The history of public participation in ecological research

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Members of the public have for centuries recorded their observations of the natural world, including plant and animal distribution and phenology, water quality, weather data, and astronomical phenomena. Given the relatively recent growth of ecological research as a professional field of study, the historical contributions of amateurs to ecology can be easily overlooked. To better understand long-term changes in ecosystems, researchers are now revisiting many of these historical datasets collected by non-professionals. Over the past 100 years, scientific organizations have increasingly included volunteers in large-scale monitoring projects to broaden the geographical extent and sample size of observations. We believe that a renewed interest in citizen science, enriched with the perspective and data provided by the long tradition of public participation in science, will broaden the engagement of the public in ecological research and lead to new scientific insights.

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In recent years, citizen science has gained greater attention as a way of tackling research questions that otherwise could not be addressed without the involvement of large numbers of data collectors, and also as a method of engaging the public in the scientific process with the goal of improving scientific literacy (Couvet 2008; Bonney *et al.* 2009a, 2009b; Silvertown 2009). Although citizen science is sometimes discussed as if it were new, members of the public have for most of recorded history investigated scientific questions, often by noting observations of the world around them. Their efforts have yielded important datasets, specimen collections, and scientific insights of all types, including many within the field of ecology. Here, we explore the history of citizen science and the contributions that it has made to current ecological understanding. Although we recognize that citizen science has a rich history worldwide (and include some international examples in this review), we focus primarily on its history in the US.

In a nutshell:

- Members of the public have been actively participating in scientific research – that is, doing citizen science – for centuries
- The relatively recent professionalization of science has changed the role of citizens in advancing ecological knowledge
- Citizen science has made substantial contributions to our current understanding of ecology and some of the most important historical datasets and museum collections
- Ecologists are increasingly turning to lesser-known datasets collected by citizen scientists to understand long-term changes in the environment and their causes and consequences

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What is citizen science?

Citizen science refers to the engagement of non-professionals in scientific investigations – asking questions, collecting data, or interpreting results (Panel 1; Table 1). Citizen-science projects generally include a partnership between amateur and professional scientists, although expert amateurs can replace the role of professional scientists. Here, we consider "amateur" to mean anyone who is not a professional scientist, and do not intend the term to reflect level of expertise, since some amateurs are in fact leading experts in their fields. In some cases, as in analyses of historical data (eg information found in journals of natural history observations), partnerships can arise where no direct contact between the amateur and professional scientists occurs.

The important characteristic of citizen science is not the level of involvement of either professional scientists or amateurs but rather the public's participation in genuine scientific research. This research can be explicitly hypothesis-driven or based simply on natural history observations or monitoring that can be used to generate or test hypotheses. Activities that do not produce new scientific knowledge – for example, "canned" teaching labs where the outcome is known, or data-collection activities where the data are not analyzed or the knowledge generated is not communicated beyond the participants – are *not* included in our use here of the term citizen science.

Deep history

Prior to the professionalization of science in the late 19th century, nearly all scientific research was conducted by amateurs – that is, by people who were not paid as scientists (Vetter 2011a). These individuals were largely pursuing research because of an innate interest in particular topics or questions (Porter 1978). Many amateurs were recognized experts in their field and conducted research

Panel 1. Categories of public participation in scientific research

Terms such as "public participation in scientific research", "volunteer-based monitoring", "citizen science", and "participatory science" frequently mean different things to different people. In part to reduce confusion, the Center for Advancement of Informal Science Education published a report helping to define the field (Bonney *et al.* 2009a). The report offers a useful categorization of citizen-science projects, grouping them into three types – contributory, collaborative, and co-created (Table 1). These groupings reflect different levels of public participation in the scientific process. Volunteer participants can simply contribute data to a scientific study, as in the contributory model of citizen science, or they can be involved in the entire scientific process, from developing a hypothesis to analyzing, discussing, and disseminating the results.

Although designed with contemporary citizen-science projects in mind, these definitions are also helpful when thinking about the history of citizen science because they highlight the variety of forms that citizen-science projects can take and provide insights into stable and changing aspects of citizen science's role in ecology. For example, although modern communications and computing technology has facilitated rapid growth in citizen-science programs that follow the contributory model, research and specimen collection programs have continued with this model for centuries (eg Brenna 2011). A substantial proportion of ecological research used to follow a co-created model, in which amateur scientists were important participants in all phases of a scientific study and often pursued such projects largely or totally independent of professional scientists. Although many research efforts are still based on this model, they make a relatively smaller contribution to the advancement of ecological knowledge than they once did because of the professionalization of science over the past 150 years.

indistinguishable from – and sometimes superior to – that done by most professional scientists of the time.

