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Can citizen science contribute to the evidence-base that underpins marine policy?

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ABSTRACT

Marine legislation is becoming ever more complex, so new cost-effective ways of obtaining and processing increasingly large data sets are required to support evidence-based policy making. Citizen science is one solution, but the uptake of the evidence generated by citizens among policy makers is often limited. Here, the importance of citizen science in delivery of the evidence-base that underpins marine policy was assessed using a series of case-studies. There was no consistent rationale for developing policy-relevant citizen science, but drivers included: lack of existing data, difficulty in collecting data by other means, the use of citizen science data by other organisations, and the capabilities of volunteers. Challenges to the uptake of marine citizen science were identified from policy-maker, scientist and citizen perspectives, and these related to data quality, data access, motivation of volunteers, and physical location. Citizen science has good potential to contribute to the evidence-base alongside traditional monitoring, remote sensing, and modelling, but only if outputs from citizen science projects are judged individually on quality. If this is the case, citizen science has an important role in delivery and understanding of future marine policy, but is only one part of an integrated solution.

1. Introduction

Marine legislation is becoming ever more complex [1] with increasingly large data sets required to support evidence-based policy making. European legislation, including the European Marine Strategy Framework Directive [2] and Common Fisheries Policy [3], aim to assess of impacts on whole ecosystems over long periods of time. For example, many years of data collected over wide geographical areas are required to assess the impact of different pressures (e.g. noise, litter, fishing) on ecosystem health for the European Marine Strategy Framework Directive [2]. As a result, the funding needed to support evidence gathering and monitoring that underpins marine legislation is considerable, but is generally limited. Hence, it is important to look at new cost-effective ways of obtaining and processing data to underpin the marine evidence-base. One increasingly common solution is to use citizen science [4], which is defined for the purpose of this paper as: “volunteers with no formal training in science collecting, categorizing, transcribing, or analysing scientific data” (following [5,6]).

Citizen science is not a new idea; volunteers and non-scientists have recorded scientific information for centuries [5]. Volunteer involvement in bird surveys are probably some of the earliest citizen science programmes, for example, the Christmas Bird Count of the National Audubon Society started in 1900 [7]. Volunteer bird surveys still represent some of the most successful examples of citizen science programmes and have been used to look at many important ecological impacts including pollution [8], climate change [9,10], and phenology [11]. The use of new technologies such as smartphone apps and the internet have broadened the scope of citizen science by making it possible to engage volunteers regardless of their physical location [12]. For example, the online platform *Zooniverse* enlists volunteers to identify whale song from sound recordings; plankton species from microscope images; and changes in kelp forests from satellite images [13]. This enables marine ecologists to process far higher volumes of data than would previously have been possible, and provides an opportunity to expand the scope of marine citizen science projects.

There are many different types of environmental citizen science project. The majority are ‘contributory’ projects, meaning they are designed by scientists, but enlist the help of volunteers to collect monitoring data (e.g. invasive species or litter sightings). However, other types of project, such as participatory mapping, equip local communities with the tools and expertise to collect evidence with

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which to lobby for local or national policy change, or have the simple goal of engaging the public with the environment [14]. Despite the fact that citizen science can represent a way of reducing costs when compared to data collection by professional scientists, citizen science still needs to be funded. The average cost of a policy-relevant citizen science monitoring project in the UK is estimated to be between £75,000 and £150,000 [15]. However, the cost will vary due the level of engagement required by volunteers and professional scientists, as projects can be contributory (designed by scientists with volunteers contributing data), collaborative (designed by scientists; volunteers contribute data, refine project design, analyse data or disseminate findings), or co-created (scientists and volunteers collaborate throughout all stages of the scientific process) [16].

