ISSUES IN ECOLOGY

Published by the Ecological Society of America

Investing in Citizen Science Can Improve Natural Resource Management and Environmental Protection

Duncan C. McKinley, Abraham J. Miller-Rushing, Heidi L. Ballard, Rick Bonney, Hutch Brown, Daniel M. Evans, Rebecca A. French, Julia K. Parrish, Tina B. Phillips, Sean F. Ryan, Lea A. Shanley, Jennifer L. Shirk, Kristine F. Stepenuck, Jake F. Weltzin, Andrea Wiggins, Owen D. Boyle, Russell D. Briggs, Stuart F. Chapin III, David A. Hewitt, Peter W. Preuss, and Michael A. Soukup

Fall 2015

Report Number 19

esa

Investing in Citizen Science Can Improve Natural Resource Management and Environmental Protection

Duncan C. McKinley, Abraham J. Miller-Rushing, Heidi L. Ballard, Rick Bonney, Hutch Brown, Daniel M. Evans, Rebecca A. French, Julia K. Parrish, Tina B. Phillips, Sean F. Ryan, Lea A. Shanley, Jennifer L. Shirk, Kristine F. Stepenuck, Jake F. Weltzin, Andrea Wiggins, Owen D. Boyle, Russell D. Briggs, Stuart F. Chapin III, David A. Hewitt, Peter W. Preuss, and Michael A. Soukup

Summary

Citizen science has made substantive contributions to science for hundreds of years. More recently, it has contributed to many articles in peer-reviewed scientific journals and has influenced natural resource management and environmental protection decisions and policies across the nation. Over the last 10 years, citizen science—participation by the public in a scientific project—has seen explosive growth in the United States and many other countries, particularly in ecology, the environmental sciences, and related fields of inquiry.

The goal of this report is to help government agencies and other organizations involved in natural resource management, environmental protection, and policymaking related to both to make informed decisions about investing in citizen science. In this report, we explore the current use of citizen science in natural resource and environmental science and decisionmaking in the United States and describe the investments organizations might make to benefit from citizen science. We find that:

- Many people are interested in participating in citizen science.
- Citizen science already contributes to natural resource and environmental science, natural resource management, and environmental protection and policymaking.
- Citizen science is a rigorous process of scientific discovery, indistinguishable from conventional science apart from the participation of volunteers, and should be treated as such in its design, implementation, and evaluation. When properly designed and used, citizen science can help an organization meet its needs for sound science.
- Citizen science can contribute to natural resource and environmental organizations' goals for public input and engagement.
- Many types of projects can benefit from citizen science. When planning to utilize citizen science, organizations need to match their needs and goals for science and public input and engagement to the strengths of particular citizen science projects and the ways in which the public can participate. Depending on the organization's needs and goals, citizen science can efficiently generate high-quality data or help solve problems while fostering public input and engagement.
- Organizational leadership is needed to provide realistic expectations for citizen science, including its limitations as well as its benefits. Leadership is also sometimes needed to lessen administrative hurdles and to create a safe space for learning from project inefficiencies and failures.

Citizen science requires strategic investments. Beyond project-specific investments, organizations should consider developing or modifying policies and technologies designed to facilitate the field of citizen science as a whole.

Cover photos: *Clockwise starting on the upper left: a) COASST program volunteers collecting information on a seabird carcass b) National Park Service staff and volunteers recording phenology of various plants and animals c) Volunteers sorting and identifying specimens for a biodiversity survey d) A Wisconsin Department of Natural Resources botanist training volunteers on survey methods for the Wisconsin Rare Plant Monitoring Program.*

Photos credits: *a) Liz Mack, COASST b) Carolyn A. F. Enquist c) Zach Kobrinsky d) Corey Raimond.*

Investing in Citizen Science Can Improve Natural Resource Management and Environmental Protection

Duncan C. McKinley, Abraham J. Miller-Rushing, Heidi L. Ballard, Rick Bonney, Hutch Brown, Daniel M. Evans, Rebecca A. French, Julia K. Parrish, Tina B. Phillips, Sean F. Ryan, Lea A. Shanley, Jennifer L. Shirk, Kristine F. Stepenuck, Jake F. Weltzin, Andrea Wiggins, Owen D. Boyle, Russell D. Briggs, Stuart F. Chapin III, David A. Hewitt, Peter W. Preuss, and Michael A. Soukup

Introduction

Red-cockaded woodpecker, Florida manatee, Gulf sturgeon … all are native to Wolf Bay, an estuary on the Gulf coast of Alabama, where freshwater streams mix with saltwater from the ocean to support habitat for a variety of native fish and wildlife. The region's marshes, forests, and waters also support a thriving tourist industry and a rich commercial and recreational fishery.

The area around Wolf Bay has grown tremendously. Baldwin County, home to Wolf Bay, has nearly doubled its population in the past two decades, with development encroaching on fragile ecosystems. Local systems and habitats depend on the delivery of clean water from coastal streams, and development has placed local water quality at risk.

In 1996, Auburn University staff, working with local citizens, launched Alabama Water Watch, a program to engage citizens in monitoring local water quality. A network of local water-monitoring groups emerged across the state, including Wolf Bay Watershed Watch, a nonprofit organization formed in 1998. With training and guidance from Alabama Water Watch, Wolf Bay Watershed Watch currently monitors almost 60 stream, bay, and bayou sites and has sampled water quality more than 8,000 times since its inception.

Photo 1. Wolf Bay, a Gulf coast estuary in Alabama. Photo credit: Eric Reutebuch, Alabama Water Watch.

In 2007, the Alabama Department of Environmental Management designated Wolf Bay as an Outstanding Alabama Water, providing stronger protections for the area's water quality and wildlife habitat. This designation limits pollutant discharges and requires managing for higher levels of dissolved oxygen and lower amounts of bacteria in the bay. This outcome is largely due to the efforts of the Wolf Bay Watershed Watch and the volunteers who solicited support from local officials, developed a management plan for the Wolf Bay watershed, and helped residents learn about the importance of protecting the bay.

The story of Wolf Bay features what is generally called "citizen science," in this case by involving the public in water quality monitoring on a watershed scale. Citizen science triggered successful local efforts to help the Alabama Department of Environmental Management reach its conservation goals. Does citizen science have broader applicability for natural resource management and environmental protection organizations across the nation in fulfilling their missions?

In making their decisions, natural resource and environmental managers and other decisionmakers often lack both the full scientific information and the full public support and involvement they need. In this report, we address the following questions:

- Can citizen science help?
- Can it deliver more of the science needed for sustainable natural resource management and environmental protection?

- Can it foster more public input and engagement in natural resource management and environmental protection and decisionmaking?
- And, if so, how do natural resource and environmental managers and decisionmakers best invest in citizen science to improve outcomes?

Our goal in this report is to help government agencies and other organizations involved in natural resource management, environmental protection, and policymaking related to both to answer these questions and make informed decisions about investing in citizen science. We aim to provide a balanced assessment of whether, when, and how organizations can employ citizen science to help meet the information and public engagement needs of natural resource and environmental managers and other decisionmakers.

What Is Citizen Science?

Citizen science means different things to different people, causing confusion about its nature and utility. We use the term to refer to the practice of engaging the public in a scientific project—a project that produces reliable data and information usable by scientists, decisionmakers, or the public and that is open to the same system of peer review that applies to conventional science. The term citizen science is sometimes used differently—for example, to describe only projects where volunteers collect data, only projects that involve professional scientists, or the engagement of nonscientists in policy discussions. However, our meaning is gaining general acceptance, and we use it throughout this paper. Citizen science, as we define it, is indistinguishable from conventional science, apart from the participation of volunteers—both can use a variety of methods and can achieve a variety of goals, including basic research, management, and education. Citizen science is science (with the addition of volunteers) and should be treated as such in its design, implementation, and evaluation.

Citizen science is not new. Before science first emerged as a profession, most scientific research was conducted by the "citizen scientists" of their day—keen amateurs who conducted or carried out scientific research. Over the centuries, amateur scientists and volunteers made key contributions to the understanding of climate, evolution, geological processes, electricity, astronomy, and other phenomena. In the United States, for example, farmers, weather observers, and naturalists

Box 1. Definitions

Adaptive management – A systematic approach for improving resource management by learning from management outcomes. Adaptive management focuses on learning and adapting through an iterative process of planning, taking actions, monitoring, learning, and adjusting and through partnerships among managers, scientists, and other stakeholders working and learning together.

Citizen science – Participation by the public in a scientific project. Projects can involve public participation in any or all stages of the scientific process. Projects can involve professional scientists or be entirely designed and implemented by volunteers. However, citizen science is science and should be treated as such in its design, implementation, and evaluation.

Conventional science – A professional-based approach to science led by paid scientists at academic, government, nonprofit, or commercial organizations and carried out by a mix of professional scientists and paid technicians or students. We use the term "conventional science" to contrast a professionals-only approach with a citizen-based approach to science, although the two approaches have long been intertwined and need not be separated in practice.

Decisionmakers – Individuals or groups of people in the public or private sector who choose among a number of alternatives that are typically delimited by internal policies, laws, or rules. In the public sector, decisionmakers include people who make routine decisions on implementing public policy as well as people who can give content and direction to public policy by enacting statutes, issuing executive orders, promoting administrative rules, or making judicial interpretation of laws. As used in this paper, the term can sometimes include policymakers.

Policymakers – Individuals or groups of people, typically within a legislature, an executive office, a judiciary, or administrative agencies, who set public policy through a range of processes and mechanisms. Policymakers can decide to adopt a particular law or make a certain rule and then decide how to implement the law or rule.

Public engagement – Officials, specialists, and other employees of natural resource and environmental organizations interacting with the public to exchange ideas about a problem or proposed solution or other management action or goal. This is frequently done through education and extension programs, public outreach, and town hall meetings.

Public input – Feedback from the public in response to a call from government or other organizations for input. Examples include public comment periods following the release of environmental impact statements and meetings of advisory committees.

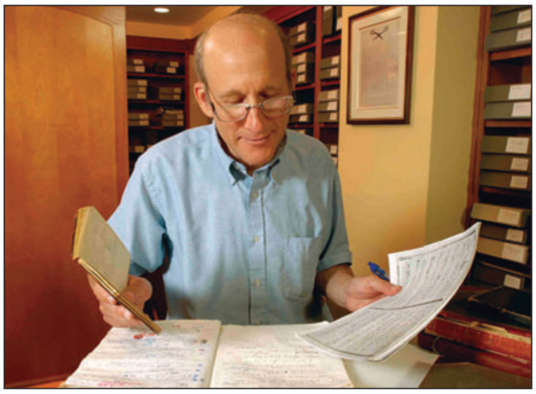


Photo 2. *A researcher compares modern-day observations of flowering plants with written records and specimens left by Henry David Thoreau in the 1850s. Photo courtesy of Richard Primack.*

documented the daily weather, the timing of harvests and pest outbreaks, and the abundance and behaviors of wildlife. Early citizen scientists in North America famously included Benjamin Franklin and Thomas Jefferson. Less well known are the data collected by naturalists, such as Henry David Thoreau. Thoreau's painstaking records from the 1850s of the first flowers, leaves, and bird arrivals each spring are now being used by scientists to identify the impacts of climate change in Concord and at Walden Pond in Massachusetts. In the 1930s and 1940s, Aldo Leopold learned from his own form of citizen science, banding birds and recording the timing of spring events. Noting a range of discoveries made by contemporary citizen science volunteers, Leopold concluded that "the sport-value of amateur research is just beginning to be realized." In fact, many of Leopold's research projects are being continued today by citizen science volunteers.

