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FORUM

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Citizen science: a new approach to advance ecology, education, and conservation

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Abstract Citizen science has a long history in the ecological sciences and has made substantial contributions to science, education, and society. Developments in information technology during the last few decades have created new opportunities for citizen science to engage ever larger audiences of volunteers to help address some of ecology's most pressing issues, such as global environmental change. Using online tools, volunteers can find projects that match their interests and learn the skills and protocols required to develop questions, collect data, submit data, and help process and analyze data online. Citizen science has become increasingly important for its ability to engage large numbers of volunteers to generate observations at scales or resolutions unattainable by individual researchers. As a coupled natural and human approach, citizen science can also help researchers access local knowledge and implement conservation projects that might be impossible otherwise. In Japan, however, the value of citizen science to science and society is still underappreciated. Here we present case studies of citizen science in Japan, the United States, and the United Kingdom, and describe how citizen science is used to tackle key questions in ecology and conservation, including spatial and macro-ecology, management of threatened and invasive species, and monitoring of biodiversity. We also discuss the importance of data quality, volunteer recruitment, program evaluation, and the integration of science and human systems in citizen science projects. Finally, we outline some of the primary challenges facing citizen science and its future.

Keywords Citizen science · History · Human-natural system · Web-based approach · Worldwide case studies

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Introduction

The term citizen science is used in many ways—indeed citizen science projects can take a variety of approaches, have different goals, and involve many disciplines of science. In this Forum, we define citizen science as engaging the public in a scientific project, a definition that is gaining general acceptance among citizen science researchers and practitioners (Bonney et al. 2014; Shirk et al. 2012; Silvertown 2009).

Citizen science has long been used to collect reliable data and information for scientists, policymakers, and the public (Miller-Rushing et al. 2012; Silvertown 2009). As a research enterprise, it should be and is open to the same system of peer review that applies to conventional science (McKinley et al. 2015; Theobald et al. 2015). At the same time it engages the public through science practice, which is distinctly different from reading digests of scientific findings. This coupling of deep engagement in the process of science with the opportunity to co-create knowledge with others is thought to have profound effects that are, as yet, largely unstudied.

In Japan, however, ecologists, the public, and decision makers have not fully recognized the significance and potential of citizen science as a way to monitor and understand some of the public's grand challenges for science and society, such as rapid global environmental change and the loss of biodiversity. There is good reason to believe that engaging the public with these problems in a hands-on way will lead to productive partnerships in science and problem solving, and that it will help to ensure that scientific information can be appreciated and understood across a broader sector of society.

Recent advances in information technology have created new opportunities for citizen science projects to invite large numbers of the public to monitor the natural environment and biodiversity over broad geographic regions (Fink et al. 2014; Sauermann and Franzoni 2015; Silvertown 2009). In many cases participants can use online tools to access, visualize, and interpret the huge data sets they contribute to. Additionally, online interfaces can allow organizations to gather information required to better understand their participants, to facilitate understanding data accuracy, build tools participants want, and provide incentives that build motivation and sustain participation.

For scientists, citizen science provides an opportunity to gather information that would otherwise be impossible to collect because of limitations on time and resources. Fields such as macroecology, geographical ecology, and landscape ecology, which focus on large spatial scales, stand to gain disproportionately (Haklay 2013; Theobald et al. 2015). Citizen science is also useful for urban ecology, where private lands provide an ecological matrix of potential importance to conservation that is usually not accessible to research and where there are large concentrations of people—potential volunteers to help collect data (Evans et al. 2005; Kobori and Primack 2003).

The benefits are already apparent. A recent analysis of 388 English-language citizen science projects that engage 1.3 million volunteers showed that projects have contributed up to US$2.5 billion in-kind annually (Theobald et al. 2015). One project alone, eBird, collects five million bird observations every month, and has contributed to at least 90 peer-reviewed articles or book chapters in ornithology, ecology, climate change, and statistical modeling (Sullivan et al. 2014).

The full potential for science has yet to be tapped—only 12 % of English-language projects provide data to peer-reviewed scientific articles, despite the fact that a third of these projects have verifiable, standardized data (i.e., observations made according to standard methods controlling for effort) that are accessible online (Theobald et al. 2015). Even so,, the use of citizen science data in peer-reviewed publications is typically underestimated because papers often neglect to mention the role of citizen science or volunteers in their studies (Cooper et al. 2014). For volunteers, citizen science allows authentic participation in research (Shirk et al. 2012). Citizen science can improve science literacy and contribute to lifelong science education (Bonney et al. 2009; Wals et al. 2014). Moreover, many federal and local governments, research institutes, museums, nongovernmental organizations (NGOs), and conservation organizations rely on volunteer-compiled datasets to inform their resource management and conservation strategies (McKinley et al. 2015).

In this Forum, we review the history of citizen science and describe pioneering case studies of citizen science in research, education, and conservation. In these sections, we include examples from the United Kingdom and United States—where the field of citizen science is better developed and described (but not older) than in Japan—for purposes of comparison. We close by discussing the importance of evaluation and some of the primary challenges facing citizen science and its future.

History

Citizen science has a history as long as science itself (Miller-Rushing et al. 2012). The first people following the scientific method to solve problems were amateur scientists; they predated the professionalization of science. Since science has become a formal profession, the role of citizen science and the contributions of non-professionals to science have become somewhat marginalized (Miller-Rushing et al. 2012). Only now is the value of citizen science becoming more widely recognized. In this section, we describe the history of citizen science in Japan, the United Kingdom, and the United States. The histories in the United Kingdom and United States have been previously described, but they provide valuable lessons and points of comparison, especially given the lesser known history of citizen science in Japan.

Japan

Some of the longest-running citizen science records in the world are from Japan. For example, the timing of cherry blossom has been recorded in Kyoto for 1200 years, so long that they have been used in climate reconstructions (Aono and Kazui 2008). Centuries-long phenology data also exist for other plant and animal species across Japan (Primack et al. 2009).

Many nationwide biodiversity monitoring surveys also have long histories. The oldest ongoing such survey is probably the Sea Turtle Survey, which censuses sea turtles laying eggs on beaches. The Sea Turtle Survey started in 1954 on one beach, and now takes place on about 40 beaches across Japan. The annual waterbird census has also occurred for more than 40 years, and takes place at about 200 locations throughout the country. The Dandelion Mapping Survey, which started in 1975, surveyed about 74,000 specimens in 2010 from the whole of the western part of Japan. Together, these projects comprise long-term data sets that today are of importance to environmental biology.

Japan's oldest citizen science projects, such as cherry blossom records, focused on culturally important events. Conservation-focused citizen science projects, in contrast, began more recently—in the 1970s when environmental issues caused by urbanization, reclamation, and air pollution were particularly acute and attracted much popular attention. Most started primarily as educational activities to increase the public's awareness of the importance of the natural environment. Now scientists and conservationists are increasingly recognizing the scientific value of the data these projects collect. For example, phenological observations made by volunteers, often thought of as primarily a cultural practice, are now used to evaluate the effects of climate change on Japan's species and ecosystems (Kobori et al. 2011).

Nationwide citizen science projects in Japan, like those in other countries, are managed primarily by national NGOs, such as the Wild Bird Society of Japan, the Sea Turtle Association of Japan, The Nature Conservation Society of Japan, and Japan Bird Research Association. These projects have been now integrated into one national project ''Monitoring Sites 1000,'' a collaboration among the Ministry of the Environment, NGOs, university scientists, and many volunteer citizens (NACS-J 2013). The Monitoring Sites 1000 project started in 2003, following from the national biodiversity strategy, and aims to detect changes in ecosystem conditions through long-term (100-year) monitoring of biodiversity at about 1000 sites in various ecosystems, including forests, lakes, beaches, satoyama (agricultural ecosystems), grasslands, and reefs.