As early as the 17th century and probably earlier, some of these amateur experts had recruited non-experts to contribute natural history observations. For example, in the mid-18th century, a Norwegian bishop created a network of clergymen and asked them to contribute observations and collections of natural objects throughout Norway to aid his research (Brenna 2011). This was a common way for early ecologists, such as John Ray and Carl Linnaeus, to collect specimens and observations from across the known world. Such contributions by non-trained scientists have helped to build some of the most valuable collections of animals, plants, rocks, fossils, artifacts, and other specimens worldwide (Figure 1).

Others who have collected information and data about the natural world in the past include farmers, hunters, and amateur naturalists. For instance, wine-growers in France have been recording grape harvest days for more than 640 years (Chuine *et al.* 2004), while court diarists in Kyoto, Japan, have been recording dates of the traditional cherry blossom festival for 1200 years (Figure 2; Primack *et al.* 2009). In China, both citizens and officials have been tracking outbreaks of locusts for at least 3500 years (Tian *et al.* 2011). In the US, among the oldest continuous organized datasets are phenological records kept by farmers and agricultural organizations that document the timing of important agronomical events, such as sowing, harvests, and pest outbreaks (Hopkins 1918).

Table 1. Categories of public participation in scientific research (adapted from Bonney *et al.* 2009a)

Category	*Definition*
Contributory	Generally designed by scientists and for which members of the public primarily contribute data; also includes studies in which scientists analyze citizens' observations, such as those in journals or other records, whether or not those citizens are still alive
Collaborative	Generally designed by scientists and for which members of the public contribute data but may also help to refine project design, analyze data, or disseminate findings
Co-created	Designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all steps of the scientific process; also includes research wholly conceived and implemented by amateur (non-professional) scientists

The professionalization of science

More recently, during the past 150 years or so, science has become professionalized, while amateurs have often been marginalized. Although amateur scientists still abound – as evidenced by the many naturalist clubs (eg bird-, insect-, mushroom-, and plant-focused groups) across the country – the role of amateurs in conducting research has diminished as the number of professional scientists has dramatically increased and the culture of science has changed.

Even so, citizen science has continued and even grown in recent years, as it has begun to fill two major niches within current scientific pursuits. The first niche involves projects that tackle ecological questions at scales that would be unachievable through professional science alone. Programs that follow a contributory or collaborative participatory model (Table 1) – such as the North American Breeding Bird Survey, the US National Weather Service's Cooperative Observer Program (NWS-COOP), North American Bird Phenology Program, and lilac monitoring programs (the latter two now a part of the USA National Phenology Network, USA-NPN, www.usanpn.org) – have yielded national- or continental-scale datasets of biological and physical data that could not have been collected otherwise. The US NWS, for example, was tasked with gathering weather data that were critical to a variety of aspects of the economy, particularly agriculture, but was provided with only a limited budget to do so (Vetter 2011b). They therefore followed the example of weather bureaus in Europe by turning to volunteers who were broadly distributed throughout the

country. The outcome of their work was one of the most important long-term datasets in North America – essential for agriculture, development planning, and assessment of recent climate change.

Other projects operating at local or regional scales, including many water, vernal pool, or plant or wildlife monitoring programs, have yielded similarly extensive datasets that could not have been collected by professionals alone. Many states, for instance, have long relied on volunteers to monitor water quality to protect drinking water supplies and adjacent swimming beaches, fish populations, or other recreational uses of river and lake water (Nerbonne and Nelson 2004).

The second major niche that citizen science has filled is in undertaking projects that professional scientists would not do on their own, whether because of the type of question or the place of study. For example, research scientists have incentives to study questions that advance knowledge of the field as a whole and to avoid projects that are too restricted in scope to be widely cited or of interest beyond a narrow audience. Thus, many local, place-based projects go uninvestigated by professional scientists and are sometimes instead carried out by local residents. A project may focus on finding causes of local problems, such as pollution, wildlife deaths, or pest outbreaks, and may also lead to management or policy solutions once the causes are found. For instance, the volunteer program Save Our Streams was founded in 1969 to monitor, protect, and restore streams in the US state of Maryland (Firehock and West 1995). The program has since been used as a model for a national program supported by the Izaak Walton League of America and has been widely recognized for its role in understanding and restoring streams throughout the US. Volunteer programs aimed at tackling local problems have long existed across the country and continue to make important contributions to science and resource management today (WebFigure 1). They are often referred to as "community science" or "participatory action research".

