African Journal of Marine Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tams20

South African marine citizen science – benefits, challenges and future directions

WM Potts, JB Mann-Lang, BQ Mann, CL Griffiths, CG Attwood, AD de Blocq, SH Elwen, R Nel, K Sink & R Thornycroft

African Journal of Marine Science 2021, 43(3): 1–14
Printed in South Africa — All rights reserved

This is the final version of the article that is published
ahead of the print and online issue

AFRICAN JOURNAL OF
MARINE SCIENCE
ISSN 1814-232X EISSN 1814-2338
https://doi.org/10.2989/1814232X.2021.1960890

Critical review

South African marine citizen science – benefits, challenges and future directions

WM Potts[1*], JB Mann-Lang[2], BQ Mann[2], CL Griffiths[3], CG Attwood[3], AD de Blocq[4], SH Elwen[5], R Nel[6], K Sink[7,8] and R Thornycroft[7]

[1] Department of Ichthyology and Fisheries Science, Rhodes University, Makhanda, South Africa
[2] South African Association for Marine Biological Research (SAAMBR), Durban, South Africa
[3] Department of Biological Sciences, University of Cape Town, Cape Town, South Africa
[4] BirdLife South Africa, Johannesburg, South Africa
[5] Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa, c/o Sea Search Research and Conservation, Muizenberg, Cape Town, South Africa
[6] Department of Zoology, Nelson Mandela University, Gqeberha (Port Elizabeth), South Africa
[7] South African National Biodiversity Institute (SANBI), Cape Town, South Africa
[8] Institute for Coastal and Marine Research, Nelson Mandela University, Gqeberha (Port Elizabeth), South Africa
** Corresponding author, e-mail: w.potts@ru.ac.za*

South Africa has a long history of engagement in citizen science (CS), particularly marine CS. This review examines the contributions made by marine CS, from the 1930s through to the current era, where websites, social media and mobile apps provide a wide range of opportunities. Largescale marine CS projects, such as the Oceanographic Research Institute's Cooperative Fish Tagging Project, have made enormous contributions to marine scientific research. Individual citizen scientists have also made considerable contributions, particularly in taxonomy and the publication of field guides. Marine CS has also contributed towards the popularisation of science and improved scientific literacy through the active engagement of many citizens. These benefits align well with the visions of policies that currently guide the South African marine research agenda. However, marine CS in the developing world is not without challenges, and practitioners should be cognisant of the time and effort required to initiate and maintain viable CS initiatives. Especially, long-term successful CS projects depend on secure, ongoing funding, institutional support and enthusiastic champions. Participation by almost exclusively the urban and middle-class sectors of society is also of concern. These challenges can be addressed through stakeholder-inclusive planning, development of novel methods that engage with broader sectors of society, and regular critical evaluations of CS projects. Where global projects on the intended taxa/subject of study already exist, it may also be preferable to enter into collaborative data-sharing agreements with these to reduce operational costs and avoid duplication.

Keywords: education, evaluation, history of marine science, public participation, public science, science communication

Introduction

Citizen science (CS) is normally defined as scientific activities that are supported by non-professional scientists who voluntarily participate in research activities as part of a scientific project (Cohn 2008), and it basically refers to the inclusion of members of the public in some aspect of scientific research (Eitzel et al. 2017). CS provides thousands of opportunities for citizens to participate in collection of scientific data across a diverse array of research fields throughout the world. Additionally, technological developments now facilitate virtual modes of contribution that enable engagement with very broad audiences (Wiggins and Crowston 2011; Hulbert et al. 2019).

The major scientific advantages of CS projects are that they allow researchers to cheaply collect large quantities of data across numerous habitats and broad geographic ranges and over extended time-periods (Bonney et al. 2009a). Some projects also enable scientists to collate information from extensive datasets by using assistance from the public. In addition to research benefits, CS projects can significantly contribute to public understanding of, and interest in, the natural world and the process of scientific investigation (Bonney et al. 2009b; Masters et al. 2016). In addition, when CS has contributed to policy or environmental regulatory changes, citizens are more likely to comply with these regulations (Vaughn and Harris 2014). CS also has the potential to foster engagement in environmental issues, through sharing information and undertaking pro-environmental behaviours (Dean et al. 2018).

While CS has clear advantages, it is not without detractors. Criticisms include the perception of reduced scientific rigour, including a lack of standardisation in data-collection methods (Silvertown 2009), lower levels of expertise and knowledge by contributors (Bonney et al. 2014), potential submission of false or even malicious data (Foster-Smith and Evans 2003), poor commitment by citizen data collectors (Galloway et al. 2006) and biases caused by non-reporting of zero data (Bear 2016).

Historically, CS research has primarily been undertaken within developed nations, with far fewer documented examples of successful CS projects in the developing world (Loos et al. 2015); however, in many coastal regions, community members work with researchers in the monitoring of fisheries, which could be considered a form of CS. South Africa is exceptional among developing nations in that it has a relatively long history and wide range of active CS projects. Hulbert (2016) summarised the CS tools available for ecological research in South Africa and concluded that there were many potential CS projects and opportunities for individuals who wanted to engage in CS. For example, the Animal Demography Unit at the University of Cape Town hosts almost 20 CS projects mapping the distributions of a wide range of organisms.

Globally, CS projects more often focus on terrestrial environments and their associated fauna and flora (Roy et al. 2012; Thiel et al. 2014) than on the marine environment (Cigliano and Ballard 2017). Cigliano et al. (2015) proposed several reasons for this, including logistical and access challenges and the relative expense of boats and specialised equipment (e.g. SCUBA diving gear) associated with working in the ocean. In addition, countries whose citizens rarely participate in marine recreational activities (often those in the developing world) are likely to lag behind those where swimming, diving and fishing are regular recreational activities. Despite these challenges, there are a host of South African marine CS (SAMCS) projects involving many participants and covering a range of taxa.

The purpose of this review is to provide an overview of SAMCS and make recommendations to improve current projects and stimulate the development of effective and inclusive new projects. We briefly review types of CS, then summarise SAMCS experiences, including a brief history and review of past and existing projects. We then assess the benefits of SAMCS projects, examine the challenges facing SAMCS, review their alignment with national policies and research strategies and identify opportunities in the current suite of projects. We conclude with recommendations for the development of marine CS projects in South Africa and other developing countries.

Types of citizen science (CS) projects

Haklay (2013) identified three types of CS: 'classic' CS, environmental management CS, and 'citizen cyberscience.' Classical CS projects normally rely on networks of observers who contribute to knowledge as part of their recreational activities. While this began with individuals bringing interesting materials, specimens, information or photographs to scientists, modern communication tools have since made the distribution and collation of such findings faster, easier and cheaper (Haklay 2013). Research areas that obtain the greatest value from classic CS usually operate over large geographic scales and utilise a large, often sparse network of observers to contribute to the science, often as part of hobbies such as photography or birdwatching. One of the best-known classic examples is the Audubon Christmas Bird Count (www.audubon.org/conservation/science/christmas-bird-count) which began on Christmas Day in 1900.

Environmental management CS often emerges out of necessity, where communities, in the face of environmental challenges, begin collecting environmental data to substantiate their assertions (Haklay 2013). In the South African context, perhaps the best example of environmental management CS is the miniSASS initiative, which uses community-collected data to quantify the health of South African river systems (see http://www.minisass.org) (Vallabh et al. 2016). While environmental health is generally the focus of these projects, their applicability to other issues, such as resource availability (e.g. fish population declines) for dependent communities, is evident.

Citizen cyberscience has developed on the back of rapid technological developments and the realisation by scientists that the public can assist and provide feedback, which in turn improves opportunities for outreach. When combined with the growing need to make science more accessible and relevant to the public, this has led to the development of numerous pioneering CS projects. These generally harness the power of personal computers in activities such as crowdsourcing (Howe 2006) or utilise the abilities of mobile telephones to operate as scientific instruments (Haklay 2013). Examples include the MyShake app, which uses seismic sensors on the smartphones of citizens around the world to provide data to support development of earthquake early warnings (Kong et al. 2016).

