - giant moray (*Gymnothorax javanicus*, Anguilliformes)	0.042					
33 - needlefishes (Syngnathidae, Syngnathiformes)	0.268**				0.141	
34 - squirrelfish (*Sargocentron* sp., Beryciformes)	-0.188*					
35 - groupers (Epinephelinae, Perciformes)	0.015					
36 - blackspotted rubberlip (*Plectorhinchus gaterinus*, Perciformes)	0.152				0.057	

Table 3. Continued

Surveyed Organisms	Tot	2007	2008	2012	2013	2014
37 - humpback batfish (*Platax* sp., Perciformes)	0.544**					
38 - red bass (*Lutjanus bohar*, Perciformes)	0.406**					
39 - glassfishes (Pempheridae, Perciformes)	0.473**					
40 - goatfishes (Mullidae, Perciformes)	0.235**					
41 - map angel (*Pomacanthus maculosus*, Perciformes)	0.338**					
42 - butterflyfishes (Chaetodontidae, Perciformes)	-0.050					
43 - longnose hawkfish (*Oxycirrhites typus*, Perciformes)	0.336**			0.453**		
44 - Red Sea clownfish (*Amphiprion bicinctus*, Perciformes)	0.247**					
45 - humphead wrasse - Napoleon fish (*Cheilinus undulatus*, Perciformes)	0.142					
46 - parrotfishes (Scaridae, Perciformes)	0.347**					
47 - barracuda (*Sphyraena sp.*, Perciformes)	0.185*					
48 - Sohal surgeon fish (*Acanthurus sohal*, Perciformes)	0.252**					
49 - caranxes (Carangidae, Perciformes)	0.179*					
50 - lionfish (*Pterois* sp., Scorpaeniformes)	0.143					
51 - spotted flatheads (Platycephalidae, Scorpaeniformes)	0.452**					
52 - titan triggerfish (*Balistoides viridescens*, Tetraodontiformes)	0.300**					
53 - boxfishes (Ostraciidae, Tetraodontiformes)	0.318**				-0.241	
54 - blowfishes (Tetraodontidae, Tetraodontiformes)	0.398**				-0.413	
55 - porcupinefishes (Diodontidae, Tetraodontiformes)	0.402**					
56 - sharks (Squaliformes)	-0.077	0.306				
57 - blue-spotted stingray (*Taeniura lymma*)	0.298**					
58 - manta (*Manta* sp.)	0.513**					
59 - torpedo (*Torpedo* sp.)	0.586**					
60 - turtles (Cheloniidae)	0.421**					
61 - dolphins (Delphinidae)	0.251**				0.379	
Other sea slugs	0.173					
Other rays and torpedos	0.470**			-0.320		
Other sponges	-0.054					
Other starfishes	0.253**			0.265		
Other bivalves	0.233**					
Other cephalopods	0.392**				0.355**	
Other corals	-0.013	0.164				
Other decapods	0.279**			0.124	-0.079	
Other bony fishes	-0.074			0.033		
Other sea urchins	0.239**					
Other sedentary worms	0.343**				0.028	

Figures

Figure 1. Survey questionnaire. Section with photographs to be used in species identification.

Please, send this questionnaire to: STE project, Marine Science Group - Department of Evolutionary and Experimental Biology, University of Bologna, Via F. Selmi 3, I-40126 Bologna Italy
www.STEproject.org

Surname ______ Name ______

Complete address ______

E-mail ______ Dive Certification (level and training organization) ______

Dive site ______ Nearest town ______

Diving Center ______

Dive date ______ Maximum depth (m) ______

Depth where yuo spent most of your dive (m) ______ Water temperature (°C) ______

Actual bottom time (minutes) ______ Dive starting time (0-24) ______

Environment where yuo spent most of your dive (choose one) ☐ coral reef ☐ sandy bottom ☐ other__________

Please select the organisms you have seen in the checklist below estimating the frequency of their occurrence. Your instructor can help you!

	RARE	FREQUENT	VERY FREQUENT
SPONGES			
1 - tube sponge (*Siphonochalina* sp., Demospongiae)	☐ 1-2	☐ 3-10	☐ more than 10
Other sponges	☐ 1-2	☐ 3-10	☐ more than 10
COELENTERATES, CORALS			
2 - fire coral (*Millepora* sp., Milleporina, Hydrozoa)	☐ 1-10	☐ 11-100	☐ more than 100
3 - leather coral (*Sarcophyton* sp., Alcyonacea, Anthozoa)	☐ 1-5	☐ 6-15	☐ more than 15
4 - soft tree coral (*Dendronephthya* sp., Alcyonacea, Anthozoa)	☐ 1-10	☐ 11-100	☐ more than 100
5 - sea fan (*Subergorgia hicksoni*, Gorgonacea, Anthozoa)	☐ 1-3	☐ 4-10	☐ more than 10
6 - red sea fans (Melithaeidae, Gorgonacea, Anthozoa)	☐ 1-5	☐ 6-15	☐ more than 15
7 - sea whips (Ellisellidae, Gorgonacea, Anthozoa)	☐ 1-2	☐ 3-6	☐ more than 6
8 - sea carpet host anemones (Stichodactylidae, Actiniaria, Anthozoa)	☐ 1-3	☐ 4-10	☐ more than 10
9 - plating acropora (*Acropora* sp., Scleractinia, Anthozoa)	☐ 1-2	☐ 3-6	☐ more than 6
10 - porcupine coral (*Seriatopora hystrix*, Scleractinia, Anthozoa)	☐ 1-5	☐ 6-15	☐ more than 15
11 - bubble coral (*Plerogyra* sp., Scleractinia, Anthozoa)	☐ 1-5	☐ 6-15	☐ more than 15
12 - mushroom corals (Fungiidae, Scleractinia, Anthozoa)	☐ 1-5	☐ 6-15	☐ more than 15
13 - lettuce coral (*Turbinaria* sp., Scleractinia, Anthozoa)	☐ 1-5	☐ 6-15	☐ more than 15
14 - pineapple corals (Faviidae, Scleractinia, Anthozoa)	☐ 1-2	☐ 3-6	☐ more than 6
15 - black coral (*Antipathes* sp., Antipatharia, Anthozoa)	☐ 1-2	☐ 3-6	☐ more than 6
Other corals	☐ 1-5	☐ 6-25	☐ more than 25
ANELLIDA, SEDENTARY WORMS			
16 - Christmas tree worm (*Spirobranchus* sp., Polychaeta)	☐ 1-5	☐ 6-15	☐ more than 15
Other sedentary worms	☐ 1-5	☐ 6-15	☐ more than 15
MOLLUSCS, GASTROPODS (SEA SLUGS)			
17 - cowries (Cypraeidae, Prosobranchia)	☐ 1	☐ 2-3	☐ more than 3
18 - spanish dancer (*Hexabranchus sanguineus*, Opisthobranchia)	☐ 1	☐ 2-3	☐ more than 3
19 - coriacea (*Chromodoris quadricolor*, Opisthobranchia)	☐ 1-2	☐ 3-4	☐ more than 4
Other sea slugs	☐ 1	☐ 2-3	☐ more than 3
MOLLUSCS, BIVALVES			
20 - tridacnae (*Tridacna* sp.)	☐ 1-2	☐ 3-6	☐ more than 6
21 - wing oyster (*Pteria* sp.)	☐ 1-5	☐ 6-15	☐ more than 15
Other bivalves	☐ 1-4	☐ 5-10	☐ more than 10
MOLLUSCS, CEPHALOPODS			
22 - squids (Sepiidae)	☐ 1-2	☐ 3-4	☐ more than 4
23 - bigfin reef squid (*Sepioteuthis* sp.)	☐ 1	☐ 2-3	☐ more than 3
Other cephalopods	☐ 1-2	☐ 3-4	☐ more than 4
ARTHROPODS, CRUSTACEANS, DECAPODS			
24 - banded boxer shrimp (*Stenopus hispidus*)	☐ 1	☐ 2-3	☐ more than 3
25 - hermit crabs (Diogenidae)	☐ 1	☐ 2-3	☐ more than 3
Other decapods	☐ 1	☐ 2-3	☐ more than 3

