Forum

A new dawn for citizen science

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A citizen scientist is a volunteer who collects and/or processes data as part of a scientific enquiry. Projects that involve citizen scientists are burgeoning, particularly in ecology and the environmental sciences, although the roots of citizen science go back to the very beginnings of modern science itself.

The origins of citizen science

Two centuries ago, almost all scientists made their living in some other profession. Benjamin Franklin (1706–1790) was a printer, diplomat and politician; Charles Darwin (1809–1888) sailed on the *Beagle* as an unpaid companion to Captain Robert FitzRoy, not as a professional naturalist. The rise of science as a paid profession is a relatively recent phenomenon, dating from the later part of the 19th century. However, citizen scientists have never disappeared, particularly in sciences such as archaeology, astronomy and natural history, where skill in observation can be more important than expensive equipment. Today, most citizen scientists work with professional counterparts on projects that have been specifically designed or adapted to give amateurs a role, either for the educational benefit of the volunteers themselves or for the benefit of the project. The best examples benefit both.

The characteristic that clearly differentiates modern citizen science from its historical form is that it is now an activity that is potentially available to all, not just a privileged few. The earliest citizen science project of this type is probably the Christmas Bird Count that has been run by the National Audubon Society in the USA every year since 1900. In the most recent count, tens of thousands of observers counted a total of over 63 million birds (see Box 1). In the UK, the British Trust for Ornithology was founded in 1932 with the express purpose of harnessing the efforts of amateur birdwatchers for the benefit of science and nature conservation. These data now contribute to the database held by the National Biodiversity Network that contains over 31 million records of over 27 000 UK species of animals and plants, the majority collected by amateur naturalists. Similar schemes exist in many other countries where citizen scientists are the bedrock of biological recording.

Citizen science now

Just how significant citizen science has become in ecology was made abundantly clear at the annual meeting of the Ecological Society of America held in Milwaukee, Wisconsin in 2008 where there were over 60 papers that mentioned the subject in their abstract and several sessions [1] explicitly devoted to citizen science or allied themes. Citizen scientists now participate in projects on climate change, invasive species, conservation biology, ecological restoration, water quality monitoring, population ecology and monitoring of all kinds. Three factors seem to be responsible for this great explosion of activity.

First is the existence of easily available technical tools for disseminating information about projects and gathering data from the public. Of course the internet is the most significant development, but mobile computing is playing a part too and will probably grow with the spread of smart phones. A PDA-based system called CyberTracker, originally developed and used in Southern Africa to enable nonliterate trackers belonging to traditional Khoi-San communities to record animal signs, is now used on five continents by both professionals and volunteers. It has been used in various BioBlitz projects [2], where experts and the general public collaborate to map and inventory as many species as they can in one location over 1 or 2 days of intense activity.

The usability of software is vitally important in helping volunteers take advantage of the information that is now potentially available to them. Robert D. Stevenson and colleagues at the University of Massachusetts have developed open source software tools that enable nonexperts to produce customised field guides [3], although these are not yet available for mobile devices. Customisation of field guides, so that they contain only the species local to the area where they will be used, makes species identification much easier for the beginner who might be confused by the large number of similar-looking species often presented in identification books that cover a whole region. Software tools do have their limitations, though, the chief ones being accessibility and keeping up with rapid changes in technology. Dead-tree format (paper) is still the most accessible and future-proof publication medium, although it has high origination costs. However, the economics of book publishing are also being changed by new technology. Print-on-demand services are increasingly affordable, and in the near future it should be possible to print identification books in localised editions using the customised content of an electronic field guide.

A second factor driving the growth of citizen science is the increasing realisation among professional scientists that the public represent a free source of labour, skills, computational power and even finance [4]. Earthwatch is a very successful organisation that annually partners environmental projects with thousands of members of the public who pay for the privilege of spending weeks of their vacation time assisting with field research [5]. Large-scale environmental science requires citizen science.

