A Vision for Global Biodiversity Monitoring With Citizen Science

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A Vision for Global Biodiversity Monitoring With Citizen Science

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Abstract

Global biodiversity monitoring is urgently needed across the world to assess the impacts of environmental change on biodiversity. One way to increase monitoring is through citizen science. 'Citizen science' is a term that we use in this chapter to describe the diverse approaches that involve people in monitoring in a voluntary capacity, thus including participatory monitoring in which people work collaboratively with scientists in developing monitoring. There is great unrealised potential for citizen science, especially in Asia and Africa. However, to fulfil this potential citizen science will need to meet local needs (for participants, communities and decision makers, including people's own use of the data and their motivations to participate) and support global needs for biodiversity monitoring (including the United Nations' Sustainable Development Goals and the Aichi Biodiversity Targets). Activities should be feasible (for participants to provide scientifically rigorous data) and useful (for data users, from local to global scales). We use examples from across the world to demonstrate how monitoring can engage different types of participants, through different technologies, to record different variables according to different sampling approaches. Overall, these examples show how citizen science has the potential to provide a step change in our ability to monitor biodiversity—and hence respond to threats at all scales from local to global.

1. INTRODUCTION

Global biodiversity losses are escalating (Butchart et al., 2010; Chapin et al., 2000; Dobson et al., 2006) and monitoring is urgently needed across the world to assess the impacts of environmental change on biodiversity, to evaluate the impact of policy and management interventions

(Balmford et al., 2005; Johnson et al., 2017; Proença et al., 2017) and to assess the benefits that people gain from biodiversity (Millenium Ecosystem Assessment, 2005). The relatively scarce information on biodiversity change (at a global scale) results largely from a lack of taxonomic and spatial coverage (Boakes et al., 2010; Proença et al., 2017). We therefore need a step change in the way we undertake biodiversity monitoring (Schmeller et al., 2017). One way to accelerate monitoring is through the application of new technologies, for example, remote sensing (Pettorelli et al., 2014) or eDNA (Bohan et al., 2017). A complementary approach is to use citizen science, which engages nonprofessionals in a voluntary capacity to undertake monitoring (Dickinson et al., 2012). Environmental monitoring conducted by volunteers has a long history in many developed countries, especially in northern Europe and North America, with some initiatives having taken place for more than a century (Cooper, 2016; Dickinson et al., 2012; Pocock et al., 2015b; Schmeller et al., 2009). In addition to benefiting from the knowledge and capabilities of local participants, citizen science (or volunteer monitoring) can be less expensive than monitoring conducted by contracted professional staff (although the two approaches are not mutually exclusive) because it has the benefit of up-scaling more cost efficiently (Roy et al., 2012; Theobald et al., 2015; Tulloch et al., 2013a).

Overall, citizen science is making a substantial contribution to global biodiversity data (Amano et al., 2016; Chandler et al., 2017; Theobald et al., 2015), but there is considerable potential for increasing its contribution. Citizen science is valuable at the global scale because it not only collects large amounts of data, it also contributes to public engagement with the environment, potentially leading to behavioural change (McKinley et al., 2017) and production of partnerships between scientists and local people (Funder et al., 2013; Toomey and Domroese, 2013). In this chapter, we provide perspectives on how citizen science can meet the demands of global biodiversity monitoring. In particular we consider that for citizen science to be sustainable, it must meet local needs (for participants, communities and decision makers) as well as supporting global needs for biodiversity monitoring.

2. CITIZEN SCIENCE FOR BIODIVERSITY MONITORING

2.1 The Definition of Citizen Science

Firstly, it is important to define what we mean by 'citizen science' in the context of this chapter. 'Citizen science' is a useful encompassing term to describe the diverse range of approaches that involve people in science and monitoring in a noncontracted or voluntary capacity (Bonney et al., 2009b). However, we note that not all activities falling under this broad description would define themselves as 'citizen science' and it is important to be sensitive to the concerns of those practitioners. There has been rapidly growing interest in the use of 'citizen science', especially in North America, Europe, Australia and New Zealand (Bonney et al., 2014; Pocock et al., 2017; Theobald et al., 2015), and interest is growing elsewhere: in Africa (Citizen Science Association, 2017), Central/South America (Cunha et al., 2017b; Fundación Ciencia Ciudadana, 2017) and Asia (http://www.citizenscience.asia).

It is helpful to consider the different approaches in citizen science. One broad distinction is between contributory approaches (where participants are primarily involved as data collectors) and collaborative/cocreated approaches (where participants are involved in additional stages of the scientific process, including identifying the question of interest, designing methodologies, analysing data and using the results) (Bonney et al., 2009a; Shirk et al., 2012). Contributory approaches comprised the vast majority of 500 projects surveyed in a recent review (Pocock et al., 2017). However, the distinctions are not clearcut: even if some people are involved in the scope and design of activities (collaborative), many others can subsequently be involved in contributing data (contributory). Citizen science also includes both mass participation activities in which anyone can get involved, and those engaging interest groups and volunteer experts (Pocock et al., 2017; Tulloch et al., 2013b), including 'biological recording', for which there is a long history of recording by volunteer expert naturalists in some north European countries (e.g. Pocock et al., 2015b).

2.2 Participatory Monitoring as a Citizen Science Approach

While there continues to be debate about the use of the term 'citizen science' (Eitzel et al., 2017), we find it helpful here as a 'term of convenience', thus including activities that may not define themselves as 'citizen science'. One such activity is participatory monitoring (also called community-based environmental monitoring). Participatory monitoring is focused on participation by local people with a strong stake in their local environment, with the aim that the monitoring is defined by local people rather than being 'top down', scientist-led activities (Conrad and Hilchey, 2011; Danielsen et al., 2005a). It is mostly found in developing countries and the Arctic where community members are dependent on living resources for their livelihood and cultural identity (Danielsen et al., 2000; Johnson et al., 2015).

A focus is on direct benefits to the local participants because the information informs their role as resource managers (Danielsen et al., 2010; Evans and Guariguata, 2008). Following Chandler et al. (2017), we include participatory monitoring within our definition of citizen science, and henceforth use the term 'citizen science' with this broad sense. We note that other interpretations are possible: Kennett et al. (2015) contrasted participatory monitoring with 'citizen science': '[participatory] monitoring could benefit from the large-scale databases and knowledge integration pioneered by citizen science… [while] citizen science could benefit from the community-based monitoring practices used to build data-collection methods, analytical tools, communication networks and skilled workforces in culturally appropriate, place-based governance structures'. Specifically, they seemed to reference 'contributory' citizen science in developed countries when making valid points about how different approaches can gain benefit from each other.

Citizen science and participatory monitoring are each growing as global communities with international communities of practice for both participatory monitoring (http://www.pmmpartnership.com/) and citizen science (Bonney et al., 2014; Citizen Science Association, 2017). Historically, 'citizen science' (typically contributory) and participatory monitoring have tended to focus on different types of participants (the general public in contributory citizen science vs people whose livelihoods depend on natural resource management in participatory monitoring), in different parts of the world (developed vs developing countries), and for different purposes (e.g. regional and national monitoring vs data for local people to benefit from). However, some activities, e.g., community-based monitoring of illegal resource use, such as poaching and logging, have been described as both collaborative citizen science and participatory monitoring (Danielsen et al., 2010; Stevens et al., 2013). The nascent Citizen Science Global Partnership (https://www.wilsoncenter.org/article/concept-note-citizen-science-global-partnership) seeks, in part, to bring these communities together.

Danielsen et al. (2009) provided a conceptual description of five different types of monitoring in discussion about participatory monitoring that was subsequently verified by statistical analysis of published monitoring programmes (Danielsen et al., 2014b). It is helpful to compare these with citizen science approaches (Table 1). Specifically, the approaches where local people are involved in data collection (categories 2, 3 and 4 in Table 1) have potential to scale-up to contribute to global biodiversity monitoring.

Table 1 Different Types of Participatory Monitoring and How These Relate to Types of Citizen Science

Category of Monitoring	Primary Data Gatherers	Primary Users of Data	Comments
1. Externally driven, professionally executed	Professional researchers	Professional researchers	Costly, does not scale cost efficiently
2. Externally driven with local data collectors	Professional researchers, local people	Professional researchers	For example, 'contributory citizen science'. Has potential to be cost efficient compared to monitoring by professionals. Has potential to contribute to global biodiversity monitoring, but relies upon the enthusiasm of volunteers
3. Collaborative monitoring with external data interpretation	Local people with professional researcher advice	Local people and professional researchers	For example, 'collaborative citizen science' and participatory monitoring. Has potential to contribute to global biodiversity monitoring but also produces locally relevant outputs
4. Collaborative monitoring with local data interpretation	Local people with professional researcher advice	Local people	For example, 'collaborative citizen science' and participatory monitoring. Produces locally relevant outputs, and when the data is shared this could contribute to global biodiversity monitoring
5. Autonomous local monitoring	Local people	Local people	Does not serve additional benefits for larger-scale monitoring (if data and information are shared it becomes defined as category 3 or 4)

The first three columns are adapted from Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P.G., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Eenghoff, M., Fjeldså, J., Holt, S., Hübertz, H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jørgensen, E., Yonten, D., 2009. Local participation in natural resource monitoring: a characterization of approaches. Conserv. Biol., 23, 31–42.

2.3 Locally Based, Yet Global, Citizen Science

When fulfilling the vision of global biodiversity monitoring with citizen science, we suggest that it needs to be 'locally based, yet global' (Chandler et al., 2012; He and Tyson, 2017) (Fig. 1). The challenging question is what this means in practice. Throughout this chapter, we contend that

1. The local perspective is *essential* to the *success* of any biodiversity monitoring activity. This is the scale at which people choose to participate and benefits would be directly experienced by people. Participation will therefore be influenced by people's interests, and the application of data.
2. The larger scale (national to global) perspective is *important* to increase the *impact* of biodiversity monitoring. This larger scale is often where policy and management decisions are made and where funding may be obtained. The international scale can give impetus and focus to monitoring, via international targets such as the Aichi Biodiversity Targets (SCBD, 2010)

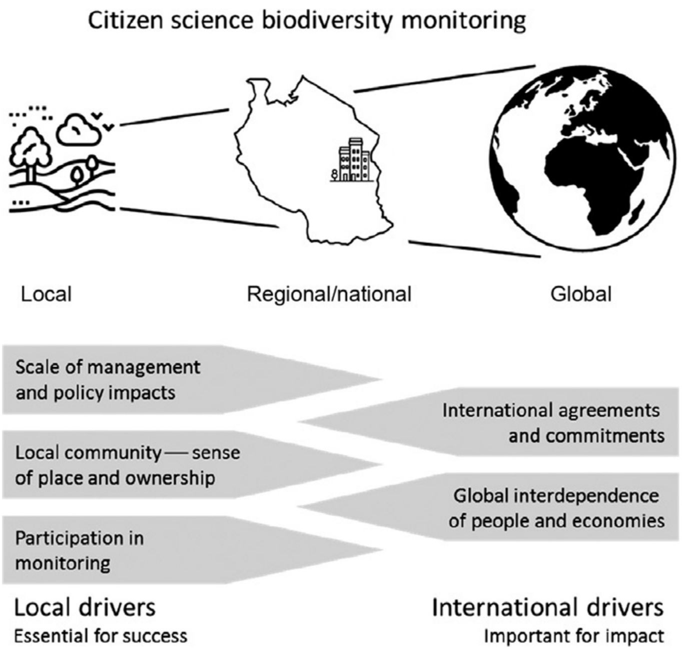

Fig. 1 There are different needs and drivers for biodiversity monitoring at different scales, as exemplified in this diagram. We contend that when considering citizen science biodiversity monitoring it is essential to meet both the needs of participants (at the local level) and it is important to meet the needs of funders and data users (at the regional to global level). *Icons CC-BY from thenounproject.com: 'landscape' by Becris, 'Tanzania' by Fatemah Manji, 'city' by Made by Made, 'earth' by David.*

and the United Nation's Sustainable Development Goals (UNGA, 2015) and via aspirations such as the essential biodiversity variables (EBVs) (Pereira et al., 2013) (see Section 3).

