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## The use of citizen science for marine biodiversity surveys: from species identification to ecologically relevant observations

Thomas Changeux  · Christophe Blazy · Sandrine Ruitton

**Abstract** The current development of citizen science is an opportunity for marine biodiversity surveys to use recreational SCUBA diver data. In France, the DORIS project is extensively used for marine species identification, while many initiatives offer volunteer divers the means to record their observations. Thanks to the scientific synergy generated by the flagship project of the artificial reefs (ARs) of Prado Bay, located off the coast of Marseille (France), a multi-annual biodiversity survey was

performed by a team of recreational divers certified by the French Federation for Submarine Sports and Education (FFESSM). The analysis of their observations with other citizen science data showed a good taxonomic coverage for fishes and mollusks. These observations also allowed (1) to follow AR colonization over the study period, with the increasing number of taxa and the growing occurrence of large fishes, and (2) to characterize taxa distribution between the different AR types, revealing the inefficiency of one type of AR which failed to provide the results expected from its design. This example demonstrates that the transition from species identification to ecologically relevant observation is perfectly feasible using volunteer naturalist SCUBA divers, on condition that both the protocols and the data are validated by professional scientists.

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**Keywords** Citizen science · SCUBA divers · Underwater monitoring · Artificial reef · Fish · Macrobenthos · Mediterranean

### Abbreviations

AIER	Aide à l'identification des espèces des récifs/Help for the identification of AR species
AR	Artificial reef
BW	Biological Watch
CS	Citizen science

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DORIS	Données d'Observations pour la Reconnaissance et l'Identification de la faune et la flore Subaquatiques/ Observation data for recognition and identification of underwater fauna and flora
FFESSM	Federation for Submarine Sports and Education
NEA	North Eastern Atlantic
UEBC	Underwater Environment and Biological Commission
WoRMS	World Register of Marine Species

## Introduction

As was pointed out by Bonney et al. (2014) following the increasing success of Citizen Science (CS) during the last decade, this new domain now encompasses many different notions that Kullenberg & Kasperowski (2016) classified into three research areas: (i) biology, conservation and ecology, (ii) geographic information and (iii) social sciences and epidemiology. Thanks to public concern regarding environmental threats, CS provides a tangible opportunity for biology and conservation, which make up the largest body of articles in terms of scientific output in their 2016 worldwide meta-analysis. In the domain of biology and conservation, current literature focuses on the validity of non-professional data. In Europe, a survey of 395 biodiversity monitoring studies underlined the benefit of accessing a large volunteer sampling effort (Schmeller et al., 2009). Another study, based on fewer examples, has demonstrated that professional data are not always more accurate (Lewandowski & Specht, 2015). In France, the contribution of CS to scientific literature is scarce but growing, with a particular focus on agriculture, biodiversity and the environment (Houiller & Merilhou-Goudard, 2016).

In this context, marine CS has lagged behind its terrestrial counterpart and now requires special attention (Garcia-Soto et al., 2017). Because of the more difficult accessibility, the majority of marine CS projects rely on fishermen and target nearshore habitats (Thiel et al., 2014). This specific involvement also explains why marine CS focuses more on resource management than on biodiversity. Another

obstacle is the multitude of unusual life forms that make up marine biodiversity. Because groups such as cephalopods, echinoderms, tunicates, brachiopods and anthozoans are exclusively marine (Grosberg et al., 2012) and are strikingly different from all familiar forms of terrestrial life, they are harder to correctly identify by non-specialists. Indeed, accurate identification of species is the major obstacle in marine CS projects (Martin et al., 2016). However, despite the cost and required certifications, SCUBA diving is becoming increasingly popular (Garrod & Gössling, 2008) and it can be said that SCUBA divers now represent one of the best opportunities for marine CS projects (Martin et al., 2016; Lucrezi et al., 2018).

The French Federation for Submarine Sports and Education (FFESSM) assembles the vast majority of divers in the country (about 150,000 diving licenses in 2016). The FFESSM has been involved in CS since its creation in 1955, even if this is undocumented in the scientific literature. In each French region there is a designated Underwater Environment and Biological Commission (UEBC) which organizes training programs with two levels of certification. The “bio 1” level is an initiation to marine life, while the “bio 2” level focuses on sharing observations with other divers and acquiring practical experience of laboratory techniques (see the FFESSM website: <http://biologie.ffessm.fr/index.php/les-formations-federales>). The learning content of both levels focuses on species identification and taxonomic classification, with the support of the very popular DORIS (“Données d'Observations pour la Reconnaissance et l'Identification de la faune et la flore Subaquatiques”/Observation data for recognition and identification of underwater fauna and flora) collaborative project, in which roughly 1,000 contributors have described more than 2,300 marine species in partnership with the French “Museum National d'Histoire Naturelle” (Natural History Museum) and the “Agence Française pour la Biodiversité” (French agency for biodiversity). In addition to this preliminary knowledge on species identification and taxonomy, the use of SCUBA diver potential for underwater observations is underway with ongoing logbook programs such as Earthdive, Reef Check or BioObs [see Kundasamy (2014) and also Goffredo et al. (2004, 2010), Zenetos et al. (2013), Gerovasileiou et al. (2016) and Cerrano et al. (2017) for the Mediterranean Sea].



Thanks to public interest, marine restoration programs often use volunteers to reduce their costs (Gollan et al., 2012; Bayraktarov et al., 2016). In France, Tessier et al. (2015b) have shown that artificial reefs (AR) have been increasingly used since the 1960s to restore and enhance coastal ecosystems. Their implementation in France is now under the strict control of local authorities as a consequence of several poor experiences in the 1980s. After the suspension of important projects during the 1990s, several large-scale experiments resulting from significant efforts of design have come to fruition in recent years. Most of the French AR projects are dedicated to sustainable artisanal fisheries. Anti-trawling AR projects have progressively developed into a new generation of production ARs, associated with marine-protected areas (Claudet & Pelletier, 2004), but they fail to associate SCUBA divers in a satisfactory way (Tessier et al., 2015a). Currently, the majority of AR-monitoring programs are performed by professional scientists. In the scientific literature, however, the sole example of volunteer data collected on ARs is out of date, concerns Florida waters, and concludes that divers failed to accomplish many tasks (Halusky et al., 1994).

Through the study of the opportunities present in France today, our aim has been to assess the contribution of volunteer SCUBA diver data to biodiversity surveys. We examine the case of the Prado Bay ARs, Marseille (Charbonnel et al., 2011), which is the largest AR project in the Mediterranean Sea. Using the data obtained from the “Veille biologique” [Biological watch (BW)] CS program, we investigate the current transition from species identification to local observation.

This paper attempts to answer three main questions: (1) What kind of biodiversity is correctly described by BW observations in comparison with other CS data? (2) Are these observations ecologically relevant regarding current knowledge of AR colonization and habitat segregation of species between different types of AR? and (3) How can these observations be used by managers and scientists? The answers to these questions then permit us to make some recommendations for future underwater CS projects.