There are many motivations for citizen science projects, but in the policy context value relates to three key benefits: delivery of evidence, provision of resource, and reputation (Fig. 1). Volunteers can provide reliable and novel evidence that could not have been collected by scientists alone [4]. For example 1 million people have contributed to the *Zooniverse*, and 146,000 biodiversity monitoring days were compiled within EUMON, a European biodiversity monitoring initiative [17]. In fact, the value of volunteer monitoring of the environment was valued at around £50 million in the UK in 2011 [18] and the contribution of volunteers in France to delivery of the Convention on Biological Diversity alone was estimated at between €0.67 and €4.41 million in 2010 [19]. Public participation also benefits the reputation of a project, by engaging, educating, and empowering communities [20,21], improving data quality through local knowledge [22], and helping to ensure that management strategies have community support [22,23]. Access to data has traditionally been difficult, but now data from multiple projects are being collated and made freely available through open access portals like eye-on-earth [24] and National Biodiversity Network Gateway [25].

Understanding the link between scientific evidence and decision-making for policy setting or management is challenging (see for example [26–29] and references therein), as policy development is not a linear process with complex connections between scientific evidence and policy decisions (e.g. [30]). The role of science in policy making has changed over time and it is likely that social science will become more important in future decision-making [31,32]. Knowledge derived from citizen science and traditional knowledge can be difficult to incorporate [33,34], so holistic interdisciplinary approaches are needed [35]. In fact, the coproduction of knowledge by technical experts and members of the public is likely to be very important in the future of decision making [36] and can help to develop trust [37]. The traditional role of scientists as “truth speakers” is changing as the uncertainties and limitations of evidence become more apparent [38] with post-normal science being developed to address these challenges [39], but new methods to improve the overall process are still required [40]. Citizen science encourages engagement between members of the public and decision-makers and may help to enhance the debate around the science-policy interface [41].

The value of citizen science has been widely recognised by national government (e.g. the Scottish Government [42]), international bodies (e.g. European Environment Agency [43]) and funding agencies (e.g. European Union Horizons 2020 “Science with and for Society” programme). A white paper has been developed on the future of European citizen science [44] and the United Nations Environment Programme has stated that citizen science is an essential means of achieving sustainability [45]. A recent review of UK citizen science estimated that 37% of case-studies informed policy, but this is based on a sample size of 35 mainly large-scale contributory projects [15]. Much of the uptake of citizen science data to underpin research and policy-making has been in the terrestrial environment, with only 14% of citizen science projects included in the aforementioned review based on marine systems [15]. An estimated 29.8% or 14 million UK adults engage in marine recreational activities [46], representing a huge potential resource for marine citizen science. Hence, there is an opportunity for marine scientists to make further use of citizen science [47] and a need to understand how best to use citizen science to deliver policy-relevant marine evidence [15].

In this study, the importance of citizen science as a means of delivering the evidence-base that underpins marine policy and regulation is assessed. The breadth of marine citizen science projects is outlined and examples of the types of project that have contributed to the marine evidence-base are identified. In addition, barriers to the uptake of marine citizen science by policy makers are assessed and complementary ways to deliver the evidence-base that underpins marine policy are considered.

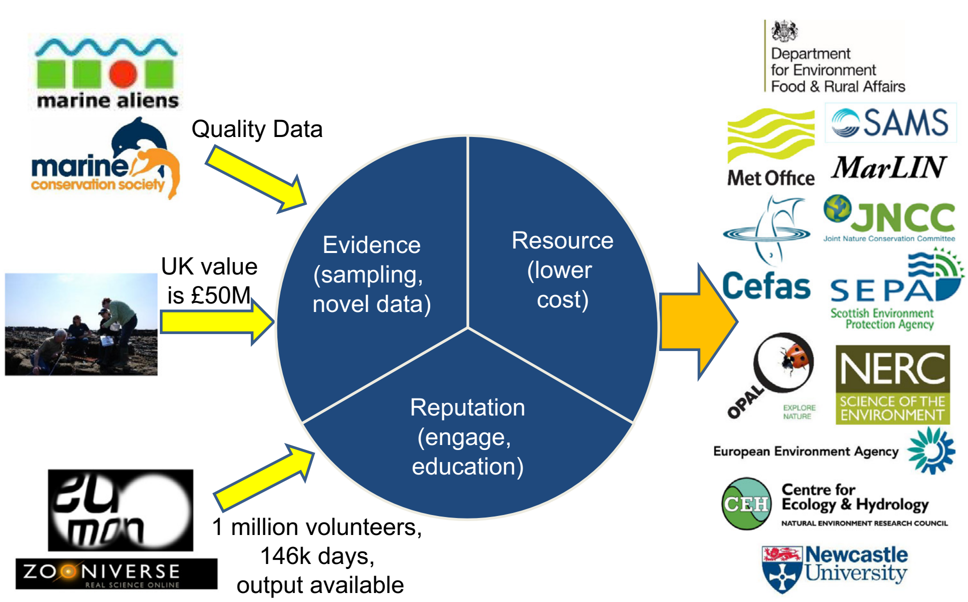

Fig. 1. Why should policy-makers be interested in citizen science?