A different way of considering this is the need to focus on both the *product* (i.e. observations added to databases and analysed) and the *process* of volunteer biodiversity monitoring (the way in which people are recruited, retained and motivated) (Lawrence, 2006). Focussing solely on the national to international scale can lead to a 'demand-driven' process that prioritises the global needs for biodiversity monitoring information, and ignores local relevance, which can exacerbate asymmetric power dynamics (Ayensu et al., 1999; Lawrence, 2006). The actors who make 'demands' for data (e.g. government environmental bodies, international nonprofit organisations and professional scientists) often hold power in terms of funding, database ownership and access to resources. In contrast, local people (typically participating in a voluntary capacity) may hold less power for setting up the monitoring programs, but their involvement is essential for data collection, for the activities to generate local benefits and for them to be sustainable. In developing countries, participatory monitoring often serves the purpose of advocacy for socio-environmental justice (Stevens et al., 2013), empowerment (Lawrence, 2006), governance (Liu et al., 2014) or sustainable management of daily-use resources (Danielsen et al., 2005a), rather than regional or national benefits (Staddon et al., 2015). The Manaus Letter (Participatory Monitoring and Management Partnership (PMMP), 2015), which sought to raise the profile of participatory monitoring, explained this further. Key messages from the Letter include:

- Initiatives should be constructed from the bottom up, incorporating local as well as academic visions and knowledge;
- It is important to ensure high data quality and to standardise data collection at the necessary scales (among monitors, among communities and among initiatives, if the scale of monitoring is regional or global);
- Monitoring initiatives must reconcile and balance the interests and motivations of local, regional and global actors involved in the initiative and
- When monitoring initiatives are designed for use at the regional or global scale, they should ensure the return of information and results to participating local communities.

These recommendations align well with the subsequent Ten ECSA Principles for Citizen Science (ECSA, 2017) including the importance of feedback, data quality and involvement of participants.

3. THE GLOBAL NEED FOR BIODIVERSITY MONITORING

The aspiration for global biodiversity monitoring stems in large part from the demands of policy instruments that have regional, national and global scope. These 'green' instruments incorporate biodiversity data as part of existing frameworks (e.g. European Common Agricultural Policy), to ensure the implementation of conventions dedicated to managing species (Convention on Biological Diversity, Convention on Migratory Species of Wild Animals), and as part of global collaborative platforms that stipulate broad national level assessments (e.g. Intergovernmental Panel on Biodiversity and Ecosystem Services: IPBES). Beyond these dedicated policies, biodiversity data can be, and is, used by governments at all levels to assess the effects of other policy decisions and investments (e.g. infrastructure development) on biodiversity (Millenium Ecosystem Assessment, 2005).

Currently there is a gap between the biodiversity information available (e.g. in the Global Biodiversity Information Facility (GBIF)) and the information required to adequately assess the impact of conservation-oriented policies (Collen et al., 2008; Joppa et al., 2016; Tittensor et al., 2014), but could citizen science monitoring help to meet these needs? Recently, Danielsen et al. (2014b) looked at indicators underpinning 12 major international agreements and mapped onto these different types of monitoring approaches, ranging from scientist-driven to those undertaken by local people (Table 1). Overall, 63% of the existing 186 indicators in the 12 agreements were found suitable for some form of 'citizen science' (including 'participatory monitoring') (Danielsen et al., 2014b). Nine agreements (in the quadrants on the right side of the graph in Fig. 2) are well suited to involving local stakeholders in collecting monitoring data (with professional input for analysis), or both collecting and analysing monitoring data. The study did not look at local or subnational environmental policies, which might have even more potential for public involvement (Haklay, 2015), but there is clearly considerable opportunity for involving local stakeholders in collecting relevant data.

The findings of Danielsen et al. (2014b) showed that citizen science and community-based monitoring could enhance monitoring progress within global environmental conventions. However, they also have the potential

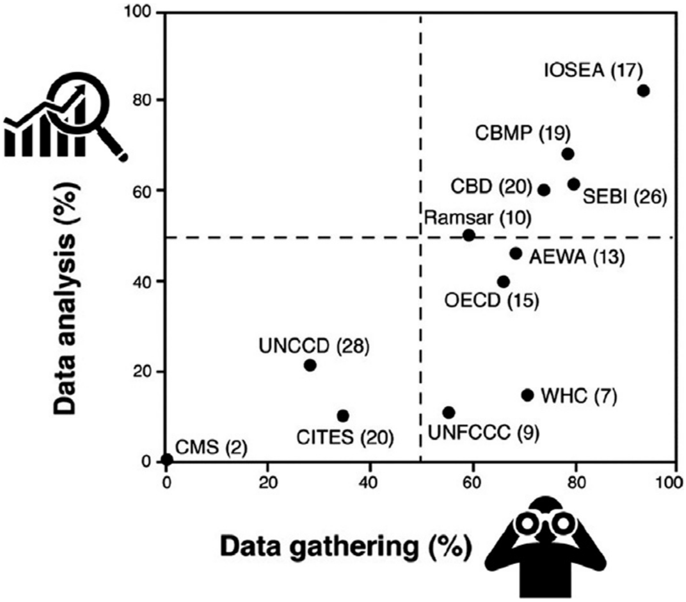

Fig. 2 Percentage of indicators from 12 international agreements that are suitable for local stakeholder involvement in data gathering and data analysis. For each agreement, we show the proportion of indicators that can be measured with the involvement of local stakeholders as data collectors (*x*-axis) and the proportion that can be measured by local stakeholders, who not only collect data but also process and interpret the data and present the findings to decision makers (*y*-axis). *Dashed lines* indicate 50% values for each axis. The number of indicators of each agreement is shown in *brackets*. *AEWA*, Agreement on the Conservation of African-Eurasian Migratory Waterbirds; *CBD*, Convention on Biological Diversity; *CBMP*, Circumpolar Biodiversity Monitoring Program; *CITES*, Convention on International Trade in Endangered Species; *CMS*, Convention on Migratory Species; *IOSEA*, Indian Ocean—South-East Asian Marine Turtle Memorandum of Understanding; *OECD*, Organisation for Economic Cooperation and Development; *Ramsar*, Convention on Wetlands of International Importance; *SEBI*, Streamlining European 2010 Biodiversity Indicators; *UNCCD*, United Nations Convention to Combat Desertification; *UNFCCC*, United Nations Framework Convention on Climate Change; *WHC*, World Heritage Convention. *From Danielsen, F., Pirhofer-Walzl, K., Adrian, T.P., Kapijimpanga, D.R., Burgess, N.D., Jensen, P.M., Bonney, R., Funder, M., Landa, A., Levermann, N., Madsen, J., 2014b. Linking public participation in scientific research to the indicators and needs of international environmental agreements. Conserv. Lett. 7, 12–24, reproduced with permission. Icons CC-BY from thenounproject.com: 'binoculars' by Luis Prado, 'analysis' by Arafat Uddin.*

to raise awareness, scientific literacy and enhance decision making for resource management (Pretty and Smith, 2004). Consequently, the social ambitions, as well as the monitoring needs, of the United Nations Sustainable Development Goals (UNGA, 2015) and the Convention on Biological Diversity's

Aichi Targets (SCBD, 2010) could also be supported by local stakeholder involvement in monitoring (West and Pateman, 2017).

Making progress internationally will benefit when biodiversity data can be harmonised globally (e.g. the EBVs; Pereira et al., 2013). For this, data from disparate sources would be harmonised for a minimum set of critical variables required to monitor biodiversity change and the impacts of interventions (Kissling et al., 2018). Citizen science can successfully contribute data into approaches such as the EBVs (Chandler et al., 2017), e.g., its role for monitoring alien species occurrence, status and impact (Latombe et al., 2017; McGeoch and Squires, 2015).

4. THE GLOBAL POTENTIAL FOR BIODIVERSITY MONITORING WITH CITIZEN SCIENCE

At present, there is a heterogeneous distribution of biodiversity monitoring and recording across the world (Beck et al., 2014; Chandler et al., 2017; Proença et al., 2017; Schmeller et al., 2009). Furthermore, there is pressing need to assess data biases and gaps in existing databases, and improve coverage (taxonomic, spatial and temporal) ensuring openness and accessibility to facilitate analysis of trends (Edwards, 2000; Hortal et al., 2008; Meyer et al., 2016; Troudet et al., 2017).