First applications of marine CS in South Africa

Anecdotal evidence suggests that, as early as the 1930s, the well-known ichthyologist JLB Smith of Rhodes University already had an extensive network of citizen scientists helping him collect fish specimens. Indeed, many of the museum curators of the time also reached out to the public for the collection of marine specimens (Summers 1975). JLB Smith's passion for fishing helped him relate to fishers, who corresponded with him on ichthyological matters and this led to the discovery of a living coelacanth (Smith 1956). These networks increased after publication of '*The sea fishes of southern Africa*' (Smith 1949). The popularity of that volume converted many South African anglers into citizen scientists, continuously on the watch for interesting fish specimens (Smith 1969). Perhaps the primary reason for the success of these early CS engagements was the dedication of JLB and Margaret Smith to public engagement; almost every contribution from a participant angler elicited a personal letter of gratitude including information about the find. As a result, countless fishes were described from specimens provided to the couple by interested members of the public (Smith and Heemstra 1986).

After the death of JLB Smith and the retirement of Margaret Smith, Phillip and Elaine Heemstra of the JLB Smith Institute of Ichthyology (later the South African Institute for Aquatic Biodiversity) took over the mantle of chief promotors of fish-related CS. Their passion for

SCUBA diving opened the door to a new network of citizen scientists. Through publication of numerous articles in diving magazines, the Heemstras quickly expanded the number of participants contributing to the discovery of new species along the coast of South Africa. The success of these contributions led to the development of the East Coast Fish Watch Project in 1998 (described below).

The following section reviews the most prominent historical and contemporary SAMCS projects. To be inclusive, a wide interpretation of the term 'citizen science' was applied. We identified 13 projects, including seven focused on fish, four on invertebrates, and one on marine mammals and seabirds, and details of their composition, extent, scientific value and websites are provided in Table 1. A brief appraisal of these 13 projects (in chronological order) is presented below.

Case studies of selected historical and existing South African marine citizen science (SAMCS) projects

Invertebrate catch statistics programme (1974–)

Recognising the need to monitor the large and diverse recreational invertebrate fishery in KwaZulu-Natal Province (KZN), a collaborative catch-reporting programme was launched in 1974 by the Oceanographic Research Institute (ORI), the Natal Parks Board (now Ezemvelo KwaZulu-Natal Wildlife [EKZNW]) and the Natal Fisheries Licensing Board. Initially, data from harvesters were collected via a system of annual catch returns, submitted through the licensing system. All the catch data were managed and analysed by ORI. Although susceptible to various biases and limitations, the data provided a reasonable indication of harvesting intensity where there was no other fishery monitoring.

To improve quality of the data, ORI implemented a comprehensive invertebrate catch statistics programme in 2002. Quarterly postal surveys were conducted with collectors, followed by telephone interviews with non-respondents. This approach improved the quality of catch data by reducing recall bias and by estimating non-response bias. The addition of an online survey, e-mails and bulk short messaging services (SMS) to contact potential survey participants has greatly increased survey reach and response rates. Ground-truthing of the questionnaire data by means of fishery independent patrols was initiated in 2017. The catch and effort data from this programme have proven invaluable in examining historical fishery trends (Steyn et al. 2019). Besides the catch statistics data that are applicable to resource management, the programme has involved harvesters in data collection and improved their understanding of the resources they use.

National Marine Linefish System (NMLS) recreational catch returns (1976–2016)

Based on the need to gather catch-and-effort data on the linefishery in South Africa, as well as the foresight of Rudy van der Elst from ORI, who recognised the desire among many anglers to assist in gathering data, seeing results and being part of research, the NMLS was introduced to collect long-term catch-and-effort data-series from recreational and commercial sectors of the linefishery to enable stock assessment and improved fishery management (van der Elst and Penney 1994). The CS component of the NMLS involved the collection of catch return cards from recreational anglers that were completed after each fishing outing. Cards were collected from popular fishing access points, primarily in KZN, and the information was validated and entered into a database. To ensure that feedback was provided to anglers, the data were regularly analysed and the results distributed annually via brochures and popular articles.

Initially, the system was remarkably successful, and data were used in over 100 publications (van der Elst and Penney 1994). However, as in many such CS projects, data validity was a problem because of the many biases in the information resulting from the way in which records were collected (Mann-Lang 1996). In addition, the use of the data to inform a suite of fisheries management regulations first introduced in 1984 (van der Elst and Garratt 1984) decreased angler trust in the system. Despite these challenges, for over 25 years the NMLS provided the most comprehensive data on recreational angling in KZN. To overcome the biases, an observer-based system conducted by trained EKZNW staff gradually replaced the catch cards in the late 1990s, and the involvement of anglers as citizen scientists was minimised (Kramer et al. 2017).

Marine protected area fish monitoring and tagging projects (MPA-FMTPs) (1983–)

There are five MPA-FMTPs: in the De Hoop MPA, Tsitsikamma National Park (TNP), Dwesa-Cwebe MPA, Pondoland MPA and iSimangaliso Wetland Park. These projects were initiated in 1983, 1998, 2009, 2006 and 2001, respectively, and all (except in the TNP) are ongoing. These projects have relied on more than 250 volunteers from the angling public to assist in monitoring and tagging fish (WMP, CGA and BQM pers. obs.) These volunteers are trained by experienced researchers during initial trips and effort is made to maintain consistency of the volunteer group to improve data precision and continuity. These projects have generated over 25 scientific publications (e.g. Attwood 2003, James et al. 2012, Mann et al. 2018) in addition to facilitating long-term monitoring in MPAs. The projects have had excellent exposure in the angling community, and some angling clubs and associations have actively supported the concept of MPAs partly because of positive feedback from their own members (BQM pers. obs.).

Oceanographic Research Institute – Cooperative Fish Tagging Project (ORI-CFTP) (1984–)

The aims of the ORI-CFTP are to: (i) develop, improve and maintain a nationwide marine linefish-tagging project with voluntary participation by anglers; (ii) provide a user-friendly scheme whereby anglers can play a meaningful role in contributing to the study of marine linefish; and (iii) ensure that the latest appropriate tagging and analysis techniques are applied to provide scientific data that can be used in biological studies and stock assessments (Dunlop et al. 2013).

Rudy van der Elst started the ORI-CFTP in 1984. While funding has come from various sources, the host institute, the South African Association for Marine Biological Research (SAAMBR), has always underwritten the project. A small, once-off membership fee entitles new members to a tagging kit and access to comprehensive training

Table 1: List of some existing and historical South African marine citizen science projects, with details on their composition, extent, scientific value and web address. Categories are as defined by Haklay (2013): CL = 'classic' citizen science; EM = 'environmental management' citizen science. Incentives: A = awards; E = economic benefit; O = other; P = prizes. NA = information not available

Project name	Year initiated	Geographic coverage	Taxonomic focus	Category	Numbers of permanent/contract staff	Registered participants	Training provided	No. of records	Postgrad students supported	Publications supported	Incentives	Communication with citizen scientists	Web address
Invertebrate catch statistics programme	1974	KwaZulu-Natal	Marine invertebrates	CL	2/0	NA	No	>1 million	>5	>20	P	Personal and popular articles	None
National Marine Linefish System (NMLS)	1976	South Africa, primarily KwaZulu-Natal	Linefish	CL	3/0	NA	No	>2 million	>10	>100	None	Brochures, popular articles	None
MPA fish monitoring and tagging projects	1983 onwards	South African MPAs	Linefish	CL	NA	250	Yes		>5	>25	O	Personal feedback	None
ORI-CFTP	1984	South Africa	Linefish	CL	1/1	6 000	Yes	335 779	>22	>83	A	Newsletters, interactive website, personal feedback	https://www.oritag.org.za
East Coast Fish Watch	1998	East coast of southern Africa	Fish	CL	0/0	NA	Yes	?	0	?	O	Newsletters	NA
Atlas of Seabirds at Sea (AS@S)	2009	South Africa	Seabirds	CL	0/0	66	?	16 056	0	0	O	Newsletters, interactive website	https://seabirds.saeon.ac.za
EchinoMAP Metadata	2012	Africa, mostly southern	Echinoderms	CL	0/0	69	No	1 927	3	6	O	Interactive website	None
SeaKeys	2014	South Africa	Marine species	CL	0/1	215		21 564				Newsletters, interactive website	http://seakeys.sanbi.org/search/node
ABALOBI app suite	2015	Western Cape	Linefish	CL, EM	?	275	Yes	?	0	0	E	Personal feedback	https://abalobi.org
CatchReport	2015	South Africa	Linefish	CL	0/1	?	No	90 000 (competition)	0		O	Interactive website	www.catchreport.co.za
Fishtory	2015	South Africa	Linefish	CL	0/1	107	No	4 045	0	1	P, A	Newsletters, interactive website	www.fishtory.co.za
Sea Search Sightings	2015	South Africa	Cetaceans	CL		*Ad hoc* reports			0		O	Interactive website	

material. There is no financial incentive for either tagging fish or returning recapture information. When a tagged fish is reported to ORI, both the angler who caught the fish and the original tagger receive information on its time at liberty, movement and growth. This feedback has proved to be a useful incentive for anglers to submit recapture information.

