Chapter 9
Involving Citizen Scientists in Biodiversity Observation

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Abstract The involvement of non-professionals in scientific research and environmental monitoring, termed Citizen Science (CS), has now become a mainstream approach for collecting data on earth processes, ecosystems and biodiversity. This chapter examines how CS might contribute to ongoing efforts in biodiversity monitoring, enhancing observation and recording of key species and systems in a standardised manner, thereby supporting data relevant to the Essential Biodiversity Variables (EBVs), as well as reaching key constituencies who would benefit Biodiversity Observation Networks (BONs). The design of successful monitoring or observation networks that rely on citizen observers requires a careful balancing of the two primary user groups, namely data users and data contributors (i.e., citizen

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scientists). To this end, this chapter identifies examples of successful CS programs as well as considering practical issues such as the reliability of the data, participant recruitment and motivation, and the use of emerging technologies.

Keywords Citizen science · Essential biodiversity variables · Biodiversity monitoring · Data reliability · Data standards · Emerging technologies

9.1   Citizen Science

The involvement of non-professionals in scientific research and environmental monitoring, termed Citizen Science (CS), has now become a mainstream approach for collecting data on earth processes, ecosystems and biodiversity. Although the term has appeared only more recently as a formal way of referring to these activities, CS actually has a very long history. In the past, amateur scientists have contributed a great deal to science, particularly with networks of weather collectors and ocean monitoring. Famous names such as Alfred Russell Wallace, Thomas Edison and Gregor Mendel are all prime historical examples of citizen scientists.

With recent changes in technology and social media enabling outreach and interaction with a much wider audience than ever before, CS is becoming an increasingly integral part of contemporary scientific research, particularly in terms of data acquisition. With limited budgets to pay for professional scientists, or to support government-sponsored environmental monitoring, engaging citizens to help with ground-based monitoring efforts and the reporting of rare events, makes sense. By achieving hitherto unrealised levels of large-scale monitoring for features which remain invisible to remote sensing, CS is likely the most realistic way of covering much of the planet's biosphere (Pereira and Cooper 2006; Pereira et al. 2010).

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This chapter provides examples of how CS can contribute to ongoing efforts in biodiversity monitoring, enhancing observation and recording of key species and systems in a standardised manner, and supporting the collection of Essential Biodiversity Variables (EBVs), as well as reaching key constituencies who would benefit Biodiversity Observation Networks (BONs). Referred to as contributory CS, which is based on a typology developed by Bonney et al. (2009a, b) and Miller-Rushing et al. (2012), involving citizens primarily in data collection is the most common form and probably the simplest starting point for those interested in developing new CS projects. Other forms of CS are also possible, such as through the Earthwatch model (http://earthwatch.org/) where members of the public join research projects; these require more training, direction and supervision of participants to ensure systematic data collection for answering specific scientific research questions.

The design of successful monitoring or observation networks that rely on citizen observers requires a careful balancing of the two primary user groups, namely data users and data contributors (i.e., citizen scientists; Pocock et al. 2015). To this end, this chapter also considers practical issues such as reliability of the data (Buesching et al. 2014), participant recruitment and motivation (Buesching et al. 2015; Silvertown et al. 2013), and the use of emerging technologies. All are important issues that determine whether useable data are collected and how a team of willing and capable participants is maintained.

9.2 Citizen Science and Biodiversity Observation Networks (BONs)

The aim of a BON is to help improve information available on the distribution and change of biodiversity in a given region or associated with a specific theme (e.g., an ecosystem domain or a particular type of monitoring) (GEO BON 2015a, b). BONs obtain baseline data, develop monitoring programs to detect change, publish biodiversity observations, and help identify the factors underlying the observed changes. This supports the modelling communities and the development of ecosystem assessments and future scenarios supporting conservation mitigation strategies (Akçkaya et al. 2016). CS can contribute to this aim in a number of different ways, as outlined below.

9.2.1 Monitoring Biodiversity Over Large Spatial and Temporal Scales

Using citizen scientists in biodiversity monitoring networks significantly expands the spatial and temporal scale of what is possible, because the additional people

allows considerably more data to be collected, both in terms of range and quantity. CS can be a practical way to achieve the geographic coverage required to document ecological patterns and address ecological questions at scales relevant to regional population trends, shifts in species range, patterns of migration, impacts of environmental processes like Human Induced Rapid Environmental Change (Sih 2013), spread of infectious disease and invasive species, and national environmental policy assessment. This is especially important for smaller, rarer or more fragmented habitats and species that may be hard to detect in coarse or infrequent surveys, but also for very common and widespread species where the sheer size of the species range may prove challenging to sample (Buesching et al. 2015). Large-scale CS projects are thus valuable when attempting to gather data on large geographical scales, such as engaging participants in national or even global surveys, with participants collecting data in many locations simultaneously. These projects can involve very substantial numbers of contributors, and can persist for a long time, making it possible to map trends. Moreover, CS can lead to the engagement and coordination of an active and long-lasting community around permanent monitoring sites such as those established by existing BONs (e.g., National Ecological Observatory Network (NEON) in the USA through its Citizen Science Academy, Terrestrial Ecosystem Research Network (TERN) sites in Australia who have partnered with Earthwatch) or long-term research and monitoring plots such as Hawkwatch Monitoring North America sites. The results can also be used to inform population management decisions and even international environmental and conservation policy.

9.2.2 Mapping Species Location and Abundance

Most biodiversity-oriented CS programs aim to record the location and abundance of species through time (Table 9.1). These observations are used to monitor population trends and geographic range dynamics (e.g., eBird http://ebird.org/content/ebird, iNaturalist http://www.inaturalist.org, iSpot http://www.ispotnature.org). Indeed, close to 50 % of all species occurrence records in GBIF are published from sources that already publish data collected through CS projects (http://www.gbif.org). Most of these programs contribute largely to collaborative projects, rely on high participation rates to reduce data errors (e.g., by 2015 eBird had over 200 million observations contributed to GBIF; http://www.gbif.org), and in many cases there is little or no formal training required for participation.