As an example of the participation in and outcomes of these citizen science programs, the Monitoring Sites 1000 Satoyama citizen science project was developed in 2003. It is run by the Nature Conservation Society of Japan, and more than 200 local NGOs with 2500 citizen scientists participating at 200 monitoring sites. The project aims to help monitor progress toward achieving the Aichi Biodiversity Targets (CBD 2010a) and the conservation of satoyama. The flora, birds, butterflies, mammals, and fireflies at various satoyama sites are recorded every year using standard protocols. More than 900,000 observations have been recorded since 2008. As a result, gradual but significant trends have been found for several biodiversity indicators (all declining), including species richness of native plants, birds, and butterflies, and population sizes of birds (MOE 2014). Additionally, volunteers participating in the project improved their taxonomic skill (MOE 2014), contributing to the goals of the global taxonomy initiative (CBD 2010b). Although the monitoring sites 1000 program has existed for just 12 years, limiting its ability to detect long-term trends, the development of a long-term, nationwide monitoring network supported by citizen involvement is itself a significant achievement whose payoffs will increase as time goes on.

United Kingdom

The history of citizen science in the United Kingdom dates back to the beginning of scientific and natural history observation in the country, including the work of John Ray, the great 17th century naturalist who involved many volunteers in collecting specimens. Volunteer involvement in science in the United Kingdom has continued through a host of programs—especially programs focused on phenology, birds, and butterflies—and has grown rapidly in recent years.

Like in Japan, phenological observations provide the longest-running citizen science data sets in the United Kingdom. In 1736, Robert Marsham started recording 27 phenological events, such as first flowering, leafing and the appearance of migratory birds, for more than 20 common plant and animal species in his family estates in Norfolk (Margary 1926). He continued recording until his death in 1797, after which the work was continued by successive generations of his family until 1958 (Sparks and Carey 1995), providing a valuable 223-year record of phenological changes. Today a citizen science project, Nature's Calendar, encourages mass observation of 67 spring and 24 autumn phenological events nationwide. Approximately 40,000 people across the United Kingdom volunteer for this project, providing extensive sampling (Amano et al. 2010a). These records, together with many other data sets, are now compiled by the UK Phenology Network as one big database with more than three million records, providing a powerful opportunity to explore the effects of long-term climate changes on species' phenology (Amano et al. 2010a).

For birds, the British Trust for Ornithology has organized at least eight ''core'' nationwide volunteer-based surveys (BTO 2015a). Together they cover a wide range of phenomena on the ecology of birds and are designed with a statistical rigor that is unusual for national biodiversity surveys (Greenwood 2012). One example, the Breeding Bird Survey—launched in 1994 as a successor to the Common Birds Census, which started in 1962—monitors the population changes of common bird species breeding in the United Kingdom. The area surveyed by the Breeding Bird Survey has more than doubled in the past 20 years. In 2013 2854 volunteers surveyed 3619 km^2 across the nation and recorded a total of 224 species (Harris et al. 2014). The Wetland Bird Survey shares the same objective with the breeding bird survey, but is targeted at non-breeding waterbirds. In the 2012–2013 season, count surveys were carried out at 2631 sites by 3100 volunteers under this scheme (Austin et al. 2014). The Nest Record Scheme, starting in 1939, has recorded the timing of breeding, the location of bird nests and the numbers of eggs and nestlings. For this scheme, over 600 volunteers locate and monitor more than 30,000 nests each year, providing a long-term dataset of over 1.35 million nest records from 232 species (BTO 2015b). These surveys by the British Trust for Ornithology have benefited from rigorous sampling schemes, a strong commitment to program management, and investment in building capacity for scientific data analysis.

Butterflies are another species group that has attracted much attention from citizen science in the United Kingdom. The UK Butterfly Monitoring Scheme has monitored changes in the abundance of butterflies since 1976, covering a total of 2302 sites across the country (Brereton et al. 2014). The wider countryside butterfly survey was established in 2009 to complement the UK butterfly monitoring scheme because the latter was biased towards good quality semi-natural habitats. In 2013 the wider countryside butterfly survey attracted more than 700 recorders, who counted over 142,217 butterflies of 45 species across 857 km^2 (Brereton et al. 2014).

United States

Initially, most citizen science in the United States was done by individual amateur naturalists exploring wilderness and reporting species new to science. One of the earliest organized efforts to recruit a large number of volunteer participants involved collection of data on bird strikes by lighthouse keepers around 1880 (Dickinson and Bonney 2012). Later, in 1890, the National Weather Service Cooperative Observer Program began to facilitate and encourage amateur meteorologists to collect weather data (Havens and Henderson 2013). That program continues today. Christmas Bird Counts, organized by the National Audubon Society, began in 1900 to survey wintering bird populations, and have continued for more than a century. Citizen science projects exploded in popularity in the United States in recent years and there are now dozens of formal programs, and many amateur naturalists who continue recording their observations independently. Formal programs are particularly focused on birds and other charismatic animals, such as amphibians and butterflies.

As in Japan and the United Kingdom, citizen science phenology monitoring has a long tradition in the United States; however, the oldest known records are not continuous and were collected mainly by individuals, such as Henry David Thoreau and Thomas Jefferson (Miller-Rushing and Primack 2008). Geographically widespread phenology monitoring began in the late 1950s with a network devoted to monitoring lilac and honeysuckle flowering (Schwartz et al. 2012). That network was created by the US Department of Agriculture, and has now been expanded by the USA National Phenology Network, which collects professional and citizen science observations of hundreds of plant and animal species (Denny et al. 2014; Rosemartin et al. 2014).

Citizen science data have contributed greatly to advances in ecology and provide information of importance to the conservation of birds, fish, insects, plants, mammals, and other taxonomic groups in the United States (Dickinson et al. 2010). For example, FeederWatch—originally organized as a regional survey by Bird Studies Canada (then Long Point Bird Observatory) in the 1970s—has expanded across North America in partnership with the Cornell Lab of Ornithology. Data collected by FeederWatch helped to reveal the impact of an emergent infectious disease, mycoplasmal conjunctivitis, which caused a wave of mortality in populations of house finches across the United States (Altizer et al. 2004; Hochachka and Dhondt 2000; Hosseini et al. 2004).

Historical and new citizen science data from biodiversity surveys, naturalists' journals, and museum collections have improved scientists' and the public's understanding of the impacts of global issues such as climate change, overexploitation, pollution, invasive species, and land-use change throughout the United States and in many other countries (e.g., Schwartz et al. 2012; Willis et al. 2008, 2010; Zoellick et al. 2012). These same sources of historical citizen science data have also been used to understand shifts in the abundance and distribution of species (Feeley and Silman 2011). Furthermore, current citizen science observations, when combined with these historical data, have revealed important new insights, such as the observation that plant phenology has responded more quickly to warming temperatures than has bird phenology (Ellwood et al. 2010; Marra et al. 2005). The long history of citizen science collection in Concord, Massachusetts, including observations by the famous philosopher and writer Henry David Thoreau, provide a particularly productive example of the scientific and communication benefits of combining old and new citizen science and professional science as well (Miller-Rushing and Primack 2008; Primack 2014; Primack and Miller-Rushing 2012; Primack et al. 2012).

Case studies: outcomes and insights

A strength of citizen science is its ability to simultaneously achieve a variety of outcomes, including scientific research, learning, and environmental stewardship behavior, goals that vary in their emphasis across projects (figure i.2 in Dickinson and Bonney 2012). The case studies in this section illustrate a variety of ecological and conservation applications of citizen science and highlight considerations that are unique to citizen science when compared to conventional or professional science. The first four case studies are from Japan, followed by examples from the United Kingdom and the United States, countries where the practice of citizen science is being studied extensively (Dickinson and Bonney 2012).