Over the past 35 years, over 6 000 members have joined the ORI-CFTP, and approximately 330 000 fish representing 368 species have been tagged, of which over 21 000 (6%) have been recaptured. Data from the ORI-CFTP have been used in at least 22 postgraduate theses and 83 published manuscripts (Dunlop et al. 2013), and the knowledge obtained has significantly improved the management and sustainable utilisation of South Africa's linefish resources (Dunlop et al. 2013). Interest in the project is maintained through advertisements in popular fishing magazines, on radio and television shows, and more recently through social media.

The ORI-CFTP has played a major role in influencing policy and decision-making on linefish management in South Africa. For example, research into the biology and stock assessment of key linefish species has incorporated information from the ORI-CFTP, enabling the development of species-specific regulations that ensure more sustainable use of our linefish resources. Feedback from participants suggest that this project has improved angler knowledge about linefish resources. The concept of tag and release has also been partly responsible for changing the ethics of recreational fishers, many of whom now release their catch, helping to ensure more-sustainable fishing into the future. The contributions of this project were summarised by Dunlop et al. (2013).

Although there have been some shortcomings, such as the low reporting rate (i.e. 40–50% of recaptured fish were unreported, based on angler responses in surveys: Dunlop 2011) and the impact of tagging on post-release survival of fishes, these have been partly resolved through angler training and improvements in tagging equipment. The greatest challenge for this long-term project is securing ongoing funding. Critical to its longstanding success has been the commitment of SAAMBR to ensuring its survival through dedicated staff. This suggests that a key factor for any CS project is the long-term commitment of the institution, not the individual who initiated the project.

East Coast Fish Watch (ECFW) (1998–2002)

This classic CS project was built on the successful relationships between individual ichthyologists (the Smiths and Heemstras) and the public. Its aims were to discover, describe and classify the fishes in the southern African region, to promote study of marine fishes, to stimulate public interest in marine fish diversity, and to facilitate transfer of knowledge between organisations concerned with the conservation of marine fishes in the region (E Heemstra pers. comm.). Funded by South African Pulp and Paper Industries (SAPPI), the project comprised surveys of marine fish diversity, the creation of a database of fish species of the east coast of South Africa, and member participation and education. Anglers, divers and aquarists interested in marine fishes were asked to supply photographs of fishes, donate specimens or supply information on fish sightings. They could also attend workshops on fish identification.

The ECFW project facilitated the description of several species and informed the distributions of many southern African coastal species (Heemstra and Heemstra 2004). The project also provided divers with a new focus and opportunity to learn. As such, it exemplified the 'content learning' role of CS, as discussed by Haywood et al. (2016). Unfortunately, following the retirement of the project leader (PC Heemstra), the ECFW endeavour largely ceased to operate, as there was no succession plan.

Atlas of Seabirds at Sea (AS@S) (2009–)

The aim of the AS@S project is to identify ocean hotspots for seabird diversity, which can contribute to the formation of protected areas. Managed collaboratively by BirdLife South Africa and the South African Earth Observation Network (SAEON), citizen scientists on vessels at sea collect seabird data according to a rigorous protocol. Data are submitted to an online, open-access database. The project is supported by the Branch: Oceans and Coasts of the Department of Forestry, Fisheries and the Environment (DFFE), who make berths available for citizen scientists on many of their research cruises. Currently, the database is biased towards South African and African waters as well as the Southern Ocean owing to the routes of South African government research cruises. Currently, 66 registered observers have contributed 16 056 transects and observed a total of 92 556 birds (ADB pers. obs.).

In 2018, the free-to-download mobile app BirdLasser was commissioned to develop functionality for the collection of data. This app requires only a smartphone with GPS capability to record and share bird sightings, negating the need for onerous data entry and submission. This advancement makes the AS@S project more user-friendly and appealing for contributors, and the app is quickly growing its international user profile, providing an opportunity for AS@S to extend its geographic reach. The main challenges for the AS@S project are a lack of funding, the slow geographic expansion of the project, and the limited number of willing observers. Although BirdLife South Africa currently coordinates the project and SAEON hosts the database, a dedicated project manager with a budget would enable the extension of participation and geographic reach.

EchinoMAP Metadata (2012–)

EchinoMAP is the only marine example in The Virtual Museum (see http://vmus.adu.org.za), which is run by the FitzPatrick Institute of African Ornithology (Department of Biological Science, University of Cape Town); the dataset was developed to support postgraduate students working on the systematics of echinoderm taxa under Charles L Griffiths (CLG). Financial support was initially provided through the SeaKeys project (Foundational Biodiversity Information Programme of the National Research Foundation [NRF]). Ongoing financial support is *ad hoc*, with contributions from other research funds held by CLG.

To date, 69 photographers have jointly lodged over 2 000 images depicting 144 identified echinoderm species (with some interesting images still unidentified: CLG pers.

obs.). These records have been used for several purposes, including: (i) to document the occurrence of species previously unknown from South Africa; (ii) to develop accurate distribution maps; (iii) to document new species records of Echinoidea (Filander and Griffiths 2014) and Ophiuroidea (Olbers et al. 2015); and (iv) to develop field guides to the regional echinoid (Filander and Griffiths 2017) and ophiuroid (Olbers et al. 2019) faunas of South Africa.

Despite these successes, only a minority of photographers have loaded images onto the site themselves, making it necessary to employ a student to load images on behalf of photographers. Another shortcoming is the uneven geographic coverage of images, the vast majority being from a few popular dive sites, notably Sodwana Bay and False Bay. Similarly, most images are of a few common, large, distinctive and attractive species, leaving smaller, cryptic, burrowing and deeper-water species underrepresented. Future challenges include the engagement of more proactive contributors and to widen the scope of data collection both along the coastline and into deeper waters.

SeaKeys atlas projects (including the Sea Coral Atlas, Sea Slug Atlas, and Sea Fish Atlas) (2014–)

The SeaKeys atlas projects, conceptualised by the South African National Biodiversity Institute (SANBI) and funded by both the NRF and the World Wide Fund for Nature South Africa (WWF-SA), uses citizen scientists to support the mapping of marine species in South Africa. These projects built on the earlier success of SANBI's Reef Atlas Project, which helped map reef ecosystems to support marine biodiversity assessment, planning and management. Participants were encouraged to contribute data in the form of photographs with GPS coordinates to an online platform, iSpot, and taxonomic experts were requested to verify identifications of submissions. To date, 215 citizen scientists have contributed 21 564 new distribution records, covering more than 1 150 species (RT pers. obs.). Members of the organising team have attended dive festivals and fishing competitions and have run photographic 'shootouts' to encourage participation.

From the iSpot platform, the Sea Coral Atlas and Sea Slug Atlas initiatives delivered 3 645 and 3 144 observations, respectively (RT pers. obs.). The Sea Fish Atlas has dominated observations, with 8 057 records from 732 species being uploaded (RT pers. obs.); this success is partly attributed to the presence of a dedicated coordinator, paid to validate online submissions, support data upload and interact with contributors. A biannual newsletter covering notable findings was also sent out to Sea Fish Atlas participants. However, it is important to point out that 70% of the fish data have come from only 10 citizen scientists. As with similar projects, key limitations include few active participants, narrow geographic coverage and a bias towards charismatic or interesting species. Nevertheless, these data contribute to mapping and marine biodiversity assessments, with potential future contributions for monitoring. Another limitation relates to the time required by the team to upload photographs, as most photographers simply contributed large databases, and without dedicated staff, servicing this aspect is unsustainable.

