Involving recreational snorkelers in inventory improvement or creation: a case study in the Indian Ocean

Philippe Bourjon, Frédéric Ducarme, Jean-Pascal Quod, Michael Sweet

Cah. Biol. Mar. (2018) 59 : 451-460
DOI: 10.21411/CBM.A.B05FC714

Involving recreational snorkelers in inventory improvement or creation: a case study in the Indian Ocean

Philippe BOURJON[1], Frédéric DUCARME[2], Jean-Pascal QUOD[3] and Michael SWEET[4]
(1) *Réseau d'observateurs volontaires « Les Sentinelles du Récif », Réserve Naturelle Marine de La Réunion (GIP-RNMR). 26, avenue des Bengalis, Saint Paul, La Réunion, France*
["Sentinels of the Reef", Volunteer Observer Network of Reunion Marine Park]
(2) *Centre d'Ecologie et des Sciences de la Conservation, UMR 7204, Muséum National d'Histoire Naturelle, 57, rue Cuvier, 75005, Paris, France*
(3) *ARVAM, La Technopole, 16, rue Albert Lougnon, Sainte Clotilde 97490, La Réunion, France*
(4) *Environmental Sustainability Research Center, College of Life and Natural Sciences, University of Derby, UK*
Corresponding author: seizhavel@wanadoo.fr

Abstract: Four amateur naturalists and underwater photographers established sixty first records and discovered three species probably new to science at Reunion Island (Indian Ocean) between January 2010 and January 2016, although the marine environment of this island has been studied for some forty years by professional scientists. These results were achieved after snorkeling in coastal areas at a maximum depth of 2 m. All records were validated by professional experts of the relevant groups, with appropriate reservations for photograph-based identifications. The analysis of the methodology used by this group of reef observers highlights three central elements: individual initiative, regular random-path snorkeling practice by local observers, and availability of correspondent observers with sufficient naturalist skills to select accurate data and manage an optimal link with professional scientists. Such achievement emphasizes the efficiency of a citizen-based approach aimed at creating or improving local fauna inventories and discovering new species. Considering that ecological data can be collected during observers' random-path snorkeling sessions, such a project is also of interest for local conservationists and marine ecosystems managers. We therefore recommend the inclusion of these practices in the process of designing standardised observation programs aimed at non-professionals everywhere snorkeling can be practiced, especially in under-studied regions.

Résumé : *Pour une participation des randonneurs subaquatiques à l'évolution ou à la création d'inventaires : une étude de cas dans l'Océan Indien*. Quatre naturalistes amateurs et photographes sous-marins ont réalisé soixante premiers signalements et découvert trois espèces probablement nouvelles pour la science à La Réunion entre janvier 2010 et janvier 2016, bien que la faune marine de l'île soit étudiée depuis une quarantaine d'années par des scientifiques professionnels. Ces résultats ont été obtenus en randonnée subaquatique sur des fonds n'excédant pas 2 mètres. Ils ont été validés, avec les réserves d'usage pour les signalements d'après photos, par des taxonomistes spécialistes des groupes concernés. Ces succès démontrent l'efficacité d'une démarche participative orientée vers l'évolution ou la réalisation d'inventaires locaux et la découverte de nouvelles espèces. L'analyse du *modus operandi* de ce groupe d'observateurs dégage trois éléments centraux : la liberté d'initiative individuelle des participants, la pratique régulière du parcours aléatoire en randonnée subaquatique par des observateurs résidents et l'existence d'observateurs-relais possédant une culture naturaliste suffisante

Reçu le 7 août 2017 ; accepté après révision le 15 décembre 2017.
Received 7 August 2017; accepted in revised form 15 December 2017.

pour sélectionner les données pertinentes et assurer efficacement la liaison avec les scientifiques. Dans la mesure où des données d'observations écologiques peuvent être recueillies durant les parcours aléatoires des observateurs, le projet peut aussi concerner les responsables locaux de la gestion et de la conservation des écosystèmes côtiers. Ces éléments devraient être retenus dans la conception de programmes d'observation standardisés à proposer à des amateurs résidents partout où la randonnée subaquatique peut être pratiquée, particulièrement dans des régions insuffisamment étudiées.

Keywords: Inventory data ● Snorkeling ● Underwater photography ● Citizen sciences ● Reunion Island

Introduction

As early as 1998, the Darwin Declaration adopted by the Conference of the Parties to the Convention on Biological Diversity highlighted the existence of a "taxonomic impediment" related to gaps in knowledge and a shortage of experienced specialists in the field of taxonomy. In addition to this impediment, we are currently experiencing an ever-increasing rate of species extinction (e.g. Urban, 2015). It is therefore likely that some species may go extinct without ever being described (e.g. Mora et al., 2011). This emphasizes the need to strengthen the production and analysis of taxonomic data. Regarding their production, this strengthening must not overlook the opportunities offered by amateurs (Pearson et al., 2011; Pisupati, 2015). However, it is a known fact that their input in the knowledge of marine biodiversity is lower than for the terrestrial biomes (Garcia-Soto et al., 2017). In the case of marine fauna, this effort should not be limited to scuba divers, already called upon by citizen sciences (e.g. Bramanti et al., 2011), but also encompass snorkelers (Arvanitidis et al., 2011), who explore the shallow depths less frequented by divers and in which specific biodiversity can be found.