## Materials and methods

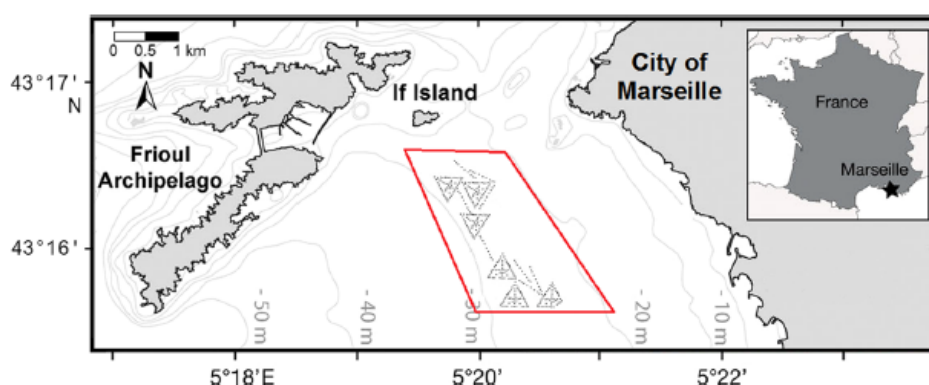
### Study site

Deployed between October 2007 and July 2008, Prado Bay ARs belong to the new generation of production ARs which are designed to enhance artisanal fisheries (Charbonnel et al., 2011). These new reefs also offset a decrease of biodiversity traceable to the destruction of an ancient *Posidonia oceanica* (L.) Delile meadow (Le Diréach et al., 2015). The Prado Bay ARs are situated between the urban coast of Marseille and the Frioul archipelago to the south of If Island (Fig. 1). They were specially designed to create new habitats on a sandy bottom overlying *P. oceanica* dead matte (Boudouresque et al., 2016). A set of 401 ARs, covering a concession of about 200 ha and ranging in depth from 25 to 31 m, were grouped into six “villages”. Each village consists of a group of equilateral triangles each of which measures 300 m per side. Eight “links” connect these villages and are designed to function as biological corridors (Fig. 1). To maximize habitat diversity, six different types of AR were designed: piled cubes (CUBES), maze (MAZE), fakir reef (FAKIR), steel basket (BASKET), floating ropes (ROPES) and rockfills (ROCKS), and all are evenly distributed in villages and along links (see Table 1, Charbonnel et al. (2011) or Le Diréach et al. (2015) for more details). BASKET, FAKIR and ROCKS are considered as having large volume and high complexity, whereas CUBES, MAZE and ROPES are smaller and less complex (Table 1). To safeguard against the anthropogenic pressure associated with the neighboring city of Marseille and also to ensure the success of the entire AR concession as a production structure, the site was protected through the implementation of strict regulations prohibiting all fishing, anchoring and diving.

### Sampling design and procedure

The monitoring of the ARs of Prado Bay by FFESSM SCUBA diver volunteers from “Provence Alpes-Cote d’Azur” (PACA) UEBC, called “Veille biologique” (Biological Watch (BW) in the following), was carried out annually from 2009 to 2015 in two successive phases: (1) a planning phase followed by (2) an implementation phase.

**Fig. 1** Location of the artificial reef (AR) field, where each AR is represented by a small dot inside the limits of the prohibition zone, indicated by the red parallelogram. The ARs are grouped into 6 villages (triangles) and 8 links (lines)



The planning phase was completed by the local UEBC at the end of the year preceding the implementation phase, with the initial objective being to visit all ARs within 3 years. Each year, a provisional schedule was fixed which spanned the months from April to November to avoid the disruptions of bad weather conditions in winter. Starting from the second year of monitoring, the ARs slated for sampling were chosen based on the list of ARs that had not been visited over the previous year up to 3 years ago. All diving sessions took place during daytime, generally in the morning, apart from a single night diving session organized in October 2015 with the objective of diversifying diver knowledge of the AR. Each session has a corresponding date. Between 20 to 37 SCUBA diver volunteers were authorized annually to dive in the protected area. They all had bio 2 level certification, meaning that they had received special training in species identification. A diver was considered as experienced when he or she had dived more than five times on the ARs in the previous year. Before going to sea, the divers were pooled in groups of 2 or 3 which always included at least one photographer and one experienced diver. Each group was assigned a list of 2 to 3 contiguous ARs, based on the fact that a standard AR requires approximately 10 min of visual inspection time for a total of 30 min diving time. The largest ARs (BASKET and ROCKS) were investigated either two to three times more than the other ARs by a given group of divers, or were investigated by two or more different groups of divers at the same time.

The first step of the implementation phase was to mark the position of the first AR assigned to each group using a buoy attached to a weighted line. After immersion, the group descended along the line to the AR. The arrival on site was filmed by at least one diver

to permit identification of any mobile fauna, mostly large fishes or fish schools, which tend to swim away when divers approach. Sampling consisted of inspecting the AR with the objectives of finding a maximum number of different species, taking photographs from 1 to 3 m distance and noting species' names on a plastic slate. Once back on shore, each group worked together to enter their observations into a data template to the most precise taxonomic level possible. Taxa identification was undertaken using the AIER (Aide à l'identification des espèces des récifs/Help for the identification of AR species) online photography data base ([http://cebs13.free.fr/Album/AIER/Index\\_AIER.html](http://cebs13.free.fr/Album/AIER/Index_AIER.html)) and the DORIS database (<http://doris.ffessm.fr/>) to identify new species. Most of the presumed "species" found were not, in fact, true species and were later identified in the text as taxon/taxa. The data template enabled the recording of abundance data for fishes in two classes only, thus permitting to distinguish between large and small fishes [small fishes having a Total Length < 1/3 Maximum Length according to FishBase data (<https://www.fishbase.org/search.php>)].







#### Data treatment and analysis

All taxa were grouped into 12 different "families" corresponding to a practical use of the DORIS database: algae, plants, sponges, cnidarians, worms, mollusks, crustaceans, bryozoans, phoronidians, echinoderms, ascidians and fishes. Even if these are not true families zoologically speaking, this appellation was retained because of being the term employed in the field by the SCUBA diver volunteers.