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Box 1. Three case studies

Christmas Bird Count

The Christmas Bird Count (CBC) was begun by Frank Chapman in December 1900 as an alternative to the traditional Christmas hunt. Since that time it has become a major source of scientific data on trends in the status of bird species in North America. The current methodology involves volunteers working in teams that conduct a coordinated count within a circle of 15 mile radius over 1 day during the Christmas period [16]. About 2000 such circles are recorded each year. Data collected in the CBC can be freely downloaded from the Audubon website (see Table 1), which also provides tools for tabulating data on specific species and for drawing graphs of how numbers have changed over time, adjusted for observer effort. Thus volunteers, if they wish, can analyse CBC data as well as help to collect it. Nearly 350 scientific papers and reports using CBC data have been published and are listed on the website. They include studies of population dynamics, community ecology, biogeography and census methods. In 2007 the CBC and the Breeding Bird Survey (BBS), a citizen science project run by the US Geological Survey, were used to evaluate the 40 year population trends of common North American bird species. 'Common' was defined as having a population of at least half a million individuals and a range of 1 million square kilometres or more. The report [16] found that over 40 years, populations of 20 common species had reduced by an average of 68%. The *New York Times* commented in an editorial [17], 'this is not extinction, but it is how things look before extinction happens.'

The Evolution MegaLab

The Evolution MegaLab is a citizen science project designed to enable the general public throughout Europe to participate in a hands-on study of evolution as part of the celebrations for Charles Darwin's double centenary in 2009. Although the original motivation for the study was not pure research, the project was planned on the basis that results of genuine scientific value should emerge. Citizen science should not be second-rate science. We chose shell polymorphism in the banded snails *Cepaea nemoralis* and *C. hortensis* as a study system because most populations within the native range of the species are visibly polymorphic for shell colour and banding (Figure I) and the genetic basis of this variation is known. The animals are abundant, widely distributed, safe to handle, easy to find and (with instruction) can readily be scored for nine basic phenotypes. The species were model organisms for ecological genetics in the 1960 s and early 1970 s, when thousands of populations were scored. These studies uncovered evidence of at least two agents of natural selection: predation by birds that favours snails with shells that are better camouflaged in the local habitat (e.g. yellow, banded shells are better camouflaged in grassland) and environmental temperature. Light-coloured shells are favoured at lower latitudes where overheating is a danger for darker shells, whereas at higher latitudes *Cepaea* with dark shells warm more quickly in sunlight and can therefore be active for longer than lighter morphs [18]. Visitors to the Evolution MegaLab website (Figure II) are invited to collect and upload data on populations in their area to help us test two evolutionary hypotheses based on changes in these selective forces. First, we are testing whether the association between morph and habitat has weakened in places where song thrushes have become locally scarce and predation has consequently declined. Second, we are asking whether the frequency of darker morphs in the north of Europe has decreased over the last 40 years as the climate has warmed over this period.

The Evolution MegaLab website is available in 14 European languages and the project involves collaborators in 15 countries. We anticipate that thousands of users of all ages will participate, and therefore the sampling procedure has been designed to be as simple and robust as possible. A uniform set of downloadable instructions is provided in all languages. There is an online quiz that simultaneously trains users to identify *Cepaea* and to score morphs and also tests their ability to do this correctly. Test scores are saved with the data that a user uploads for use in validation. These scores can be used to weight the data when they are analysed. As soon as a user submits data they receive personalised, automated feedback that compares their sample with the nearest historical sample within a 5 km radius. Where a valid comparison can be made, the results of a statistical test are given and possible evolutionary interpretations are suggested. If there are no historical records within 5 km, we emphasise the unique value of the new data and invite the user to record another sample at a historical location. To make this possible, a Google map on the website displays the locations of the 8000 or so historical samples that we have in our database. Current data are displayed separately so that users can see their personal contribution to the project displayed on a map. The scientific results of the project will be reported in a peer-review journal in due course.