	RARE	FREQUENT	VERY FREQUENT
ECHINODERMS, CRINOIDS (SEA LILIES)			
26 - sea lilies (Crinoidea)	☐ 1-5	☐ 6-15	☐ more than 15
ECHINODERMS, HOLOTHURIANS (SEA CUCUMBERS)			
27 - sea cucumbers (Holothuroidea)	☐ 1-2	☐ 3-10	☐ more than 10
ECHINODERMS, ASTEROIDS (STARFISHES)			
28 - pearl red star (*Fromia* sp.)	☐ 1	☐ 2-3	☐ more than 3
29 - spiny starfish (*Acanthaster planci*)	☐ 1-2	☐ 3-6	☐ more than 6
Other starfishes	☐ 1-2	☐ 3-5	☐ more than 5
ECHINODERMS, ECHINOIDS (SEA URCHINS)			
30 - fire urchin (*Asthenosoma* sp.)	☐ 1-2	☐ 3-4	☐ more than 4
31 - pencil urchin (*Phyllacanthus* sp.)	☐ 1-3	☐ 4-10	☐ more than 10
Other sea urchins	☐ 1-3	☐ 4-7	☐ more than 7
VERTEBRATES, BONY FISHES			
32 - giant moray (*Gymnothorax javanicus*, Anguilliformes)	☐ 1	☐ 2-3	☐ more than 3
33 - needlefishes (Syngnathidae, Syngnathiformes)	☐ 1-2	☐ 3-4	☐ more than 4
34 - squirrelfish (*Sargocentron* sp., Beryciformes)	☐ 1-5	☐ 6-15	☐ more than 15
35 - groupers (Epinephelinae, Perciformes)	☐ 1-5	☐ 6-15	☐ more than 15
36 - blackspotted rubberlip (*Plectorhinchus gaterinus*, Perciformes)	☐ 1-3	☐ 4-10	☐ more than 10
37 - humpback batfish (*Platax* sp., Perciformes)	☐ 1-10	☐ 11-100	☐ more than 100
38 - red bass (*Lutjanus bohar*, Perciformes)	☐ 1-10	☐ 11-100	☐ more than 100
39 - glassfishes (Pempheridae, Perciformes)	☐ 1-100	☐ 101-1000	☐ more than 1000
40 - goatfishes (Mullidae, Perciformes)	☐ 1-10	☐ 11-100	☐ more than 100
41 - map angel (*Pomacanthus maculosus*, Perciformes)	☐ 1	☐ 2-3	☐ more than 3
42 - butterflyfishes (Chaetodontidae, Perciformes)	☐ 1-5	☐ 6-15	☐ more than 15
43 - longnose hawkfish (*Oxycirrhites typus*, Perciformes)	☐ 1	☐ 2-3	☐ more than 3
44 - Red Sea clownfish (*Amphiprion bicinctus*, Perciformes)	☐ 1-3	☐ 4-15	☐ more than 15
45 - humphead wrasse - Napoleon fish (*Cheilinus undulatus*, Perciformes)	☐ 1	☐ 2-3	☐ more than 3
46 - parrotfishes (Scaridae, Perciformes)	☐ 1-5	☐ 6-25	☐ more than 25
47 - barracuda (*Sphyraena* sp., Perciformes)	☐ 1-5	☐ 6-25	☐ more than 25
48 - Sohal surgeonfish (*Acanthurus sohal*, Perciformes)	☐ 1-5	☐ 6-15	☐ more than 15
49 - caranxes (Carangidae, Perciformes)	☐ 1-5	☐ 6-15	☐ more than 15
50 - lionfish (*Pterois* sp., Scorpaeniformes)	☐ 1-5	☐ 6-15	☐ more than 15
51 - spotted flatheads (Platycephalidae, Scorpaeniformes)	☐ 1-2	☐ 3-4	☐ more than 4
52 - titan triggerfish (*Balistoides viridescens*, Tetraodontiformes)	☐ 1-2	☐ 3-4	☐ more than 4
53 - boxfishes (Ostraciidae, Tetraodontiformes)	☐ 1-2	☐ 3-4	☐ more than 4
54 - blowfishes (Tetraodontidae, Tetraodontiformes)	☐ 1-3	☐ 4-10	☐ more than 10
55 - porcupinefishes (Diodontidae, Tetraodontiformes)	☐ 1	☐ 2-3	☐ more than 3
Other bony fishes	☐ 1-10	☐ 11-65	☐ more than 65
VERTEBRATES, CARTILAGE FISHES, SHARKS			
56 - sharks (Squaliformes)	☐ 1	☐ 2-3	☐ more than 3
VERTEBRATES, CARTILAGE FISHES, RAYS AND TORPEDOS			
57 - blue-spotted stingray (*Taeniura lymma*)	☐ 1-2	☐ 3-6	☐ more than 6
58 - manta (*Manta* sp.)	☐ 1	☐ 2-3	☐ more than 3
59 - torpedo (*Torpedo* sp.)	☐ 1	☐ 2	☐ more than 2
Other rays and torpedos	☐ 1	☐ 2-4	☐ more than 4
VERTEBRATES, REPTILES, TURTLES			
60 - turtles (Cheloniidae)	☐ 1	☐ 2-3	☐ more than 3
VERTEBRATES, MAMMALS, CETACEANS			
61 - dolphins (Delphinidae)	☐ 1-2	☐ 3-6	☐ more than 6

Attention: please indicate the possible presence of the following negative conditions

62 - PARTIALLY OR TOTALLY DEAD CORALS	☐ 1-10	☐ 11-100	☐ more than 100
63 - BLEACHED CORALS	☐ 1-10	☐ 11-100	☐ more than 100
• - BROKEN CORALS	☐ 1-10	☐ 11-100	☐ more than 100
• - SEDIMENT COVERED CORALS	☐ 1-10	☐ 11-100	☐ more than 100
• - LITTER	☐ 1	☐ 2-10	☐ more than 10

Attention: please give information about snorkelers and scuba divers behaviour

How many snorkelers and scuba divers were present on the dive site?	☐ 1-25	☐ 26-50	☐ more than 50
How many snorkelers and scuba divers contacts with the reef did you see during your dive? (both voluntary or involuntary contacts)	☐ 1-5	☐ 6-10	☐ more than 10

Figure 2. Survey questionnaire. Section for recording data obtained by volunteers on censuses taxa.

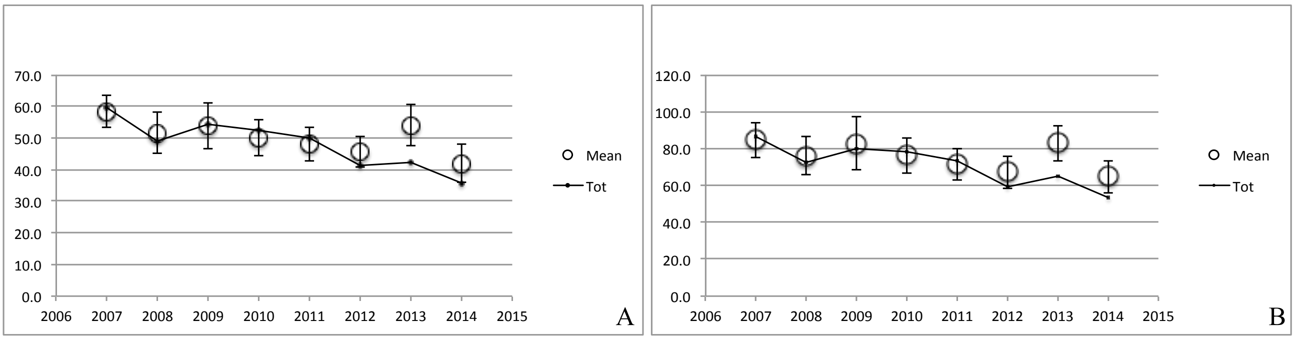

Figure 3. Sighting frequency (A) and abundant score (B) of lettuce coral. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

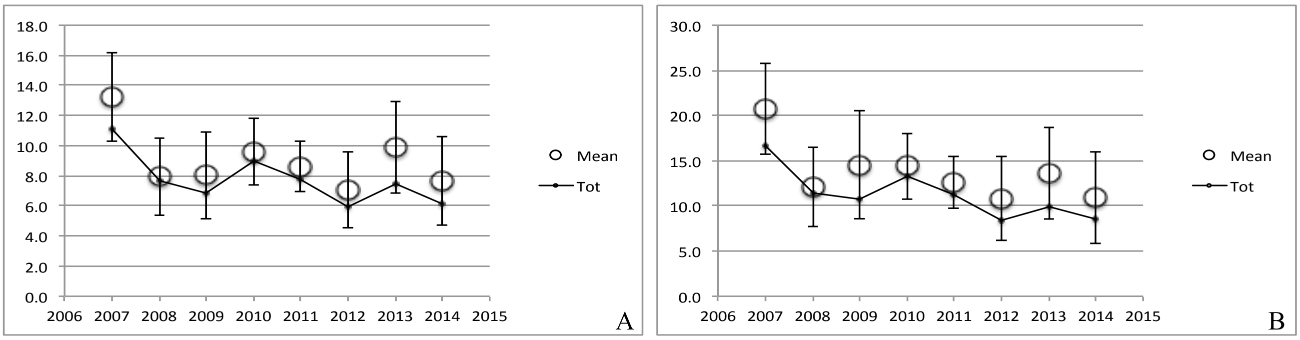

Figure 4. Sighting frequency (A) and abundant score (B) of fire urchin. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

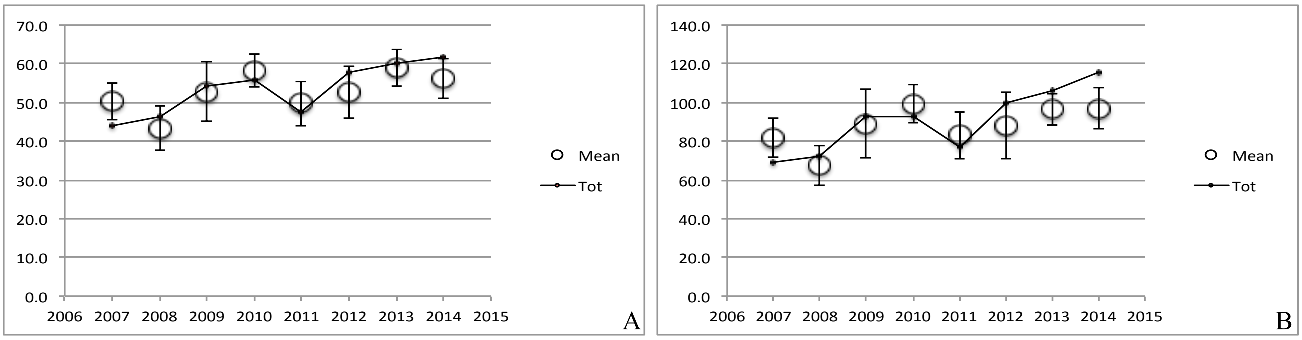

Figure 5. Sighting frequency (A) and abundant score (B) of goatfishes. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

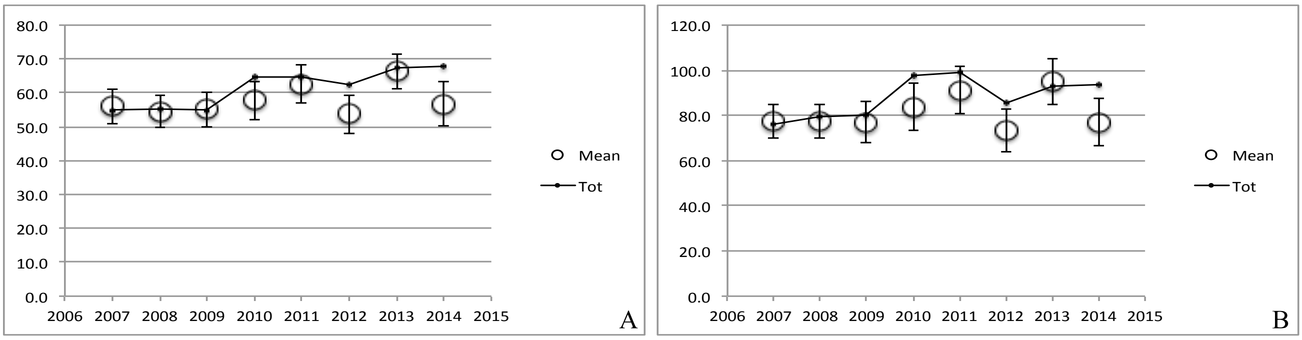

Figure 6. Sighting frequency (A) and abundant score (B) of blowfishes. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