Some programs are designed to ensure a balance between providing regular scientific updates on species location and movements while engaging the public in enjoyable, hobby-like activities. Some of these programs have stemmed from rapid biodiversity surveys that involve both researchers and the public, e.g. a BioBlitz (Lundmark 2003). They are often run in association with local museums, naturalist clubs and schools on international days of environmental recognition. BioBlitzes are still immensely popular and continue to contribute to the discovery of new

Table 9.1 Potential contribution of citizen science projects to the candidate Essential Biodiversity Variables

EBV Class	CandidateEBV	Description	Project/Database Name	Website	Country
Genetic composition	Breed and variety diversity	Number of animals of each livestock breed and proportion of farmed area under each local crop variety, at multiple locations	No known CS projects as yet, but CS approaches could be used to study this EBV—see Bohmann et al. (2014)		
Species population	Species distribution	Presence surveys for groups of species easy to monitor, over an extensive network of sites with geographic representativeness. Potential role for incidental data from any spatial locations	iNaturalist	http://www.inaturalist.org/	World
			iSpot	http://www.ispot.org.uk/	World
			Observado	http://www.observado.org/	World
			eBird	http://ebird.org/	World
			eMammal	http://eMammal.org	World
			The Great SunFlower Project	http://www.greatsunflower.org/	US
			Breeding Bird Survey	http://bto.org/bbs/index.htm/	UK
			French Common Bat Monitoring	http://mnhn.fr/vigie-nature/	France
			Pan European Common Bird Monitoring	http://ebcc.info/pecbm.html/	Europe
			FrogWatch USA	http://www.nwf.org/frogwatchUSA/	USA
			Ontario Turtle Tally	http://torontozoo.com/adopttapond/	Canada
			German Butterfly Monitoring	http://science4you.org	Germany
			Spiders Web Watch	http://spiderwebwatch.org/	Canada, US
			Anglers Monitoring Initiative	http://riverflies.org/	UK
			Great Lake Worm Watch	http://nrri.umn.edu/worms/	US
			Plant Watch	http://www.naturewatch.ca/	Canada
			BioDiversity4All	http://www.biodiversity4all.org/	Portugal
			Coral Watch	http://www.coralwatch.org/	World

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Table 9.1 (continued)

EBV Class	CandidateEBV	Description	Project/Database Name	Website	Country
Species population	Population abundance	Population counts for groups of species easy to monitor and/or important for ecosystem services, over an extensive network of sites with geographic representativeness	eBird	http://ebird.org/	World
			German Butterfly Monitoring	http://science4you.org	Germany
			Garden Moths Count	http://www.mothcount.brc.ac.uk/	UK
			REEF (Coral Reef Fish)	http://www.reef.org/	World
			Custodians for Rare and Endangered Wildflowers	http://www.sanbi.org/biodiversity-science/state-biodiversity/biodiversity-monitoring-assessment/custodians-rare-and-endan	South Africa
Species traits	Phenology	Record timing of periodic biological events for selected taxa/phenomena at defined locations	National Phenology Network	https://www.usanpn.org/	US
			BudBurst	http://windows.ucar.edu/citizen_science/budburst/	US
			Seasons Observatory (plant bloom and migratory birds)	http://www.obs-saison.fr	France
Species traits	Natal Dispersal Distance	Record median/frequency distribution of dispersal distances of a sample of selected taxa	No projects known at present, but advanced CS observers could contribute to professional databases such as TRY		
Species traits	Migratory behaviour	Record presence/absence/destinations/pathways of migrant selected taxa	eBird	http://ebird.org/	World
			Migrant Watch in India	http://www.migrantwatch.in/	India
			Migrant watch in UK	http://butterfly-conservation.org/612/migrant-watch.html	UK

(continued)

Table 9.1 (continued)

EBV Class	CandidateEBV	Description	Project/Database Name	Website	Country
Community composition	Taxonomic diversity	Multi-taxa surveys (including by morphospecies) and metagenomics at selected in situ locations at consistent sampling scales over time	iNaturalist	http://www.inaturalist.org/	World
			iSpot	http://www.ispot.org.uk/	World
			Observado	http://www.observado.org/	World
			BioDiversity4All	http://www.biodiversity4all.org/	Portugal
			Watchers—Intertidal Monitoring	http://www.beachwatchers.wsu.edu/	US
Community composition	Species interactions	Studies of important interactions or interaction networks in selected communities, such as plant-bird seed dispersal systems	Naturalist	http://www.inaturalist.org/	World
			iSpot	http://www.ispot.org.uk/	World
			Observado	http://www.observado.org/	World

species and range extensions. In some countries (e.g., Ireland), nationally organised Bioblitzes have become an important avenue to collecting biodiversity data as well as engaging citizens. Environmentally distributed ecological networks (EDENs) are growing increasingly important in ecology, coordinating research in more disciplines and over larger areas than ever before (Craine et al. 2007).

9.2.3   Timing of Nature's Events

Recently, the potential for broad scale analyses of phenology and migration has increased considerably due to public interest in conservation and particularly the development of several online CS projects (Table 9.1). Ranging from national to international efforts, examples include Nature's Notebook https://www.usanpn.org/natures_notebook, which supports large-scale plant phenology observations to collect ecological data on the timing of leafing, flowering, and fruiting of plants across the USA, attracting thousands of participants, and Project Budburst in the USA http://www.budburst.org/, which also has a strong educational focus. In the UK, Nature's Calendar http://www.naturescalendar.org.uk/ addresses the lack of long term phenological data available, as does BirdTrack http://www.bto.org/volunteer-surveys/birdtrack/about. ClimateWatch http://www.climatewatch.org.au asks volunteers to record the seasonal behaviour and location of over 180 marine and terrestrial animals across Australia. Engaging educators in the program has increased the number of sightings recorded significantly, while raising awareness about the impacts of climate change. Other national systems include Observatory of Seasons http://www.obs-saisons.fr/ in France, NatureWatch https://www.naturewatch.ca/english/ in Canada, and MigrantWatch http://www.migrantwatch.in and SeasonWatch http://www.seasonwatch.in/ in India. Finally, Journey North http://www.journeynorth.org is global in scope, aiming to study wildlife migration and seasonal change via various projects, e.g. the Spring Monarch Butterfly Migration Monitoring project http://www.learner.org/jnorth/monarch/index.html, which allows participants to track monarch butterfly migrations each fall and spring. Collectively, these projects span a vast range of plant and animal species, using web platforms and mobile apps to record data from the field.