Here, we undertook a simple analysis to describe the global potential for citizen science and community-based monitoring to contribute to biodiversity monitoring. We are rapidly approaching a global human population of 8 billion which is distributed unevenly across the world (Fig. 3A). We considered the capacity for species to be recorded within a location (i.e. a 5 arc-minute grid cell in our analysis) to be a function of the number people and the number of species at that location. We used the species richness of mammals, birds and amphibians as a proxy for total species richness (Jenkins et al., 2013), which is heterogeneously distributed (Fig. 3B). The product of human population and species richness gives the potential for people to record species: the observation potential (Fig. 3C). Specifically, we use log-transformed human population and species richness [$y = \log_{10}(x+1)$ to account for zeros in the data], and scaled these to lie within the range (0,1) [scaled $y = y/y_{\max}$]:

$$\text{Observer potential} = \text{human population (scaled and log transformed)} \times \text{species richness (scaled and log transformed)}$$

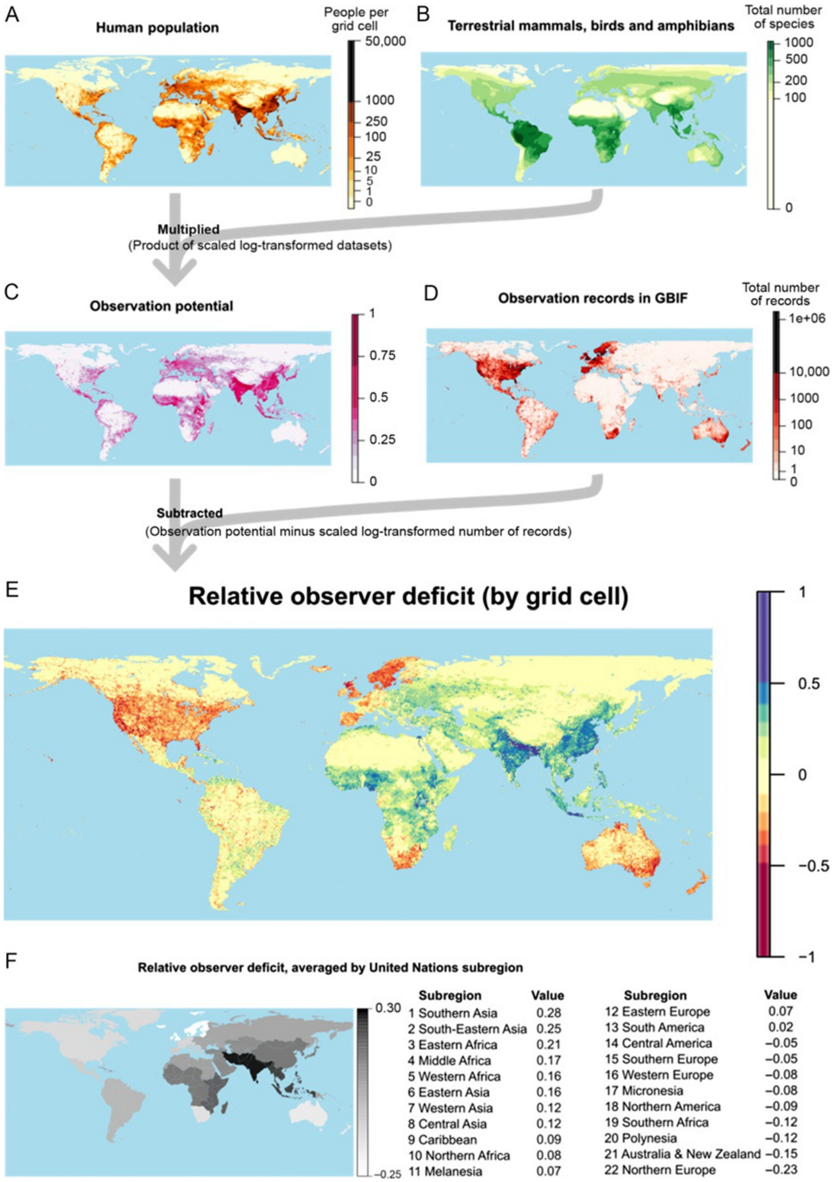

Fig. 3 The global distribution of (A) human population and (B) total species richness of mammals, birds and amphibians. The product of these, once log transformed and scaled to lie in the range (0,1) was (C) the observation potential. The observation potential minus (D) the number of records in GBIF (log transformed and scaled to lie in the range (0,1)) gives the index of (E) the relative observer deficit, which is (F) aggregated (using arithmetic mean) to the United Nations subregion (*darker colours* indicate higher relative observer deficit). All data are shown for 5 arc-minute grid cells.

(Continued)

There are nearly 1 billion records in GBIF (https://www.gbif.org) from many biodiversity monitoring activities. Each record represents a single species observation at a specified time and place. Over half of records are from citizen science, although with a strong bias towards birds (especially via eBird, a dominant provider) and towards Europe and North America (Amano et al., 2016; Chandler et al., 2017). Comparing the observer potential with the number of records in GBIF (Fig. 3D) gives an indication of how well the observer potential is being met. To quantify this, we calculated the observer deficit as the difference, for each location, between the observer potential and the count of GBIF records (Fig. 3E). As with human population and species richness, the count of GBIF records was log transformed ($y = \log_{10}(x + 1)$) and scaled to lie in the range (0,1).

$$\text{Relative observer deficit} = \text{observer potential} - \text{number of GBIF records (scaled and log transformed)}$$

Observer deficit therefore ranged from +1 (high observer deficit: few GBIF records relative to the number of people and the richness of biodiversity, and greatest potential to increase records, e.g. through citizen science) to −1 (low observer deficit: many GBIF records relative to the number of people and the richness of biodiversity). Of course, whatever the value of observer deficit, there is still potential to increase the amount of observation effort in that location. Relative observer deficit provided a standardised measure to compare locations and showed that there is substantial unevenness in\its distribution across the world (Fig. 3E and F; Table 2). The highest relative observer deficits are southern and south-eastern Asia and sub-Saharan Africa (except Southern Africa). South America has moderate observer deficit because relatively few people live in the most species-rich

Fig. 3—Cont'd *Data on vertebrate species was downloaded from BiodiversityMapping.org and is based on Jenkins, C.N., Pimm, S.L., Joppa, L.N., 2013. Global patterns of terrestrial vertebrate diversity and conservation. Proc. Natl. Acad. Sci. U. S. A. 110, E2602–E2610. Data were provided by IUCN (mammals and amphibians) and BirdLife International and NatureServe (birds). Human population data were obtained from GPWv4 (Center for International Earth Science Information Network—CIESIN—Columbia University, 2016). Note that the human population data are aggregated at different spatial resolutions depending on availability of data in each country. We thank Tim Robertson at GBIF for support in downloading the data.*

Table 2 The Countries in the World With the Highest and Lowest Average Value of Observer Deficit

Rank of Country	Highest Observer Potential (Highest First)	Lowest Observer Potential (Lowest First)
1	Bangladesh	Sweden
2	Burundi	UK + Isle of Man
3	Nigeria	Denmark
4	Rwanda	Norway
5	India	Luxembourg
6	North Korea	Estonia
7	Moldova	New Zealand
8	Vietnam	Portugal
9	Uganda	Costa Rica
10	Sierra Leone	Belgium
11	Cote d'Ivoire	South Africa
12	Togo	Spain

Averages were calculated as the mean across 5 arc-minute grid cells covering each country. Very small countries (less than 10 grid cells) were excluded.

areas and has relatively good data in GBIF (although see Section 6.1 for discussion about opportunities and barriers to citizen science biodiversity monitoring in Chile).

While this is a simplistic measure of the potential of citizen science, it demonstrates the unrealised potential for citizen science (i.e. highest observer deficit). This could help in identifying where to focus efforts for greatest gains in global knowledge of biodiversity, especially when considering other cultural factors, including access to technology (Section 5.4). For instance, the burgeoning middle class in emerging economies in Asia (Kharas, 2017) are likely to have good access to technology and are in regions with high observer deficit, meaning that it could be fruitful to engage with them as potential participants. Also, taxa of functional importance, for example, many plants and pollinating insects, are underrepresented in GBIF (Chandler et al., 2017) and could be fruitful focus of future effort (Troudet et al., 2017).

5. APPROACHES FOR BIODIVERSITY MONITORING WITH CITIZEN SCIENCE: WHO, WHAT AND HOW?

We have discussed the global-to-local approach required for sustainable and impactful biodiversity monitoring with citizen science (Section 2), the international need for biodiversity information (Section 3) and the potential for citizen science to meet this need (Section 4). The question is how this can be achieved. Here, we discuss different issues relating to the implementation of biodiversity monitoring with citizen science. Ultimately any recording, whether initiated by local participants or by programme organisers, should meet two important requirements:

1. Recording should be *feasible* for participants: it should engage participants, fit with their motivation and interests (which could include their own use of the data) and it should enable them to contribute with confidence.
2. Recording should be *useful* by being of sufficient quality for its intended scientific purpose. Quality can be considered in two ways. Firstly, individual records should be accurate (within prescribed limits of acceptability). Efforts should be put in place during the project design to support accuracy, and appropriate verification should be used to prove that accuracy that is fit-for-purpose (Kosmala et al., 2016). Secondly, the dataset as a whole should (after analysis) be able to provide valuable, unbiased and reliable information, e.g. on the status of an individual species, or as a measure/proxy of habitat quality (Buckland and Johnston, 2017).

In this section we discuss: who is recording, what they are recording and how the information should be used.

5.1 Who Are the Potential Volunteers?

Broadly we suggest that biodiversity monitoring could involve three types of participants: people who are already interested and have expertise in recording wildlife (Pocock et al., 2015b); local stakeholders who are involved in participatory monitoring to protect land and resources (Danielsen et al., 2005a,b); and the general public who become engaged with existing activities. Opportunities and challenges are associated with each potential audience, and all are key to scaling up to increase coverage of global biodiversity monitoring.

Understanding what motivates people to engage in citizen science is important (Conrad and Hilchey, 2011; Geoghegan et al., 2016;

Lawrence, 2006). It may be helpful to distinguish between intrinsic and extrinsic motivations (Blackmore et al., 2013). Extrinsic frames are those that relate to self-interest; so for citizen science this would include an appeal to monitoring the benefits we get from nature. However, long-term participation is better supported through reference to intrinsic frames, which are about connections with nature and people, positive action, the appreciation of beauty and self-discovery (August et al., in review). Participatory citizen science approaches can result in personal transformation and sustain long-term motivation among participants (Lawrence, 2006), but more participatory approaches may have a stronger impact in terms of the volunteers' engagement, interest and empowerment (Rotman et al., 2012; West and Pateman, 2016; Wilderman et al., 2004). Motivations can also be influenced by level of education and the expectation of a reward, as found in a recent study on the potential of citizen science for agricultural research (Beza et al., 2017). The long-term motivation of participants in the United States, India and Costa Rica was found to be affected by many different aspects, but poor communication and inadequate technical infrastructure were found to be strong demotivators (Rotman et al., 2014). Overall, there is much to be learned about how people in cultures and demographics across the world are motivated to engage with citizen science. However, for individual activities, the best approach is to codesign monitoring activities along with potential participants.

5.2 How Should Biodiversity Be Recorded?

Related to the motivations of the participants is the way in which biodiversity is recorded. This can be done in many different ways (Pocock et al., 2017) (Table 3). Whichever approach is used, it is important to be clear about the aims of the project (Buckland and Johnston, 2017; Lindenmayer and Likens, 2010; Pocock et al., 2015a).