Our dataset was then compared with the two other principal French marine CS data bases: DORIS, which



**Table 1** Description and partition of the six artificial reef (AR) types with details of sampling design and results

Type	N of ARs	Height (m)	Floor surface (m <sup>2</sup> )	Volume/unit (m <sup>3</sup> )	Total volume (m <sup>3</sup> )	N of samples	Median of taxa richness	Materials and structure	Figure (various scales)
BASKET	21	3	15	187	3,927	35	41	Composed of cubic, concrete modules supported by iron beams. The inside part is complemented by octopus pots, oyster shell bags and breeze blocks. This design confers various living conditions for different organisms, allying protected and exposed surfaces	
CUBES	202	1.2	1.44	10.4	2,100.8	244	31	Composed of piles of six cubic, concrete modules. This AR does not provide a specific architecture but its surfaces are quite exposed to current and sunlight	
MAZE	100	1.95	8.16	187	18,700	134	27	Composed of three stacked horizontal concrete platforms which are supported by internal vertical walls. The vertical sides provide protection from sunlight and current whereas the horizontal platforms do not	
ROCKS	43	1 (0.5 to 2)	100	100 to 160	4,300 or 6,880	55	33	Chaotic assemblage of rocky blocks of different sizes with vertical and rough walls exposed to the sunlight	
FAKIR	21	3.25	25	75	1,575	22	42	This AR is entirely made of concrete and is composed of a cubic module surrounded by vertical beams. It offers numerous cavities allowing to diversify habitat and to supply spaces within which species can hide	
ROPES	14	7 to 6	36	252	3,528	22	25	Composed of a concrete platform with two polypropylene ropes attached to buoys suspended beneath the surface. This AR is very exposed to currents and sunlight	
Total	401			703.1	27,300	512			

pools the North Eastern Atlantic (NEA) and Mediterranean Sea taxa, and BioObs (<http://bioobs.fr/>), which after filtering the data, pools only the Mediterranean

taxa identified around Marseille. More than simply using the maximum number of taxa which can be identified by CS divers in the study area, it is the

comparison with the taxa richness profile across the different families and the proportion of identified taxa for a given family which have been used to estimate the bias of our dataset. The taxa lists were validated in detail by local specialists (Marc Verlaque (algae), Jean Vacelet (sponges) and Jean-George Harmelin (fishes and other macro-benthos)) using WoRMS (the World Register of Marine Species) [(<http://www.marinespecies.org/>)].

Statistical analysis was performed using R software (R Core Team, 2014). Taxonomic richness was examined using accumulation curves of the Vegan package (Oksanen et al., 2016) which considers the number of ARs as a measurement of sampling effort. Non-parametric tests such as the Kruskal–Wallis (KW) or Wilcoxon tests were used since variables were not normally distributed. Correspondence analysis was employed to obtain a synthetic view of fish community distribution between the different AR types. Jaccard distance was used to measure the similarity between different samplings of a given AR at a given time.

## Results

### Sampling and validation

The sampling effort is highly variable in terms of the number of sessions, the number of visited ARs, the number of divers and the number of observations (Table 2). From 2009 to 2015, a total of 631 ARs were sampled, with a mean value of 90 ARs per year. From

the beginning of this period up to and including 2011, more than one hundred ARs were sampled each year. However, from 2012 on this value was halved, and was sometimes even less frequently sampled, for instance in 2013 when only four sessions were organized and just 22 ARs were sampled. It also became apparent that the data frame used in 2009 was not sufficiently accurate to produce usable taxonomic data. For this reason, that year's data set was excluded from this work which thus covers only the period from 2010 ( $N + 2$ ) to 2015 ( $N + 7$  after AR installation), with a total of 17,196 taxonomic observations (mean 2,866 per year). The taxa validation process by specialists led to the modification of 9 taxa of algae, 4 taxa of mollusks, 2 taxa of ascidians, 1 taxon of echinoderms and 1 taxon of fishes, out of total number of 26 modified taxa. The majority of these modifications (20) concerned (i) inappropriate taxonomic level of identification, (ii) misspelled scientific or vernacular names, and (iii) the elimination of *Algae* sp due to the permanent presence of algae on the ARs.

### Cumulative number of taxa

The cumulative number of observed taxa at a monthly resolution shows a strong increase for all families during the first year (Fig. 2), especially between July and August. After the first year, the progression was maintained until 2013, and continued to show a steeper increase between June and August. From 2013 onward, as sampling declined, the progression of the cumulative number of taxa was limited for all families with the exception of October 2015, when a single

**Table 2** Annual sampling design with total number ( $N$ ) of divers, number of novice and experienced divers, number of sessions, total number of artificial reefs (ARs) visited, total

number of taxonomic observations, number of different taxa and overall number of taxa (NA: not available)

Variables	2009	2010	2011	2012	2013	2014	2015	Sum	Mean
$N$ divers	19	25	37	20	15	22	22	160	22.9
$N$ novice divers	13	12	15	4	8	9	10	71	10.1
$N$ experienced divers	6	13	22	16	7	13	12	89	12.7
$N$ sessions	12	19	24	8	4	10	10	87	12.4
$N$ visited ARs	119	151	146	53	22	74	66	631	90.1
$N$ taxonomic observations	NA	3,683	5,253	2,391	966	2,551	2,352	17,196	2,866
$N$ different taxa	NA	144	172	166	147	167	187	NA	NA
Overall $N$ of different taxa	NA	144	180	203	214	221	237	NA	NA



