Whitepaper on Citizen Science for Environmental Research

Date: April, 2015

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Executive Summary

Citizens and amateur naturalists have been involved in monitoring their natural surroundings for centuries. Recently, the rapid expansion of mobile phone technology, the phenomenon of the social web, and a societal awareness and concern for environmental conservation issues has created a surge of interest in citizen science for environmental research. This report describes some of the key characteristics of citizen science projects, including the different ways that citizens can be involved in projects, how citizen science is deployed for research and monitoring, benefits and challenges of citizen science, and design considerations for successful project implementation. The nature of citizen science is highly heterogeneous. User involvement can vary from citizens acting as passive sensors to acting as engaged collaborators. One of the key insights found in this report is that citizen science is not free, but requires active engagement and management from scientists and host organizations. Clearly articulated research questions, well-designed data collection protocols, and tailored information products relayed back to participants are minimal requirements for successful projects. Citizen science can also provide enormous value in terms of expanding the spatial and temporal scope of sampling, providing scientific and educational benefits to project participants, and answering real research questions related to ecology, especially over large spatial and temporal scales. Careful design and linking of social and scientific components of citizen science can provide important engagement of citizens in science, enhance their understanding of the natural world, and aid in the development of scientific knowledge for environmental stewardship and management.

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1. Description of citizen science

Canada is today at an important transition point in citizen science. While membership in many traditional formal naturalist organizations is waning, interest in new environmental non-governmental organizations (ENGOs) like David Suzuki Foundation, attendance at the Canadian Museum of Nature and other museums, and enrolments in post-secondary environment-related courses are all growing rapidly – *citizens of all demographic profiles and backgrounds are interested in the environment and contributing to its conservation*. With this growth has come a resurgence in harnessing concerned citizens as environmental monitors and scientific information gatherers, with new citizen scientist initiatives springing up as part of national, regional and local initiatives.

The expansion of citizen science in Canada and across the globe has been greatly facilitated by the development of web 2.0 technologies and the phenomenon of user-generated content, whereby individuals have become comfortable sharing many aspects of their lives through digital intermediaries like social networks, websites, knowledge repositories, and other online tools. Increasingly, researchers and NGOs are turning to these tools as a source of information for a wide variety of applications, from astronomy to biodiversity to conservation; citizen science approaches are proving valid and useful as sources of observational data. As citizen science projects make use of emergent mobile computing, online mapping (i.e., geoweb technologies) and social networking tools to crowdsource environmental data, the ability to launch new projects is eased.

Citizen science is also increasingly relevant in many scientific disciplines. While amateur involvement in some aspects of science has occurred for centuries, today citizens are able to contribute to the monitoring and tracking of long-term environmental changes over vast spatial and temporal scales, and ultimately provide observations that can be used by scientists to detect patterns, test theory, and develop hypotheses, as well as serving to educate and engage citizens. Participation in citizen science initiatives is typically open to the public, has a low barrier to entry in terms of financial costs, equipment, and skill-level, and requires cooperative engagement on an ongoing basis with researchers. For example, environmental citizen science activities often combine aspects of ecological research with environmental education and natural history observation (Dickinson et al 2010). In this report, we will focus exclusively on environmental citizen science – that is – citizen science initiatives that are directed at answering environmental and ecological research questions.

The ideas and methodologies for scientific use of environmental observations provided by amateur and hobbyist naturalists came mainly from ornithologists. The widely regarded Christmas Bird Count (CBC) has occurred annually since 1900, and has provided data that have been used in hundreds of scientific reports[1], covering aspects of distribution, population dynamics, community ecology, and methodology. For example, Rybicki and Landwehr (2007) used CBC data to show how waterfowl population change was related to several water quality parameters. Similarly, Hochachka and Dhondt (2000) used CBC data to represent denominator data in a study of infectious disease dynamics in house finches. The CBC has a relatively low barrier-to-entry that relates to its ongoing success: the timing of once-per-year lends itself to an annual activity for families on a

