Introduction

CHRISTOPHER A. LEPCZYK, OWEN D. BOYLE,
and TIMOTHY L. V. VARGO

Citizen science. These words convey a variety of ideas and meanings, depending on one's background and training. In fact, not too long ago these words often stirred controversy in the scientific community. Today, however, citizen science is a fully fledged field that has contributed a great deal to our understanding of the world and provided an opportunity for countless numbers of individuals to participate with, and become, scientists.

While citizen science is widely practiced today, it is important to keep in mind that it is not a replacement for professional science. Science will continue to need highly trained professionals who have a formal education and experience in the scientific process, which often requires years of apprenticeship (i.e., graduate school). Just as we need doctors and dentists to have training and professional experience prior to practicing medicine on their own, we need similar requirements for scientists. Training and experience are particularly important in applied science contexts, such as conservation biology and natural resource management, where ignorance can result in long-term or permanent environmental problems.

Another important point to keep in mind is that citizen science is not a license to use unpaid volunteers to collect data. When considering a scientific project, it is important to avoid implementing a citizen science approach simply to reduce costs or because a grant did not provide the desired level of funding. Likewise, it is important for nonprofit organizations, government agencies, and academics not to turn to citizen science simply because of a lean budget year or as a means to reduce costs. In other words, citizen science should not be viewed as free labor.

Well-designed citizen science not only aids in scientific discovery, but can serve to educate the participants. In fact, one large reason for considering a citizen science approach is to improve scientific literacy (or, as in the case of this book, ecological literacy). Many people who engage in citizen science gain not only an improved understanding of the system or project they work with, but an increased general interest in science. Thus, citizen science is something to consider for people of all ages as a way to increase their appreciation for, and understanding of, science. Indeed, as we will see in this handbook, citizen science is being used as an educational tool and as a means to engage in outreach. Cooperative Extension programs, for example, have used it to connect people to the world they live in.

Because citizen science offers a powerful approach to answering questions and educating the public, it is important that it be carried out correctly. Hence, the focus of this handbook is on the practice of citizen science as it relates to conservation and ecology, which includes conservation biology, applied ecology, basic ecology, and natural resource management. The book is written primarily for practitioners working for government agencies, non-governmental organizations, and academic institutions who are interested in beginning partnerships with the community or enhancing and improving existing citizen science projects. However, the book should hold value for anyone interested in citizen science and science education.

WHAT THIS BOOK IS NOT

We have sought to cover a wide swath, but we acknowledge that no handbook is perfect or can address everything, particularly with regard to an actively innovating field like citizen science. Hence, there are a handful of topics that we do not cover in this handbook, but we will note them here, given their importance.

First and foremost is funding. As the old saying goes, there is no such thing as a free lunch, and this is true in citizen science. *All* projects require financial resources of some type (if only money to pay for gas or paper to record data). Even if at first you cannot identify the financial costs of a project, simply consider the time involved, the number of people, and the tools they will need and it should become clear that all projects have (and require) a financial component. How projects are funded varies greatly, from grants to online funding aggregators. However, the type and amount of funding needed often depend on the type of project. Furthermore, organizations that fund projects vary markedly in what they are looking to fund and what they require of the grantee. Ultimately, there is no single pathway to funding and most projects will need to have individuals dedicated to raising funds and applying for grants. In the end, if your project does not have the resources to be completed, then the project should not be pursued.

Second, this handbook does not explicitly focus on experimental design. Any scientific project needs to have a methodology, including a framework in which to test questions, if it is to be successful. However, given the vast array of questions and hypotheses that ecologists and conservation biologists address, and the many approaches available and statistical tools needed, a primer on experimental design would require more space than is feasible in a handbook like this. That said, we strongly recommend that at least one member of any team planning a citizen science project understands experimental design; this may mean seeking out a professional scientist who can assist with that aspect of the project.