9.2.4   Early Detection and Mapping of Pests and Invasive Species

CS projects can contribute to finding and tracking invasive species, which is especially important in detecting early outbreaks of important pests and exotics. At a more local level, apps developed for Outsmart Invasive Species http://masswoods.net/outsmart, and IveGot1 http://www.eddmaps.org/florida/report/index.cfm allow

species observations to be submitted directly from the field in order to help detect and map the extent of invasive species in Massachusetts and Florida. CS programs are increasingly working at larger scale such as monitoring marine invasive species along the east coast of North America (Invasive Tracers, http://www. InvasiveTracers.com), with a focus on recently introduced non-native crabs, and tracking the spread of exotic lionfish in the Caribbean (e.g., http://www.reef.org/ programs/exotic/report and http://nas.er.usgs.gov/SightingReport.aspx). In the UK, the Big Seaweed Search http://www.nhm.ac.uk/nature-online/british-natural-history/seaweeds-survey/ is asking citizens to record sightings of 12 species of live seaweed in order to track and monitor the effects of climate change and invasive species such as wireweed (*Polygonum aviculare* L.) on the UK's sea-weeds. Larger and collaborative government sponsored initiatives have been developed that bundle together reporting of exotics by CS, verification by experts, automated notification of agencies to act on potential threats, as well as tools to manage exotics (http://www.imapinvasives.org).

9.2.5   Desk Assessment and Field Validation of Imagery

CS can help to process large amounts of digital footage created by the recent explosion of low cost-high resolution video, photographic and satellite imagery. Previously, such footage would have been too cumbersome to analyse in its entirety by any single researcher or institution. While automated software can assist in this process, online crowdsourcing is particularly useful in instances where the human eye performs better than image analysis algorithms. For example, Digital Fishers http://digitalfishers.net/ allows volunteers to analyse deep sea video footage and describe what they see through a web interface that resembles the control panel of a deep sea submersible. As volunteers become more experienced, they are asked to improve their descriptions and are rewarded with new facts about deep sea species. The same video is analysed by multiple volunteers to improve consistency of descriptions. The program provides the public with an opportunity to see under-water habitats and rarely sighted deep sea species. Moreover, it continually pro-vides new 'missions' for volunteers to maintain interest while providing researchers with valuable biodiversity data. Another example is the crowdsourcing of species from photographs taken by a camera trap, e.g. the Zooniverse Wildcam Gorongosa project http://www.wildcamgorongosa.org/ and Snapshot Serengeti (Swanson et al. 2015) as well as the multitude of other Zooniverse projects http://www.zooniverse. org that involve citizens in analysing photographs and images.

Crowdsourcing of digital imagery analysis has been shown to improve existing online data sets such as global land cover. Geo-Wiki http://www.geo-wiki.org/ involves volunteers in clarifying discrepancies between different land cover maps from their observations of Google Earth images. This removes areas of ambiguity for the development of integrated land cover maps and, as a more accurate baseline, to inform integrated assessment models. Other programs such as ForestWatchers

http://forestwatchers.net/ ask volunteers to clean satellite images by selecting those with the least cloud cover, or identify areas of deforestation by marking suspect areas on a satellite image using online drawing tools. Moreover, other CS programs such as http://www.tela-botanica.org/page:herbonautes and http://herbariaunited.org/atHome/ are now engaging citizens to assist in interpreting and digitizing their museum collections making historic records accessible to wider audiences.

9.2.6 Linking Citizen Science and Large Scale Biodiversity Monitoring Databases

The global scale of anthropogenic change and the significant variance in its impact across regions has resulted in international environmental agreements, such as the Convention on Biological Diversity (Balmford et al. 2005). GEO BON aims to develop a global observation system that provides regular and timely information on biodiversity change to the CBD and other users. The examples above demonstrate the power of CS in data collection and science communication at both local and regional levels. We think there are three key initiatives that could be developed to scale up CS efforts to a global level:

- Foster data compatibility, standards, quality, storage and sharing of CS data in nationally or internationally recognised databases and support CS programs in choosing which of these are most appropriate for their program. Wiggins et al. (2013) have produced a guide on data management for CS projects that covers the full data management cycle and provides best practice guidance on many CS data issues;
- Identify data that can be collected by CS projects around the world (see Table 9.1) and carry out a gap analysis to determine where existing and future CS programs can best compliment or enhance other global data sets. For example, GEO BON has produced a candidate list of Essential Biodiversity Variables (Pereira et al. 2013) that may be appropriate to be collected by CS; and
- Build capacity globally within organisations to develop, lead and sustain CS programs that achieve sufficient rigor to collect valid data, and meaningfully engage participants over the spatial and time scales needed.

The first initiative could be realised through inviting CS programs that operate at scales larger than the local community (i.e., state, national or international programs) to join the larger scale initiatives (e.g., GEO BON), involving clear linking mechanisms (e.g., a GEO BON representative) providing guidance to this effect. For example, this representative could ensure that the data are standardized internationally, e.g. Darwin Core (GBIF 2012), and assist in identifying the most suitable national or international databases for storage. Such guidance would reduce the costs associated with developing web interfaces and web server costs associated

with housing online databases. The outcome would provide global biodiversity observatories and the broader scientific community with access to usable, standardised data and provide a mechanism that can be communicated to the general public. Institutions wishing to support global biodiversity observatories can also assist CS by designing and testing both existing and new methods of data collection, analysis and interpretation, as well as by scaling these to protocols of international standards. Protocols could then be disseminated to other agencies and thereby improve both the research and communication quality of CS programs globally.

