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Environmental Citizen Science

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Contents

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Images
Page 3, Source: ©istockphoto.com/fstop123; Page 7, Fig 1. Butterfly Conservation (2013); Page 8, Fig 2. Haklay, M. (2012); Page 9, Fig 3. EEA. Gee, D. (2011); Page 10, Fig 4a. Vincent, Bruce. Fig 4b/4c. YardMap.org. (2013); Page 23, Fig 5a. Tweddle *et al.* (2012), Fig 5b. Shirk *et al.* (2012)

EXECUTIVE SUMMARY

Environmental Citizen Science

Citizen science encompasses many different ways in which citizens are involved in science. This may include mass participation schemes in which citizens use smartphone apps to submit wildlife monitoring data, as well as smaller-scale activities, for example, grassroots groups taking part in local policy debates about fracking.

This In-depth Report from Science for Environment Policy explores academic research into citizen science practice and theory, and outlines a number of case study projects. The value of such projects for science, society, education and environmental policymaking are considered.

It can be difficult to separate the scientific, social, educational attributes of a project and in some citizen science initiatives, the aims may be complex or unclearly defined. Overall, the report finds that the potential value of citizen science is high, but that this potential, particularly for citizens and policymakers, remains largely untapped. In addition, while new technologies, such as smartphones and tablets, may enable mass participation, it is worth considering whether more valuable interactions and discussions between those involved in citizen science are being missed.

In the EU, a number of new citizen science initiatives funded by the Seventh Framework Programme (FP7) for Research are underway. Several explore the potential of citizen science for informing environmental policymaking. Because these initiatives are new, their benefits remain to be seen. At present, case studies and examples drawn from the UK and US make up the vast majority of citizen science projects referenced in the academic literature. However, a review of these projects may be informative for shaping current and future projects within the EU.

Most current citizen science projects identified by this report are 'contributory' projects, such as those organised and run by scientists in which citizens help gather data. Case studies are included, not necessarily as examples of best practice, but rather to illustrate the range of subject areas covered and approaches adopted by citizen scientists. Examples cover citizen involvement in monitoring of air quality and fish populations, and games to facilitate policy discussions about pollution. Examples of informal, citizen-led citizen science initiatives are harder to identify but are important because they often focus on solving environmental problems that affect people locally. In this respect, the questions that citizens – not just scientists – seek to answer can set the agenda for environmental research and policy debate.

Introduction

In 1995, the term 'citizen science' was used by social scientist Alan Irwin to describe expertise that exists among those who are traditionally seen as ignorant 'lay people' (Irwin, 1995). Scientists such as Rick Bonney have since re-defined it as a research technique that enlists the help of members of the public to gather scientific data (Bonney *et al.*, 2009b), or simply as the involvement of volunteers in science (Roy *et al.*, 2012). Today, citizen science is also used to refer to knowledge of local environments, and knowledge gained through experience, as well as the submission of scientific data by large numbers of online volunteers. Some researchers suggest that citizen science can and should involve the public in the development and design of projects addressing real-world problems (Wiggins and Crowston, 2011). In practice, the term 'citizen science' is used to refer to a diverse range of projects with widely different aims and objectives, and different approaches to working with volunteers.

There is an established tradition in the environmental sciences of using volunteers to collect monitoring data, such as bird monitoring projects that work with amateur bird enthusiasts (Bonney *et al.*, 2009b). These traditions may have their roots in the 19th century, long before the term 'citizen science' was coined, but volunteers are now often referred to as citizen scientists. Today, members of the public can contribute to environmental research projects focusing on everything from air pollution monitoring to the activities of predators in backyard chicken coops.[1]

With the internet has risen a 'new wave' of online crowd-sourcing projects sometimes termed 'citizen cyberscience'. Possibly the most oft-cited and high profile example is Galaxy Zoo[2] , an online project in which astronomers enlisted unpaid volunteers to classify hundreds of millions of galaxies by analysing images taken by space telescopes (Raddick *et al.*, 2010). There has also been a growing recognition of the role that citizen science can play in participatory democracy and active citizenship (Rowland, 2012). Opportunities presented by the internet, smartphone sensors and gaming, alongside other emerging technologies, now offer new ways to potentially influence how science and policymaking is carried out (Graham *et al.*, 2011; Haklay, 2012). These opportunities extend, of course, to environmental research and monitoring, and to environmental policymaking.

The nature and application of so-called citizen cyberscience projects and the potential for citizen scientists to shape environmental policy provide two major foci for this report, which also explores the educational and societal impact of citizen science. In addition, the report addresses important questions about quality assurance, and the real purpose and value in producing environmental data versus environmental education and awareness.

Key questions addressed and highlighted in this report include:

1. How could new and developing technologies help citizen science projects feed into environmental policy processes?

2. Is environmental data produced by citizen scientists as accurate as environmental data produced by professional scientists?

3. How can citizen science benefit environmental monitoring and policymaking?

The first chapter provides a brief historical perspective on citizen science and an overview of different approaches within the environmental sciences, as well as current challenges and opportunities, and future directions. Chapter 2 explores the value of citizen science both as an environmental research technique and as a route to reconceptualising the environmental governance system. Chapter 3 considers the practical implications of designing and managing a successful citizen science project within the environmental sciences, providing a summary of relevant frameworks and guidelines. Case studies are included throughout.[3]

[1]http://chickencoopstakeout.wordpress.com/ [2]www.galaxyzoo.org
[3]Note that most of the examples of citizen science in this report relate to environmental studies, except where projects from other disciplines offer useful context or insights into different approaches to citizen science.

1. The rise of citizen science

Citizen science is often considered an emerging trend. However, examples date back at least to the 19th century, even if these projects were not recognised as such at the time; the environmental sciences provide a number of early examples. Some brief historical context is useful in understanding the development of modern day citizen science and what is truly new or cutting edge about the present movement.

Recent years have seen a proliferation of projects labelled as 'citizen science', with many now harnessing new technologies, such as mobile internet and smartphone apps, to increase accessibility and remote participation. In practical terms, this means volunteers can now use familiar tools to report sightings of rare species or record noise pollution, for example, and that data from numerous global sources can be collected centrally and rapidly via the internet.

In light of these developments, it is important to ask what today's citizen scientists can do to improve the way that environmental research is carried out, and whether new wave citizen science represents any threat to the quality of environmental science and its outputs.

1.1 A short historical account

Prior to the 20th century, it was common for the work that we now refer to as science to be carried out by amateurs (Haklay, 2012; Rosner, 2013). Charles Darwin (1809-1882), for example, had no formal training in science and yet is widely regarded as one of the most important scientists in history. When considering the modern day 'citizen scientist', it is worth remembering that until 1833 the word 'scientist' did not exist at all, and so those who were involved in 'science' prior to that time can be viewed simply as ordinary people making a living in a world of politics and business (Fara, 2009). By some accounts, then, it is the professionalisation of science that has led to the exclusion of citizens. Modern day citizen science can be seen as representing a return to a centuries-old approach to doing science, and to challenge the notion that science must be done by 'experts'.

The term 'citizen science' was coined by the social scientist Alan Irwin in his 1995 book Citizen Science, in which he describes how people accumulate knowledge in order to learn about and respond to environmental threats. Irwin was concerned with the uncertainty of scientific knowledge and contended that alternative forms of knowledge – such as those constructed by 'lay publics' – can and should be considered as complementary. Around the same time, the American researcher and educator Rick Bonney used the term 'citizen science' to refer to public participation in scientific research (Rosner, 2013). An influential figure in citizen science, Bonney is based at the Cornell Lab of Ornithology in New York where scientists have been engaging members of the public in ornithology research since the 1950s (Bhattacharjee, 2005). The Lab's founder, Arthur Allen, asked members of the public attending his weekly public seminars to report sightings of different bird species so that he could collect relative abundance data. This is a crude example of citizen science, but in the following decades, Cornell Lab projects progressed to gathering tens of millions of observations each year and involving participants in analysing as well as submitting and visualising data.

Thus, there are two common interpretations of the term 'citizen science'. One is related to Irwin's definition and to forms of knowledge beyond the scope of professional science, often referred to as lay, local and traditional knowledge (also known as LLTK). While these alternative forms of knowledge are recognised as important sources of environmental data when gaps in scientific knowledge or data exist, they are probably undervalued (Thornton and Maciejewski Scheer, 2012). The second interpretation is related to Bonney's public participation in science, although in practice, it is sometimes closer to simple crowdsourcing.

> *"Crowdsourcing is the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call."*
> Howe (2010)

The advent of the internet has now made it possible for amateurs – often enlisted by professional scientists – to participate in science en masse, providing a means for raising public awareness of scientific projects and issues, and submitting scientific data. One of the longest-running citizen science projects, the Audubon Society's Christmas Bird Count[4], began in North America in 1900 with 27 dedicated 'birders' (National Audubon Society, 2013). It is still running, open to anyone living within designated survey areas, and attracts thousands of participants each year, with no specialist knowledge or experience required. In 2012, over 63,000 field observers and feeder watchers took part. The results, which help researchers and conservation biologists to study the health and status of North American bird populations, are collected and distributed online.

According to Wiggins and Crowston (2011), recent decades have seen a growing emphasis on 'scientifically sound practices and measurable goals for public education'. Some of the best known projects were and are run by the Zooniverse[5] team, or Citizen Science Alliance[6], which launched the Galaxy Zoo galaxy-classifying project in 2007 (Zooniverse, 2013) (see Case Study 1), and its crowdsourcing model has been adopted by other groups. Meanwhile, its original astronomy focus has broadened, with current Zooniverse projects encompassing climate (Old Weather[7]), bat monitoring (Bat Detective[8]) and ocean exploration (Seafloor Explorer[9]). However, there are many more examples, encompassing different models of citizen science and within the environmental sciences these span a diverse range of subjects.

Citizen science may be considered as a discipline in its own right; academic groups and collaborations include the Citizen Cyberscience Centre[10], a Swiss partnership involving CERN, the UN Institute for Training and Research and the University of Geneva; and Open Air Laboratories[11] (OPAL), led by Imperial College London and the Natural History Museum in the UK.

[4]http://birds.audubon.org/christmas-bird-count [5]www.zooniverse.org [6]www.citizenciencealliance.org [7]www.zooniverse.org/project/oldweather
[8]www.zooniverse.org/project/batdetective [9]www.zooniverse.org/project/seafloorexplorer [10]www.citizencyberscience.net [11]www.opalexplorenature.org/aboutOPAL

Case study 1: Galaxy Zoo

Key facts
Location: Global
Partners: Citizen Science Alliance
Timescale: 2007-current

Galaxy Zoo is one of the best-recognised citizen science projects. Launched in July 2007, it asks participants to participate in astronomy research by classifying images of galaxies online. Originally, the images came solely from the Sloan Digital Sky Survey, an astronomical survey covering a quarter of the sky and over 930,000 galaxies (SDSS, 2013). Now, images from the Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey (CANDELS) are also used (Galaxy Zoo, 2013).

Following publicity via BBC radio and the BBC website, tens of thousands of volunteers registered to take part within the first week and by April 2009, more than 100 million galaxy classifications had been made (Raddick *et al.*, 2010). (Each galaxy is classified by more than one volunteer, helping to increase confidence in the results). To date, over 20 scientific papers have been published based on data from the Galaxy Zoo project. Volunteers have helped astronomers to make numerous discoveries, such as the first planet with four stars (University of Oxford, 2012).

1.2 Development in environmental research, monitoring and policymaking

In some areas of environmental science, citizen science programmes channel the existing interests, dedication, and in certain cases, expertise, of amateur enthusiasts and skilled professionals with no formal scientific qualifications. Many of these programmes were not originally acknowledged as examples of citizen science, having arisen before the term itself.