Citizen science as a producer of ''big data'' for spatial ecology

Trans-disciplinary collaborations between conservation ecology and data engineering have provided novel ways to contribute, manage, analyze, and engage with data, including growing amounts of spatially explicit ''big data'' (i.e., data sets too large or complex for traditional methods of storage and analysis) (Dickinson et al. 2010; Hochachka et al. 2012). In Japan, two new prototypes of monitoring programs highlight the potential for collaboration between conservation ecology and data engineering to engage in large-scale data collection to address conservation issues. The first, Invasive Alien Bumblebee, is a monitoring program in Hokkaido aimed at early identification of an invasive bumblebee species, *Bombus terrestris* (which is listed in the Invasive Alien Species Act of the Ministry of Environment), with the goal of preventing their invasion into native ecosystems. The second is Butterflies in Tokyo, which provides opportunities to appreciate and share experiences with wild nature by monitoring butterflies in a rapidly changing urban environment.

In addition to providing opportunities for environmental education and enjoyable outdoor activities, the programs strengthen public engagement and contribute to research. To provide evidence for this point, program organizers and researchers evaluated the scientific value of the data collected by two of the citizen science monitoring programs: Invasive Alien Bumblebee in Hokkaido and Butterflies in Tokyo. Evaluation focused particularly on accuracy of species identification and sufficiency of the data—that is whether the data cover a large enough area to be useful for scientific modeling or hypothesis testing. Program organizers attempted to improve the accuracy of species identifications by providing field manuals and an Internet-based learning service with experts available to help with proper identification.

Invasive Alien Bumblebee in Hokkaido—The target invasive species, *Bombus terrestris*, was first introduced into Japan from Europe in early 1990s as a commercial pollinator, and soon naturalized in northern Japan where it expanded its range across Hokkaido (Matsumura et al. 2004; Washitani 2004). The invasive bumblebee is highly competitive, and rapid declines in native bumblebees have been observed in areas where this species has become established (Inoue et al. 2008). In the monitoring program, volunteers catch the invader bumblebees they find and send data (including when, where, and how many bees were caught) via an online interface to the laboratory of conservation ecology in the University of Tokyo. In the early stages of the program, volunteers sent specimens to the lab to check the accuracy of identifications. Misidentification rates were very low, less than 1 %, probably because the color pattern of the bee species is distinctive compared to common native bumblebee species (Kadoya et al. 2009).

This citizen science monitoring program has played an important role in the management of the invasive bumblebee, both through capture and removal of individual bees (direct management) and by providing data to inform modeling of species range expansion. Through the monitoring program, 300,000 invasive bees were caught and removed from the wild. To inform models of range expansion, volunteers expanded their monitoring to include areas not yet invaded by the bees. These additional data allowed for successful observation of the species' rapid range expansion (Kadoya et al. 2009) and the development of models to forecast future range expansion (Kadoya and Washitani 2010).

Butterflies in Tokyo—Identification of butterflies is particularly difficult because of the large number of butterfly species. In this project volunteers submit butterfly photographs online along with their proposed species identifications. Experts check each photograph, and if necessary, images are checked by more than two experts to ensure correct identification. Then data are compiled into a project database, at which point volunteers can check their species identifications online. This learning process has proven to be effective. Each year the volunteers' ability to identify species correctly increases—i.e., a greater proportion of their identifications are correct as confirmed by experts.

Data collected from the program are also useful for hypothesis testing. More than 18,000 butterfly records over 4 years allowed researchers to test whether the abundance or commonness of butterfly species depends on the prevalence of host plants and length of reproductive cycles. Researchers found that the most commonly observed species relied on small weeds common in urban environments as host plants and also went through several reproductive cycles each year. For example, *Pseudozizeeria maha*, the most commonly observed species, relies on a host plant, *Oxalis corniculata*, very common in urban landscapes. Additionally, *P. maha* is known to reproduce 5–6 times annually (Washitani et al. 2013).

Researchers also tested whether range expansions of butterflies from southern areas are linked to warming in Tokyo caused by the heat island effect and global climate change. New citizen science monitoring, when compared with past butterfly records made by amateur naturalists, showed that all species new to Tokyo are from southern regions. In contrast, species that specialize on woodland and grassland communities have tended to disappear from Tokyo. These results suggest that warming temperatures and the loss of woodland and grassland communities are both contributing to shifts in the composition of butterfly species in Tokyo.

In conclusion, ‘‘big data’’ collected by a carefully designed citizen science monitoring program can be valuable for modeling and hypothesis testing in the field of spatial ecology, even for studies of insects, which tend to be more difficult to identify and attract less interest than other animal species, such as birds. Heavy investment in monitoring data quality could be reduced through automation if engineers interested in machine learning could work with experts to ‘teach’ computers to recognize species from images. Further collaborations between conservation scientists, ecologists, and data engineers promise to result in new ways to improve and expand these big-data citizen science efforts to provide important data for pressing conservation problems.

Overcoming barriers to participation: matching projects with volunteers

When planning a citizen science project, organizers must consider not only the field methods but also ways to recruit and retain volunteers with skills and interests that match the needs of the project. Barriers to volunteer participation in citizen science projects can vary and may include asking volunteers to submit data too frequently, in inconvenient locations, or using protocols that are too complex. Many techniques can help to overcome these barriers and attract appropriate audiences; techniques include implementing simple sampling methods, targeting audiences already interested in the activity, providing recognition for volunteers, and facilitating positive social interactions among participants. In this section we discuss examples of barriers to participation for two types of citizen science surveys: (1) one-time surveys that require relatively little skill and (2) one-time surveys that require more skill.

Examples of entry-level surveys include the Spring and Autumn Watch programs run by the Japan Bird Research Association (JBRA). In these surveys, volunteers record the first sighting or sound of breeding or wintering birds. The target species are easy for novice birdwatchers to identify, and the project interests many birdwatchers and nature-lovers; in 2013, 589 volunteers participated. Barriers to participation are low. Every year, JBRA notifies its members about the start of the Spring and Autumn Watch programs and announces the programs on the JBRA’s public website. Volunteers enter observations using an online map interface. Data from the project can be used to investigate variation in bird phenology and its relationship with climate (Ueta and Koyama 2014).

The Duck Sex Ratio Survey, also run by JBRA, has higher barriers to participation: it requires higher identification skill, is more time consuming for volunteers, and interests a narrower audience; 184 volunteers participated in 2014. Volunteers are asked to identify duck species and to count the numbers of male and female ducks. They submit their data through email and the resulting data show geographical and temporal changes in sex ratios of duck species.

Barriers to participation affect the recruitment strategies for both programs. In the relatively low-skill Spring and Autumn Watch, the pool of potential volunteers is large, so announcements are sent to both JBRA members and the general public. In contrast, the duck sex ratio survey requires skilled volunteers, more effort, and interests fewer people, so announcements are sent to the JBRA members and to volunteers already registered for duck surveys (i.e., those already interested in this type of monitoring). Survey coordinators also cultivate relationships with volunteers; volunteers investing greater effort and time expect more from the survey coordinators.

The spring and autumn watch and duck sex ratio surveys do not require volunteers to make repeated observations; volunteers can participate in one year, and different volunteers can participate in another year. Certain types of surveys, especially those requiring occupancy analysis, require volunteers to make observations repeatedly across months or years. These types of surveys present barriers to participation and require different solutions.