Fully structured recording has advantages because the data will be consistent and can easily be analysed and aggregated. As the sites are selected by the organisers of the activity, they can be chosen strategically or randomly, and the resulting data is representative, rather than being biased by the participant's choice (Fragoso et al., 2016; Newson et al., 2005). However, participants are required to travel and visit specific locations so this requires dedication and is most suited to participation by volunteer experts. It can require a lot of investment by volunteer coordinators to support

Table 3 Summary of Different Approaches for Recording Suitable for Biodiversity Monitoring, as Discussed in the Text

Monitoring Approach	Choice of Location and Time	Use of Sampling Protocol
Fully structured recording	Organiser's choice	Following a protocol at all times and places selected by project organisers (the scientific ideal being randomised locations)
Semistructured recording	Participant's choice	Following a monitoring protocol but at times and/or places of the participant's choice
Unstructured recording, with assessment of effort	Participant's choice	None, although 'effort' should be recorded in a consistent way
Unstructured recording	Participant's choice	None
Participatory assessment	In the participant's locality	Focus group discussions, interviews, documentation of oral history

the retention and recruitment of volunteers to ensure sufficient spatial and temporal coverage.

Semistructured recording also uses specific monitoring protocols, but the time and/or location of the sampling is at the participant's choosing. This ranges from high-skilled ecological surveys through to mass participation projects where a structured protocol is followed, e.g., making observations in one location for a fixed period of time. The benefit of having a structured protocol is that it helps to standardise sampling effort, thus making the results more comparable across surveys. It can also be suitable for participation by less-skilled volunteers because the protocol is very clear, although for ensured success, protocols should be designed in collaboration with professionals and potential participants. Selection bias can be expected where volunteers choose sites and/or times for recording because, for example, recorders tend to favour locations closer to home or in protected areas (Boakes et al., 2010; McGoff et al., 2017; Tulloch et al., 2013a), or where there are currently presences (Buckland and Johnston, 2017). This can make it more difficult to generalise about the state of the overall environment. One step to help account for selection bias is the incorporation of species distribution modelling, by combining remotely sensed habitat information with species occurrence data (Coxen et al., 2017) or statistical correction (Robinson et al., 2018).

Unstructured recording is typical of biological recording and 'mass participation' citizen science (Pocock et al., 2017). For expert naturalists, this is beneficial because they are not constrained by specific protocols, but there is the same risk of selection bias as semistructured recording. New statistical approaches can be used to extract information from these unstructured data (Hill, 2012; Isaac et al., 2014; Maes et al., 2015; van Strien et al., 2013) including on the impacts of environmental change, e.g., the impacts of pesticide use (Woodcock et al., 2016). However, the lack of clarity and structure could be demotivating for public contributors (August et al., in review). The quality of the information can be enhanced by including an assessment of effort, e.g., distance travelled, time spent observing or using list-based recording (Sullivan et al., 2014; van Dyck et al., 2009).

All the methods above are primarily to collect direct observations of the current state of biodiversity. There is also value in considering approaches from social sciences for gathering information, e.g., focus group discussions (Danielsen et al., 2014a,c), interviews (Jones et al., 2008; Topp-Jørgensen et al., 2005), oral history documentation (Fernández-Llamazares and Cabeza, 2017; Mustonen, 2015) and participatory mapping (Rich et al., 2015). These are probably particularly useful for gaining accurate information on change in state over time (i.e. trends in abundance).

5.3 What Should Be Recorded?

5.3.1 Different Variables That Can Be Recorded

Biodiversity recording traditionally has involved recording the presence of an organism at a certain place and time, and undertaking analysis on the collation of such occurrence records (Hochachka et al., 2012; Powney and Isaac, 2015). In parts of the world and for many species groups this is the only quantitative biodiversity information available and so many decision makers rely on this information, e.g., in creating Red Lists of threatened species (Gardiner and Bachman, 2016). The simplicity of these records means that they can be easily harmonised and collated in large-scale databases such as GBIF (Chandler et al., 2017) and used for EBVs (Kissling et al., 2018; Pereira et al., 2013). However, other variables can also be recorded and may be as, or more, useful for biodiversity monitoring (Table 4).

Table 4 Variables That can be Recorded to Contribute to Monitoring Biodiversity

Biodiversity Variables	Description	
Uniquely identifiable individuals	Recording individually identifiable organisms across space and time	
Occurrence	Reporting when a species has been recorded in a given area. This is presence-only data, so there is no information on nondetections	
Presence/absence	Reporting whether a species has been detected or not in a given area (including recording against a checklist)	
Abundance	Total number of individuals of a species recorded over a discrete period of time in a given area	
Physiological attributes	Assessment of health or quality of an organism, e.g., measurement of size	
Phenology	Reporting periodic biological events for selected taxa/phenomena at a given location, e.g., timing of breeding, leaf coloration, flowering, migration	
Interactions	Interactions between species, which could be long-lasting or short-term, e.g., insects visiting flowers	
Habitat quality	Presence/absence of indicator species, or assessment of habitat attributes, e.g., vegetation height	
Ecosystem function	Measurement of a specific aspect of ecosystem functioning, e.g., fruit and seed set or decomposition	

See text for further description.

Icons CC-BY from thenounproject.com: 'zebra' m. turan ercan, 'stork' by Georgiana Ionescu, 'beetle' by Ben Davis, 'fish' by Vladimir Belochkin, 'calendar' by Aleksandr Vector, 'pollination' by Jurac Sedlák, 'grass' by Hamish, 'strawberry' by Yeonkun.

Interpreting occurrence records is challenging because observer coverage varies across space and time (Isaac and Pocock, 2015): i.e., does the absence of a record mean the absence of the species or the absence of an observer? More informative analysis can be undertaken when we have knowledge of, or can infer, nondetections so creating 'presence–absence' datasets (Table 4). These can be available in structured and semistructured recording (Table 3), although for single species the motivation to report a presence is different to the motivation to reporting an absence. One simple approach to achieve this is encouraging observers to report a full list of sightings (Szabo et al., 2010), as can be facilitated through reporting systems such as eBird (Sullivan et al., 2014).

Another commonly collected biodiversity variable is abundance. This is most valuable when it is standardised and the effort is recorded (see Sections 6.2 and 6.3), e.g., the number of individuals in a location over a set time period (trends in time) or revisiting set transects (Dennis et al., 2017; Vianna et al., 2014). For mobile or cryptic species the number seen is often taken as an index of relative abundance so changes in counts are often taken as an index of change in true abundance, although this can be confounded with seasonal or long-term changes in detectability.

For a few animal species and some plants, each individual can be uniquely identified or marked, allowing true population size and other demographic parameters to be estimated using mark-recapture analysis, e.g., using photographic records from volunteers for large whales and sharks (Davies et al., 2013) or zebras (Parham et al., 2017), or mark-recapture or mark-resighting which is especially popular for birds (Greenwood, 2007). This is also relevant for recording plant phenology, especially for trees, for which individuals can be tracked through seasons and across years.

The presence and/or abundance of specific indicator species or communities of species are often used as a measure of habitat quality, including to assess the impact of interventions. Measures of other attributes of individuals, e.g., fish size, tree size or disease status (Danielsen et al., 2014c) are valuable because they provide more information about the quality of the individuals, and so are especially relevant where species are being harvested (although care needs to be taken to account for sampling biases when interpreting the data). Species interactions are also important because these generate many ecosystem services and disservices. The individual interactions can be long-lasting, e.g., epiphytic lichens or fungi on host plants, or short term, e.g., predation and flower–pollinator interactions. Finally, as well as recording functionally important groups, it can also be useful to monitor ecosystem function directly, e.g., decomposition (Keuskamp et al., 2013), pollination (Birkin and Goulson, 2015) or pest control.

5.3.2 Species-Level Recording: A Benefit or a Constraint?

For many biodiversity scientists, species-level data are of key interest, but for citizen science, species-level recording could be constraining because we are limited (i) by the availability of people who can, or want to be able to, accurately identify taxa to the species level and (ii) to the taxa where this could be feasibly achieved (thus excluding the majority of invertebrate groups). Birds, in particular, are extremely well recorded by volunteers, but even for them there is still patchy coverage of recording by volunteers (see Section 6.2). We should be careful not to 'cling on to the sanctity of the species' (quoting Raffaelli, 2007 who describes this in a different context) when developing a vision for global biodiversity monitoring with citizen science.

Rather than recording to the species level, it may be suitable to record aggregated groups (e.g. 'morphotypes' comprising individuals that look similar). This is used by 'parataxonomists' in rapid biodiversity assessments in highly biodiverse locations (Krell, 2004; Schmiedel et al., 2016). Morphotypes are also used as indicators of habitat quality where there is knowledge of their sensitivity to particular drivers of environmental change, e.g., air quality (Seed et al., 2013) and water quality (Graham et al., 2004; Wright et al., 1998). Morphotype classifications could be codesigned with professional scientists (who can ensure that the groups are functionally informative for the intended purpose; Lawler et al., 2003) and potential participants (who can test whether distinguishing these groups is practicable; Roy et al., 2016), ensuring the groups are morphologically and functionally distinctive (e.g. Ullmann et al., 2010). For instance, trends in the numbers of bright blue butterflies in European grasslands could be just as informative as the trends in the counts of the individual species (comprising bright blue males and brown females, but with subtle differences between species). However, effective sharing of morphotype data is a challenge, especially if it is not known which species are in each morphotypes.

5.4 How Can Technology Support Recording?

The technological revolution of the late 20th and early 21st century has brought dramatic changes to citizen science for biodiversity monitoring: shaping what is possible, and how monitoring can be undertaken (August et al., 2015). Data of many types can now be captured, including images, videos and sounds. These new data can support better verification and allow new questions to be addressed, e.g., Pipek et al. (2018). Networks of technologies allow these data to be shared, via the internet, in globally accessible datasets. Finally, the data and their analysis can be made available locally, to further motivate participants and inform them, e.g., about the impacts of local resource management.

5.4.1 Data Collection

When used in citizen science, technology must be *accessible*, *useable* and *useful*, all of which have increased in recent time. The gradual reduction in cost of hardware has increased accessibility while advances in design and sensors have increased usability and usefulness. Modern sensors allow a range of data to be collected in the field by volunteers. These technologies include, digital cameras, acoustic recording devices, GPS, drones and eDNA among many others. At a local scale, technological developments can lead to greater potential for local action. For example, small and low-cost pollution sensors can be used in participatory monitoring to detect local pollution events and prompt local government action (Borghi et al., 2017; Glasgow et al., 2004; Toivanen et al., 2013).