As outlined in Section 1.1, birds have been studied by amateurs for many years and are important indicators of environmental change and ecosystem health (Sullivan *et al.*, 2009). In the EU, wild birds are protected by The Birds Directive[12] and in a number of European countries they are monitored by networks of volunteers through the Pan-European Common Bird Monitoring Scheme, jointly led by BirdLife International and the European Bird Census Council (EEA, 2013). In France, the National Museum of Natural History organises the Vigie-Nature monitoring programme, which relies on citizen scientists and saves the French government an estimated €1-4 million per year (Levrel *et al.*, 2010). A 2011 study based on volunteer-collected data from the Swedish Bird Survey concluded that monitoring by citizen scientists could prove useful in future assessments of wild bird populations and help to inform more targeted and efficient conservation efforts (Snäll *et al.*, 2011).

As with birds, there is a long history of amateur observation of butterflies among nature enthusiasts (Van Swaay *et al.*, 2008). The UK started its national butterfly monitoring scheme in the 1970s and over the following decades, countries across Europe developed their own schemes. Today, butterfly monitoring in around 20 European countries is carried out largely by skilled volunteers, with the results being checked by experts. Sensitive to changes in the quality of grassland habitats and climate change, butterflies have been proposed as indicators for the Streamlining EU Biodiversity Indicators (SEBI) process (Van Swaay and Warren, 2012). Under SEBI, they may be useful for reporting on progress towards the EU target of halting biodiversity loss by 2020[13].

Many projects now attempt to draw attention to local or larger-scale environmental issues that citizens may not have been previously aware of, or interested in. For example, one schoolteacher involved students in conducting research on a degraded coastal habitat in their local area (see Case study 3) (Moore, 2011). Other projects harness mobile technologies and the internet to gather environmental data on large geographical scales, using citizens to collect and submit data (see Section 1.4).

Those environmental activities explicitly labelled as citizen science often fit the mould of 'public participation in scientific research' – many at the lower levels of participation (see 1.3) – rather than alternative forms of knowledge. However, there are also examples from all over the world of individuals and communities tackling environmental issues by harnessing lay, local and traditional knowledge. These projects may not be conceived as citizen science projects and are therefore harder to identify. For example, in the 1990s, an international development charity started working with a local community in Zimbabwe to improve land management practices and tackle famine (Wakeford, 2004). The programme harnessed the knowledge of local farmers and encouraged more women, who were responsible for much of the agricultural work, to attend community meetings where management priorities were set. The villagers utilised local and traditional knowledge that had been forgotten or ignored to increase productivity and reduce reliance on food aid.

In 1998, the United Nations Economic Commission for Europe (UNECE) adopted the Aarhus Convention[14], giving European citizens the right to participate in environmental decision-making. More recently, the European Commission and European Environment Agency recognised the value of citizen science and lay knowledge for environmental research, monitoring and policymaking with the establishment of the European Citizen Science Association (ECSA)

[12]http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm
[13]http://ec.europa.eu/environment/nature/biodiversity/comm2006/2020.htm
[14]http://ec.europa.eu/environment/aarhus/

Case study 2: The Big Butterfly Count

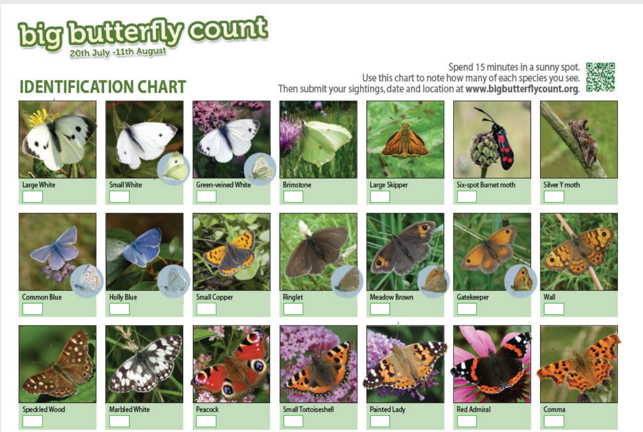
Key facts
Location: UK-wide
Partners: Butterfly Conservation, Marks & Spencer
Timescale: 2010-current

The Big Butterfly Count takes place between July and August each year and asks members of the public to get involved in monitoring butterfly populations in their area. Volunteers spend 15 minutes recording the numbers of butterflies they see in parks, school grounds, gardens, fields or forests. Butterfly Conservation, an NGO, provides an identification chart to help volunteers to recognise species of interest and they submit their results online via the project's website, or via a smartphone app (introduced in 2013). The project has several celebrity backers including Sir David Attenborough.

27,000 people took part in the 2012 survey, recording over 24,000 counts and more than 223,000 individual butterflies and moths from 21 target species. The results showed several species of butterfly declining by 50% or more since 2011, probably due to poor summer weather.

Butterfly Conservation uses the data collected by volunteers across various schemes to assess the effectiveness of ongoing conservation work and direct its future conservation efforts. It also claims that data gathered in its monitoring schemes are used by the UK government to indicate the health of the environment.

www.bigbutterflycount.org



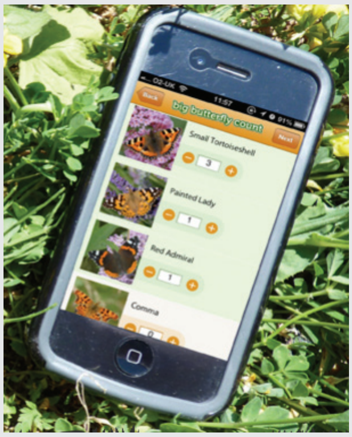


Figure 1: Big Butterfly Count species identification guide and smartphone app for submitting butterfly counts.

(Imperial College London, 2013). ECSA's goals include advancing knowledge about sustainable development and engaging with disadvantaged communities to encourage them to "take an active role in the development of a sustainable society helping to protect and improve health and the environment." (European Commission, 2013; Imperial College London, 2013)

1.3 Scope and variety: categorising citizen science projects

Placing citizen science projects into categories is difficult owing to the wide variety of potential subject areas, aims and approaches. However, it is useful for comparing and contrasting similar projects, and as a route to understanding what constitutes a project's success. While some authors of citizen science studies focus on project scale and hierarchy, others focus on approaches to working with volunteers and project goals.

In a recent review of 234 citizen science projects, scientists working on behalf of the UK Environmental Observation Framework split environmentally-focused projects described as citizen science into four categories according to their degree of mass participation (local or mass) and 'thoroughness' (a measure of investment of time and resources) (Roy *et al.*, 2012). These categories provide a way of classifying projects without in-depth knowledge of their aims and methods, although they do not provide particularly distinct groups of projects. However, their review also considered project approach in terms of whether projects were contributory (led by experts), community-led, or co-created, and provided a list of projects divided into these categories. The same categories were previously applied in a 2009 Centre for Advancement of Informal Science Education (CAISE) Inquiry Group Report (Bonney *et al.*, 2009a), which reviewed US citizen science projects.

Other strategies also classify citizen science projects according to their approach. Wiggins and Crowston (2012) propose a typology dividing citizen science into action, conservation, investigation, virtual and education. In 'action' projects, citizens collaborate with scientists in action research approaches, often to address local environmental issues and concerns, such as building development plans. 'Conservation' projects focus on protecting and managing natural resources, while educating the public. 'Investigation' projects focus on answering scientific questions; 'virtual' projects may have similar goals but all activities are carried out remotely, usually via online platforms. Finally, in 'education' projects, educational outcomes are primarily goals, while scientific rigour may be considered less important.

Haklay's (2012) scheme classifies citizen science projects based on the depth of their engagement with volunteers, within a four-level framework of participation (see Figure 2).

The least participatory projects are termed 'crowdsourcing' and use volunteers simply as a means to collect data from distributed sensors, or to provide computing power. Level 2 projects include well-known examples of citizen science, including Galaxy Zoo and eBird (an online birding project), which may provide participants with some basic skills before asking them to collect and potentially interpret data. At Level 3, participants are more involved in steering the direction of the research. The most participatory are referred to as 'extreme citizen science', where citizens are involved at all stages in the development of the project and work to achieve their own goals. Extreme citizen science can include projects where citizens are the driving force behind the research and professional scientists are not involved at all. This classification scheme is not intended to encourage judgments about how good specific projects are, based on their level of engagement, but Haklay (2012) suggests that participants will benefit most from projects that operate at the highest levels of engagement as appropriate to their aims.

Table 1 shows how the three aforementioned schemes can be used to classify a select number of citizen science projects. Two projects are classified by more than one scheme. Note that Haklay (2012) does not provide examples of Level 3 and 4 citizen science and thus it is unclear how 'extreme' an initiative should be to fit into the most participatory categories.

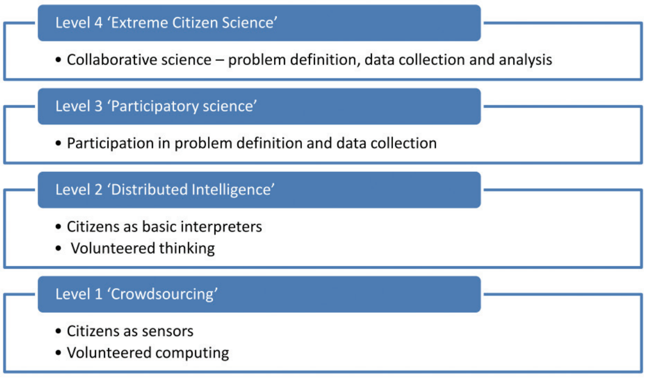


Figure 2: Participatory levels of citizen science. Source: Haklay (2012).

As indicated in Table 1, the majority of environmental projects termed 'citizen science' – or, at least, those selected for review – are contributory rather than community-led or co-created, i.e. citizens are usually assigned the roles of data gatherers and are less often involved in leading projects or setting aims and objectives. Of 30 projects selected as case studies for Roy *et al.*'s (2012) review, all but one were contributory projects and, of the 234 projects reviewed in total, 42% were led by academics and 41% by NGOs. In addition, around two thirds of the projects reviewed focused on biodiversity recording or monitoring. Thus, despite the broad potential of citizen science, it appears many projects may use similar approaches and methods.

A fourth framework for citizen science activities, developed by the European Environment Agency (EEA, 2011), is more diverse in its scope, attempting to integrate the concept of citizen science with that of lay, local and traditional knowledge. This framework recognises six different types of activities. The first three are 'gathering data', 'analysing data' and 'co-production of knowledge', akin perhaps to the increasing levels of engagement in Haklay's (2012) scheme and partly to the contributory and co-created categories for citizen science projects proposed by Bonney *et al.* (2009a). However, the framework is distinct in that it highlights the importance of contributions from people who might not be considered scientific experts, but do have specialist knowledge of particular species, habitats and skills, particularly in relation to local environments.

Project	Brief description of project	Wiggins and Crowston classification	Roy et al classification	Haklay classification
Galaxy Zoo	Classifying images of galaxies	Virtual*	Mass* Contributory*	2 – distributed intelligence*
eBird	Collecting bird observations	Investigation*	Mass* Contributory*	2 – distributed intelligence
What's Invasive	Locating invasive plants	Conservation*	Mass Contributory	2 – distributed intelligence
ReClam the Bay	Restoring local bay's clams and oysters	Action*	Local Community-led	**3 – participatory science**
Corfe Mullen Bio-blitz	Identifying species in Corfe Mullen village and local area	Investigation / Education	Local Co-created*	3 – participatory science
Climateprediction.net	Volunteers' computers used to run climate prediction models'	Virtual	Mass Contributory	1 - crowdsourcing

Table 1: Classifying citizen science projects. *Indicates example classifications proposed by authors of classification schemes.