ABALOBI (2015–)

The ABALOBI app suite is a fisher-driven, South African-based enterprise; it comprises five, simple, free, interconnected smartphone apps specifically developed for small-scale fishers. Together these allow fishers to generate data to improve their own productivity and safety (ABALOBI FISHER app), facilitate transparent collection of climate-related and catch and effort data by participating small-scale fishers and government monitors (ABALOBI MONITOR app), increase visibility of the fishers to authorities and fisheries managers (ABALOBI MANAGER app), allow stakeholders (including fishers themselves) in the food products cold chain to track trends and operations (ABALOBI CO-OP app), and facilitate the sale of fish directly to restaurants at fair market prices (ABALOBI MARKETPLACE app). Developed in collaboration with fishers, ABALOBI has been endorsed by the Branch: Fisheries Management of DFFE as the official catch monitoring system of the new small-scale fisheries policy (Petrik and Raemaekers 2018).

Small-scale fishers hear about the ABALOBI project via their peers or through advertising (S Raemaekers, ABALOBI, pers. comm.). After registration, they receive training on use of the apps. ABALOBI currently serves the needs of, and collects data from, approximately 275 fishers from eight fishing communities (S Raemaekers, pers. comm.). However, its reach is rapidly expanding and, with increasing international interest, is expected to extend beyond South Africa.

CatchReport (2015–)

The aim of CatchReport is to collate information from social and competitive angling in South Africa and use this to develop a reliable recreational fishery monitoring database. The project was developed cooperatively with the Fishtory project (see below) as part of the WWF-SA FishForLife project. A web-based CS platform was designed to accept information on anglers' daily catches, and anglers are incentivised by being provided with information that includes species ID catalogues and length–weight relationships. The data are written to a database that can be accessed only by the angler who entered them and by researchers. The database has two components: social angling records and competition angling records. The latter has been more successful in generating data, both in terms of quantity and quality. Over 90 000 records from competition anglers are now loaded, representing the largest single repository of data on recreational fish catches outside KZN (where most of the NMLS recreational angler data are collected: CGA pers. obs.). Many of the fish species on record are not recorded or are poorly represented in the commercial databases held by DFFE. These data provide standardised abundance series, to estimate the ecological footprint of recreational angling and to provide information on Red List species (typically sharks) which are not elsewhere recorded (CGA pers. obs.).

The uptake of social angling records has been less successful, and it is unlikely to provide sufficient records to constitute a valuable data source for researchers. Technological problems account for some of the reasons for the failure of individual recreational anglers to submit their records. Lessons learned include the importance of ensuring that the website has been well-tested and is fully functional and simple to use before launching. Cybersecurity should be tight, including installation and updating of security applications. The social angling component will need a new injection of public relations to promote further uptake.

Fishtory (2015–)

The aim of this project is to use information in the form of historical photographs, newspaper clippings, magazine articles and angler diaries to provide historical baseline data on the population dynamics and demographics of South Africa's marine recreational fishery species. Like CatchReport, it forms part of a greater CS initiative called FishForLife funded by WWF-SA. The web-based CS platform is designed to accept photographs and relevant catch information such as fish species, size, location, and date of capture from the public. To encourage participation, presentations have been given at relevant forums. The project is also advertised on recreational fishing social media platforms. Once photographs are submitted, the associated information is validated by a scientific team and added to the database. Angler diaries and newspaper articles (or their copies) are also solicited, and relevant data are transferred to the database. Recreational angling catches from photographs in popular angling magazines have also been included (see Potts et al. 2019).

By June 2018, 4 045 historical catch records dating from 1890 to 2005 were recorded, providing evidence of changes in catch composition in the marine recreational fishery (Potts et al. 2019). Interestingly, although local depletions were evident, the size composition and geographic distribution of some trophy fish species remained largely unchanged over the past 60 years (Potts et al. 2019).

While the outputs from this project are useful, the majority (~95%) of records have been collected by the project team. Although 107 citizens contributed to the database and these represent some of the oldest and most valuable data, the project has not built the momentum initially anticipated. After lodging one submission, registered users seldom return to the website, suggesting that the project failed to retain the interest of participants. User feedback suggested that data entry was too onerous, and many users agreed to continue submitting catch records only if the site administrator entered the data and uploaded the photographs for them. While this will provide a short-term fix, it significantly increases the administrative burden, which is likely unsustainable in the long-term.

Sea Search Sightings (2015–)

Sea Search Sightings is a CS project that forms part of a larger programme called the 'Effects of Climate Change on Cetaceans'. This programme aims to maximise cetacean data collection using standard scientific approaches and the use of local ecological knowledge. The CS component involves the collation of current sightings or existing records of cetaceans off the Western Cape Province. The project partners with a third-party app, called SeaFari, that was developed with input from other marine mammal researchers. This app provides most data fields needed for the effective reporting of marine mammal sightings and delivers an existing spreadsheet format. It also immediately posts sighting data to a dedicated Facebook page. Although a total of 5 271 records of cetaceans have been obtained, these are primarily from just 10 users (SGE pers. obs.). In addition, a vast number of sightings observed on other social media platforms are not currently captured. This is most likely due to the lack of success in converting people who use other reporting platforms (e.g. tour company web pages or WhatsApp groups) to this app. The lack of responsiveness of the SeaFari app may be one reason people chose to contribute to other platforms where feedback in the form of 'likes' or 'comments' is instantaneous.

Independent citizen scientists

While not CS projects *per se*, it is important to note that some individual citizen scientists have made, and continue to make, major, often serendipitous, contributions to taxonomic and ecological projects. These contributions usually comprise observations of previously unreported species (or events) that alert professional researchers to carry out follow-up studies. These independent citizen scientists might also assist with follow-up work or might simply pass an initial observation over to researchers or their students to pursue.

Several examples of this have occurred between Charles L Griffiths and a small group of key citizen scientists (e.g. Valda Fraser, Georgina Jones, Guido Zsilavecz and Craig Foster), who are all excellent photographers, not only intimately familiar with the marine fauna of their regions, but who have also independently published popular books on marine life (i.e. Zsilavacz 2005, 2007; Jones 2008; King and Fraser 2014; Foster and Frylinck 2018). These projects have resulted in the discovery of numerous undescribed species; for example, five newly described mysid species were all found within a small section of False Bay (Wittman and Griffiths 2014, 2017, 2018). Mixed-gas divers have also provided new locality records for coelacanths (Fraser et al. 2020) and many deep-water records for fish and invertebrates.

Other citizen scientists are themselves independent researchers, perhaps more similar to the naturalists of old. An excellent example is Dennis King, a structural engineer, who is the author (or co-author) and photographer of the field guides '*Reef fishes and corals: east coast of southern Africa*' (King 1996), '*More reef fishes and nudibranchs*' (King and Fraser 2002) and '*The reef guide*' (King and Fraser 2014). King also discovered the rare, deepwater tiger angelfish *Apolemichthys kingi* and has contributed towards a myriad of marine educational projects.

Benefits of SAMCS

Scientific output

This review confirms that especially the longer-running marine CS projects have made considerable contributions to scientific knowledge, government policy, ocean literacy and environmental monitoring. The well-established projects (such as ORI-CFTP, NMLS) as well as independent citizen scientists have generated the greatest scientific output (Table 1). In addition, many scientific outputs have benefitted from the additional spatial and temporal coverage that CS provides. Success in these cases can be attributed to citizens whose recreational activity (e.g. fishing) can be directly associated with collection of CS data. Similarly, SCUBA divers have made many contributions, although they form a far smaller pool of practitioners with more diverse interests.

Contribution to management

There is good evidence to suggest that SAMCS projects have influenced policy and regulations. For example, ORI-CFTP and NMLS data have supported the development of several species-specific regulations in the linefishery (Mann 2013), whereas data from SANBI's Reef Atlas and the SeaKeys atlas projects were used in ecosystem classification and mapping to support the expansion of MPAs (Sink et al. 2011).

Educational impact

Although challenging to quantify, there is no doubt that SAMCS projects have contributed to public learning. In terms of participation, there are around 7 000 registered users in SAMCS projects (Table 1). Projects with training components, such as the ABALOBI app suite, ORI-CFTP, ECFW and MPA-FMTP, have contributed to science literacy. However, a lack of rigorous assessments of marine CS projects has limited our understanding of the real impact of these on learning, skills and scientific literacy. Similarly, the lack of assessments of CS projects limits our knowledge of their impacts in enhancing the interest of citizens in the natural world and their environmental engagement. Additional benefits of CS include increases in confidence, pride and other intangible benefits, and should also be assessed, as research suggests that the intangible benefits of participating in CS may be more supportive of environmental engagement than fact-based learning (Dean et al. 2018).