The second initiative requires global coordination and mobilisation of efforts. There has been a proliferation of CS programs in recent years (see list on scistarter.com and citsci.org), which means added competition for human resources. CS activities are often small scale and respond to local needs. The strength of CS is to develop and implement new research programs rapidly and can also expose challenges in linking to other programs with common interests. Often these programs are regional variations of the same basic theme (e.g., phenology programs such as Nature's Calendar, ClimateWatch, Project Budburst). Scistarter and others are looking into how best to simplify and serve interested participants who may want to contribute to multiple projects without needing to navigate, sign up and learn how to interact with different interfaces, tools and systems (Azavea and Scistarter 2014). Moreover, there are clearly trade-offs between projects focused on the local level and the needs of larger scale monitoring. A more coordinated approach and global framework to CS, such as the Wiki model (e.g., Geo-Wiki), would better address global issues such as climate change, land use, or introduced pests. Such a global framework would also reduce program operating costs in each participating country significantly, while simultaneously increasing the value of these data and enhance educational benefits that link local actions to global consequences. Such a global framework would also benefit from the identification of gaps where existing and future CS programs could compliment or enhance global data sets. Danielsen et al. (2014) have made progress in this area by examining how different approaches can contribute to the monitoring of the CBD Aichi Targets and 11 other international environmental agreements, including community-based projects but a comprehensive gap analysis is still lacking.

The third area is currently being addressed in part through the development of professional CS associations across the globe that are helping to coordinate and support training and capacity building around the creation and delivery of CS programs. Moreover, a number of CS toolkits (e.g., Roy et al. 2012; Tweddle et al. 2012; http://www.birds.cornell.edu/citscitoolkit/toolkit/steps; https://crowdsourcing-toolkit. sites.usa.gov/) are now available online to assist in the creation of new CS programs. GEO BON is also developing the BON-in-a-Box toolkit, which includes specific tools for CS projects aligned with BON efforts.

The rest of this chapter deals with practical issues around implementing CS programs including data quality, recruitment and motivation of participants, and the role of emerging technologies.

9.3   Enhancing Data Reliability and Reuse

CS projects span a spectrum of citizen engagement, from education and raising awareness on one end, where data collection is not necessarily a key component, to rigorous CS, where the data collected by citizens will be used for scientific research. Below we discuss two key aspects for enhancing data reliability: data quality and data standards.

9.3.1   Data Quality and Control

Accurate species identification including the identification of species through secondary field signs, such as scat surveys, bird song recording, cetacean calls (Buesching et al. 2014), is one of the most common and essential components of many CS projects. Generally, citizen scientists are better at identifying higher taxonomic categories that show a higher difference in physical characteristics and can struggle with genera lacking simple distinguishing characteristics among species. Another tendency is for participants to misidentify rarer species with limited or highly localised distributions. While an increase in data quality has been associated with the length of time and confidence of the person participating in the project (and the more familiar they become with the species monitored; e.g., Buesching et al. 2014), it is often best to leave difficult species to taxonomists. This generalisation does not always hold: for some taxa and in some places, the most reliable identifier may be an experienced and passionate lay person. Some CS systems establish a hierarchy of observers, and use the more experienced and tested observers to assess and moderate data supplied by less experienced observers. On the other hand CS participants are often willing to try and make identifications to a finer level from photographs than taxonomists are. Part of this issue is that keys and identification tools are not necessarily geared to advances in technology (e.g., digital camera and sound recordings) so that CS initiatives may result in a rethink about how tools are constructed by taxonomists, e.g. the use of Bayesian keys for biological identification on mobile devices (Rosewell and Edwards 2009).

In addition to issues of species identification, sources of bias may be present in the data, such as uneven recording intensity over time, uneven spatial coverage, uneven sampling effort per visit, uneven species detectability and variation in the types of data collected (i.e., presence-only versus presence-absence data; Bird et al. 2014; Isaac et al. 2014). Each source of variation has the potential to introduce substantial bias in trend estimates for individual species (Isaac et al. 2014). These concerns have encouraged CS practitioners to maximise data quality through improved sampling protocols and training, data standardisation and database management, and filtering or subsampling data to deal with error and uneven effort (Bird et al. 2014). For large projects or for broadly distributed databases it may be challenging to implement rigid protocols, or to effectively train volunteers or to

eliminate all sources of error and bias. In these situations new statistical and high-performance computing tools can help address data-quality issues such as sampling bias, detection, measurement error, identification, and spatial clustering (Bonney et al. 2014). Whilst there are a number of proposed methods in the literature based on filtering the data to remove bias, methods of statistical correction procedure to treat recorder activities are less frequent but have (according to Isaac et al. 2014) a greater variety of mechanisms to control for recorder activity (see Isaac et al. 2014; Bird et al. 2014) for a description of statistical methods). In order to maximise data quality in citizen science, basic principles of data collection, management and analysis need to be carefully planned, and collaborations with statisticians should be considered, potentially leading to the development of new statistical approaches and survey designs for CS (Bird et al. 2014).

Training is essential and can be through online instruction and quizzes, training courses, workshops or field sessions. Face-to-face training is the most effective (e.g., Newman et al. 2003), but it is typically limited to smaller regional projects although larger scale projects can partner with local organisations to hold regional workshops. Videos are a particularly powerful way of training participants (e.g., http://masswoods.net/outsmart-workflow), as they bring a personal feel, and can also be re-watched when volunteers need a refresher. McShea et al. (2015) found that online training with videos was just as effective as in-person training while Newman et al. (2010) found that online training tools improved the quality of citizen observations in measuring percentage plant cover. Aside from introductory training, careful supervision is necessary to minimise observer error and to enhance volunteer performance (Newman et al. 2003; Buesching et al. 2014). This has proven to be particularly important in the initial training period, with follow-up spot-checks and intensive training sessions concentrating on any emergent issues to do with quality (Buesching et al. 2005, 2014).