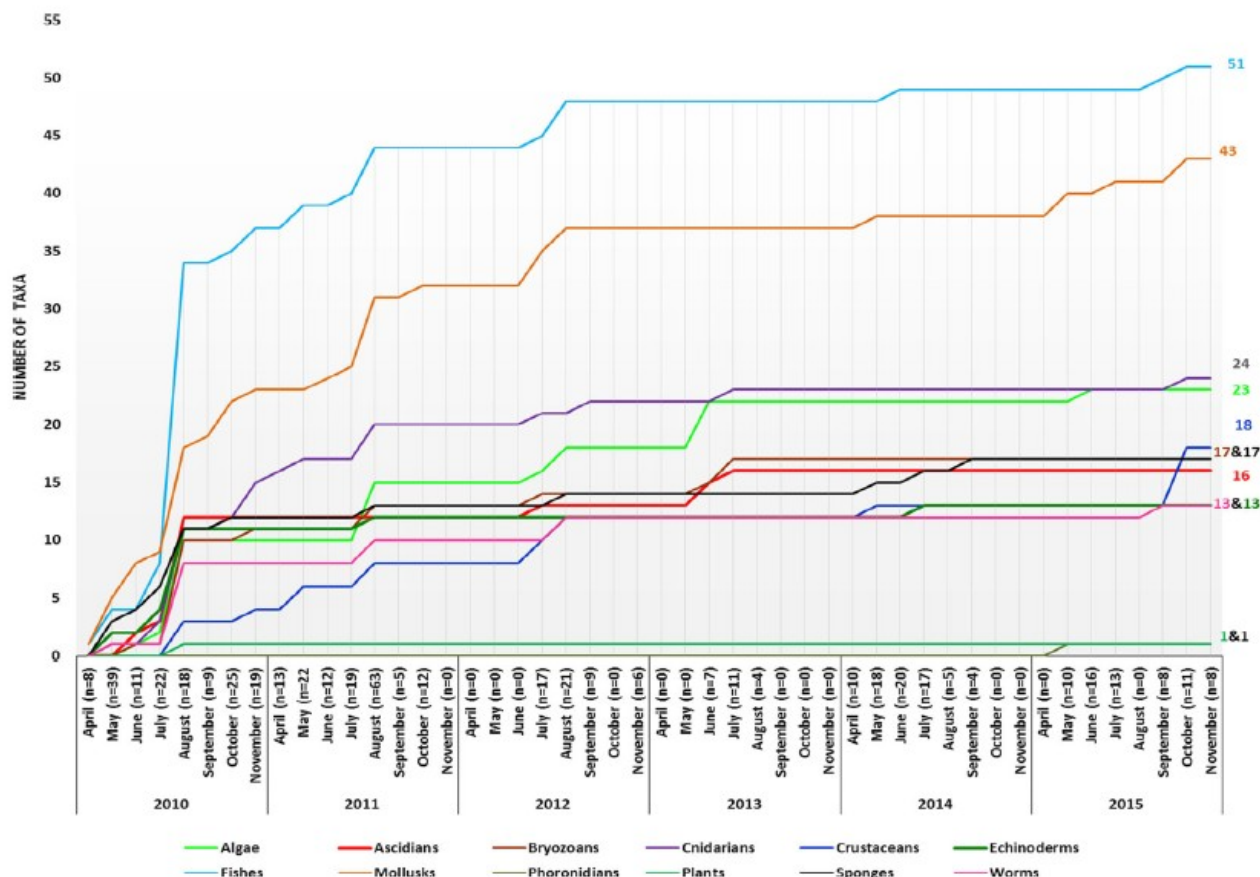


Fig. 2 Evolution of the cumulative number of taxa per month, excluding winter months, with the distinction of the 12 families ( $n$  is the number of sampling sessions per month; the terminal number of taxa is given to the right of each curve)

night dive brought 9 new taxa, essentially crustaceans (5 taxa). When cumulated over the whole period, the total taxa richness is 237 (Table 2). The richest families are fishes (51) and mollusks (43), while the poorest are plants (1) and phoronidians (1). All the others range between 13 and 24 taxa.

By randomizing the taxonomic observations, accumulation curves (plotted with the number of taxa on the Y axis and the number of sampled AR on the X-axis) enable comparison of the results at the same sampling level (Fig. 3). All the families exceed 50% of their final taxa richness value with at least 50 ARs sampled (Table 3), with the noticeable exception being crustaceans, which continue to progress even after 400 ARs sampled. In terms of final taxa richness (Fig. 2), our dataset is still smaller than the DORIS database (Fig. 4a). The overlap between our dataset and the DORIS database for the following families never exceeds 33%, with the noteworthy scores of 33% for phoronidians and 30% for fishes. Sponges

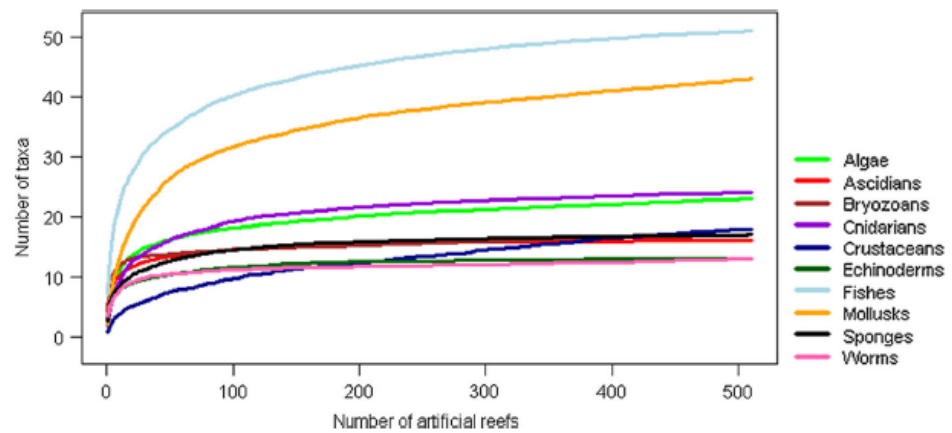
(9%), crustaceans (11%), mollusks (13%) and algae (14%) all have less than 15% representation. However, the comparison of our data with the BioObs dataset is generally more favorable, with only two families (plants and phoronidians) scoring less than 33% representation in both datasets (Fig. 4b). The taxa richness of BW observations exceeds that of BioObs for crustaceans (120%) and ascidians (107%), and never falls below 25% coverage. Plants (25%), phoronidians (33%), algae (49%) and sponges (52%) are all under 60% coverage while mollusks (93%), bryozoans (94%), fishes (73%), cnidarians (71%) and echinoderms (68%) produce higher results.

#### Global taxa richness

The variations over time of annual taxa richness accumulation curves show a clear progression from 2011 to 2013 (Fig. 5), even taking into account the lack of sampling effort during that last year. The



**Fig. 3** Randomized accumulation curves with number of artificial reefs for the ten major families



**Table 3** Number of taxa for each of the 10 major families with calculation of the proportion of detected taxa for 20, 50, 60, 80 and 120 artificial reefs (ARs) visited, following randomized accumulation curves of (Fig. 3)

Taxonomic families	Total <i>N</i> of taxa	<i>N</i> of taxa observed by number of ARs visited				
		20	50	60	80	120
Algae	23	13 (57%)	16 (70%)	17 (74%)	18 (78%)	19 (83%)
Ascidians	16	12 (75%)	13 (81%)	14 (88%)	14 (88%)	15 (94%)
Bryozoans	17	12 (71%)	13 (76%)	14 (82%)	14 (82%)	15 (88%)
Cnidarians	24	13 (54%)	16 (67%)	17 (71%)	18 (75%)	20 (83%)
Crustaceans	19	5 (26%)	7 (37%)	7 (37%)	9 (47%)	10 (53%)
Echinoderms	13	9 (69%)	10 (77%)	11 (85%)	11 (85%)	12 (92%)
Fishes	51	27 (53%)	35 (69%)	36 (71%)	38 (75%)	41 (80%)
Mollusks	43	18 (42%)	24 (56%)	27 (63%)	30 (70%)	32 (74%)
Sponges	17	10 (59%)	13 (76%)	13 (76%)	14 (82%)	15 (88%)
Worms	13	9 (69%)	10 (77%)	11 (85%)	11 (85%)	12 (92%)

recovery of the sampling effort until 2014 leads to curves in the same group of trajectories, all of which are higher than the 2011 results. Knowing that annual variations of taxa richness are significant (Kruskal–Wallis  $Z = 131.85$ ,  $P = 3.93\text{e}^{-06}$ ), the first year value is significantly lower than the others (paired post hoc Wilcoxon test,  $P = 4.3\text{e}^{-13}$  for 2011,  $P = 3.2\text{e}^{-16}$  for 2012,  $P = 1.5\text{e}^{-05}$  for 2013,  $P = 3.9\text{e}^{-09}$  for 2014 and  $P = 5.3\text{e}^{-09}$  for 2015).