More recently, researchers have benefited from the information technology revolution and the advent of the Internet and location-aware mobile technologies equipped with cameras and other sensors. Such technologies have made it easier for professionals and non-professionals alike to access, store, manage, analyze, and share vast amounts of data and to communicate information quickly and easily. Central to the rapid evolution of citizen science, technological advances have driven its growth. Now, for example, citizen science projects can deploy large numbers of volunteers and record huge volumes of observations in centralized databases that can be analyzed in near-real time. Increased capacity has spurred recent rapid growth in citizen science, leading to the rising use of citizen science data in peer-reviewed publications (Figure 1). Powered by public interest, today's citizen science can help answer the most challenging ecological and environmental questions, addressing issues that affect everyday lives.

Citizen science projects can pursue basic or applied science, with purposes that include baseline ecological or environmental monitoring as well as crisis response and taking management actions, such as habitat restoration. Citizen science can tackle local questions, such as identifying the source of pollution in a single stream; it can also provide insights into continental or global processes, such as climate change or the world's great animal migrations. Volunteers can participate in a little or a lot of the scientific process. For instance, they might formulate a scientific question and then contract with professional scientists to conduct the research; or they might collaborate closely with professional scientists to jointly develop a project, collect and analyze data, and report the results. Private citizens, alone or in groups, can even pursue scientific research wholly on their own, independent of professional scientists. However, volunteers usually contribute by collecting data in projects designed by professional scientists.

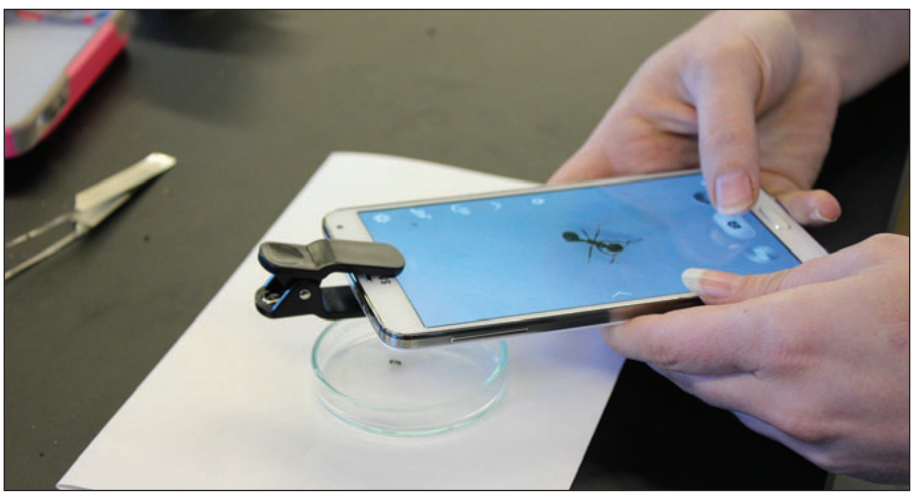


Photo 3. *A participant in iNaturalist (a citizen science program) uses a smartphone with a clip-on macrolens to photograph a specimen. Photo credit: Yurong He.*

Converging Citizen Science "Pathways"

Resource and environmental management organizations generally invest in citizen science for two reasons: (1) to do science that might not otherwise be feasible because of scale or for other practical reasons, and (2) to better engage the public in helping to make decisions through generating new scientific knowledge and through learning gained from participating in the scientific process. These goals reflect the two primary ways that citizen science can inform and assist managers and other decisionmakers (Figure 2). The pathways converge and can be mutually reinforcing; a citizen science project can lead volunteers down both pathways at once, generating synergies between science and public input and engagement. We separate the pathways here only to describe them.

One pathway is the same one followed by conventional research. Volunteers help generate scientific information for natural resource and environmental managers and other decisionmakers, who take the information into account in making decisions.

The other pathway involves the public in scientific research while stimulating public input and engagement in natural resource and environmental management and policymaking. Volunteers can directly provide input—for example, they might comment on a proposed government action on the basis of what they learned in a citizen science project. Their input and engagement can also be indirect—for example, they might share information within their communities, motivating others to get involved in natural resource and environmental management and policy discussions and decisions.

Although most citizen science projects involve both pathways (often at the same time), projects can vary, and the design of a project influences the type of scientific information it provides and the quality and method of public engagement it facilitates.

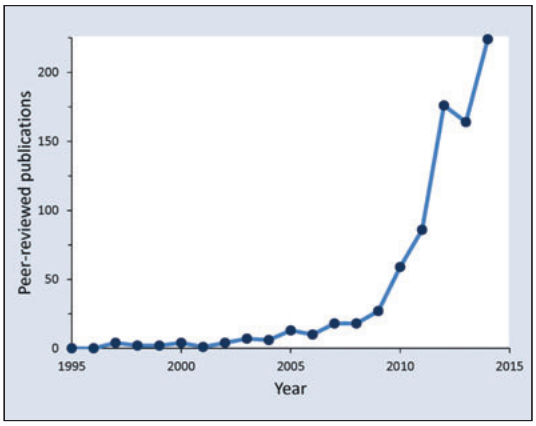


Figure 1. Growth in the number of scientific publications that have used or studied citizen science since 1995. Data are based on a search of the Web of Science for the keyword "citizen science" and likely represent a fraction of all scientific publications using or studying citizen science because many publications fail to acknowledge when they include contributions from citizen science.

Organizations that use citizen science carefully choose project designs that match their needs and goals. Alternatively, community members or other stakeholders might initiate, design, or implement projects themselves, filling roles unmet by agencies or other organizations.

Together, the two pathways can help organizations meet their goals by contributing at various points in a typical policy cycle (Figure 2). Citizen science can make valuable systematic observations and identify problems or issues; help in formulating public policy, along with contributions by industry, environmental groups, and other stakeholders; strengthen public input into policymaking by legislators and other decisionmakers; help government

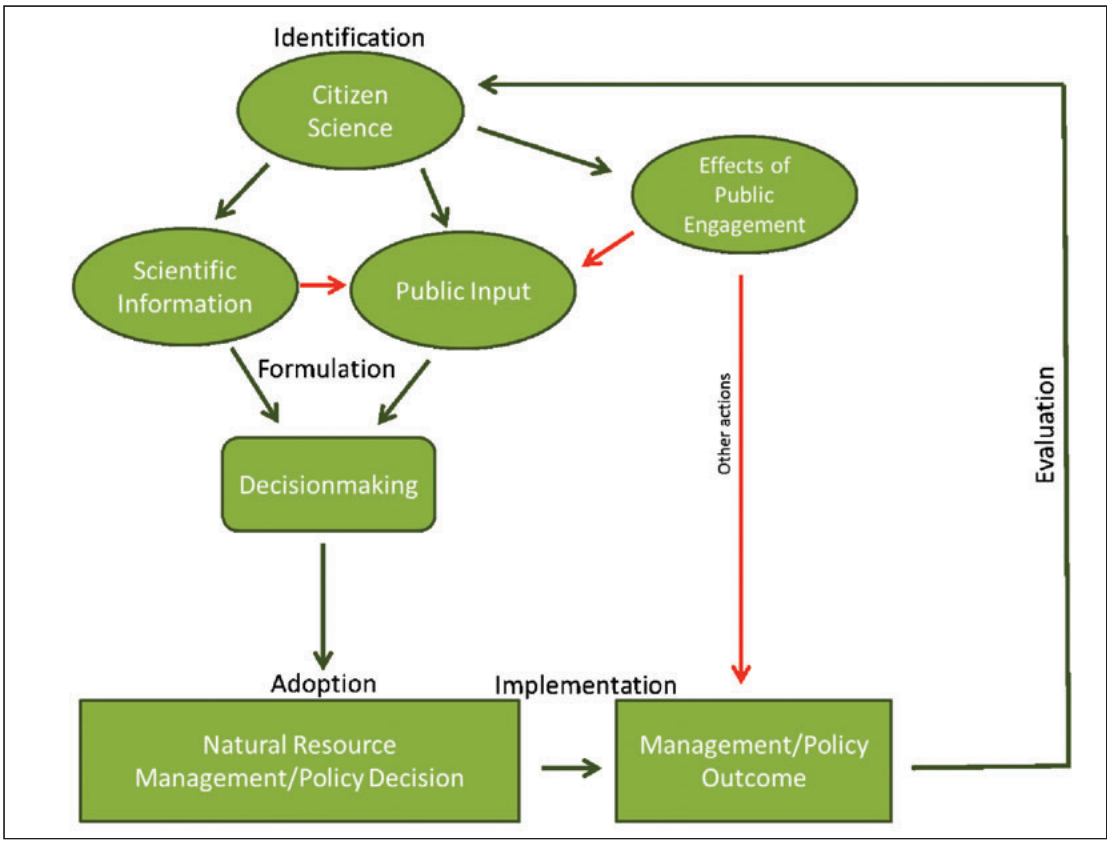


Figure 2. Pathways that citizen science can take to influence natural resource management and environmental protection by (1) generating scientific information, and (2) facilitating direct (green arrows) and indirect (red arrows) public input and engagement. Direct public input and engagement include, for example, comments on proposed government actions; indirect input and engagement include communication with peers that might stimulate community engagement in natural resource management, environmental protection, and policy decisions. Text in black refers to the policy cycle: problem or issue identification produces a need; option formulation addresses the issue; policy adoption points to a way of resolving the issue; policy implementation entails taking action; and outcome evaluation assesses policy effectiveness, initiating the next policy cycle.

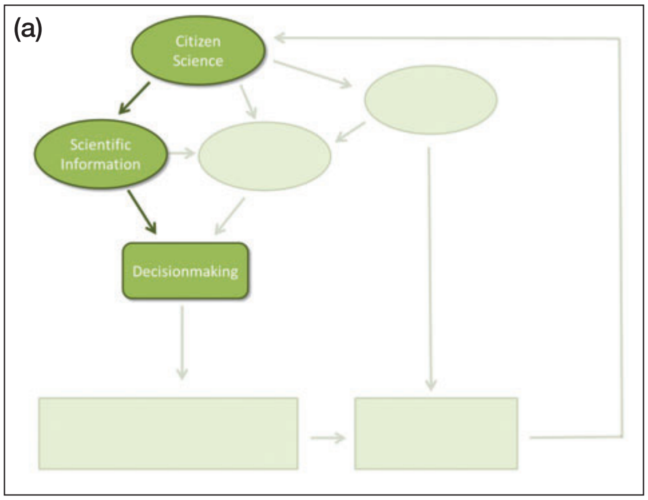


Figure 3. a) The beginning of the science pathway in citizen science (see Figure 2). b) A team of participants selects a site for biodiversity data collection using a cubic foot sampling frame. Photo credit: Zach Kobrinsky. c) Participants in Biocubes (a citizen science program) use smartphones to help identify species and submit data. Photo credit: Andrea Wiggins.

agencies and other organizations implement the corresponding policies; help evaluate the impact of a policy or decision; and help in enforcing laws and regulations pertaining to natural resources and the environment.

In what follows, we explain the two pathways. Then we discuss the pathway synergies that strengthen both the capacity for scientific discovery and the ability to effectively use science in natural resource management and environmental protection. Lastly, we evaluate the opportunity to use citizen science to achieve natural resource management and environmental protection goals and meet related challenges.

Acquiring Science

To make decisions, organizations rely on scientific information that is relevant, credible, and accurate (Figure 3) – the "best available science." The best science does not necessarily come from the best peer-reviewed scientific publications with the most robust designs and inferences; rather, it is the best scientific information available to answer a specific question. Organizations can acquire this information through a variety of means, including original reports or publications, summaries or memos, expert testimony or briefings, and conversations with experts. Some organizations conduct research in-house or solicit research, and sometimes the research is conducted independently by other organizations or individual scientists. Wherever the science comes from, its relevance, credibility, and accuracy are key.