Online communities of support such as iSpot and iNaturalist can help citizen scientists to reduce errors in their identification by drawing on the experience of others—users upload photographs of a species with a suggested identification and the online community confirms the identification or suggests other possibilities. The development of online communities can take several forms including one where members of the online community can be awarded badges to reflect their individual abilities and for the taxonomic groupings they are best able to identify. The maintenance of these communities of practice through recognition and reward systems is one of the most promising avenues of growth for helping to identify the more challenging species when using crowdsourced CS projects. iSpot provides one of the best developed systems for supporting citizens scientists and uses a multi-dimensional reputation and reward system, which is also used to verify observations (Silvertown et al. 2015).

In the process of submitting data, automated online forms can be used to highlight suspect species identification (i.e., species that are outside their known range) to both the observer as they enter these data and for data users after sub-mission—see eBird http://ebird.org/content/ebird/ and Project FeederWatch http://feederwatch.org/ who use such systems (Bonter and Cooper 2012). Asking

volunteers to upload photographs of the species recorded allows experts to carry out spot checks and address common identification issues. Innovative smartphone applications such as Leafsnap http://leafsnap.com/, which uses visual recognition software to help identify tree species from photographs of leaves, can further advance accurate species identification. Camera trap based surveys have the added advantage that all records can be verified by expert review (McShea et al. 2015) or through consensus identification by multiple crowdsourced volunteers (Swanson et al. 2015).

Validation can be further enhanced at the data entry phase, with data being filtered as they are entered in a database, using specific criteria that generate an instantaneous automated evaluation of data submissions, achieved with a checklist of species for a certain area and/or species count limits for a given date and location. Any information added that is inconsistent with predicted values should then be reviewed by an expert, e.g. depending on the type of survey, verification of an observation by photo identification, supported by extra information about the observation from the volunteer including metadata. A subset of these data can also be requested, or a few participants may be accompanied and their measurements observed, thus providing another way to understand how they are following the project protocols.

A number of papers have appeared on the quality of the data collected by citizens. Some suggest that volunteers are able to collect data of a quality similar to professionals (Brandon et al. 2003; Engel and Voshell 2002; Fore et al. 2001) while others showed variable performance; e.g. Gollan et al. (2012) found that volunteers were in less agreement with benchmark measurements compared to scientists but that this varied by individual and attribute while Kelling et al. (2015) examined data from eBird and showed variability in quality between participants. However, those with high quality submissions also tended to be the ones who contributed the most data. Techniques like those outlined above as well the big data approaches of Kelling et al. (2015) are needed to ensure that data quality is controlled for in CS projects.

In addition to the quality of those primary data that are collected (e.g., species identification), the quality of ancillary data should also be considered, e.g. the accuracy of land cover/land use maps and other demographic and ecological data obtained. Mobile apps can be used to help volunteers verify this information or some data may be checked automatically, e.g. by electronic comparison of entries against existing map layers and checklists. Feedback to contributors is essential and can be a valuable component of training or follow-up/refresher training. Statistics on frequent contributors can contribute to detecting inconsistencies in definitions and differing interpretation of instructions.

9.3.2 Data Sharing and Standards

CS projects must adopt data uniform standards if these data are to be shared across multiple projects and networks, nationally or globally. The Darwin Core (DwC) is a

commonly used metadata standard for biodiversity applications, which consists of a vocabulary for taxa and their occurrence in nature. The DwC has been adopted by the Global Biodiversity Information Facility (GBIF). GBIF's website (http://tools.gbif.org/) also provides links to a number of tools that can be adopted by CS projects to facilitate the publishing of biodiversity data for further scientific use. iNaturalist, for example, was an early adopter of data standards and they now share their data openly through the GBIF portal.

Another site that promotes the sharing of species and ecosystem data is the NatureServe network (http://www.natureserve.org/) which has operated for almost 30 years. Using a set of standards and protocols referred to as the natural heritage methodology, more than 75 distributed databases have been linked successfully, searchable via a resource discovery tool on the site. NatureServe is also a data provider to GBIF and provides templates that may be of use to CS projects. DataONE is a distributed framework that links together 75 data centres, networks and organisations in order to openly share environmental data. The site includes a data management guide specifically written for the CS community that discusses the eight stages within the data management life-cycle including data discovery and sharing (Wiggins et al. 2013) while more information on standards can be found at https://www.dataone.org/all-best-practices.

9.4 Recruiting, Motivating and Retaining Participants

There are three key issues in developing a committed community of participants that will help CS projects collect reliable data successfully. These are the recruitment of contributors; the importance of considering participant motivation in the project design; and how participation can be retained and supported over the longer term, as well as ensuring that the experience is safe and well-managed. Much has been written on these topics and the reader is referred to a number of good guidance documents and articles (Dickinson et al. 2012; Roy et al. 2012; Pandya 2012; Tweddle et al. 2012; Van den Berg et al. 2012; Silvertown et al. 2013; Buesching et al. 2015).

Searchable databases are available from sites such as CS Central (http://www.birds.cornell.edu/citscitoolkit), SciStarter (http://scistarter.com/) and CS Alliance (http://www.citizensciencealliance.org/) for finding scientists and other project partners. Not surprisingly, these sites are dominated by projects for participants in English. National portals for CS projects also afford important avenues to selecting projects (e.g., Artportalen.org (Sweden), Observation.org (Netherlands), Atlas of Living Australia). Most of these sites also provide many resources and best practice guidelines on CS projects in general. Emerging technologies (see Sect. 9.5) can also play a potentially powerful role in finding partners, developing virtual communities and appealing to those people with a particular interest in technology. Simplifying and enhancing how participants can choose and participate in the right

project(s) is an active area of exploration, especially for larger networks such as SciStarter (Azavea and SciStarter 2014) or iNaturalist.