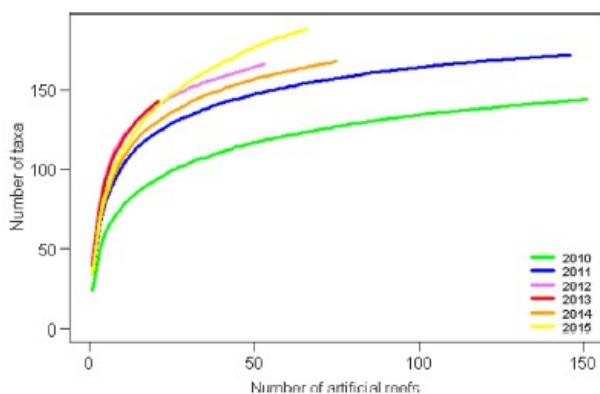
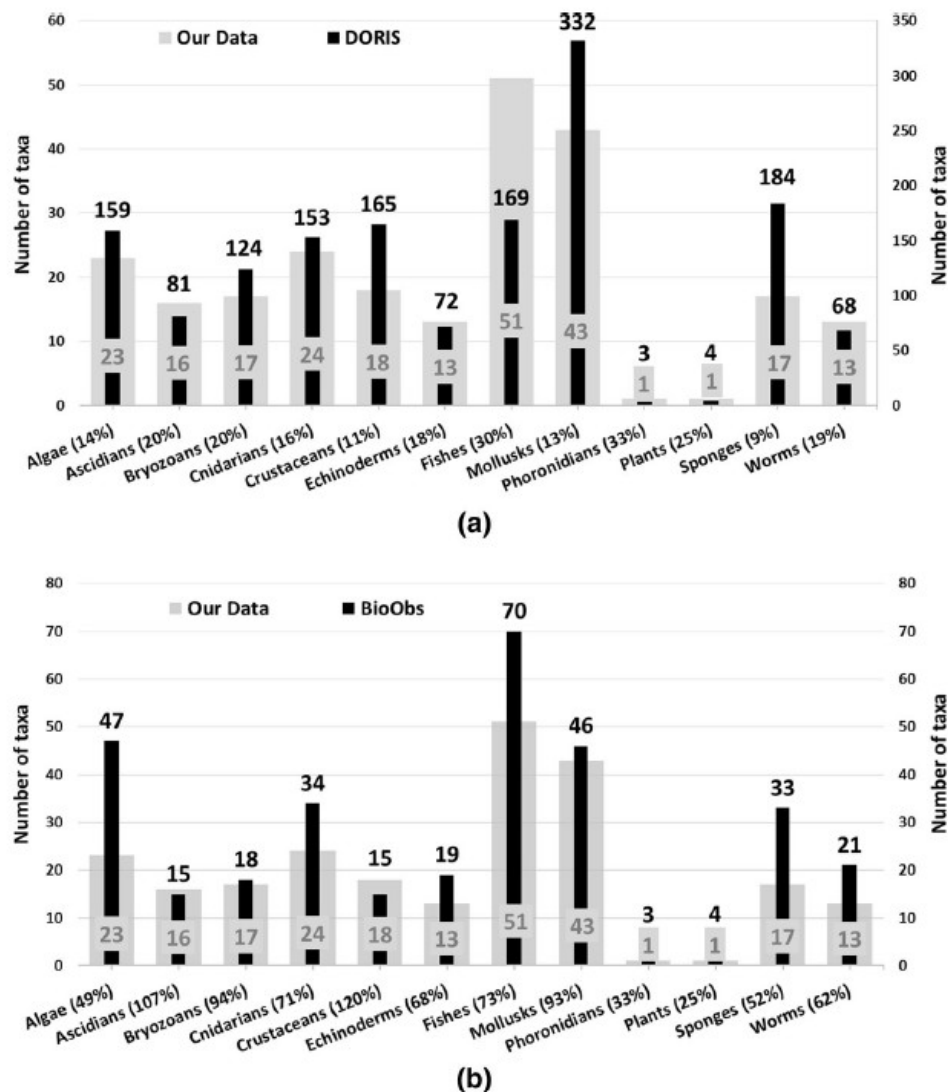
In the spatial dimension, the variations of taxa richness at the large scale, between different villages and links, are poorly significant. Village 6 appears to be richer than the others (Kruskal–Wallis  $Z = 88.477$ ,  $P = 0.0406$ ) and the links are globally poorer than the villages (Kruskal–Wallis  $Z = 90.599$ ,  $P = 0.02904$ ). Examination of the effect of AR type on taxa richness provides more significant results, with FAKIR and

BASKET types being richer than all others (CUBE, MAZE and ROPES paired post hoc Wilcoxon tests lead to  $P = 0.0156$ ,  $P = 0.0012$  and  $P = 0.0171$  for FAKIR and  $P = 0.0013$ ,  $P = 9.5\text{e}^{-06}$ ,  $P = 0.0048$  for BASKET, respectively). The accumulation curves (Fig. 6) reveal 4 distinct progressions: (1) FAKIR and BASKET, always higher than the others, (2) ROCKS slightly lower, (3) CUBES and MAZE, numerous, with curves positioned one above the other but below the previous group of curves, and (4) ROPES, systematically the poorest.

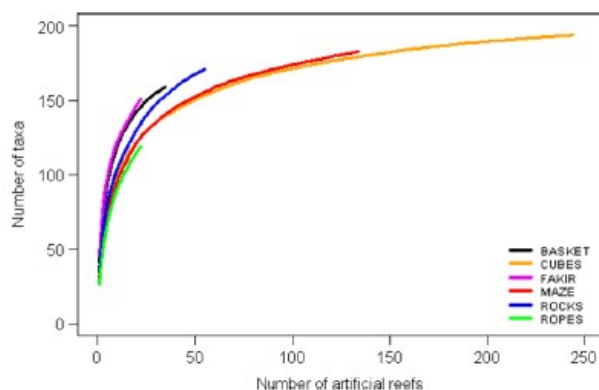
#### Fishes

Across all families of BW observations, fishes count for not only the highest number of taxa, but are also particularly well described, and therefore, deserve

**Fig. 4 a, b** Comparison of taxa richness between our data set (wide grey bars), and a DORIS (2016/05/19) (narrow black bars), and b BioObs (2016/06/02) (narrow grey bars), for the 12 families. Values are specified in the same shade of grey. Percentages indicate the proportion between our data set and a DORIS or b BioObs. Note the difference of scale of the y-axes for BioObs and our data



**Fig. 5** Randomized accumulation curves of taxa richness for the different years. Length of curves depends on the number of artificial reefs sampled per year



**Fig. 6** Randomized accumulation curves of taxa richness for the different artificial reef (AR) types. Length of curves depends on the number of artificial reefs sampled per type



further statistical analysis. First, at the community level, the size classes progressed from a small to a large size-class domination between 2010 and 2015 (Fig. 7). Second, after elimination of rare taxa (exhibiting less than 10% occurrence), the correspondence analysis reveals 75.48% of the total array's inertia in the two first axis plans (Fig. 8). The horseshoe-shaped disposition of taxa, also called the Guttman effect (Escofier & Pagès, 1998), is typical of a strong gradient structure of the array which orders the taxa from low-diversified ARs, such as ROPES, MAZE and CUBES that have mean taxa numbers less than 10, to more highly diversified ARs, such as FAKIR, BASKET and ROCKS that have mean taxa numbers greater than 10.

