Designing Local Citizen Science Projects to Address Scientific Questions and Contribute to Collaborative Conservation Efforts

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Abstract-- *Citizen science allows volunteers to actively participate in the scientific inquiry process and as a discipline has increased in recent years. Many citizen science efforts work across broad spatio-temporal scales, making it possible to address questions that typically cannot be assessed through single studies due to budgetary, time, and scale constraints. Citizen science provides an opportunity to collect data that would otherwise not be collected, contributes to knowledge of ecological and management topics, and involves citizens in ecological science and management issues. Citizens often are eager to participate in scientific efforts but may lack experience with design and implementation of rigorous monitoring programs. We present a general framework for designing a citizen science project to address scientific and management questions. We outline important steps in designing a smaller regional scale (confined to single locations or multiple locations within a region) citizen science effort, including selecting objectives that could be achieved with expected data, and conducting a pilot study to gauge volunteer workload and identify technical challenges. The Madrean Archipelago contains rich plant and wildlife communities as a biodiversity hotspot and supports a large population of engaged citizens. In our discussion, we describe how two citizen science case studies (i.e., partnering with a local non-governmental organization to sample Arizona Sky Island birds, BioBlitzes) can contribute to collaborative conservation efforts.*

INTRODUCTION

Citizen science has gained traction as a way to engage and increase public interest as well as address ecological science and management questions (Cooper et al. 2007; Dickinson et al. 2010; Kelling et al. 2009) over broad spatial and temporal scales (i.e., National Audubon Society's Christmas Bird Count [Droege 2007]). Citizen science is described as engaging citizen volunteers in scientific inquiry through participation in the structuring of science or management questions, collecting samples, and/or processing data (Silvertown 2009). Citizen science projects often have multiple objectives of evaluating scientific questions and increasing public engagement. In our paper, we focus on projects with both of these objectives and not with citizen science projects developed primarily to gather support for a particular issue. In many instances, the temporal and spatial scope of scientific studies is limited by budgetary and time constraints. Citizen science data tend to be collected at broad spatial scales but with coarse resolution (i.e., eBird [http://www.ebird.org; Sullivan et al. 2009], North American Breeding Bird Survey [BBS; Peterjohn 1994]). Such data can complement traditional studies conducted with greater resolution at fine spatial scales, but also limits the types of questions that can be addressed. There is often a tradeoff between data quality and quantity (Pacifici et al. 2017), whereby more data may be available at broader scales but with lower quality and effort. This tradeoff is particularly noticeable in broad-scale citizen science efforts. There are opportunities, however, for additional citizen science projects collected at fine spatial scales to address science and management questions and generate local community support. These small scale projects are better suited to answering more narrowly targeted (or focused) monitoring questions (*sensu* Nichols and Williams 2006), that address specific objectives under rigorous sampling designs that improve study relevance, data durability, and data integrity.

The Madrean Archipelago contains rich plant and wildlife communities, and is a biodiversity hotspot (Van Devender et al. 2013; Spector 2002). The region also has many engaged citizens, willing to contribute to scientific efforts. This provides a great opportunity to design and implement rigorous monitoring programs using these citizens (e.g., https://www.coronadooutdoors.org/). Organizations (e.g., Sky Island Alliance [https://www.skyislandalliance.org/], USDA Forest Service Rocky Mountain Research Station) within the region have recognized and capitalized on the interests of these citizens to include them within monitoring efforts. Several broad-scale (i.e., eBird, BBS, Sky Island Alliance crossborder projects) and fine-scale (i.e., Sky Island Alliance mountain range projects) citizen science efforts also occur within the Sky Islands and the Southwest. These endeavors are notable for energizing citizens and providing conservation education opportunities through data collection activities. The goal of this paper is to strengthen the link between citizen science data collection efforts and realized potential of their data by providing guidance in study design for targeted science or management questions. Well-designed citizen science projects can result in greater motivation and participation among observers, because those observers are able to appreciate and directly witness the scientific impact of their efforts. These projects can also contribute towards broader recognition of citizen science as a valid tool within the research and monitoring toolbox.