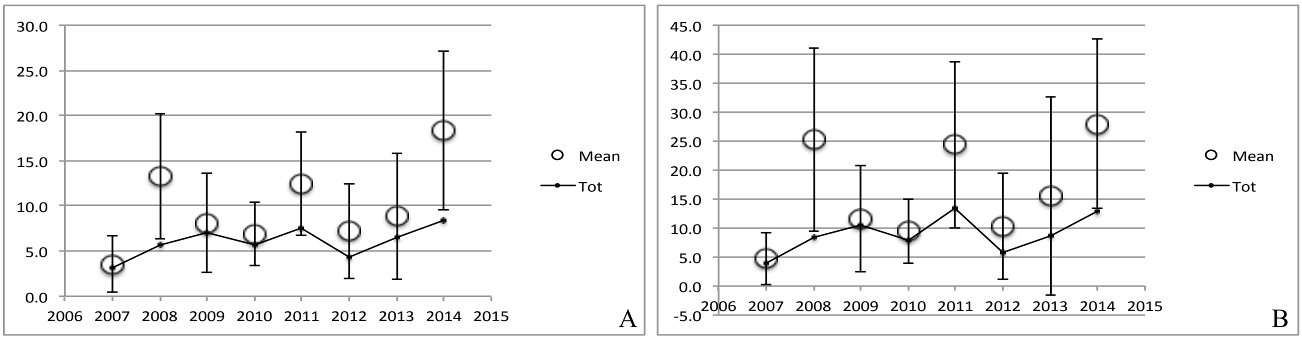

Figure 7. Sighting frequency (A) and abundant score (B) of sharks. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

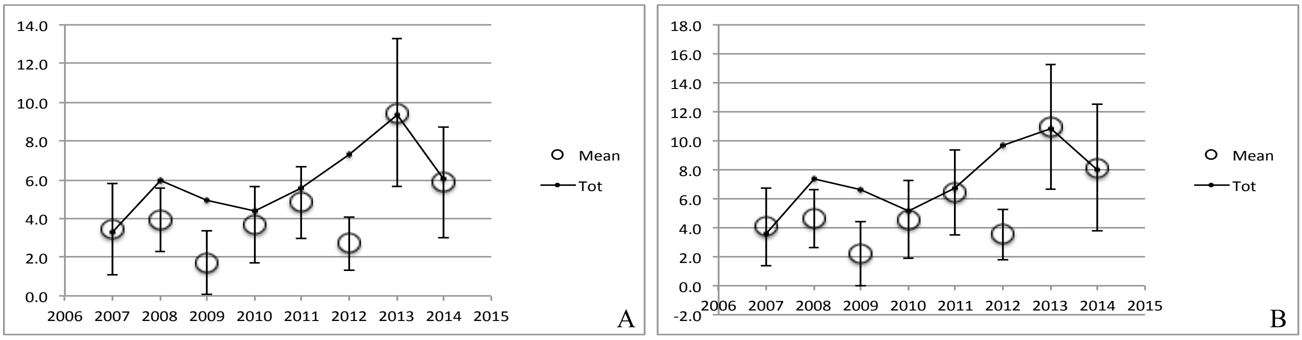

Figure 8. Sighting frequency (A) and abundant score (B) of other rays and torpedos. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

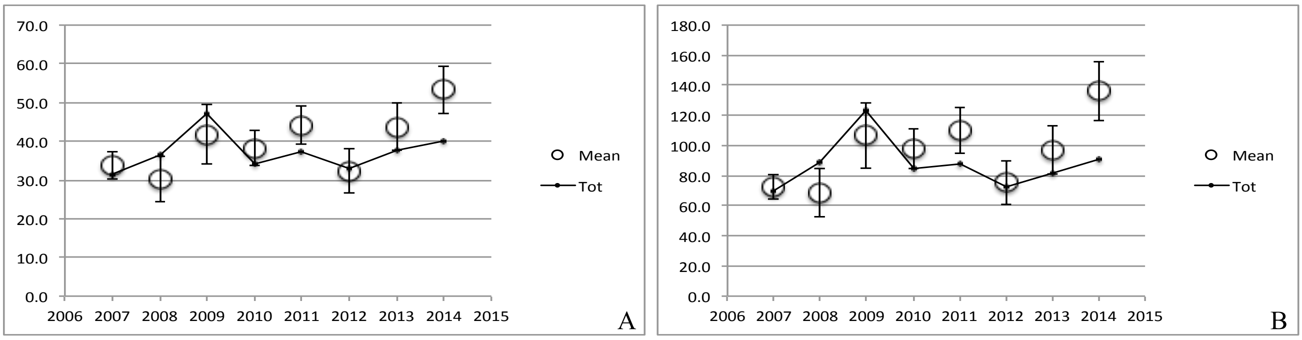

Figure 9. Sighting frequency (A) and abundant score (B) of other corals. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

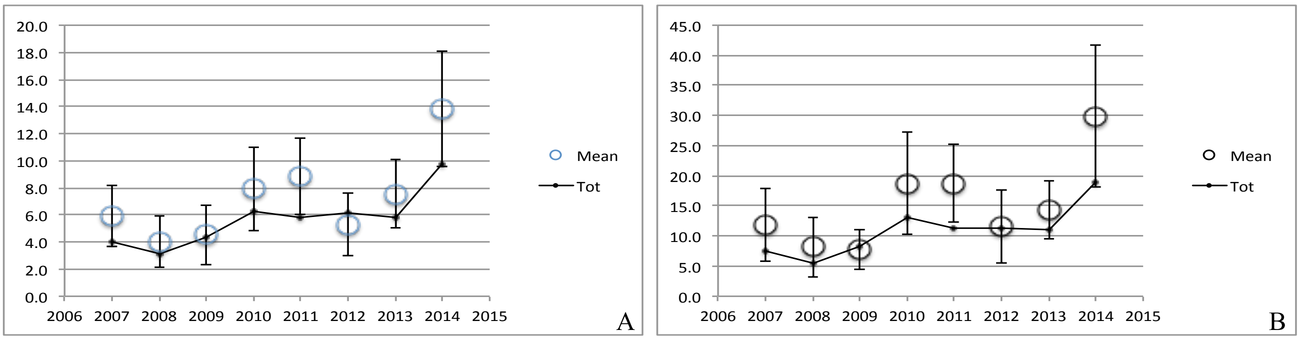

Figure 10. Sighting frequency (A) and abundant score (B) of other decapods. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

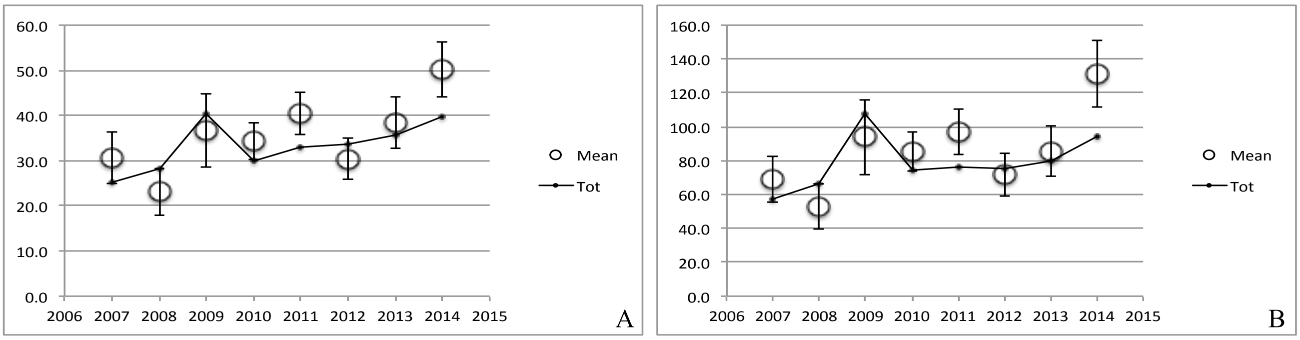

Figure 11. Sighting frequency (A) and abundant score (B) of other bony fishes. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

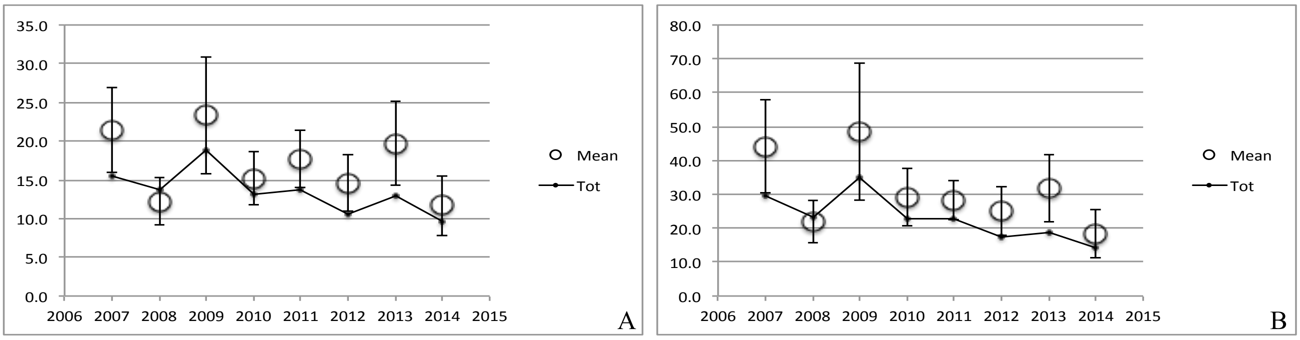

Figure 12. Sighting frequency (A) and abundant score (B) of other sea urchins. *Mean* represents the values (± confidence limit) among the station surveyed in each year. *Tot* represents the value calculated on the total number of questionnaires.