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[1] See http://www.audubon.org/content/christmas-bird-count-bibliography for full bibliography

day when most are home and not engaged in work or school, and a simple sampling design using pre-selected areas and simple bird counts makes the actual data collection relatively simple. A complementary program, the North American Breeding Bird Survey (BBS) is a more in-depth citizen science initiative run by government departments in Canada, the USA, and Mexico which has been running since 1966. The BBS aims to track the status and trends of North American bird populations by surveying birds along roadside survey routes across North America each spring. The BBS requires advanced ability to identify all breeding birds in the area in order to participate, and requires a significantly greater investment in time and effort (requiring driving along the survey route). According to the BBS, the data has been used in over 450 scientific papers and reports.

The importance of baseline population data is only ever apparent after the fact, and while government-funded baseline ecological monitoring programs have seen reductions throughout most of North America over the last few decades, the public interest in bird behaviour has evolved into a passionate hobby for individuals; one requiring patience, significant intellectual effort, and much time. It is unsurprising that avian citizen science projects have seen the widest success and provided a motivation for citizen involvement in environmental science more broadly. The degree to which these successes can be replicated for other animals and environmental issues depends on a number of factors related to the design of the project, the perceived and actual barriers to entry, and the suitability of research objectives (Dickenson et al. 2010).

With citizen science, it is not simply a case that if you build the tools people will use them. The success of citizen science projects hinges on many factors including a clear question, careful design, stakeholder involvement, appropriate technology, and ongoing participant feedback. Sustaining and expanding participation in citizen science initiatives can also benefit from development of innovative, durable tools for educators and community groups that become champions for participation, and providing active support and encouragement for participants. The specific tools, activities and initiatives that are appropriate for a given project depend on the characteristics of the user communities, the objectives of the project, and the governance, regulatory, and political context within which the project operates.

A recent report for the United Kingdom Environmental Observation Framework completed a comprehensive synthesis of citizen science including a review of over 200 projects, interviews with end-users, and illustrative case studies (Roy et al. 2012). What emerged from this comprehensive report was that the perceived quality of user-generated data by end users (e.g., government, NGOs) severely limited its use, while the case studies and reviews indicated that the quality of the data were often sufficient for many of the applications that those users required. There is often a disconnect between the *collection* and *use* of user-generated environmental data. It is therefore critical to involve stakeholder feedback from data users as well as contributors into the design of any citizen science project. In fact, every type of data contributor to a project should also be viewed as a data consumer, and outputs should be developed that cater to their needs and characteristics. This is an almost universal truth of citizen science: **providing tools and information products back to project contributors is at least as important as providing tools to collect data from contributors**. Studies of citizen science-generated data show that, when obtained through carefully constructed protocols, data can be of a reliability comparable with traditional scientific data collection (Bonney et al 2009, Obrecht et al 1998, Oscarson & Calhoun 2007, Delaney et al 2008, Beaubien & Hamman 2011).

1.a – Citizen Involvement

One way to stratify classes of citizen science projects is by the characteristics of citizen involvement. The scope of citizen involvement varies from game-driven or matching applications where the science aspect of the application is hidden or de-emphasized to the user, to projects like the Breeding Bird Survey that require extensive training/expertise, investment of time and effort for scientific purposes. The type of involvement is directly related to the motivation of project participants, and ultimately the project sustainability. When barrier-to-entry is low, large numbers of participants are drawn into the project, however these can be considered weak-ties in terms of commitment, which may result in large participant drop-offs over time. Alternately, where barriers-to-entry are high, participants may be more committed and willing to participate for longer periods of time resulting in more vibrant and sustainable initiatives. Building on evidence of *produsers* (information producers who are also users) in open source projects and Wikipedia contributors, the motivations and of data-producing participants (in the context of citizen-based mapping) were summarize in a typology by Coleman as moving from neophyte to expert authority (Table 1). And while these classifications are in relation to knowledge/competence, they are impacted by the type of information context, whether market-driven, social networking, or civic/governmental, as well as the level of accountability (e.g., the consequences of providing incorrect information).