We focus on research questions specific to monitoring plants and animals; however, the same general principles of study design are applicable to other project types (i.e., evaluating springs and water resources). Ecological citizen science efforts typically aim to answer questions related to change in ecosystem structure and function as a result of different stressor types. In the Southwest, environmental stressors can include climate change, wildfire, and insect outbreaks (Kupfer et al. 2005; O'Connor et al. 2015). Ecosystem change in the Southwest could also result from mechanical treatments, grazing, urbanization, prescribed fire, and other habitat modifications (Bock and Bock 1992; Krueper et al. 2003). We present a general framework for establishing guidelines that can result in effective citizen science monitoring efforts. These guidelines can be used to assess whether questions are appropriate for citizen science projects, and whether or not those projects can meet desired objectives. We illustrate this framework through two case studies from the Southwest.

GENERAL FRAMEWORK

Our framework for designing citizen science monitoring projects follows general monitoring study design guidelines to determine what, where, when, and how sampling should occur (Block et al. 2001; Morrison et al. 2008), highlighting caveats unique to citizen science projects. The framework includes the following sequential steps: (1) identifying objectives, (2) selecting appropriate state variables and vital rates to meet objectives, (3) conducting a pilot study, (4) conducting a power analysis to estimate variability and expected effort from citizen observers, and (5) adjusting the study design as appropriate based on results of that pilot study (Figure 1). Citizen science monitoring projects, if placed in an adaptive management framework (an iterative process where management actions are implemented and response variables are monitored and evaluated repeatedly), can assist with evaluating management actions and gaining knowledge about natural resources. In this framework, there will be thresholds that trigger specific actions related to determining if the right variables are being monitored, if modifications are needed in the study design, and if study objectives are being met (Moir and Block 2001; Nie and Schultz 2012; Schwartz et al. 2015).

Developing study objectives

The most important component of any monitoring project is identifying clear objectives (Yoccoz et al. 2001). Again, citizen science projects will often have multiple objectives related to evaluating scientific questions and increasing public engagement. Our focus here is primarily on the scientific objectives, but we do provide linkages between these two objective types. Objectives will dictate what is measured, why it is being measured, how change is assessed and overall study design. As with all potential studies, selecting an appropriate question that could feasibly be answered with expected granular (how much biological and sampling noise in the system) data in many citizen science projects is integral to project success. Both broad-scale (i.e., climate change correlates on migratory birds across the United States) and targeted (i.e., bird population response to forest thinning in a portion of a single National Forest) questions may be appropriate with citizen observer data. The type of citizen involvement may influence study design. Citizens may be more

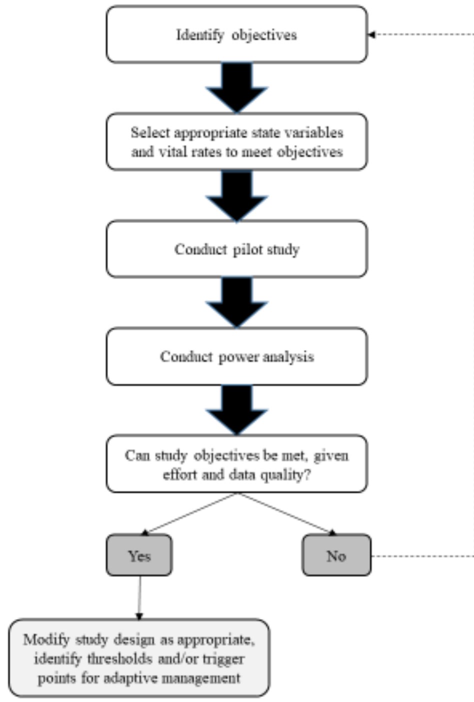

Figure 1--Framework for designing citizen science monitoring projects.

intimately tied to the resources of interest, so could have full understanding of the types of research questions that would support specific objectives. Therefore, citizens could be productive and active participants with this step in the process of developing research questions.

Data quality is an important consideration in determining achievable study objectives, and they can be evaluated via training and a pilot study (see below). In particular, studies have documented differences while comparing citizen and professional observers (Fitzpatrick et al. 2009; Sauer et al. 1994). For example, objectives related to assessments of rare species (which are typically difficult to detect) are less likely to be appropriate with citizen observer studies because the proportion of false positives is increased and the resulting data thus are more unreliable. In addition, the potential negative consequences from incorrect decisions are increased with rare species (McKelvey et al. 2008).