2. Methods and approach

In July 2014, marine citizen science projects were identified using searches of scientific literature and internet searches. Literature searches of the bibliographic databases Scopus and ISI Web of Science were performed using the search terms "citizen science" and "volunteer". Duplicates were identified and removed, leaving around 400 references. Internet searches were conducted on Google (https://www.google.co.uk) using the same search terms to identify web-based citizen science projects and relevant 'umbrella' websites hosting environmental citizen science projects including Citizen Science Central and the *Zooniverse* were explored. Finally, Smartphone apps were identified through searches of GooglePlay (https://play.google.com/store) and the Apple AppStore. This output was used to identify examples of marine citizen science for further analysis.

Two significant systematic reviews of citizen science were also identified that utilised the similar search terms in the academic literature database ISI Web of Science and were mined for information specifically about marine citizen science projects [15,48]. The first review, Roy et al. [15], conducted a semi-structured systematic review of all citizen science projects using internet searches, following internet links on the top one hundred webpages, and catalogues of projects, leading to identification and collection of attributes on 244 projects (see Appendix 1 of [15] for a full description). Thirty UK case-studies were analysed in greater depth including a self-assessment of policy impact, but only three of these were marine [15]. The second review, Thiel et al. [48], collated marine citizen science publications in books and journals identifying 227 publications that had a reference to contributions to data by citizens, but excluded projects that only reported through a website. It is likely that more publications exist that were not identified and there is a bias towards scientist-led projects. However, this review was viewed to be sufficiently representative to provide an overview of the contribution of marine citizen science [48].

In order to understand the potential utility of citizen science in the delivery of policy relevant marine evidence, it was first necessary to divide up the policy landscape. Due to the complexity of the policy landscape (see e.g. [1]) there are many different possible categorisations. Here, policy was split into four broad themes: biodiversity, physical environment, resource management, and pollution (Table 1). Each policy theme was further divided into key areas. For example, biodiversity covered species distributions and abundance, invasive non-native species, and rare or endangered species (Table 1). The occurrence of marine citizen science projects that contribute to the evidence-base that underpins policy development was already available from an existing review [48], so the categories identified were mapped to the policy areas to give an overview of the potential of marine citizen science. A further categorisation based on the expert judgement of existing projects was also made by the authors and compared to the overall categorisation from the existing review [48].

Whilst citizen science can provide insight and evidence that informs policy, it was difficult to demonstrate a causal link between citizen science and policy-making. This was because policy-making is normative and reflects societal values, alongside the evidence-base [49]. As a result, examples of citizen science projects were selected here to demonstrate a connection to a particular policy goal through a contribution to the evidence-base across a broad range of policy themes and countries. This is not intended to be an exhaustive list of the policy impact of citizen science, rather to provide a set of useful examples of citizen science that have contributed to the evidence-base. A set of common themes were identified from these studies to illustrate how citizen science studies can have impact and make a contribution. The barriers to uptake of citizen science from the perspectives of policy-makers, citizens, and scientists were collected and synthesised from existing studies alongside discussions with policy-makers and scientists. These barriers are discussed in the context of evidence from existing citizen science projects.

3. Results and discussion

3.1. Marine citizen science

There are a number of existing reviews of citizen science including marine citizen science (e.g. see [48]) that discuss projects with different objectives and engage with anyone from school children to amateur experts [15,48]. There are many marine citizen science projects that cover topics including turtles [50],

Table 1
Key policy areas in marine science. Number of publications derived from Thiel et al. [48]. Frequency relates to the abundance of marine citizen science programmes in these areas categorised as high, medium and low using expert judgement by the authors.