An alternate lens through which to view citizen involvement is through the motivation participants have to contribute information. Coleman et al. (2009) describe a list of both positive and possible negative motivations for participating in mapping projects, which we have adapted to environmental citizen science in Table 1. The list of motivations covers a wide range of possible reasons why people might contribute. These are important to consider when making design choices that can exploit these motivations to build a more successful project, as well as when considering data anomalies and undertaking data quality assessments.

Table 1 Motivations for contributions to environmental citizen science (adapted from Coleman 2009).

Motivation	**Example**
Altruism	Desire to make a contribution to improving scientific understanding
Professional / personal interest	Improve species identification or fieldwork skills and/or experience
Intellectual stimulation	Learn more about scientific data collection methods
Protection or enhancement of personal investment	Document presence of a listed species to prevent a development project
Social reward / reputation	Be part of a streamkeepers community / become known as a local naturalist expert
Pride of place	Document and all species of bird in a park, or fish in a river in one’s local community

Mischief*	Purposefully misreporting observations to cause confusion
Agenda*	Over or under-counting a species to promote environmental regulation or promote policy change
Criminal intent*	Reporting incorrect information with the aim to benefit from stock market transactions

An implicit assumption in the discussion above is that the role of citizens in citizen science is that of data collector – with the purpose of engaging citizens being solely to increase the sampling size of the research initiative. While this is by far the most common scenario, other roles for citizens in science are possible and actively encouraged by many in the citizen science community. Haklay (2013) provides a typology of involvement which begins at the lowest level of 'crowdsourcing', which employs the 'citizen-as-sensor' method whereby participation is limited to automatic recording (through physical sensors or computers). A higher level of participation is that of 'distributed sensing' where participants are included as basic interpreters of environmental phenomena, requiring some cognitive ability on behalf of participants. Typically, basic training is provided to participants and then they are asked to conduct relatively simple data collection and/or interpretation activities. The majority of environmental citizen science projects can be characterized as 'distributed sensing'.

A higher level of involvement can occur when participants are directly involved in the problem definition and data collection methodology, which requires a greater degree of consultation and interaction with scientists. Haklay (2013) describes this as 'community science' – and highlights the potential that higher-level involvement may have in terms of project sustainability and the relevance of the findings to stakeholders. A final collaborative stage is that of 'collaborative science", whereby professional and non-professional scientists work together on all aspects of the scientific enterprise from problem definition, data collection protocols, and even analysis and interpretation in some cases. This requires scientists to engage as both facilitators and experts when conducting projects. While each of these levels of participation may be suited to specific types of projects, this stratification also exposes the divide between the public and scientists, and moves towards reducing this divide as level of participation is increased.

1.b – Research and Monitoring

Citizen science can be deployed for a variety of reasons. In environmental applications, species conservation research, stewardship, and monitoring are common areas where citizen science is used. As has been noted earlier, the integration of conservation and environmental stewardship science with citizen-involvement is in fact an activity that predates the professionalization of science itself. The specific aims of conservation-oriented citizen science can vary, but typically programs are designed around questions that are large in spatial and temporal scale, and benefit greatly from expanded sample size. Often, the scientific domains that meet these requirements center around population monitoring problems such as range expansion or effects of habitat fragmentation on species abundance or diversity. Devictor et al. (2010) describe the potential applications of citizen science in conversation biogeography, highlighting applications related to invasive species (e.g., green crabs), birds in fragmented forests, various programs run by the Toronto Zoo such as FrogWatch Ontario and the Ontario Turtle Tally, and the garden moth count in the United Kingdom. Dickenson et al (2010) also note that the greatest growth in citizen science has been in monitoring biodiversity across broad geographical scales, answering questions about colonization and extinction dynamics, landscape pattern on ecological process, and ecological niche mapping. The salient point highlighted by these programs and throughout the literature is that citizen science is best applied when and where people are ordinarily living. This connects citizens with nature in and around areas that are completely familiar to them, links biodiversity and species conservation to a human scale of experience, and acts to reinforce place attachments that foster further conservation activities and mindsets (Miller 2005; Evans et al. 2005).