Can Citizen Science Meet Core Information Needs?

Natural resource managers and environmental protection organizations need scientific information to meet a wide variety of goals. Like conventional science, citizen science is flexible and can take a wide variety of approaches. Citizen science can be used in a variety of ways, including:

- Monitoring studies assessing 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., zeroes "count").
- Process studies assessing the impacts of factors (e.g., hazardous fuels 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 (which might be 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).

Citizen science projects already tackle major challenges for managing natural resources and the environment, such as species management, ecosystem services management, climate change adaptation, invasive species control, and pollution detection and regulation (table 1).

What Scientific Value Does Citizen Science Add?

Understanding the relative strengths of citizen science can help determine when it can provide advantages over conventional science:

- **Citizen science can often operate at greater geographic scales and over longer periods of time than conventional science—and sometimes at greater resolutions.** Only volunteers can cost-effectively collect some types of data, such as observations of breeding birds and other physical and biological phenomena, in sufficiently large areas and over long enough periods of time to be scientifically reliable and meaningful. The North American Breeding Bird Survey, for example, has relied on volunteers to track the abundance of bird populations across the continent (Case Study 1). Other projects, such as Nature's Notebook, encourage volunteers and professional scientists to regularly submit observations of plant and animal occurrences, behaviors, and seasonal events such as tree leafout and the timing of animal breeding. 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. Organizations use online applications such as IveGot1 and Bugwood to track the presence or absence of invasive species and other attributes, to better understand how invasive species spread, and to collect other vital information. In addition, hundreds of air and water quality monitoring programs across the country depend largely on data and samples collected by citizen science volunteers (Case Study 2). The resulting observations are used by professional scientists, government agencies, nongovernmental organizations, and other decisionmakers.

Table 1. Sample citizen science projects/programs used to meet needs for science and public input/engagement common to many natural resource and environmental organizations.

Management goal	Science needs	Public input and engagement needs	Sample projects[a]
Species management	Providing information on species abundance, distribution, phenology, and behavior	Public support for and involvement in management decisions	North American Breeding Bird Survey;[a] Monarch Watch; eBird;[a] Grunion Greeters
Ecosystem services management	Providing resource valuation; mapping ecosystem services	Public appreciation for ecosystem services	USGS's Social Values for Ecosystem Services (SoLVES)
Climate change, impact assessment, adaptation	Assessing the status, rates, and trends of key physical, ecological, and societal variables and values	Stakeholder engagement in program development, implementation, and evaluation	Nature's Notebook; Community Collaborative Rain, Hail and Snow Network
Invasive species control	Providing real-time monitoring (an early-alert system)	Public support for and involvement in management decisions	IveGot1 app; Bugwood app
Pollution detection and enforcement	Providing information on water and air quality	Stakeholder engagement in identifying problems and solutions; public support for and involvement in management decisions	Bucket Brigade; Global Community Monitor; Clean Air Coalition;[a] Alabama Water Watch Program[a]

a. Different citizen science projects can take different approaches and engage volunteers in different ways to achieve the science and public input and engagement needs associated with each management goal.

Photo 4. Volunteers preparing butterfly specimens for iDigBio. Photo: courtesy of the Florida Museum of Natural History.

- **Citizen science can speed up and improve field detection.** Having many eyes on the ground can help detect environmental changes (e.g., detecting changes in the onset of spring through plant phenology), identify phenomena that require management responses (e.g., population declines, incidences of pollution, and introduction of an invasive species), and monitor the effectiveness of management practices. Volunteers have filled data gaps and detected unusual occurrences that might have eluded conventional science and monitoring. For example, the Cornell Lab of Ornithology's FeederWatch program was able to track rapidly spreading disease in house finches and other wild birds across 33 states based on information that volunteers collected at bird feeders. Citizen science data combined with laboratory studies gave critical new insights into how to slow or prevent future epidemics among wildlife and humans.
- **Citizen science can improve data and image analysis.** People are able to recognize patterns and interpret large amounts of data as well as to distinguish subtle differences among characteristics. Volunteers with no specialized training (such as high school students) have performed as well as or better than highly trained scientists and state-of-the-art algorithms in certain analytical tasks, for example in "protein folding" to help scientists better understand proteins (through the Foldit computer game). Volunteers can also extract information from digitally collected primary data (such as images or audio) by identifying and recording secondary information (e.g., species identity; the presence or absence of a species; and the abundance, behavior, and frequency or duration of various phenomena), tasks that are often difficult for computers. In some cases, highly trained volunteers such as retired professionals might be able to contribute to higher level data analysis. Finally, volunteers can use local or traditional knowledge to help professional scientists interpret results, particularly in explaining unusual data and in research projects that explore how people interact with 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 relevancy of location-specific research questions and make them more useful to managers and local communities. For example, people in Washington state harvest salal, a culturally and economically important forest shrub used in floral arrangements and also important for wildlife habitat. Concerned about the decline of salal, scientists worked with people who harvest the shrub to formulate research questions about sustainable use of the plant. The results helped everyone involved understand why salal might decline and how to harvest it without diminishing the resource. A full understanding of natural resource and environmental issues often requires a holistic perspective, including human dimensions; citizen science can help provide this perspective and improve research.
- **Citizen science can help researchers better identify and study 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 an understanding among managers, scientists, regulators, decisionmakers, volunteers, and others of the social dimensions of the natural systems where people live.

What Are the Limitations of Citizen Science for Achieving Science Goals?

Many scientific projects are not appropriate for citizen science. The most common factor limiting volunteer participation in a scientific project is the ability of trained volunteers to meaningfully contribute to the science. Questions, methods, and analyses sometimes require specialized knowledge, training, equipment, and time commitments that make citizen science inefficient or impractical as an approach.

Additionally, not all citizen science projects stimulate widespread public interest, whether driven by 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 more public attention (and support for public funding) than other species, including most plants. Similarly, water bodies near tourist destinations and college campuses tend to receive more attention than do those in urban and industrial areas. In addition, studies in small or remote communities might be of great local interest, yet the pool of potential participants in a citizen science project might be small. For certain taxa and ecological processes and for some biogeographic regions or geographic locations, it is difficult to sustainably do many types of citizen science projects.

For field work, potentially hazardous conditions or 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 therefore might 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 might be available primarily on weekends, when staff is unavailable. As a result, it might be difficult to recruit citizen science volunteers for certain projects.

At the other extreme, infrequent (e.g., annual) sampling might make it harder to sustain collection of high-quality data, because participants might 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.

Citizen science projects that simultaneously engage volunteers in scientific research and in public input into decisionmaking processes must be careful to guard against bias. But professional scientists must also guard against bias, especially those who are involved in both conducting research and informing decisionmakers. Similar quality controls can be used for both citizen science and conventional science; they can include training, collection of duplicate samples, and postdata collection analyses designed to identify outliers and biases in the data. Quality controls should be used in most citizen science projects, even when volunteers are not involved in decisionmaking. There is nothing particularly special about quality controls in citizen science that science does not already have the tools to handle.

Public Input and Engagement

For federal, state, and municipal agencies as well as many nongovernmental organizations, public input and engagement are essential in formulating and achieving natural resource management and environmental protection goals (Figure 4). Federal law requires federal agencies to disclose the impacts of their major activities and to solicit public input or participation at important stages in the land management and policy development process. We define "public input" as feedback from the public in response to a call from government or other organizations for input. Examples include public comment periods following the release of environmental impact statements and meetings of advisory committees, such as those set up under the Federal Advisory Committee Act.

Government agencies and other organizations also foster public engagement in natural resource and environmental management and policymaking. Accordingly, we define "public engagement" as officials, specialists, and other employees interacting with the public to exchange ideas about a problem or a proposed solution or other management action or goal. This is typically done through education programs, public outreach, and town hall meetings. Public participation was originally intended to prevent special interest groups from unduly influencing federal decisionmaking. Now, public input and collaboration are increasingly viewed as essential in crafting sustainable management activities and policies (Case Study 3).

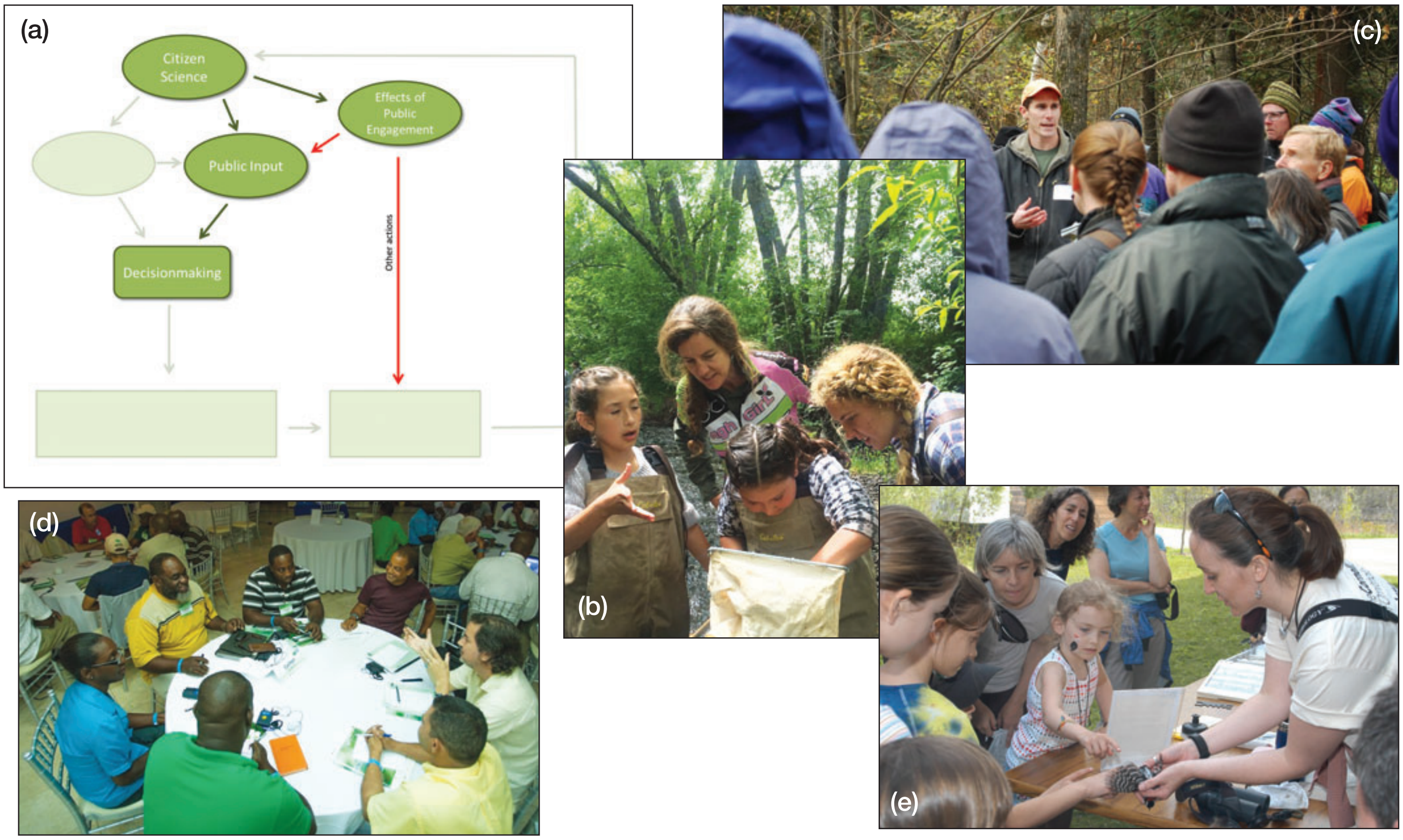


Figure 4. a) The beginning of the public input and engagement pathway in citizen science (see Figure 2). b) Collecting stream arthropods with children. c) and d) Discussing the science of potential impacts of climate change on forest processes with volunteers. e) Volunteers training children on bird identification. Photo credits: b) Kristine Stepenuck, c) Gerald Bauer, USDA Forest Service, International Institute of Tropical Forestry, d) Eli Sagor, Sustainable Forest Education Cooperative, e) Susan S. Pear, courtesy of the Cornell Lab of Ornithology.