Policy theme	Areas covered	Publications [48]	Frequency (expert judgement)
Biodiversity	• Changes in numbers, types and distributions of species	75	High
	• Rare, protected, and endangered species	Included in 75 above	High
	• Invasive and non-native species	6	Medium
	• Marine protected areas (MPAs)	9	Medium
Physical environment	• Habitats and seafloor integrity	Not classified	Medium
	• Prevailing hydrodynamic conditions	2	Low
	• Environmental change impacts, adaptation, and mitigation	Not classified	Medium
Resource management	• Exploitation of resources including fisheries, oil, gas, and aggregates	32	Medium
	• Marine spatial planning including renewable energy, and biofuels		Medium
	• Food production, safety and security		Low
Pollution	• Litter	16	High
	• Chemicals and heavy metals	Others-5	Low
	• Spills and emergency response		Medium
	• Eutrophication		Low
	• Noise		Low
	• Light		Low

sharks [51], rays [52], dolphins [53], seabirds [54], fish [55,56], crabs [57] sponges [58], coral [59], plankton [60], seagrass [61,62], rocky reefs [63,64], coral reefs [65,66], invasive species [67], subtidal habitats [68], fisheries [69], nutrients [70], pollution [21], litter [71,72], oceanographic data [73], marine protected areas [74], beach profiling [75], and coastal protection [76].

The number of citizen science projects [15] and the numbers of publications including volunteer data in the marine field have increased rapidly over the past 30 years (see Fig. 1 of [48]). There has also been a diversification to include internet-based marine citizen science and sensors on mobile devices [12]. Marine citizen science projects are often focused on the coastal zone and generally found in North America, Europe, and the Indo-Pacific [48]. They are generally in-depth local and simple mass participation projects, with very few in-depth mass participation projects in the marine arena [15].

3.2. Delivering policy-relevant marine evidence using citizen science?

The occurrence of marine citizen science projects was mapped to potential policy areas using studies from an existing review [48], literature searches, and web queries. This provided an indicator of the ease of carrying out citizen science projects and the attractiveness to volunteers. For example, there are many marine citizen science studies that deliver species distributions as a presence-absence measurement that involve simple protocols that do not require much volunteer time and can be validated with photographs. Many projects are focussed on biodiversity monitoring or pollution caused by marine litter (Table 1), but fewer exist in the areas of resource management and characterising the physical environment. The attractiveness to volunteers is often related to the species that are being assessed, for example many citizen science projects focus on charismatic species including sharks and whales, or on birds where there are well trained enthusiasts that can easily be mobilised.

Some examples of citizen science that contribute to the policy evidence-base have been identified (Table 2), but there are many other good examples that are not discussed here. These studies that have been selected illustrate key points about the types of citizen science that can be used. There is no consistent rationale for developing policy relevant citizen science, but the main drivers appear to be a lack of existing data, difficulty in collecting data by other means, the use of citizen science by other similar organisations, and the fact that sites are in areas that are commonly visited by amateur experts.

The OSPAR beach litter project [71,77] was set up to fill an evidence gap on the amount of marine litter in the environment and how it changes over time, and similar surveys are routinely used across the world (e.g. United Nations Environment Programme, Marine Strategy Framework Directive [2], and Regional Seas Conventions). The citizen science project 'Send us your skeletons' collects data on catches of recreational fishers to provide fishery-dependent data on the stock structure [78]. The remoteness and size of the areas targeted by recreational fishers in Western Australia make the collection of data using fishery-independent techniques prohibitively expensive, so a programme that uses the skeletons of recreationally caught fish offers a reasonable and cost-effective way of obtaining lengths and ages for use in the stock assessment and management of important recreational species.