Following the spatial classification by Harmelin (1987), the mobile open water fishes (Cat. 1) such as *Boops boops* L. and *Spicara maena* L. are found in the vicinity of ROCKS and BASKET. The sedentary open water fish (Cat. 2) *Chromis chromis* L. remains close to BASKET and FAKIR. The (Cat. 3) necto-benthic fishes *Diplodus sargus* L., *Diplodus vulgaris* (Geoffroy Saint-Hilaire, 1817), *Diplodus annularis* L. and *Diplodus puntazzo* (Walbaum, 1792) that undertake medium size vertical displacements have a central position between ROCKS, BASKET, FAKIR, CUBES and MAZE. *Mullus surmuletus* L. is a Category 4 necto-benthic fish making large lateral displacements and is associated with ROCKS. Several Category 5 sedentary necto-benthic fishes such as *Labrus merula* L., *Labrus mixtus* L., *Symphodus tinca* L., *Symphodus mediterraneus* L., *Coris julis* L., and *Serranus cabrilla* L. make small displacements and

are present in all ARs, while the diurnal crypto-benthic Category 6a fishes *Parablennius rouxi* (Cocco, 1833), *Tripterygion delaisi* (Cademant & Blache, 1970), and *Gobius vittatus* (Vinciguerra, 1883) find refuge mainly in MAZE and CUBES. Finally, the nocturnal crypto-benthic Category 6b fishes *Conger conger* L., *Phycis phycis* (Linnaeus, 1766), *Scorpaena scrofa* L., *S. porcus* L., and *S. notata* (Rafinesque, 1810) are found mainly in BASKET, and *Apogon imberbis* L. are found mainly in ROCKS.

## Discussion

### Taxonomic description

The overall taxa richness of 237 cannot be considered as an absolute measurement of biodiversity since it encompasses too many different families for which volunteer expertise is heterogeneous and finally contributes to various biases within our dataset concerning families. However, the different accumulation curves (Figs. 3, 5, 6) and Table 3 show that, in any case, the taxa richness curve plateau is not reached before 50 ARs, which appears to be a minimum when considering absolute values of global taxa richness. This reinforces the observation that the number of ARs to be visited is rarely reached in the BW observation plan. Since our analysis requires limited parametric calculations (such as mean or variance), we had to limit our representations to accumulation curves which illustrate the effect of AR sampling variations.

The comparison of the BW results with DORIS and BioObs necessitates to work with two different scales. The DORIS database sources on a very large scale, considering the NEA and the Mediterranean together with their different habitats. Consequently, the number of taxa recorded is six times higher for DORIS than for BioObs. Consideration of the distribution profile between families, reveals that the prevalence of crustaceans and mollusks in DORIS is conform to the global counting of marine species (Costello & Chaudhary, 2017). The prevalence of sponges follows the geography of 'Porifera' species distribution, and the NEA and Mediterranean Sea are identified amongst the few regions with more than 200 recorded species for this phylum (Van Soest et al., 2012; Fig. 11). Voultsiadou (2009) enumerates a total of 629 demosponges for the Mediterranean, with 255 species

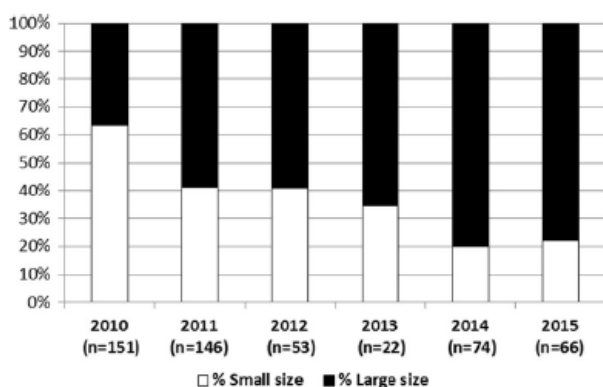


Fig. 7 Temporal variation of proportion of small- versus large-sized fishes. The number of sampled artificial reefs (AR) per year is in parentheses

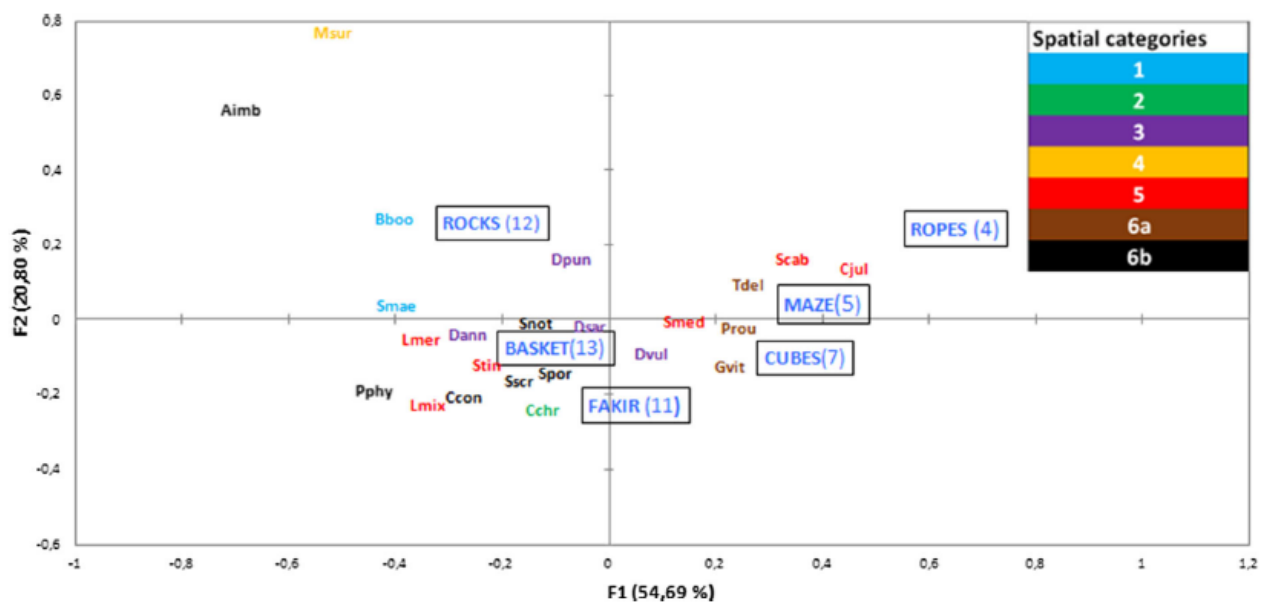


Fig. 8 Plot of the first two dimensions obtained through correspondence analysis of fish taxa distribution across the different artificial reef types (in boxes identified with names following Table 1; mean taxa richness in parentheses). The taxa are colored according to their spatial categories from Harmelin (1987): (1) mobile open water fish, (2) sedentary open water