2. Benefits of Citizen Science

As discussed above, the purpose of citizen science projects can vary greatly. However one of the more frequent scientific reasons for taking a citizen-science approach is to expand the sampling effort of an ecological monitoring or research program. Many projects have succeeded in this regard, with for example, Cornell's eBird project recording over 100 million observations of over 10,000 species and the CBC recording over 68 million birds in 2014. As noted by Devictor et al (2010), research objectives that are facilitated by greatly expanded sampling are particularly suitable for citizen science. Expanded sampling efforts on account of citizen involvement can include expansion geographically to new areas, densifying existing sampling, and in some cases, creating temporally continuous monitoring which can be vital for examining population processes over large spatial and temporal scales. For example, a recent paper published in Proceedings of the National Academy of Sciences was able to link outbreaks of bovine spongiform encephalopathy in Europe with beef exports from North America and haying practices in North American agricultural landscapes, that directly impacted grassland bird populations as recorded in Breeding Bird Survey (Nocera and Koslowsky 2011). Given that the linkages in this study occurred over two continents and included 3 year time lag effects between cause and population response, this could only have been realized with population data recorded continuously over very large areas.

A review of examples of research results related to birds obtained from citizen science data is provided in Dickenson et al. (2010) – which includes response to climate change, population dynamics, landscape ecology, and macroecology. While bird research is probably a 'best-case' scenario in terms of citizen science research outputs, increasingly the methods and technologies pioneered by ornithologists are being transplanted to new ecological domains. Citizen science data has proven to be useful for scientific purposes in plant phenology (Jeong et al. 2013), climate change-driven adaptations in indicator species (Silvertown et al., 2011) in addition to the numerous papers using data from The Cornell Lab of Ornithology projects (Bonney et al., 2009).

It is important to note the distinction between systems where citizens are used by necessity (and in ideal world, would be replaced by scientists) from those in which citizens must be used to collect data as part of the problem being investigated. For example, the NatureWatch project aims to provide portals for a variety of citizen observations – including Frogs, Ice, Plant, and Worms. The NatureWatch project, originally conceived out of a partnership between Environment Canada, NGO Nature

Canada, and other organizations, was one of the early and leading environmental citizen science projects in Canada (and since transferred to University of Ottawa, now Wilfrid Laurier University). The objectives of NatureWatch include data collection for tracking change in the environment, but also utilizing new web-based tools to connect citizens with nature and provide educational opportunities for citizens related with environment and science generally. Almost all major citizen science projects today now consider educational benefits to the community as a key objective. One of the world leaders in citizen science methodology, the Cornell Lab of Ornithology (with over 600 projects) which focuses on citizen science for bird research and conservation, includes educational resources for all levels of participants and makes education and outreach a component of all citizen science projects. As described in section 4 of this report, education and outreach also serve the dual function of facilitating the knowledge flow-back to participants and thereby increasing opportunities to build a user-community dedicated to the project.

3. Challenges of Citizen Science

There are many well-documented challenges associated with citizen science. Depending on the aims of the project, these may take on greater or lesser degrees of importance. The challenges can relate to the project itself or the characteristics of the data. Here we will review challenges of working with citizen science *data* in environmental research:

1. Variable Data quality – error (misclassification) due to variable expertise and/or training
2. Sampling bias – data clustered in accessible areas at opportune times (bias in space and time)
3. Data format issues (numbers entered as text, incomplete descriptions etc.)