Capacity augmentation

Limited government environmental monitoring capacity is a global challenge (Stokes et al. 1990; Pollock and Whitelaw 2005; Conrad and Daoust 2008; Conrad and Hilchey 2011). CS offers alternative options to traditional, cost-intensive monitoring programmes. Where the number and/or skills of government employees is insufficient, or not suited to the monitoring projects, CS has filled this gap. For example, the MPA-FMTPs have relied on skilled recreational anglers to collect catch per unit effort and tagging data in programmes organised by scientists. These recreational anglers have dedicated much of their time (almost a month per year, in some cases) to assisting with data collection. Given the limited funding available to these projects, this voluntary contribution has enabled the projects to achieve considerably more than if every angler was paid.

Challenges associated with SAMCS projects and possible solutions

Funding

Secure, ongoing funding is a challenge facing the sustainability of most CS projects. Successful long-term projects, such as the ORI-CFTP, have been possible through institutional support via the employment of permanent or long-term contract staff, regardless of external funding sources. The development, implementation and maintenance of CS projects that yield both scientific and educational outcomes clearly require substantial effort, which should not be underestimated. Securing long-term funding is not only critical to cover staff costs, but also costs associated with communication, website maintenance, etc., which are essential for successful CS projects.

Attracting and retaining participants

With a plethora of potential projects for interested citizens, one of the biggest challenges of new CS projects is to attract and, perhaps more importantly, maintain public interest and participation. Even though several of the marine CS projects (e.g. Fishtory, CatchReport) secure a large amount of data through their scientific teams, they have been unable to harness widespread public support and their membership remains low. Barriers to participation in CS projects include a lack of awareness, unwillingness to participate, lack of trust, lack of confidence, lack of access to technology, and the plethora of other (often international) options available (Martin et al. 2016a).

Retaining participation is another challenge noted in most case studies. For example, although the SeaKeys project has 215 registered users, 70% of records were logged by only 10 users, with most others contributing only a single record. Research to understand the barriers to participation and the motivations of participants in CS projects can improve the recruitment and retention of citizen scientists (Wright et al. 2015; Martin et al. 2016b; Larson et al. 2020). In the absence of this information for marine CS projects, several techniques have been attempted to retain participants.

Personal communication appears to be among the most vital components for continued engagement of citizens in any science project. Almost all CS projects reviewed here highlighted the importance of giving feedback. Participants want to know that their contributions are both appreciated and of value (Bruyere and Rappe 2007). For instance, the personal letters of thanks written by the Smiths were one of the key reasons for the support of anglers in the early days of SAMSC.

Digital communication may help to enhance retention. For most CS projects in this study, regular newsletters, highlighting research findings and demonstrating the use and impact of submitted information, are crucial. Social media now offers opportunities to provide timeous feedback, create a sense of community (Bell et al. 2008) and provide a 'face' of the project (West and Pateman 2016). Through managed interaction between participants, social media can harness the competitive and addictive nature with which it is associated (Van Den Berg et al. 2009; Asah and Blahna 2012; Jacobson et al. 2012) and give participants the opportunity to provide feedback on the project. Enabling two-way communication between scientists and participants builds a sense of belonging to a community, which can be a powerful motivator to increased participation (Martin et al. 2016b).

Providing rewards and incentives may also increase retention (O'Brien et al. 2010). For example, the ORI-CFTP names top taggers in their annual newsletter, creating natural competition, while certificates of achievement and personal letters providing information on the recapture of tagged fish also reward participants. More recently, social media posts on significant recaptures also recognise individual taggers.

Increasing geographic range

One of the often-claimed strengths of CS projects is additional spatial coverage of data collection, but this is not always the case. In fact, the distributional range of the CS reports for the ECFW, SeaKeys and EchinoMAP projects were strongly biased towards a few renowned dive sites. This bias can be addressed only by increasing the numbers of participants from a wider geographic range, and by encouraging participants (through rewards) who dive regularly to submit data from less popular areas.

Diversifying participation

A global problem with CS, but particularly relevant to South Africa and the developing world, is the inclusion of a broader spectrum of citizens. The most-avid marine citizen scientists are generally young (<45 years old), have some education in science and an interest in the natural world, and participate in relatively costly activities such as recreational diving, underwater photography or sport fishing (Martin et al. 2016b). As those participants are mostly wealthier, urban individuals, the paucity of CS participants from other socioeconomic groups is not surprising. Because of its importance in the South African context, this issue is addressed in more detail below.

Simplifying participation

The user interface of CS projects is critical to their success. Some, such as the ORI-CFTP, have made significant strides; since their participation originally through the postal system, anglers can now report tagging and recaptures using mobile phone technology. This has helped the project maintain relevance, as anglers appreciate rapid feedback. Several CS projects noted users' dissatisfaction with project websites, particularly the time taken to upload their information or pictures, or to obtain feedback, and issues of online security have also arisen (e.g. EchinoMAP, CatchReport, Fishtory). Well-designed technological interfaces are necessary to maintain contributions from citizen scientists (Martin et al. 2016b).

Data maximisation

There was little evidence to suggest that the projects reviewed had maximised the quality of the data collected. Some projects mentioned data validation (e.g. Fishtory, NMLS, independent citizen scientists) and training (e.g. ABALOBI, ORI–CFTP, ECFW), but none emphasised the importance of metadata to describe the sampling process, made use of reference data to facilitate standardisation (Bird et al. 2014), referred to methods in database management (Crall et al. 2010), or indicated the role of filtering or subsampling data to understand the potential error or effects of uneven distribution of effort (Wiggins et al. 2011). This may have significant implications for the validity, and perceptions of validity, of CS data and could undermine uptake of the data into conservation efforts. In fact, concern about the validity of the catch returns submitted by recreational anglers to the NMLS was one reason for the change to observer-based data collection (JBML pers. obs.). Bird et al. (2014) recommended modern analytical approaches to account for typical bias and error in CS datasets. These approaches include the use of mixed-effects modelling to examine the impact of pseudoreplication, use of hierarchical modelling to account for bias in the sampling process, and use of machine-learning tools to uncouple the effects of related explanatory variables. Incorporating these methods to enhance data quality would be particularly valuable to increase the value of citizen contributions and counter data-quality scepticism.

Internal evaluations

None of the projects reviewed incorporate regular internal evaluations. Evaluation in this context can be described as the systematic collection of data to determine the strengths and weaknesses of CS programmes (Phillips et al. 2014). The lack of evaluation has inhibited the quantification of indicators, such as participant demographics, psychographics and learning. Evaluation should quantify project successes and failures to guide funding allocation. Rigorous evaluation should be budgeted for and included in all CS projects (Phillips et al. 2014).

Gaps and opportunities in SAMCS

Fish and fisheries

The interest of anglers and their widespread distribution around the coast provide many opportunities for future CS projects, especially in light of anticipated climate-change-induced impacts in the marine environment. These include projects to:

(i) capture information on fish disease and parasites (as anglers regularly post photographs of their findings on social media platforms);
(ii) document changes in fish distribution (as has been undertaken in Australia in the Red Map CS project [Champion et al. 2018]);
(iii) assess or reassess life-history parameters (as undertaken in the 'Send Us Your Skeletons' project in Western Australia [Fairclough et al. 2014]);
(iv) map the topography of the ocean floor (using echosounders linked to geographic positioning systems [GPS] on fishing vessels).

The majority of the SAMCS projects discussed here are 'classic' CS projects (Table 1), suggesting that there may be opportunities to develop 'environmental management' CS and 'citizen cyberscience' projects.

Environmental monitoring

Interestingly, no CS projects focus on South Africa's estuaries (Graham and Taylor 2014). Although there are examples of citizens recording the daily mouth status of several temporarily open/closed estuaries, a CS programme that coordinates this, and the collection of other estuarine information (e.g. fishing effort, birdlife, etc.) would provide valuable information on long-term trends. Such a project, known as the Estuary Observer Programme (EOP) focusing on KZN estuaries, has recently been initiated by ORI (F MacKay, ORI, pers. comm.).

With anthropogenic activities increasingly impacting coastal and estuarine habitats, it is likely that coastal communities will become more concerned with water quality and pollution in their areas. This may provide an opportunity for scientists interested in monitoring marine or estuarine pollution impacts to initiate environmental management CS projects. For example, The Beach Co-op (www.thebeachcoop.org) has recently partnered with citizens to remove and record plastic debris from the intertidal zone in the Cape Town area.