Figure 1. *Students working in the Arnold Arboretum Herbarium in Jamaica Plain, Massachusetts. Amateur naturalists contributed many of the specimens held in this collection and other important collections of plant, animal, and fossil specimens and observations.*

Ecological insights from historical citizen science

Museums, herbaria, and other collections

Collections of specimens, photographs, and similar records held at museums and other institutions around the world have yielded innumerable insights into ecology, evolution, and conservation biology. These collections

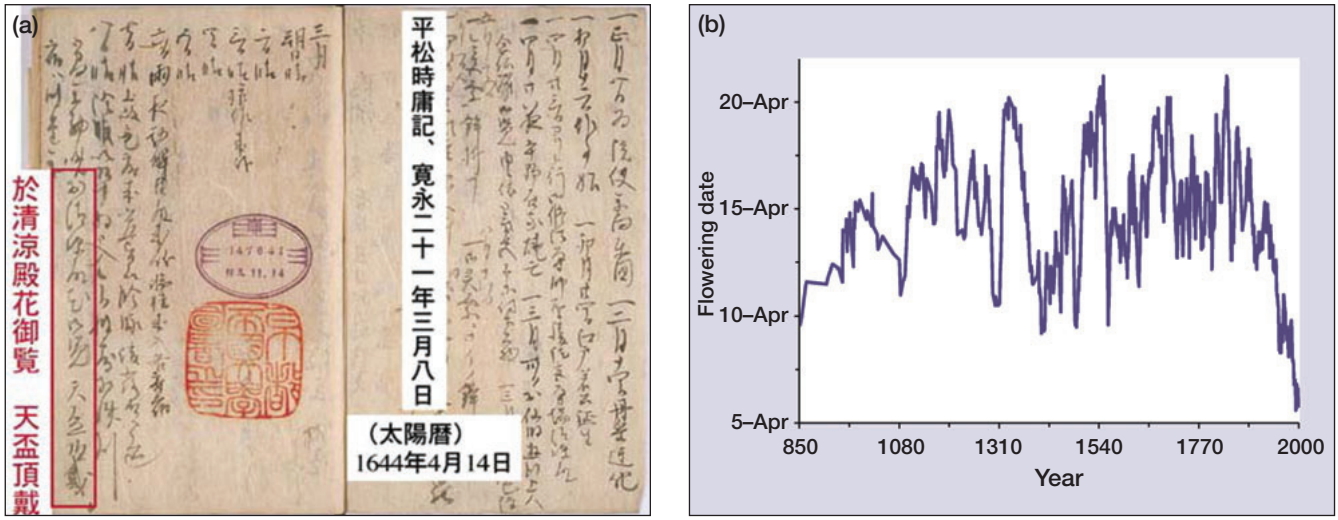

Figure 2. *Old court diaries provide a long-term record of dates of cherry blossom festivals in Kyoto, Japan. (a) This diary of Tokistune Hiramatsu, a well-known court figure of the Edo Era, provides the following entry on April 14, 1644: "In Seiryoden Palace, Kyoto, we enjoyed watching cherry blossoms and took sake provided by the emperor". The translation of the highlighted sentence is shown in red; the black entry is the date, according to the Japanese calendar. (b) A running 10-year average of cherry blossom peak flowering in Kyoto. Images from Primack* et al. *(2009) and Primack and Higuchi (2007) using image and data provided by Y Aono, Osaka Prefecture University.*

were often expanded by contributions from a combination of professional scientists and untrained or self-trained amateurs. Such collections have been used extensively to develop modern taxonomic systems of naming and classifying and to understand the dynamics of evolution and the distribution of species.

More recently, historical collections have been used to analyze shifts in the abundance and distribution of species due to land-use change, climate change, and other anthropogenic forces (Araujo and Rahbek 2006; Feeley and Silman 2011). For example, herbaria in the northeastern US tend to have large numbers of specimens collected between 1870 and 1940. By comparing the abundance and distribution of herbarium specimens with the modern abundance and distribution of the same species using intensive field surveys, researchers can document the decline of rare and endangered species and the arrival and spread of non-native invasive species (Lavoie and Saint-Louis 2008; Lavoie *et al.* 2012). Similarly, by comparing the flowering dates of herbarium specimens with flowering records gathered by current observers, we can detect shifts in flowering times associated with a warming climate (Primack *et al.* 2004). Other biological phenomena, such as the adult phases of butterflies, dragonflies, and moths, can be investigated through the same approach. Collections of dated photographs – in particular old landscape photos – also represent an enormous resource for studying transformations caused by climate change, land use, air pollution, invasive species, and the impact of deer, cattle, and other large herbivores (Miller-Rushing *et al.* 2006; Webb *et al.* 2010).