Red Sea coral reef species distribution analyses through data collected by citizen scientists

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Appendix 1. Results of spatial trends detection

Table 1. Result of the Permanova analyses. F value and P value are displayed for each taxon. For the temporal homogeneous taxa, the column *TOT* refers to the overall years (2007-2014). For the temporal non – homogeneous taxa the column *TOT* refers only to the homogenous years, F value and P value of non homogeneous years are displayed in the single year columns. The column LDS refers to the LSD post-hoc, *X* means that it was not performed, *S* means that it was significant and *N* that it was non significant.

Taxon	TOT			07		09		12		13		14	
	F	P	LDS	F	P	F	P	F	P	F	P	F	P
1 - tube sponge	0.59964	0.695	X										
Other sponges	2.2693	0.031	N										
2 - fire coral	3.6252	0.004	S										
3 - leather coral	2.9001	0.009	S										
4 - soft tree coral	8.2619	0.001	X										
5 - sea fan	3.3082	0.004	S										
6 - red sea fans	2.2085	0.067	X										
7 - sea whips	4.1372	0.004	N										
8 - sea carpet host anemones	2.286	0.061	X										
9 - plating acropora	2.1419	0.070	X										
10 - porcupine coral	1.9128	0.104	X										
11 - bubble coral	3.3906	0.002	S										
12 - mushroom corals	1.3862	0.238	X										

Table A1. Continued

13 - lettuce coral	8.4222	0.001	S					1.9053	0.107				
14 - pineapple corals	0.8306	0.552	X										
15 - black coral	5.3797	0.002	N										
Other corals	1.6216	0.136	X							1.6162	0.204		
16 - Christmas tree worm	0.93752	0.447	X										
Other sedentary worms	3.6408	0.001	N							2.8889	0.02		
17 – cowries	2.6914	0.010	N					1.6869	0.163				
18 - spanish dancer	6.4896	0.001	S							0.84734	0.528		
19 – coriacea	2.4469	0.02	N					0.27191	0.949				
Other sea slugs	1.2891	0.264	X										
20 – tridacnae	6.3633	0.001	N										
21 - wing oyster	1.7558	0.094	N										
Other bivalves	3.1356	0.010	N										
22 – squids	2.7087	0.005	N										
23 - bigfin reef squid	2.3152	0.008	N									0.70076	0.628
Other cephalopods	1.981	0.068	N					4.2321	0.01	2.5218	0.038		
24 - banded boxer shrimp	1.5841	0.159	N			0.73128	0.619			1.2368	0.297		
25 - hermit crabs	2.8836	0.015	N			2.5408	0.055						
Other decapods	1.4416	0.199	N			0.7327	0.663					0.85347	0.499
26 - sea lilies	0.95132	0.453	X										
27 - sea cucumbers	2.3833	0.038	N										
28 - pearl red star	3.2869	0.002	N					0.67191	0.647	1.8398	0.132		
29 - spiny starfish	7.3997	0.001	S					1.9333	0.105	2.5721	0.046		
Other starfishes	1.8792	0.072	N					1.5487	0.187	2.2565	0.082		
30 - fire urchin	3.3796	0.001	S							2.0026	0.113		
31 - pencil urchin	2.3833	0.044	N										
Other sea urchins	42.137	0.001	S							0.58745	0.675		
32 - giant moray	3.7646	0.001	S										

Table A1. Continued

33 – needlefishes	2.5748	0.012	N							1.0139	0.429		
34 – squirrelfish	4.9863	0.001	S										
35 – groupers	2.8254	0.006	S										
36 - blackspotted rubberlip	2.1169	0.035	N							1.4826	0.204		
37 - humpback batfish	4.5424	0.001	S										
38 - red bass	1.5314	0.131	X										
39 – glassfishes	1.6281	0.177	X										
40 – goatfishes	4.4699	0.001	S							0.53381	0.743		
41 - map angel	5.1683	0.001	S										
42 – butterflyfishes	3.8083	0.001	N										
43 - longnose hawkfish	1.4502	0.186	X					0.4751	0.845				
44 - Red Sea clownfish	1.0858	0.366	X										
45 - humphead wrasse	5.9529	0.002	N										
46 – parrotfishes	2.5415	0.026	N										
47 – barracuda	2.6986	0.019	N										
48 - Sohal surgeon fish	2.6986	0.028	N										
49 – caranxes	2.6986	0.015	N										
50 – lionfish	3.7629	0.002	N										
51 - spotted flatheads	3.7499	0.002	N										
52 - titan triggerfish	4.2109	0.006	N										
53 – boxfishes	2.4406	0.015	N							0.8294	0.537		
54 – blowfishes	8.933	0.001	S							0.97398	0.427		
55 – porcupinefishes	1.7611	0.097	X										
Other bony fishes	2.0594	0.032	N							1.1213	0.345		
56 – sharks	2.9588	0.004	S	4.0761	0.004								
57 - blue-spotted stingray	7.4852	0.001	N										
58 – manta	1.8893	0.107	X										
59 – torpedo	2.1303	0.085	X										

Table A1. Continued

Other rays and torpedos	7.5588	0.001	X					0.95524	0.431				
60 – turtles	3.3905	0.012	N										
61 – dolphins	3.2784	0.006	N							1.6216	0.197		

Following the outputs of MDS analyses of taxa that showed a significant LDS post-hoc.

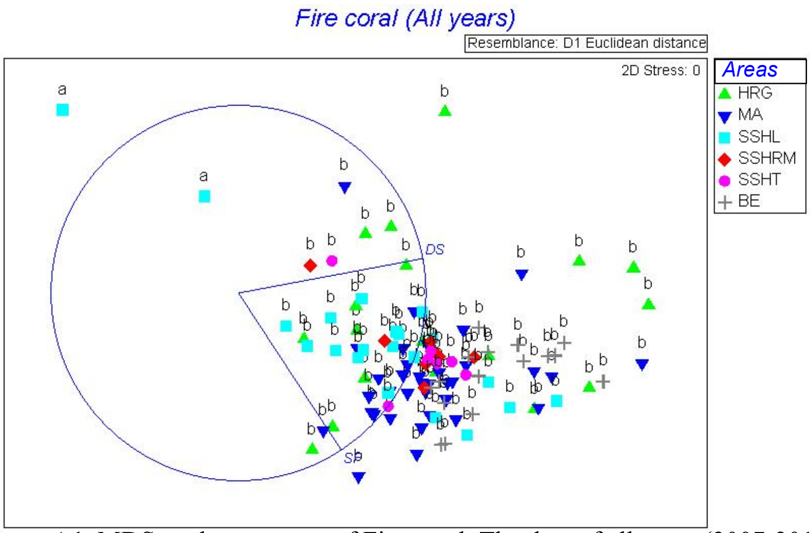

Figure A1. MDS analyses output of Fire coral. The data of all years (2007-2014) were included in the analyses.

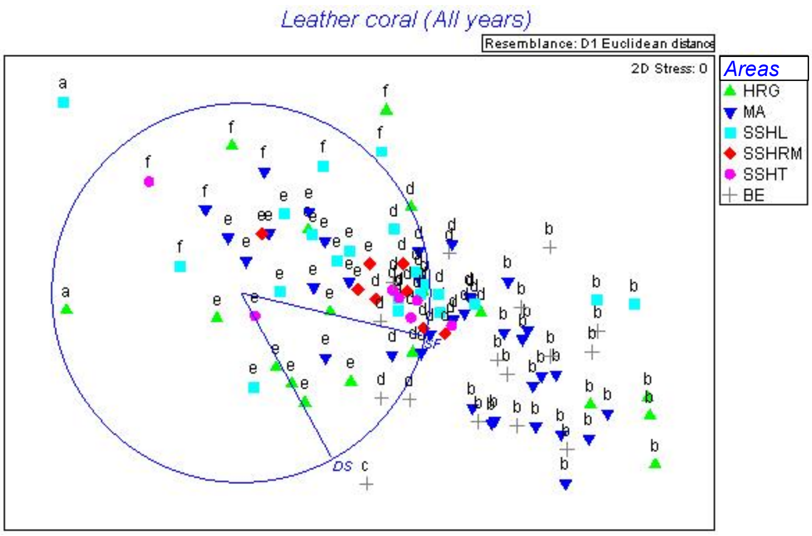

Figure A2. MDS analyses output of Leather coral. The data of all years (2007-2014) were included in the analyses.

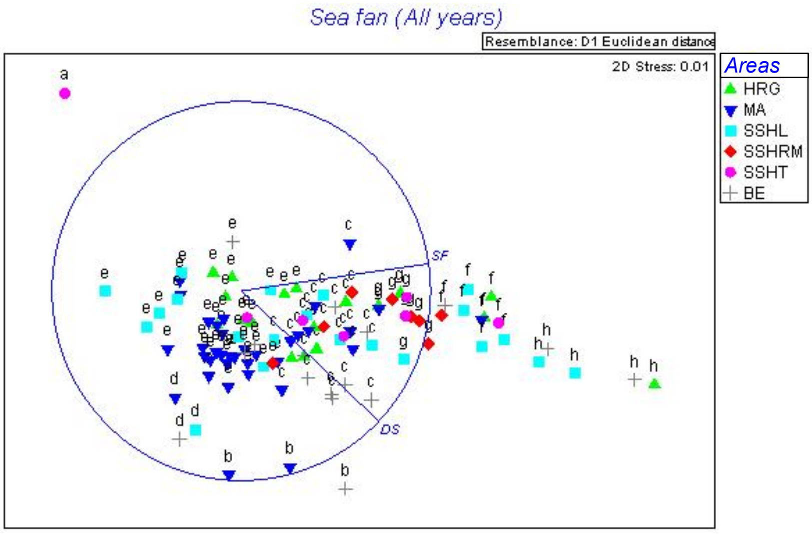

Figure A3. MDS analyses output of Sea fan. The data of all years (2007-2014) were included in the analyses.