In this paper, we highlight a case study, where four amateur naturalists and underwater photographers, practicing snorkeling in coastal waters less than 2m deep, recorded 60 first sightings and three species probably new to science in Reunion Island between January 2010 and January 2016, although the marine environment of this island has been studied for some forty years by professional scientists. These records were validated based on high-resolution photographs by professional taxonomists. All observations were carried out outside any scientific program and without any funding. The purpose of this study is to 1) analyse the spontaneous methodology of this informal group in order to identify the key factors of their success, 2) suggest guidelines for a standardized observation program designed for such observers wherever snorkeling can be practiced, and 3) discuss some of the issues related to such data collection.

Material and Methods

Study sites

Observations were made on the western and south-western coasts of Reunion Island (21°07'S-55°32'E), a French overseas department which is part of the Mascarene Archipelago. The fringing reefs of this geologically young island are 8,500 years old (Dercourt, 2002). The snorkeling areas under study are located between the Saint-Gilles-La Saline reef and the Saint-Pierre reef (Fig. 1). All are less than 2 m deep. These areas include fringing reefs and rocky coastal areas. Only one additional first record comes from the East coast, from Sainte-Rose. Except for Sainte-Rose, the rocky area south of l'Etang-Salé and the reef of Saint-Pierre, all other observations were made within the Reunion Island Marine Protected Area (Réserve Naturelle Marine de La Réunion, RNMR), which spans over 40 km of coastline, covering 3.500 hectares and including approximately 80% of the coral reefs of the island.

Method

The group of observers was informal. No protocols were followed by the participants, each being independent, and none of them had followed any specific training program. There was no pre-established program linking the scientists and the observers: communication with experts depended on the findings made in the field. The experts did not ask for specific photos except when those submitted were of insufficient quality to accurately identify any given species.

Depending on the observer, the average time spent in the field ranged from 90 to 300 hours per year, and the average length of sessions ranged from 1 to more than 3 hours. The photographs could be sent by the participants to the observer who was in regular contact with the scientists responsible for the inventories or could be posted on a social network, but each observer could himself contact an expert.

All observations were made by snorkelers. They encompassed both benthic and demersal macroscopic fauna (individuals bigger than or equal to 1 mm). Each observer

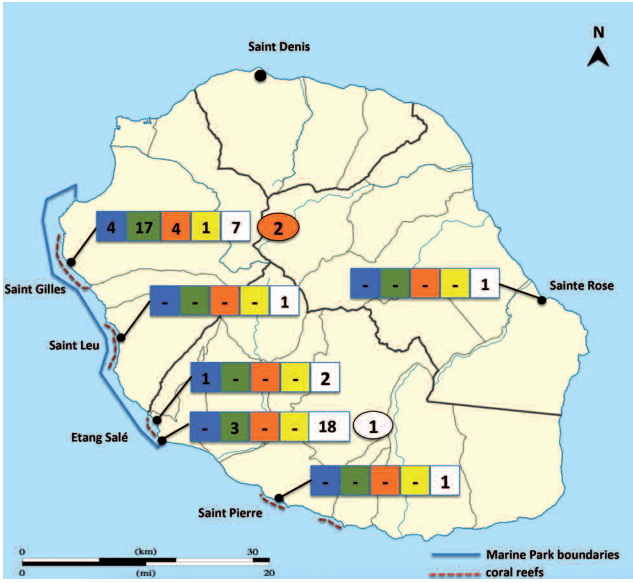

Figure 1. Geographical distribution of the specimens observed by the snorkelers: first records and records of species probably new to science are reported. Information boxes indicate the site location and contain the number of records per site for each taxonomic group. Different taxonomic groups are indicated with different colours (blue = fish; green = decapod crustaceans; orange = sea cucumbers; yellow = shelled gastropods; white = opisthobranchs). Numbers included in an ellipse refer to species probably new to science.

was equipped with an underwater camera and attempted to explore every type of habitat within reach. Observation circuits were random, and limited neither in perimeter nor duration. Each observer chose the sites and the schedule themselves. All the observers had a good knowledge of their specific sites and had visited them regularly, day or night, throughout both the dry or rainy seasons. As the more common biodiversity of these sites was already known, the research criterion was the detection of specimens rarely or never yet encountered by each observer. Any uncommon species found within the area was therefore photographed. Photos of the whole organism and, where possible, of specific details associated with the organism in question (i.e. macro-images) were taken for each animal. In addition, information on the location and date of observations was also recorded, as well as details on the biotope of the photographed individual.

In some instances, non-lethal tissue samplings were taken by trained observers only, when asked by associate taxonomists and with the authorization of the RNMR in its geographical jurisdiction.