Citizen cyberscience

Citizen cyberscience projects also have potential in SAMCS. For example, it may be possible, with adequate training (and validation), to develop a CS programme to assist with the collection of data from baited remote underwater video (BRUV) footage that is used to monitor fish populations in MPAs, although with the low speed and high cost of the Internet in South Africa, this may not yet be possible.

Alignment with national strategies

There are several national strategy documents relevant to SAMCS, including the South African NRF's 2020 Strategy (NRF 2016), the Marine and Antarctic Research Strategy (MARS 2016), and the Science Engagement Strategy (SES). Strategic outcomes in these documents that are relevant to CS are: (i) to popularise science as an attractive and relevant pursuit and to make it accessible in order to improve scientific literacy and increase interest in relevant careers; (ii) to increase public engagement and participation in the national discourse of science and technology, particularly in the way that it can benefit society; (iii) to promote communication (through the media, and science communicators) that will enhance science engagement in South Africa; (iv) to enhance the profile of South African scientific achievements by demonstrating their contribution to local and international science (NRF 2016); and (v) to improve public awareness and engagement in marine science, particularly development of platforms to engage with the public in two-way exchanges, to raise the profile of the ocean environment and the consequences of human actions (MARS 2016). In addition, broadening participation in marine science is seen as a critical theme throughout all three strategy documents mentioned above, and dedicated efforts should pilot and report on the success of different approaches to diversify participation.

While the existing marine CS projects align well with most of the strategic outcomes in these national strategies, there are also areas of concern. These include the active engagement of a wider range of citizens, training of individuals in marine science data collection, provision of regular communications that popularise science, and improving the scientific literacy of participants. With only approximately 7 000 participants engaged in marine CS nationwide, of which approximately 6 000 are registered with the ORI-CFTP, more engagement with the public is clearly needed.

In terms of enhancing the profile of South African science, the ORI-CFTP has been recognised as a world-class CS project (see Dunlop et al. 2013). However, recognition of the other projects has largely remained local. While it is hoped that this will change over time, long-term commitment to CS projects by the lead institutions is key for international success.

There is limited evidence for transformation of both the participants and project leadership in SAMCS. While increasing the diversity of the participants in CS is discussed in the next section below, it is also important to transform the project leadership and the students active on SAMCS projects. The NRF has made great strides in encouraging transformation, particularly via the allocation of student scholarships in both their freestanding and grant-holder-linked funding programmes. This should create opportunities for historically disadvantaged individuals to participate in CS projects. However, for this to happen, project leaders should create an enabling, inclusive environment that will attract potential students. Clear and achievable project succession plans should be developed, with the aim of transforming project leadership, and this should be considered a critical component of the design and evaluation process of CS projects to improve their alignment with national strategies.

Future directions of CS in the developing world

Scientists wishing to embark on a CS initiative should be cognisant of the time, effort and money required. Bonney et al. (2009a) concluded that scientists and funders should take a long-term view of CS projects and set realistic objectives and expectations. Cigliano et al. (2015) proposed a focus-group approach with relevant stakeholders as an appropriate way of setting objectives. Some projects may only require short-term information (e.g. habitat mapping for spatial planning). However, long-term projects are often more successful, and large spatiotemporal datasets are often more valuable (Delaney et al. 2008; Bonney et al. 2009a; Dickinson et al. 2010). Long-term projects are also more likely to succeed, as it takes time for projects to establish their own identity, develop momentum and secure a critical mass of participation (Cigliano and Ballard 2017). Thus, unless the objectives are short-term, initial planning should incorporate efforts to secure long-term funding, or a financially sustainable model (Bonney et al. 2009a). Funding should also cover evaluation and sharing of project lessons.

Given the limited funding available in developing-world marine science, a cost–benefit analysis prior to initiation of a CS project would be valuable (Tulloch et al. 2013). Existing CS projects should be evaluated for potential overlaps or opportunities for collaboration (Hulbert et al. 2019). Established global projects normally have staff and infrastructure, including appropriate technological interfaces, data management systems and communication capacity (Cigliano and Ballard 2017). Local scientists could reduce the costs of obtaining their CS data by developing partnerships with existing projects and encouraging their target audience to contribute to these. The international partner will benefit from an increased global footprint, while local scientists will gain access to data that extend beyond the country boundaries. However, it is critical to establish clear partnership and data-sharing agreements at the early stages of this kind of collaboration.

This review has established that a lack of inclusivity in participation in CS is likely to be a major problem for marine CS in the developing world. Broadening participation could increase the distribution of the data collected, but, more importantly, would increase the reach of public learning. The ABALOBI suite of apps has contributed to this, through a collaborative approach with small-scale fisheries; the project's recent expansion to fishers beyond South Africa's borders suggests that its approach may be suitable for other developing countries. However, for the other CS projects, explicit plans to extend their reach to a broader sector of society may be necessary. Ideally, CS projects should identify potential new participant groups, build an understanding of what would motivate them to participate and then develop clear engagement strategies for each target audience.

While diversifying existing projects is clearly necessary, new projects that specifically aim to include currently underrepresented communities are needed. For example, many communities have a connection to nature and a wealth of indigenous knowledge about the environment (Mann-Lang 2016), yet accessing these communities to involve them meaningfully in community-orientated CS will require innovation. Projects that work with communities to enable meaningful knowledge-sharing should be developed.

To further encourage the development of inclusive CS projects, steps to ensure tangible benefits are required. Given that incentives such as those provided by the ABALOBI project (e.g. direct access to more-lucrative restaurant markets and improved profitability) are seldom possible in CS projects, other motivators should be explored to encourage ongoing participation. Projects that provide tangible and intangible benefits for participation are more likely to succeed in the future than those that rely purely on the interest of traditional citizen scientists.

To address many of the issues facing participation in SAMCS it is recommended that research, of the type undertaken by Martin et al. (2016a), on the benefits and barriers to engagement in marine CS be conducted. While project teams have a deep understanding of the topic, their understanding of participants is often limited. However, it is engagement with participants that will ultimately determine the success or failure of a CS project. Therefore, research to uncover the profiles, psychographics and motivation of current and future CS participants, as well as to identify and overcome barriers to participation, would greatly contribute to the development of CS in South Africa. Such research should be undertaken with all stakeholders, thereby enhancing support for the project through more-effective two-way engagement to support mutual benefits.

Conclusions

The success of many SAMCS projects demonstrates that marine CS is not only beneficial but also achievable in the developing world. However, lessons gleaned from the successes and failures need to be articulated to improve future marine CS projects. For example:

(i) Projects should be carefully planned, ideally in collaboration with relevant stakeholders. Realistic expectations should be drafted, and where possible the aims of the project should align with national priorities and policy frameworks.

(ii) Research should be used to identify the benefits and barriers to participation in marine CS to enable the attraction and retention of participants from a broad range of society.

(iii) The use of modern communication methods, technological interfaces and data-collection tools is encouraged.

(iv) Where possible, partnerships with existing (international) projects could be beneficial.

(v) Critical evaluation, highlighting the strengths and weaknesses of every project, is essential. Sustainability of the project should be a central component of these evaluations.

(iv) Projects should aim to collaborate with other CS projects on common science themes, such as the impacts of climate change or anthropogenic activities on ecological processes (Hulbert et al. 2019). To facilitate this, a community of practice agreement which identifies appropriate methods of data-sharing and resource-sharing and the development of combined databases may be necessary.

Acknowledgements — The authors would like to acknowledge the numerous citizen scientists and funding agencies who have contributed to the projects described herein, including many who have commented on the project strengths and weaknesses. Serge Raemaekers is thanked for information on the ABALOBI project. WMP was funded by the WWF's FishForLife project.

ORCID

Colin Attwood: https://orcid.org/0000-0002-1045-3439
Simon Elwen: https://orcid.org/0000-0002-7467-6121
Charles Griffiths: https://orcid.org/0000-0001-5791-4725
Bruce Mann: https://orcid.org/0000-0002-7130-6301
Judy Mann: https://orcid.org/0000-0001-5534-7229
Ronel Nel: https://orcid.org/0000-0003-2551-6428
Warren Potts: https://orcid.org/0000-0002-6707-0383
Kerry Sink: https://orcid.org/0000-0001-5051-573X

References

Asah ST, Blahna DJ. 2012. Motivational functionalism and urban conservation stewardship: implications for volunteer involvement. *Conservation Letters* 5: 470–477.