Citizen scientists offer a valuable resource in the wide-scale monitoring of rare, non-native, or patchily distributed species, and the data collected are commonly used as part of the evidence-base of species ranges. Good examples of this include the monitoring of cetaceans by the Sea Watch Foundation used to underpin the UK Biodiversity Action Plan [79], and the Marine Invader Tracking and Information System that provides a portal that collates information on non-native species distributions in the Northeast US [80]. The Billfish Foundation is based in Florida and works with anglers worldwide to tag billfish in order to collect data on species distributions and movement that can be used in stock assessments [81]. Mapping of habitats and pollution events provide examples of where data can only be collected at the scales required using citizen science, and probably represent the most commonly used form of citizen science. Good examples mapping impacts of oils spills in the Gulf of Mexico [82], tributyl tin concentrations in dogwhelks [21], seagrass distributions provided by Seagrass Watch [62], wetland bird distributions and abundance by the Wetland Bird Survey [54], marine protected areas provided by divers in Seasearch [68] and reefs by the Earth Watch Institute [65].

Another area that is gaining interest among policy makers is the 'passive' collection of data by users of the marine environment using simple sensors. A good example is the collation of temperature data from scuba diver dive computers [83] which can subsequently be used to fill existing data gaps for temperature profiles in the inshore areas. The incorporation of sensors such as accelerometers and GPS trackers within mobile devices and the development of new low-cost DIY sensors as peripheral devices is an area that has the potential to grow significantly over the coming years. This is attractive to policy makers as the quality of the data can easily be understood through simple calibration exercises.

3.3. Challenges to the uptake of marine citizen science

Our examples demonstrate that citizen science can contribute to the provision of the evidence-base that underpins policy. However, it is entirely appropriate that not all citizen science projects produce policy-relevant marine evidence, because there are many other motivations for citizen science programmes (e.g. engagement with the marine environment, education etc.) [48], and citizen science works better in some areas than others (reflected by the frequency in Table 1). Only 14% of marine projects deliver policy relevant evidence in comparison with 37% of all citizen science projects generally [15]. In this section, the challenges for uptake of marine citizen science are identified and how these might be overcome discussed.

There are a number of potential reasons for the comparatively low uptake of evidence from marine citizen science projects. These include differences in the types of project being done in the marine arena (e.g. in-depth local and simple mass participation projects, with very few in-depth mass participation projects [5]), challenges inherent in working in the marine environment, and a lack of familiarity with marine citizen science among the public. As the barriers to the uptake of marine citizen science vary between user communities, they are discussed below in relation to policy makers, scientists, and citizens (Table 3).

The main challenges to the uptake of citizen science from a policy perspective relate to the quality of the data in terms of accuracy and precision, spatial and temporal resolution, robustness, documentation, and access (see e.g. [44,48]). It is a common perception that data collected by citizens are in some way lower quality than scientist-led data sets, so should only be used where no other data exist (e.g. marine litter [77] or in the designation of MCZs [68]). Studies have shown that volunteers and professional scientists can yield very similar results (e.g. [67,84–86]), but that the level of agreement varies with training, guidance, and experience (e.g. [64,84,87–89]). Interestingly, in many of the comparisons between volunteers and scientists, no account was taken of variation among scientists (e.g. [84]). From the perspective of a policy maker, it is vital that any data used to underpin the evidence-base are robust as they may be subject to legal challenge. To maximise the utility of citizen science and the uptake by policy makers it is

Table 2
Examples of citizen science projects that provide evidence that underpins each of the key policy areas identified in Table 1 (some examples may cover more than one policy area).