Small-scale datasets – individuals and groups

Historical records held by amateur naturalists or other individuals or small groups hold great potential for understanding long-term changes in ecosystems. Some of these naturalists are famous, like Meriwether Lewis and William Clark (of the 19th-century Lewis and Clark expedition) or former US President Thomas Jefferson, but most are relatively unknown beyond their local communities. Generally, the people who made these historical observations were not intentionally participating in scientific projects, or were collecting data to address questions unrelated to their current use. However, their observations, particularly those for which the methods of collection and other metadata are well documented, provide key data for current scientific studies. Researchers have begun using these datasets to gain important insights into ecological responses to climate change.

One particularly noteworthy dataset is the record of first flowering dates, first leaf-out dates, and first arrival dates for migratory birds in Concord, Massachusetts, made by the famous writer and early environmentalist Henry David Thoreau between 1851 and 1858. What makes this record so valuable is that Thoreau's observations were collected from one well-defined place over many years, and that he was able to accurately identify the large numbers of species involved. Later botanists (professional and amateur alike) continued his observations of first flowering times, and also recorded the abundance of different plant species in Concord. A series of ornithologists and amateur birdwatchers recorded the first arrival dates of birds in later decades. These historical records, combined with modern observations, have been used to demonstrate that plant phenology is responding more strongly than bird phenology to warming temperatures (Miller-Rushing and Primack 2008; Ellwood *et al.* 2010; Primack and Miller-Rushing 2012). These data can also reveal relationships between phenological changes and declines in the abundance of many native species, as well as increases in the abundance of different invasive species (Willis *et al.* 2008, 2010).

Many groups of amateur naturalists have also kept important ecological records. For instance, members of the Cayuga Bird Club in Ithaca, New York, have been recording the arrival dates of migratory birds each spring since 1903. Although their goal is simply to preserve a record of sightings and arrival dates, their observations over the years have been a valuable source of data for ecologists interested in studying the impacts of climate change on bird migration patterns, and show that many bird species are arriving earlier over time (Butler 2003).

Large-scale programs and datasets

Many of ecology's most important and widely used datasets come from citizen-science programs. For example, the aforementioned NWS-COOP has been collecting basic weather data across the US since 1890. The results inform much of what we know about variability and directional changes in climate over the past 120 years (Figure 3).

Other datasets collected by citizen-science programs provide the basis for many policy and management decisions. Perhaps the best example is the widespread involvement of volunteers in monitoring water quality across the US. The data they have collected have frequently been used by management agencies to define baseline conditions, identify problems, and determine what management actions were needed. These data are so important that many states have passed rules providing guidelines for their use in policy and management decisions, sometimes considering volunteer-collected data analogous to data collected by state agencies (Firehock and West 1995).

Many wildlife ecologists, agricultural scientists, and resource managers also rely on citizen science for critical data. For example, some of the best datasets describing migrations, population dynamics, phenology, and pest outbreaks were generated by citizen-science programs, such as the North American Breeding Bird Survey, the Christmas Bird Count, and extensive agricultural monitoring initiatives. These datasets have led to insights regarding bird population dynamics and conservation status (Sauer and Link 2011) and climatic constraints on bird wintering ranges (Niven *et al.* 2009). They have also