Figure 3: The rainbow of lay, local, traditional and citizen science activities. Source: EEA (2011)

Together, these schemes provide a representative example of those available in the research literature, reflecting a variety of approaches to citizen science. Appendix I contains a full list of example citizen science projects cited in this report.

1.4 Emergence of new technologies

The rise of the internet has seen a 'new wave' of online citizen science projects sometimes termed 'citizen cyberscience'. Opportunities presented by the internet, smartphone sensors and online or phone-based games, alongside other emerging technologies, now offer new ways to potentially influence how science and policymaking are carried out (Graham *et al.*, 2011; Haklay, 2012).

As citizen cyberscience emerged during the late 1990s and 2000s, some early projects passively involved citizens by volunteering their computing power through the internet to help scientists process large volumes of data and solve complex problems. For example, the SETI@ Home project, released in 1999, allowed volunteers to contribute computing power to searching for potential radio signals from space (Raddick *et al.*, 2010). This might be described as crowdsourcing rather than citizen science *per se*.

The level at which citizens engage with scientific content deepens in projects where citizens use technology to interpret their environment and collect data. Projects including What's Invasive[15], Project Budburst[16] and Picture Post[17] already make use of smartphone apps to encourage volunteers to collect and submit data relating to the natural environment, and a number of new EU projects plan to utilise mobile technologies to harness citizens as sensors (see Key Question 1, page 10). In What's Invasive, volunteers download an app that allows them to report sightings of invasive plants and animals by selecting species from a list and submitting photos taken using their phones (Graham et al., 2011). By 2011, 1,900 registered users had collected 6,000 observations of invasive species in participating American parks.

Recently, scientists from the Center for Embedded Networked Sensing at the University of California, Los Angeles, developed a 'floracaching' game as a smartphone application, based on the principles of geocaching[18] (Han *et al.*, 2011). Users received points for finding and photographing plants at given GPS coordinates, and inputting information about the plant's phenophase – a visible stage in its life cycle.

Online communities may provide the motivation for participating and continuing to participate in citizen cyberscience. While citizen cyberscience communities are hierarchical, unlike social networking sites, such as Facebook and Twitter, which are self-organising (Wiggins and Crowston, 2011), François Grey[19] has argued that the social interactions that occur within some citizen cyberscience communities are similar to those of social networks and may represent a strong incentive for users to take part (Grey, 2009).

The YardMap[20] project created by the Cornell Lab of Ornithology claims to be the first interactive citizen scientist social network. It combines an interactive mapping application with an online community site. The mapping application allows users to map their gardens, with habitats for wildlife in mind (see Figure 4), and the community elements encourage discussion among map creators.

Box 1: How do scientists use YardMap data?

YardMap is funded by the National Science Foundation (NSF) and run by researchers at the Cornell Lab of Ornithology in Ithaca, New York. It aims to help scientists answer the following questions:

- What practices improve the wildlife value of residential landscapes?
- Which of these practices have the greatest impact?
- Over how large an area do we have to implement these practices to really make a difference?
- What impact do urban and suburban wildlife corridors and stopover habitats have on birds?
- Which measures (bird counts? nesting success?) show the greatest impacts of our practices?

Source: http://app.yardmap.org/map/92673#!/about

[15]whatsinvasive.org [16]www.budburst.org [17]http://picturepost.unh.edu/ [18]Geocaching: Outdoor activity or game using GPS technology to locate items hidden by other geocachers (National Trust, 2013). [19]François Grey is one of the founders of the Citizen Cyberscience Centre in Geneva, Switzerland. [20]content.yardmap.org

a)

b)

c)

Figure 4: The CornellLab of Ornithology YardMap application. Discussion threads are embedded within individual maps to stimulate conversation about specific habitats and visiting species. YardMap also integrates with Cornell Lab's Ebird (see Table 1) project to display recent bird sightings automatically. a) Garden mapped by YardMap user Brucebird; b) Mapped garden. The user draws their backyard by creating an overlay on a map, editing it to show different areas of land cover and where specific garden features are positioned; c) Clicking on a button brings up information about habitat types and bird sightings. Users can also share their maps on social networking sites. Source: http://app.yardmap.org/map/92673#!/map

Because they are portable and widely used, mobile phones, tablets and other personal computing devices are becoming essential tools for citizen cyberscience. However, challenges remain. For example, the quality of data obtained from some low-cost sensors used in citizen science projects may be useful for educational purposes, but not necessarily for high-level science (Rant, 2013). Roy *et al.* (2012) suggest that automating communications between sensors and project databases reduces opportunities for engagement and learning between people involved in citizen science projects. Sharing location-specific data also raises data security concerns (Cuff *et al.*, 2008), perhaps particularly in projects where contributors act as passive participants, rather than opting in as citizen scientists. In addition, Graham *et al.* (2011) suggest there is a conflict between technology and 'escaping' to nature that may limit participation in environmental citizen science.

"when people "escape" to parks or other natural areas where making plant observations might be useful, they often want to leave technology behind. How do app developers motivate people to use their mobile phones to make citizen science observations?"
– Graham *et al.* (2011)

Key question 1: 'How could new and developing technologies help citizen science projects feed into environmental policy processes?'

The widespread use of mobile internet now provides an opportunity for mass participation in projects contributing to environmental policy. In recognition of this, several EU-funded citizen observatory projects are developing frameworks that will enable citizens to use their mobile devices to collect environmental data for use in monitoring and decision-making. These include five Seventh Framework Programme (FP7) projects included in the list below. Some are also exploring the potential of citizen science for informing policy and participatory democracy.

- CITCLOPS[21]: Funded through FP7, the Citizens' Observatory for Coast and Ocean Optical Monitoring aims to involve citizens in collecting data on seawater colour, transparency and fluorescence, using camera phones as sensors (CITCLOPS, 2013). The CITCLOPS Consortium includes academic institutes and technology centres in France, Germany, The Netherlands and Spain.

- CITI-SENSE[22]: A FP7 project focusing on air and noise pollution. The project aims to enable citizen participation in community decision-making and planning relating to these issues, through use of personal microsensors and mobile devices.

- COBWEB[23]: Involving 13 partners (academic, industry, non-profit, social enterprise and government) from five European countries, the Citizen's Observatory WEB is exploring the concept of 'people as sensors', using mobile technologies, and initially focusing on citizen involvement in environmental decision-making for the Welsh Dyfi Biosphere Reserve (COBWEB, 2013). Funded through FP7.

[21]www.citclops.eu
[22]www.citi-sense.eu/Project/tabid/10642/Default.aspx
[23]http://cobwebproject.eu/

- Eye on Earth[24]: An online platform for sharing citizen observations and visualising data. Citizens can contribute observations on marine litter via the European Environment Agency's (EEA) Marine LitterWatch smartphone app, with the EEA aiming to assess the extent to which these data can be used to support beach litter monitoring under the Marine Strategy Framework Directive[25] (Goodman, 2013).

- EVERYAWHERE[26]: The EVERYAWHERE project uses low-cost sensors and social networking to collect data and opinions about the state of the environment. It is hoped that increased environmental awareness will improve environmental behaviour and act as a source of pressure on policymakers, as well as providing data to test the effectiveness of existing policies (Everyaware, n.d.).

- OMNISCIENTIS[27]: Local odour monitoring and mitigation project combining real-time measurement and citizen observations submitted through smartphones and tablets (OMNISCIENTIS, 2013). Pilots are based at an Austrian pig-fattening farm and a Belgian industrial site. FP7-funded.

- WESENSEIT[28]: A FP7-funded project harnessing citizens' collective intelligence to develop a citizen observatory for water (Ciravegna, 2013). Data will be used as inputs for models to support planning, for instance, to prevent flooding. Partners hope to encourage communication between authorities and citizens, and active participation of citizens in decision-making. FP7 project.

In addition, the European Commission's flagship project FuturICT[29] is extending the concept of participatory computing – using volunteered computing power via a network – to exploit vast volumes of networked, location-specific information about the behaviour of citizens as data sources for its proposed Earth simulation platform (Helbing *et al.*, 2012; Cantanzaro, 2012). As part of an all-embracing project that aims to solve problems in complex social, economic and financial systems, the creators plan to assess the impact of climate change on society and economics, as well as the impact of human behaviour changes on the environment (FuturICT, 2013). Complexity scientists will draw together data from a wide variety of sources, including mobile phones and monetary transactions, and use them as inputs for complex models, generating simulations that businesses and policymakers can use in decision-making processes.

Games, including online and mobile games, offer the potential to involve citizens in complex problem-solving and decision-making tasks, for example, they can help scientists explore public perceptions of complex environmental issues; investigate potential policy solutions to environmental problems, or simply educate players about the issues addressed in games. In one sustainability-focused game, SusClime, teams were involved in investing in renewable energies and trading fossil fuels (De Vries, 2010). The outcomes were revealing in that players found the social aspects of the game, such as negotiating for oil, more engaging than devising long-term strategies for dealing with climate change. Thus collaborative and social aspects need to be considered, both for their positive and negative influences on engagement and user contributions.

Technology increases the public's access to science while potentially changing the balance of control between professional scientists and the wider public. Cuff *et al.* (2008) highlight the importance of technology in the decentralisation of science – the shifting of control away from scientists. This shifting of control also applies to environmental policy processes, with the potential for public good emerging from the engagement of a diverse array of actors in decision-making processes (Buckingham Shum *et al.*, 2012). However, at the same time, it is important to be aware of how increasing levels of remote participation affect the type and levels of participation in citizen science, and whether this limits potential value in policy processes.

1.5 Challenges and opportunities

Whereas in the past science was practiced by untrained amateurs, it is now largely the preserve of professionals; the work of amateur scientists may be viewed as substandard or of doubtful quality (Gollan *et al.*, 2012). Herein lies the first and perhaps biggest challenge facing citizen science: gaining the acceptance and recognition of the scientific community and potential end-users of volunteer-gathered data.

In a UK study involving amateur naturalists contributing to biodiversity action planning processes, Grove-White *et al.* (2007) concluded that there needs to be more explicit recognition of the work of 'amateur experts' by government, conservation agencies and leading NGOs. However, Riesch and Potter (2013) highlight the need to set modest goals for citizen science, pointing out that the literature is often too enthusiastic about what it can achieve. Careful design of citizen science projects and application of appropriate quality assurance methods are vital.

With appropriate training and support, citizen scientists could help scientists to address knowledge and funding gaps in the environmental sciences, for example, by addressing species that are often passed over in global conservation efforts. Invertebrates make up 80% of all known species globally and provide important ecosystem services such as pollination, water purification and nutrient cycling (Cardoso *et al.*, 2011). However, while the World Conservation Union's Red List of Endangered Species includes most vertebrates, less than 1% of arthropods (the group of invertebrates that includes insects and spiders) are listed. Cardoso *et al.* suggest amateur taxonomists involved in citizen science programmes, aided by 'cybertaxonomy' tools and systems, could provide part of the solution by helping to identify and catalogue invertebrates. One challenge in this respect could be

[24]www.eyeonearth.org [25]http://ec.europa.eu/environment/water/marine/directive_en.htm [26]www.everyaware.eu [27]www.omniscientis.eu [28]www.wesenseit.com [29]www.futurict.eu

Box 2: Key challenges and opportunities

Key challenges facing citizen science can be summarised as:
* Recognition of scientific value
* Maintaining scientific rigour and data quality
* Involvement of citizen scientists representing a broad spectrum of society
* Political and financial guarantees for action on findings

Its key opportunities can be summarised as:
* Timely data from disperse sources
* Power to address large knowledge and funding deficits
* Educating public about environmental policy issues such as biodiversity
* Participatory democracy

difficulty in marketing programmes that focus on species that have traditionally received less public and media attention.