fish, (3) necto-benthic fish making medium size vertical displacements, (4) necto-benthic fish making large lateral displacements, (5) sedentary necto-benthic fish making small displacements, (6a) diurnal crypto-benthic fish, (6b) nocturnal crypto-benthic fish. Taxa codes are listed in Appendix 1

for the French coasts only. As far as the BioObs data set is concerned, taxonomic observations were sorted to retain only sightings recorded around Marseille, thus the BioObs focused scale is approximately the same as our data set, which facilitates comparison. The number of taxa is of roughly the same magnitude in both data sets, and fishes and mollusks figure in first and second position, respectively. The differences between the BW and BioObs data sets can be interpreted by variations of sampling design, given that our data cover only one type of habitat, i.e., ARs which can be assimilated to coastal rocky habitat at depths of between 25 and 30 m. At these depths, the development of plants and algae is limited by low light conditions. This explains why algae and plants have low identification coverage with BW. Conversely, ascidians have good coverage with BW because they are favored both by the hard substrate of ARs and by the presence of a strong marine current bringing nutrients into the area. Since crustaceans are generally better sampled at night (Triay-Portella et al., 2018), the night dive we conducted may explain why there are more crustacean taxa in the BW observations than in those of the BioObs.

Finally, even if the absolute values of taxa richness of BW are not sufficient to make a complete biodiversity assessment, it can be seen that a sampling effort with a minimum of 50 ARs allows to obtain a taxonomic description comparable with other CS database programs for the 12 families. The main variations of family descriptions are easily explained by the specific characteristics of ARs that can be assimilated to rocky habitats, or by the sampling protocol (e.g., night dive).

#### Ecological significance

The first ecological process occurring at ARs after deployment was colonization. In the Mediterranean Sea, it is commonly admitted that the pioneer phase lasts 1 year and is followed by a maturation phase which lasts for around 4 years (Cépralmar, 2015). Most AR communities require 6 years ( $N + 6$ ) from the moment of structure immersion for settlement and stabilization in such habitats.

In our data set, the global taxa richness shows a progression over time from year  $N + 2$  (2010) to  $N + 4$  (2012), followed by relative stabilization in year  $N + 5$  (2013). This evolution is in accordance



with the previous assumption of pioneer and maturation phases, and with the dynamic observed in other studies of macro-benthos AR colonization (Relini et al., 1994; Manoudis et al., 2005; Boaventura et al., 2006; Hanner et al., 2006). The substantial progression of the cumulative taxa richness for all families in July 2010 can be related to both the colonization process and to an additional seasonal effect, consisting of the appearance of new taxa following the spring depletion observed by Relini et al. (1994). The effect of the colonization process is also significant through the evolution of small fish numbers (Fig. 7). The first settlement, mainly composed of small individuals, occupies the empty ARs because rocky habitat globally favors recruitment, especially when surrounded by sandy bottom (Bohnsack et al., 1994; Tessier, 2010; Pinault, 2013), even if this may vary from one species community to another. After this, the progressively decreasing proportion of small fishes can be interpreted as an effect of the increase in sedentary fish populations, which leaves less opportunity for new juveniles to settle. This phenomenon shows that certain functions targeted in AR design, such as shelter against predators (Caley & StJohn, 1996; Mercader et al., 2019) and access to additional trophic resources (Cresson et al., 2014) regarding different trophic groups of fish (Cresson et al., 2019), are fully operational. In addition, this result is coherent with Syc & Szedlmayer (2012), who found that the older the AR, the larger and older are its red snappers [*Lutjanus campechanus* (Poey, 1860)].

The second significant ecological effect expected is habitat segregation of taxa according to AR type. Globally, diversity varies with the complexity of the AR structure (Moura et al., 2007). These variations occur in such a predictable way that these parameters have become the main factors influencing the design of ARs (Baine, 2001). In our BW observations, the larger and more complex the ARs (BASKET, FAKIR and ROCKS types), the richer they are. Likewise, the smaller and less complex ARs (CUBES, MAZE and ROPES) generally exhibit lower taxonomic richness. This global tendency has been confirmed by previous scientific monitoring of fish (Le Diréach et al., 2015). Given this general assumption, fish distribution with regard to spatial classification (Fig. 8) allows us to describe the effect of habitat variations between AR types. First, the ROCKS type, which is composed of a chaotic assemblage of rocky blocks of different sizes

that are spread over a sea bed area of 100 m<sup>2</sup>, is large enough to attract mobile species such as *B. boops* and *S. maena*. This AR type also offers numerous shelters of different sizes and provides the obscurity favorable to sciaphilous species such as the small *A. imberbis* or the larger *P. phycis*. More than for any other type of AR, ROCKS assemblages create a sizeable interface with the surrounding sandy substrate where *M. surmuletus* finds its food. At the opposite end of the factorial map (Fig. 8) is the ROPES type, which is made up of a 6 m per side concrete frame topped by a web of buoy-supported polypropylene ropes. ROPES assemblages are poorly inhabited by fishes, and at best, attract only the most common taxa (*C. julis* and *S. cabrilla*). This situation can be explained by the fact that after being immersed for a few years, these ARs collapse under their own weight due to fouling and compression of their buoys. The initial design of 7 m height, which was intended to mimic large algae forests and attract both the juveniles of many species as well as schools of open water fishes, has not resisted over time. In the middle of the taxa richness gradient, the small CUBES type with a surface area of less than 2 m<sup>2</sup> provides sufficient cavities to host diurnal crypto-benthic fishes (Cat. 6a) such as *P. rouxi*, *T. delaisi* and *G. vittatus*. The very similar but larger MAZE type (8 m<sup>2</sup> surface area) appears to be less successful than CUBES, probably because of the absence of oyster shell bags which have a pantry function for small fishes, and also because MAZE structures have a large and inaccessible interior cavity which is difficult to sample. The FAKIR type is clearly richer than both the CUBES and MAZE types due to its 25 m<sup>2</sup> surface area, its 3.25 m height, and its numerous cavities. The FAKIR type manages to attract both sedentary open-water fishes (Cat. 2) such as *C. chromis* and also the necto-benthic fishes that make medium-sized vertical displacements (Cat. 3) such as *D. sargus*, *D. vulgaris*, *D. annularis* and *D. puntazzo*. Finally, the BASKET type is globally the richest of the different types of AR. Its large size (15 m<sup>2</sup> surface area and 3 m height) and diversified habitats (oyster shell bags, breeze blocks held together by an iron beam) render these structures attractive to all the categories of fishes.