How Can Citizen Science Promote Participation in Decisionmaking and Environment Stewardship?

Citizen science projects can enhance a bi-directional flow of information between the public and natural resource managers and environmental policy organizations. Volunteers, through the training they receive for a citizen science project, can come to better understand the ability (or inability) of science to answer a question of interest. They can also learn from a project's science outcomes, particularly if the project advances knowledge or sheds light on an issue of concern. In turn, natural resource managers and environmental organizations receive input from volunteers, providing them with a better understanding of public priorities and social contexts and thereby contributing to a richer, more productive public dialogue.

Under the right circumstances, citizen science projects can have the following benefits:

- **Citizen science can engage people in decisionmaking processes**. Participation in a citizen science project can increase firsthand understanding of conservation or environmental issues and encourage participants to be more responsive to the issues they care about. Participants might become more likely to appear at public meetings and to provide constructive comment on proposed actions. For example, members of Golden Gate Audubon participate in bird monitoring and invasive species removal projects and present their findings to local agencies. They also recognize that science is important for achieving other local conservation goals and form committees to recommend and implement additional citizen science projects.
- **Citizen science can promote collaboration.** Citizen science is inherently collaborative. It can bring people to work together with organizations in collaborative ways, creating synergies and improving outcomes. Some federal agencies engage the public in multiparty monitoring, a collaborative form of citizen science in which people with diverse interests work together to understand a problem, conduct monitoring, and evaluate project results. Multiparty monitoring often enlists volunteers. For example, the Uncompahgre Plateau Project in western Colorado specifically calls for citizen science volunteers in its monitoring strategy (Case Study 4).

- **Citizen science can bring fresh perspectives into decisionmaking.** In soliciting public input, natural resource managers and environmental organizations seek a range of perspectives and stakeholder participation in crafting sustainable solutions to the problems they face. The participatory nature of citizen science can facilitate the inclusion of diverse perspectives in decisionmaking. Volunteers might represent a different constituency than participants in other types of public engagement. Fuller public representation can better ensure that outcomes meet the needs of more people. In some cases, citizen science can shorten the time from data collection to decisionmaking. For example, the Coastal Observation and Seabird Survey Team (COASST) collects information on beached birds on almost 300 beaches spanning northern California, Oregon, Washington, and Alaska. Thanks in part to the program's extensive network of about 850 volunteers, its robust protocol, and its sound reputation, COASST has provided near-real-time information to decisionmakers on the impacts of such events as oil spills and avian diseases on coastal sea birds, even as an event unfolds.
- **Citizen science can foster environmental stewardship.** Collecting environmental data can prompt volunteers to care more about the environment and develop a sense of place. After participating in citizen science, people might make different personal choices, changing their own management practices. Engaging in Monarch Watch, for example, has changed the behavior of volunteers in their own backyards. Sponsored by the Kansas Biological Survey and the University of Kansas, Monarch Watch volunteers across the United States and Canada tag individual monarch butterflies to help scientists study monarch populations and migrations. After learning how habitat for monarchs is vanishing, many volunteers have planted pollinator gardens in their own backyards (for example, with milkweed to support monarch caterpillars).
- **Citizen science can spread knowledge.** Citizen science is an inherently social endeavor. Participants routinely communicate with friends, family, and colleagues, spreading information about their citizen science activities and about the issues they care about through a wide range of social networks. The information they impart and the example they set can motivate others to get involved or to change their own behavior. In general, people are more likely to change their behavior in response to examples set by their friends and neighbors than in response to public information campaigns.
- **Citizen science can answer local community questions of concern.** Some questions that are important for local management and policy might go unaddressed by professional science. Such questions might be too scientifically novel or not novel enough; they might not be a priority for funding by federal or state agencies; and local organizations might not have enough scientific capacity to address them. As a result, many citizen science projects have sprung from

Photo 5. COASST program volunteers identifying a seabird carcass and collecting data on what might have killed the bird. Photo credit: Liz Mack, courtesy of COASST.

Photo 6. iDigBio volunteers tagging Monarch Butterflies for release. Photo courtesy of the Florida Museum of Natural History.

local community concerns impossible to address in any other way. In one study in Tonawanda, NY, for example, community members undertook an air quality investigation in their heavily industrialized town, leading to law enforcement actions (Case Study 5). In such cases, the public contributes local perspectives that professional scientists might otherwise miss. Involving local volunteers in a project can bring out questions, ideas, and techniques that might not otherwise surface, with professional scientists furnishing support, training, and advice. The Environmental Protection Agency office that serves the people of New York State has launched a website (http://www.epa.gov/citizenscience/) providing resources for citizen science, including data collection guidelines, case studies, and information about funding.

- **Citizen science can incorporate local and traditional knowledge into science and management.** Local and traditional knowledge can be helpful in interpreting research results, setting science and management priorities, and crafting management activities. For example, the Wallowa-Whitman National Forest in Oregon worked with the nongovernmental organization Wallowa Resources to include ranchers and others in a collaborative watershed assessment (a version of multiparty monitoring). The partners monitored how livestock interacted with water resources in the national forest and contributed information about the history of grazing practices across the forest. Forest Service managers used the information to decide on management actions to relieve livestock pressure around lakes and rivers while improving animal production and distribution, a measure supported by local ranchers.
- **Citizen science can build awareness of an organization's mission.** Engaging volunteers in citizen science projects allows an organization to relate the project to its mission, raising its public profile. Citizen science projects can build bridges, connecting grassroots interest in natural resource and environmental science and management issues with the missions of government and nongovernmental organizations.
- **Citizen science can improve science literacy and build expertise**. Citizen science can increase public understanding of a particular issue by helping volunteers better access and understand scientific information. Well-designed citizen science projects can build science literacy and even steer volunteers toward science- or management-related careers. Professional scientists are finding that some citizen science volunteers, particularly young adults, show enthusiasm and aptitude for scientific research. Citizen science can increase and diversify the pool of candidates available for jobs in science, management, and environmental protection.

What Are the Limitations of Citizen Science for Public Input and Engagement?

Citizen science projects can sometimes be less efficient and effective than direct public outreach at encouraging public input and engagement, particularly when the connection between the science and management or policy decisions is weak or not obvious. Citizen science is only one of many ways of engaging the public in decisionmaking processes and environmental stewardship. If scientific knowledge is already adequate, for example, then citizen science is not needed—the knowledge can be communicated and input and engagement can be sought through conventional means such as newsletters, science cafés, or public meetings.

Moreover, designing a citizen science project in ways that will change personal choices, such as discussing topics with friends, submitting formal comments on proposed policies, or improving personal stewardship behaviors, is difficult, and evidence for actual change in behavior is limited and largely anecdotal. Successful projects are usually designed to encourage particular behaviors, whether planting butterfly gardens or attending public meetings. The goals must be reasonable—for example, encouraging gardeners to switch to native or wildlife-friendly plants is likely easier to achieve than getting nongardeners to plant native gardens. Achieving goals for public input and engagement requires planning and expertise, and many citizen science projects do not have the resources to reach such goals. This is an active area of research, and more work is needed.

Synergy between Pathways

Citizen science is most valuable for natural resource management and environmental protection when it generates science and increases substantive public input and engagement. Few people have the opportunity to engage in scientific research, and most never participate in natural resource management and environmental decisionmaking. Through citizen science, participants can learn how science is done and how it contributes to natural resource management and environmental decisionmaking, which can be a powerful and transformative experience.

Most examples of citizen science highlighted in this report capitalize on synergies between science acquisition and public input and engagement. For example, volunteers help monitor birds at scales impossible to do otherwise and also promote bird conservation (Case Studies 1 and 7); through their observations, and sometimes action, volunteers take on local problems that scientists and officials had overlooked, contributing to both science and decisionmaking (Case Studies 2 and 5); and a federal agency encourages diverse stakeholders to engage in identifying science and management goals and then participate in the monitoring and adaptive management process (Case Studies 3 and 4).

Perhaps the greatest potential for synergies is when citizen science contributes to an adaptive management process, which often engages a variety of stakeholders and the public. In adaptive management, problems are assessed; management actions are designed and implemented; and management outcomes are monitored, evaluated, and adjusted as necessary in an iterative cycle. The success of adaptive management is measured by how well it increases scientific knowledge, helps meet management goals, and reduces conflict among stakeholders.

Despite the utility of adaptive management, it can be difficult to implement because of time constraints, lack of funding, and other limitations. Citizen science can facilitate adaptive management, especially when the monitoring is appropriate for volunteers and when the management issue in question is of local interest. For example, the National Park Service is working with local organizations and volunteers in and around Acadia National Park in Maine to use citizen science as part of an adaptive management approach to maintaining and improving the resilience of ecosystems facing rapid environmental change, particularly climate change, invasive species, and air and water pollution. Without volunteers, the park staff and professional scientists would not be able to accomplish the necessary monitoring of wildlife, invasive plants, and water quality. Many of the same volunteers and organizations are also engaged in decisionmaking processes regarding park management.

Photo 7. *Volunteers identifying plants during a species richness survey at Acadia National Park. Photo credit: Abraham Miller-Rushing.*

The Effects of Federal Policy on the Feasibility of Using Citizen Science

Many citizen science projects involving federal agencies are done in partnership with nongovernmental organizations and academic institutions. Depending on the federal role in a citizen science project, federal policy considerations might apply. Such policy considerations include intellectual property, privacy, and the special obligations of federal agencies under the law. Intellectual property concerns include data ownership and access. Organizations can deal with such concerns by crafting terms of use and user agreements. The agreements specify the roles and responsibilities of the organizations and participants with respect to citizen-generated data.

Privacy concerns revolve around personal and location-based information as well as photographs, videos, and audio files, all of which are governed by the Privacy Act. Federal agencies that implement citizen science projects have two options for complying with the Privacy Act: (1) they can avoid collecting personally identifiable information about volunteers and avoid using databases that retrieve data based on personally identifiable information; or (2) they can set up a process for handling personally identifiable information and have it reviewed and approved by the Office of Management and Budget (OMB). Some citizen science programs have found technological ways of eliminating personally identifiable information from their databases.

Federal agencies are required to meet special obligations under the law. Most citizen science projects ask volunteers to record standardized observations and submit them on data sheets or online forms. Projects involving federal agencies can trigger the Paperwork Reduction Act, intended to reduce the burden of paperwork for the public. The act applies to federally sponsored or conducted work, including scientific research. It requires federal agencies to examine what information volunteers are asked to provide and to issue a request for public comment relating to the justifications for and estimates of the burden. The process typically takes from several months to more than a year to complete. Agencies generally anticipate this "cost of doing business" and plan project timelines accordingly. However, long lead times might limit an organization's ability to use citizen science for certain activities, such as rapid response to oil spills, volcanic eruptions, wildfires, and other events. For such activities, federal agencies might need to rely on existing OMB-approved projects, projects that can be fast-tracked through the clearance process, or projects that do not require OMB approval.