Data quality is perhaps the most-cited and researched dimension of citizen science information. However, it is important to consider that data quality is not inherent, but must be approach through utility. Most data quality research centers on the concept of *fitness for use*, whereby data quality evaluations are referenced to a specific use-case. To this end, the design of data collection protocols that are specific to an over-arching research question is an essential aspect of citizen science design. Most concerns over data quality relate to the capacity for error due to the inherent variability in ability relative to professional scientists. The importance of this aspect of data quality is therefore highly contextual – and related to the tasks required of participants. For example, projects requiring species identification by visual or auditory recognition may require different levels of training and skills assessment in order to ensure a baseline level of competence. Typically, the propensity to commit classification errors is reduced as experience in the project increases (Jiguet 2009), however assessing this is contingent on interactive project activities that include periodic data quality assessments.

Sampling bias is a more pernicious characteristic of citizen science data. Sampling bias is the result of variation in citizen participation with respect to time, space, species of interest and/or habitats that leads to variability in the resultant data. As much of the research focus of citizen science relates to spatial and temporal patterns, understanding sources of sampling bias is critical. Note that sampling bias is found in all participant-generated data sources, and methods do exist to deal with it. For example, Robertson et al. (2011) used a latent-effects statistical model to identify sampling bias in participant-generated animal health surveillance data which showed that submissions varied with technical ability, age, and gender. Such techniques can be used to recalibrate training activities as well as to filter data such that analysis can still be performed once sources of sampling bias have been controlled for. When sampling bias is ignored in citizen science data, analysis may find over-reported rare species, under-reported common species, as well as day-of-the week effects. Standardizing sampling efforts over time can be an important design strategy to reduce temporal sampling bias.

Spatial sampling bias is even more common and difficult to handle than temporal bias, as this is greatly impacted by access. Often, maps of user-contributions to citizen science projects will follow road-networks and populated areas. The key problem with spatial sampling bias is that resultant spatial patterns mask this bias, because the gaps or absences observed in the pattern do not reflect true absence, but simple lack of sampling. This makes interpreting patterns wrought with error and subjective interpretation. A typical way to handle spatial bias is to only compare areas that have equivalent levels of participation (e.g., urban parks or ravines). Alternately, anomalies can be detected through spatial statistics, and removed, or general spatial trends can be estimated over densely sampled areas only. However, design-based approaches to develop spatial sampling plans that reduce spatial (and other) sampling biases are more effective than trying to handle biases statistically after data has been collected.

A final challenge of working with citizen science data pertains to issues related to the inherent variability that results from having less control over data collection compared to a more traditional field research project. Many unforeseen issues can arise that impact the characteristics of the data such as: numeric data entered into a computer interface as text, variable levels of descriptive information in text-fields, different formats of photos or text submissions, different and variable interpretation of project tasks, definitions, and activities, and many more. While many of these are technical in nature and can be handled or easily spotted, even the most carefully designed training and collection protocols can yield data with surprises. Analysis of citizen science data requires high attention to detail, extensive data cleaning, processing, and exploratory analysis, and ongoing verification of data collection technologies.

4. Design Strategies for Citizen Science Projects

The design of effective citizen science projects requires careful consideration of scientific, social/cultural, and technological requirements. Bonney et al. (2009) provide a roadmap for citizen science projects. The key steps in program design are:

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. Analyze and interpret data
8. Disseminate results
9. Measure outcomes

These steps are covered in detail in Bonney et al. (2009), and can be broadly used to specify design strategies for nascent citizen science projects and/or reformulate existing projects.