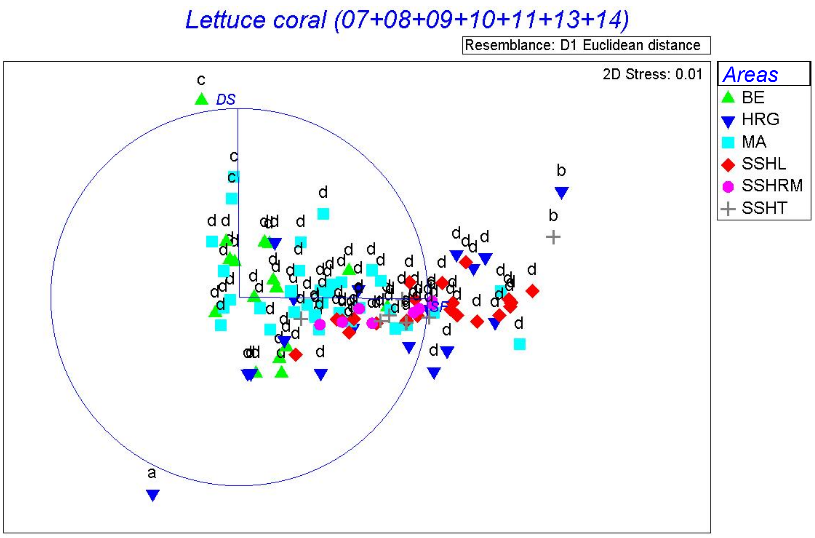

Figure A4. MDS analyses output of Lettuce coral. The data of years 2007 + 2008 + 2009 + 2010 + 2011 + 2013 + 2014 were included in the analyses.

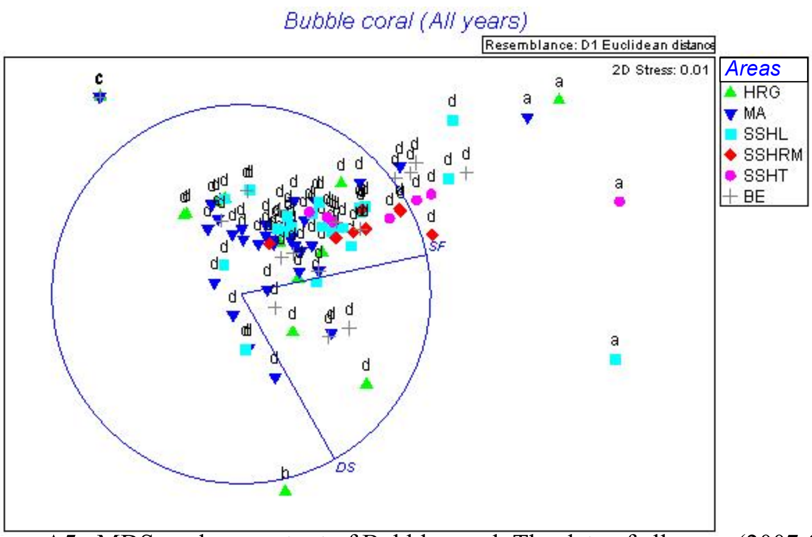

Figure A5. MDS analyses output of Bubble coral. The data of all years (2007-2014) were included in the analyses.

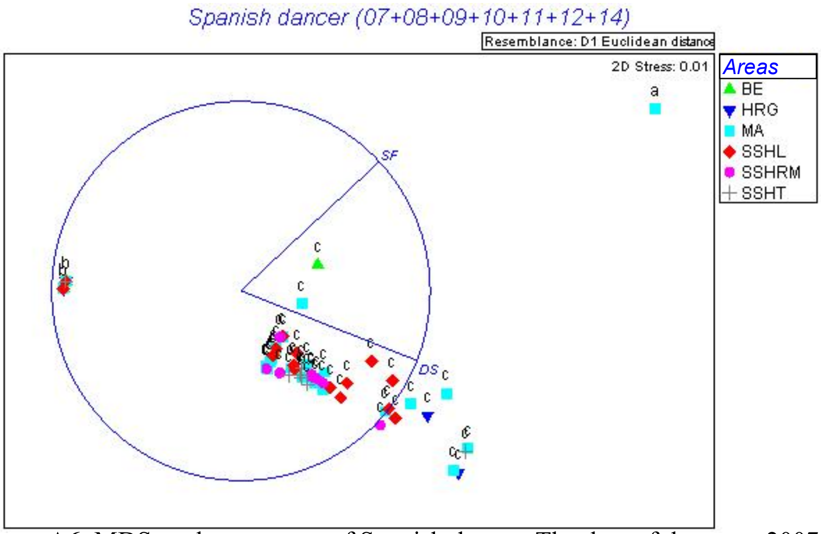

Figure A6. MDS analyses output of Spanish dancer. The data of the years 2007 + 2008 + 2009 + 2010 + 2011 + 2012 + 2014 were included in the analyses.

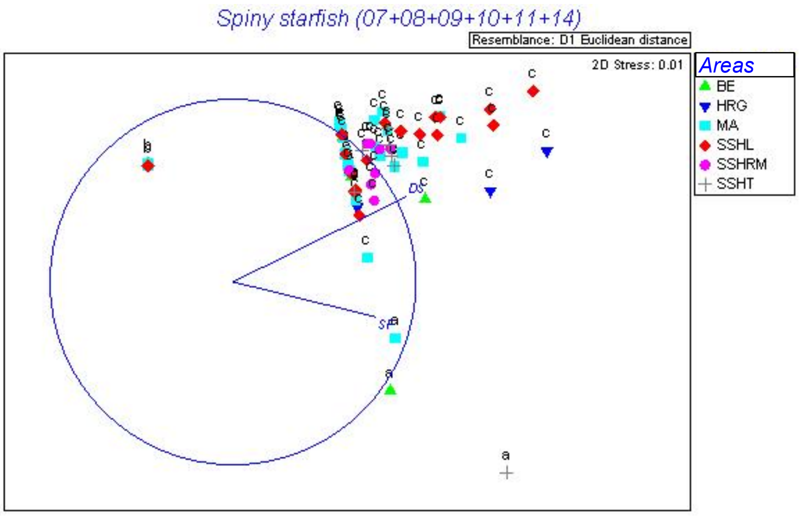

Figure A7. MDS analyses output of Spiny starfish. The data of the years 2007 + 2008 + 2009 + 2010 + 2011 + 2014 were included in the analyses.

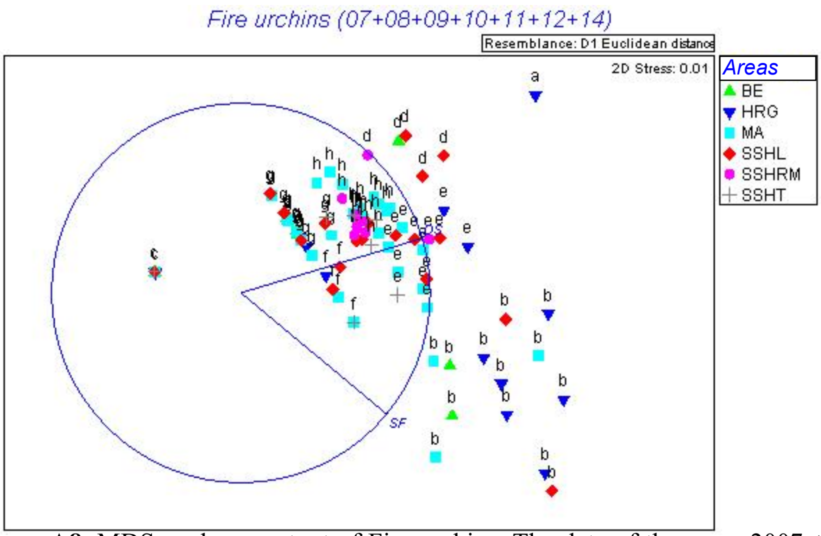

Figure A8. MDS analyses output of Fire urchins. The data of the years 2007 + 2008 + 2009 + 2010 + 2011 + 2012 + 2014 were included in the analyses.

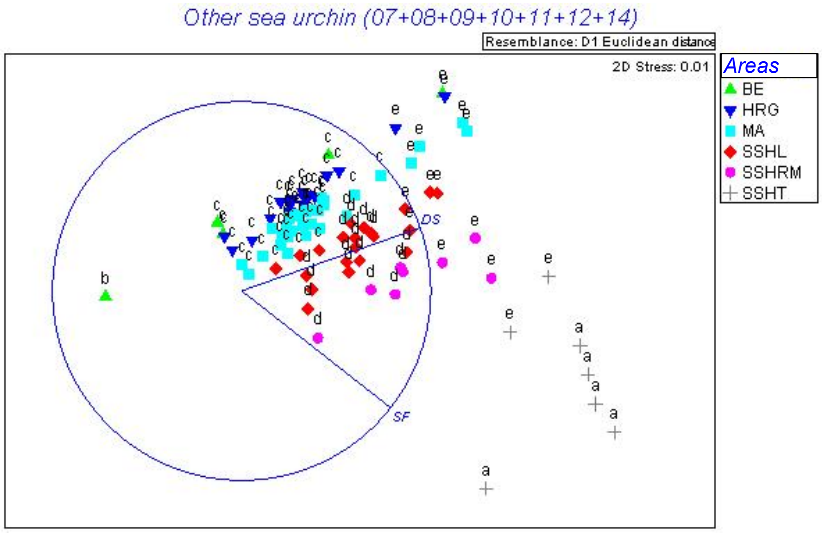

Figure A9. MDS analyses output of Other sea urchins. The data of the years 2007 + 2008 + 2009 + 2010 + 2011 + 2012 + 2014 were included in the analyses.