Under the Data Quality Act (sometimes called the Information Quality Act), federal agencies are required to ensure that the data they disseminate meet standards for quality, utility, objectivity, and integrity. The OMB and the agencies themselves write the corresponding guidelines, which apply to both citizen science and conventional science.

When to Choose Citizen Science

In the case of environmental monitoring, citizen science is often initiated at the grassroots level in response to local environmental concerns. When a federal agency or other conservation organization is considering investing in a citizen science project, it should carefully consider what it wants to achieve. Other choices might be preferable, such as funding conventional science or soliciting public comment and holding public meetings to obtain public input. In deciding whether to use citizen science, it might help to ask a fundamental question: Can it improve the scientific process and elicit the most useful public input and engagement?

Citizen science might be most advantageous when:

- **Volunteers can collect high-quality data.** Sometimes, volunteers need only minimal training. For example, collecting insects and making simple measurements, such as tree circumference, are easy to do 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. However, volunteers should not be expected to use sophisticated analytical instruments or participate in activities that require extensive training or certification. Generally speaking, the simpler the methods, the easier it is to engage volunteers in the collection of high-quality data; simple tasks also make it feasible to increase the number of contributors and make it 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.
- **Participation by volunteers makes 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 of time and to process large amounts of data (such as images) simply because the number of volunteers exceeds the number of professionals (including researchers, faculty, and students) by as much as several orders of magnitude. In some cases, volunteers can obtain data inaccessible to government employees, such as data on private lands or on hunting impacts on a species. When a rapid response is needed, such as to environmental disasters or sudden large-scale bird or fish dieoffs, research efforts can benefit from the ability to swiftly mobilize large numbers of volunteers.

- **Public participation in the scientific process serves the organization's goals for public input and engagement and helps in decisionmaking 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 might 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. For example, local or traditional knowledge, such as harvesting or hunting practices in a given area, can help scientists understand human behaviors, local ecology, and threats to species, enabling them to formulate research questions and methods that can best help managers and other decisionmakers.

What Investments Does Citizen Science Require?

The Internet and mobile devices have further expanded opportunities for volunteers to make real-time observations in the field (e.g., eBird and Project Budburst's smartphone apps) and for organizations to recruit and train volunteers (e.g., Trout Unlimited YouTube water quality monitoring videos). The Internet has also made it possible to engage millions of volunteers in online processing and analysis of images and other data for environmental protection and natural resource management applications (e.g., SkyTruth.org and Snapshot Serengeti).

Investing in citizen science requires time and money. Although citizen science relies on volunteers, it is not free; an organization must invest in the capacity for a citizen science project to succeed. Capacity building includes investing in personnel (both staff and volunteers) and in all the tools and other resources that volunteers need to successfully carry out the project. Additionally, organizations must create a culture and policy environment conducive to citizen science.

In many cases, organizations can rely on existing projects or tools, either as they already are or as modified for a specialized use—for example, asking volunteers to use eBird to monitor bird populations (Case Study 7). In other cases, organizations might need to develop entirely new projects and tools and the supporting infrastructure. For example, they might need to designate staff to research appropriate data collection methods; to develop a database for accessing, archiving, and analyzing data; and to recruit and train volunteers.

Initial investment in citizen science can save on overall costs to an organization. Federal, state, and local agencies and nongovernmental organizations already depend heavily on volunteers for various types of services; some organizations have three or more volunteers for every paid employee. The educational system in the United States at both the high school and college levels stresses community service, creating a large pool of potential volunteers for citizen science. Organizations can take advantage of such opportunities (Case Study 6), enlisting volunteers to accomplish tasks that would be impossible for staff alone. For example, Paleo Quest, a citizen science program where volunteers scour various landscapes for fossils, found that having volunteers assist in field work increased its scientific productivity and reduced its cost per scientific paper from tens or hundreds of thousands of dollars to sometimes less than a thousand dollars.

Investments in Specific Projects

The precise investments an organization makes to implement a citizen science project depend on the particular goals, scale, and scope of the project. Many citizen science projects are small, so little or no organizational investment is needed. A project led by a single investigator might use a small team of volunteers to collect samples; or a single citizen science volunteer might have the knowhow and resources to conduct and publish research alone. Larger projects and projects with multiple goals often require thoughtful investment by organizations.

Organizations often underestimate the requirements of citizen science projects. To be effective, a project must have a sound scientific design and a method for recruiting, training, and retaining volunteers. The project must also gather, store, and analyze data and communicate the results. A citizen science project must do everything a conventional science project does while also engaging volunteers, which can require special expertise and always takes time and resources. Some citizen science projects require fewer resources than a comparable conventional science project, but some require more. In large projects and through partnerships, organizations can take advantage of economies of scale.

Professional scientists usually play key roles in citizen science projects. Because credibility is essential, scientists help ensure rigorous experimental design, quality control and assurance, and use of accepted standard analytical and statistical techniques. Sometimes, organizations need to develop a skilled multidisciplinary team, furnish tools necessary to implement a project, and provide a system for evaluating the quality of the project.

Having a skilled multidisciplinary team is often critical for reaching a project's goals for generating science as well as public input and engagement. In general, no one person knows enough about every aspect of a citizen science project or has the time to run the project alone. Having both social and biophysical scientists and specialists working together on the same team can improve research outcomes for both science and management while also improving the design of future projects. Such multidisciplinary teams are often built through partnerships among multiple organizations.

Furnishing tools for citizen science projects is also important, whether new tools are needed or existing ones can be used or adapted. The tools needed to support participation depend on a project's goals, technology, information management systems, data policies and guidelines, and communication systems. CitizenScience.org lists many of the tools available and the steps that should be considered when planning a citizen science project.

Citizen science projects also require investments in systems for evaluating the quality of processes and outcomes. Is the process engaging the right people and generating the right data? Are volunteers engaged and remaining involved? Are the goals for science and public input and engagement being met? The evaluation systems can be internal or external to a project or organization. They should be part of an adaptive management system, with mechanisms in place for improving a project's implementation based on the results of ongoing monitoring and evaluation. An expanding suite of reports, peer-reviewed papers, and other resources describes methods for evaluating projects and their outcomes and provides techniques for designing projects in ways that facilitate their evaluation (see Further Reading for examples).

Investments in Data Management

Considering how to best manage data is an important investment decision to ensure data quality, access, and transparency. The amount of data available to the public is still a small fraction of the data that exists, and although data repositories are beginning to change the landscape, scientific data are scattered far and wide. Standardizing data collection is critical when organizations want to share information to make more robust inferences or increase scale of observations over time and space. When data are shared or published, they are often not publicly accessible because they are shielded by publishers or need to be translated into digital formats for redistribution and broader use. Even when "open" data can be easily downloaded, they rarely come with adequate documentation of data collection and analysis methods, information on important caveats (e.g., appropriate level of inference and presence of questionable data), or instructions for appropriate use and citation.

Citizen science is a notable exception in that data are often more readily shared, but they still fall prey to many of the same problems as conventional research data. Data that are not well documented can be impossible to interpret appropriately and use responsibly. For example, without information about the context of data collection and details about data quality processes, data users might judge the data to be useless or make inappropriate assumptions. DataONE is developing resources for citizen science project organizers and professional scientists alike to help them better manage, document, and share their data. Practitioner guides to data management and data policies are a first step to improving access to citizen science data and increasing potential for reuse. The first of these guides has been published (see Further Reading), but more resources are being developed and published all the time (see DataONE.org and CitizenScience.org).

Investments in Citizen Science as a Whole

In addition to investments that individual organizations can make to specific citizen science projects, broader investment in the field of citizen science as a whole is needed to spur innovation and the development and adoption of best practices. Investments are needed in shared resources, particularly tools for planning and implementing citizen science projects, and in platforms for fostering communication across projects and disciplines. Such investments will cut costs, reduce the time it takes to generate results, and facilitate growth and maturity in the field of citizen science. Some major areas to consider are:

Standard Protocols. Developing a shared protocol library (such as the National Environmental Methods Index) and encouraging the use of common data standards (such as for water quality monitoring) will enable standardization of protocols and datasets, maximizing the value and durability of the data collected. The North American Breeding Bird Survey is a prime example of using standardized protocols and datasets (Case Study 1). Making sample budgets available would help organizations anticipate project startup and operational costs.

Technology. Investing in the development of sensor technology will improve the quality and lower the cost of data produced through citizen science projects. For example, lack of readily available low-cost air quality monitoring technology has made community air quality monitoring lag behind volunteer monitoring in other areas, such as water quality. In response, the Environmental Protection Agency has launched the Next-Generation of Air Monitoring initiative to promote the development and use of low-cost portable air sensors for air quality monitoring.

Data Collection and Analysis. Developing techniques to share and analyze large quantities of data collected by different projects across large areas will further improve the value of citizen science in tackling major challenges, such as tracking great migrations or documenting changes in species ranges. What features should generalized tools for citizen science have? Assessments are underway to identify the corresponding needs and develop strategies for meeting them. For example, CitSci.org is assessing needs, piloting technical solutions, and evaluating and refining the resulting tools in an effort to develop a customizable, reusable plug-and-play package that provides much of the software needed to develop and run a citizen science project for natural resource management. Other organizations are pursuing similar projects. Such efforts will minimize the need to develop independent software for each new citizen science project.

Communication. Citizen science—and science in general—depend on collaboration for the smooth flow of information. Corresponding social and organizational structures and policies improve the communication of data, facilitating awareness of best practices and innovation as ideas are exchanged across projects, disciplines, and organizations. A consortium of universities, government groups, and nongovernmental organizations that invest in citizen science has worked with the broad community of citizen science researchers, educators, and practitioners to form the international Citizen Science Association. Various agencies are developing complementary internal and external coordination networks across and within disciplines and geographic regions (Case Study 8). The association and its complementary networks will help meet communication needs; provide points of entry for people new to the field; and promote best practices and professional development while providing project evaluation and other supporting services. The association aims to help the field of citizen science set and attain high standards of scientific rigor and provide opportunities for professional development. Most of the coordination networks are very new and need more funding and other support. Federal, state, and municipal agencies might consider investing in the activities of the Citizen Science Association.

Centers. Citizen science centers focused on various disciplines, such as conservation, public health, and biochemistry, will promote citizen science standards, technology, data collection and analysis, and communication. A center (virtual or physical) for citizen science on natural resource management and environmental protection, for example, could bring together leaders operating at different scales (from global to individual protected areas) to develop solutions to shared and complex challenges. Challenges could include integrating data from across projects; creating visualizations and other data products that are useful to managers, policymakers, and the public; evaluations or systematic reviews of techniques to maximize positive science, management, or engagement outcomes; and efficient methods for planning, implementing, and sustaining projects that involve multiple organizations. The USA National Phenology Network (Case Study 8) is a successful model that is relatively focused.

Conclusions

Citizen science is already contributing to science and natural resource and environmental management and policymaking. Every year, tens of thousands of volunteers take to the forests, grasslands, wetlands, coasts, lakes, streams, and even their own backyards to provide high-quality, usable scientific information. Many large and longstanding projects would not be possible without volunteers; they produce long-term datasets, collect data over large geographic areas, detect rare events and species, and address areas of research that would otherwise be neglected. Citizen science has made clear contributions to science, contributing to many peer-reviewed publications and extensive datasets that natural resource and environmental managers need. Citizen science increases the potential for serendipitous knowledge discovery and creates information that goes into policy formulation, planning, and management activities at various levels of government.