OPAL

OPAL (OPen Air Laboratories) is a large programme of environmental citizen science activities funded by a £12 million grant over 5 years that has been awarded by the Big Lottery Fund for England to a consortium of 16 institutions led by Imperial College London. The overall aim is to increase public engagement with, and understanding of, the environment, particularly among the socially disadvantaged. Community scientists from universities are working with local people to develop projects about local environmental issues of importance to them. Together they will record local wildlife and the quality of air, soil and water. They will analyse and interpret these data to understand how local conditions can affect species diversity, distribution and population size.

A suite of new, interactive resources is being developed to help simplify complex issues such as climate change and to demonstrate how they can directly affect local biodiversity and environmental quality. The aim is to inspire a new generation of environmentalists to protect our natural heritage. Five national surveys of different bio-indicators are being used to engage with the public and iSpot (see Table 1), a social networking website for natural history, will help people develop a sustained interest in biodiversity. Data from all activities will contribute toward a 'State of the Environment Report' at the end of the project.

Figure I. Shell polymorphism in a typical population of *Cepaea nemoralis*. Photo courtesy of Robert Cameron.

Figure II. Logos.

Almost any project that seeks to collect large volumes of field data over a wide geographical area can only succeed with the help of citizen scientists. For example, the National Institute of Invasive Species Science, based at the US Geological Survey in Fort Collins, Colorado, is using citizen scientists to conduct a nationwide survey of invasive species in the USA. A range of tools is provided for use by local and regional partners in the survey. Nationwide surveys of this kind depend upon building a coalition of regional and local partners that share data standards and a cyber-infrastructure for gathering data. The National Biodiversity Network in the UK, for example, has 75 partner organisations.

Third, citizen science is likely to benefit from the condition that research funders such as the National Science Foundation in the USA and the Natural Environment Research Council in the UK now impose upon every grantholder to undertake project-related science outreach. This is outreach as a form of public accountability. If we want to continue to spend taxpayers' money, it is in scientists' own interest to make sure that the public appreciates the value of what they are paying for. Undoubtedly the best way for

Table 1. A sampling of citizen science in ecology and evolution

Hypothesis-driven research		
Evolution MegaLab	Range-wide survey of shell polymorphism in banded snails in Europe, comparing new records with historical data to test for evolutionary change in response to climate warming and changes in predation pressure. See Box 1.	http://www.evolutionmegalab.org
Peppered moth	National survey of evolutionary change in peppered moth polymorphism carried out by first-year undergraduate students of the Open University in the UK.	[15]
Project PigeonWatch	Investigation of assortative mating and other behaviours in feral rock doves to test mechanisms that could maintain plumage polymorphism.	http://www.birds.cornell.edu/pigeonwatch
Volunteer mapping and monitoring		
British Trust for Ornithology	Nongovernmental organisation dedicated to using volunteers who follow statistically designed sampling strategies in research on birds.	http://www.bto.org
Christmas Bird Count	Annual bird survey run by the National Audubon Society (USA) for over a century. See Box 1.	http://www.audubon.org/Bird/cbc
OPen Air Laboratories (OPAL)	Consortium of universities and other institutions in England that is involving the general public in environmental research on water and air quality, soil science, climate and biodiversity. See Box 1.	http://www.OPALexplorenature.org
Citizen Science Canada	Citizen science site concentrating on ecological monitoring and run by Environment Canada.	http://citizenscience.ca
Invasive species survey	Mapping invasive species in the continental US.	http://www.citsci.org
National Biodiversity Network	Repository for UK biodiversity data, much of it collected by volunteers. Offers web services that enable other websites to dynamically access the data.	http://www.nbn.org.uk
Protea Atlas Project	A completed project that employed nearly 500 volunteers to map 377 species of Proteaceae in the Cape Floristic Region. The data have since been used in several ecological studies of the Cape flora [6–8].	http://protea.worldonline.co.za
Swedish Species Gateway	Well-designed site that collects observations of birds, butterflies, mammals, plants, fungi, fish and marine invertebrates from the public in Sweden.	http://www.artportalen.se
Chicago Wilderness Project	For volunteer conservationists in the Chicago area. Includes links to several citizen science projects.	http://www.chicagowilderness.org
The Lost Ladybug Project	Survey of native and alien coccinelid beetles.	http://www.lostladybug.org
eBird	Website for North American birders to record and contribute personal sightings to a continental database. More than 4.3 million records were submitted in 2006.	http://ebird.org
Tools, guidance and resources		
Citizen Science Toolkit	A systematic guide to designing a citizen science project, including links to existing projects and resources.	http://www.birds.cornell.edu/citscitoolkit/toolkit
CyberTracker	Widely used, customisable freeware for data capture in the field. Runs on PDAs and certain mobile phones.	http://www.cybertracker.org
Discover Life	A miscellany of online keys for identification of various North American and some tropical taxa.	http://www.discoverlife.org
Earthwatch	International organisation that matches volunteers with approved environmental research projects.	http://www.earthwatch.org
Electronic Field Guide	Open source software for producing hierarchically structured keys.	http://www.electronicfieldguide.org
iSpot	New social networking site for natural history observations. Links beginners with sources of help for identification.	http://www.ispot.org.uk
Mushroom Observer	Website for recording observations of fungi and lichens and getting help with identification.	http://www.mushroomobserver.org
The Volunteer Monitor	Newsletter of the Volunteer Watershed Monitoring project run by the Environmental Protection Agency (USA) and published for 20 years. The summer 2008 issue, available from the website, contains several articles of general interest including a list of scientific publications generated from volunteer data.	http://www.epa.gov/owow/monitoring/volunteer/issues.htm