Third, the focus of this book is general and not aimed at one subdiscipline or segment of ecology and conservation. However, while subdisciplines and fields are not specifically called out in the chapters that follow, the approaches described are relevant for all. A case in point is environmental justice. One key element of evaluating environmental justice questions is environmental monitoring, which is a common form of citizen science. Keep in mind that we are focused here on process and the value of citizen science, not on specific taxa, ecosystems, or subdisciplines.

Fourth, we initially had a placeholder for a chapter related to systemic imbalances of power in the world of science and the importance of focusing on justice and the dignity of each stakeholder. We soon realized that a single chapter on these extremely important issues would run the risk of trivializing them and that to address them properly would require a separate book. With this in mind, we encourage all practitioners to strongly consider the social effects of their work. In true collaborations, one side is not deemed more important and it should not be assumed that one side is going to control the budget or write the grants. Nor should one assume that citizen scientists are replacing professional scientists, but one should recognize that all parties bring important and necessary skills to the table.

Finally, this book is not a philosophical discussion on the pros and cons of citizen science or on what citizen scientists should be called or how they should be valued. We view many arguments about citizen science to be settled (e.g., data quality) and others as minor in relation to the larger value of the field. That said, we do tend to use the words *participant* or *citizen scientist,* rather than *volunteer,* to describe individuals who participate in projects, in order to avoid the view that citizen science is free.

ORGANIZATION OF THE HANDBOOK

We have laid out the handbook in three main sections. The first provides an introduction to citizen science and a history of its emergence. This history is valuable in framing the larger view of the handbook and provides the context in which citizen science has grown and become useful. The second section is the heart of the book and focuses on the specifics of citizen science, from project conception to completion. The final section focuses on real-world examples of citizen science projects at scales from local to continental, in different ecosystems and locations, and on a variety of topics. The goal of this final section is to illustrate existing citizen science projects in conservation, ecology, and natural resource management that can serve as role models for other projects.

PART ONE

BACKGROUND

ONE

What Is Citizen Science?

JENNIFER L. SHIRK and RICK BONNEY

The broad field, and history, of citizen science encompasses many different ways that members of the public can become involved in scientific work. In natural resource management contexts, people often think of citizen science as long-standing bird-count projects that now span a century and that have led to peer-reviewed publications about global trends. To others the term may evoke the contributions of amateur natural historians that established our understandings of many species, work that predates the term *science* itself (think Darwin, or even Aristotle). Still others may reference decades-long, volunteer water-monitoring traditions, or newer low-cost sensor networks, each of which enables communities to bring scientific data to the defense of environmental integrity in their neighborhoods and watersheds. A milestone was reached in 2014 when the *Oxford English Dictionary* included the term *citizen science* with a definition broad enough to embrace all of these traditions: *"Scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions."*

Citizen science is real science—and therefore it reflects as wide a diversity of purpose and design as does the realm of more conventional science. Scientific work through citizen science may be intended for peer-reviewed publication or to inform management. Likewise, citizen science work may address timely problems or monitor long-term trends. A given citizen science research question may call for precision in data collection, or it may be better served by accuracy and statistical power. In every case, citizen science results are subject to the same system of peer review that applies to conventional science—in all cases, this review must be based on the intended purposes and merits of the research efforts.

Although acceptance of volunteer contributions to conventional science has been slow, ecologists and natural resource managers have been among the first to acknowledge the value of citizen science efforts. Thoughtfully designed citizen science projects produce reliable data that are usable by scientists, policymakers, and the public. Data from such projects have now been used in hundreds of scientific articles and have informed numerous natural-resources policy and planning efforts (Dickinson et al. 2010). Indeed, our current understanding of the natural environment is due, in large part, to the amateur scientist community's decades of dedication and expertise.