Citizen science also provides benefits beyond science, offering the opportunity for an open discourse based on scientific knowledge that more people can access, understand, and trust. Through citizen science, organizations benefit from partnerships and from broad public perspectives, including local and traditional knowledge. Citizen science can increase scientific and environmental literacy and extend public involvement with natural resource and environmental managers and other decisionmakers in decisionmaking. Through citizen science, organizations can better see patterns and gaps, helping them set priorities and allocate resources. By spreading scientific knowledge and engaging more people in policy formulation, citizen science can help organizations make choices that lead to better environmental and social outcomes and avoid unnecessary conflict.

However, citizen science is not a panacea. Although it offers many advantages, it is not always the right instrument to meet an organization's needs for scientific information or public input and engagement. Before beginning a citizen science project, an organization should weigh its needs against the strengths and weaknesses of possible citizen science designs. If an organization chooses to proceed with citizen science, then it should set clear expectations for what citizen science can and cannot do. Further research is needed to better understand the extent to which engaging the public through citizen science can build understanding and deliver other benefits for natural resource management and environmental protection and policymaking.

Case Study 1. North American Breeding Bird Survey (BBS)

Spatial range:	Temporal range:	Level of training:
local to national	long term (> 10 years)	basic, but engages experienced birders

History: Established in 1966, the BBS is a cooperative effort between the U.S. Geological Survey's (USGS's) Patuxent Wildlife Research Center and Environment Canada's Canadian Wildlife Service (ECCWS) to monitor the status and trends of North American bird populations.

Management goals: The main goal of the program is species management by monitoring changes in bird populations and distributions across North America and informing researchers and wildlife managers of significant changes.

Level of volunteer participation in scientific process: Volunteers conduct bird surveys and enter the information collected into a professionally managed online database, but they do not formally participate in project design or in analysis and interpretation of the data.

Level of volunteer participation in public involvement: Public engagement is not a central focus, although the project might stimulate public action.

Bird counting group.
Photo credit: Joan Condon. Courtesy of the Cornell Lab of Ornithology.

Sustainability: Professional managers, coordinators, researchers, and statisticians compile, curate, analyze, and deliver volunteer-collected information to policymakers, managers, and the general public. Researchers and the general public have free access to processed data in perpetuity.

Science: Data generated by the BBS have contributed to over 500 peer-reviewed papers.
Public input and engagement: Educators use BBS data for basic instruction in a number of scientific disciplines.

Investment: The project has long-term funding through the USGS and ECCWS. Additional funding from other sources supports researchers' use of data for publication.

Outcomes/outputs/benefits: An analysis of BBS citations in the Federal Register (the daily journal that records and documents federal actions) shows that BBS data are used in many policy decisions, including in the implementation of far-reaching legislation such as the Endangered Species Act, the Migratory Bird Treaty Act, and the National Environmental Policy Act. For example, the Federal Register cited the BBS in a Petition to List Two Populations of Black-Backed Woodpecker as Endangered or Threatened (April 2013), a proposal for endangered status for the Gunnison sage-grouse (January 2013), and a proposal to list the streaked horned lark as threatened and to designate critical lark habitat (October 2012) (can be accessed at www.regulations.gov).

The following quotes reflect the value of the BBS to decisionmakers:

> We conclude that, while the BBS is the only long-term trend information available for the mountain plover on its breeding range, it is an imprecise indicator of mountain plover population trends. … Even so, we acknowledge that this is the best available information on trends for this species and BBS survey results suggest a recent (1999 through 2009) moderated rate of decline. (U.S. Fish and Wildlife Service, from the withdrawal of the petition to list the mountain plover as threatened, May 2011)

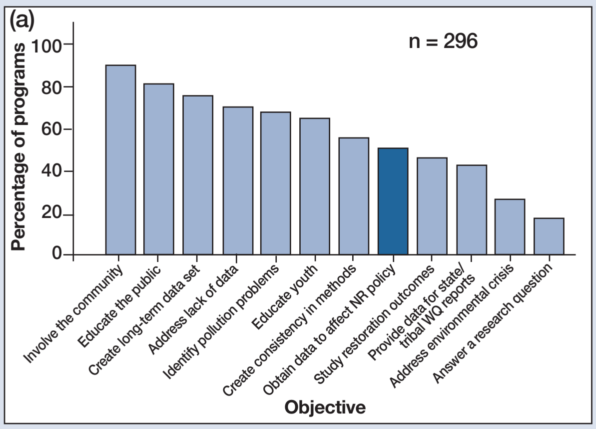
> [L]ong-term estimates of Sprague's pipit abundance have come from the Breeding Bird Survey (BBS), a long-term, large-scale survey of North American birds that began in 1966. The BBS is generally conducted by observers driving along set routes. … Since there is some evidence that Sprague's pipits avoid roads (Sutter et al. 2000, p. 114), roadside surveys may not be the best measure of abundance of Sprague's pipits, for example. Nonetheless, the methods of the BBS have been consistent through time, and the BBS provides the best available trend information at this time. (U.S. Fish and Wildlife Service, from the 90-Day Finding on a Petition to List Sprague's pipit as Threatened or Endangered, December 2009)

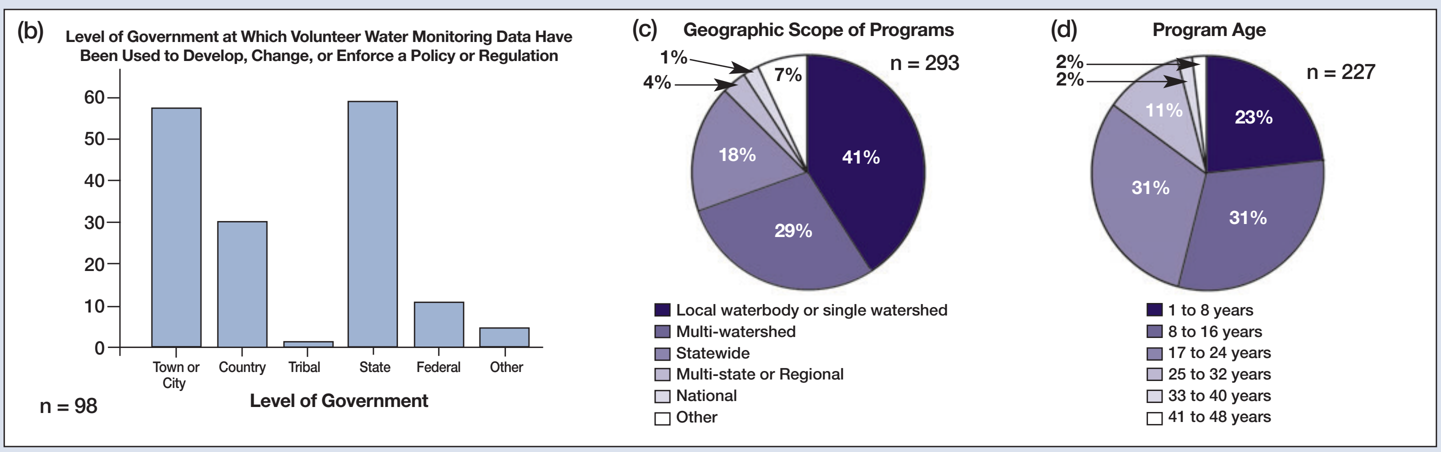
Case Study 2. Volunteer Water Monitoring: Natural Resource and Environmental Policy Outcomes

Program coordinators of U.S. volunteer water monitoring programs were surveyed in 2013, with the survey covering 345 programs supporting more than 1,300 subprograms. Fifty-one percent of the 296 respondents indicated that one of their program objectives was to obtain data for use in effecting change to natural resource and environmental policy (see the first graphic below), and a third reported having used the data collected for just this purpose. Most used the data to affect outcomes at the state and local levels (see the second graphic below). The scope of volunteer water monitoring programs varies: about 40 percent monitor a single water body or watershed, and about half operate statewide or across multiple watersheds. Fewer programs operate across state lines or nationally. Programs were initiated between 1965 and 2012. Nearly half have been collecting data for more than 16 years.

A volunteer collects a water sample in a stream.
Photo credit: Kristine Stepenuck.

About three-quarters of the survey respondents indicated using data collected by volunteers to develop, change, or enforce a policy or regulation. Examples include the development of ordinances to: stop shoreline waterfowl feeding; create oyster sanctuaries; require mandatory pet waste cleanup in specified areas; expand ultraviolet disinfection periods at a wastewater treatment plant; and require slow zones or no-wake zones for boats to minimize the spread of invasive species. The programs also used data to identify faulty septic systems, improper wastewater treatment plant discharges, illegal connections in municipal stormwater systems, and (in an impressive 67 percent of all cases) failure to meet water quality standards. These data also contributed to listings of impaired waters and to definitions of total maximum daily loads (TMDLs) for state reporting to EPA under the Clean Water Act (TMDLs describe allocation limits for pollutants in water bodies). Dam owners, city and county stormwater districts, wastewater treatment plants, and individuals required to comply with forestry best management practices have had permits altered based on results of volunteer monitoring. Moreover, additional monitoring has been required by permittees. Among other factors, program age was significantly related to increased natural resources policy and management outcomes at larger geographic scales. In one instance, volunteer data from a 32-year-old program became the sole source of water quality data for the natural resources agency due to budget cuts. These examples clearly show that citizen science can contribute to natural resource and environmental policy and management.





a) Survey responses on program objectives, b) level of government at which data have been used to develop, change, or enforce a policy or regulation, c) geographic scope of monitoring programs, d) distribution of program ages. Data source: Stepenuck, K.F. 2013. Improving understanding of outcomes and credibility of volunteer environmental monitoring programs. Doctoral Dissertation. University of Wisconsin, Madison. Available at: http://aquadoc.typepad.com/files/stepenuck_dissertation-final.pdf

Case Study 3. The U.S. Forest Service's New Planning Rule

Spatial range:	Temporal range:	Level of training:
local to national	long term (>10 years)	basic to extensive

History: The U.S. Forest Service manages 193 million acres of forest, grassland, and other ecosystems. The National Forest Management Act requires each national forest or grassland to adopt a long-term management plan designed to guide projects and other management activities over a 10- to 15-year period. An agencywide planning rule is used to guide development of resource management plans. In 2012, the Forest Service adopted a new rule for land management planning. The new rule recognizes that scientific knowledge, though essential, is not the exclusive basis for effective management of the National Forest System. The rule calls on Forest Service units to utilize local and traditional knowledge. It also directs each unit to engage the public at the beginning of its planning process for maximum transparency.

Forest Service employees gathering public input during a planning process.
Photo credit: USDA Forest Service National Collaboration Cadre.

Management goals: The Forest Service's fundamental goal is maintaining and restoring ecosystem and watershed health and resilience in order to protect water, air, soil, and other resources. The planning rule calls for monitoring species diversity and viability, activities that are particularly well suited to citizen science. Satisfying such robust science needs in support of management proposals might only be possible with volunteers.

Level of volunteer participation in science: The public and volunteers associated with nongovernmental organizations provide substantial input on what to monitor. Volunteers monitor a wide range of ecological, social, and economic indicators in order to provide feedback that natural resource managers can use in the planning process.

Science: Because the planning rule is new and only now being implemented, volunteers are still collecting the data required for the science outcomes that land managers need. The type of monitoring has expanded to include effectiveness (management goals) and validation monitoring (test hypothesis) in addition to the implementation monitoring (projects/targets) that the agency has been doing for decades.

Public input and engagement: The 2012 planning rule calls on Forest Service units to utilize local and traditional knowledge in addition to the best available science in planning their management activities. The planning rule directs each unit to engage the public at the beginning of its planning process for maximum transparency. In addition, it calls for collaboration with the public in identifying what to monitor, and it encourages public participation in the monitoring process to assess the ecological, economic, and social impacts of management actions.