the public to understand and appreciate science is to participate in it.

Despite its deep roots, recognition that the modern form of citizen science is a distinct activity with its own constituency of practitioners is recent. In January 2009, the ISI Web of Knowledge database contained only 56 articles explicitly dealing with 'citizen science,' fewer than the 60 new presentations made under the citizen science banner at the ESA meeting in August 2008. Nearly all the articles (80%) listed in Web of Knowledge had been published in the last 5 years. The apparent underrepresentation of citizen science in the formal literature probably has two causes. First, the term itself is relatively recent, and in fact hundreds of scientific papers have resulted from the data collected in Christmas Bird Counts and other long-running volunteer monitoring programmes. Second, projects that fit uneasily into the standard model of hypothesis-testing research are written about only in the grey literature, or even not at all.

A comprehensive survey is beyond the scope of this article, but the sample of projects listed in Table 1 is, I believe, representative of the current state of citizen science. First, there are very few projects that have been set up to test an explicit scientific hypothesis. Only one of the three projects (The Evolution MegaLab; see Box 1) listed is active at the time of writing. By contrast, there are hundreds of volunteer surveys, of which I have listed 11 examples, including the very successful Protea Atlas Project that has now been completed. The publications from this project [6–8] demonstrate that good science can, indeed often does, come from surveys that would probably never be approved by peer-review committees that demand rigorous tests of explicit hypotheses. Of course it helps such papers to emerge if the data collected by volunteer surveys are made freely available. The third category contains projects that provide the tools and resources that are now so abundantly available for citizen science. These include CyberTracker and some of the other projects already mentioned, but to this list ought to be added all the generic resources that are available to aid collaboration on the web, but which are not specifically designed for science projects. Flickr, Facebook, Google maps, Twitter, iPod apps, YouTube, Wikis and other web 2.0 applications can all be used to reach and engage with a large audience.

Challenges and opportunities for citizen science

Some guidelines for good practice in citizen science have begun to be formulated, for example in a draft toolkit hosted on the website of the Cornell Laboratory of Ornithology (see Table 1), but at the moment most of us engaged in this activity are probably learning by doing, if only because the technological possibilities are advancing so fast. Some of the principles are of course general to all of science:

- data collected by the public must be validated in some way;
- methods of data collection must be well designed and standardised;
- as many assumptions as possible must be made explicit;
- it is desirable to have a hypothesis in mind, even if it is only a question like: 'how is X changing' or 'how is Y distributed?'
- volunteers must receive feedback on their contribution as a reward for participation.