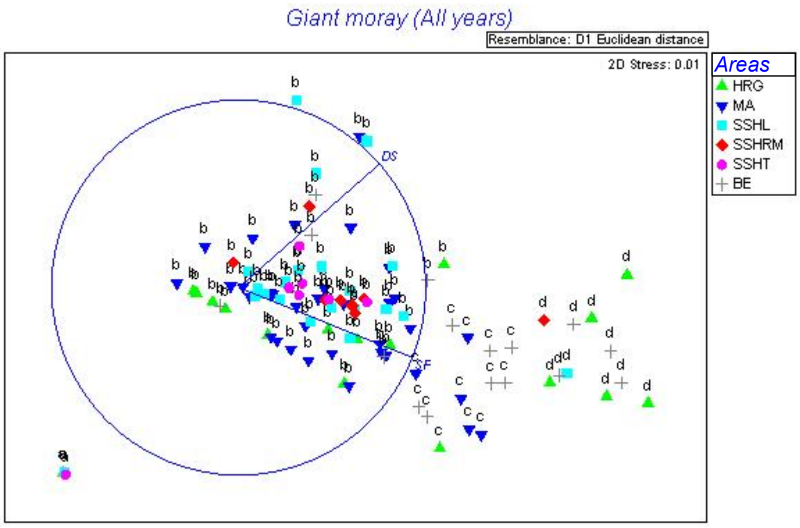

Figure A10. MDS analyses output of Giant moray. The data of all years (2007-2014) were included in the analyses.

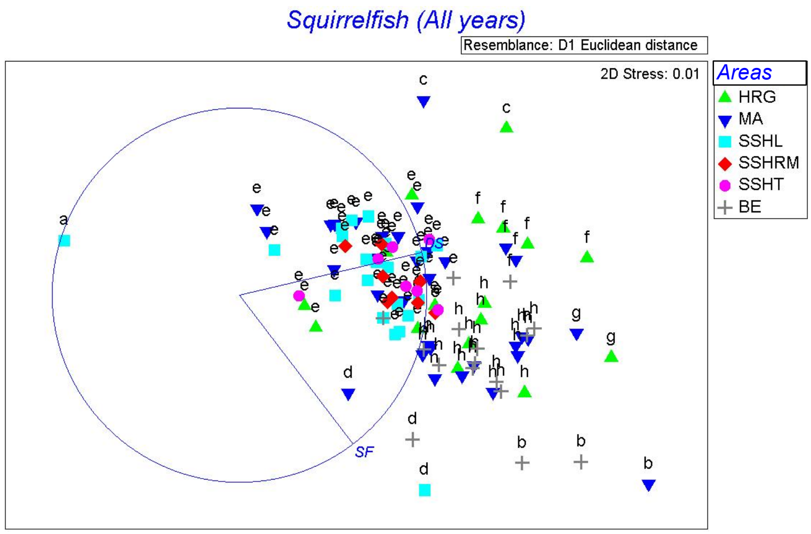

Figure A11. MDS analyses output of Squirrelfish. The data of all years (2007-2014) were included in the analyses.

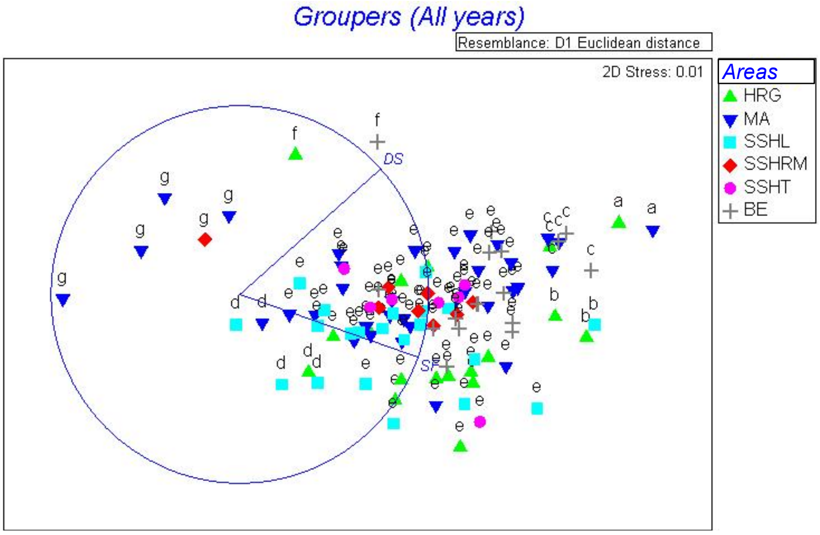

Figure A12. MDS analyses output of Groupers. The data of all years (2007-2014) were included in the analyses.

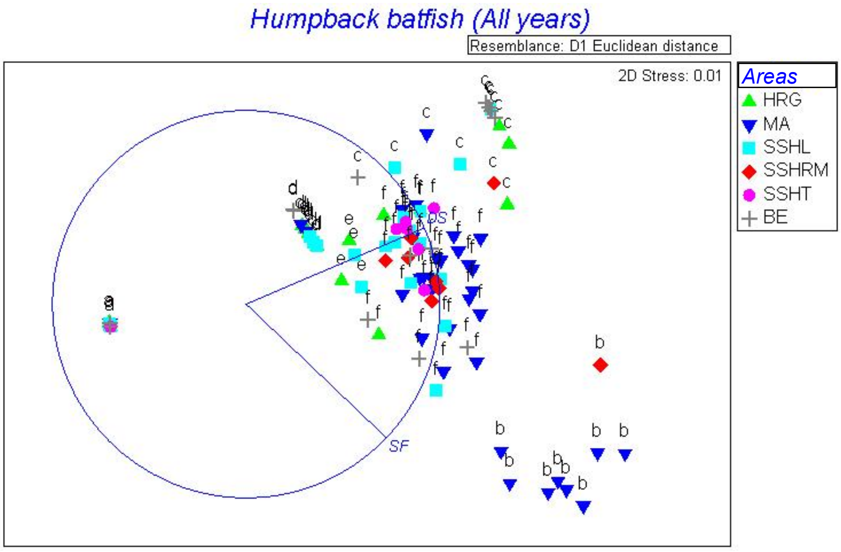

Figure A13. MDS analyses output of Humpback batfish. The data of all years (2007-2014) were included in the analyses.

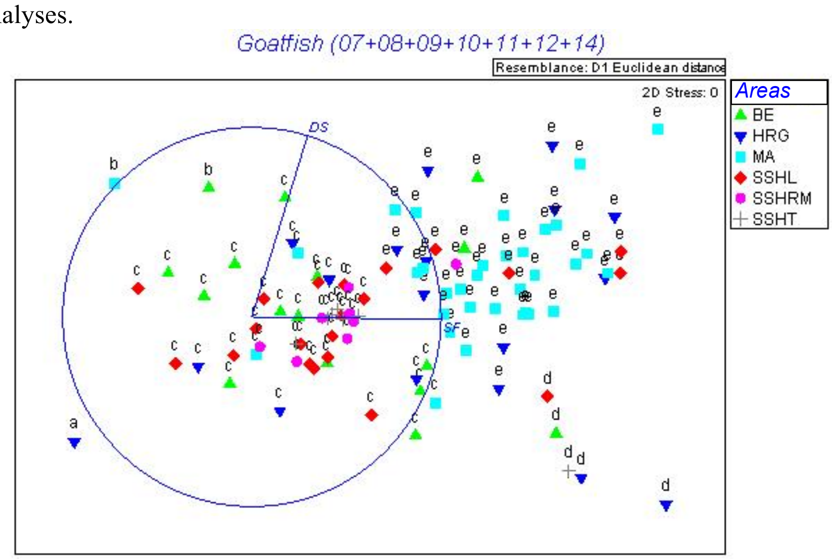

Figure A14. MDS analyses output of Goatfish. The data of the years 2007 + 2008 + 2009 + 2010 + 2011 + 2012 + 2014 were included in the analyses.

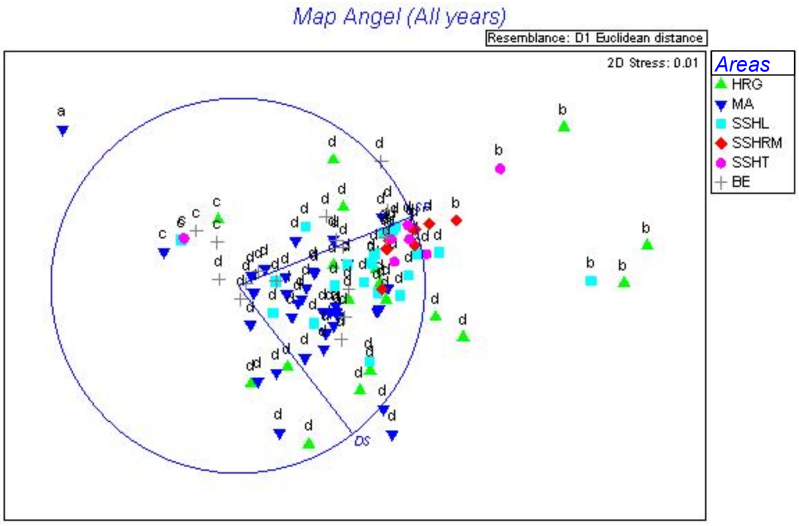

Figure A15. MDS analyses output of Map angel. The data of all years (2007-2014) were included in the analyses.

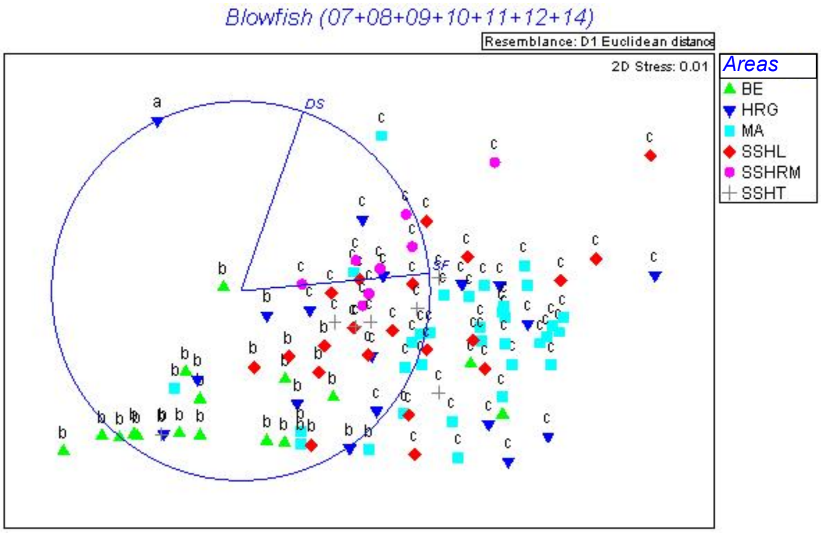

Figure A16. MDS analyses output of Blowfish. The data of the years 2007 + 2008 + 2009 + 2010 +2011 + 2012 + 2014 were included in the analyses.