Recruitment is necessary so that citizens become aware of a project's existence. The starting point for recruitment is to determine who the target audience is (e.g., school children vs. bird watchers) and to then tailor the promotion and recruitment process towards this group (Tweddle et al. 2012).

The creation of a safe and meaningful experience requires careful forethought about the nature of the participant's experience, including where, what, when and how the data will be collected, any inherent risks that may arise and how to avoid, mitigate or manage those risks. This is especially important when participants may encounter challenging or hazardous conditions, such as observations which take place on or near waterbodies, from light aircraft, in remote or risky areas or involving dangerous or poisonous species. Addressing these considerations early on with careful planning and a response plan in case problems arise is essential to creating a sustainable CS program. Earthwatch has created templates for planning and managing risk on field-based CS projects as part of a broader approach to developing field-based CS projects (Earthwatch Institute 2013).

For those individuals already engaged with these subjects, promotion and support via e-mail, newsletters, Facebook and Twitter may be sufficient. Other actions might, however, be necessary to recruit new participants, such as through the use of the national, local or regional press or utilizing different types of media (e.g., TV, radio, print, online) and specialist publications. Holding a launch event, or an event at an existing festival or fair, can provide valuable face-to-face contact that will inform potential volunteers about the aims of the project, why their help is important and what they will gain from the project. These types of events also allow citizens to interact directly with the scientists involved and establish close relationships. Word-of-mouth recruitment by existing participants is one of the most powerful means of growing the base of volunteers for a program (Prestopnik and Crowston 2012a, b; Tweddle et al. 2012).

With respect to volunteer motivation, there are many studies (Bramston et al. 2011; Bruyere and Rappe 2007; Buesching et al. 2015; Raddick et al. 2013; Silvertown et al. 2013; Van den Berg et al. 2009) that have examined this aspect of CS projects. Understanding motivation is a critical prerequisite to developing successful CS projects. For example, Van den Berg et al. (2009) surveyed volunteers enrolled in a conservation program, and revealed a number of motivations including: the desire to learn more about the science behind the project; enjoyment of the outdoors; the feeling that they are helping the environment; getting to know other people with similar interests and as a way to make new friends; and having fun. The main motivation found by Raddick et al. (2013) in participating in the Galaxy Zoo CS project was the desire to contribute to science while other motivators included interest in the scientific subject and the possibility of making new scientific discoveries. Although this list of motivations is far from exhaustive, it highlights the need to recognise that individuals are motivated by a number of different drivers and that these may differ across communities and across different demographic groups. Some communities may feel excluded and identifying the

barriers to participation is important for finding solutions to widening the participation (Pandya 2012).

Project design will inevitably involve trade-offs between achieving scientific goals, e.g. gathering comprehensive, high quality data according to rigorous scientific protocols, and the ease of data collection. If the data collection is too complex or too time consuming, volunteers often lose their desire to participate and thus understanding and adapting the program to the skills, expectations and interests of the volunteers is critical (Roy et al. 2012).

Motivation is also clearly linked to maintaining participation in the longer term and data quality. Giving rapid feedback and providing regular communication about their contribution and the outcomes from the project are also excellent tools to motivate participants (Rotman et al. 2014). This can be done in different ways, such as through field events, email, phone, newsletters, blogs, discussion forums and various forms of social media.

Volunteers like the idea of knowing that their work is important and that their contributions can help scientists make better and more comprehensive analyses (Rotman et al. 2014). Rewarding citizen scientists is therefore an effective way to encourage and support participation (Tweddle et al. 2012). A reward system can be implemented in several different ways, e.g. highlighting the identity of contributors with observations to acknowledge their contributions explicitly (e.g., in Observado, iSpot and iNaturalist); providing participants with certificates of recognition (Dickinson et al. 2012); thanking participants and acknowledging their role, e.g. through organisation of a closing event, which can also be used to solicit further inputs and present the project results (Tweddle et al. 2012); providing open access to all of the non-sensitive records in the database; holding a competition to encourage participation, e.g. a photography contest (Dickinson et al. 2012); and recognizing the degree of volunteer expertise (e.g., progressing from amateur to expert levels in iSpot). Websites should make an effort to provide easy access to scientific, institutional, managerial and/or legislative products produced from project data, and to summarise these in ways of interest to contributors. It may not be readily apparent to citizens what contributions a few species observations might make collectively, e.g. to alert authorities to the arrival of invasive/pest species that appear on a list published under a national or provincial law. Encouraging these types of outreach and communication activities with citizen scientists may help to increase motivation.

Corporate engagement, fellowships and sponsorship (such as Earthwatch's 'Student Challenge Award Program/Ignite' for teenagers, the Sustainability Leadership Program for senior corporate executives (e.g., HSBC Bank) and the African Fellows program to build capacity among conservation managers) help to fulfil cross-sector participation. Integrating volunteer service directly into educational programs is another effective way to recruit and motivate individuals (Van den Berg et al. 2009). Master Naturalist programs have been established in several states such as California, Virginia, Texas and Florida that partner universities with extension services and wildlife management agencies at the state level while the Conservation Stewards Program has been established in Michigan. These programs

provide individuals with a certification and require a certain number of volunteer hours, both as part of the certification and to retain certification in the future. This type of approach caters towards educational motivations for participation in CS projects and encourages longer term engagement (Van den Berg et al. 2009). School children can become highly motivated contributors in the long term to BONs, becoming networks in and of themselves. The GLOBE (Global Learning and Research to Benefit the Environment) network is one very successful example of involving students aged 13–18 in CS (Bowser and Shanley 2013). Enabling features include the development of learning elements that align with relevant core curriculum standards. Partnerships between schools and BONs are likely to become much more important in the future.