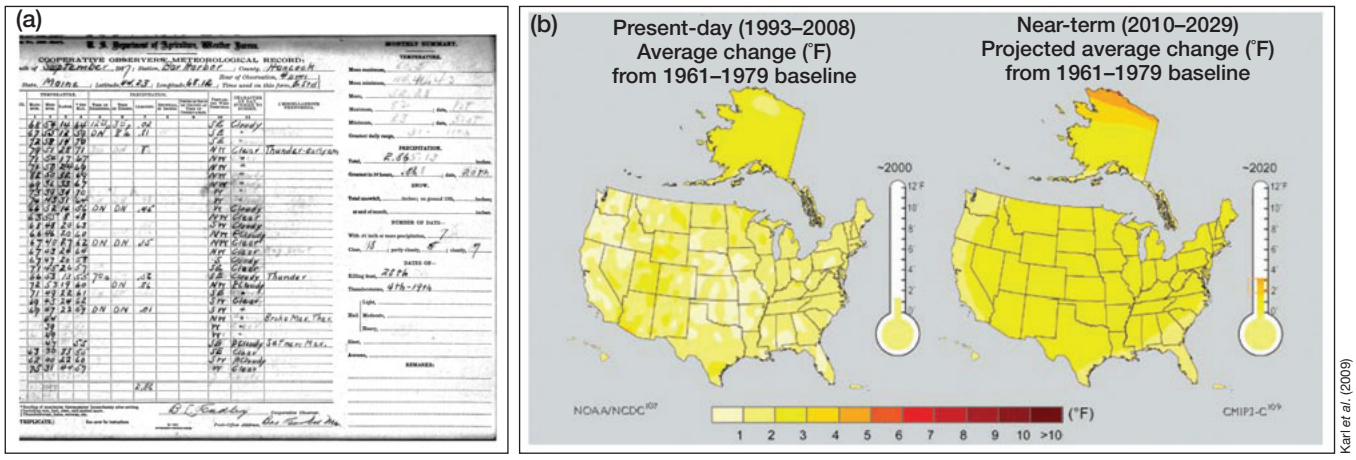

Figure 3. *Volunteer weather observers contribute to some of the datasets used to document changes in climate. (a) A datasheet completed as part of the US National Weather Service's Cooperative Observer Program and the US Historical Climatology Network. (b) Maps and thermometers showing temperature differences (either measured or projected) from conditions as they existed during the period 1961–1979. Data for (b) are from the US Historical Climatology Network.*

contributed to insights that are now central to our understanding of ecology and agriculture, such as the recognition of the relationships among temperature, latitude, elevation, and plant and insect phenology (Hopkins 1918). Wildlife agencies also rely on hunters for data on wildlife diseases, such as chronic wasting disease; this information improves our understanding of disease prevalence and transmission, as well as helping to guide management and policy responses (Williams *et al.* 2002). Long-term records kept by both amateur and commercial fishermen are increasingly being analyzed to detect changing patterns in the abundance and structure of fish populations and to determine whether fisheries management is having the desired effect (Rosenberg *et al.* 2005; Granek *et al.* 2008).

Discovering and analyzing past citizen-science data

Interest in climate change, land-use history, invasive species biology, and conservation has resulted in a search for historical records gathered through citizen-science methods. Such records include observations of species occurrences, population sizes, behaviors, and phenology, as well as community-level records, such as local floras and faunas, gathered by individuals or groups of people with specialized interests. Although such datasets can be challenging to find, an unexpectedly large number exist and are being organized and archived by government agencies and research institutions, such as the USA-NPN.

For citizen-science efforts that are driven primarily by the interest of amateurs, the involvement of scientists can often energize participants by validating the work they are doing and by providing them with new directions. However, researchers working with datasets gathered by amateurs need to be cautious (Lepage and Francis 2002). Historical datasets of all types must be interpreted carefully because we do not always know how the data were gathered. Additionally, because many of these datasets have been collected by several different observers over time, determining whether patterns or trends in the data are genuine or were caused by changes in observer or methods can be challenging. A variable as simple as the number of days per week that two observers gathered data could substantially affect the results (Miller-Rushing *et al.* 2008). Nevertheless, we have found a surprising number of historical citizen-science datasets that are documented reasonably or very well and include high-quality data (Primack and Miller-Rushing 2012).

■ Progress in citizen science

Over time, the techniques involved in developing and managing citizen-science projects have changed, improving both the scientific and educational outcomes of many projects. Advances in communications, transportation, and computing have made it easier for volunteers to contribute and for scientists and volunteers to manage and analyze the resulting data. For example, the development of railroads and the telegraph were integral to the development of the NWS-COOP (and other, similar observer networks) and the near-term weather forecasts it supported (Vetter 2011b). More recent advances in data management, online resources (eg www.citizenscience.org), and communications technology, as well as studies of the quality and value of citizen-science data, have continued to transform the field (Dickinson *et al.* 2012; Newman *et al.* 2012).

Citizen science is also increasingly seen as a way to engage the public in science, improve scientific literacy and interest in science, and inform participants about particular topics, such as butterfly ecology, vernal pool conservation, or climate change (Lowman *et al.* 2009). This is a major departure from most of the history of citizen science, when projects were set up mainly to achieve scientific objectives. Instead, many are now being organized primarily as a means to improve participants' scientific literacy and understanding of the topics they are studying (Bonney *et al.* 2009a). Scientists are also increasingly aware of the

potential for combining historical citizen-science datasets with current observations to gain insights into the ecological impacts of changes in climate, land-use, and other drivers of environmental change. We believe that this renewed interest in citizen science, enriched with the perspectives and data provided by the long tradition of public participation in science, will broaden the engagement of the public in ecological research and lead to improvements in scientific education and insights.

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