Reference materials and authorities

The reference documents included both academic and *de facto* inventories. The academic inventories were compiled by taxonomists during their previous work. These include inventories for fish (Fricke et al., 2009), decapod crustaceans (Legall & Poupin, Internet-CRUSTA which is regularly updated, http://crustiesfroverseas.free.fr/iles.php?ile=Reunion), and sea cucumbers (Conand et al., 2010).

In contrast, "*de facto*" inventories were established by high-level amateur naturalists regularly working with specialists of the relevant groups. These include shelled gastropods and opisthobranchs. The first inventory consists in the Maurice Jay collection (http://vieoceane.free.fr/mollusques/intro_frame.htm). This collection was bequeathed to the French National Museum of Natural History (Muséum National d'Histoire Naturelle, MNHN, Paris) and is considered a scientifically valid inventory by the French National Inventory of the Natural Heritage (Inventaire National du Patrimoine Naturel, INPN), which is part of the MNHN. The second inventory combines opisthobranchs and polyclad flatworms (the South-west Indian Ocean Seaslug and Flatworm site http://seaslugs.free.fr/). It is also recognized by the INPN.

Eighteen experts participated in the validation of the photographic images (see Table 1, validation column). However, it should be noted that experts all agree that genetics should be conducted whenever possible in order to ascertain reliability of species level identification.

Results

Sixty first records belonging to five taxonomic groups, and three species probably new to science were recorded (see table 1). Because some taxonomic groups have not yet been systematically inventoried in Reunion Island, first records could only refer to ray-finned fish (five species), crustaceans (20 species), sea cucumbers (four species), shelled gastropods (one species) and opisthobranchs (30 species) (Fig 1). Inventories increase percentages are provided in Table 2. In addition, two species of sea cucumber and one species of opisthobranch previously unknown to science were found. However, it should be noted that about two of these (the opistopbranch and one of the two sea cucumbers), the experts' judgments have been based on photographs, and genetic data analysis could only be conducted on the other sea cucumber.

First records and records of species probably new to science have been included in the scientific and *de facto* inventories. Inventories of crustaceans, opisthobranchs and shelled gastropods are available online (see above); that of holothurians was updated in an identification book for general public on Reunion Island's echinoderms (Conand et al., 2016); and that of fish has not yet been updated by its authors.

Table 1. First records and new species records.

FISH						
Species	**Family**	**Site**	**Date**	**Observer**	**Validation**	**Institution**
Cirrhitichthys cf. oxycephalus	Cirrhitidae	St Gilles-La Saline	12/30/13	Morcel	Mulochau-Fricke	BE Biorécif-Staatliches Museum für Naturkunde Stuttgart
Diplogrammus infulatus Smith, 1963	Callionymidae	St Gilles-La Saline	2/24/15	Cadet	Fricke-Mulochau	Staatliches Museum für Naturkunde Stuttgart-BE Biorécif
Enchelycore cf. schismatorhynchus	Muraenidae	L'Etang Salé (reef)	12/24/14	Vasquez	Durville-Fricke	BE Galaxea-Staatliches Museum für Naturkunde Stuttgart
Nectamia sp.	Apogonidae	St Gilles-La Saline	12/5/14	Bourjon	Fricke	Staatliches Museum für Naturkunde Stuttgart
Novaculoides macrolepidotus (Bloch, 1791)	Labridae	St Gilles-La Saline	1/28/12	Bourjon	Durville-Mulochau	BE Galaxea-BE Biorécif
CRUSTACEANS						
Species	**Family**	**Site**	**Date**	**Observer**	**Validation**	**Institution**
Actaeodes hirsutissimus (Rüppel, 1830)	Xanthidae	St Gilles-La Saline	5/20/15	Bourjon	Poupin	IRENav
Alpheopsis yaldwyni Banner & Banner, 1973	Alpheidae	St Gilles-La Saline	10/14/15	Morcel	Poupin	IRENav
Alpheus edamensis de Man, 1888	Alpheidae	St Gilles-La Saline	7/14/15	Bourjon	Poupin	IRENav
Alpheus ? lobidens	Alpheidae	St Gilles-La Saline	5/20/15	Bourjon	Poupin	IRENav
Callianidea typa H. Milne Edwards, 1837	Callianideidae	St Gilles-La Saline	11/19/10	Bourjon	Dworschak	Naturhistorisches Museum Wien
Cyclax cf. suborbicularis	Majidae	St Gilles-La Saline	5/23/15	Bourjon	Poupin	IRENav
Dardanus scutellatus (H. Milne Edwards, 1848)	Diogenidae	St Gilles-La Saline	6/10/15	Morcel	Poupin	IRENav
Etisus bifrontalis (Edmonson, 1935)	Xanthidae	St Gilles-La Saline	6/20/15	Bourjon	Poupin	IRENav
Huenia grandidierii A. Milne Edwards, 1865	Epialtidae	St Gilles-La Saline	1/6/16	Bourjon	Poupin	IRENav
Hypocolpus stenocoelus Guinot-Dumortier, 1960	Xanthidae	L'Etang Salé (rocky shore)	1/22/15	Vasquez	Poupin	IRENav
Leptodius exaratus (H. Milne Edwards, 1834)	Xanthidae	St Gilles-La Saline	5/31/15	Bourjon	Poupin	IRENav
Micippa platipes Rüppel, 1830	Majidae	St Gilles-La Saline	12/11/10	Bourjon	Poupin	IRENav
Neoliomera pubescens (H. Milne Edwards, 1834)	Xanthidae	St Gilles-La Saline	11/10/14	Bourjon	Poupin	IRENav
Pagurixus haigae Komai & Osawa, 2007	Paguridae	St Gilles-La Saline	12/22/15	Cadet	Poupin	IRENav
Processa sp.	Processidae	L'Etang Salé (rocky shore)	2/18/10	Cadet	Noël	MNHN
Processa sp.	Processidae	L'Etang Salé (rocky shore)	11/30/12	Cadet	Noël	MNHN
Saron neglectus de Man, 1902 (?)	Hippolytidae	St Gilles-La Saline	9/17/14	Morcel	Poupin	IRENav
Thalamita aff. picta	Portunidae	St Gilles-La Saline	6/20/15	Bourjon	Poupin	IRENav