9.5   New Tools and Technologies

CS has gained in popularity over the last decade due to the emergence of a number of new tools and technologies. Web 2.0 and the Internet of Things have radically changed the way that individuals interact, collaborate and share data online. Good overviews of the technology available for CS along with the strengths and weaknesses are provided in Roy et al. (2012) and Newman et al. (2012). Here we briefly outline the potential of a range of new tools and technologies that can be used in CS projects.

9.5.1   Websites and Portals

Websites are now an established media for disseminating information, where many CS projects have online forms for data collection. Some projects also provide visualisation and analysis tools and facilities to download the data (see, for example, eBird http://ebird.org).

In some countries, national level web portals exist, which provide the ability to customise local projects to suit the needs and interests of key stakeholders (i.e., project leads, participants) at the same time as feeding into larger databases using standardised data collection and curation protocols. Moreover, these web portals provide extensive training and support to prospective and ongoing programs. Examples include Artportalen in Sweden, the Norwegian Biodiversity Information Centre, Observation.org (Netherlands), National Biodiversity Network (UK), Atlas for Living Australia, India Biodiversity Portal among others. These portals create a bridge between the needs of large BONs and addressing local needs by reducing many of the barriers that would facilitate data flow. Namely, these portals provide many of the tools, systems access to expertise, feedback and other resources that otherwise make connecting local projects to global programs challenging.

9.5.2 Mobile Devices

Smartphones and tablets have fundamentally altered CS. Through software applications or 'apps' developed specifically for these devices, training materials can be disseminated and data collection on the ground is now much easier. Since most of these mobile devices have an integrated GPS (Global Positioning System), these data can be spatially referenced automatically, with a specified degree of accuracy. Constant internet connectivity is not required as these data, collected while in the field, can be stored locally and then uploaded to a server once a wireless connection is available. With the high quality cameras that are now a common feature of many mobile devices, photographic evidence can readily accompany observations, which makes the verification of species possible. In the context of biodiversity monitoring, there are many different species identification apps available, e.g. the iNaturalist (http://www.inaturalist.org/) and iSpot (http://www.ispot.org.uk/) apps, which cover a broad geographical area, as well as more localised apps to address a specific issue, e.g. the US Department of Agriculture provides a list of apps for reporting invasive species locally (http://www.invasivespeciesinfo.gov/toolkit/monitoringsmart.shtml). Other apps include phenological information for key species (http://www.climatewatch.org.au; http://www.budburst.org).

9.5.3 Sensors

Mobile devices can also act as sensors for measuring environmental variables, e.g. the built-in microphone in these devices can be used to measure noise levels (e.g., the NoiseTube project; http://noisetube.net/) while new sensors have emerged that can measure environmental variables where the sensor communicates directly with the mobile devices using Bluetooth and other wireless technologies, e.g. SenseBox, which is a DIY sensor box for measuring environmental variables such as weather and air quality (http://www.sensebox.de/). Citizens can also wear or transport many of these new devices and take measurements as they move around in space during their daily routine. In the EU, a number of environmental citizen observatories have been developed to measure air quality, air pollution, water quality and flooding (http://www.citizen-obs.eu/). In the USA, Public Lab is a non-profit initiative to allow communities to develop and mobilise low cost, open source sensors for environmental monitoring (https://publiclab.org/). Their first project involved mapping the BP oil spill on the Gulf Coast using balloons, kites and digital cameras and they now have several ongoing community-led projects. As the Internet of Things continues to become more prevalent, sensors will become a common part of everyday citizen life.

9.5.4   Camera Traps

Camera traps are motion-sensitive sensors that record a photograph or video when an animal passes in front of it. The photographs can be verified by experts for accurate species identification. Used by scientists since the 1920s, recent developments in digital photography and the cost reduction resulting from mass commercial production have finally made them an appropriate tool for citizen use. Camera traps are used to record which species live where, to estimate their abundance, to establish rarity in the endangered species context, to capture interesting behaviours or rare events and to potentially put off poachers. Choosing a camera model can be complicated because they are constantly improving with better technology becoming available. The website http://trailcampro.com provides an annual test of commercial units in their 'trail camera shootout'. Swann et al. (2011) provide a good overview of different types of cameras, the most frequent types of problems encountered and a framework for assessing needs, while other guides are available for Australian and Malaysian contexts (Ancrenaz et al. 2012; Meek et al. 2012). The eMammal project (http://emammal.si.edu/) has developed robust cyber-infrastructure and software to have volunteers process and upload pictures directly to a digital archive at the Smithsonian. In their first year, volunteers processed over 1.5 million pictures from 1200 camera locations (McShea et al. 2015). The Snapshot Serengeti project used scientists to set cameras in Africa, but recruited citizens to help them identify the animals in their 1.2 million pictures (Swanson et al. 2015). Live image transmission from cameras via phone networks is relatively expensive, but offers a powerful way to engage the public through the unpredictable flow of animal pictures to their screen. This has been used, for example, by the Instant Wild project (http://www.edgeofexistence.org/instantwild/), which asks volunteers to use a smartphone app or website to identify animals that have been photographed from camera traps in remote places such as Kenya, Sri Lanka and Indonesia. @Camtrap live is a similar Twitter feed that streams live images and commentary from two cameras in the USA.

9.5.5   Social Media and Social Networking

There has been considerable growth in social media and social networking sites. In 2015, Facebook was estimated to have 1.55 billion active monthly users worldwide, with 1.31 billion accessing the application through their mobile devices (Statista 2015), while Twitter was estimated to have more than 320 million monthly active users (Twitter 2015). Instagram, which is another popular social media site, had more than 182.5 million users who uploaded around 58 million photos per day based on statistics for September 2015 (Statistic Brain Research Institute 2015). There has been a recent trend away from smaller, local social platforms to these large global sites, which has implications for CS projects wanting to establish a

presence via social media. Social networking sites represent a very powerful way for building and maintaining CS communities and for providing virtual support mechanisms to a wide geographical audience. Many CS projects already provide integration via Facebook (e.g., iSpot), while Twitter is used to report sightings of invasive species in Ontario, (e.g., to @invspecies). Discussion forums and blog sites have been around for longer but also represent effective methods of virtual communication while Skype is now being used by teachers live from the field to reach out to children in their schools.