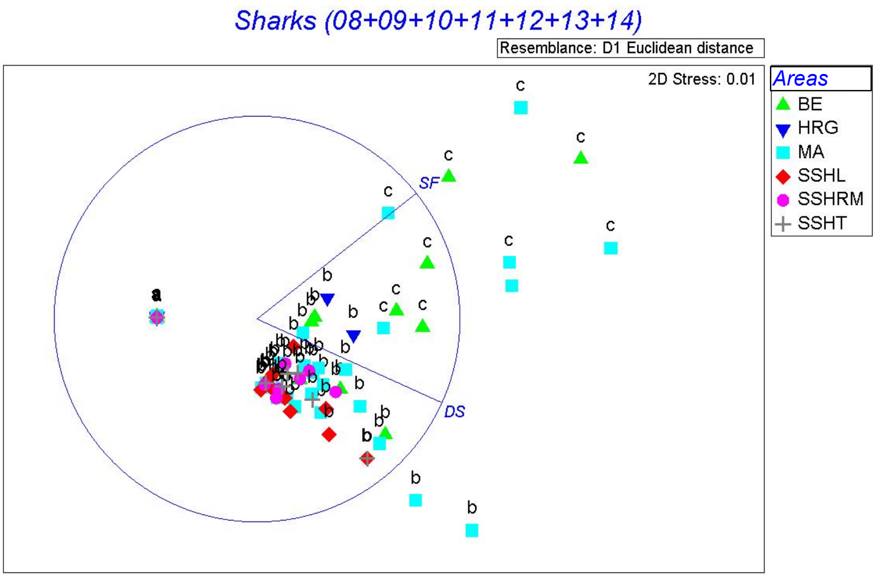

Figure A17. MDS analyses output of Sharks. The data of the years 2008 + 2009 + 2010 +2011 + 2012 + 2013 + 2014 were included in the analyses.

Chapter 4.

PARTICIPATING IN A CITIZEN SCIENCE MONITORING PROGRAM: IMPLICATIONS FOR ENVIRONMENTAL EDUCATION

Submitted to PLoS ONE

Participating in a citizen science monitoring program: implications for environmental education

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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.

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. 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 (Fig. 1a and 1b). 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 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?". 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. 2) 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. 2) dealt with the awareness on the impact of human behaviour on the environment, hereafter called human impact questions. 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.

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. 3)

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 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 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 first 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 it. According to the reef biology and the human impact 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 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. STEproject has collected significant and reliable data on the health status of the coral reefs that has been exploited by the local environmental authorities to improve the environmental conservation management. At the same time, STE project, thanks to the recreational approach, 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.

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FIGURES

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HOW YOU CAN HELP TO DEFEND CORAL REEFS

Once upon a time only a fortunate few had the opportunity of exploring the wonders of a coral reef. Times have surely changed and, thanks to quick and efficient means of travel, many now have the chance of enjoying the beauty and pleasure of diving into and exploring these fascinating ecosystems. Corals and the life forms they host are extremely delicate. So, in order to make sure that the impact and the potential harm that could be done is reduced to a minimum, please follow the instructions in this pamphlet. Let them be of value to you in making your dive even more exciting and in helping you to preserve the beauty of your diving experience for future generations.
We wish you an enjoyable vacation.

Alma Mater Studiorum
University of Bologna
Italian Ministry of the Environment and Land and Sea Protection
Ministry of Tourism of the Arab Republic of Egypt
Egyptian Tourist Authority
ASTOI (Association of Italian Tour Operators)
PROJECT AWARE FOUNDATION
SNSI (Scuba Nitrox Safety International)
SSI (Scuba Schools International Italy)
ULP (Underwater Life Project)
EULF (Egyptian Underwater & Lifesaving Federation)
TUTTOTURISMO
MSG (Marine Science Group Association)

BEFORE LEAVING HOME

- Choose tour operators and diving schools that honor the environment and that teach respect and safety for human life and nature: refer to associations and agencies that vouch for their affiliated members (www.astoi.com, www.projectaware.org, www.snsi.it, www.ssi-italy.org, www.underwaterlifeproject.it, www.msgassociation.net).

LOOK FOR QUALIFIED TOUR OPERATORS ONLY
READ UP ON THE CULTURE AND ECOLOGY OF THE PLACE YOU PLAN TO VISIT

- Get informed by reading books and magazines on scuba diving and tourism: read up on geography, culture, and customs of the country you'll be visiting so you'll be more sensitive to the local population; read up on the most important ecological features of the place to heighten your awareness about the nature there.
- Be prepared to be very careful when diving in coral reefs: a single coral is the result of the long and hard construction efforts of the "polyps", very small and delicate animal organisms.

BEFORE DIVING

Boats

- Ask your tour operator, diving school, tour leader, and/or dive master which is the best boat available and rent that one: avoid boats that pollute the waters because they have engines that leak oil, diesel, or gasoline; remember that the cheapest package deal does not usually correspond to safety for you or for the environment.

DO NOT CAST ANCHORS

- Do not cast anchors – stop this destructive habit that causes harm to coral reefs by mooring the boat to buoys.
- Give your support locally to having buoys placed in diving areas: it is a custom that defends nature and supports ecological sustainability and that is not practiced nearly enough in tourist localities.

The Weather

- Find out about the local weather conditions, currents and underwater visibility where you are planning your dive: for your own safety, seek advice from local certified diving instructors.
- Do not go out to sea until you have become acquainted with the safety precautions specifically related to where you are planning to dive.

Equipment

- Never dive alone and never push yourself beyond safety limits: prepare all your diving equipment and go through the safety checklist with your diving partner before the diving.

KEEP YOUR BELT AS LIGHT AS POSSIBLE

- Do not put too much weight in your belt, extra pounds require more exertion and this increases air consumption during the dive, thus reducing safety levels and causing more harm to the environment: when they are on the sea bottom, overly weighted divers tend to fall onto the corals causing breakages.
- Attach all extra equipment (manometer, alternative air supply, torch, etc.) to clasps that keep objects close to the body: if you leave them dangling they could catch on the corals causing damage and/or breakages.

KEEP EQUIPMENT CLOSE TO YOUR BODY

- Always begin with a check-dive to get familiar with the equipment and with the area.

Land Access

- If your dive starts on land, it is best to enter the water from a platform or gangway: the better hotels and diving centers provide these platforms so that tourists and divers do not step on and harm the coral reefs.
- Support this and do not enter the water directly from the shore trampling on corals but use gangways.

USE GANGWAYS WHEN ENTERING THE WATER FROM LAND

Illustration Maura Marinozzi

PROJECT DEVELOPED BY
Stefano Goffredo, Corrado Piccinetti, Francesco Zaccanti.
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Figure 1a. STE project questionnaire. The figure shoe the section with guidance for limiting impacts on the reef during a recreational dive and throughout the vacation period. Part A.

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HOW YOU CAN HELP TO DEFEND CORAL REEFS

THE DIVE

Buoyancy

- Keep checking your buoyancy. Much damage is done to the coral reefs when divers go down too fast and "crash" into the reef. The right amount of weight and good buoyancy control are essential to safe diving and environmental protection. To find out more, take a course on neutral buoyancy diving techniques.

While swimming

- Always maintain a distance of at least 2 meters from the sea bottom and sea walls.
- Maintain a gentle movement with your fins: the more fragile marine organisms may be damaged even without direct contact; sometimes stirring up the water around them is enough to harm them.
- When swimming on sandy bottoms, be careful not to stir up the sand – this could suffocate organisms.

What to, and what not to, hold on to

- Do not hold on to live corals. If you are swimming against the current and are having a hard time moving forward, grab on massive dead corals only: they are easy to recognize, they are colorless and look like rocks (if you are not sure, ask your dive master to point them out to you).

Meeting up with corals and other life forms

- Never touch corals: some may look tough but they are really very fragile and pieces break off easily even if you just touch them lightly, you could even damage the delicate polyps.
- Do not collect corals, shells, or anything else: chances are you'll throw them away before leaving for home because they start to smell once they're out of the water and if you should decide to take something home with you, you may get stopped at customs and have to pay a heavy fine – it is illegal to take anything collected from the reef or sea out of the country.
- Do not feed the fish: you can get close enough to take pictures but please do not give them anything to eat as this changes their behaviour and upsets the natural balance in the food chain.

DO NOT FEED THE ANIMALS

- Marine animals are wary and distrustful, but also very curious: the best way to interact with them, without frightening them, is to approach them very very slowly and being careful of how you breathe: even the sound of the air bubbles often frightens them.
- If you should meet up with larger animals, remain still on the sea bottom or wall: it is probable that the larger animals are the ones that will become curious and come in for a closer look.

Taking pictures and videos

- Avoid being a typical amateur photographer or home video operator and be careful not to frighten the animals. Don't rush towards them; go up to them slowly, carefully aiming the camera.
- If you need to lean on something to snap a picture, look around until you find a rocky or sandy area or a dead coral area. Remember to always swim with your fins towards the surface and never lie down on the live coral sea floor!
- Once you've taken your pictures, don't use your fins to turn around, push off the rocks or dead corals with your hands so that you don't harm live corals with your fins.

At the end of the dive

- Once you are back on the surface and you are sure your boat has seen you, move away from the reef to avoid damaging the coral and so you can get back on to the boat more easily and safely.