Mobile phones have created an amazing resource for citizen science (Fig. 4). Smart phones combine connectivity technologies (i.e. mobile

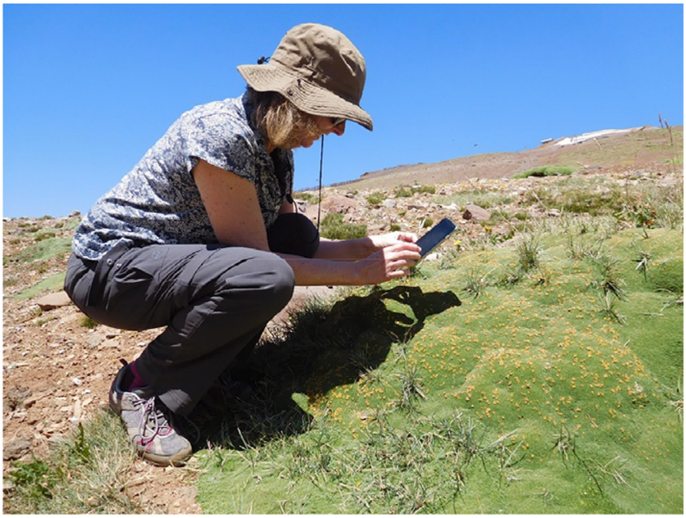

Fig. 4 One of the authors (H.E.R.) as a participant in citizen science demonstrating the way technology facilitates biodiversity recording. She is using a smartphone to upload a ladybird beetle sighting in the high Andes in Chile (see Section 6.1) to the Chinita arlequín project (http://www.chinita-arlequin.uchile.cl/).

network and internet) with sensor technologies such as cameras, GPS and microphones. The ubiquity of mobile technology in much of the world (Pew Research Center, 2016), and the ease with which data can be captured and transmitted to central data stores has made them a popular tool for both locally focused participatory monitoring, e.g., EpiCollect (Aanensen et al., 2009), and global citizen science, e.g., eBird (Sullivan et al., 2014). However, mobile phone use varies: in a study of farmers in India, Honduras and Ethiopia more than 90% of people owned mobile phones, but less than 60% were always connected to mobile phone networks, and very few (<10%) used the internet via their phones (Beza et al., 2017). Smartphone ownership varies; it is currently very high in developed countries, high in China and Turkey (58%–59%), low in India, Indonesia, Kenya and Nigeria (17%–28%) and very low in other countries, including Ethiopia (4%) (Pew Research Center, 2016). There will also be substantial variation within countries and across demographics due to access to mobile networks and the interrelated variables of income, education and location (e.g. rural vs urban). There are few studies available on the role of technology in locally based biodiversity monitoring in real-life cases (Brammer et al., 2016), but a recent study in Cambodia's Prey Lang forest (Brofeldt et al., in press) was able to successfully collect large amounts of high-quality data using smartphone apps. Multiple entry points along a decreasing technological hierarchy such as smartphone, web application and face-to-face communication is one way to address generational and cultural differences in use of new technology.

Social media, such as Facebook and Twitter, provides a valuable tool for the organisation and support of monitoring by acting as a forum. Through social media, disparate people can come together and share knowledge and discuss topics of interest. It can also be used for groups to self-organise, such as the Garden Bioblitz in the United Kingdom (http://www.gardenbioblitz.org/) which was initiated and established via social media. Despite its prevalence, social media does not facilitate the efficient databasing of biodiversity observations: platforms designed for biodiversity recording are better because they provide consistency for taxonomic names, locations and dates.

5.4.2 Making Global Databases From Local Datasets

Greater global connectivity, facilitated by technology, has given rise to greater sharing of data. Centralisation of data, e.g., in GBIF, allows large-scale analyses to be undertaken. There are practical barriers to the flow of data from local to global scales. These include the time and resources required to submit the data in a standardised format (Wieczorek et al., 2012). The submission of local data to global datasets often does not have a tangible benefit for individual organisers, so if data are collated locally then sharing the data can be low on the list of priorities of busy local organisers and could even threaten the sustainability of participation (Pearce-Higgins et al., 2018). Additionally, sensitivities may mean that data are shared with reduced locational precision or with limits on who can view the data (Groom et al., 2016). These barriers to data sharing are not technological, but economical, institutional and motivational (Thessen and Patterson, 2011), but they must be addressed to realise the potential of the local to global scaling in citizen science.

Some projects allow individuals to submit directly to a central global platform, bypassing the need for local organisers to summarise, format and submit data themselves. This also saves the cost of maintaining individual databases for each project. This process directly links the local to the global but may bypass established data quality processes and personal interactions that may exist with local coordinators. Also where databases are maintained centrally (e.g. in North America or Europe) there can be issues with perceived ownership of the activity and its data (Pulsifer et al., 2011), and there is the risk of developing 'one size fits all' solutions. One solution is the development of international databases with locally relevant data portals, developed and run by local organisations. This approach has been adopted by eBird (see Section 6.2), iNaturalist (e.g. its Mexican version Naturalista http://www.naturalista.mx/), iSpot (e.g. its South African version https://www.ispotnature.org/communities/southern-africa) and for the Kenyan Bird Map (see Section 6.3). This can also be done locally, with projects such as iRecord in the United Kingdom (http://www.brc.ac.uk/irecord/) being a single data infrastructure but with local instances for specific user groups (e.g. those interested in recording bees or fungi). The City Nature Challenge is an example of a project benefitting on the local to global potential of citizen science. It was a distributed global bioblitz (>60 cities on four continents in 2018) enabled through the use of a common app using the iNaturalist platform.

5.4.3 Data Analysis and Feedback to Participants

The centralisation of data has allowed for analyses and data visualisation at large spatial scales. These can be shared with widely with participants via web and mobile interfaces. While traditionally analyses would be carried out by a project organiser or third party analyst, interactive websites now allow users to control the visualisation of data and in some instances the nature of the analysis (Belbin and Williams, 2016). These advances help to close the data flow cycle, enriching the experience of participants and empowering them in local resource management. This has been shown to increase the retention of volunteers as well as the quality of their data (Blake et al., 2012).

Data collated by projects can be used to create systems that aid participants in future data collection, including systems that validate new records based on expectations from previous records. For example, these systems are typically able to identify records that come from outside the known geographic distribution of the species (e.g. the United Kingdom's 'record cleaner' developed by the National Biodiversity Network) and more verified images of species aids iNaturalist's species recognition software to more accurately propose identifications to users. More advanced systems are able to use collected data to predict which species a participant is likely to observe, given their location and time of year, and present them with a guide to those species (Goldsmith et al., 2016). These technologies can create a virtuous cycle whereby data collected are used to improve the quality of future data collection and the motivation of those collecting the data (van der Wal et al., 2016).

5.5 How Should the Data Be Used to Produce Relevant Outputs?

Ultimately one of the aims of monitoring is its impact on natural resource management and conservation (Danielsen et al., 2007). There can be impact at a local scale, with the participants being users of the data, as for some participatory monitoring and collaborative citizen science projects (Earthwatch Institute, 2017). However, often it is valuable for the information to be collated at a larger scale to influence national policy making through provision of trends in 'indicator' groups or calculated metrics (e.g. of ecosystem health). This requires two things: that the data are analysed and interpreted; and that the information is collated, and this can be done in either order (Fig. 5).

The most intuitive way of collating information is to collect data into a single database or database framework at a regional, national or international level. This is the approach of projects such as iNaturalist, eBird (see Section 6.2) and the Freshwater Information Platform (FIP; see Section 6.6),

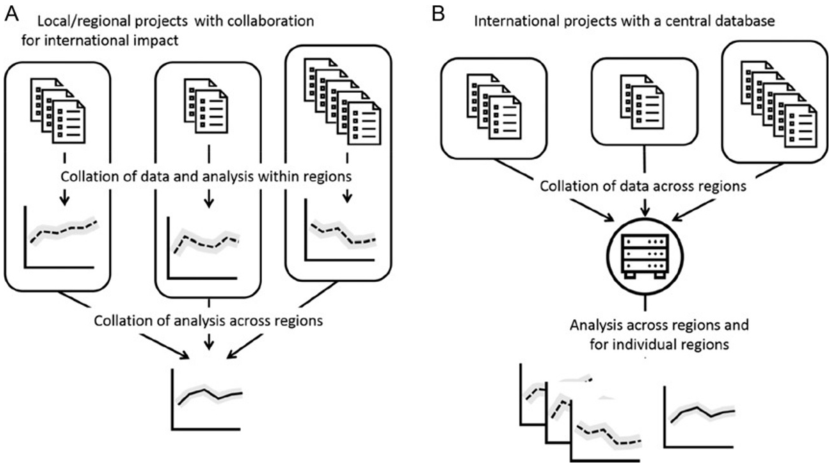

Fig. 5 Examples of two different approaches for adding value to individual monitoring projects by collating information at a larger scale (regional, national or global). *Icons CC-BY from thenounproject.com: 'list' by unlimicon, 'database' by Chameleon Design. Graphs by the author.*

which also then share their data with GBIF as a global repository of biodiversity data. Alternatively, meta-analytic approaches can be used to collate analysis, rather than collate the data themselves, e.g., the collation of country-level trends to create supranational indices for butterflies (van Swaay et al., 2008). These outputs can be used to report on biodiversity trends and monitor the impact of management interventions, including through policy.

6. CASE STUDIES OF STEPS TOWARDS GLOBAL BIODIVERSITY MONITORING WITH CITIZEN SCIENCE

Thus far we have discussed some principles related to the potential for global biodiversity monitoring with citizen science. In the following section we illustrate these principles with reference to current and proposed activities. We explore the benefits and barriers of citizen science in a country (Chile) with no long history of citizen science (Section 6.1). We compare two projects based on birds showing how: activities can have local and global perspectives (eBird: Section 6.2); and how structured monitoring adds value to the data (Kenya Bird Map: Section 6.3).

We discuss how working with local participants supports sustainable recording with examples from community monitoring in New Zealand (Section 6.4), developing technology for plant recording in Madagascar (Section 6.5) and working locally but in a global network through Freshwater Watch (FWW) (Section 6.6). Finally, we bring these together in a proposal for global monitoring of pollinators with citizen science (Section 6.7).

6.1 Assessing Opportunities for Biodiversity Monitoring in Chile With Citizen Science

Chile is considered to be one of the 35 biodiversity hotspots in the world (Mittermeier et al., 2011), and about 25% of the described species are endemic (Gligo, 2016; Ministerio del Medio Ambiente, 2014). Biodiversity monitoring is important here, especially because of the potential impact of major environmental change, including volcano eruptions, forest fires and land use change (Martinez-Harms et al., 2017; Sala, 2000). There is a recognised need for biodiversity information across Chile (Gligo, 2016; Ministerio del Medio Ambiente, 2014), but, despite government efforts, information is still incomplete. Participation in recording from Chile's 17.5 million inhabitants would greatly increase our knowledge.