Policy	Area	Project	Policy impact
Biodiversity	Species distribution	Seagrass-Watch [98]	Seagrass-Watch is a seagrass assessment and monitoring programme that started in 1998 in Australia and now monitoring approximately 259 sites across 17 countries. Outputs are used by the South-East Queensland Healthy Waterways Partnership supplementing water quality data in their Ecosystem Health Monitoring Program [62]
	Species distribution	Wetland Bird Survey (WeBs) [99]	WeBs uses volunteers to monitor non-breeding waterbirds in the UK providing information on population sizes, trends and distributions. WeBS outputs are used to satisfy the UK's monitoring obligations under the Bonn Convention on the Conservation of Migratory Species of Wild Animals, and provided evidence for protected areas and environmental impact assessments [54]
	Non-native species	Marine Invader Tracking and Information System (MITIS) [80]	MITIS is a web-based data service intended to support marine introduced species monitoring in the Northeast United States. It hosts data collected as part of government-funded scientific survey initiatives and volunteer monitoring programs. Species sightings may be reported directly to the database via online forms. This initiative enables reporting under the US National Invasive Species Act (NISA)
	Rare, protected, and endangered species	Sea Watch Foundation [79]	The Sea Watch Foundation uses volunteer to monitor the distribution and abundance of cetaceans in the UK. The data have been used to provide information to government, non-governmental, industry, commerce, and recreational organisations. It has been used in support of the UK Biodiversity Action Plan for Cetaceans and Environmental Impact Assessments
	Marine protected areas	Seasearch [100]	Seasearch gathers information on seabed habitats and associated marine wildlife in Britain and Ireland through the participation of volunteer recreational scuba divers. Since 1981 reports have been produced around the UK with around 51,000 species records in 2013. These surveys are used by many government bodies and have been important in support of Marine Conservation Zones and identifying priority species for conservation [68]
Physical environment	Environmental change.	EarthWatch Institute [101]	The EarthWatch institute has many projects that involve volunteers in monitoring biological systems including coral reefs in Jamaica. Data from 2000–2008 were used to inform a conservation action plan submitted to the Jamaican National Environmental Protection Agency [65]
	Prevailing conditions	Dive into Science [83]	Dive into science is an online citizen science programme that collates temperature data from scuba divers computers. Temperature profiles are sparse in inshore areas, so the data will be used alongside traditional temperature data to inform ocean models and the impacts of climate change
	Habitats and seafloor integrity	Coastwatch	Coastwatch was a project that started in the UK in 2000 to engage volunteers in coastal zone management [76]. Volunteers in Portugal have been collecting beach profiles that produce robust data and are important for coastal management decisions [75]
Resource management	Fisheries	Send us your skeletons [102]	Lack of data on recreational fisheries in Western Australia lead to restrictive management of stocks. Send us your skeletons is fishery-dependent monitoring programme, where recreational fishers donate skeletons of filleted fish that can be used to collect size and age distributions of demersal fish. This provides data for stock assessments, so that reliable and timely scientific advice can be provided to fishery managers [78]
	Fisheries	Billfish Foundation Tagging [81]	The Billfish Foundation has been working with anglers and captains around the globe to tag and release billfish since 1990, and have a database that contains over 200,000 records. The data gathered help to understand growth rates, migratory patterns, habitat utilization, and post-release survival rates. They also provide data on the socio-economic value of the recreational billfish fishery. These data have been used in stock assessments and management of Atlantic and Pacific billfish
Pollution	Chemical	Tributyl tin contamination in the North Sea	Volunteer collected data on imposex in dogwhelks was used to assess recovery of populations and inform the debate on the use of TBT antifouling paints on boats [21]
	Oil spill	Impacts of the oil spill in the Gulf of Mexico	A number of projects have been set up to track the distribution and impact of oil released by the Macondo platform. A number of web-based systems have been set up to monitor impacts including OilReporter and the Mobile Gulf Observatory. Crowdsourcing was also used for real time assessments of health-related exposures [82]
	Marine Litter	OSPAR Beach Litter	OSPAR has monitored the levels of beach litter since 1998 using a voluntary monitoring programme [77] with guidance on protocols for the collection of beach litter [71]. There are less data on floating and seabed litter, but the data that exist are compiled by volunteers from the fishing community under the Fishing for Litter initiative. Volunteers have also contributed to the stomach contents of birds through the beach bird survey, where volunteers collect fulmar corpses for assessment of the levels of plastic [72]. These data have been used to assess the trends in litter for the Regional Sea Conventions, MSFD [2], and the United Nations Environmental Programme. Similar programmes also exist in the US

Table 3
Challenges to the uptake of citizen science to inform policy from a policy, science and, citizen perspective.