Colonization of ARs and habitat segregation between AR types is clearly visible in BW taxonomic observations. The identification level of fishes by volunteer divers is sufficient to explain these two main

ecological processes and to show that the AR design has globally reached its targets. Finally, observations made by recreational divers regarding the efficiency of the ROCKS, BASKETS and FAKIR types and the inefficiency of the ROPES type of AR in terms of taxa diversity are congruent with scientific monitoring (Astruch et al., 2016).

#### Uses and recommendations

Our results surpass the simple measurement of biodiversity and show that BW observations clearly reflect a) the colonization process in time and b) habitat segregation between AR types in space, despite the high variability of sampling between years. The fish observations are detailed enough to allow the assessment of the efficiency of the different ARs. In addition, the BW project is the first to record the presence of rare and emblematic species such as *Homarus gammarus* L. or *Sciaena umbra* L. thanks to the diversity of ARs visited. To improve efficiency, the observation design of scientific studies tends to focus on a limited number of ARs. It is noteworthy that the BW program is the only program to have conducted a systematic survey of the 400 ARs. It also provides access to an extensive reporting of fishing gear (mostly lost nets and entangled lines inventoried at the beginning of the survey) and enables to follow the evolution of the AR structures (collapse of ROPES, compression of buoys, displacement of a small number of CUBES).

As underlined by Garcia-Soto et al. (2017), marine CS projects need more serious collaboration with scientists than other CS projects do. This issue is illustrated by our BW study which suffered from the absence of direct implication of scientists during the data collection frame design phase at the beginning of monitoring, leading to the loss of the entire 2009 year. We can affirm that the minimum taxonomic knowledge necessary for acceptable description of marine flora and fauna is attained by SCUBA divers trained to level bio 2 by the regional UEBC of the FFESSM. The overlap of these descriptions varies from one family to another, but in the context of the ARs of Prado Bay, once more than 50 ARs have been sampled, the bio 2 diver observations exceed at least 50% of total taxa detection in all families except crustaceans (Table 3). As opposed to fishes (Santos et al., 2002), crustaceans are better sampled at night (Triay-Portella et al., 2018) and require more night dive sampling sessions for

correct assessment. With the cost reductions associated with digital technology, photography and video now play a key role in CS, not only for training (e.g., AIER) but also for the validation and traceability of data. A mean number of 4,000 photographs and 35 videos have been archived every year since 2014. They are utilized only once to fill the data frame but the use of annotation software would be of great interest for future treatment (Gomes-Pereira et al., 2016).

The difficulty of obtaining abundance data for fishes from untrained volunteers has long been identified (Harmelin-Vivien et al., 1985) and more recently, other authors have found that the same is true for other marine coastal organisms (Foster-Smith & Evans, 2003). Unsurprisingly, the observations collected by BW show an irregular variation of the three abundance classes (low, medium, high) used for all organisms. For future monitoring, we strongly recommend strict supervision of abundance data acquisition with different calibration methods, depending on whether the organisms are countable or not and if they develop on a hard surface or not.

The variation of observations from one diver to another should also be considered (Bernard et al., 2013), but this information is not available because data for one sampled AR are the compilation of 2 or 3 divers' observations. When two or three groups of divers sample a given AR at the same time, the mean Jaccard distance between their observations for the given AR type is always superior or equal to 0.5, which means that variation exceeds 50% within the collected data. To control this substantial bias, we recommend limiting the proportion of novice divers and systematic pairing of beginners with experienced divers.

#### Conclusion and perspectives

The BW CS program illustrates that the transition from species identification to local observations is now totally feasible for marine biodiversity surveys in association with the FFESSM and the PACA UEBC. After correction by specialists of a small number of minor errors, the taxonomic descriptions produced by SCUBA divers with bio 2 level certification are sufficiently accurate to enable detailed surveying of the main ecological processes that ARs are expected to



undergo. In the future, if properly validated by specialists, such volunteer data (at present collected by the BioObs program) will be comparable with other sources, in particular, with data collected by professional scientists. These data will then allow CS to contribute significantly to marine biodiversity surveys, as is already the case for many taxa of terrestrial ecosystems. With the multiplication of CS initiatives, the most challenging for naturalist divers will then be to choose a program with which to affiliate: this is a complex choice which may justify the creation of professional intermediaries toward divers, as suggested by Lucrezi et al. (2018).

The comparison with the BioObs and DORIS programs has shown that the ambitious objective of making an extensive description of flora and fauna has not been reached. The sampling procedure and observation design were not always convenient for a total biodiversity assessment (inappropriate data collecting frame in 2009, too few ARs sampled in 2013, crustaceans under-sampled prior to the night dive). The meteorological adversity in winter as well as the occasional lack of available volunteers hampered compliance with the provisional schedule, with the result that measurement of the seasonal effect was not possible. Similarly, due to the lack of AR sampled replicates, geographical comparisons between villages and links in the AR field, along with distinctions between the northern and the southern part of the studied area, were also unattained. The poor taxonomic descriptions for certain taxonomic groups may be the result of identification difficulties in the field (e.g., sponges) due to lack of specialists (Rodman & Cody, 2003). Sampling bias (e.g., crustaceans) and specialization of divers on peculiar taxonomic groups (e.g., fishes, nudibranchs) are two sources of variability which may be better investigated in the future with bigger datasets from diver observation-based marine CS programs.

Nevertheless, the success of the BW program rests upon the very prominent AR project in Prado Bay, Marseille, and is the starting point for several virtuous circles. First, allowing volunteers to access an otherwise unauthorized dive site is gratifying and stimulates their involvement. Second, permitting volunteers' access to these areas can be beneficial to authorities and may palliate opposition by the local population to diving prohibition in these areas. Finally, as underlined by Weng (2015), such

restoration projects are good opportunities for knowledge-sharing between professional practitioners and volunteers. For example, the putative role of ARs as fish nurseries was revealed by the evolution of the proportion of small fishes (Fig. 7), and came as a surprise since most nursery zones are not thought to occur at depths of 25–30 m (Cheminée et al., 2017; Mercader et al., 2018). The role that these relatively deep coastal zones may play needs to be addressed by further research.

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