Plans for an EU-wide shared environmental information system (SEIS)[30] highlight the important role that citizens could play in contributing timely environmental data online. The 2008 SEIS Communication on a Shared Environmental Information System calls for information systems to enable citizen participation. Furthermore, a 2013 Commission Staff Working Document (Commission Document SWD(2013) 18) that summarises progress in improving systems for environmental monitoring and reporting highlights the potential power of crowdsourcing and citizen science approaches:

> *"Citizens are not only recipients of information, but also important providers. The public should be given the means to aggregate, combine and generally re-use information according to their various needs; and to contribute with their own information, in their own language. The development of communication technologies through the internet creates highly valuable opportunities for citizen science and crowd sourcing, offering enhanced levels of participation in assessing (and determining) the success of EU environment policies. Crowds of citizens are often well-placed to monitor the state of the environment on the ground at any one time. However, current information systems rarely offer such flexibility and where relevant and justified, feedback systems could be promoted and encouraged, to capture and use information wherever useful."*

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The 2008 SEIS Communication also calls for data to be made fully available to the general public. This principle of open data, along with the use of open source software, is one that is often allied to the citizen science movement (Ala-Mutka, 2009; Roy *et al.*, 2012; Zapico, 2013). However, the sharing of information – the 'data commons' – risks drawing public attention to the extent of environmental decline with no guarantee of practical actions to effect change (Cuff *et al.*, 2008) . Therefore, political and financial commitments to tackle environmental degradation will be required to avoid public disillusionment.

In the best case scenario, citizen science empowers citizens, through education and involvement in scientific and decision-making processes, to adopt more active roles in society. This can help them improve their own local environments and drive a new, more participatory form of democracy (Ala-Mutka, 2009; Mueller *et al.*, 2012). However, while participatory approaches to governance more generally are increasingly seen as superior, criticism surrounds their practical implementation, including the willingness of authorities to take on board citizens' views (Leino and Peltomaa, 2012). In addition, a true participatory democracy involves contributions from the widest possible spectrum of society, whereas those typically involved in projects recognised as 'citizen science' may be more likely to come from the middle class (Haklay, 2012). Therefore, more inclusive approaches to engaging citizens are required, to ensure that all sections of society are represented in citizen science projects.

[30]http://ec.europa.eu/environment/seis/

2. The value of citizen science

In this section, the value of citizen science is discussed in relation to a range of projects of different types. For simplicity, 'value' is divided into scientific, educational, social and policy aspects. It should be noted that the value in most citizen science projects is not easy to categorise and may emerge from broad aims, or as projects develop beyond their original scope. It is common for projects fitting the public participation in research model to have both scientific and educational goals. However, social and policy benefits may also emerge, for example, when projects are based around local people motivated by solving local environmental problems. Unfortunately, because these types of projects may be less clearly identifiable as 'citizen science' and may be led by members of the public rather than scientists, they do not necessarily appear in academic publications on citizen science. However, they can serve to demonstrate the value of more participatory approaches in environmental policymaking and should therefore be included (see Section 2.4).

Many scientists have published scientific papers about the outcomes and potential value of citizen science projects. However, there is a need to be critical in considering these results, due to a lack of independent analysis by social scientists and a probable bias towards publishing about successful – and not unsuccessful – projects (Riesch and Potter, 2013).

2.1 Scientific value

The scientific value of citizen science is dependent on the quality of data collected and how these data are used. For example, low quality bird monitoring data, if widely used, could give a false impression of population trends, whereas high quality data, if rarely used, might represent a wasted opportunity to understand bird populations, migrations and ecosystem health more broadly.

For some citizen science projects, scientific data quality may not be the priority. Educational benefits (see Section 2.3) and awareness-raising are also common aims, although the distinction between scientific and other outcomes is not always explicitly made. In citizen-led initiatives, the aims may be related to solving local planning or environmental issues, and scientific data may be drawn from a variety of different sources. See Section 2.4 for examples.

Key question 2: Is environmental data produced by citizen scientists as accurate as environmental data produced by professional scientists?

A recent review of citizen science projects suggests that many projects aspire to collect high quality data and use quality assurance methods, while others rely on the often large sample sizes to cancel out the effects of individual errors on overall accuracy (Roy *et al.*, 2012). Within scientific circles, however, there remains reluctance to use data collected by citizen scientists due to doubts about accuracy and reliability (Crall *et al.*, 2013; Riesch and Potter, 2013). The issue has been the subject of much debate in academic literature. While some studies suggest that data collected by citizen scientists and experts yield similar results (Devictor *et al.*, 2010), it is often noted that accuracy varies widely from one person to the next and depends on the type of data that participants are asked to collect. Practical approaches to quality assurance are addressed in Section 3.4.

In one study examining the integrity of volunteer data, Gollan *et al.* (2012) compared scientist and volunteer efforts to collect data assessing the effectiveness of a rehabilitation project. The project had focused on reintroducing native plants to an area previously used for farming and industry in the Hunter Valley in New South Wales, Australia. Volunteers and scientists collected data on various vegetation attributes, including foliage cover, leaf litter cover and leaf damage, with some data depending on visual estimates. Whilst the results showed that scientists collected data that was in better agreement with benchmarks, on an individual basis, some volunteers collected more accurate data than some scientists. In addition, there was better agreement between scientists and volunteers for certain attributes, suggesting that it may require experience to make accurate estimates for more subjective attributes.

Data on ladybirds collected by volunteers in the UK Ladybird Survey, Lost Ladybug Project and Buckeye Lady Beetle Blitz was found to be less accurate than data collected by professional scientists, with volunteers overestimating the occurrence of rare ladybird species and underestimating more common species (Gardiner *et al.*, 2012). While citizen scientists were able to identify most species correctly over 80% of the time, in the Buckeye Lady Beetle Blitz, individual volunteers differed widely in terms of their accuracy. This supports the assertion of Cuff *et al.* (2008) that data quality varies with the knowledge of each volunteer. It can therefore be difficult to make quality statements about entire datasets.

Geographic data submitted by volunteers to the OpenStreetMap project, also in the UK, which aims to create a free digital map of the world, is considered 'fairly accurate', to within 6 metres of positions recorded by the Ordnance Survey, the UK's national mapping authority (Haklay, 2010). Haklay highlights the fact that this project mapped over a quarter of England in less than four years at a fraction of the cost of expensive survey methods. Similarly, Gardiner *et al.* (2012) show that using volunteers to collect data is more cost-effective, meaning it is possible to collect a greater number of samples, potentially compensating for any reduction in accuracy.

In some cases, it appears to be the perception of data quality, rather than the actual data quality, that influences the value and use of citizen science data (Riesch and Potter, 2013). Thus, whether or not data quality issues are resolved, citizen science faces a difficult battle in persuading scientists and policymakers of its worth. Meanwhile, lingering concerns about data quality may drive scientists to develop innovative approaches to data interpretation in order to increase scientific value.

2.2 Educational value

A citizen science project might focus on a specific species, habitat, ecosystem or environmental process, in which case its most obvious value might lie in increasing participants' understanding of that species or habitat, for example. Citizen science can also be valuable in enhancing understanding of how science works through firsthand experience (Bonney, 2009a; Tweddle, 2012). However, educational value depends to some extent on the baseline level of knowledge of those taking part – recognising that adult participants are often drawn to projects because they have an existing interest – as well as the level at which they are engaged in the scientific content (Haklay, 2012). Asking participants to contribute computing power or categorise data remotely, for example, may offer little educational value.

The educational benefits of citizen science may be experienced by participants in formal education (mostly children and young people) or as part of informal learning (adults and children). Within a formal education context, it is important to recognise the role that teachers play as gatekeepers and facilitators, and that without the appropriate support and resources, they are unlikely to encourage their students to participate (Gray, 2012; Mathieson, 2013a). Designing a citizen science project (see Section 3.3) that connects with both teachers and students therefore requires catering to two different audiences.

Teachers may be able to identify the value of citizen science more quickly in those projects that outline their intended use in teaching resources, and particularly if links to the curriculum are provided. Environmental projects that target teachers and their students via teaching resources include The Great Sunflower Project[31] (counting pollinators' visits to sunflowers and other plants), CreekFreaks[32] (gathering water quality data) and the National BioBlitz Network[33] (community biodiversity recording events). For example, BioBlitz's teaching resources specifically highlight links to the UK's official science curriculum for schools:

"In Key Stage 2 Science a BioBlitz is ideal for developing your pupils' scientific enquiry skills in [the unit on scientific enquiry] while providing rich, real-life scenarios in [the unit on life processes and living things]:

Variation and Classification
...how locally occurring animals and plants can be identified and assigned to groups,
...that the variety of plants and animals makes it important to identify them and assign them to groups

Living things in their environment
...about the different plants and animals found in different habitats"

('Variation and Classification' and 'Living things in their environment' are specific sections of the key stage 2 science syllabus, which is taught to 7-11 year-olds). Besides providing opportunities to gain knowledge about the environment and develop scientific, problem-solving and creative skills, it is argued that citizen science projects address environmental education goals through hands-on, outdoor activities that promote connections with and an appreciation of nature (Kountoupes and Oberhauser, 2012). While these activities must be fun in order to be engaging, the research aspect must also be taken seriously if children are to appreciate that they are contributing to 'real science'.

The Barnegat Bay project (see Case study 3) provides an example of a co-created project carried out in a formal education setting, but with a goal of generating high quality scientific data – suitable for publication – as well as to influence the local environmental policy agenda (Gray *et al.*, 2012). A key aspect of this US project was its close association with professional scientists, who provided advice and feedback on methods and results. The project was time-consuming and required the commitments of a wide range of local people, but the financial support required was minimal and it is noteworthy that the teacher who led the project reports continuing to work on 'solving local environmental projects' with her students every year (Nicosia, 2013). Some students became far more engaged in the Barnegat Bay project than others and took on extra work, particularly in the writing and editing of the scientific publication.

Bonney *et al.* (2009a) investigated the impacts of ten[34] US-based citizen science projects carried out in an informal education context. Participants in these projects gained knowledge in a range of areas, from environmental issues and regulations to bird biology and the ecology of invasive plants. In The Birdhouse Network, (now NestWatch[35]), participants monitored bird nesting boxes in their gardens or neighbourhoods and submitted the results to scientists. Those taking part significantly increased their knowledge of bird biology although not, apparently, of the scientific process (Brossard *et al.*, 2005). While some participants set up their own experiments and posed questions that helped scientists develop new studies, these outcomes were not captured in the evaluation survey, demonstrating that the educational value of citizen science can sometimes be difficult to quantify. In three other case studies, participants gained data analysis skills (Bonney *et al.*, 2009a). Often, however, significant time had to be invested in training and one-to-one support.

Citizen cyberscience approaches increase opportunities for mass participation and potentially learning, but Roy *et al.* (2012) suggest

[31]http://scistarter.com/project/44-The%20Great%20Sunflower%20Project [32]www.creekfreaks.net [33]www.bnhc.org.uk/home/bioblitz/ [34]The Birdhouse Network (http://nestwatch.org/); Spotting the Weedy Invasives ; ALLARM Acid Rain Monitoring Project (www2.dickinson.edu/storg/allarm/index.htm); Monarch Larva Monitoring Project (www.mlmp.org); Community Collaborative Rain, Hail & Snow Network (www.cocorahs.org); Salal Harvest Sustainability Study (see Ballard and Belsky, 2010); Community Health Effects of Industrial Hog Operations (see Wing et al, 2008); Invasive Plant Atlas of New England (www.eddmaps.org/ipane/); Shermans Creek Conversation Association (www.shermanscreek.org); and Reclam the Bay (www.reclamthebay.org). [35]http://nestwatch.org/

Case study 3: The Barnegat Bay survey

Key facts
Location: Ocean County, New Jersey, US
Partners: West Windsor-Plainsboro High School North, Rutgers University, Barnegat Bay Partnership
Budget: $1,000, funded by the National Science Foundation
Timescale: 2010-2011

The Barnegat Bay Watershed is an area of 1,716 square kilometers on the New Jersey coast that incorporates a range of important habitats including wetland, forest and dunes (Nicosia *et al.*, In Press). The quality of these habitats has been degraded by human activity and industry, reducing the value of the important ecosystem services they provide, such as fishing and tourism. The bay is also home to hundreds of thousands of people.