Table 1. Continued

Trichopagurus trichophthalmus (Forest, 1954)	Paguridae	St Gilles-La Saline	12/30/15	Bourjon	Komai	Natural History Museum and Institute, Chiba
Xanthias punctatus (H. Milne Edwards, 1834)	Xanthidae	St Gilles-La Saline	11/26/10	Bourjon	Poupin	IRENav
			SEA CUCUMBERS			
Species	**Family**	**Site**	**Date**	**Observer**	**Validation**	**Institution**
Actinopyga aff. *obesa*	Holothuriidae	St Gilles-La Saline	7/1/15	Bourjon-Morcel	Michonneau	Florida Museum of Natural History
?	Dendrochirotida (ordre)	St Gilles-La Saline	11/12/14	Bourjon	Michonneau	Florida Museum of Natural History
Holothuria aff. *fuscogilva*	Holothuriidae	St Gilles-La Saline	9/6/15	Bourjon	Michonneau	Florida Museum of Natural History
Plesiocolochirus sp. ?	Cucumariidae	St Gilles-La Saline	11/26/14	Bourjon	Michonneau	Florida Museum of Natural History
			SHELLED GASTROPODS			
Species	**Family**	**Site**	**Date**	**Observer**	**Validation**	**Institution**
Smaragdia rangiana (Récluz, 1841)	Neritidae	St Gilles-La Saline	12/22/15	Cadet	Huet	Web manager of the Maurice Jay collection
			OPISTHOBRANCHS			
Species	**Family**	**Site**	**Date**	**Observer**	**Validation**	**Institution**
Aglaja sp. 1	Aglajidae	Saint Gilles-La Saline	2/2/12	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Babakina indopacifica Gosliner, Gonzales-Duarte & Cervera, 2007	Babakinidae	L'Etang Salé (rocky shore)	9/2/10	Cadet	Bidgrain-Gosliner	Vie Océane-California Academy of Sciences
Carminodoris bifurcata Baba, 1993	Dorididae	L'Etang Salé (rocky shore)	10/6/10	Cadet	Gosliner-Yonow	California Academy of Sciences- Swansea University
Costasiella sp.2	Costasiellidae	L'Etang Salé (rocky shore)	2/8/13	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Dermatobranchus piperoides Gosliner & Fahey, 2011	Arminidae	L'Etang Salé (reef)	1/23/11	Cadet	Bidgrain-Gosliner-Yonow	Vie Océane-California Academy of Sciences-Swansea University
Doris immonda Risbec, 1928	Dorididae	Sainte Rose	1/4/11	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Elysia sp. 4	Elysiidae	Saint Gilles-La Saline	9/27/10	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Elysia sp. 5	Elysiidae	L'Etang Salé (rocky shore)	10/6/10	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Elysia pusilla (Bergh, 1871)	Elysiidae	L'Etang Salé (rocky shore)	2/23/13	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Ercolania coerulea Trinchese, 1892	Limapontiidae	L'Etang Salé (rocky shore)	2/12/10	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Hallaxa fuscescens (Pease, 1871)	Actinocyclidae	L'Etang Salé (rocky shore)	12/20/14	Vasquez	Bidgrain-Yonow	Vie Océane-Swansea University
Lobiger souverbii P. Fischer, 1857	Oxynoidae	St Leu	3/15/10	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Melibe engeli Risbec 1937	Tethydidae	L'Etang Salé (rocky shore)	12/5/10	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University