A broad conceptual framework for citizen science project design was given by Devictor et al (2010), and includes ongoing interaction between scientists and citizens (Figure 1). The variable levels of participation (as articulated by Haklay 2013) are represented in Figure 1 as dotted areas, such that in higher-level scenarios (community science and collaborative science) the interaction between citizen and scientist is reciprocal for aspects question design, protocol formulation, and outreach activities. In classical citizen science, only the data collection process goes from citizen-to-scientists. The linkages expressed in Figure 1 are supported by factors that drive success of projects. Firstly, **simplicity** is a key design virtue. The project objectives and methods should be transparent to potential participants, easy to explain and understand without technical jargon. A structured data collection **protocol** is required that matches participant abilities and interests with research objectives. The protocol must include both detail data collection interfaces as well as relevant training required for participation. Realistic descriptions of participant expertise should be clearly stated. **Feedback** of data to participants is mandatory. This can include reports, graphs, charts, and should be made available rapidly to participants. The design of information products can be tailored to match the anticipated or recorded motivations of project participants. A clear **communication** strategy is essential to citizen science. This should include press releases, networking events, and a clear and communicative project website. Finally, a **sustainability** strategy is required. Citizen science projects must be actively managed by researchers and managers that ensure continuity of data collection, user-community outreach and technical support, and that scientific objectives are being met. If a citizen science project champion is no longer with the organization, replacement leaders must be established or the project should be discontinued.

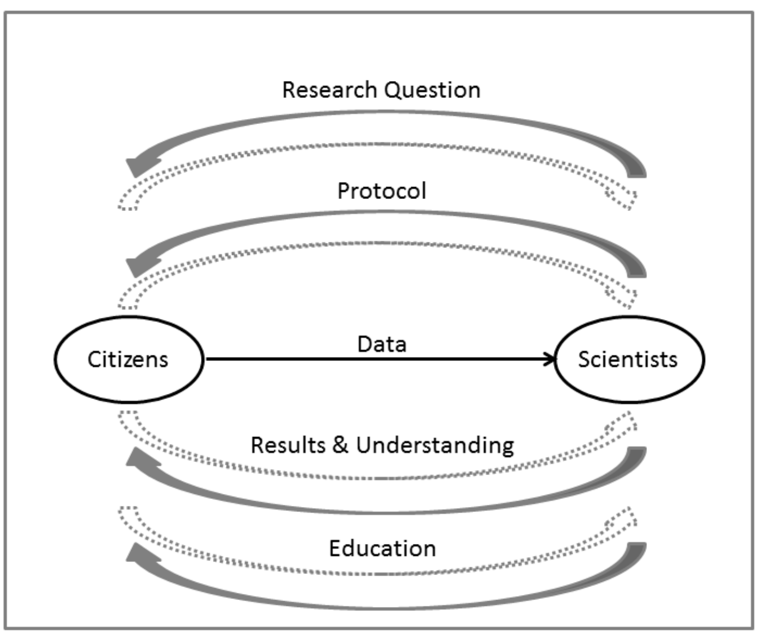

Figure 1 General conceptual framework for citizen science program design (adapted from Devictor et al. 2010).

An excellent review of citizen science projects in the UK is given by Roy et al. (2012). In this paper, a summary of many projects is provided. In addition to the introduction and status, the following project characteristics are documented: geographic scope, routes to involvement, type of data collected, data storage and availability, quality assurance, training involved, partners involved, number of participants, successes, lessons learnt, and policy links. These study reviews can provide a template for finely tuned project designs that link outcomes and policy impact to design choices.

4.a – Technology

Technology decisions for citizen science can be a critical determinant of project success. Key considerations in technology choice for data collection should include the technical aptitude of potential users, costs, learning curve, and sustainability. While still a relatively new phenomena, best practices for web-based citizen-science are starting to emerge. For example, Newman et al. (2010) describe a number of key attributes of successful projects that include allowing users to making outcomes derived from user data visible and accessible to users on the project website, reducing data entry errors by simplifying user interface designs, and providing areas for user-feedback and feature suggestions as important factors in successful web-based citizen science. Interestingly, a survey of users found that paper forms were still highly useful for field surveys, as these were more amenable to data collection outdoors. It was suggested that the design of paper-forms closely match the design of web-interfaces for data entry.