Under the guidance of their biology teacher and scientists from Rutgers University and the University of Hawaii, pupils at the West Windsor-Plainsboro High School North designed and carried out a study to establish whether residents would be willing to pay the estimated US $6.63 million required to restore the bay. (The estimated funding was based on plans outlined by the Barnegat Bay Partnership). They carried out literature research, surveyed approximately 200 residents and used a Wiki website to put together a scientific paper about their research, working closely with scientists at each stage (Gray, 2012). All support for the project was provided in-kind, besides a small grant of $1,000 for posting the surveys.

Their survey showed that residents were, on average, willing to pay $11 a month to restore the bay. Based on this result, the project team calculated that over $29 million a year could be raised, if all 220,000 households were willing to pay the same amount (Moore, 2011). The students presented their findings at the Barnet Bay Partnership's science and technical committee meeting, and at other environmental agency and scientific meetings. Over the following two years, the results were written up and edited for a scientific paper (Nicosia *et al.*, In Press) due to be published in the peer-reviewed scientific journal Ecological Economics, with students as co-authors.

One student's response to the project:

> *"Through this research, I learned that science is not done in isolation. This project involved the hard work and dedication of not only my classmates, but also of teachers, scientists in the field, university professors, and community leaders. And the opportunity to participate in a study that not only combined biological and ecological science, but also citizen and social science to solve complex real world problems, opened my eyes to the many ways in which science helps make our world make more informed decisions. Looking back on this study, it has had a tremendous influence on the way I view the world. Not only did it provide me with my first glimpse into scientific research is conducted, but it has given me a greater appreciation for nature."*
> Rashika Verma, former student at West Windsor-Plainsboro High School North (Verma, 2012)

that using smartphones eliminates the need for contact between users and project owners, thus risking a reduction in engagement levels and in the educational value of citizen science. However, smartphones have other benefits, such as increasing the time available for doing outdoor practical work. Naturalists leading a butterfly monitoring project engaging young people in the US remarked that children disliked the data entry aspect of the project because it meant sitting inside in front of a computer (Kountopes and Oberhauser, 2013). Instead, adult volunteers took turns at submitting the data.

Various researchers have argued that citizen science should go further to resolve issues of participation in science or promote scientific literacy (Mueller *et al.*, 2012; Gray *et al.*, 2012). Edelson (2012) argues that most citizen science projects benefit scientists (through data collection) more than they do citizens. If participants are only involved in simple activities, such as taking measurements or recording observations, they are likely to have few opportunities to learn. Mueller *et al.* (2012) suggest the reimagining of entire science education systems could provide the basis for societies that take a more participatory approach to decision-making, starting with teachers, who become 'active agents of democracy'. For example, as part of their training, teaching students at the West Visayas State University, Panay, in the Philippines, spend time living in the local community, learning about its culture and working with community members to solve local environmental problems that require a scientific approach, such as erosion in flood prone areas and water quality in local wells. The immersion process is intended to provide teachers with experiences that influence their teaching and notions of citizenship. Gray *et al.* (2012) argue this vision of the future of citizen science is grounded in theory rather than practice, and constrained by a lack of resources within education. However, while the full potential of citizen science in education may not have been realised, some studies suggest that with adequate time and resources, high value educational outcomes can be achieved.

2.3 Societal value

There may be many difficult-to-measure social benefits of citizen science projects. Gollan *et al.* (2012) suggest citizen science has the potential to bring society closer to science and to nature, bringing about a sense of ownership and helping create the kind of society that works to protect its natural environment. However, while many projects have recorded measurable improvements in scientific literacy, changes in attitude are notoriously difficult to measure.

Few studies on public participation in science and environmental education have rigorously assessed changes in attitudes towards science and the environment, and environmental behaviours (Crall *et al.*, 2013; Davies *et al.*, 2013). For example, there were no discernible changes in attitudes towards science or the environment among participants in The Birdhouse Network project (Brozzard *et al.*, 2005) (see Section 2.3). In an invasive species research programme involving volunteer researchers, there was only a modest positive effect on volunteers' intentions to take part in pro-environmental activities (Crall *et al.*, 2013).

Through community-driven research and the environmental justice movement, communities can create opportunities to influence local policymaking (see Section 2.4) and thereby improve public health, quality of life, social cohesion and awareness of local issues and networks. One project recruited people from rural communities in North Carolina, USA, to collect data about emissions from commercial pig farms. In this project (Wing *et al.*, 2008), participants were exposed to pollution and odours in their homes. The project was intended to produce evidence to present to industry and government. However, it also resulted in participants making new connections with neighbours and local organisations, and becoming more aware of local environmental justice groups.

Asking volunteers to collect scientific data may reduce the cost of scientific studies (Gardiner *et al.*, 2012), potentially offering better value for public money. However, because projects vary widely in their goals and scope, it is difficult to generalise – they may incur costs that do not apply to many traditional science projects, such as attracting contributors. In their review of environmental citizen science projects, Roy *et al.* (2012) note that the cost of projects that have directly informed policy have been in the range of £70,000- 150,000 (€81,500 -175,000) each. Costs can escalate as projects grow in scale to involve large numbers of volunteers.

2.4 Value for policymaking

Citizen science can serve policymakers by providing evidence to support regulatory compliance and inform policymaking. It can also serve citizens by providing opportunities to address environmental issues that directly affect citizens – at local, national and global scales – and influence decision-making about these issues.

In viewing citizens as simple data collectors, their potential to provide valuable evidence to underpin policy may have been underestimated (Roy *et al.*, 2012), perhaps because of doubts about the quality of volunteer-collected data. Within environmental monitoring programmes, the advantages of a workforce bolstered by volunteers are clear. Citizen scientists can help meet data collection targets when programmes need to monitor a large geographical area, or require frequent sampling, for instance, to ensure early detection of invasive species (Delaney *et al.*, 2008). The application of citizen science data to environmental policy may be direct, as in the collection of data to support biodiversity action planning (Grove-White *et al.*, 2007), or indirect, as when volunteer-collected data highlights the impacts of environmental change, such as the decline in pollinator species (Roy *et al.*, 2012; Biesmeijer *et al.*, 2006).

The value of lay knowledge may also have been underestimated in considering more participatory forms of democracy. Irwin and Michael (2003) suggest that invitations to participate in policymaking have, in the past, been based on the desire to gain public support and trust rather than to address public concerns or find real value in citizens' contributions. They suggest that lay knowledge, should be considered of equal value to that of scientific expertise. In Europe, there has been a shift towards a new form of scientific governance involving public dialogue and engagement (Irwin, 2006). However, engagement initiatives such as the 'GM Nation?' debate[36] on genetically modified crops have been criticised for being too limited in scope and budget, and not, as they purported to be, 'framed by the public'.

Lay knowledge can perhaps best be utilised at the local level as part of local decision- and policy-making (Irwin and Michael, 2003). Such local initiatives may provide opportunities for closer interactions between governments and citizens. The UK-based social enterprise Mapping for Change enables communities to make a difference to their local environments by providing them with the skills to create and update interactive community maps based on geographical information systems (GIS)[37] (Ellul *et al.*, 2009; Mapping for Change, 2013a). The organisation has partnered with schools, authorities and universities to address environmental issues. One Mapping for Change project focuses on training citizens in southern Poland in the use of a community mapping platform, with the aim of informing local plans for sustainable development (Mapping for Change, 2013b). The data collected are based on the European Common Indicators[38], which are intended to help local authorities assess the quality of their urban environments based on factors such as air quality, transport, sustainable land use and citizen satisfaction. Mapping for Change also worked with a London community to collect noise pollution data for a local scrap yard and went on to discuss the issue with both the local authority and national Environment Agency, resulting in an action plan and the scrap yard's licence being withdrawn (LSX, 2013; Gura, 2013).

Citizen science is increasingly viewed as a way to empower communities by involving them in research that can be used to drive forward policy changes (Rowland, 2012). However, citizen-led examples are harder to identify, perhaps because they do not fit the more recognisable model of citizen science – essentially a contributory model akin to the participation of volunteers in bird monitoring programmes or Galaxy Zoo. Groups involved in these citizen-led movements may

[36]GM Nation? was a public engagement initiative carried out by an independent body on behalf of the UK Government in 2003. The initiative was intended to inform the Government about the public's views on genetically modified crops (Irwin, 2006). [37]Geographical information system (GIS): "[A] computer system for capturing, storing, checking and displaying data related to positions on the Earth's surface. GIS can show many different types of data on one map. This enables people to easily see, analyze, and understand patterns and relationships." (National Geographic, 2013) [38]http://ec.europa.eu/environment/urban/common_indicators.htm

emerge spontaneously, for example, in response to local environmental issues, and separately from the formal processes set up for participatory governance (Leino and Peltomaa, 2012). Goals and motivations may be more complex than collecting scientific data, or education, and the results do not appear in scientific journals. For example, in Peru, the Achuar people have for decades been opposed to oil companies who drill and dispose of produced water in their territory (Amazon Watch, 2013). In part by collaborating with the NGO Amazon Watch, the Achuar learned how to use GPS equipment and cameras to document the environmental effects of these activities (Kheder *et al.*, 2013). They went on to win a legal case against an oil company, and travelled to Canada to demand that an energy company withdraw from their territory, as well as to the Peruvian capital to petition the government to stop the drilling. In 2012, the energy company ceased its activities in Peru. Here, scientific evidence played a crucial role, lending legitimacy to the Achuar's claims, but the case itself was motivated by environmental justice.

Crucially, to recognise the most extreme examples of citizen science and participatory democracy it must be accepted that citizens as well as scientists can be the driving force for scientific research, and for policy debate. Environmental and scientific controversies that affect citizens at the local level – such as in the Achuar case – can provide strong motivations for citizens to take the lead in the debate. Another example of such an environmental controversy is the debate on the effects of hydraulic fracturing ('fracking') in the US, where community groups have formed to lobby governments against fracking in their local areas (Food & Water Watch, 2013). A range of different citizen science initiatives have emerged during the debate, such as the scientist-led The Shale Network, which is enlisting citizens to collect data on water quality near to fracking sites (Rosen, 2013), and a forum on 'Science, Democracy and Community Decisions on Fracking' convened by university scientists to bring together representatives from academia, government, industry and citizen groups (Phartiyal *et al.*, 2013). One citizen-led example is the formation in Erie, Colorado, of the grassroots anti-fracking group Erie Rising.[39] The group started as a collective of women, mothers and business owners concerned about the effects of local drilling of natural gas wells on their families. Its position statement on fracking is as follows:

> *"We believe the onus lies squarely with the gas companies and our elected officials to prove that natural gas drilling and mining by fracturing is safe and does not pose a real or imminent threat to our children, our health or our environment. We are seeking scientific studies and other information to prove we are not at risk from this activity.*
>
> *We pledge that, in the absence of that proof, we will take action to keep it out of our community and away from our schools until such proof is available."* ErieRising.com

The group cited a scientific study, providing evidence of propane pollution, to bring about a six-month moratorium on fracking starting in March 2013 (Aguilar, 2013). In July 2013, Erie Rising partnered with non-profit organisation Global Community Monitor to offer local residents training in air pollution monitoring. Its website provides resources for citizens interested in participating in the debate, including glossaries of oil and gas terms, and for reading technical reports. Erie Rising also uses a Facebook page[40] to communicate online with over 1,200 people interested in the impacts of oil and gas operations. Thus, in this example, new technologies are used for the benefit of citizens, to reinforce local connections and to provide access to information.