Table 1. Continued

Odontoglaja mosaica Gosliner, 2011	Aglajidae	L'Etang Salé (rocky shore)	2/22/10	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Philine orca Gosliner 1988	Philinidae	L'Etang Salé (reef)	1/23/11	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Phyllodesmium sp. 1	Glaucidae	L'Etang Salé (rocky shore)	1/2/12	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Placida cremoniana (Trinchese, 1892)	Limapontiidae	Saint Gilles-La Saline	12/28/10	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Platydoris pulchra Eliot, 1904	Dorididae	L'Etang Salé (rocky shore)	9/24/10	Cadet	Bidgrain-Valdés	Vie Océane-California Polytechnic University
Platydoris scabra (Cuvier, 1804)	Dorididae	L'Etang Salé (rocky shore)	1/9/12	Cadet	Bidgrain-Valdés	Vie Océane-California Polytechnic University
Phyllaplysia lafonti P. Fischer, 1872	Aplysiidae	L'Etang Salé (rocky shore)	11/27/10	Cadet	Bidgrain-Yonow	Vie Océane-Swansea University
Polybranchia sp.1	Caliphyllidae	L'Etang Salé (rocky shore)	12/27/15	Cadet	Bidgrain-Behrens	Vie Océane-California Academy of Science
Siphopteron tigrinum Gosliner, 1989	Gastropteridae	Saint Gilles-La Saline	9/27/10	Cadet	Bidgrain-Gosliner	Vie Océane-California Academy of Sciences
Tenellia minor (Rudman, 1981)	Tergipedidae	L'Etang Salé (rocky shore)	2/9/15	Vasquez	Bidgrain-Yonow	Vie Océane-Swansea University
Thuridilla flavomaculata Gosliner, 1995	Elysiidae	Saint Gilles-La Saline	10/28/10	Cadet	Bidgrain-Jensen	Vie Océane-Natural History Museum of Denmark
Thuridilla hoffae Gosliner, 1995	Elysiidae	Saint Gilles-La Saline	6/19/10	Cadet	Bidgrain-Rudman	Vie Océane-Australian Museum
Thuridilla livida (Baba, 1955)	Elysiidae	Saint Gilles-La Saline	9/27/10	Cadet	Bidgrain	Vie Océane
Trapania euryeia Gosliner & Fahey, 2008	Goniodorididae	Saint Pierre	11/14/15	Vasquez	Bidgrain-Gosliner	Vie Océane-California Academy of Sciences
Trapania sp. 1	Goniodorididae	L'Etang Salé (rocky shore)	5/9/10	Cadet	Bidgrain-Gosliner	Vie Océane-California Academy of Sciences
Trapania toddi Trapania toddi	Goniodorididae	L'Etang Salé (rocky shore)	1/5/15	Vasquez	Bidgrain-Yonow	Vie Océane-Swansea University
Tritoniopsis elegans (Audouin, 1826)	Tritoniidae	L'Etang Salé (rocky shore)	11/9/14	Vasquez	Bidgrain-Yonow	Vie Océane-Swansea University

SPECIES PROBABLY NEW TO SCIENCE

Species	Familiy	Site	Date	Observer	Validation	Institution
Dendrodoris sp.	Dendrodorididae	L'Etang Salé (rocky shore)	2/22/15	Vasquez	Yonow	Swansea University
Holothuria (*Stauropora*) sp.	Holothuriidae	St Gilles-La Saline	7/20/14	Bourjon	Michonneau-Conand	Florida Museum of Natural History - Université de La Réunion
Stichopus sp.	Stichopodidae	St Gilles-La Saline	9/26/15	Morcel-Bourjon	Michonneau-Paulay	Florida Museum of Natural History

Table 2. Inventories increase percentage. *: State of on-line inventories as of October 15, 2015. **: Regarding on-line inventories, percentage is computed based on lists from which the present records were extracted. ***: The opisthobranchs inventory covers Reunion, Mauritius, Seychelles islands, Mayotte and Madagascar.

Groups	Confirmed first records	Number of species present in inventories* (without present records)	Percentage**	New species
Fish	5	984	0.5	0
Crustaceans	20	582 (on line. continuous since 2008)	3.43	0
Sea cucumbers	4	37	10.81	2
Opisthobranchs***	30	284 (on line. continuous since 2005)	10.56	1
Shelled gastropods	1	2500	0.04	0

Discussion

Assessment of methodology

The exploration method used by the snorkelers in this case study can be compared to the roving diver technique (RDT) highlighted by Schmitt & Sullivan (1996), which was evaluated by comparing its results with those obtained on two types of transects (Schmitt et al., 2002; Holt et al., 2013). Although more difficult to quantify (due to the variation in length of reef covered by any given observer and the variation in time), we estimate that the random-path snorkeling practice has the same advantages as the RDT for a rapid biodiversity assessment, which is the first step in detecting uncommon species. Besides, Schmitt et al. (2002) also note that RDT allows a greater number of species rarely observed to be detected in less time than the transect method. Therefore, this method is the most effective way to detect newly established, and rare or unknown species in a given area without the constraints of transects or a specific length of time in the water.

With regard to the group itself, the analysis of its *modus operandi* brings out three central elements that appear to be the key factors of their success: (1) freedom of initiative of each participant, (2) regular practice of random-path snorkeling sessions by resident observers, and (3) the existence of correspondent observers with sufficient naturalist skills to select relevant data for transmission to experts and authorities in charge of the management and conservation of coastal areas.