Investment: Funding for the Forest Service's land and resource management planning and forest plan implementation is provided by the federal appropriations process on an annual basis. In some cases, partnerships with other organizations are important, including with nongovernmental organizations and industry groups.

Outcomes/outputs/benefits: The planning rule presents new opportunities to engage the public beyond existing requirements for public notices and formal processes. In addition, by encouraging citizen engagement early on in the planning process, the new rule creates direct opportunities for knowledge gained through citizen science to affect land management and public policy discussions. Citizen science (mainly through monitoring) can provide continuous information to meet science needs and possibly more capacity to respond to unplanned events, such as catastrophic wildfires and insect epidemics.

Case Study 4. The Collaborative Forest Landscape Restoration Program: Uncompahgre Plateau Project

Spatial range:	Temporal range:	Level of training:
regional	long term (> 10 years)	basic

History: The Collaborative Forest Landscape Restoration Program (CFLRP) encourages the collaborative, science-based restoration of high-priority forested landscapes managed by the U.S. Forest Service and its partners. The program addresses the uncertainties of managing landscapes exposed to damaging wildfires. To minimize conflicts over management activities, the CFLRP involves a wide variety of local, state, and federal partners, as well as numerous private organizations, including environmental nongovernmental organizations. The program has implemented 23 projects across the country using an adaptive management approach, with an emphasis on multiparty monitoring. A number of CFLRP projects use citizen science.

A professional trains volunteers on how to measure tree cover for lynx habitat.
Photo credit: Pam Motley, Uncompahgre Partnership.

Management goals: The primary goal of the CFLRP is to reduce wildfire management costs by reestablishing natural fire regimes and to reduce the risk of uncharacteristically severe wildfires. For example, the Uncompahgre Plateau Project in Colorado calls for prescribed burning and reestablishing native vegetation in the Grand Mesa, Uncompahgre, and Gunnison National Forests. Citizen science volunteers are measuring key vegetation and wildlife variables before and after treatment and will continue to do so at specified intervals.

Level of volunteer participation in scientific process: Forest Service personnel typically conduct field measurements as part of normal operations, with help from outside experts (such as academic researchers) and citizen science volunteers. Partners (including local residents) are helping to formulate research questions and experimental design as part of adaptive management. Citizen science volunteers are organized by the Uncompahgre Partnership, a collaborative group that includes the Forest Service and other partners and guides project implementation.

Level of volunteer participation in public involvement: The project emphasizes collaborative decisionmaking, with multiple opportunities for public input. At monitoring meetings held at least twice a year, partners discuss monitoring priorities. By project design, citizen science is a major tool for public engagement.

Sustainability: The program's funding authority expires in 2019. The project's many partners contribute to project funding.

Science: Citizen science volunteers measure various ecological indicators, including ground cover, plant composition and height, and the presence of various plant and animal species. Science outcomes are used directly by the forest managers. Data are archived and published in technical reports and peer-reviewed scientific journals.

Public input and engagement: Public input is solicited early and often. The Forest Service and its partners engage the public throughout the adaptive management cycle, from issue identification, to decisionmaking, to monitoring of project outcomes. Public input also comes from the usual formal processes, such public comment periods.

Investment: Total funding for the Uncompahgre Plateau Project, including partner funds, was about $1.7 million in fiscal year 2012, with about $165,000 allocated for monitoring activities. Monitoring is required during the project and for 15 years after its completion.

Outcomes/outputs/benefits: In 2012, the Uncompaghre project improved, restored, or enhanced 8,202 acres of wildlife habitat, improved 1,205 acres of forest vegetation, managed noxious and invasive plants on 222 acres, sold over 500,000 cubic feet of timber, decommissioned about 30 miles of roads, and reduced hazardous fuels on 771 acres in the wildland-urban interface, just to name a few accomplishments.

Case Study 5. Clean Air Coalition of Western New York: Tonawanda Air Quality Study

Spatial range:	Temporal range:	Level of training:
Local	short term (1-3 years)	basic

History: Tonawanda, NY, is an urban area in western New York with some of the state's largest industrial facilities.

Management goals: Concerned about smells and smoke, citizens suspected a connection to chronic health problems in their community. The goal was to identify the cause of the health problems with the hopes of ultimately mitigating them.

Level of volunteer participation in science: Volunteers collected air samples using the bucket method to find out what was in the air.

Level of volunteer participation in public involvement: Volunteers, organized as the Clean Air Coalition of Western New York, presented their data to the New York Department of Environmental Conservation (DEC) and to the Environmental Protection Agency (EPA).

Sustainability: The coalition has moved on to other projects. According to its website, "The Clean Air Coalition builds power by developing grassroots leaders who organize their communities to run and win environmental justice and public health campaigns in western New York."

Science: Following standard protocol, the bucket takes a 3-minute "grab sample"—a single sample of air, at one point in time, with no other information collected. The study included such factors as wind speed and direction. Elevated levels of benzene, a known carcinogen, were found to be above the DEC's health-based annual guideline concentrations.

Public input and engagement: Citizens articulated community concerns and presented air quality data to state and federal regulatory agencies. The evidence collected by the citizens and subsequent public input to the DEC were compelling enough to warrant the attention of the agencies.

Investment: The initial volunteer-led project did not require any agency investment. Based on results from the citizen science project, the New York DEC used funding from an EPA Community-Scale Air Toxics Ambient Monitoring Grant to undertake a year-long study of the air quality in Tonawanda using EPA air monitors.

Outcomes/outputs/benefits: Spurred by what the citizens initially found, the DEC used air monitors at four locations to measure 56 air toxins. Its year-long investigation formed the basis for compliance monitoring and regulatory actions by EPA and the New York DEC. As a result, the Tonawanda Coke Corporation agreed to improve operations, monitor for leaks, and upgrade pollution controls, decreasing benzene levels in the air by 86 percent.

Case Study 6. Strategic Investment in Citizen Science: The Wisconsin Citizen-Based Monitoring Network

The community of professionals and volunteers engaged in monitoring natural resources and the environment in Wisconsin formed the Wisconsin Citizen-Based Monitoring (CBM) Network, a comprehensive group of stakeholders who are collaborating to improve the efficiency and effectiveness of monitoring throughout the state. The network is made up of CBM practitioners from over 150 programs representing an array of organizations, including primary and secondary schools; county, state, and federal agencies; nature centers; conservation clubs; land trusts; and other nongovernmental organizations.

The network is coordinated and supported by the Wisconsin Department of Natural Resources (WDNR). A WDNR employee serves as full-time network coordinator, and the department invests $100,000 each year in small ($5,000) competitive contracts for CBM projects that meet high-priority needs for data. In addition, 10 to 20 department scientists lead individual projects or provide advice, and the department supports an advisory council drawn from volunteer groups. The council works with the department to identify monitoring priorities, help evaluate the effectiveness of the network, and ensure agency responsiveness to network needs.

Volunteers wait for dusk to count bats emerging from roost boxes at Yellowstone Lake State Park. Data they collect helps the Wisconsin Department of Natural Resources monitor native bat populations.
Photo credit: Heather Kaarakka.

Through these investments, the state is able to meet its data needs over much larger areas and timespans than could be covered by staff scientists alone. Financial support for the network allows the state to stretch its limited conservation dollars; for every $1 spent on CBM contracts, the state receives more than $3 worth of volunteer time. Wisconsin's state-supported network for citizen science helps engage and inform thousands of students and citizens every year, broadening public support for the state's conservation goals.

Case Study 7. Using Existing Citizen Science Tools: eBird and iNaturalist

Spatial range:	Temporal range:	Level of training:
local to national	long term (> 10 years)	basic, online, or workshop training

History: Many citizen science programs facilitate collection of data important for natural resource management and environmental protection organizations. In recent years, the National Park Service and U.S. Fish and Wildlife Service have encouraged volunteers to use eBird and iNaturalist to record observations of birds and other species in national parks and wildlife refuges. These programs have online interfaces that volunteers can use to submit data, and they provide data storage, curation, and quality control services. They help parks and refuges solve one of their most basic science and management problems: tracking the identity and abundance of species.

Management goals: Parks and refuges use these programs to keep up-to-date information on the species that occur on their lands and to monitor changes in their abundance and life cycles.

Level of volunteer participation in scientific process: Participants in both eBird and iNaturalist primarily record observations of species in the field. Participants can also explore online visualization and analysis tools.

Level of volunteer participation in public involvement: Many parks and refuges use these programs to develop relationships with local volunteers who already have or will develop expert knowledge on local biodiversity. Park and refuge staff can later turn to these volunteers for information and input related to management decisions.

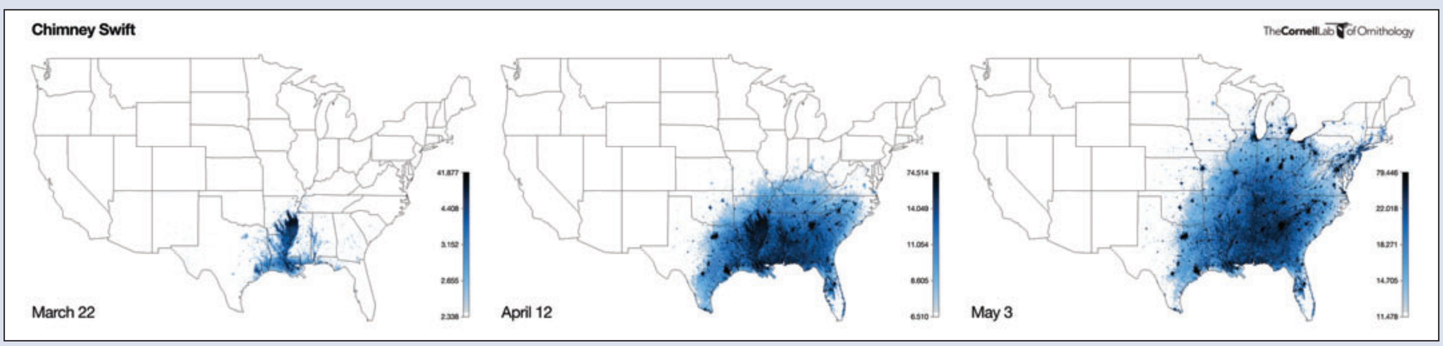
Sustainability: The projects are generally sustainable as long as the park or refuge is able to train, coordinate, and retain volunteers. By using existing online infrastructures, the parks and refuges greatly reduce project costs.

Science: eBird and iNaturalist have been utilized in dozens of peer-reviewed papers and national assessments, such as reports on the state of birds on public and private lands.

Public input and engagement: Parks and refuges use these programs to encourage public input and engagement in management decisions, as appropriate. For example, a refuge might ask its most active eBird volunteers to comment on management decisions that affect bird habitat.

Investment: Parks and refuges train and coordinate volunteers. They also invest in other activities, such as national training for park and refuge staff; the deployment of kiosks or displays to facilitate volunteer recruitment, data entry, and education; and development of techniques to integrate citizen science data into agency data management structures, such as NPSpecies, the system that national parks use to track species within their borders.

Outcomes/outputs/benefits: By using citizen science programs, refuges and parks can affordably meet some of their most basic monitoring needs. Programs like eBird and iNaturalist already engage tens of thousands of volunteers and generate hundreds of millions of observations. They provide data that park and refuge staff can use in making a variety of management decisions. Volunteers can also become important resources for park and refuge managers as sources of expertise on local biodiversity.