More recently, the advent of the Internet and mobile technologies has enhanced opportunities to collect, store, share, manage, and analyze vast amounts of data quickly and easily. As a result, scientific projects can now deploy large numbers of volunteers and can record huge volumes of observations in centralized databases that can be analyzed in near real time. Building on this opportunity, citizen science participation has become much more widely possible at both large and small scales, and thousands of projects now engage millions of participants around the world. In fields ranging from astronomy to zoology, citizen science is helping to answer many challenging questions—in ecological disciplines, in particular, it can help address issues that affect both the environment and our everyday lives.

WHEN IS CITIZEN SCIENCE AN APPROPRIATE TOOL?

In order to maximize the potential for citizen science to achieve intended results, researchers and managers must decide whether work with volunteers is an appropriate approach to the research at hand. Citizen science projects can tackle major challenges in managing natural resources and the environment, such as species management, ecosystem services management, climate change adaptation, invasive species control, and pollution detection and regulation. Understanding the relative strengths of citizen science can help determine when it can provide advantages over conventional science. These strengths include the following:

Citizen science can often operate at greater geographic scales and over a longer time than conventional science. Only volunteers can cost-effectively collect some types of data over sufficiently large areas and long enough periods of time to produce scientifically reliable and meaningful datasets. For example, eBird, a project of the Cornell Lab of Ornithology, collects five million observations of birds each month from locations across the globe. At maturity, a project's dataset can be geographically broad, locally dense, and temporally consistent, offering many powerful opportunities for analysis.

Citizen science can increase resolution of data collection. Even at small geographic scales, citizen science can benefit from mobilizing a large number of observers in a given area. In addition to increasing observational power, citizen science can also enhance access to data in new places such as private lands, thereby filling in gaps in datasets. In some cases, projects have benefited greatly from volunteers collecting data when scientists are not typically present, such as during the Arctic autumn and winter.

Citizen science can speed up and improve field detection. Having many eyes on the lookout can help detect environmental changes (e.g., changes in the onset of spring through plant phenology), identify phenomena that require management responses (e.g., population declines, incidences of pollution, introduction of an invasive species), and monitor the effectiveness of management practices.

Citizen science can improve data and image analysis. Humans have the ability to recognize patterns and interpret large amounts of data as well as to detect individual diversity. Volunteers with no specialized training can outperform state-of-the-art algorithms in certain analytical tasks. Volunteers can also extract information from digitally collected primary data (e.g., images or audio) by identifying and recording secondary information (e.g., the abundance, behavior, and frequency or duration of various phenomena), tasks that are often difficult for computers. Finally, volunteers have additional knowledge and perspectives that can complement or improve professional scientists' interpretations of data and results, whether from local or traditional knowledge that can shed light on patterns or seeming anomalies, or by bringing attention to unappreciated social dimensions of management, livelihoods, or ecological processes.

Citizen science can help refine research questions. Participants in citizen science are affected by and observe local natural resources and the environment in their daily lives, so they can help improve the relevance of location-specific research questions and make them more useful to managers and local communities. A full understanding of natural resource and environmental issues often requires a holistic perspective, including human dimensions. Citizen science can help provide this holistic perspective and improve research relevance.

Citizen science can help researchers appreciate connections between humans and their environment. Citizen science is well suited for interdisciplinary collaboration, particularly for projects that include both natural and social dimensions. Natural resource and environmental managers increasingly address the social aspects of difficult ecological issues, such as managing wildfires in the wildland-urban interface. By engaging local community members, citizen science can facilitate a shared understanding among managers, scientists, regulators, policymakers, volunteers, and others of the complex social dimensions of the natural systems where people live.

WHEN AND HOW *NOT* TO DO CITIZEN SCIENCE

Some scientific inquiries are not appropriate for citizen science. It is often assumed that the most common factor limiting volunteer participation in a scientific project is the ability of trained volunteers to meaningfully contribute to the science. Some research questions, methods, and analyses do require specialized knowledge, training, equipment, and time commitments that can make citizen science inefficient or impractical as an approach. However, an increasing number of new citizen science projects—and associated data-quality studies—indicate that unexpected areas of scientific inquiry are successfully being advanced through citizen science.