Suggestions for a standardized observation program

We suggest that these characteristics be considered in a standardized observation program organised by geographic regions, designed with professional taxonomists and intended for such observers. This program would be implemented regardless of location, including in regions without current scientific inventories. In order to advance the use of citizen science in this field, we suggest the following first steps: 1) loaning of inexpensive underwater photography equipment to volunteers willing to participate in the program; and 2) creation of a website containing: a) an identification tool (see as an example the abyssal fauna guide designed by the Monterray Bay Aquarium Institute, http ://www.mbari.org/products/data-repository/deep-sea-guide/) with photographs of the species listed in local inventories (if any) of a few target groups, as well as unreported species of these groups likely to occur in the region, b) a photo gallery organized by geographic region for the photographs of first records taken by participants, c) a forum where observers can share their experiences and learn from each other, and d) a training program. Such a program, designed for groups of volunteers, would be divided into two main parts. Part one would be dedicated to beginners and aimed at naturalist photography apprenticeship in order to set standard parameters (how to photograph diagnostic characters of specimens belonging to any taxonomic group in order to allow identification), in conjunction with the teaching of good practices in the field. Part two would be devoted to 1) advancing the volunteer's taxonomic culture (for example by teaching them how to identify the most common families of fish and invertebrates based on their body shape), and 2) selecting the future correspondent observers and training them to select relevant data among those collected by participants, based on the available local inventories, if any (this could include the use of some taxonomic determination keys associated to lists of species potentially present in their region, for example). The latter observers could thereafter be encourage to expand their skills through self-training, using web-based identification networks that link amateurs and professionals. Some of these programs have been established in this way, such as, iNaturalist, initiated by Berkeley University, or iSpot, created by the Milton Keynes Open University. Other examples include more social media driven tools such as Facebook "ID Please (Marine Creature Identification)" group. Frequent species identification requests made on network dedicated forums would reinforce the quality of data selection at the same time as the skills of the correspondent observer. Correspondent observers would then decrease the demands and reliance on professional taxonomists.

If the first program evaluation by involved taxonomists is positive, further training could then be undertaken and built into the data collection. For example, it could include training in the GIS positioning of the observations (which can be done by snorkelers and would enhance the possibility to exploit the data collected), or in the use of mobile applications. Indeed, the use and development of application based depositories for such observations may be the future of citizen sciences and should be explored further. From a volunteer retention standpoint, this step would also invigorate participants' motivation by allowing results to be published and observers to be acknowledged as sources, or to be part of the author list (Pettibone et al., 2016).

Value associated with data collected from photographs

All but one species in this case study were identified from photographs by professional taxonomists. Taxonomic identification based on colour patterns or other external morphological traits is usual in the domain of taxonomy, including correcting taxonomic errors (e. g. Randall & Smith, 2001). Furthermore, there are also more subtle external traits that can enable the identification of certain species from photographs. These include, for example, sub-hepatic cavities on a crab carapace in the genus *Hypocolpus*, a squat lobster's rostrum, the profile of a frogfish's head showing the illicium, esca and second dorsal spine, or the aperture of a shelled gastropod. Indeed, the use of field photographs taken by both researchers and amateurs is considered a valid and non invasive method to validate first records (e.g. Fricke et al., 2015). The value of the data collected by underwater photographers is therefore far from negligible, especially if training programs are initiated in the first place to ensure images contain enough detail of the external morphological characteristics of any given species.

Issues related to the use of citizen scientists in this context

The reliability of data collected by non-professionals has been debated (Danielsen et al. 2014; Forrester et al., 2015), and the use of citizen science is drawing some criticism among the scientific community (e.g. Riesch & Potter, 2014). However, inventory data such as those described here could be considered a significant contribution, and therefore the resulting information should be integrated in academic or national inventories (e.g. Marchand et al., 2013) in the same way as it can enrich the Global Biodiversity Information Facility (GBIF), to which citizen science already contributes (Chandler et al., 2017).

The benefits of using citizen scientists for the improvement or creation of inventories include: 1) improved cost-efficiency (which is relatively low), 2) more time spent by non-professionals compared to scientists (if any) in a study area, 3) potential for fine-scale observations, and 4) data transmission speed. Moreover, finding volunteers among coastal resident populations would provide an opportunity to initiate long-term programs aimed at improving or creating inventories on a larger geographical scale (Devictor et al., 2010).

However there are various challenges related to this approach which should be mentioned here. These include as a primary factor the irregular retention of participants. Indeed this issue has been discussed in other studies (e.g. Rotman et al., 2012). This concern is particularly linked to the constraints pertaining to this kind of survey (protocols, schedules, distances, etc.) and to their repetitiveness. Conversely, the continuity of the Reunion group's results is conditioned by the independence of its members. As a result, a standardised observation program for such observers (as suggested above) should not entail the same difficulties.

We therefore believe that in terms of evolution or creation of inventories the benefits outweigh the disadvantages associated with the participation of non-professionals. In addition to inventories, this participation provides local, regional and national agencies with an effective and inexpensive way to improve knowledge of biodiversity in their areas of responsibility.