When the period of the survey or monitoring is long, coordinators must take steps to keep volunteers motivated (Theobald et al. 2015). Promptly reporting survey results, providing the right tools and clear protocols, and explicitly recognizing volunteers’ effort can help maintain volunteers’ interest and can acknowledge their contribution. Social bonds formed by participating in citizen science surveys or meetings can also contribute to maintaining volunteer participation in long-term surveys. Volunteer-based organizations usually regard social relationship as vital and provide opportunities for volunteers to meet each other (Krasny and Tidball 2012; Sakurai et al. 2015). Although many online citizen science projects provide guidance remotely, a few provide opportunities for online social interaction among participants or facilitate the organization of in-person gatherings or trainings. Positive social relationships are not only beneficial for individual citizen science projects, but can also contribute to growing an entire organization, such as JBRA. Ultimately, only organizations supported by many volunteers can sustainably implement good citizen science surveys, and the relationships developed and nurtured through long-term participation, whether in person or online, can be critical to maintaining and growing that volunteer community.

One-time or short-term citizen science surveys, like the spring and autumn watch and duck sex ratio surveys, can be excellent introductions to citizen science participation and can be used to recruit volunteers for longer-term participation in citizen science monitoring projects.

For all citizen science projects, though, coordinators must match the science needs of projects with the interests and skills of volunteers, while also providing adequate training if they want participants to develop skills necessary to contribute to more advanced projects.

Informing urban conservation: birds' use of urban gardens

The extent and quality of urban green areas in Japan and the biodiversity they support have declined since the 1960s as a result of rapid development and population growth (Kobori et al. 2014). There is currently interest in reversing this trend—for example, by improving the quality and quantity of small private green areas such as gardens, which comprise much of the urban ecological matrix and are important for maintaining biodiversity (Kobori et al. 2014; Sakurai et al. 2015). To inform urban greening efforts that aim to reduce the loss of biodiversity, studies must collect long-term and large-scale data from many urban areas. Citizen science is well suited for collecting these data (Dickinson and Bonney 2012). In particular, some studies have explored the types of animals or plants seen in private gardens and green areas (Nakao and Hattori 1999; Owen 2010); however, few studies have investigated the characteristics of gardens that are associated with use by particular species or overall support of biodiversity. In this section, we assess the results of the citizen science project, Garden Wild Life Watch, a nationwide web-based project investigating the relationships among birds observed in private gardens, traits of the gardens, and characteristics of the surrounding area.

Garden Wild Life Watch, organized by the center for ecological education, consists of three programs, wildlife watch for beginners, garden bird watch, and index of wildlife. Participants report observations of animals in private gardens during a four-month period, from May to August, each year. To investigate garden traits that were associated with the presence of birds, we analyzed observations of 15 species of birds made by 130 volunteers over four years, 2010 to 2013, as a part of Garden Bird Watch. Volunteers also reported characteristics of gardens and surrounding areas. We used a general linear model to quantify the relationship between the number of species of birds observed in gardens and various characteristics of gardens and surrounding areas (Table 1).

Tree sparrows (*Passer montanus*) were the species observed most frequently in private gardens (n = 122, 94 %). Brown-eared bulbuls (*Hypsipetes amaurotis*, n = 88, 68 %), eastern turtle doves (*Streptopelia orientalis*, n = 68, rate = 52 %), Japanese tits (*Parus minor*, n = 67, 52 %), and barn swallows (*Hirundo rastica*, n = 56, 43 %) were also abundant in gardens (Fig. 1). The number of species of birds observed increased significantly as the size of garden areas increased—i.e., bigger gardens hosted more species. Gardens with clumps of trees and hedges of deciduous trees had significantly more bird species than gardens with isolated trees or no trees at all. Gardens with parks and forests nearby also tended to have more birds (Table 1).

Although we did not monitor survival and reproduction, many of the species observed in private gardens can persist in areas with little greenery; they do not necessarily require green areas. Volunteers rarely observed forest and grove-loving species, such as bull-headed shrikes and varied tits, suggesting that urban green spaces are not yet adequate in quality or extent for these species. When designing new green spaces and improving existing spaces, results from the Garden Bird Watch suggest that planting trees in clumps or hedges would help to maximize the diversity of bird species served. Further research, including monitoring of reproductive success, could further help to assess the value of enhanced gardens for bird populations.

Without volunteer participation, this project would have been prohibitively expensive. It is also difficult for researchers to study private gardens without engaging householders. Engaging volunteers to contribute to science by measuring the value of their gardens to biodiversity can help to engage householders to take action to improve their gardens. We believe that this project reflects the larger role that citizen science projects can play in biodiversity and restoration research.

Adaptive management of a threatened bird species

Citizen science can contribute to conservation of endangered species by developing and implementing conservation programs for target species, and by informing conservation practices and policies of government agencies, NGOs, and other relevant organizations. In recent years, many NGOs have been applying

Table 1 Relationship between number of bird species and characteristics of private gardens observed as a part of Garden Bird Watch, a project of Garden Wild Life Watch

Environmental factors of the garden		Estimate	SE	LR.Chisq	*P* value
Area		0.001	0.001	8.028	0.005
Components	Clamp of trees	0.228	0.113	4.115	0.043
Green area near the garden	Park	0.240	0.110	4.793	0.029
	Forest	0.277	0.124	5.019	0.025
Border	Hedge of deciduous trees	0.345	0.149	5.216	0.022

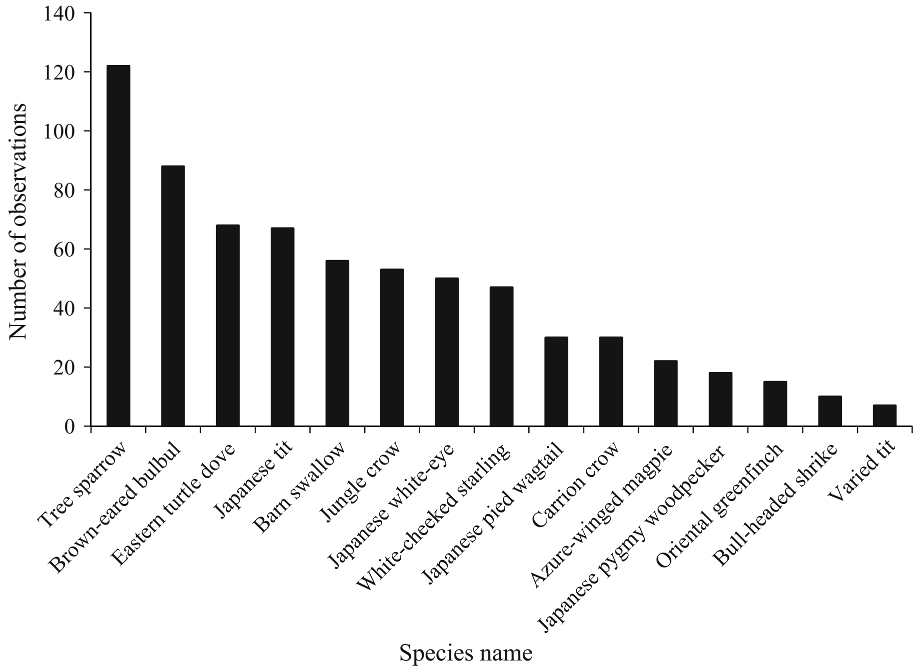

Fig. 1 Number of observations in birds in Garden Bird Watch during the years 2010–2013. Tree sparrow (*Passer montanus*), Brown-eared bulbul (*Hypsipetes amaurotis*), Eastern turtle dove (*Streptopelia orientalis*), Japanese tit (*Parus minor*), Barn swallow (*Hirundo rustica*), Jungle crow (*Corvus macrorhynchos*), Japanese white-eye (*Zosterops japonicus*), White-cheeked starling (*Sturnus cineraceus*), Japanese pied wagtail (*Motacilla alba lugens*), Carrion crow (*Corvus corone*), Azure-winged magpie (*Cyanopica cyana*), Japanese pygmy woodpecker (*Dendrocopos kizuki*), Oriental greenfinch (*Carduelis sinica*), Bull-headed shrike (*Lanius bucephalus*), Varied tit (*Parus varius*)

citizen science to achieve their conservation goals, including the protection of endangered species. Here, we show the activities of a Japanese NGO, little tern project, as an example of this type of project.