Policy	Science	Citizens
• Data accuracy and precision	• Scientific objectivity	• Reticence to get involved in collecting data to support policy
• Spatiotemporal scale of observations	• Engagement with volunteers	• Enjoyment and payback for involvement
• Robust and repeatable protocols	• Robust and repeatable protocols	• Ease of engagement
• Quality of documentation	• Access to data	• Limited interactions with the marine environment
• Access to data	• Other existing datasets	
• Other existing datasets	• Demonstrating benefits of projects	

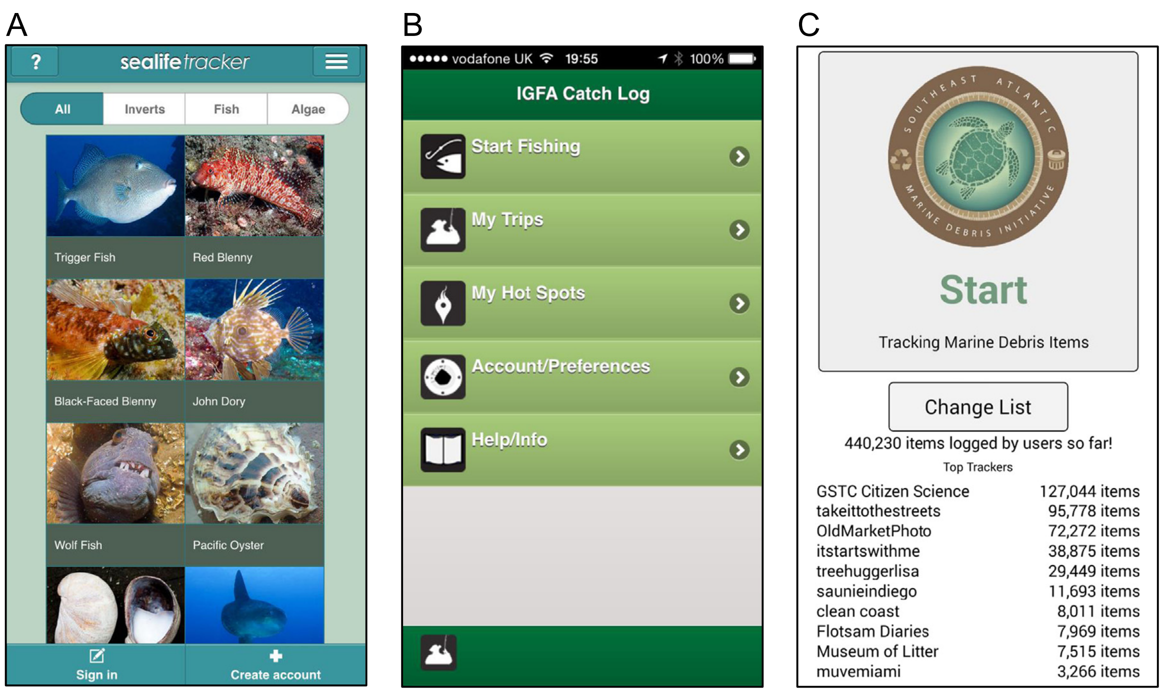

Fig. 2 Smartphone apps for data collection. A. sealife tracker, B. IGFA Catch Log, and C. Marine Debris Tracker (see text for links to websites).

important to provide appropriate and robust quality assurance measures throughout the data collection process. Such measures should include validation (robust processes for preventing data entry errors), verification (for example, the use of photographs or checks by experts to judge the reliability of the reported observation), and account for observer error [90]. Transparency can also be improved by making the data and associated metadata freely accessible online (e.g. National Biodiversity Network Gateway [25]). Such quality assurance methods are routinely provided for traditional data used for regulatory processes (e.g. fish stock assessment) and access is simple, so similar quality statements and access should be provided for citizen collected data. This will allow the selection of evidence used to underpin policy to be based on an assessment of data quality and availability rather than the method used to collect it [6].

Many of the challenges for scientists are similar to those for policy makers, and so the same arguments are applicable. One of the key issues is the acceptance of citizen science, by the academic community [84]. However, this is beginning to change as researchers recognise the huge potential that citizen science has in generating data at appropriate scales to address large scale environmental issues [4], the variety of research that can be conducted by citizen scientists [15], and the large number of organisations that support citizen science (e.g. European Commission [44], European Environment Agency [43]). As such, the number of peer-reviewed papers continues to increase rapidly with over 400 publications identified for this study.

Some citizen scientists have reservations about collecting data for policy [15]. It is important to understand the motivations of volunteers to avoid tensions between personal and project objectives [15]. These motivations are described in detail in a number of publications [48,91], but are vitally important in the development of a successful citizen science project and may not match with the types of studies that are likely to impact on policy.