Attwood CG. 2003. Dynamics of the fishery for galjoen *Dichistius capensis*, with an assessment of monitoring methods. *African Journal of Marine Science* 25: 311–330.

Bear M. 2016. Perspectives in marine citizen science. *Journal of Microbiology and Biology Education* 17: 56–59.

Bell S, Marzano M, Cent J, Kobierska H, Podjed D, Vandzinskaite D et al. 2008. What counts? Volunteers and their organisations in the recording and monitoring of biodiversity. *Biodiversity and Conservation* 17: 3443–3454.

Bird TJ, Bates AE, Lefcheck JS, Hill NA, Thomson RJ, Edgar GJ et al. 2014. Statistical solutions for error and bias in global citizen science datasets. *Biological Conservation* 173: 144–154.

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J. 2009a. Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience* 59: 117–128.

Bonney R, Ballard H, Jordan R, McCallie E, Phillips T, Shirk J, Wilderman CC. 2009b. *Public participation in scientific research: defining the field and assessing its potential for informal science education*. CAISE Inquiry Group report. Washington DC: Center for Advancement of Informal Science Education (CAISE).
Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK. 2014. Next steps for citizen science. *Science* 343: 1436–1437.
Bruyere B, Rappe S. 2007. Identifying the motivations of environmental volunteers. *Journal of Environmental Planning and Management* 50: 503–516.
Champion C, Hobday AJ, Tracey SR, Pecl GT. 2018. Rapid shifts in distribution and high-latitude persistence of oceanographic habitat revealed using citizen science data from a climate-change hotspot. *Global Change Biology* 24: 5440–5453.
Cigliano JA, Ballard HL. 2017. *Citizen science for coastal and marine conservation*. Abingdon, UK: Routledge.
Cigliano JA, Meyer R, Ballard HL, Freitag A, Phillips TB, Wasser A. 2015. Making marine and coastal citizen science matter. *Ocean and Coastal Management* 115: 77–87.
Cohn JP. 2008. Citizen science: can volunteers do real research? *Bioscience* 58: 192–197.
Conrad CT, Daoust T. 2008. Community-based monitoring frameworks: increasing the effectiveness of environmental stewardship. *Environmental Management* 41: 358–366.
Conrad CC, Hilchey KG. 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental Monitoring and Assessment* 176: 273–291.
Crall A, Newman G, Jarnevich C, Stohlgren T, Waller D, Graham J. 2010. Improving and integrating data on invasive species collected by citizen scientists. *Biological Invasions* 12: 3419–3428.
Dean AJ, Church EK, Loder J, Fielding KS, Wilson KA. 2018. How do marine and coastal citizen science experiences foster environmental engagement? *Journal of Environmental Management* 213: 409–416.
Delaney DG, Sperling CD, Adams CS, Leung B. 2008. Marine invasive species: validation of citizen science and implications for national monitoring networks. *Biological Invasions* 10: 117–128.
Dickinson JL, Zuckerberg B, Bonter DN. 2010. Citizen science as an ecological research tool: challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics* 41: 149–172.
Dunlop SW. 2011. An assessment of the shore-based and offshore boat-based linefisheries of KwaZulu-Natal, South Africa. MSc thesis, University of KwaZulu-Natal, South Africa.
Dunlop SW, Mann BQ, van der Elst RP. 2013. A review of the Oceanographic Research Institute's Cooperative Fish Tagging Project: 27 years down the line. *African Journal of Marine Science* 35: 209–221.
Eitzel MV, Cappadonna JL, Santos-Lang C, Duerr RE, Virapongse A, West SE et al. 2017. Citizen science terminology matters: exploring key terms. *Citizen Science: Theory and Practice* 2: article 1.
Fairclough DV, Brown JI, Carlish BJ, Crisafulli BM, Keay IS. 2014. Breathing life into fisheries stock assessments with citizen science. *Scientific Reports* 4: article 2749.
Filander Z, Griffiths CL. 2014. Additions to and revision of the South African echinoid fauna (Echinodermata: Echinoidea). *African Natural History* 10: 47–56.
Filander Z, Griffiths CL. 2017. Illustrated guide to the echinoid (Echinodermata: Echinoidea) fauna of South Africa. *Zootaxa* 4296: 1–72.
Foster C, Frylinck R. 2018. *Sea change: primal joy and the art of underwater tracking*. Cape Town, South Africa: Quivertree Publications.
Foster-Smith J, Evans SM. 2003. The value of marine ecological data collected by volunteers. *Biological Conservation* 113: 199–213.
Fraser MD, Henderson BAS, Carstens PB, Fraser AD, Henderson BS, Dukes MD, Bruton MN. 2020. Live coelacanth discovered off the KwaZulu-Natal south coast, South Africa. *South African Journal of Science* 116: article 7806.
Galloway AWE, Tudor MT, Haegen WMV. 2006. The reliability of citizen science: a case study of Oregon White Oak Stand Surveys. *Wildlife Society Bulletin* 34: 1425–1429.
Graham M, Taylor J. 2014. *Development of citizen science water resource monitoring tools and communities of practice for South Africa, Africa and the world*. WRC Report No. TT 763/18. Pretoria, South Africa: Water Research Commission.
Haklay M. 2013. Citizen science and volunteered geographic information – overview and typology of participation. In: Sui DZ, Elwood S, Goodchild MF (eds), *Crowdsourcing geographic knowledge: volunteered geographic information (VGI) in theory and practice*. Berlin: Springer. pp 105–122.
Haywood BK, Parrish JK, Dolliver J. 2016. Place-based and data-rich citizen science as a precursor for conservation action. *Conservation Biology* 30: 476–486.
Heemstra PC, Heemstra E. 2004. *Coastal fishes of southern Africa*. Grahamstown, South Africa: National Inquiry Service Centre and South African Institute for Aquatic Biodiversity.
Howe J. 2006. The rise of crowdsourcing. *Wired Magazine* 14: 1–4.
Hulbert J. 2016. Citizen science tools available for ecological research in South Africa. *South African Journal of Science* 112: a0152
Hulbert JM, Turner SC, Scott SL. 2019. Challenges and solutions to establishing and sustaining citizen science projects in South Africa. *South African Journal of Science* 115: 7–8.
Jacobson SK, Carlton JS, Monroe MC. 2012. Motivation and satisfaction of volunteers at a Florida natural resource agency. *Journal of Park and Recreation Administration* 30: 51–67.
James NC, Götz A, Potts WM, Cowley PD. 2012. Temporal variability of a temperate fish assemblage in Africa's oldest marine protected area. *African Journal of Marine Science* 34: 15–26.
Jones G. 2008. *A field guide to the marine animals of the Cape Peninsula*. Hout Bay, South Africa: SURG (Southern Underwater Research Group) Press.
King D. 1996. *Reef fishes and corals: east coast of southern Africa*. Cape Town, South Africa: Penguin Random House.
King D, Fraser V. 2002. *More reef fishes and nudibranchs*. Cape Town, South Africa: Struik.
King D, Fraser V. 2014. *The reef guide*. Cape Town, South Africa: Struik Nature.
Kong Q, Allen RM, Schreier L, Kwon YW. 2016. MyShake: a smartphone seismic network for earthquake early warning and beyond. *Science Advances* 2: e1501055.
Kramer RW, Mann BQ, Dunlop SW, Mann-Lang JB, Robertson-Andersson D. 2017. Changes in recreational shore anglers' attitudes towards, and awareness of, linefish management along the KwaZulu-Natal coast, South Africa. *African Journal of Marine Science* 39: 327–337.
Larson LR, Cooper CB, Futch S, Singh D, Shipley NJ, Dale K et al. 2020. The diverse motivations of citizen scientists: does conservation emphasis grow as volunteer participation progresses? *Biological Conservation* 242: article 108428.
Loos J, Horcea-Milcu AI, Kirkland P, Hartel T, Osváth-Ferencz M, Fischer J. 2015. Challenges for biodiversity monitoring using citizen science in transitioning social–ecological systems. *Journal for Nature Conservation* 26: 45–48.
Mann BQ (ed). 2013. *Southern African marine linefish species profiles. Special Publication* No. 9. Durban, South Africa: Oceanographic Research Institute.
Mann BQ, Cowley PD, Dunlop SW, Potts WM. 2018. Is

catch-and-release shore angling compatible with the conservation goals of marine protected areas? A case study from the iSimangaliso Wetland Park in South Africa. *Fisheries Research* 208: 179–188.