9.5.6 Gaming

Another approach used in CS for generating participation is 'gamification', or the addition of game elements to existing applications (Deterding et al. 2011). This approach can help to improve volunteer motivation as a tangible form of recognition by linking their contributions to levels of achievement or badges of expertise. For example, the iSpot project allows individuals to progress to 'expert' status as they identify more species, as well as a quiz to test oneself (http://www.ispotnature. org/quiz/try). The Biotracker app, which is used to contribute phenology data to Project Budburst, and uses badges and a leader board, was shown to attract an additional user group referred to as Millennials, which is the younger, technologically experienced generation (Bowser et al. 2013). Other examples of gamification in CS include Tiger Nation, which tracks the movements of tigers (Mason et al. 2012), and Happy Soft, which uses gamification in species identification (Prestopnik and Crowston 2012a, b).

9.5.7 Cyber-Infrastructure and Networked Databases

Cyber-infrastructure refers to the IT systems that support various data and system functions and ensures interoperable data exchange via networked databases. Functions include support for data storage and management, geospatial analysis tools, visualisation capability, social networking tools, quality control and training. Newman et al. (2011) provide a framework that advises CS project managers in developing and/or selecting data management systems based on the scope, scale, activities and the system approach taken within a given project. They have also developed the CitSci.org cyber-infrastructure system as a flexible open source solution (Wang et al. 2015). Other available cyber-infrastructure systems are compared by system features in Newman et al. (2011), which may help guide the choice of a system to meet project needs. More recently, some CS projects have begun to provide the otherwise expensive cyber-infrastructure to help facilitate scaling up. For example, iNaturalist lets you create a group within their program, which allows use of their cyber-infrastructure to record the location and time of any

sub-group of biodiversity desired, and they offer their code as open access. Zooniverse has developed a platform for setting up CS projects, which can then be showcased on the Zooniverse platform for tapping into the Zooniverse network of users. eMammal is providing the same service for camera traps. Finally, SciStarter is preparing to upgrade their system to serve as a better basic sign-up infrastructure for simpler projects.

9.6   Challenges and Opportunities for the Future

CS provides many opportunities for increased data collection and greater involvement of citizens in scientific research across many areas that are of relevance to BONs. Indeed every day, new CS programs are launched in every corner of the globe offering people new opportunities to monitor or track species or environmental events. While this proliferation of projects offers great opportunity, there are also a number of challenges that will need to be resolved.

There are trade-offs between localised, customised projects focusing on a restricted taxonomic group or location where the advantages are more local buy-in, ownership and control, versus more interconnected or networked larger scale efforts, where there are economies of scale with data that are often more accessible and shared. How are participants to choose between similar sounding programs? How can localised programs feed into larger scale initiatives, and vice versa? Resolving questions around data standards, interoperability of systems, and attribution will be important in creating a more coherent 'marketplace' of CS opportunities. Two promising avenues are opening up. One explores how to simplify the choice of projects and reduce the barriers to learning new tools and systems for citizen scientists by improving the front end of engagement by participants (Azavea and Scistarter 2014). The other is the development of web portals that simplify much of the data management, processing and sharing across many projects. These web portals may be national in scope such as Artportalen (Sweden), the National Biodiversity Network (UK), Atlas of Living Australia and the India Biodiversity portal; taxonomic in scope (e.g., eBird), observation tool based (e.g., iNaturalist, iSpot); or EBV based (e.g., National Phenology Network). While many of these programs are mainly focused on species occurrence data, they bring together tools, processes and systems that link the local with the large scale databases.

There are also trade-offs between the collection of rigorous or reliable data gathered in a systematised fashion, on the one hand, and the ease of use or accessibility of CS programs, on the other (Pocock et al. 2015). Easing data collection protocols and reducing the number of variables collected can reduce barriers and increase or broaden involvement. Environmental education and other engagement goals are important but they can simultaneously act to increase the volume of data collected. Yet, verifiable and reliable data are often seen as essential for management decision making and scientific research outcomes. Moreover, ensuring data quality is important in attracting more scientists to use and engage

with CS programs. More explicit statements about a CS program's goals, whether they seek more rigorous science or a broader environmental education effort is an important step in avoiding confusion, in expectations and outcomes, among participants and scientists alike (Pocock et al. 2015). Secondly, the development and adoption of more robust statistical approaches can help programs reduce sampling error, allowing a better balance between quantity and quality of data collected (Isaac et al. 2014; van Strien et al. 2013).

A key challenge in the next few decades is to extend the reach of CS into places where it has not had a prominent role in the past. Current CS networks are predominantly active in Europe, North America and some former colonies, such as Australia, New Zealand and South Africa. Africa, Latin America and Asia are under-represented. Growing wealth and education in these areas, along with near-universal penetration of internet services and cell phones, creates an opportunity to extend CS into these biodiversity-rich regions. The motivations and social mechanisms to do so may differ from those found in 'western' societies, but there is nevertheless a rich vein of traditional knowledge and interest in biodiversity which can be tapped.

CS is already playing an important role in ground-based monitoring, complementing and corroborating the global satellite-based observations and more focused government or institution led efforts. This chapter outlined some of the tools and opportunities for building on existing and developing new CS initiatives to help BON efforts increase our understanding of the status and trends of biodiversity. Perhaps most importantly, a growth of CS programs that engage a broader constituency of people collecting biodiversity information will build the essential social equity and foster the necessary dialogue that stimulates the political will to make the decisions necessary for a sustainable and biodiverse planet.

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