As innovators continue to overcome more and more perceived barriers to volunteer-based research, it is difficult to outline any hard-and-fast rules about what will not work. Some general concerns are outlined by Michael Pocock and colleagues (Pocock et al. 2014). Additionally, any given research area will have case-specific constraints. We suggest that you proceed with caution if any of the following statements apply:

Your primary goal is public education. Citizen science can be an effective means of facilitating learning and can be utilized to great effect in both formal and informal educational settings. However, research suggests that people participate in citizen science because they want to make a contribution or a difference in the world. If your project is not grounded in purposeful research, expect participation to fall flat.

There is significant concern about biasing decision making. This is not a reason to avoid citizen science, but it is definitely a reason to be careful in project planning. Even professional scientists must proceed with caution—and ideally transparency—in circumstances where they are both conducting research and informing decision makers. Similar quality controls can be used for both citizen science and conventional science. These quality controls can include training, collection of duplicate samples, and post-data-collection analyses designed to identify outliers and biases in the data. Quality controls should be used in most, if not all, citizen science projects, even when volunteers are not involved in decision making.

Participant interest is unknown. Not all citizen science projects stimulate widespread or even sufficient public interest, from either curiosity or concern. Because interests vary, people are selective about participating in citizen science. For example, charismatic species such as wolves, bears, and certain birds receive—in general—more public attention (and support for public funding) than other species, including most plants. Similarly, study sites near tourist destinations and college campuses tend to receive more attention than those in urban and industrial areas. In addition, studies in small or remote communities may be of great local interest, yet the pool of potential participants for a citizen science project may be small. For certain taxa and ecological processes and for some biogeographic regions or geographic locations, citizen science could be difficult to sustain if large or ongoing datasets are required.

Activities put volunteers, species, or habitats at risk. Fieldwork can involve potentially hazardous conditions for volunteers. Such hazards may include physical dangers but can also include issues of privacy, such as public data revealing home addresses or patterns of activity. Citizen science also has the potential to draw unwarranted or unexpected attention to sensitive species, and to increase environmental impacts in remote areas. Some level of risk is unavoidable—be aware of the risks that volunteers, organizations, and landscapes will tolerate. Also be sure that volunteers are aware of any dangers to themselves and to species or habitats, and that policies and procedures are in place as safeguards. These may include liability policies, privacy policies, and mitigation techniques for sensitive data.

Sampling frequency is high—or low. The need for frequent sampling can limit the feasibility of citizen science. Few volunteers are able to devote extended periods of time to scientific projects. Extremely frequent (e.g., daily) sampling needs may therefore discourage participation and increase turnover. There can also be a mismatch between the availability of volunteers and the availability of managers or their staffs. For example, participants may be available primarily on weekends, when staff is unavailable. As a result, it may be difficult to recruit citizen science volunteers for certain projects. At the other extreme, infrequent (e.g., annual) sampling could make it harder to sustain collection of high-quality data, because participants may have to relearn even basic protocols. A successful sampling design for volunteers lies in between, where sampling frequency is just enough to keep participants well practiced and able to gather consistent data, but not so high as to become onerous and discourage participation.

Skills needed do not align with skills available. Running a citizen science project calls for an individual or team with a diverse skill set, ready to manage everything from protocol development to outreach to data management. Additionally, citizen science can increase research efficiency, but only if the benefits of having volunteer assistants are not outweighed by the task of training or recruiting skilled volunteers. Keep in mind, however, that most projects will require an investment in planning, vetting, and training early on that may take some time to show returns.

In short, consider the value of citizen science for answering the question at hand, in comparison to other approaches. Innovative research teams continue to adapt citizen science approaches to overcome potential pitfalls and succeed despite perceived odds, so where you or others see challenges, be careful not to overlook innovative solutions and possibilities. But do consider the value of adapting to challenges, and then proceed if the potential benefits seem worth the investment or at least worth a try. In general, if you have reasonable expectations that align with volunteer interests, and if training opportunities and research protocols are vetted and refined through pilot testing, you have a fair shot at a successful citizen science project.