The little tern project was established for conservation of little terns, *Sterna albifrons*, which are threatened in Japan. Little terns are summer migrants and they form breeding colonies of ten to several thousands of individuals (del Hoyo et al. 1996). In the absence of human disturbance they prefer to nest on bare ground on sandy coasts or graveled riversides (del Hoyo et al. 1996); however, in Japan these sites have been destroyed by human activities. As a result of this habitat loss, breeding populations of little terns have declined in abundance, and the little tern is now listed as vulnerable on the Japanese Red List (MOE 2014). Without their native habitat, little terns now nest on artificial bare ground on developed lands, airports, car parks, and other areas. For example, a colony has formed on the rooftop of the Morigasaki water reclamation center, in Ota City, Tokyo (Fujita et al. 2009).

Since this rooftop breeding colony was discovered in 2001, the Little Tern Project has constructed and managed the artificial breeding habitat on the rooftop with help of the Ota City Office and the Sewer commission of the Tokyo metropolitan government (LTP 2011). Volunteers maintain the colony site, remove plants to maintain bare ground, use decoys and calls to attract little terns, monitor breeding, spread sand and stones on the rooftop to prevent eggs from rolling in the wind, and erect shelters to protect eggs and nestlings from predators. For the 10 years from 2001 to 2010, approximately 5500 nests have been found and over 3000 nestlings have been hatched at this colony-site (LTP 2011). The results of the project's work have been published in international scientific journals (Fujita et al. 2009) and presented at academic meetings.

The little tern project's citizen science monitoring has contributed to adaptive management of little terns. Monitoring data suggested that little terns preferred to nest at sites with a white-colored surface substrate. To investigate further, little tern project volunteers and scientists worked together to conduct an experiment to test this observation; specifically, they spread white shell pieces on some of the nest sites. Sites with white-colored substrate attracted a significantly higher nest density than did unchanged rooftop (Kitamura et al. in preparation). As a result of this experiment, the Little Tern Project now treats the entire colony site with white surface substrate.

The conservation activities of the Little Tern Project have also received support from the local government in Ota City and have informed local policy. Little tern conservation and citizen science were, for example, included in the basic environmental plan of Ota City (Ota City 2012). For one of the six fundamental objectives of the plan, "establishing a society that coexists with nature," the rooftop colony was identified as an important habitat for the threatened species and designated as a core area in Ota City's ecological network. Data and knowledge related to little terns living in this area are treated as an indicator for achieving this fundamental objective. Governments may be particularly disposed to work with conservation programs that use citizen science because they involve citizens (and often other key stakeholders) while also being based on scientific methods and evidence.

Citizen science and conservation: a perspective from the United Kingdom

The use of data acquired by citizen science is particularly well integrated into formal biodiversity monitoring, research, and policy-making processes in the United Kingdom (Greenwood 2012), probably more thoroughly and for longer than in Japan. Thus, it is useful to review the approaches, outcomes, and lessons learned from conservation applications of citizen science in the United Kingdom. Some of these programs and approaches could be repeated in Japan—some already are being done or could be done with existing data—while others would require modifications to be applied in Japan.

Perhaps the best example of the application of citizen science for conservation in the United Kingdom relates to birds (Greenwood 2012). For example, data based on the Breeding Bird Survey, Common Bird Census and the Nest Record Scheme, together with other volunteer-based surveys, form the basis for assessing the population status of common breeding birds in the United Kingdom. For each of the 120 species, annual reports provide the latest information on temporal trends in population size, breeding performance and survival rates (Baillie et al. 2014). Such species-level information is then used to identify species of conservation concern (Eaton et al. 2009) and to develop wild bird indicators (DEFRA 2014), which summarize composite population trends of birds as measures of environmental health (Gregory and van Strien 2010). Most notably, these efforts have led to the finding of severe population declines and range contractions among farmland birds since the mid-1970s in the United Kingdom (Fuller et al. 1995; Siriwardena et al. 1998), which has stimulated huge growth in research on the impact of agricultural intensification on biodiversity as well as the effectiveness of potential interventions (for birds, see Wilson et al. 2009). As a consequence in 2002, the UK government adopted a public service agreement target to reverse the long-term decline in farmland birds by 2020, and its progress is measured annually against the indicators developed for farmland birds (Gregory and van Strien 2010).

Similarly, in Japan citizen science data from programs such as the National Surveys on the Natural Environment and "Monitoring Sites 1000" project have been used extensively in national-scale studies on bird conservation. For example, citizen science data have been used to assess long-term range contractions (Amano and Yamaura 2007; Yamaura et al. 2009) and population declines (Amano et al. 2010b; Kasahara and Koyama 2010), to understand the role of landscape heterogeneity in explaining spatial distribution (Katayama et al. 2014), and to identify priority areas for conservation (Naoe et al. 2015).

Data based on citizen science projects have also shed light on how species are responding to and being influenced by recent climate change. Many of the first studies showing the evidence of climate change impacts on species, such as poleward range shifts in butterflies (Parmesan et al. 1999; Warren et al. 2001), earlier laying in bird species (Crick et al. 1997) and earlier flowering in plants (Sparks and Carey 1995), have based their findings on long-term data sets derived from citizen science projects in the United Kingdom. Citizen science often provides extensive data on large-scale ecological phenomena for a number of species and these data enable us to describe detailed responses by species to climate change. For instance, Amano et al. (2010a) used 395,466 observation records for 405 plant species from 1753, supplied by the UK Phenology Network, and quantified 250-year changes in first flowering dates in British plant communities. Amano et al. (2014) further combined the outputs of this study with another citizen science data set on changes in spatial distribution of plant species (Botanical Society of Britain and Ireland 2008), and revealed a link between the level of phenological changes and the degree of northward range shifts; species that failed to track an increasing temperature by advancing flowering dates showed greater northward range shifts. These studies would have been impossible without both of the above citizen science data sets, which together cover different types of ecological phenomena (changes in phenology and spatial distribution over the last few decades, in this case) for hundreds of species.

Citizen science has also shown a great potential to raise public awareness about the changing status of biodiversity by involving a large number of citizens in observing nature. One of the United Kingdom's biggest citizen science projects, the Big Garden Birdwatch, led by the Royal Society for the Protection of Birds, involves nearly half a million citizens every year in bird count surveys in gardens during just one weekend of January (http://www.rspb.org.uk/discoverandenjoynature/discoverandlearn/birdwatch/). Results from the project attract significant media interest. The survey method for this project is easy enough for anyone, including children, to participate without training, providing excellent opportunities to engage people with nature and to introduce them to citizen science. The same is true for the Nature's Calendar project. This project has been supported by United Kingdom's popular television programmes, BBC Springwatch and Autumnwatch, since 2004 (Kate Lewthwaite, personal communication). The coverage has helped to attract more people and has boosted the number of records being submitted (see figure S1B in Amano et al. 2010a). The project now serves as a basis for informing people of how climate change is affecting species—it produces live maps online showing submitted observations of phenological events and also produces annual reports (Woodland Trust 2014).

Rapid advances in computer and communication technologies are also transforming the way citizen science works in the United Kingdom. One such example is iSpot, which launched in 2009 (Woods and Scanlon 2012). iSpot provides a web-based system where participants post photographs of animals and plants. The iSpot community, in turn, helps to identify them reliably (Scanlon et al. 2014). A key feature of iSpot is its sophisticated means of assessing the credibility of those who identify species. Specifically, the system assesses their previous activities and accuracy of identification (Clow and Makriyannis 2011). The iSpot community now has over 31,000 registered users and 200,000 observations (Scanlon et al. 2014). Over 80 % of observations are identified within 24 h after they are posted (Snaddon et al. 2013). This project thus represents an excellent opportunity to nurture and inspire a new generation of naturalists by enabling people to learn more about their local environment efficiently.