Mann-Lang JB. 1996. Recreational linefishery data – a critical review. Unpublished Report No. 136. Durban, South Africa: South African Association for Marine Biological Research.

Mann-Lang JB. 2016. Exploring the implications of cultural diversity for environmental learning at an African aquarium. PhD thesis, University of Queensland, Australia.

MARS (Marine and Antarctic Research Strategy). 2016. South African Marine and Antarctic Research Strategy, Version 4.5. Pretoria, South Africa: Department of Science and Technology and Department of Environmental Affairs.

Martin VY, Christidis L, Lloyd DJ, Pecl GT. 2016a. Understanding drivers, barriers and information sources for public participation in marine citizen science. *Journal of Science Communication* 15: A02.

Martin VY, Christidis L, Pecl GT. 2016b. Public interest in marine citizen science: is there potential for growth? *BioScience* 66: 683–692.

Masters K, Oh EY, Cox J, Simmons B, Lintott C, Graham G et al. 2016. Science learning via participation in online citizen science. *Journal of Science Communication* 15: A07.

NRF (National Research Foundation). 2016. National Research Foundation Strategy 2020. Pretoria, South Africa: NRF.

O'Brien L, Townsend M, Ebden M. 2010. "Doing something positive": volunteers' experiences of the wellbeing benefits derived from practical conservation activities in nature. *Voluntas* 21: 525–545.

Olbers JM, Samyn Y, Griffiths CL. 2015. New and notable records of brittle stars (Echinodermata: Ophiuroidea) from South Africa. *African Natural History* 11: 83–116.

Olbers JM, Griffiths CL, O'Hara TD, Samyn Y. 2019. Field guide to the brittle and basket stars (Echinodermata: Ophiuroidea) of South Africa. *Abc Taxa* 19: 1–346.

Petrik M, Raemaekers S. 2018. *The case for supporting small-scale fisheries governance through ICT. Policy Briefing* No. 177. Johannesburg, South Africa: South African Institute of International Affairs.

Phillips T, Ferguson M, Minarchek M, Porticella N, Bonney R. 2014. *User's guide for evaluating learning outcomes from citizen science.* Ithaca, New York: The Cornell Lab of Ornithology.

Pollock RM, Whitelaw GS. 2005. Community-based monitoring in support of local sustainability. *Local Environment* 10: 211–228.

Potts WM, Jordan T, Childs AR. 2019. Can long-term content analysis of print media be used to examine species composition, population demography and distributional range of recreational fishery species? *African Journal of Marine Science* 41: 231–245.

Roy HE, Pocock MJO, Preston CD, Roy DB, Savage J, Tweddle JC, Robinson LD. 2012. Understanding citizen science and environmental monitoring. Final Report on behalf of UK Environmental Observation Framework. Lancaster, UK: NERC Centre for Ecology and Hydrology, and London: Natural History Museum.

SES (Science Engagement Strategy). 2015. The Department of Science and Technology (DST) Science Engagement Strategy. Pretoria, South Africa: DST.

Silvertown J. 2009. A new dawn for citizen science. *Trends in Ecology and Evolution* 24: 467–471.

Sink KJ, Attwood CG, Lombard AT, Grantham HS, Leslie R, Samaai T et al. 2011. Systematic planning to identify focus areas for offshore biodiversity protection in South Africa. Final report for the Offshore Marine Protected Area Project. Cape Town, South Africa: South African National Biodiversity Institute.

Smith JLB. 1949. *The sea fishes of southern Africa*. Cape Town, South Africa: Central News Agency Ltd.

Smith JLB. 1956. *Old fourlegs*. London: Longmans, Green & Co.

Smith JLB. 1969. *Ichthyological papers 1931–1943*. Grahamstown, South Africa: JLB Smith Institute of Ichthyology, Rhodes University.

Smith MM, Heemstra PC (eds). 1986. *Smiths' sea fishes*. Johannesburg, South Africa: Macmillan Publishers.

Steyn E, Groeneveld JC, Santos J, Kruger A, Mselegu XI, Schleyer MH. 2019. Trends in a recreational fishery for mussels in eastern South Africa, based on postal, telephone and online surveys. *Ocean and Coastal Management* 179: article 104863.

Stokes P, Havas M, Brydges T. 1990. Public participation and volunteer help in monitoring programmes: an assessment. *Environmental Monitoring and Assessment* 15: 225–229.

Summers R. 1975. *A history of the South African Museum, 1825–1975*. Published for the Trustees of the South African Museum. Cape Town, South Africa: Balkema AA.

Thiel M, Penna-Díaz MA, Luna-Jorquera G, Salas S, Sellanes J, Stotz W. 2014. Citizen scientists and marine research: volunteer participants, their contributions, and projection for the future. *Oceanography and Marine Biology: An Annual Review* 52: 257–314.

Tulloch AIT, Possingham HP, Joseph LN, Szabo J, Martin TG. 2013. Realising the full potential of citizen science monitoring programs. *Biological Conservation* 165: 128–138.

Vallabh P, Lotz-Sisitka H, O'Donoghue R, Schudel I. 2016. Mapping epistemic cultures and learning potential of participants in citizen science projects. *Conservation Biology* 30: 540–549.

Van Den Berg HA, Dann SL, Dirkx JM. 2009. Motivations of adults for non-formal conservation education and volunteerism: implications for programming. *Applied Environmental Education and Communication* 8: 6–17.

van der Elst RP, Garratt PA. 1984. Draft management proposals for the Natal deep-reef linefishery. Unpublished report. Durban, South Africa: Oceanographic Research Institute.

van der Elst RP, Penney A. 1994. Strategies for data collection in marine recreational and commercial linefisheries of South Africa. In: Hancock DA (ed.), *Recreational fishing: what's the catch? Australian Society for Fish Biology Workshop Proceedings, Canberra, 30–31 August 1994*. Canberra, Australia: Australian Government Publishing Service. pp 31–41.

Vaughn S, Harris M. 2014. Converging opportunities: environmental compliance and citizen science. *Chinese Journal of Urban and Environmental Studies* 2: article 1450001.

West SE, Pateman RM. 2016. Recruiting and retaining participants in citizen science: what can be learned from the volunteering literature? *Citizen Science: Theory and Practice* 1: article 15.

Wiggins A, Crowston K. 2011. From conservation to crowdsourcing: a typology of citizen science. *Proceedings of the Forty-fourth Hawaii International Conference* on *System Science (HICSS-44), January 2011, Kauai, Hawaii*. Piscataway, New Jersey: IEEE. pp 1–10.

Wiggins A, Newman G, Stevenson RD, Crowston K. 2011. Mechanisms for data quality and validation in citizen science. *IEEE Seventh International Conference on e-Science Workshops, 5–8 December 2011, Stockholm, Sweden*. Piscataway, New Jersey: IEEE. pp 14–19.

Wittmann KJ, Griffiths CL. 2014. Description of the 'stargazer mysid' *Mysidopsis zsilaveczi* sp. nov. (Mysida, Mysidae, Leptomysinae) from the Cape Peninsula, South Africa. *Crustaceana* 87: 1411–1429.

Wittmann KJ, Griffiths CL. 2017. Three new species of *Heteromysis* (Mysida, Mysidae, Heteromysini) from the Cape Peninsula, South Africa, with first documentation of a mysid–cephalopod association. *ZooKeys* 685: 15–47.

Wittmann KJ, Griffiths CL. 2018. A new species of *Mysidopsis*

G.O. Sars, 1864 from the Atlantic coast of South Africa, with supplementary descriptions of two additional species and notes on colour and feeding apparatus (Mysida: Mysidae). *Journal of Crustacean Biology* 38: 215–234.

Wright DR, Underhill LG, Keene M, Knight AT. 2015. Understanding the motivations and satisfactions of volunteers to improve the effectiveness of citizen science programmes. *Society and Natural Resources* 28: 1013–1029.

Zsilavecz G. 2005. *Coastal fishes of the Cape Peninsula and False Bay*. Cape Town, South Africa: Southern Underwater Research Group.

Zsilavecz G. 2007. *Nudibranchs of the Cape Peninsula and False Bay.* Cape Town, South Africa: Southern Underwater Research Group.

Manuscript received October 2019 / revised May 2021 / accepted June 2021