Key question 3: How can citizen science benefit environmental monitoring and policymaking?

As discussed, different projects have different aims and these may be scientific, educational or policy-focused. Many examples of citizen science are formalised projects that utilise citizens as data collectors. Whilst these demonstrate the power of citizen science for generating evidence, both citizens and policymaking can benefit from more participatory approaches. In addition, questions remain as to how environmental monitoring data is used. One study (Mueller *et al.*, 2012) went as far as to make the bold claim that some citizen science projects presented as 'environmental monitoring' generate awareness around issues that scientists deem important, helping them to raise funds for their own research without generating useful data or meaningfully engaging the public. In such situations, citizen science may not necessarily benefit citizens or environmental policymaking.

At present, there appear to be relatively few examples of participatory citizen science having a tangible impact on decision-making – though the potential is very often noted (Cohn, 2008; Grove-White *et al.*, 2007; Davies *et al.*, 2013). Many European projects make links to key policy objectives, and even provide data to support monitoring as outlined under European law, for example, the National Bat Monitoring programme[41] delivers "information needs" to help fulfil the UK's obligations under the Habitats Directive (Roy *et al.*, 2012). But few formalised citizen science projects have so far provided evidence of directly influencing policymaking. This may be because it is not always clear how decisions have been made and it may be difficult to obtain concrete evidence of influence. On the other hand, some informal, citizen-led examples, particularly those in the environmental justice mould, demonstrate that citizen science can influence decision-making.

For the concept of a participatory democracy to succeed, the approach of citizen science must be inclusive and accessible to all sections of society; not restricted by education and access to resources and technology. According to Haklay (2012) there is already a bias in participation favouring well-educated, well-paid individuals who have the time and resources to take part. Grove-White *et al.* (2007) highlight the need for conservation agencies and NGOs to think 'systematically' about the design of projects to ensure that by encouraging the inclusion of certain groups they are not excluding others whose inputs are equally as valuable. Meanwhile, the rise of citizen cyberscience

[39]www.erierising.com [40]www. facebook.com/pages/Erie-Rising/194079134019565 [41]www. bats.org.uk/pages/nbmp.html

means participation may increasingly be based on access to smartphones and the internet and it is acknowledged that online projects are more likely to attract a technically literate audience (Raddick *et al.*, 2010). However, these biases seem to relate to participants in formalised citizen science projects, whereas in citizen science movements emerging in response to specific environmental and local threats, the situation may be different.

According to Roy *et al.* (2012), the use of citizen science data by scientists and policymakers will 'undoubtedly' increase. However, for value to emerge from lay knowledge and citizen participation in environmental governance, policymakers must understand that value and accept participatory processes as legitimate ways to carry out policymaking (Leino and Peltomaa, 2012). A certain amount of flexibility is also required to accommodate the views and knowledge of citizens as they respond to emerging environmental situations.

Roy *et al.* (2012) call for a comprehensive review of current use of citizen science data by scientists and policymakers within the UK. Such a comprehensive review also appears to be lacking at a broader European level.

3. Citizen science in practice

3.1 Case studies

The following case studies provide examples of current and recent projects illustrating a range of subject areas, approaches and potential impacts, although with an emphasis on those utilising new technologies. They are not intended as examples of best practice as reports of their results are often difficult to obtain and few independent perspectives of these projects are available. See the project websites for further details of each case study.

For case studies 1-3, refer back to Sections 1.1 (Case study 1: Galaxy Zoo), 1.2 (Case study 2: The Big Butterfly Count) and 2.2 (Case study 3: The Barnegat Bay Survey).

Case study 4 describes 'Air Quality Egg' an example of a global citizen science project with strong European links, in which citizens monitor local air quality at home, using sensors that detect nitrogen dioxide and carbon monoxide levels (Air Quality Egg, 2013). This might be considered a community-led, participatory project. The current locations of sensors across Europe – and the US – are mapped at airqualityegg.com

Case study 5 provides an example in which gaming has been used to engage citizens in environmental policy issues. Students at the University of Delaware played the game and later went on to interview local environmental scientists, decision-makers and officials (University of Delaware, 2012). The focus is primarily educational, although the creators claim the UVA Bay game can also be used by policymakers and industry as a 'test bed' (University of Virginia, 2013).

In order to collect data on certain species, some project organisers target groups of people who are particularly well-positioned to collect data on those species, through their occupations or leisure pursuits. Examples include fishermen and birdwatchers. In the Tag A Tiny Tuna project (Case study 6), fishermen are asked to tag tuna fish in order to help scientists estimate population sizes.

The Bat Detective project (Case study 7) uses a similar model of online participation to Galaxy Zoo and other Citizen Science Alliance projects. Participants classify bat sounds online. These sounds in term have been collected by volunteer contributors to the Indicator Bats (iBats) programme, currently covering parts of the UK, eastern

Case study 4: Air Quality Egg

Key facts
Location: Europe, North America and online
Partners: Sensemakers, xively.com
Budget: US $144,592 (€109,000)
Timescale: April 2012-current

Air quality monitoring stations used by authorities and scientists are often relatively far apart, providing only regional averages. However, air pollution can vary considerably on a local scale. Air Quality Egg sets out to involve the public in the debate on air pollution standards and policies by enabling them to monitor air quality in their immediate vicinity – at home or their place of work.

Members of the public are invited to purchase a small, easy-to-use air quality monitor. The sensor itself is placed outside and transmits data to the 'air quality egg' which is set up inside, and connected to the internet. The data are uploaded to the internet, and the egg also has an interactive function that allows the owner to check air pollution levels instantly. Air Quality Egg is a community-led, crowd-funded project born out of the 'Internet of Things' meetings, which bring together people interested in computer networking applications. Initial funding was raised online via a crowd funding website and product development is carried out partly via an open online discussion group.

The project is intended to engage members of the public in, and raises awareness of, air quality issues. The eggs are promoted as teaching aids in schools, providing data that can be discussed with pupils in the context of their local environment. The Air Quality Egg project has run several workshops in schools to explore the concepts of the eggs and engage in debate regarding air pollution.

Although the eggs currently provide relatively low quality data, as the sensors are uncalibrated, the developers hope to improve this, allowing the network of eggs to provide a freely available detailed dataset of local variations in air quality.

http://airqualityegg.com/

Case study 5: The UVA Bay Game

Key facts
Location: Maryland & Virginia, US
Partners: Azure Worldwide, IBM
Timescale: April 2009-current

Chesapeake Bay in the USA is the world's third largest estuary and extends over 165,000 square kilometres. In the past, nitrogen and phosphorus pollution have led to algal blooms and widespread fish deaths. Pollution remains a major threat to the bay today.

The University of Virginia developed the UVA Bay Game, which helps local communities understand the role of different stakeholders and activities on the Bay. The game combines real demographic, economic and ecological data into a video-game format and allows players to assume the roles of different stakeholders and make their own decisions which influence their own livelihoods as well as the health of the Bay itself. For example, a player assuming the role of a farmer can decide how much fertiliser to apply to their crops and then witness the effects of that decision on their own income as well as the health of the watershed.

The UVA Bay Game serves as both an educational and research tool. It has been used in universities to raise awareness and explore issues with students studying a variety of different subjects, from architecture to environmental sciences. It has also been played by 'real world' stakeholders and has facilitated useful discussion between parties that do not normally engage in such dialogue.

A more detailed version of the game is also being developed that will enable evaluation of specific policies and services. Global applications are being explored and a preliminary simulation for the Murray-Darling Basin in southeastern Australia has already been completed.

www.virginia.edu/baygame/

Case study 6: Tag A Tiny

Key facts
Location: Atlantic Ocean
Partners: Large Pelagics Research Center at the University of Massachusetts-Amherst
Budget: Unknown, funded by US National Oceanic and Atmospheric Administration
Timescale: 2006-current

Under the Tag A Tiny project, sports fishermen are recruited to measure and tag any juvenile Atlantic bluefin tuna they catch and release, as well as being encouraged to recover tags from previously tagged fish. The tags, which provide a unique identification for each fish, can provide information on population numbers. This is important because although it is thought that this species has suffered from over-fishing, exact population sizes are unknown.

So far, 1,258 recreational fishermen have helped tag 1,645 juvenile Atlantic bluefin tuna. The project relies on recaptures of tagged fish. It will require years or decades to accumulate enough of these returns for a full analysis. Currently, under 100 tags have been recovered, however, as more data are added, the researchers hope to increase accuracy of assessments of population size - vital information for sustainable fisheries management. The data are stored by the International Commission for the Conservation of Atlantic Tunas.

This project is also designed to engage fishermen and raise awareness of the importance of fisheries research, and may help to increase understanding of annual migrations and habitat use by tuna.

www.tunalab.org/tagatiny.htm

Europe, Ukraine, Russia and Japan (iBats, 2013). The programme has recently released smartphone applications for recording bat sounds and uploading them directly to the iBats website. iBats data can be viewed at: www.ibats.org.uk/OurProgram.aspx?ReportName=AllProjectsSummary

Case study 8 is an example of a citizen-led initiative that emerged spontaneously in response to local environmental problems in Finland. It demonstrates the complexities and limitations of working within the bounds of regulations to address citizens' concerns about their local environment.

3.2 Motivations for citizen scientists

Reasons for taking part in citizen science projects vary from project to project and from person to person. Understanding motivations of contributors – and project partners – can be key to the success of a project, but there can be a tendency to misunderstand or make assumptions about citizen scientists and their reasons for contributing (Grove-White *et al.*, 2007). For instance, in an initiative involving amateur naturalists in UK Biodiversity Action Planning, the Natural History Museum in London worked with various established naturalist communities. Grove-White *et al.*(2007) found that the organisers often oversimplified the participants' reasons for contributing, viewing them as unskilled enthusiasts, and taking their inputs for granted, rather than recognising individual motives.

> *"Conservation agencies need to rethink some of their own seldom-recognised assumptions and stereotypes. Amateur expert naturalists are not simply 'nerds' or 'anoraks' available to be harnessed, but skilled individuals with their own drives and motivations."*
> Grove-White *et al.*, (2007)

These misunderstandings may extend to policymakers, particularly because the important role of the volunteer is usually masked from the policymaker, who receives information through a third party (Ellis and Waterton, 2004). Equally, this distance between policymaker and volunteer can lead to volunteers feeling alienated from the policy process and concerned about how the data that they are collecting are being used. While Case study 9, taken from Ellis and Waterton (2004), is not new, it serves very well to illustrate the complexities of motivation and alienation for just one individual collecting data on mosses.

Case study 7: Bat Detective

Key facts
Location: Europe
Partners: University College London, Zoological Society of London, The Bat Conservation Trust, BatLife Europe, University of Auckland, and the Citizen Science Alliance (Zooniverse)
Budget: Unknown, funded by a Sloane Foundation grant
Timescale: October 2012-current

Bats provide important services to humans, including pollination and pest control, and they may also serve as 'indicator species' so that bat population changes can be used to monitor the health of whole ecosystems. However, as bats are difficult to catch and are mainly nocturnal, they are also very challenging to study.

The most effective method of surveying bats is using a bat detector which can transform bat calls into sounds that are audible to humans, but deciphering the different calls and recording the data takes a significant amount of time and current technology is not effective at identifying the calls of different species.

In the Bat Detective project, members of the public are invited to identify different species of bats from detector recordings that have been collected by volunteers across Europe as part of the Indicator Bats programme. Once the data have been assessed, the researchers hope to use the volunteers' classifications to develop sophisticated bat-call identification software that can be used worldwide. This could aid bat monitoring efforts and the study of environmental change.