Possible further use of such collection method

This observation potential could also be used in structured programs for surveys directly aimed at management and conservation targets, without changing significantly the snorkelers' practice. Regular trips by snorkelers to any given site could act as an early warning system for the identification of invasive species, algal proliferations, disease outbreaks, coral bleaching, evidences for poaching and instances of pollution, for example. These observations could be rapidly fed back to local decision-makers, stimulating intervention at small or larger scale (Beeden et al., 2014). Such a strategy is considerably shorter than a large-scale scientific study with the same purpose (e.g. Danielsen et al., 2010).

Finally, it can be assumed that many regular snorkelers who would get initiated to naturalist photography and species identification would fast broaden their range of interest. They could then become active members in the global survey of their marine ecosystems, and become awareness agents in their communities (e.g. Pisupati, 2015). This dynamic could help protect the relevant areas through the education of coastal residents, fostering their engagement and encouraging the emergence of spokespersons for local communities in areas seldom studied, if at all, by scientific missions. Such initiative would be even more necessary, considering that the involvement of citizens is a major challenge in the context of current global socio-ecological crisis (Couvet & Teyssèdre, 2013), and that citizen scientist's potential is largely under-exploited (Couvet et al., 2008).

Acknowledgements

We would like to warmly thank all the scientists who were willing to establish a trustful and respectful relationship, sometimes even friendship, with amateur naturalists of Reunion Island around the results discussed in this article, as well as these naturalists themselves. All names are provided in Table 1 (see validation and observer columns). We apologize to the other enthusiasts of marine life in Reunion Island, whose discoveries could not be mentioned in this paper due to the lack of timely information. We are also grateful to the Reunion Island Direction de l'Environnement, de l'Aménagement et du Logement (DEAL), as well as the RNMR Scientific Council for the tissue sampling and night survey authorizations granted to some of the observers in its perimeter of authority. Lastly, we would like to thank the anonymous reviewers whose comments greatly improved this manuscript.

References

Arvanitidis C., Faulwetter S., Chatzigeorgiou G., Penev L., Banki O., Dailianis T., Pafilis E., Kouratoras M., Chatzinikolao, E., Fanini L., Vasileiado, A., Pavloud, C., Vavili, P., Koulouri P. & Dounas C. 2011. Engaging the broader community in biodiversity research: the concept of the COMBER pilot project for divers in ViBRANT. *ZooKeys,* **150**: 211-229**.**

Beeden R.J., Turne *M.A.,* Dryden J., Meri F., Goudk K., Malon *C.,* Marshall P.A., Birtle A. & Maynard J.A. 2014. Rapid survey protocol that provides dynamic information on reef condition to managers of the Great Barrier Reef. *Environmental Monitoring and Assessment,* **18**: 8527-8540.

Bramanti, L., Vielmini, I., Rossi, S., Stolfa, S. & Santangelo, G. 2011. Involvement of recreational scuba divers in emblematic species monitoring: the case of Mediterranean red coral (Corallium rubrum). *Journal for Nature Conservation,* **19**: 312-318.

Chandler M., See L., Copas K., Astrid M. Z. Bonde A. M. Z., Claramunt B., Danielsen F., Kristoffer Legind J., Masinde S., Miller-Rushing A. J., Newman G., Alyssa Rosemartin A. & Turak E. 2017. Contribution of citizen science towards international biodiversity monitoring, *Biological Conservation*, **213**: 280-294.

Conand C., Michonneau F., Paulay G. & Bruggemann J.H. 2010. Diversity of the holothuroid fauna (Echinodermata) at La Réunion. *Western Indian Ocean Journal of Marine Science,* **9**: 145-151.

Conand C., Ribes-Beaudemoulin S., Trentin F., Mulochau T. & Boissin E. 2016. *Oursins, étoiles de mer & autres échinodermes. Biodiversité de La Réunion.* Les Editions du Cyclone: Salines les Bains. 168 pp.

Couvet D., Jiguet F., Julliard R., Levrel H. & Teyssedre A. 2008. Enhancing citizen contributions to biodiversity science and public policy. *Interdisciplinary Science Review,* **33**: 95-103.

Couvet D. & Teyssedre A. 2013. Sciences participatives et biodiversité : de l'exploration à la transformation des socio-écosystèmes. *Cahiers des Amériques latine,s* **72-73**: 49-64.

Danielsen F., Burgess N.D., Jensen P.M. & Pirhofer-Walzl, K. 2010. Environmental monitoring: the scale and speed of implementation varies according to the degree of people's involvement. *Journal of Applied Ecology,* **47**: 1166-1168.

Danielsen F., Jensen P.M., Burgess N.D., Altamirano R., Alviola P.A., Andrianandrasana H., Brashares J.S., Burton A.C., Coronado I., Corpuz N., Enghoff M., Fjeldså J., Funder M., Holt S., Hübertz H., Jensen A.E., Lewis R., Massao J., Mendoza M.M., Ngaga Y., Pipper C.B., Poulsen M.K., Rueda R.M., Sam M.K., Skielboe T., Sørensen M. & Young R. 2014. A multi-country assessment of tropical resource monitoring by local communities. *BioScience,* **64**: 236-251.

Dercourt J. 2002. *Géologie et géodynamique de la France outre-mer et européenne.* 3ème edition. Dunot: Paris. 330 p.