How to measure change

Most ecological studies are not structured as experiments (Block et al. 2001), and many monitoring efforts are not tightly linked to evaluating correlations related to stressors. However, monitoring is best done with specific objectives. Therefore, correlations to changes in ecosystem structure and function can be measured by changes in species richness, occupancy from local colonization or extinction, abundance, range, and/or diversity (Table 1). *A priori* knowledge about the system and research into similar ecosystems will help determine initial response variables that are biologically meaningful. The adaptive management process will determine if the right response variables are being measured. Appropriate response variables need to be biologically meaningful, sensitive to change, and easy to sample. Monitoring vital rates such as survival or reproduction is possible but requires skilled observers, greater effort (time, money), and may be infeasible with citizen science projects. Monitoring wildlife reproduction and survival may require physically handling animals, which has additional challenges with citizen observer studies due to requirements for extensive training and regulatory permits. However, citizen observers may monitor nests by counting number of young and sometimes number of fledged.

Table 1—Types and description of quantitative measures (monitoring state variables and vital rates) to assess change in ecosystem structure and function with citizen science projects. Although other quantitative measures are available, we list the most common and feasible variables and rates given typical citizen science projects. Appropriate response variables will be biologically meaningful, sensitive to change, and easy to sample. The table is adapted from Holthausen et al. (2005: Table 4), Schwartz et al. (2015), and Sanderlin et al. (*unpublished data*).

Monitoring state variable(s) and vital rates	Description	Achievable by citizens	Derived state variable(s) and vital rates from data collected
Occupancy	Occupancy is the presence of an organism at a given location, estimated via site-occupancy models to account for imperfect detection (Mackenzie et al. 2006; MacKenzie et al. 2002).	Species detections, nest detections, camera or hair snare surveys, track detections, scat collection, eDNA samples	Several derived state variables and vital rates are possible with data collected in an occupancy framework. Changes in occupancy status over time are estimated with local extinction and colonization probability with multi-season occupancy models. The range distribution (geographic range at a particular point or points in time) can be estimated via occupancy models with presence-absence data (Mackenzie et al. 2006; MacKenzie et al. 2002) or via maximum entropy modeling with presence-only data (Phillips et al. 2006). Range distribution change over time can be estimated across multiple points in time where populations expand, contract, or remaining constant. Species richness (number of species in a given area) is best estimated with multi-species occupancy models (Dorazio et al. 2006; Mackenzie et al. 2006). Species evenness and diversity both require the number of species and abundance of each species. Species turnover can be estimated with local colonization and extinction (i.e., Sauer et al. 2013) while accounting for imperfect detection. Density (number per unit area), λ or finite rate of increase (abundance change over unit of time)
Abundance	The number of plants or animals in a given location at a specific time.	Counts, camera surveys, non-invasive genetic surveys (i.e., hair snare or scat surveys)	
Phenology	First observed date of phenological state.	Bird arrival dates, first flowering dates, first incubation dates at monitored nests	

Pilot Study

Given specific objectives and quantifiable measures of change, the next step is conducting a pilot study to gauge volunteer workload and physical capabilities, technical challenges with communication and training, and system variability. Schedules are often more irregular with volunteer-based sampling than with a paid workforce, and study designs must be robust in this regard. A pilot study will also expose citizen observers to field sampling and potentially demanding physical environments. Such exposure will provide valuable information to both researchers and volunteers as to citizen observer physical capabilities. The field sampling exposure may also highlight potential deficiencies or strengths in observer training and data collection abilities. This information can then be used to modify methodologies prior to beginning the full study (see *Case Study 1*). Finally, there may be technical challenges related to communication and training that need to be identified through this process. Training needs may differ by observer age, experience, knowledge, etc. Therefore, identification of training needs for citizens is a critical component of the pilot study. If modifications are implemented, a pilot study must show that parameters of interest can still be measured and adequate data collected for the desired precision in point estimates.

One of the most important pilot study components is evaluating observer detection probability as well as the frequency of misidentification. These processes can lead to false negative and/or false positive errors. Misidentification may be greater in citizen science data sets (Dickinson et al. 2010) and a potential source of error (Miller et al. 2011; Ruiz-Gutiérrez et al. 2016). Incorporating study design actions to quantify species misidentification (i.e., double-observers [Nichols et al. 2000], ancillary data like online quizzes [Bonney et al. 2009; Ruiz-Gutierrez et al. 2016]), will reduce parameter bias. Additionally, extensive training should mitigate some of these detection errors. Another potential pitfall is differences in detection between common and rare species for citizen versus professional observers, which could lead to inflated species richness estimates (Gardiner et al. 2012).