A 1-day meeting on citizen science on biodiversity was held at Pontificia Universidad Católica de Chile in January 2017 to assess opportunities, barriers and topics for using citizen science to gather biodiversity data in Chile (using the same approach as implemented previously in East Africa; Pocock et al., in review). This meeting involved 31 professional participants (http://www.kauyeken.cl/con-exito-se-realizaron-el-taller-y-los-seminarios-sobre-ciencia-ciudadana/) from a range of organisations with an interest in citizen science including universities, colleges, NGOs, the Ministry of the Environment, the National Forestry Corporation (CONAF) and the Chilean Navy. In summary: (1) participants completed a short questionnaire in advance of the workshop to list the barriers, opportunities and topics they considered to be a priority for advancing citizen science in Chile; (2) responses were compiled and refined through discussion during the workshop; and (3) participants anonymously voted for priorities in each category (scoring 3, 2 and 1 for their top, second and third priority) and these scores were summed to rank the barriers and opportunities (Table 5) and the priority topics (Table 6) for biodiversity citizen science in Chile.

Table 5 The Top Opportunities (a) and Barriers (b) to Implementation of Citizen Science for Biodiversity Conservation in Chile

a.

Overall Rank	Opportunities	Total Number of Votes	Total Score
1	Increase in sampling (improved spatial and temporal coverage of data)	19	45
2	Improved knowledge of the natural environment for citizens and scientist	17	36
3	Sense of belonging with our natural and social environment	14	33
4	Improved networks between citizens, scientists and government agencies for managing environmental problems	14	22
5	Produce useful information for decision making	12	21
6	Empowerment of local communities	11	18
7	Strengthening the relation between citizens and science	6	11
8	Free access to engage and participle in science projects	3	6

b.

Overall Rank	Barrier	Total Number of Votes	Total Score
1	Disconnection between scientists and citizens	26	63
2	Lack of adequate resources (e.g. funding, time)	15	26
3	Citizens disconnection with the natural environment	8	17
4	People do not find the research problem a priority	7	15
5	Lack of validation of citizen science from the scientific community	6	12
6	Data quality and its management	5	12
7	Lack of commitment from volunteers and scientists	4	10
8	Limited outreach and publicity for citizen science projects	5	9
9	Technology limitations for some groups of citizens (e.g. lack of access to internet; lack of technology literacy by older people)	5	6
10	Complexity of the research methods	3	6

Table 6 Topics Suggested as Priorities for Citizen Science for Biodiversity Conservation in Chile

Overall Rank	Topic	Total Number of Votes	Total Score
1	Species distribution and diversity (both native and alien)	25	66
2	Monitoring the effects of humans on ecosystems	16	28
3	Assessing abiotic variables important for biodiversity conservation	14	23
4	Illegal or harmful activities (poaching, close season times, etc.)	9	17
5	Assessing ecosystem services (e.g. pollination)	8	16
6	Assessing habitat quality through indicator species	9	14
7	Human dimension of conservation biology (e.g. native biodiversity use and management)	6	14
8	Emerging wildlife diseases	5	8
9	Species phenology (e.g. blooming, migration)	4	6

A number of overarching themes emerged from the collaborative prioritisation (Tables 5 and 6). For example, scientists were seen as disconnected from citizens, but citizen science was seen as an opportunity to improve communication between citizens, scientists and government agencies. It was also suggested that there is a need to improve the scientific literacy of people and consequently increase their confidence to participate in science and engage in scientific debates. In order to identify organisms to the species there is a need for additional resources and training for experts and nonexperts alike, which would support the gathering of information on the distribution and diversity of species (Table 6). However, monitoring functional morphotypes (rather than species) may be sufficient for addressing several of the topics, including human impact on ecosystems (see Section 5.3.2).

There has been a recent growth in citizen science activities in Chile developed by different organisations, for example, to monitor rainfall (http://milluvia.dga.cl/index.php), beach litter (http://www.cientificosdelabasura.cl/) and an invasive species of ladybird (http://www.chinita-arlequin.uchile.cl/).

Social media has a major role in promoting citizen science activities (see Section 5.4), e.g., Facebook groups for Murciélagos de Chile (monitoring bats), Moscas Florícolas de Chile (monitoring flower-visiting flies) and Salvemos Nuestro Abejorro (monitoring an endangered bumblebee). The growth of new initiatives has led to the creation of Fundación Ciencia Ciudadana (http://cienciaciudadana.cl/), a Chilean organisation that promotes citizen science and has recently published a Citizen Science Guide (Fundación Ciencia Ciudadana, 2017). Participatory monitoring was piloted in protected areas of Patagonia (Aysén; Region XI) by CONAF and the National History Museum of Santiago in 2003 (Danielsen et al., 2005b).

Citizen science is a relatively new concept in Chile, meaning it serves as a useful case study in exploring the potential for global biodiversity monitoring with citizen science. Assessments of the potential for citizen science as in Chile (as discussed here) and in East Africa (Pocock et al., in review) provide evidence to prioritise issues and raise the profile of citizen science.

6.2 eBird: Being Relevant to Local Participants While Global in Ambition

As we have discussed in this chapter, one way for citizen science to contribute to global biodiversity monitoring is to collate observations globally via a single project. Birdwatching is a popular pastime across the world, and the observations that people make have great value for scientists if they can be collated and analysed. eBird is one project collating information on sightings of birds and is the largest source of global information about the distribution and abundance of bird species currently available, with most of the data from volunteers (Amano et al., 2016; Sullivan et al., 2009, 2014). As of May 2018, more than 400,000 unique observers had submitted over 29,000,000 complete checklists to eBird, including 98% of the world's bird species and representing over 30 million hours of time in the field.

eBird is based in the United States, and this is where it has its highest levels of participation. However, eBird enables project coordinators to tailor the infrastructure to meet their specific needs, including language. In Mexico, for example, the local version of eBird Averaves (http://ebird.org/content/averaves/acerca/) allows for more relevant local programming (Ortega-Álvarez et al., 2012). Currently the eBird website is available in 11 languages, and its app in 26 languages. There continues to be discussion how a platform like eBird meshes with existing well-supported platforms and projects elsewhere in the world (e.g. BirdTrack http://www.birdtrack.net or Trektellen https://www.trektellen.nl/).

One of the reasons that eBird is successful in collecting data is that it serves the needs of a community by providing a tool for birders to store their records, both locally and when travelling (which shows the value of combining ecotourism with citizen science, although spatial coverage by travelling birders will be biased towards ecotourism hotspots). However, by providing some structure to the data that people submit, the records have added value for analysis and use. Participants in eBird generate bird abundance and distribution data at high spatial and temporal resolution by submitting checklists of birds they have seen. They also can choose to add additional information such as breeding status and to attach photos. Although participants can enter records made anytime and at any place, there are simple ways in which eBird requires people to record their effort (see Section 5.2). Firstly, people record when, where and for how long (both time and distance) they spent birding, and eBird provides various options of the protocol used for data gathering, such as point counts, transects and area searches. Secondly, observers are encouraged to fill out checklists of all the birds they have seen (not just the 'special' species), thereby providing information on nondetections as well as presence. The checklists are automatically created in real time based on the likelihood data for the time and region where the observations are being made. This is an excellent example of a way in which a citizen science project can encourage people to provide more informative data, without making it a burden. When checklists of sightings are submitted, automated filters provide an instantaneous first layer of screening. Flagged records are sent to regional editors for verification by one of the approximately 1500 regional editors spread around the globe. Once verified, flags are removed and the data enter the permanent database.

eBird data summaries are available on the project website along with data exploration tools that allow anybody to create maps and frequency distributions of bird species around the world. The data are used to make distribution maps, model migration of individual species, indicate species in decline, demonstrate relationships between bird populations and habitat quality, and inform management and policy decisions affecting birds (Callaghan and Gawlik, 2015; Hochachka et al., 2012). It is also used for bird atlases in three US states: Wisconsin, Virginia and Maine. Data users include national and state agencies, nongovernmental organisations, academic researchers, birders and students of all ages. Data products are available in a variety of forms and data visualisations. As of early 2017, 150 scientific publications used eBird data, appearing in a variety of fields including ecology, statistics, computer science and public policy.

Other projects use a similar approach to eBird, with all the data being submitted to a single data infrastructure, but also having local versions of data portals to make the project locally relevant to participants. Examples include iNaturalist (e.g. its Mexican version Naturalista http://conabio.inaturalist.org) and iSpot (e.g. its South African version https://www.ispotnature.org/communities/southern-africa).

6.3 Citizen Science With Semistructured Recording: Kenya Bird Map

Kenya has long been known to have a rich and diverse avifauna (Bennun and Njoroge, 1999). However, vast areas of many of its habitats have been dramatically altered by human impact over the past 40–50 years. This has, without a doubt, affected the distribution and occurrence of Kenya's rich biodiversity—but to what extent? It is important to know this for effective conservation management to take place (Loftie-Eaton, 2015), but currently there is not effective monitoring of the trends in biodiversity. The Kenya Bird Map project seeks to address these questions (Wachira et al., 2015). A key factor in the success of the Kenya Bird Map (http://kenyabirdmap.adu.org.za/) is the carefully designed protocol that was adopted from the Southern Africa Bird Atlas Project 2 (SABAP2). This was designed to reduce observer bias due to, e.g., observer effort and skill, time of day, observation conditions and conspicuousness of a species (Underhill, 2016), while maximising ease and the observer's enjoyment of the data collection process (Fig. 6). Both of these factors are critical to a successful citizen science project—and the results so far for SABAP2 (10,688,000 records) and the bird atlases in both Kenya (167,000 records over 4 years from 230 observers) and Nigeria (48,000 records over 2 years from 76 observers) suggest that balance of structured vs unstructured and ease vs rigour of the protocol has been successful.

Feedback on the success of the protocol indicates the importance of the 'customer satisfaction' that the participant receives from their involvement and contribution to the project. This may be self-pursued, in that one can check for oneself the status of her/his contribution, or through active feedback from the organisers of the project to provide updates on project progress. A primary feature of this project is that the atlas is based on a grid system for the country coverage that is combined with real-time updates

Fig. 6 (A) Young Kenyan birders taking part in citizen science bird surveys, Malindi, Kenya. Although here they are using a notebook to record sightings, the use of a smartphone app has supported increased participation in the Kenya Bird Map project. (B) A birdwatcher following a structured protocol to contribute to the Kenya Bird Map around Lake Mikimba in pentad 0305_4000 just inland from Malindi, Kenya.

of that coverage on the atlas website, so that observers can choose to focus their effort on underrecorded squares and have the satisfaction of seeing their contribution to the overall project. This is supported by project Facebook pages where discussion takes place among recorders.