Citizen science as a human computation system: a perspective from the United States

The United States has a history of engagement in citizen science, especially with birds. The Internet age, however, has contributed to major growth in use of citizen science methodologies. In part, this was due to the development of Internet-based Web applications, such as those pioneered at the Cornell Lab of Ornithology and National Audubon Society (Kelling et al. 2004). Today over 300,000 people participate in the six citizen science projects (Great Backyard Bird Count, eBird, NestWatch, FeederWatch, YardMap, and Celebrate Urban Birds) run by the Lab (some of these six are co-led by Bird Studies Canada or the National Audubon Society). Citizen science, when done at these scales, is a form of crowdsourcing, with a central organization providing protocols, learning content, and Web architectures that allow contributors to collect, enter, and see their data within the context of larger temporal and geographic patterns generated by the collective. This is best seen in eBird, which allows participants to count birds anywhere in the world, enter the data online, and visualize information by species, time period, and locale. This feedback allows participants to see what they and others have seen, as well as what they might be able to see at a particular place or time of year; the project's success has largely been due to emphasis on building in features known to be attractive to birdwatchers (bird hobbyists).

Citizen science architectures, when built in this way, not only crowdsource biodiversity data collection, they represent a "virtuous circle" in which the data collected enhance the experiences of participants by providing information that allows them to see and enjoy more birds. The resulting data set is longitudinal and allows researchers to account for changes in the skill levels of participants and to use this information to develop machine learning algorithms that help build better models of bird distributions (Fink et al. 2014). Because eBird was built with the interests of birders in mind, it was able to garner a loyal following, grow, and encourage the most engaged participants to follow more rigorous and standardized protocols (Sullivan et al. 2014). By helping a robust and growing community of birders parse their data in ways that they enjoy (i.e. seeing their life lists, county lists, monthly lists) and integrating social tools that allow people to build reputations, eBird became a community. Today an online leader board allows eBird participants to compete in their favorite sport (birding) and map features provide social visibility around bird sightings (it is possible to zoom into the map and see who reported what and where). This social awareness allowed eBird to build the largest global data set on bird occupancy and abundance.

In mining information on the observers and their observations, eBird has become a human computation system that can generate dynamic maps and provide new insights into which geographic areas may be most important for a particular bird species. The model results are fine grained enough to determine that a particular species may in fact be two subspecies that breed in allopatry. These models can provide peeks at previously undetected macro-scale patterns and can lead to new insights that can be followed with more detailed studies on the ground.

New technologies play a major role in crowdsourcing models of citizen science. These include apps for smart phones that facilitate species identification and data entry as well as development of automated filters that request verification from participants when data are geographically or numerically outside the expected range. By producing automated emails to participants these filtering systems can confirm rare or out-of-range sightings, while records lacking such confirmation are flagged in the database. Filtering, in combination with robust informatics approaches and data mining efforts, is often necessary to make large and somewhat "messy" data useful for scientific research, which even then requires innovation in data mining based on marrying statistics with computer science (Fink et al. 2014).

Citizen science has led to a range of ecological studies tracking the movement, correlates, and impacts of introduced bird species (e.g., the Eurasian Collared Dove) (Bonter et al. 2010), tracking the impact of recent introductions of non-native insects on native bird populations (e.g. the Emerald ash borer) (Koenig et al. 2013), examining the correlates of eruptions of boreal birds (Koenig and Knops 2001), testing hypotheses about latitudinal variation in hatching success (Cooper et al. 2005), and documenting advancing lay dates (Dunn and Winkler 1999), extinctions, and shifting distributions of birds as a result of multiple stressors, including climate change and habitat loss (Pimm et al. 2014). Measures of probability of occurrence gleaned from eBird data have been used in the near-annual State of the Birds Report, a collaborative effort between the US government and conservation NGOs organized to provide the US Department of the Interior with information to help identify the relative conservation importance of different federally and state-managed lands as well as private lands (North American Bird Conservation Initiative 2014).

The Cornell Lab of Ornithology's newest citizen science project, YardMap, combines bird monitoring with data on human practices on privately held lands to study the effects of restorative acts in residential landscapes across the urban-to-rural gradient. Briefly, people mark off a site, then map the site characteristics (e.g., trees, shrubs, lawn, feeders, etc.), and indicate which practices they engage in (e.g., using pesticides and fertilizers or not, keeping cats out of the wild, planting native plants). The project suggests a broad palette of restoration activities and practices that participants can adopt, and many use eBird to monitor birds on their sites. Today, with nearly 16,000 maps, YardMap is becoming the largest network of on-the-ground, conservation practitioners in the world. Its research goal is to test socially explicit hypotheses describing the kinds of interventions that increase the range of conservation efforts that participants engage in (Dickinson and Crain 2014; Dickinson et al. 2013), while also exploring the complex relationship between social interaction, interactions with the YardMap app, and learning. In terms of ecology, YardMap (much like Japan's Garden Wild Life Watch mentioned earlier) can help address questions regarding which combinations practices have positive impacts on wildlife, and under what conditions, densities, and landscape regimes, backyards can be managed to become habitats for wildlife. Ultimately, we expect YardMap to enable the study of various feedbacks among learning, behavior, and ecological outcomes within a complex, but tractable, socio-ecological system (Crain et al. 2014).

Project sustainability and evaluation

Nearly all projects benefit from built-in mechanisms for evaluation and adaptive project management, but citizen science and its complex and highly interdisciplinary nature make evaluation and adaptive project management particularly important. Here we describe methods for and benefits of evaluating citizen science, discuss the recruitment and retention of volunteers, and provide insights from a survey of leading citizen science NGOs in Japan.

Evaluation and human dimensions research to increase project effectiveness

Many citizen science projects focus on ecology and conservation and were started by natural scientists—e.g., ecologists and biologists—with minimal involvement of social scientists (Romolini et al. 2012). This is understandable as many conservation-related activities such as observing nature, monitoring bird populations, and censusing species that inhabit certain areas, are the domains of natural scientists, not social scientists. However, the skills of social scientists are critical for motivating and educating participants, transferring research skills, effectively communicating research results and other project outcomes to the public, and evaluating project impacts (Dickinson and Bonney 2012). These topics make up the human dimensions of citizen science projects. In this section, we discuss how human dimensions research and social science approaches are important to the effective implementation of ecological and conservation citizen science projects. In particular, we focus on four tools: logic models, front-end evaluation, formative evaluation, and summative evaluation.

Logic models A logic model is a diagram that shows resources invested in the program, contents of activities, and intended goals or outcomes. The specific factors included in logic models can vary, but they all aim to achieve the same goal of clearly outlining the roadmap of the program to get from inputs to desired outcomes. Here we show elements of logic models as recommended by Ernst et al. (2009) and an example logic model (Table 2), but see Phillips et al. (2014) and Kellogg Foundation (2004) for templates with other elements:

1. Situation: needs, setting, or context in which program is developed,
2. Inputs: resources needed to accomplish the project's outcome,
3. Outputs: activities, events, or services provided through the project,
4. Outcomes: changes expected, categorized as learning (immediate changes), actions (changes in behavior), and impacts (long term changes in environmental and social conditions)
5. Assumptions: principles that guide the project.