Often, technology for data collection can be made to run on a web-based form or via a mobile phone application. The relative merits of web and mobile data collection were summarized by Roy et al. (2012) and are outlined in Table 2.

Table 2 Data collection technologies (summarized from Roy et al. 2012)

Platform	Advantages	Disadvantages
Website	• Relatively easy and cheap to implement • A range of services available, from surveys to map-based digitizing • Easy to feedback to participants via data visualisation • Easy to update	• Separation between data collection (in the field) and data entry (at a computer)
Smartphone	• Easy in-field data collection • Media data easy to collect (photo, video, voice) • Expandable sensor set • GPS usually embedded, providing exact location information	• Limited screen size • More complicated to develop and update (multiple platforms) • Smartphone requirement may exclude some potential participants • Data package and mobile signal required – higher cost of entry for participants

4.b – Reporting and Engagement

A critical component of project success is developing a user-community around the project. A user-community can be facilitated by the addition of several project features web-based discussion forums, social media outlets that are updated regarding project activities, chat functions and gamification features. Community building features serve two important purposes: they are likely to keep participants returning to the site or project by engaging socially with them, and they facilitate self-learning and project championing among participants that are key determinants of project success and longevity.

Participant-engagement can be encouraged through educational activities, networking events and project events (e.g., mapping parties). Additional, project information products should be tailored towards specific user-subsets or target participant motivations directly. Understanding what these are can be determined through periodic surveys.

5. Recommendations for Bird Conservation Citizen Science

A citizen science project aimed at conservation of grassland birds should attempt to answer a specific research question or set of questions. This should be informed through consultation with ecologists familiar with the species' of interest and the landscape types. The habitat requirements of grassland birds may, for example, suggest a project aimed at incorporating landowners as project participants. Ideally, a survey aimed at eliciting motivations and attitudes towards grassland bird conservation could support design strategies for a suitable citizen science project.

Technology choices for citizen science depend on the capabilities of the host organization as well as the participant community. In general, open-sourced software tools can be used to develop data collection interfaces over the web (e.g., Google Map interfaces) or over mobile devices. The most important design choice for seasonal projects such as grassland birds in Ontario pertain to data collection protocol and technology.

6. References

Beaubien, E., and A. Hamann. 2011. “Plant Phenology Networks of Citizen Scientists: Recommendations from Two Decades of Experience in Canada.” *International Journal of Biometeorology* 55 (6): 833–41.

Bonney, R., C.B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K.V. Rosenberg, and J. Shirk. 2009. “Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy.” *BioScience* 59 (11): 977–84.

Coleman, D, Y Gerogiadou, and J Labonte. 2009. “Volunteered Geographic Information: The Nature and Motivation of Produsers.” *International Journal of Spatial Data Infrastructures Research* 4: 332–58.

Delaney, D. G, C. D Sperling, C. S Adams, and B. Leung. 2008. “Marine Invasive Species: Validation of Citizen Science and Implications for National Monitoring Networks.” *Biological Invasions* 10 (1): 117–28.

Devictor, V., R.J. Whittaker, and C. Beltrame. 2010. “Beyond Scarcity: Citizen Science Programmes as Useful Tools for Conservation Biogeography.” *Diversity and Distributions* 16 (3): 354–62. doi:10.1111/j.1472-4642.2009.00615.x.

Dickinson, J.L., B. Zuckerberg, and D.N. Bonter. 2010. “Citizen Science as an Ecological Research Tool: Challenges and Benefits.” *Annual Review of Ecology, Evolution, and Systematics* 41 (1): 149–72.

Evans, C., E. Abrams, R. Reitsma, K. Roux, L. Salmonsen, and P.P. Marra. 2005. “The Neighborhood Nestwatch Program: Participant Outcomes of a Citizen-Science Ecological Research Project.” *Conservation Biology* 19 (3): 589–94. .