One of the challenges at the start of the project in 2014 was whether it would work in Kenya, where most birders are young Kenyans who do not have their own vehicles and often not even their own computers, compared to South Africa, where most participants came from the more affluent white communities. Initially in Kenya there was participation mainly from a small group of keen birders. However, the development of a Kenyan version of the BirdLasser app in 2013 (developed by a participant in the Kenya Bird Map project), coincided with a rapid increase in the availability of smartphones in Kenya and this led to a substantial leap in participation. The design of BirdLasser focussed on allowing birders to do the thing that they enjoy: birding. One benefit of the smartphone app was that it automated the detection of an observer's location, allowing birders to focus on birdwatching, rather than map reading. The app was designed to function without mobile network coverage, and subsequent submission of data is a simple process when mobile coverage is gained. The focus on the participant's needs is believed to have been vital in its contribution to the growth of bird atlassing not just in southern Africa but now across the whole continent.

6.4 Codesign of Monitoring Protocols: New Zealand Environmental Community Groups

Within the past 700 years, human colonisation and the arrival of exotic biota (both intentionally and unintentionally introduced) have resulted in substantial loss of biodiversity across New Zealand. Now, over 500 community environmental groups protect and restore flora, fauna and habitat in diverse ecosystems: forests, rivers and streams, freshwater and saline wetlands and coastlines (Peters et al., 2015). These groups are generally small (<20 active volunteer participants), but many have been active for over a decade and some larger projects employ coordinators. Partnerships, mostly with land management agencies, play a crucial role visiting sites and providing labour (e.g. pest and weed control), technical advice (e.g. monitoring design, species identification) and funding (Hardie-Boys, 2010; Peters et al., 2015). Many groups have achieved important biodiversity conservation gains through sustained control of animal pests and weeds, revegetation with native species, constructing predator-proof fenced sanctuaries, and translocating native flora and fauna species to managed sites (Campbell-Hunt and Campbell-Hunt, 2013; Cromarty and Alderson, 2012; Hardie-Boys, 2010; Sullivan and Molles, 2016).

Many groups carry out environmental monitoring to quantify their restoration management activities and to a lesser degree, the outcomes of their management (Peters et al., 2016). Ecosystem monitoring toolkits have been designed to provide protocols for monitoring the health of forests, wetlands, streams, coastal areas, rivers and estuaries, e.g., Biggs et al. (2002), Handford (2004), Robertson and Peters (2006), Tipa and Teirney (2003). These toolkits help community groups because they facilitate the collection of standardised data. In some cases, new protocols have been developed to meet community needs or existing protocols simplified to enhance their usability. Uptake of these toolkits, however, has generally been low, mostly due to a lack of ongoing technical and logistical support (e.g. from land management agencies and nongovernment agencies) as well as online platforms to facilitate analysing, storing and reporting on findings (Peters et al., 2016).

However, the bewildering array of biomonitoring protocols available is confusing for groups. This has prompted one local government (Auckland Council) to consolidate the most suitable methods into a technical guide specifically for nonspecialist community users in preparation. Wide consultation with agency staff as well as a cross-section of community groups resulted in 11 criteria for assessing monitoring methods (including level of skill, resourcing, scientific robustness) of about 30 established protocols, including simplified methods drawn from the aforementioned ecosystem monitoring toolkits. The wider rationale for the guide is simple: to build consistency among groups' monitoring efforts and enable agency staff to deliver uniform advice to community groups. This directly addresses a lack of technical expertise, which is a known barrier for groups to undertake monitoring. Currently, monitoring data are mostly used to shape the management of groups' own project sites, support funding applications and report back to funders (Peters et al., 2016). A future prospect is to aggregate groups' data for State of the Environment reporting with the guide playing a pivotal role in directing groups to use a limited but cohesive suite of methods. Therefore, working with community groups to equip them to undertake scientifically rigorous monitoring of the impact of their ecosystem management supports their efforts and gives wider benefit through sharing data.

6.5 Zavamaniry Gasy: Making Recording Accessible Through Investment in Training and Internet Platforms

Madagascar has a rich diversity of more than 11,000 native plants species, 80% of which are endemic (Goyder et al., 2017; Madagascar Catalogue, 2017) and despite hundreds of years of botanical collecting and study, new species are still being added to its flora (Andriamihajarivo et al., 2016; Darbyshire et al., 2017; Vorontsova et al., 2013). Documenting the distribution and ecology of species has become increasingly urgent as threats to biodiversity in Madagascar increase (Hannah et al., 2008; Harper et al., 2007), especially because only about 9% of plants native to Madagascar have been assessed for their level of extinction risk according to the IUCN Red List Categories and Criteria (IUCN, 2016).

Responding to this lack of information requires innovative solutions and citizen science offers great potential for species discovery and monitoring in Madagascar. The contribution of public participation, via technology, is exemplified by the story of a palm enthusiast, resident in Madagascar, who posted a photo of an unidentified species on a web-based forum. The photo was eventually examined by experts from the Royal Botanic Gardens, Kew, who were able to relocate the population in wild. When the plants were analysed they turned out to be not only a new species (*Tahina spectabilis*), but an entire new genus of palm (Dransfield et al., 2008). Its restricted range, threats from fire and grazing, small known population size and lack of protection immediately warranted a classification of Critically Endangered on the IUCN Red List (Rakotoarinivo and Dransfield, 2012).

Acknowledging the potential role that georeferenced photos of plants could play in contributing towards the Madagascar plant inventory and the assessment of extinction risk, a project was initiated in 2014 by the Kew Madagascar Conservation Centre (KMCC) called Zavamaniry Gasy (Plants of Madagascar) with funding from the JRS Biodiversity Foundation. Utilising the existing infrastructure of iNaturalist (http://www.inaturalist.org) the project was quickly and easily established and started to accumulate plant observations. The project was coordinated by KMCC who undertake regular expeditions to the field and their aim was to supplement collections of voucher specimens with observations which are quicker and easier to generate. Plant species could then be mapped across their ranges more accurately, and could also be used to report on localised threats, both of which support the production Red List assessments of extinction risk.

The iNaturalist observation workflow was conceived in developed countries where it relies on technology such as GPS-enabled smartphones and good internet connectivity; however, this presented challenges in developing countries like Madagascar. To bridge this gap, development by iNaturalist improved the functionality of the app to make records where internet connectivity is low and smartphones were purchased for local participants. KMCC curated observations and used their taxonomic expertise to verify observations as 'Research Grade'. Research grade observations are subsequently harvested from iNaturalist by the GBIF. It was important that the observations contributed to globally important datasets like GBIF, but at the same time were freely accessible for more localised research and conservation activities. To date, nearly 14,000 observations have been made representing 2692 species (nearly a quarter of native plant species), 5052 research grade observations have been submitted to GBIF and records are beginning to be used for Red List assessments.

Efforts were made to engage other members of the plant science community in Madagascar by conducting BioBlitz events, which are sustained 2–3-day biological surveys of a particular area with multiple participants. These events lead to a noticeable increase in observations (Fig. 7). More recently, growth in observations has been supported by tourists, who are already engaged with iNaturalist. They are adding observations that can be subsequently verified by the KMCC team or other Madagascar plant experts. While records from tourists are valuable, future work must focus on engaging with the custodians of Madagascar's parks and reserves such as guides and park rangers who can undertake repeat visits so that observations can be used to document population trends, not just presence or absence, and support people's engagement with their local environment.

6.6 The Importance of Local Advocates to Support Participants: FreshWater Watch

Freshwater ecosystems are among the most degraded of habitats on the planet owing to land use intensification, point and nonpoint pollution sources, river channel modification, and over exploitation (Vörösmarty et al., 2010). They occupy only 0.8% of the world's surface but support disproportionally high biodiversity (Dudgeon et al., 2006; WWF, 2016). They also provide a wide range of ecosystem services, such as flood regulation, food provision and cultural importance, which are intrinsically linked to the diversity of functions provided by the organisms present (Diaz and Cabido, 2001; Millenium Ecosystem Assessment, 2005) and so can unite human societies with their environment (Vörösmarty et al., 2015).

FWW comprises of a core standardised global method for the assessment of nutrient pollution (nitrate and phosphate concentrations) and turbidity by citizen scientists and a suite of questions related to ecosystem condition (e.g. presence of aquatic vegetation, water level and land use). Protocols for water sampling and testing and ecosystem evaluation are delivered through a consistent training approach developed by Earthwatch Institute. However, regional partners (research institutions, NGOs or governmental departments) specify additional parameters that support a local defined research priority. Such local priorities vary from anthropogenic litter at Great Lakes sites in the United States (Vincent et al., 2017) to algal blooms in urbanised Brazilian streams (Castilla et al., 2015; Cunha et al., 2017a) or nutrient