Front-end evaluation Human dimensions research prior to implementing citizen science projects, called front-end evaluation or needs assessment, can help project organizers understand the needs of potential participants and assess the feasibility of running the program (Ernst et al. 2009; Phillips et al. 2014). For example, if an organization is planning a new citizen science project to study dragonflies in a certain town, a survey of residents could reveal important factors—such as the number of residents interested in participating; characteristics of those potential participants; and times, places, and activities that would attract the most people or that would attract specific target audiences—that would be very helpful in guiding the design and development of a project (more topics listed in Table 3). Interviewing representative samples of target audiences or convening focus group discussions (usually 8–12 participants) can reveal useful information about the

Table 2 Sample of a logic model based on results of front-end evaluation (needs assessment) before the program started. Modified from Sakurai et al. (2012)

Inputs	Outputs		Outcomes		
What we invest	Activities: what we provide	Participation: who we reach	Short term: learning (one year after the program started)	Medium term: action (three years after the program started)	Long term: impact (ten years after the program started)
Staff: prefectural government/University/ City Government	Site visits to damage sites in the region	30 residents	70 % of local residents will foster motivation to engage in interventions to prevent damage by boars	90 % of local residents engage in interventions to prevent damage by wildlife	Participatory damage prevention interventions conducted by residents will create local region in which wildlife damage rarely occur
Money: budget of prefectural government (transportation fees of lecturers)	Seminars to learn how to prevent damage by boars	20 residents	Half of local residents know how to prevent damage by boars	Local residents will have higher awareness and knowledge regarding wildlife issues than residents in surrounding regions	
	Clearing brush around residential area	30 residents	Local residents will answer 70 % of questions regarding interventions to prevent damage by boars correctly		
	Seminar to learn wildlife issues and interventions to prevent damage	20 residents			

Situation: increase of agricultural damage by wildlife/depopulation and aging of local community
Assumptions: having seminars and site visits to damage sites will increase residents' awareness and knowledge of, and willingness to prevent wildlife damage

Table 3 Example questions explored during front-end, formative, and summative evaluations

	Front-end evaluation	Formative evaluation	Summative evaluation
Items	Who is the appropriate target audience of the program?	How well do activities educate participants?	Did participants develop skills and interests for conducting citizen science activities?
	What are characteristics and needs of target audience?	Is the information provided in activities accurate and balanced?	Did participants' knowledge regarding local nature and dragonflies increased after series of activities?
	What are the appropriate activities that would attract local residents?	What are the reaction of participants?	Did participants change their behaviors after activities?
	What are potential barriers to the success of program?	Was expected number of participants showed up in activities?	Did local residents' awareness of the program increase?

needs, interests, and motivations of potential participants. With insights from front-end evaluations, citizen science organizers can establish realistic objectives and improve the design of their projects to achieve specific goals.

Formative evaluation Formative evaluation is used to guide program improvement and is usually conducted in the early stages of a project to see whether it is generating the intended outcomes. This evaluation can include monitoring of many factors, including how activities are conducted (e.g., number of participants, materials used for recruiting participants, and number of activities implemented) and how satisfied participants are. Potential questions addressed by formative evaluation are shown in Table 3. Formative evaluation can reveal whether projects are achieving the intended outputs and short-term outcomes (as described in project logic models) and can be used to identify areas of success and areas for improvement.

Summative evaluation—In the later stages of projects, organizations must understand whether their projects achieved their intended goals or impacts (Table 3). Summative evaluations reveal this type of information by assessing changes in participants' knowledge, attitudes, and behaviors after a reasonable period of time (e.g., 2–3 years) (Ernst et al. 2009; Phillips et al. 2014). Results from summative evaluations can inform decisions on whether citizen science programs should continue as is, be revised and re-evaluated, or be discontinued. In terms of logic models, summative evaluations can reveal mid-term and long-term outcomes. Ideally, these tools of human dimensions research should be used throughout the development of a citizen science project. By monitoring, communicating, and responding to findings from evaluation research, project leaders can substantially enhance the significance of citizen science projects for conservation, education, and research.

Recruiting and retaining volunteers

Strategies for attracting, sustaining, and growing the numbers of participants in citizen science projects, and for incentivizing high quality contributions, are critical to the success of citizen science projects; however, successful strategies are not always intuitive and are receiving increasing attention from researchers, including work well beyond project evaluations (Easley and Ghosh 2013; Ghosh and McAfee 2011). The first challenge is attracting people to participate in a project, which requires communication. These efforts can include reaching out through media (e.g., radio, television, newsletters, and print media), launching competitions, developing strategic partnerships, recruiting corporate sponsorships or partnerships (e.g., television stations, field equipment manufacturers, or big data companies), or asking participants to help recruit and publicize (e.g., by writing articles for local newspapers) (Chu et al. 2012).

The second challenge—making a project "sticky" enough to elicit and sustain significant effort over the long term—is even more difficult to solve. Participation in citizen science projects can often be described by the "Zipf curve," in which a small share of participants contribute most of the data and many contribute very little (Zipf 1949). Highly active participants may expect a lot of feedback or reward for their contributions; less active participants may turn over frequently, as described for the Spring and Autumn Watch programs run by the Japan Bird Research Association mentioned earlier. Project FeederWatch, however, provides a counterintuitive example; participants make field observations on two consecutive half-days and repeat these observations every 7–10 days between October and May. FeederWatch participants also pay an annual fee that supports the project (Bonter 2012). The project retains 70 % of participants annually and some participants have stayed with project since it began in 1987. It is clear that identity and motivation are crucial to maintaining committed volunteers, but it is much less clear just how projects can best cultivate that identity and motivation of their participants; future research in this area (and more rigorous evaluations of individual projects) is badly needed.

Challenges identified through interviews with NGOs

In Japan, conservation NGOs, such as The Nature Conservation Society of Japan (NACS-J), host nation-wide citizen science projects—e.g., citizen-based monitoring of Satoyama, a rural landscape of Japan (Kobori and Primack 2003)—in which residents monitor biodiversity of local environments (NACS-J 2015). Similar citizen science projects are conducted across Japan by NGOs, local governments, and residential associations; however, no one has summarized all of those activities, attempted to assess their effects, or identified their challenges (Sakurai et al. 2014). One of the few studies that reviewed citizen science activities across Japan found that one of the biggest challenges facing most citizen science projects and organizations was a lack of young volunteers and the loss of older volunteers as they age (NACS-J 2013). In this section, we examine the impacts of and challenges facing three organizations that implement nation-wide citizen science projects, as determined by interviews with personnel from each organization. Three organizations were NACS-J, the Center for Ecological Education, and the Japan Bird Research Association. The results of the interviews are summarized in Table 4.

The interviews indicate that Japanese conservation organizations and citizen science projects are run with limited numbers of staff (Sakurai et al. 2014). For example, the NACS-Japan has 28 staff members, only a few of whom are involved in running the citizen science projects. As a point of comparison, the Cornell Lab of Ornithology, which is a leader in citizen science and runs several nation-wide and global citizen science projects, has more than 250 staff and scientists, although most of their individual citizen science projects, such as NestWatch and FeederWatch, have few dedicated staff (1–4 staff members per project). Lack of staff is often associated with lack of funding, which is another common challenge for NGOs in Japan and elsewhere. Interviewees indicated that support from the Japanese government, companies, and citizens will be important for the NGOs to continue or expand their citizen science activities.

The lack of young participants in citizen science projects and difficulty of recruiting them was also mentioned by interviewees from two organizations. To foster the participation of younger people, who may be busy with school or raising families, citizen science activities must meet their needs and pique their interest. For example, citizen science organizations might collaborate with universities so that students can participate in citizen science projects as part of their coursework. Additionally, studies (Imai et al. 2014; Sakurai et al. 2015) have found that citizen science projects in Japan must consider cultural norms that may differ from Western cultural norms—e.g., a sense of collective responsibility is common in East Asian cultures whereas Western cultures generally place greater emphasis on individual identity and responsibility—when designing recruitment and retention strategies for citizen science projects (e.g., Krasny and Tidball 2012; Svendsen and Campbell 2008). Overcoming the challenges of attracting large numbers of participants and understanding the role of culture in participation in citizen science requires further research and collaboration among many organizations and individuals.