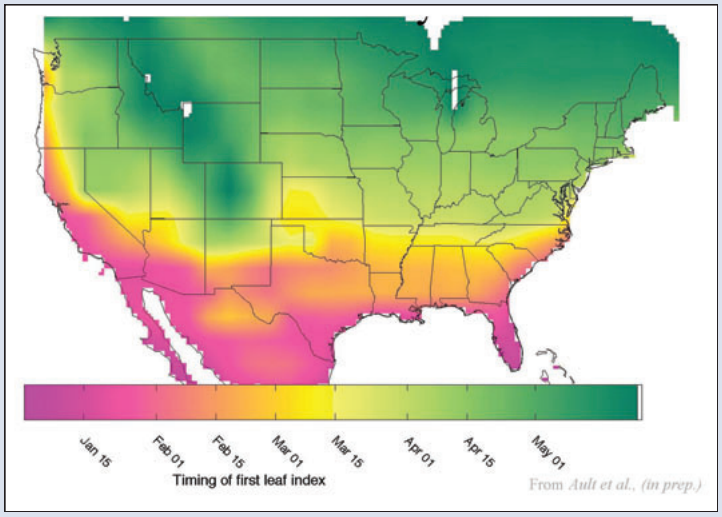


Heat maps show the northward migration of the chimney swift as modeled by the eBird network. Darker colors indicate higher probabilities of finding the species.

Case Study 8. Investing in Capacity: The USA National Phenology Network

Spatial range:	**Temporal range:**	**Level of training:**
local to national	long term (> 10 years)	basic, online, or workshop training

History: Changes in the timing of seasonal events, such as flowering, migrations, and breeding, amount to some of the most sensitive biological responses to climate change. Such changes in timing can affect ecosystems, causing mismatches between plants and their pollinators or disruptions in predator-prey interactions, and they can alter the timing of management actions, such as invasive species control. Until recently, however, there have been few monitoring or research programs focused on the topic. The USA National Phenology Network (USA-NPN) is a nationwide science and monitoring initiative focused on phenology (the study of events in the life cycles of plants and animals and changes in their timing). Stakeholders include researchers, resource managers, educators, and the public. The network relies on both conventional and citizen science.



Modeled onset of spring across the nation for 2014; color ramp illustrates date when enough warmth has accumulated to initiate leafout of temperature-sensitive native and cultivated plants. The model links gridded meteorological data with observations of plant leafout date collected by citizen scientists since 1956; citizen science data are now being used to validate the model as part of a "springcasting" campaign being conducted by the USA National Phenology Network.

Image: T. Ault, Cornell University.

Management goals: The USA-NPN seeks to enhance scientific understanding of phenology, improve decisionmaking using phenological data and information, support adaptive natural resource management and environmental protection, facilitate societal adaptation to environmental variation and change, and improve public understanding of climate change and the science of phenology.

Level of volunteer participation in scientific process: Participants in Nature's Notebook, the multitaxa phenology-observing program run by the network to collect data observed on the ground, include both volunteers and professional scientists and managers. Participants record phenology of plants and animals according to standardized published protocols and enter the data into a professionally managed database. Other governmental and nongovernmental organizations use Nature's Notebook for information while contributing their own data to the broader effort. In early 2014, network staff estimated that about half of the data in Nature's Notebook came from professionals and professionally trained participants and the other half from individuals or small volunteer groups participating in the project. The professionals and volunteers use the same protocols for monitoring.

Level of volunteer participation in public involvement: Public engagement in data collection is key to the network, as are education and outreach. Public involvement in resource management and policymaking, though of secondary importance, does happen as a part of partner projects, for example where phenology monitoring is part of local conservation projects.

Sustainability: The network's national coordinating office, operated in cooperation with University of Arizona, is almost entirely federally funded. The project has long-term funding from the U.S. Geological Survey. Additional funding from other sources, both governmental and nongovernmental, supports expansion of operations; the production of tools (such as mobile applications and custom websites); and research, development, and delivery of products for a variety of purposes. Researchers and the general public have free and easy access to raw and processed data in perpetuity.

Science: Data and data products generated by the USA-NPN have been used in seventeen peer-reviewed publications to date. The USA-NPN facilitates a community of practice among phenology researchers, identifies the needs of resource managers and environmental protection specialists for data and decision support tools, and communicates new insights.

Public input and engagement: The USA-NPN does not directly seek public input and engagement in management decisions, but many partner projects do. The USA-NPN infrastructure establishes science methods and tools and lets local organizations focus on conservation applications and engagement.

Investment: The U.S. Geological Survey and other organizations provide about $1 million per year to the network. Many local, regional, and national partners leverage the network's central infrastructure and make their own investments for research, management, and education applications.

Outcomes/outputs/benefits: To maximize limited resources, the network was designed as a national framework for phenology science and monitoring. Other governmental and nongovernmental organizations leverage its capacity for their own applications while contributing to the national dataset. Applications include identification of wildlife species vulnerable to climate change, parameterization and validation of models of carbon sequestration and water cycling, management of invasive species, planning of seasonal cultural activities, forecasting seasonal allergens, managing agricultural production on working farms and ranches, and tracking disease vectors between continents and in human population centers.

For Further Reading

Aceves-Bueno, E., A.S. Adeleye, D. Bradley, W.T. Brandt, P. Callery, M. Feraud, K.L. Garner, R. Gentry, Y. Huang, I. McCullough, I. Pearlman, S.A. Sutherland, W. Wilkinson, Y. Yang, T. Zink, S.E. Anderson, and C. Tague. 2015. Citizen science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: Criteria and evidence. *Ecosystems* **18**: 493-506. DOI: 10.1007/s10021-015-9842-4

Ballard, H.L., M.E. Fernandez-Gimenez, and V.E. Sturtevant. 2008. Integration of local ecological knowledge and conventional science: a study of seven community-based forestry organizations in the USA. *Ecology and Society* **13**: 37.

Bowser, A., and L. Shanley. 2013. *New Visions In Citizen Science*. Woodrow Wilson International Center for Scholars. Washington, DC. Available at: http://www.wilsoncenter.org/sites/default/files/NewVisionsInCitizenScience.pdf

Bowser, A., and A. Wiggins. 2013. Data Policies for Public Participation in Scientific Research: A Primer. DataONE: Albuquerque, NM. Available at: http://www.birds.cornell.edu/citscitoolkit/toolkit/policy/

Danielsen, F., M.M. Mendoza, A. Tagtag, P.A. Alviola, D.S. Balete, A.E. Jensen, M. Enghoff, and M.K. Poulsen. 2007. Increasing conservation management action by involving local people in natural resource monitoring. *AMBIO: A Journal of the Human Environment* **36**: 566-570.

Danielsen, F., K. Pirhofer-Walzl, T.P. Adrian, D.R. Kapijimpanga, N.D. Burgess, P.M. Jensen, R. Bonney, M. Funder, A. Landa, N. Levermann, and J. Mad. 2013. Linking public participation in scientific research to the indicators and needs of international environmental agreements. *Conservation Letters* **7**: 12-24. DOI: 10.1111/conl.12024

Dickinson, J.L. and R. Bonney (eds.). 2012. Citizen Science: Public Participation in Environmental Research. Cornell University Press, Ithaca.

Ecological Society of America. 2012. Citizen science (special issue). *Frontiers in Ecology and the Environment* **10**: 283-335.

Shirk, J.L., H.L. Ballard, C.C. Wilderman, T. Phillips, A. Wiggins, R. Jordan, E. McCallie, M. Minarchek, B.V. Lewenstein, M.E. Krasny, and R. Bonney. 2012. Public participation in scientific research: A framework for deliberate design. *Ecology and Society* **17**: 29.

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

Theobald, E.J., A.K. Ettinger, H.K. Burgess, L.B. DeBey, N.R. Schmidt, H.E. Froehlich, C. Wagner, J. HilleRisLambers, J. Tewksbury, M.A. Harsch, and J.K. Parrish. 2015. Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation* **181**: 236-244.

Wieler, C. 2007. Delivery of ecological monitoring information to decisionmakers. A report for the Ecological Monitoring and Assessment Network, Environment Canada. International Institute for Sustainable Development. Available at http://www.csinrcid.ca/downloads/delivering_onitoring_info.pdf.

Relevant Websites

CitizenScience.org
DataONE.org
CitSci.org
http://www.scientificamerican.com/citizen-science/

Acknowledgments

Funding for this project was provided by Cooperative Agreement 12-CA-11221633-096 between the U.S. Forest Service and the Ecological Society of America (ESA). Other funding and services were provided by the National Park Service and the Schoodic Institute at Acadia National Park. We would like to thank Kevin Bryant at the Meridian Institute for facilitating the workshops. We also thank Cliff Duke, Jennifer Riem, and Jill Parsons at ESA for logistical support. The views expressed in this paper do not necessarily represent the views of the U.S. government or any of its departments. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. government.

About the Scientists

Heidi Ballard, School of Education, University of California, Davis, CA 95616
Rick Bonney, Cornell Lab of Ornithology, Cornell University, Ithaca, NY, 14850
Owen Boyle, Wisconsin Department of Natural Resources, Madison, WI 53707
Russell Briggs, Division of Environmental Science and Forestry, State University of New York, Syracuse, NY 13210

Hutch Brown, Research and Development, USDA Forest Service, Washington, DC 20250
Stuart Chapin III, Department of Biology and Wildlife Institute of Artic Biology, University of Alaska Fairbanks, Fairbanks, AK 99775
Daniel M. Evans, AAAS Science & Technology Policy Fellow, Research and Development, USDA Forest Service, Washington, DC 20250
Rebecca French, AAAS Science & Technology Policy Fellow, Office of Research and Development, US Environmental Protection Agency, Washington, DC 20460
David Hewitt, Academy of Natural Sciences, Philadelphia, PA 19103 and Evidential Planning and Management, LLC, Philadelphia, PA 19128
Abraham J. Miller-Rushing, Schoodic Education and Research Center, Acadia National Park, National Park Service, Bar Harbor, ME 04609
Duncan McKinley, Research and Development, USDA Forest Service, Washington, DC 20250
Julia Parrish, School of Aquatic and Fisheries Sciences, University of Washington, Seattle, WA 98105
Tina Phillips, Cornell Lab of Ornithology, Cornell University, Ithaca, NY 14850
Peter Preuss, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC 20460
Sean Ryan, Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556
Lea Shanley, Commons Lab of the Science and Technology Innovation Program, Woodrow Wilson International Center for Scholars, Washington, DC 20004
Jennifer Shirk, Cornell Lab of Ornithology, Cornell University, Ithaca, NY 14850
Michael Soukup, Schoodic Institute at Acadia National Park, Winter Harbor, ME 04693
Kristine Stepenuck, University of Wisconsin Extension, University of Wisconsin, Madison, WI 53706
Jake Weltzin, National Coordinating Office of USA National Phenology Network, U.S. Geological Survey, Tucson, AZ 85721
Andrea Wiggins, College of Information Studies, University of Maryland College Park, College Park, MD 20742

Layout

Bernie Taylor, Design and layout

About Issues in Ecology

Issues in Ecology uses commonly understood language to report the consensus of a panel of scientific experts on issues related to the environment. The text for *Issues in Ecology* is reviewed for technical content by external expert reviewers, and all reports must be approved by the Editor-in-Chief before publication. This report is a publication of the Ecological Society of America. No responsibility for the views expressed by the authors in ESA publications is assumed by the editors or the publisher.

Additional Copies

This report and all previous *Issues in Ecology* are available electronically for free at

www.esa.org/issues.

Print copies may be ordered online or by contacting ESA:

Ecological Society of America
1990 M Street NW, Suite 700
Washington, DC 20036
(202) 833-8773, esahq@esa.org

ECOLOGICAL SOCIETY OF AMERICA
esa