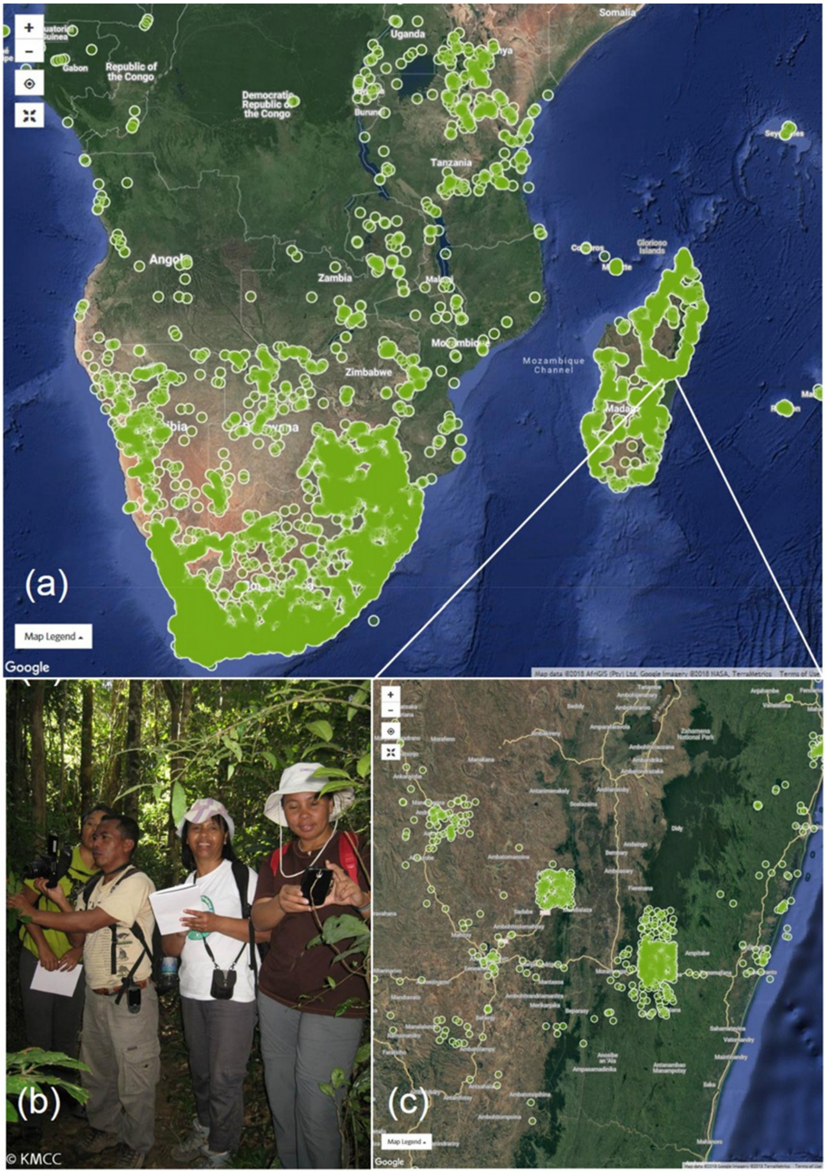

Fig. 7 (A) The impact of developing a localised implementation of iNaturalist can be clearly seen because records for Madagascar are more abundant than other countries in mainland Africa (excluding South Africa). (B) Local 'bioblitz' participants contribute many records, as demonstrated by (C) the density of records from Mantadia/Andasibe National Park and Analamazaotra Reserve (with records shown randomly within 20 km grid squares). *Map data: Search of 'research grade' and 'verifiable' records of plants from www.iNaturalist.org, accessed 20 June 2018 (A) ©2018 AfriGIS (Pty) Ltd., Google Imagery ©2018 NASA Terrametrics; (B) ©2017 Google Imagery ©2017 Terrametrics. (C) © Kew Madagascar Conservation Centre, used with permission.*

pollution in small waterbodies in the United Kingdom (McGoff et al., 2017). This dual track approach allows both data to be globally harmonisable as well as locally relevant and all projects feed into a single online platform. In this way, all core data are both high resolution and comparable across local projects, e.g., in the Americas (Loiselle et al., 2016) or across regions in China (Thornhill et al., 2017).

Over the first 5 years (2012–2016), FWW focused primarily upon corporate volunteers, training over 8000 citizen scientists and generated more than 15,000 datasets. The presence of such local 'champions' or environmental ambassadors helped spread freshwater conservation lessons, and recruit new volunteers (see https://freshwaterwatch.thewaterhub.org/volunteer_day) and the most active and dedicated volunteers are recognised through online tools and awards. Participants and principal investigators valued being able to contribute to global research via consistent methods (Earthwatch Institute, unpublished data).

A challenge to using a global approach to nutrient testing can be compatibility with approaches that are already established in the country or region. However, the automated feedback function within the FWW website and app, and the capacity to contrast local measures of nitrate with global values empowered participants making records from a Brazilian spring to alert the principal investigator to high nitrate values, who then alerted the local authority, and informed the community of the implications of drinking this water (Earthwatch Institute, 2017). Being part of the decision-making process can embed stewardship and overcome the feeling of 'monitoring for the sake of monitoring' that has been reported as a barrier in some citizen science initiatives (Ballard et al., 2017; Sharpe and Conrad, 2006; Sinclair and Diduck, 2001).

In summary, FWW is both a global and local project, and so provides an example for biodiversity monitoring. The FWW core dataset allows comparisons across the globe, while additional parameters support local researchers answer specific questions. The project demonstrates the potential for citizen science to complement professional monitoring through data with high spatiotemporal resolution (Krasny et al., 2014), to generate social capital (Overdevest and Stepenuck, 2004) and support behaviour change (Toomey and Domroese, 2013). This global–local approach has resulted in a wide range of scientific publications, e.g., Castilla et al. (2015), Loiselle et al. (2017), Thornhill et al. (2016), local actions and increased environmental awareness (Earthwatch Institute, 2017).

6.7 A Proposal for Global Monitoring of Pollinators With Citizen Science

Drawing on the discussion in the chapter so far, we now apply this to create a conceptual approach for how citizen science could be utilised to address the global challenge to monitor pollinators. The recently published record on pollinators and the ecosystem service of pollination by the Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES 2016) demonstrated the importance of pollinators and pollination and showed that there is limited information on trends in insect pollinators at large spatial scales. Specifically, the only information is on declines in the occurrence and range size of individual species that have been detected in parts of northern Europe and North America (Biesmeijer et al., 2006; Cameron et al., 2011), although information was also gathered from indigenous honey hunters (Tengö et al., 2017). However, "although there is some evidence for changes [in abundance], this is a topic for which much additional work is needed before we have a clear picture for trends on a global scale" and this is "because of a lack of baseline datasets and monitoring schemes" (IPBES 2016). Another important report stresses that "there is the need for a global monitoring program to track trends in pollinator diversity and abundance" (LeBuhn et al., 2016).

Standardised methods have been proposed to develop global pollinator monitoring, e.g., using insect traps with experts paid to undertake the identification of insects. It will cost an estimated $2 million per region to generate trends in abundance (LeBuhn et al., 2013, 2016). While this may be modest compared to the value of pollination to agriculture (globally >$200 billion per year): (1) it is expensive in absolute terms, (2) it does not scale efficiently (doubling the number of samples roughly doubles the cost), (3) it requires large amounts of long-term funding and (4) it does not engage nonspecialist communities in valuing pollinators. However, if we develop methods (i.e. citizen science or participatory monitoring) that are suitable to be used by people who are not skilled in insect identification or ecological sampling techniques, then many of these issues will be ameliorated.

We suggest that a standardised approach of identifying and counting taxa at specific 'lure' plants for a set period of time could be a valuable approach to be scaled-up to global pollinator monitoring (Fig. 8). This has been used at small scale in citizen science projects (Roy et al., 2016) and forms a citizen science component of the UK Pollinator Monitoring Scheme (Carvell et al., 2016; https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring). The focal monitoring plants could be selected from a small set of widespread

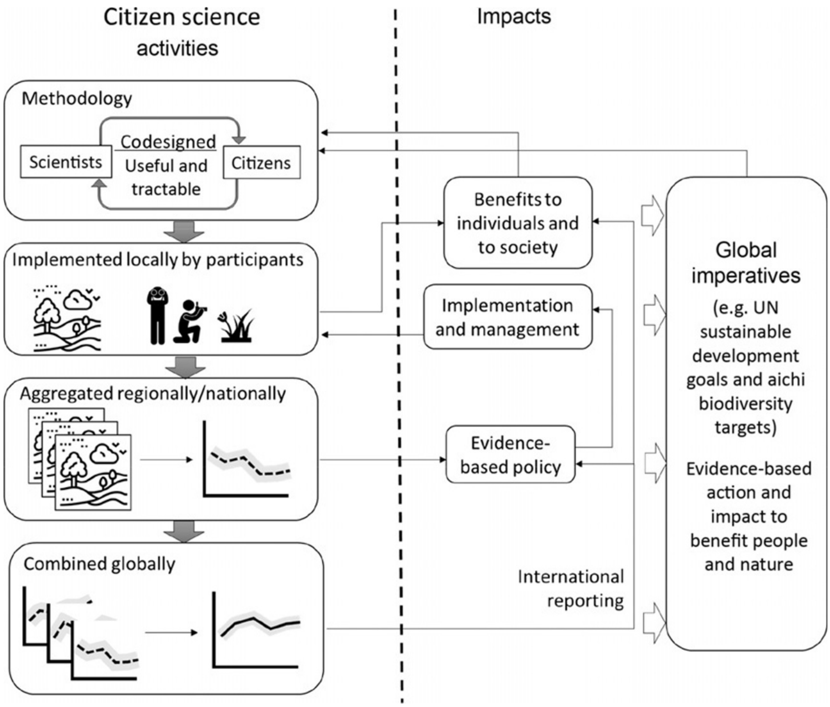

Fig. 8 A proposed framework for global pollinator monitoring, which is based on the principles discussed in this paper to create local–global monitoring. *Icons CC-BY from www.thenounproject.com: 'landscape' by Becris, 'binoculars' and 'man taking picture' by Gan Khoon Lay, 'plants' by Hamish. Graphs by the author.*

(wild, cultivated or ornamental) lure plants, with the lists of species created regionally. One crucial aspect is how the insects should be classified. We suggest that functional-indicator morphotypes should be used, because they are informative and tractable (see Section 5.3). This will require interaction between pollinator experts (who can define the useful functional categories) and potential participants (who can assess whether they can be accurately distinguished without much expertise). A different, or complementary, approach would be to monitor the benefits we gain from pollinators, i.e., pollination. This has been done by recording seed set in a plant requiring cross-fertilisation through the Great Sunflower Project (Domroese and Johnson, 2017) in the United States. Being an indirect measure of pollinators, if would only be able to detect change below a certain threshold, but if the same assay species were used across regions then the results could be used for monitoring in space and time, and it does provide information of direct relevance to people growing their own food (i.e. whether pollination is limiting food production).

Any global pollinator monitoring would have to be 'locally based, yet global' (He and Tyson, 2017), so while a global core methodology would be valuable, activities must be designed collaboratively so that the information is useful to and useable by local participants. Our proposal has similarities with The Global Mosquito Alert as a 'locally based, yet global platform' through linking successful projects in individual countries including Spain, the Netherlands, the United States, Indonesia, Hong Kong and Colombia (He and Tyson, 2017), where knowledge on mosquitoes as vectors of disease has direct bearing on people's health. Facilities should also be created so that data are easily shared and made globally accessible, so contributing to our current lack of information on pollinator trends; this could include adopting 'older' technologies such as SMS (text messages) to facilitate participation in regions where smartphones and the internet are less accessible. Paradoxically, if those participating are empowered and informed to go and improve their local environment for pollinators, based on their monitoring evidence, then this does create a problem for the global monitoring. This is because the sites monitoring would be an improving subset of the wider environment, rather than being representative (see Buckland and Johnston, 2017): this is an important issue that would need to be solved.

7. CONCLUSION

Citizen science is being increasingly promoted as a tool for global solution to many different problems. For biodiversity monitoring, there are many people living in regions where there is relatively little data on biodiversity and its trends, and there is a long history of biological recording by volunteers in some parts of the world; both of these show the potential for citizen science to contribute to global biodiversity monitoring. However, we will never achieve this potential by only adopting 'top down' control of citizen science activities, because local motivations and participation are essential for the success of any activity: we need a 'local to global' perspective (Chandler et al., 2017), based on learning from the communities of practice in citizen science and participatory monitoring. Ultimately, the need is great, the potential is great and together citizen science, and related activities, could provide a step change in our ability to monitor biodiversity—and hence respond to its threats in the lights of the benefits we gain locally, regionally and globally.

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