Power analysis and evaluation of study feasibility

Conducting a power analysis will determine how much effort is needed to detect a given effect size (in this context, how much effort is needed to detect change in response variables by a predetermined amount). Basic power analysis principles apply (Morrison et al. 2008). The unique challenge of citizen science studies is the sampling effort (frequency and intensity) expected through time, and often there is a tradeoff between data quality and quantity. It can be challenging to sustain a consistent sampling effort through time, and biological time constraints may apply (i.e., breeding birds can only be sampled at certain times of the year). Increased number of participants could potentially mitigate some data quality issues. Another important component is optimizing study design based on required accuracy and precision tradeoffs for parameter estimates and costs required to achieve those accuracy goals (Field et al. 2005; Sanderlin et al. 2014). If objectives cannot be met with available resources, monitoring should not be implemented (Legg and Nagy 2006) because it is difficult to justify hard work of citizen observers without tangible results, and poorly designed efforts could lead to poor morale, and potentially lower future citizen recruitment. Public engagement may be a secondary objective, however, and in some cases may be more achievable than scientific or management monitoring objectives.

After the power analysis is completed, an evaluation of study objectives must be conducted that considers the expected effort and data quality. If objectives are not achievable, either modify objectives and continue the process again, or discontinue project efforts altogether. If objectives are achievable, adjust the study design (if needed) and proceed with identifying thresholds and/or trigger points for adaptive management (Moir and Block 2001; Nie and Schultz 2012; Schwartz et al. 2015), if appropriate.

CASE STUDIES

Case Study 1

Our first case study from Ganey et al. (2017) illustrates how citizen science was used to monitor change in occupancy of bird species and species richness after a wildfire in the Chiricahua Mountains, Arizona. The local communities of Portal and Sierra Vista rely heavily on ecotourism for their livelihoods, which in turn relies on a vibrant bird community, consisting of specific birds sought for viewing. Thus, the communities have a vested interest in conservation efforts. Rocky Mountain Research Station (RMRS) scientists studied bird communities and their associated habitats within five Sky Island mountain ranges, including the Chiricahua Mountains, in the early 1990s (Block et al. 1992; Sanderlin et al. 2013). Using a structured sampling design and previously developed sampling protocols, RMRS partnered with local Portal and Sierra Vista community members via Friends of Cave Creek Canyon to re-sample birds within the same general areas in the Chiricahua Mountains from 2013-2014, following the 2011 Horseshoe II fire.

A pilot study was implemented to: (1) evaluate whether or not the biological population of interest could be sampled to meet objectives, (2) determine amount of sampling effort expected (including observer detection probability), (3) identify coordination challenges, and (4) evaluate whether or not it was physically possible to conduct the monitoring using citizen observers. One identified challenge was that some volunteers were not physically able to traverse randomly-located RMRS transects sampled during the 1990s. Therefore, new bird monitoring transects were established along trails and roads in the vicinity of initial RMRS transects. Pilot study data confirmed these new transects yielded similar vegetation and bird occurrence data as original transects (Ganey et al. 2017; Sanderlin et al. *unpublished data*). In addition, RMRS had a 4-person professional crew sample birds for an additional year at both the original (1990s) and modified locations, to evaluate potential differences in data quality between professional and citizen observers (Ganey etal. 2017; Sanderlin et al. *unpublished data*). Results suggested that citizen data could be used (Sanderlin et al. *unpublished data*) with modifications of additional visits by citizens to increase parameter accuracy (Sanderlin et al. 2014). The citizen science project thus extended number of years data were collected, including years after large wildfires. Supplemental years can be critical in population trend studies, especially with rare species missed during one time period, even if present.