Devictor V., Whittaker R.J. & Beltrame C. 2010. Beyond scarcity: citizen science programs as useful tools for conservation biogeography. *Diversity and Distributions*, **16**: 354-362.

Forrester G., Baily P., Conetta D., Forrester L., Kintzing E. & Jarecki L. 2015. Comparing monitoring data collected by volunteers and professionals shows that citizen scientists can detect long-term change on coral reefs. *Journal of Nature Conservation,* **24**: 1-9.

Fricke R, Mulochau T, Durville P, Tessier E. & Letourneur Y. 2009. Annotated checklist of the fishes species (Pisces) of La Réunion, including a Red List of threatened and declining species. *Stuttgarter Beiträge zur Naturkunde A Neue Serie*, **2**: 1-168.

Fricke R, Cadet C. & Mulochau T. 2015. First record of the sawspine dragonet *Diplogrammus infulatus* Smith 1963 (Actinopterygii: Perciformes: Callionymidae), from La Réunion, south western Indian Ocean. *Acta Ichthyologica et Piscatoria,* **45**: 407-410.

Garcia-Soto C., van der Meeren G.I., Busch J.A., Delany J., Domegan C., Dubsky K., Fauville G., Gorsky G., Von Juterzenka K., Malfatti F., Mannaerts G., McHugh P., Monestiez P., Seys J., Węsławski J.M. & Zielinski O. 2017. *Advancing citizen science for coastal and ocean research.* In: (V. French, P. Kellett, J. Delany, N. McDonough eds), European Marine Board: Ostend, Belgium. 112 pp.

Holt B. G., Rioja-Nieto R., MacNeil M.A., Lupton J. & Rahbek C. 2013. Comparing diversity data collected using a protocol designed for volunteers with results from a professional alternative. *Methods in Ecology and Evolution,* **4**: 383-392.

Legall N. & Poupin J. Internet - CRUSTA: Database of Crustacea (Decapoda and Stomatopoda), with special interest for those collected in French overseas territories. Available at http://crustiesfroverseas.free.fr/.

Marchand I., de Mazieres J., Aish A. & Poncet L. 2013. Rapport préparatoire pour l'élaboration d'une note méthodologique : Intégration des données issues des programmes marins de sciences participatives dans l'INPN. Rapport SPN 2013-17, Service du Patrimoine Naturel, Muséum National d'Histoire Naturelle : Paris. 60 pp.

Mora C., Tittensor D.P., Adl S., Simpson A.G.B. & Worm B. 2011. How many species are there on Earth and in the Ocean? *PLoS Biology,* **9**: e1001127. https://doi.org/10.1371/journal.pbio.1001127.

Pearson D.L., Hamilton A.L. & Erwin T.L. 2011. Recovery plan for the endangered taxonomy profession. *BioScience,* **61**: 58-63.

Pettibone L., Vohland K., Bonn A., Richter A., Bauhus W., Behrisch B., Borcherding R., Brandt M., Bry F., Dörler D., Elbertse I., Glöckler F., Göbel C., Hecker S., Heigl F., Herdick M., Kiefer S., Kluttig T., Kühn E., Kühn K., Oswald K, Röller O., Schefels C., Schierenberg A., Scholz W., Schumann A., Sieber A., Smolarski R., Tochtermann K., Wende W. & Ziegler D. 2016. Citizen science for all – a guide for citizen science practitioners. Bürger Schaffen Wissen (GEWISS) publication. German Centre for integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Helmholtz Centre for Environmental Research (UFZ), Leipzig; Berlin-Brandenburg Institute of Advanced Biodiversity Research (BBIB), Museum für Naturkunde (MfN). Leibniz Institute for Evolution and Biodiversity Science: Berlin. 61 pp.

Pisupati B. 2015. Taxonomy: the science and art of species. *Current Science,* **108**: 2149-2150.

Randall J.E. & Smith D.G. 2001. *Thalassoma mascarenum* Fricke, 1999 (Perciformes: Labridae), a synonym of *T. genivittatum* (Valenciennes, 1839). *Journal of South Asian Natural History,* **5**: 117-120.

Riesch H. & Potter C. 2014. Citizen science as seen by scientists: methodological, epistemological and ethical dimensions. *Public Understanding of Science,* **23**: 107-120.

Rotman D., Preece J., Hammock J., Procita K., Hansen D., Parr C., Lewis D. & Jacobs D. 2012. Dynamic changes in motivation in collaborative citizen-science projects. In: *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*. pp. 217-226. ACM: Seattle. 217-226.

Schmitt E.F. & Sullivan K.M. 1996. Analysis of a volunteer method for collecting fish presence and abundance data in the Florida Keys. *Bulletin of Marine Science,* **59**: 404-416.

Schmitt E.F., Sluka R.D. & Sullivan-Sealey K.M. 2002. Evaluating the use of roving diver and transect surveys to assess the coral reef fish assemblage off southeastern Hispaniola. *Coral Reefs,* **21**: 216-223.

Urban M.C. 2015. Accelerating extinction risk from climate change. *Science,* **348**: 571-573.