ALWAYS

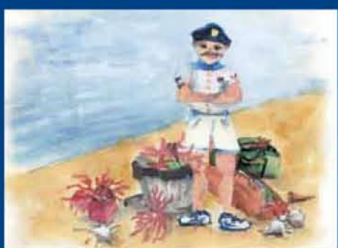
- Remember to take your garbage with you: trash is harmful to life. Many marine animals take plastic bags for prey and die from suffocation after they've swallowed them. If possible, collect trash you see during the dive and throw it away when you get to the surface.

TAKE YOUR TRASH WITH YOU

Illustration Maura Marinozzi

- Use as little water, detergent and soap as possible: the latter modify the ecosystem.
- Don't buy souvenir corals, shells, or dried fish: this only increases demand and the commerce of these animals and objects.

BEHAVE RESPECTFULLY: OUR OCEANS' DWELLERS WILL THANK YOU FOR IT



DO NOT COLLECT CORALS OR SHELLS AND DO NOT BUY THEM AS SOUVENIRS

BE CAREFUL WHEN YOU TAKE PICTURES: DO NOT LIE DOWN ON THE SEA FLOOR

PROJECT DEVELOPED BY Stefano Goffredo, Corrado Piccinetti, Francesco Zaccanti. Marine Science Group www.marinesciencegroup.org Alma Mater Studiorum University of Bologna for project news visit www.STEproject.org

Figure 1b. STE project questionnaire. The figure show the section with guidance for limiting impacts on the reef during a recreational dive and throughout the vacation period. Part B

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.

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Figure 2. 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.

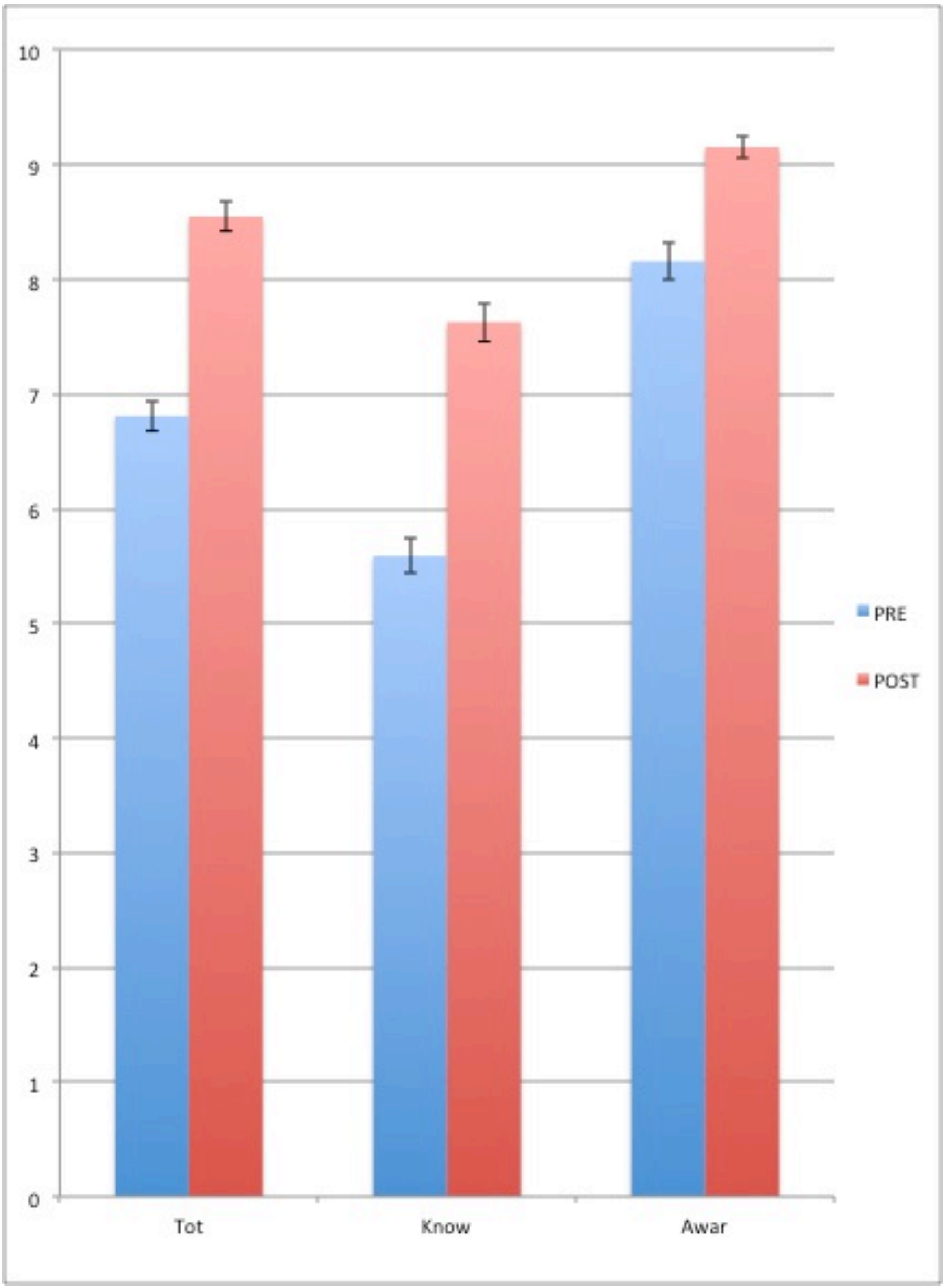

Figure 3: **Mean score of the environmental education evaluation questionnaire**. *Tot* represents the mean score of the overall questionnaires, *Know* represents the mean score of the reef biology questions and *Awar* represents the mean score of the human impact questions. Error bars are 95% confidence intervals (CI), N=212

TABLES

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
	4: Master Degree
	5: Doctorate of Philosophy
Diving qualification	1: None
	2: Open Water Diver
	3: Advanced Open Water Diver
	4: Rescue Diver
	5: Divemaster
	6: Instructor

Table 2: Result of T student test between the score of the pre-questionnaire and the score of the post-questionnaire for the overall questionnaire, the reef biology and the human impact questions. The non-significant differences are in bold.

			Overall questionnaire		***Knowledge questions***		***Awareness questions***	
		df	**T**	***p***	**T**	***p***	**T**	***p***
Gender	Female	166	-12.500	< 0.001	-11.129	< 0.001	-6.237	< 0.001
	Male	254	-14.300	< 0.001	-13.331	< 0.001	-8.025	< 0.001
Age	< 15 years old	18	-3.813	0.001	-2.722	0.014	-3.500	0.003
	16 – 30 years old	86	-7.374	< 0.001	-7.365	< 0.001	-3.428	0.001
	31 – 45 years old	166	-13.171	< 0.001	-11.957	< 0.001	-6.093	< 0.001
	46 – 60 years old	130	-10.743	< 0.001	-10.493	< 0.001	-9.707	< 0.001
	> 61 years old	14	-3.086	0.011	-3.111	0.008	-3.874	0.002
Level of education	Compulsory School	82	-8.435	< 0.001	-7.078	< 0.001	-4.912	< 0.001
	High School	186	-13.746	< 0.001	-11.733	< 0.001	-7.119	< 0.001
	Bachelor Degree	52	-5.610	< 0.001	-6.263	< 0.001	-3.151	0.003
	Master Degree	90	-8.022	< 0.001	-8.421	< 0.001	-4.614	< 0.001
	Doctorate of Philosophy	4	-15.76	< 0.001	**-2.226**	**0.086**	**-1.131**	**0.321**
	Under-graduate	324	-8.825	< 0.001	-15.010	< 0.001	-8.938	< 0.001
	Post-graduate	96	-2.311	0.022	-8.735	< 0.001	-4.727	< 0.001
Diving qualification	None	270	-14.080	< 0.001	-14.055	< 0.001	-7.716	< 0.001
	Open Water Diver	38	-6.068	< 0.001	-5.911	< 0.001	-3.371	0.002
	Advanced Open Water Diver	60	-9.722	< 0.001	-6.028	< 0.001	-5.871	< 0.001
	Rescue Diver	14	-3.685	0.003	**-2.090**	**0.055**	**-1.118**	**0.282**
	Divemaster	8	-4.470	0.004	-6.094	< 0.001	-2.708	0.027
	Instructor	22	-4.533	< 0.001	-4.462	< 0.001	**-0.811**	**0.426**
	Snorkelers	270	-14.08	< 0.001	-14.055	< 0.001	-7.716	< 0.001
	Divers	150	-13.421	< 0.001	-10.181	< 0.001	-6.589	< 0.001

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 first, in the post-questionnaire and the its increase between the first and the post-questionnaire. The significant differences are in bold.

* 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).

					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 vs. post-graduate	Overall	T-student	210	**-2.311**	**0.022**	-1.104	0.271	1.175	0.243
		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. divers	Overall	T-student	210	-1.251	0.212	**-2.906**	**0.004**	-1.294	0.199
		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

Table 4: Results of T student test between the mean score of the reef biology and the human impact questions, in the first and in the post-questionnaire. The non-significant differences are in bold.

			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

Chapter 5.

CONCLUSIONS

The present research contributed to increase the knowledge on the citizen science field. These studies have shown the value of citizens' engagement in the scientific process both as ecological research tool, to perform reliable large-scale and long-term monitoring and as educative instrument, to increase the environmental awareness of the public to lead a more sustainable use of natural resource.

"STE: Scuba Tourism for the Environment" has represented a successful case study of collaboration among researchers, private sector, local authorities and the public, confirming the effectiveness of citizen science projects as fundamental tools to provide robust, objective and repeatable data for large-scale and long-term monitoring. This project has showed that with appropriate recruitment and training, volunteer-collected data are qualitatively equivalent to those collected by professional researchers and useful for resource management, representing a novel, reliable and cost-effective model for biodiversity monitoring, that can help local and holistic environmental management decisions and actions, matching the dynamics of the natural system. The project has also demonstrated the effectiveness of the method in having a positive influence on the environmental education of volunteers of all genders, ages and levels of education and experience. Educated people take more care of the environment and could change their behaviour consequentially, reducing their impact on natural ecosystems and leading to a more sustainable use of natural resources.

STE project 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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