BEST-FIT OPPORTUNITIES FOR CITIZEN SCIENCE

Considering all the aforementioned points, citizen science may be most advantageous under the following circumstances.

Volunteers Can Collect High-Quality Data

Sometimes volunteers need only minimal training to be able to collect high-quality data. For example, it may be easy to collect insects or make simple measurements, such as tree circumference, without extensive instruction or instrumentation. Volunteers can also collect data that require following elaborate protocols or developing certain specialized skills, such as in many water-quality monitoring programs. Research has shown that volunteers with proper training and guidance can accurately identify specimens at various taxonomic levels and accurately assess important population attributes, such as species abundance and distribution. Individual volunteers can even develop the skills to use sophisticated analytical instruments. However, projects that depend on numerous volunteers should not expect a sophisticated level of skill from all individuals, nor should volunteers be expected to undertake activities that require extensive training or certification. Generally speaking, the simpler the methods, the easier it is to engage volunteers in collecting high-quality data. Simple tasks also make it feasible to increase the number of contributors and easier to sustain collection of high-quality data. Organizations should also use data quality controls to identify questionable data and correct or discard them. The use of quality controls is relevant for all types of survey and assessment, whether implemented by volunteers or by professional scientists.

Volunteers Can Address Unanswerable Questions

Participation by volunteers can make it possible to address questions that would be unanswerable in any other way. Public participation can be integral to the ability to collect, analyze, and interpret certain data. A major strength of citizen science is its ability to collect fine-grained information over broad areas and long periods and to process large amounts of data (such as images), simply because the number of volunteers may exceed the number of professionals (including researchers, faculty, and students) by several orders of magnitude. In some cases, volunteers can obtain data inaccessible to government employees, such as data on private lands or data related to individual activities such as hunting or fishing. When a rapid response is needed, such as to environmental disasters or sudden large-scale bird or fish die-offs, research efforts can benefit from the ability to swiftly mobilize large numbers of volunteers. A few types of studies that lend themselves well to citizen science include the following:

Monitoring studies that assess patterns, in space and/or time, of one or more ecosystem components (e.g., Is this species here now? How many individuals of this species are here now?) or functions (e.g., Is this process happening now?). Data collection is standardized (the same for all sampling locations) and effort-controlled (data are recorded even if none are found—i.e., zeros count!).

Process studies that assess the impacts of factors (e.g., hazardous-fuel reduction treatments or pollution) on ecosystem components or functions (e.g., nutrient and water cycling). The researchers control the level and duration of the exposure, and there is a control (e.g., the status quo).

Opportunistic and observational studies that do not follow a strict design but are often deliberate in the subject and timing of observation. These studies can be useful because of the scale of the data collection, the rarity of the phenomena observed (e.g., a rare species or infrequent weather event), or the timeliness of the observations (e.g., collecting information for crisis response, such as after earthquakes or oil spills).

Public Participation Meets Organizational Goals

Public participation in the scientific process can serve the organization's goals for public input and engagement and helps in decision making through the generation of both scientific knowledge and learning. Public input can help identify the most relevant questions that a scientific study is designed to answer and the best methods to carry out the study, particularly if the research is focused on an issue that affects or involves local people. If research is intended to affect natural resource management or environmental policymaking decisions, then public participation could aid in developing locally appropriate research questions and methods, particularly if the management or policymaking question requires understanding how human behavior interacts with ecological processes. In addition, local or traditional knowledge can reveal complementary ways of understanding local ecology, environmental trends, and threats to species and livelihoods. When the research problem is informed by the best available knowledge and by multiple perspectives, research questions and methods can be formulated that take into account the integrated social and scientific dimensions that managers and policymakers must address.