Case Study 2

Our second case study is the development of BioBlitz events in the U.S. southwest. BioBlitzes are comprehensive, multi-taxa species inventories collected at a single location during a single day or weekend. These events are becoming popular to increase local community involvement and provide conservation education. Data are usually collected and uploaded to larger databases (i.e., iNaturalist) for broad-scale pattern analyses. It is challenging to standardize sampling effort (i.e., time of year, number of participants, locations) with data collected under these protocols. We describe species inventory development and operation steps that will assist in ability to address science and management questions (Table 2).

Presence-only data are difficult to use for monitoring or answering targeted questions, due to sampling differences over spatial and temporal scales and sampling methods, often violating assumptions required to build species distribution models (Yackulic et al. 2013). However, species inventories can be combined with studies standardized by sampling effort (Pacifici et al. 2017; Miller et al. *unpublished data*) to generate species distribution maps for monitoring distribution change (expansion, contraction), species richness, and colonization and extinction probabilities. BioBlitz events often focus on public engagement objectives; however, there is great potential for also meeting scientific objectives with the use of these advanced statistical models.

SUMMARY AND CONCLUSIONS

Data collected by citizen observers can contribute to collaborative conservation efforts by expanding the spatio-temporal scope of monitoring efforts. These efforts can increase interest in and commitment to resource management among interested citizens. However, special care must be taken to evaluate feasibility of meeting monitoring objectives given resulting data quality in citizen science efforts. Our general study design framework provides a template for key steps in ensuring citizen monitoring data provides useful information. The five steps we described will help ensure the best use of valuable resources and citizen observer time commitments.

Data integrity is important for any project, and includes use of data quality controls in the field and within databases, relational databases for sorting and cleaning data, and data archiving procedures (Sanderlin et al.,

Table 2—Steps in developing and conducting a species inventory (i.e., BioBlitz) with citizen observers. We include important considerations for each step in the process that increase data usability in addressing science and management questions.

Project step	Description
Research	Identify event objectives (what, where, when, how). Practice using technology applications with event device(s) to identify any potential issues citizen observers might encounter. A visit to the event location will identify if cellular service is available, and plan accordingly (e.g., paper data sheets if not). Label and create the event with the event date and location within the project database (i.e., iNaturalist) before event.
Event preparation	Develop clear instructions about how to use technology applications (i.e., iNaturalist) and confirm expert participation to help in field identification during the event, in addition to helpers for each expert to take/upload pictures to app at the event. This helps ensure all data are recorded (thus available for analysis). Participants must be trained in specific BioBlitz protocols of data collection. Finally, participants should be encouraged to take/upload pictures to increase diversity in participation opportunities.
Species inventory event	Participants should take pictures of observations and upload to application. Emphasis during the event should be on taking pictures and (at least) placing observations in general categories (i.e., plant, animal, structure). Further identification can be completed later, by citizen observers and/or experts. Spending more time on recording observations with a device (i.e., phone, tablet) than identifying observations allows for a more complete inventory.
After event	If pictures were not uploaded during the event, observations from data sheet(s) should be uploaded, preferably with pictures to aid in proper identification (data integrity).
Project evaluation	Provide evaluation form for participants to fill out before leaving the event (i.e., what worked, what did not work, suggestions for future events, were objectives achieved). These questions aid project organizers in study design modifications, gauging satisfaction in volunteer experience, and predictions of future participation (survey effort).

unpublished data). In addition to using these standard data integrity measures, statistical expertise may be necessary to overcome statistical and computational challenges of incorporating citizen observer data uncertainty so data can contribute towards science and management questions. Furthermore, attention with how to display data as they are collected (or soon thereafter), disseminating results, and measuring outcomes are especially important with citizen science projects to demonstrate links between citizen efforts and scientific results and maintain enthusiasm for participation (Bonney et al. 2009). This includes providing results from previous years (if possible), sending participants data collection summaries (i.e., number of units observed, any rare or unusual sightings) after data are collected for the year, providing PDFs of published studies with all names listed in the acknowledgments, and offering to present results at local organization meetings (i.e., local Audubon chapters, Native Plant Society, school groups).

Finally, citizen science projects often have multiple objectives: to evaluate scientific questions and to promote science in society through educational opportunities. Arguably, projects labeled as citizen science may be heavily weighted towards one or the other objective, but ideally both components are given consideration. Furthermore, efficient use of citizen observers and data they collect will likely result in a better citizen experience and greater participation with knowledge that their efforts contribute towards answering pertinent science and management questions.

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