Table 4 Summary of results of interviews with personnel leading citizen science projects in Japan. NACS-J represents the Nature Conservation Society of Japan. Modified from Sakurai et al. (2014)

Name of organizations	The nature conservation Society of Japan (NACS-J)	Center for ecological education	Bird research
Name of projects*	Shizenshirabe (nature study)	Garden Wild Life Watch	Birdwatching at terrace
Characteristics of organizations/activities	One of the biggest nature conservation organizations in Japan/Nation wide network	Activities were designed based on British citizen science project	Staff are researchers and have high IT skills
Contents of activities	Sending information of butterflies observed through email or mail	Report wildlife observed in gardens	Report number of birds seen from terrace or windows
Number of staff	28	Full-time: 6, part-time: 3	6
Participants	Citizen: majority is more than 40 years old	Most of participants are members of Sekisui House (homebuilding company)	Citizen: majority is 40 and 50 s
Way to recruit participants	Fliers, advertisement in newspaper	Distribute information on web-page and mailing list	Advertising through web-page, emails, magazines and books
Impacts of programs	Foster citizen's understanding of nature conservation	Participants understand wildlife in gardens and raise awareness for conservation	Collecting broad scale data of bird population/increase of people who get interested in activities
How results are used/presented	Books, web-pages, newspaper, symposiums	Newspaper	Feedback to participants
Barriers for continuing the projects	Lack of participants of next generation (successors)	Lack of enough staff to increase communication with participants/maintain quality of data applicable for scientific research	Lack of young participants/lack of trust on data citizen collected by government

* Although NACS-J and Bird Research implement various citizen science projects, in this study, we focused on one project for each organiztion

Conclusion and future perspectives

The Web has greatly altered our ability to gather participants, deliver content, collect data, and provide opportunities for interactions with and among participants. Keeping up with advances on the Web presents a major challenge spurring continued innovation and requiring collaborations with the fields of machine learning (artificial intelligence), human computation, and social computing. These are exciting areas of research in their own right and these cross-disciplinary connections will be vital to taking full advantage of advancing mobile technologies, sensors, and human data collection to study coupled human and natural systems. Electronics are inevitably involved in the coupled systems of today and working to develop and test new design principles will be vital to maintaining a robust collection of ecological data for both local and macro-ecology studies in coupled systems of the future.

Although Web-based citizen science is remarkably well suited to questions in spatial and macro-ecology, the field as a whole will benefit from moving beyond pattern detection and into the realm of testing important

Table 5 Websites of select organizations and programs described in this paper

Organization or program	URL
International	
Citizen Science Association	citizenscienceassociation.org
Japan	
Center for Ecological Education	www.wildlife.ne.jp/
Japan Bird Research Association	www.bird-research.jp
Little Tern Project	www.littletern.net/
Monitoring Sites 1000	www.nacsj.or.jp/project/moni1000/about.html
The Nature Conservation Society of Japan	www.nacsj.or.jp
Sea Turtle Association of Japan	www.umigame.org
Wild Bird Society of Japan	www.wbsj.org
United Kingdom	
British trust for ornithology	www.bto.org
iSpot	www.ispotnature.org
Nature's calendar	www.naturescalendar.org.uk
Royal Society for the protection of birds	www.rspb.org.uk
UK butterfly monitoring scheme	www.ukbms.org
United States (and Canada)	
Bird Studies Canada	www.birdscanada.org
Christmas Bird Count	www.audubon.org/conservation/science/christmas-bird-count
Cornell Lab of Ornithology	www.birds.cornell.edu
CitizenScience.org	citizenscience.org
CitSci.org	citsci.org
DataONE	www.dataone.org
eBird	ebird.org
FeederWatch	feederwatch.org
National Audubon society	www.audubon.org
National weather service cooperative observer program	www.nws.noaa.gov/om/coop
USA National Phenology Network	www.usanpn.org

ecological hypotheses. Although not unique, we have seen an excellent example of this in Japan (Washitani 2004) and we expect to see more such examples into the future. Citizen science can be designed to support the critical scientific loop among data collection, results, and management, and is particularly well suited to the adaptive management paradigm (Cooper et al. 2007). This is a transition we expect to see as citizen science projects mature. Once a faithful and skilled participant base is committed to citizen science, it should be possible to increase investment in doing experimental work to strengthen the inference that can be gleaned from citizen science research. A future in which national experiments are launched to address specific environmental or biodiversity problems would certainly bode well for engaging the public in the problems of the day, such as pollinator declines, control of invasive species (Washitani 2004), and climate change. These impacts depend largely on the proliferation of project designs that integrate tools that help ensure data validity (Amano et al. 2014) and also adapt to the needs and desires of the intended audience.

The rapid growth of citizen science projects in the world is inspiring. More than 500 English-language citizen science projects on biodiversity research are known. With so many projects, some may appear (or may actually be) redundant in the questions they address and the data they collect; the number of options and the apparent redundancy may confuse potential participants. Recently, efforts have been made to create databases, such as can be found at CitizenScience.org and SciStarter.com, to help project organizers avoid redundancy and enable participants to find projects that match their interests. Efforts also exist, especially in the United Kingdom and United States, to integrate small local projects into larger scale or nation-wide projects to increase the value, utility, and accessibility of data. The USA National Phenology Network and it's citizen science project, Nature's Notebook, is one example of a national-level project comprised of many local and regional efforts (Rosemartin et al. 2014). Expanding citizen science projects internationally through collaboration—such as is happening through projects like eBird and iSpot, and through the newly formed Citizen Science Association—may help to further reduce redundancy and improve utility to science and conservation. Table 5 shows the website of Citizen Science Association as well as websites of select organizations and programs described in this paper.

Recommendations for future work

Increase coordination among existing citizen science projects and enhance the development of services, such as CitizenScience.org and SciStarter.com, that help connect citizen science project organizers and volunteers with projects related to their interests. This work will be key to making the most efficient use of volunteer efforts, meeting their needs and interests, and sustaining their involvement.

Develop cyberinfrastructure and other resources to support the long-term management and sharing of citizen science data, metadata, and related digital media. Cyberinfrastructure is a major hurdle to many citizen science projects in large part because it can require a large team of programmers, designers, and others to implement well. Platforms like CitSci.org and DataONE.org are taking important steps toward this, but much more work is needed. Museums may be valuable contributors to development of these resources given their expertise with curation, communication, and providing access to resources.

Increase social science research (including project evaluations) exploring how and why people participate in citizen science, what they gain, and how best to match people with projects that interest them. How does the importance of learning compare to the role of identity and agency or civic responsibility? How can we best recruit, maintain, and grow citizen science participation so that it benefits science and participants?

Explore questions of privacy, credit, and intellectual property regarding volunteer contributions to citizen science. To what extent should citizen scientists be considered helpers versus collaborators with full rights to co-authorship on a project? How should citizen science projects serve the needs and interests of diverse participants, some of whom will want more involvement, credit, and ownership, and others of whom will want more privacy?

Increase the use of citizen science in ecology and conservation, including by expanding its use in experimentally testing hypotheses. There are many pressing questions that citizen science can help address, many of which are difficult or impossible to address otherwise. As we gain understanding of how to implement citizen science well, we should further use this important tool to advance science and learning simultaneously.

Conclusion

Citizen science can contribute to a paradigm shift taking place in science, wherein scientists and the public work together to investigate and address emergent environmental issues. Quality collaborations among scientists, project organizers, government agencies, and the public are still relatively rare, but are necessary to make full use of citizen science to support community resilience and policy decisions (Enquist et al. 2014; McKinley et al. 2015). By generating data unachievable otherwise and by engaging the public in authentic science, we can increase our ability to understand and respond to environmental challenges and stem the continued degradation of ecosystems in Japan and worldwide.

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