To date, 1,592 users have created accounts on the website and submitted classifications and an unknown number have also provided classifications anonymously. The project is intended to raise awareness about bat populations in Europe and across the world. The website provides a blog highlighting these issues and a forum where users can discuss the different types of calls they have discovered in the recordings.

www.batdetective.org

Case study 8: Citizen-led activities at Lake Kirkkojärvi

Key facts
Location: Kangsala, Finland
Stakeholders: Local citizens in Kangsala, regional environmental centre, municipal authorities
Budget: None
Timescale: 2002-2006

In the 1990s, Lake Kirkkojärvi near Kangsala in Finland was recognised as an important habitat for birds and became part of the EU's Natura 2000 network of protected sites. However, the lake was in a poor condition due to eutrophication and unpleasant odours from algae, which were affecting local citizens. In 2002, the regional environmental authorities organised a public discussion event addressing the future of the lake. However, following the meeting it was concluded that no action could be taken due to lack of funding and the lake's protected status.

In 2004, local citizens became frustrated with the lack of action and contacted a local environmental official proposing to use an 'effective micro-organisms' (EM) solution to purify the water in the lake. The environmental official gave permission without informing the relevant authorities, assuming that the solution would be harmless but ineffective. The citizens' activity was then covered by local media, after which the regional environmental authorities banned further use of the EM solution in the lake.

By 2006, the condition of the water in the lake had markedly improved, but the environmental authorities did not want to acknowledge any connection to the EM solution due to lack of scientific evidence, and offered alternative explanations. In media coverage, citizens were unconvinced by the authorities' explanations.

Interviews with those involved suggest that the authorities felt they were bound to defend norms and regulations, and did not have the resources to nurture the growing interests and activities of local citizens. Citizens viewed the authorities as being inflexible and their expertise as questionable. The case demonstrates the potentially complex nature of interactions between citizens and local authorities.

Source: Leino and Peltomaa (2012)

Adults volunteering for projects in the environmental sciences may already have a keen interest in the natural world. But there are other possible motivations:

- The desire for social, environmental or political change (see Section 2.4.2)
- Gaining skills, increasing employability or changing career paths (Gollan *et al.*, 2012)
- Visiting attractive surroundings – if this is a major motivating factor for involvement, it can lead to problems sourcing volunteers for less attractive study sites (Van Swaay and Warren, 2012)
- Social groups and connections (Grey, 2009; Grove-White *et al.*, 2007)
- Pre-existing knowledge or even expertise in area being investigated – in large-scale projects, especially citizen cyberscience projects, it will often be unknown how many amateurs are actually experts (Wiggins and Crowston, 2011)

After a volunteer has begun contributing, other factors also come into play, such as attribution and recognition, and the perceived value of contributions. For example, in Old Weather (see Section 1.1), participants can gain the rank of 'lieutenant' or 'captain' after transcribing a certain number of ships' logs online (Gura, 2013). Citizen cyberscience projects that visualise data submissions in real-time provide instant gratification for participants. Roy *et al.* (2012) report that 42% of the environmental citizen science projects they reviewed – with many being mass scale, contributory projects – were able to provide dynamic updates. They view this as a strong motivating factor for continuing participation. Some projects also reward the most skilled or enthusiastic participants by inviting them to take on extra responsibilities, such as analysing data or managing groups of volunteers (Gura, 2013).

Community aspects are thought to be strong motivating factors for continued participation (Grey, 2009). Harnessing the now familiar functionalities of social networking sites, projects like YardMap (see Section 1.4) and eBird (see Box 2) offer platforms for social interaction between participants who may or may not be connected in the real

Case study 9: Judith

"Judith is a volunteer bryologist and an active member of the British Bryological Society. She can be described as contributing to policy in two related ways. On the one hand, she records the presence of moss species. She transmits the data into the cogs of the biological recording machinery by passing it first to a referee and Lead Partner; from there it enters into the [Biodiversity Action Plan (BAP)] reporting system… She has also contributed to a survey commissioned by a county council of a specific Site of Special Scientific Interest… Judith is highly ambivalent about her commitment to biodiversity conservation. In the past, she used to link her tireless efforts to know nature directly to the benefits she thought her knowledge might bring to biodiversity conservation. More recently, as she has been going out to record the mosses in her local 'patch', she has begun to feel a sense of alienation from the conservation world. A sense of resentment is gradually being borne based on the recognition that her data have being passed through many hands and perhaps undergone a series of manipulations… The data can be used both as part of a survey for planning reports and for the wider ongoing species reporting that enters more directly into the BAP… [Judith] muses that she no longer really understands the significance of such efforts: "Where does this information go, god knows!"… Her language and posture smack of the subversive; her marginalised status she believes is twofold. It places her in a unique alignment with(in) nature, something she cherishes and covets, but it is also a positioning that denies her control over the final processing and practical translation of her data. Judith's story illustrates the peripatetic nature of volunteer identity as she navigates the spaces of inclusion and exclusion in biodiversity policy. She moves in between a world of responsible biological recording in the name of conservation and a world of passionate engagement with nature. The policy framework only demands a fraction of her total engagement with nature in that it is ostensibly interested only in record cards and new data to inform the UK picture of the distribution of mosses. Judith's passion and loyalty become a 'residue' that is left behind and apparently has no recognised function in the policy domain."

Source: Ellis and Waterton (2004).

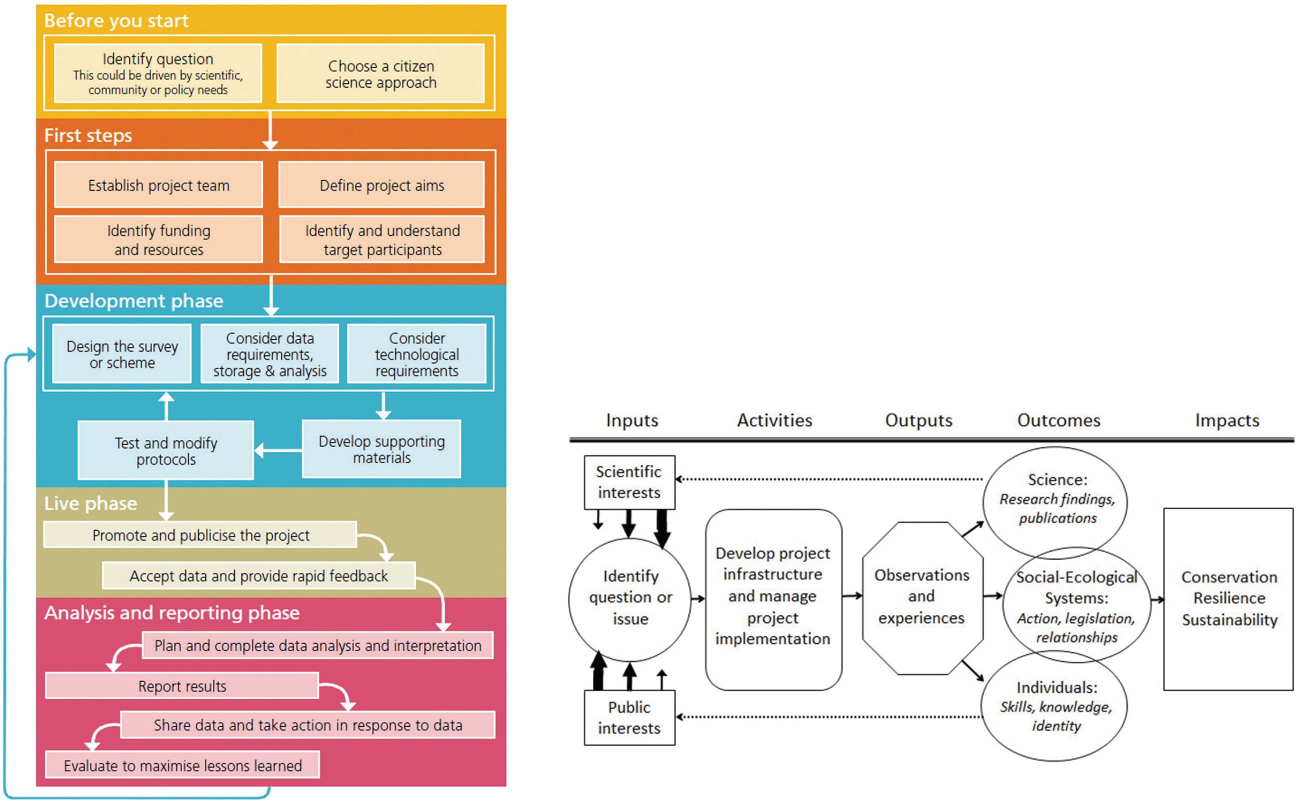

Figure 5 a) Tweddle *et al.*'s (2012) proposed method for developing, delivering and evaluating a citizen science project b) Shirk *et al.*'s (2012) framework for public participation in scientific research, within an ecology context.

world. While social connections may be more easily characterised online, they are clearly important in more traditional projects too. Thus, collaborative and co-created projects that involve face-to-face interactions between partners serve to build a sense of community (Bonney *et al.*, 2009a) that may aid their cause. In some cases, however, organisations with pre-existing social groups are involved in data collection – examples might include ramblers or anglers – and in these cases it may be important for organisers to understand group dynamics (Grove-White *et al.*, 2007).

3.3 Frameworks and guidelines for projects

Frameworks

A number of researchers have provided frameworks for the design and management of citizen science projects that are relevant to environmental studies. The process is perhaps most simply summarised in the nine basic action points of Bonney et *al.'s* (2009b) model (see Box 4), based on experiences over two decades at the Cornell Ornithology Lab. A roughly similar and self-explanatory model is outlined by Tweddle et al. (2012), drawing on outcomes from the UK Environmental Observation Framework's report on citizen science and environmental monitoring (see Figure 5a).

Another framework (Figure 5b) developed by the Cornell Lab of Ornithology (in partnership with other US universities, the Carnegie Museum of Natural History and DataONE) offers a more thoughtful perspective on inputs and outcomes (Shirk *et al.*, 2012). Inputs are divided into scientific and public interests – these interests can be used to define the goals of the project. For instance, some scientists may be interested only in collecting data about bird populations, while others may be more interested in educating the public about bird biology, behaviour and habitats. As such, it is possible to approach the first task of identifying or defining the research question from two subtly different perspectives: whether a citizen science project is the best method for answering the research question being addressed (Tweddle *et al.*, 2012); or whether the proposed research question is appropriate for citizen scientists (Bonney *et al.*, 2009b). Either way, there is a need to consider what kind of scientific questions, and which questions specifically, can be answered through citizen science (Haklay, 2012). A clear definition of aims is key, whether education, science or other outcomes are to the fore.

In Shirk *et al.'s* model (2012), outcomes are clearly divided into science outcomes; social-ecological systems, including action and legislation; and outcomes for individuals, such as skills and knowledge. The social-ecological systems category is potentially most affected by the quality of inputs, depending on 'deep collaboration' between stakeholders in the early stages to achieve environmental policy and management goals.

Guidelines

For practitioners, Tweddle *et al.* (2012) provide a practical guide to the process of setting up and managing a citizen science project. This guide is freely available at: www.ceh.ac.uk/products/publications/documents/citizenscienceguide.pdf. Van Swaay and Warren's (2012) report on butterfly monitoring in Europe includes a guide to setting up a butterfly monitoring scheme. In addition, Mathieson (2013b) offers advice for teachers considering using citizen science in the classroom, emphasising that students should be contributing to real science, relating to locally relevant issues – such as air quality or soil health – and with a sense of realism about resources.