Ease of engagement is an important factor for maintaining the input of citizen scientists. The advent of the internet is making the collection and uploading of data much more straightforward. Many projects now have an option for citizen scientists to use internet-based technologies, with a proliferation of Smartphone apps being launched for marine citizen science. These are generally aimed at collation of data, for example non-native species (e.g. sealife tracker - http://www.brc.ac.uk/sealife_tracker/), sea angling catches (e.g. IGFA Catch Log - http://www.igfacatchlog.org/), and marine litter (e.g. Marine Debris Tracker - http://www.marinedebris.engr.uga.edu/) (Fig. 2). Smartphone apps have simplified the data collection (e.g. location, images, data entry) and allow presentation of information in near real-time. However, there are development costs and the risk of alienating people without the necessary technologies [15]. Smartphone apps also need to be well designed and easy to use as they compete with all other apps from

Minecraft to Angry Birds for attention rather than solely with other citizen science projects.

The final challenge is the proximity of citizens to the coast and difficulties of accessing the marine environment. Participation in marine citizen science is therefore likely to be more limited than terrestrial. By 2020, it is projected that some 60% of the world population (about 6 billion) will live in coastal areas, but this leaves 40% of the populace with a much less direct link to marine environments, limiting the types of projects that can be undertaken easily. One potential solution is the advent of citizen cyberscience, allowing citizens interaction with the marine environment regardless of their location [6,12]. For example classifying the numbers and types of species observed in a set of images (e.g. Seafloor Explorer [92]) or in underwater video transects (e.g. [93]).

4. The role of citizen science in the delivery of future marine evidence

It is very unlikely that citizen science will ever replace traditional marine monitoring efforts as some tasks are not amenable to volunteers (e.g. specialist equipment required, inaccessible locations, frequency of reporting), but it is clear that citizen science can play a large and increasingly important supplemental role in future evidence provision, science, and monitoring [94]. The increasingly large spatial scales that are addressed by policy makers (e.g. regional, global) and the reduction of funding means that new methods are needed to provide the evidence-base. Citizen science is one method of addressing tasks that cannot easily be automated and providing data at scales that would not be possible using scientists alone.

Citizen science is one possible component of the solution for future evidence provision to underpin marine policy and management, but needs to be addressed as part of an integrated overall scheme. Remote sensing by satellites and sensors attached to platforms (e.g. floats, buoys, gliders, mammals, ships of opportunity) will also provide data at appropriate scales that add to the evidence-base. At present these are often limited to physical, chemical, and simple biological measurements (e.g. chlorophyll), but advances in technology and sensors will become increasingly important. Mathematical and statistical models may provide another component, but making robust predictions is a significant challenge in the biological domain. For example, ecosystem models have been developed that have helped with understanding of processes (e.g. sensitivity of environmental indicators to changes in pressures, nutrient transport), but are still a long way from delivering accurate ecosystem level predictions in real-time.

There are many challenges to the uptake and use of marine citizen science in underpinning policy, but it is a powerful technique that, if harnessed correctly, can add value to the evidence-base through the collection, entry, synthesis and analysis of large data sets that are difficult to obtain by any other means. There are many users of the marine environment, representing a huge potential resource for marine citizen science. As such citizen science should be an integral part of the solution for evidence provision as long as formal statements of data quality and accessibility are resolved, and selection of data for inclusion in the evidence-base is made on the basis of quality rather than simply the methodology. Marine citizen science has additional challenges of access in comparison to terrestrial studies, but internet-based citizen science should partly resolve these challenges.

Unlocking the potential of citizen science is a challenge, but this will be enhanced by the changing interface between science and policy, that include a broad range of stakeholders and different forms of knowledge in decision making [95–97]. Finally, the more that citizen science is used as part of the evidence-base, the more familiarity there will be with the methods, the more understanding of what is required, and the more projects will be set up with these goals in mind. To this end, more engagement between evidence collectors, policy makers and citizen scientists is needed to ensure that the potential benefits of marine citizen science in underpinning policy are fully realised [40].

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