The first of these principles is widely appreciated, and checking of volunteer data by experts is usual in most studies [9–14]. The other principles are applied in some studies but not others. The British Trust for Ornithology is a paragon of statistical design and directs its volunteers to precise locations dictated by stratified random sampling where they must follow a strict protocol. Other schemes will accept observations from wherever volunteers happen to report them. The preponderance of surveys and the dearth of citizen science projects that test an explicit hypothesis might suggest that the methodology is better suited to the aims of the former rather than the latter. I would argue that this is not necessarily the case, and that more scientists ought to consider using citizen science in large-scale projects and not just as a means of educating the public or monitoring the environment, laudable though those goals are. 'Science for the People' was a slogan adopted by activists in the 1970 s. 'Science by the people' is a more inclusive aim, and is becoming a distinctly 21st century phenomenon.

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Letters

Assisted colonization: evaluating contrasting management actions (and values) in the face of uncertainty

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In their recent Opinion article in *Trends in Ecology & Evolution*, Ricciardi and Simberloff [1] argue that assisted colonization is not an appropriate management option because the impacts of introduced species are too difficult to predict, and can have harmful consequences for recipient ecosystems, including the extinction of native species. Invoking the precautionary principle, the authors argue that alternative conservation tactics must be pursued, even for species faced with extinction in their native range. We concur with the authors that there are risks associated with introducing species outside of their current range. However, we disagree for three reasons that these risks are so great that assisted colonization should not be considered among possible management options.

First, the probability of translocated organisms causing significant damage to native species might be overstated. Indeed, the sources on which the authors base their analyses (http://www.issg.org and Ref. [2]) report impacts on native species that are sometimes based on anecdotal or correlative evidence, a common challenge when evaluating the impact of non-native species [3,4]. For example, the extinction of a Puerto Rican bullfinch subspecies from St. Kitts (*Loxigilla portoricensis grandis*) is attributed in the authors' data set to the introduced green monkey (*Cercopithecus aethiops*) [2] even though the monkeys were uncommon within the bird's range, the two species had coexisted for more than 200 years and the demise of the local Puerto Rican bullfinch population coincided with two catastrophic hurricanes [5]. Furthermore, for each species with multiple introductions, the authors scored only the most extreme impact, rather than an average one (Figure 1 caption in Ref. [1]). Reports of extreme examples are important because they describe worst-case scenarios, but these should also be accompanied by modal outcomes, which are more likely to occur.

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Second, there is a need to weigh the risks of assisted colonization versus the risk of extinction using more traditional conservation practices. Data provided by the authors (Figure 1 in Ref. [1]) suggest that 85% of intracontinental mammalian translocations resulted in no detectable effect in recipient ecosystems. Translocations within a species' former range were not included in the authors' analyses (A. Ricciardi, pers. commun.), and might have even lower probabilities of adverse effects. We suspect that if a species were under imminent threat of extinction, could not migrate to suitable habitat, was unlikely to cause ecological harm and benefited from broad public support, few would argue against assisted colonization.

Third, risk assessments need to be evaluated and debated in a framework that recognizes that different stakeholders might place a premium on different outcomes. Even among conservation biologists, there appear to be divergent value systems that influence conservation targets and management tactics. Ricciardi and Simberloff appear to place a premium on protecting species in their native habitat, whereas proponents of assisted colonization are willing to translocate species to prevent their extinction even though in some cases this could result in adverse effects [6].

There is a need for a framework that integrates both biological information and socioeconomic data, and allows for debates regarding more subjective values surrounding species conservation. Hoegh-Guldberg *et al.* [6] proposed a relatively simple framework based on three categories: the need of a taxon (how imperiled is it?), technical feasibility (can it be translocated?) and suitability (do biological, social and economic benefits outweigh costs?). More comprehensive (K.B.S. *et al.*, unpublished) and alternative [7] frameworks are being proposed to help stakeholders evaluate the numerous, complex questions embedded within each of these three categories.

Proponents and opponents of assisted colonization share a concern for biodiversity and, as the impacts of climate