These frameworks and guidelines provide for the public participation in scientific research model of citizen science, particularly at lower levels of engagement, but advising on the most 'extreme' and participatory forms of citizen science is complex. Wakeford (2004) argues that there is no single mechanism or optimal formula for participatory initiatives and that attempts to standardise or replicate protocols across widely different projects, involving widely different groups of people and institutions, would be misguided.

Box 3: eBird – Friendly competition

"Today eBird is almost like Facebook for birders, a social network they can use to track and broadcast their birding lives. The eBird database, as well as an associated smartphone app, lets birders organize everything from their life lists -- all the species they have ever seen -- to the number of times they have seen a particular species, to lists of what they have seen at favorite spots. Just as important, they can see everyone else's lists -- then try their damnedest to outdo them. When [an eBird user] saw two least flycatchers at an eastern Colorado grassland, he could quickly see that his was the earliest sighting of the bird that spring. 'Yes, we got the record!' he exclaimed."

(Rosner, 2013)

Box 4: Bonney *et al.*'s (2009b) 9-step process for developing a citizen science project

1. Choose a scientific question.
2. Form a scientist / educator / technologist / evaluator team.
3. Develop, test, and refine protocols, data forms, and educational support materials.
4. Recruit participants.
5. Train participants.
6. Accept, edit, and display data.
7. Analyse and interpret data.
8. Disseminate results.
9. Measure outcomes.

3.4 Quality assurance of citizen data

Citizen science projects can be split into two types depending on the quality assurance methods employed: verified citizen science, in which observations are checked by experts; and direct citizen science, in which observations are submitted without verification (Gardiner *et al.*, 2012). When the two approaches were compared for US and UK ladybird monitoring projects, researchers found that with verified approaches, accurate estimates of insect abundance could be obtained using fewer volunteers. While direct citizen science was the cheapest method, verifying citizen science data was still more cost-effective in terms of data gathered per dollar than a traditional approach involving no volunteers.

Roy *et al.*'s recent review (2012) suggests most environmental citizen science projects do use quality assurance methods at some level. Common measures include filters to remove data that fall out of a study's range due to time or geographical limits. More rigorous approaches include testing and observation of study participants to establish common errors and how often these errors are likely to occur. For example, in OPAL (see Section 2.4), which involves volunteers in community wildlife and environmental monitoring, participants were asked to take online tests during the project design stage.

Many projects require citizen scientists to complete training before participating. For example, around 1,000 participants in a US monitoring study of crab distribution were trained in hour-long sessions focusing on practical skills for identifying species and gender, and measuring carapace width (Delaney *et al.*, 2008). They were also provided with teaching texts and field guides. Among citizen cyberscience initiatives, forums and frequently asked questions (FAQs) pages are common, and videos and interactive tutorials are sometimes provided (See Old Weather (oldweather.org) and YardMap (yardmap.org) for examples). Online training tools and video-sharing websites could also be put to better use in supporting training for field studies, as a way to revisit content and reach remote participants (Gollan *et al.*, 2012).

Following submission of data, mathematical models can be used to deal with bias – in particular when it is not feasible to use standardised field protocols. For example, geographical bias can occur in projects that are coordinated online, because participants are self-selected; the locations of sites depend on where participants live, rather than on any pre-determined, even distribution. In a recent study focusing on butterfly and dragonfly distribution data collected by citizen scientists in the Netherlands, 'occupancy models' were successfully used to control for geographical bias[42], as well as observation and reporting bias , yielding usable data (Van Strien *et al.*, 2013). The authors of the study suggest this approach can help increase the value of citizen science data.

Some researchers argue quality assurance methods should be viewed as essential aspects of all citizen science projects (Delaney *et al.*, 2008; Gollan *et al.*, 2012). Given concerns about data quality, such methods offer a way to increase confidence in the validity of scientific findings from citizen science projects.

3.5 Communication and recruitment

Through years of experience in setting up national monitoring schemes in a number of European countries, the charity Butterfly Conservation has developed procedures for recruiting participants based around the work of a project coordinator who is tasked with giving lectures, writing articles for journals and magazines, and meeting with volunteers (Van Swaay and Warren, 2012). Some large, funded projects also benefit from the efforts of dedicated staff. However, smaller but equally valuable projects may rely on scientists, teachers and community organisers with limited time and resources for recruitment and communications. In such cases, support and commitment from a wide variety of different stakeholders can be sought - whilst accepting a reasonable degree of uncertainty about project outcomes (Gray *et al.*, 2012).

The Cornell Lab of Ornithology's citizen science toolkit offers advice on recruiting volunteers (Cornell University, 2013), highlighting the importance of considering incentives and motivation, as discussed above, and remembering that it is not helpful to talk about 'using' volunteers:

> *"Avoid perception (or reality) of exploitation. One tip: avoid the phrase: 'this project **uses** volunteers to' ..."*

According to the toolkit, it is also crucial to consider how chosen recruitment strategies will influence the participant profile. Using new technologies such as smartphones could be a useful way to engage young people, or it could present a barrier to participation for those who are less likely to have access to such technologies.

[42]Observation bias refers to differences in detection and identification; reporting bias describes incomplete or selective reporting (Van Strien, et al., 2013).

Closing remarks

Citizen science encompasses a range of different ways in which citizens are involved in science. Most formalised citizen science projects are contributory projects led by scientists and NGOs, in which citizens collect scientific data on behalf of experts. These projects represent powerful approaches to data gathering and could help address research and resource gaps in the environmental sciences. However, they may fail to recognise the greater potential of citizens to define scientific research questions, contribute local and situation-specific knowledge, carry out more complex analyses and participate in decision-making about environmental issues.

One barrier to the use of information produced through citizen science is the perception that the quality of research carried out by citizens does not match that of research carried out by scientists. However, while data quality may be variable due to differences in the skills and expertise of individual participants, citizens can certainly attain the same levels of scientific rigour given the access to appropriate information and training. In addition, citizens can help define and address research questions – through scientist- or citizen-led initiatives – that may be more relevant to their local environment and society.

New mobile technologies, such as smartphones and tablets, offer citizens the chance to contribute to environmental science and discussions about environmental policy remotely. Used appropriately, these technologies hold the potential to change the way that environmental research, monitoring and policymaking are carried out. However, the increasing use of these tools in citizen science initiatives may risk distracting from more meaningful interactions between scientists, policymakers and citizens about the environment.

It is difficult to provide evidence for the influence of citizen science on environmental policymaking, particularly as in Europe at least, many initiatives that emphasise participatory forms of democracy are in their early stages. Informal examples such as environmental justice cases, often centred around local environmental issues, are less well defined as citizen science and are not necessarily cited in academic literature. However, they demonstrate what can be achieved by citizens when motivated by local environmental threats. As such situations arise spontaneously, it may be beneficial for authorities to consider how they can work together with citizen scientists to address local environmental issues when they arise.

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Appendix I: Example projects

The following is a list of citizen science projects cited in this In-depth Report. They provide a representative example of those available in the research literature and reflect a variety of approaches to citizen science.

Achuar-Amazon Watch initiative
http://amazonwatch.org/work/achuar

Air Quality Egg
http://airqualityegg.com/

ALLARM Acid Rain Monitoring Project
www.dickinson.edu/about/sustainability/allarm/

Amateurs as Experts
www.lancaster.ac.uk/fss/projects/ieppp/amateurs/

The Audobon Society's Christmas Bird Count
http://birds.audubon.org/christmas-bird-count

The Barnegat Bay Partnership
http://bbp.ocean.edu/pages/145.asp

Bat Detective
www.zooniverse.org/project/batdetective

Citizen-led activities at Lake Kirkkojärvi
www.sciencedirect.com/science/article/pii/S1449403512000215

The Big Butterfly Count
www.bigbutterflycount.org/

The Birdhouse Network (now NestWatch)
http://nestwatch.org/

Buckeye Lady Beetle Blitz
http://ladybeetles.osu.edu/

Butterfly Conservation Europe – Butterfly Monitoring
www.bc-europe.eu/index.php?id=339

The Chicken Coop Stakeout
http://chickencoopstakeout.wordpress.com/

CITCLOPS - Citizens' Observatory for Coast and Ocean Optical Monitoring
www.citclops.eu/

CITI-SENSE
www.citi-sense.eu/Project/tabid/10642/Default.aspx

ClimatePrediction.net
www.climateprediction.net/

COBWEB – Citizen's Observatory WEB
http://cobwebproject.eu/

Community Collaborative Rain, Hail & Snow Network (CoCoRaHS)
www.cocorahs.org

Community Health Effects of Industrial Hog Operations
www.ncbi.nlm.nih.gov/pmc/articles/PMC2446444/

Corfe Mullen Bio-Blitz
http://www.dorsetwildlifetrust.org.uk/corfe-bioblitz

CreekFreaks
www.creekfreaks.net

eBird
http://ebird.org/content/ebird/

Eco21.PL
www.mappingforchange.org.uk/portfolio/eco21-pl/

Erie Rising
www.erierising.com

EVERYAWHERE
www.everyaware.eu

Eye on Earth
www.eyeonearth.org

FuturICT
www.futurict.eu

Galaxy Zoo
www.galaxyzoo.org

The Great Sunflower Project
www.greatsunflower.org

Hunter Valley rehabilitation project
www.ncbi.nlm.nih.gov/pubmed/22875540

Invasive crabs (US) project
http://link.springer.com/article/10.1007%2Fs10530-007-9114-0

Invasive Plant Atlas of New England
www.eddmaps.org/ipane/

ITDG Zimbabwe project to restore local food security (p9)
http://practicalaction.org/docs/advocacy/democratising_technology_itdg.pdf

Lost Ladybug Project
www.lostladybug.org/

Monarch Larva Monitoring Project
www.mlmp.org/

Appendix I: Example projects

National Bat Monitoring Programme
www.bats.org.uk/pages/nbmp.html

National BioBlitz Network
www.bnhc.org.uk/home/bioblitz/

Nestwatch (was The Birdhouse Network)
http://nestwatch.org/

Old Weather
www.zooniverse.org/project/oldweather

OMNISCIENTIS – Odour Monitoring and Information System based on Citizen and Technology Innovative Sensors
www.omniscientis.eu

OPAL – Open Air Laboratories
www.opalexplorenature.org/aboutOPAL

Open Street Map project
www.openstreetmap.org

Pan-European Common Bird Monitoring Scheme
www.ebcc.info/pecbm.html

Picture Post
http://picturepost.unh.edu/

Project Budburst, including floracaching game
www.budburst.org

Reclam the Bay
www.reclamthebay.org

Royal Docks Noise Mapping
www.mappingforchange.org.uk/portfolio/royal-docks-noise-mapping

Salal Harvest Sustainability Study
http://nature.berkeley.edu/community_forestry/People/Final%20 Reports/ballard_report.pdf

Science, Democracy and Community Decisions on Fracking
www.ucsusa.org/assets/documents/center-for-science-and-democracy/ Decisions_On_Fracking_Forum_Summary.pdf

Seafloor Explorer
www.zooniverse.org/project/seafloorexplorer

SETI@Home
http://setiathome.berkeley.edu/

The Shale Network
www.shalenetwork.org

Sherman's Creek Conservation Association
www.shermanscreek.org

Spotting the Weedy Invasives
http://trails.rutgers.edu/

SusClime
www.pbl.nl/en/publications/1995/SusClime_a_simulation_game_ on_population_and_development_in_a_resource

Tag a Tiny
www.tunalab.org/tagatiny.htm

UK Ladybird Survey
www.ladybird-survey.org

UVA Bay Game
www.virginia.edu/baygame/

Vigie Nature
http://vigienature.mnhn.fr/

WESENSEIT
www.wesenseit.com

West Visayas State University teacher training
http://democracyeducationjournal.org/home/vol20/iss1/2/

What's Invasive
http://whatsinvasive.com/

Yardmap
content.yardmap.org