Haklay, M. 2013. “Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation.” In *Crowdsourcing Geographic Knowledge*, edited by D. Sui, S. Elwood, and M. Goodchild, 105–22. Springer Netherlands.

Hochachka, W.M., and A.A. Dhondt. 2000. “Density-Dependent Decline of Host Abundance Resulting from a New Infectious Disease.” *Proceedings of the National Academy of Sciences* 97 (10): 5303–6. doi:10.1073/pnas.080551197.

Jeong, S.-J., D. Medvigy, E. Shevliakova, and S. Malyshev. 2013. “Predicting Changes in Temperate Forest Budburst Using Continental-Scale Observations and Models.” *Geophysical Research Letters* 40 (2): 359–64. doi:10.1029/2012Gl054431.

Jiguet, F., V. Devictor, R. Julliard, and D. Couvet. 2012. “French Citizens Monitoring Ordinary Birds Provide Tools for Conservation and Ecological Sciences.” *Acta Oecologica*, Sino-French Cooperation on Biodiversity and Natural Resource Management, 44 (October): 58–66. doi:10.1016/j.actao.2011.05.003.

Miller, J.R. 2005. “Biodiversity Conservation and the Extinction of Experience.” *Trends in Ecology & Evolution* 20 (8): 430–34. doi:10.1016/j.tree.2005.05.013.

Newman, G., D. Zimmerman, A. Crall, M. Laituri, J. Graham, and L. Stapel. 2010. “User-Friendly Web Mapping: Lessons from a Citizen Science Website.” *International Journal of Geographical Information Science* 24 (12): 1851–69.

Nocera, J.J., and H.M. Koslowsky. 2011. “Population Trends of Grassland Birds in North America Are Linked to the Prevalence of an Agricultural Epizootic in Europe.” *Proceedings of the National Academy of Sciences* 108 (12): 5122–26.

Obrecht, D. V, M. Milanick, B. D Perkins, D. Ready, and J. R Jones. 1998. “Evaluation of Data Generated from Lake Samples Collected by Volunteers.” *Lake and Reservoir Management* 14 (1): 21–27.

Oscarson, D. B, and A. J.K Calhoun. 2007. “Developing Vernal Pool Conservation Plans at the Local Level Using Citizen-Scientists.” *Wetlands* 27 (1): 80–95.
Robertson, C., K. Sawford, T. A. Nelson, S Gunawardena, F Nathoo, and C Stephen. 2011. “A Hidden Markov Model for Analysis of Frontline Veterinary Data for Emerging Zoonotic Disease Surveillance.” *PLoS ONE* 6 (e24833).
Roy, H.E., M.J.O. Pocock, C.D. Preston, D.B. Roy, and J. Savage. 2012. *Understanding Citizen Science and Environmental Monitoring*. UK Environmental Observation Framework.
Rybicki, N.B., and J.M. Landwehr. 2007. “Long-Term Changes in Abundance and Diversity of Macrophyte and Waterfowl Populations in an Estuary with Exotic Macrophytes and Improving Water Quality.” *Limnology and Oceanography* 52 (3): 1195–1207.
Silvertown, J. 2009. “A New Dawn for Citizen Science.” *Trends in Ecology & Evolution* 24 (9): 467–71.

Appendix A: Related Internet Resources

eBird Citizen Science Project **- http://ebird.org/content/ebird/**

Cornell Lab of Ornithology **- http://www.birds.cornell.edu/**

Citizen Science Report from North American Bird Conservation Initiative - **http://www.nabci-us.org/bulletin/bulletin-fall2014.pdf**

Audubon Tribal Grasslands Project - **http://wa.audubon.org/tribal-grasslands**

The Tamarix Cooperative Mapping Initiative - **http://www.tamariskmap.org/**

Audubon Pennsylvania Bird Habitat Recognition Program Case study in Appendix 2 of Roy (2012)