When Citizen Science Works Best

In brief, citizen science works best when

- the project's aims are clearly defined and shared from the start;
- the research activities are beneficial to both scientists and participants;
- the project team includes expertise in all aspects, from data analysis to communication;
- evaluation is built into the project design, and there is a willingness to listen and adapt;
- small-scale pilot trials are undertaken as proof-of-concept and to improve procedures;
- the participants are meaningfully recruited and supported;

- the motivations and skill levels of all involved are understood;
- the participants feel they are part of the team;
- the project is an efficient and enjoyable way to gather and analyze the data; and
- the quality of the data is measurable.

Around these basic guidelines, researchers continue to open new possibilities and frontiers for citizen science. Citizen science can be done in almost any setting, but it takes a particular combination of skills, intentions, interests, and careful design to make it work (see box 1.1).

WHAT *IS* CITIZEN SCIENCE?

Citizen science, in all of its diverse forms, is a means of public engagement in scientific work that can expand the scope, reach, and impact of research. Citizen science can provide opportunities to collect data at scales otherwise not feasible for professional scientists alone and can engage members of the public in compiling and using issue-relevant evidence to effect change. Taken together, these opportunities have the potential to bring new power to addressing major challenges in conservation and natural resource management, particularly those that require attention to both social and scientific aspects of a problem.

But citizen science is a complex undertaking, often demanding dedicated time and money as well as a willingness to understand what it means to engage with the public. In ecology in particular, with so much at stake, citizen science gives us the opportunity to reflect on and learn about the human dimensions of ecological research and environmental management, as well as about the science. Citizen science provides an opportunity to do more than hand off this task to educators or outreach specialists. If we, as researchers and managers, embrace the opportunity—and challenge—to listen and learn as well as interpret and share, we may be best prepared to fulfill the potential of citizen science to expand knowledge for science-based conservation.

BOX 1.1 Not *Whether* but *How* to Do Citizen Science

In order to maximize the potential for citizen science to achieve intended results, it is important to understand how the structure of a project—particularly the ways volunteers are engaged—will affect the project's outcomes. Projects undertaken to address questions or issues that require large amounts of data to be collected over time and space are often *contributory* in their approach to participation. These contributory projects are typically top-down in design, with scientists controlling all aspects of research: determining the questions or issues to be addressed, designing data-collection protocols, processing and analyzing the data collected by public participants, and communicating the results. A contributory approach thus allows scientists to rigorously structure the procedures for data collection and submission. Meanwhile, a contributory approach can provide volunteers a chance to hone their skills and learn research techniques, but with limited opportunities to engage with scientists (in large-scale projects) or with the process of science, which limits deeper learning.

Alternatively, research opportunities can emerge in response to a need identified by community members. Such community-driven projects, called *co-created* or *community science,* typically focus on studying issues of pressing concern for local residents, such as environmental health or degradation. The co-created approach to citizen science is most relevant to projects addressing a specific environmental question or problem that will benefit from establishing a community- or volunteer-led monitoring scheme in which all parties have a stake in the outcomes. Such projects can involve significant volunteer commitment, and all parties must be willing to listen, plan, adapt, and reach consensus about mutually beneficial research goals and approaches. As a result, co-created projects can provide deep insights—for participants and researchers alike—into science and management processes, but they can also be difficult to operate at large geographic scales.

Despite these generalities, individual citizen science projects themselves cannot always be easily categorized. Some large-scale contributory projects have distinct goals for policy and management and can be leveraged in a co-created fashion by local communities. The global eBird dataset, for example, is accessed by the Nature Conservancy to determine areas of California's Central Valley that the Conservancy can pay farmers to flood during times of peak migration. Likewise, community science projects can yield outcomes with implications at broader geographic scales, such as by aggregating community-level data to look at statewide trends in water quality. Therefore, it is worth taking into account the significance of participant engagement when considering not just *whether* but *how* to employ citizen science as a tool to meet needs in ecological science, management, or policy (Bonney et al. 2009, Shirk et al. 2012).