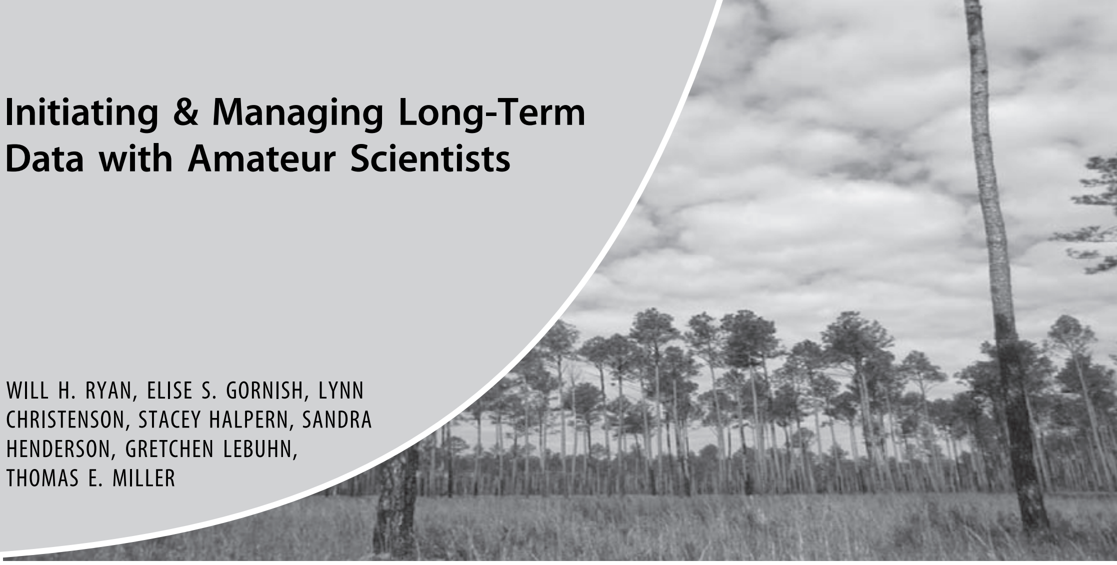
Initiating & Managing Long-Term Data with Amateur Scientists



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Abstract

The value of long-term data (generally >10 years) in ecology is well known. Funding agencies clearly see the value in these data and have supported a limited number of projects to this end. However, individual researchers often see the challenges of long-term data collection as insurmountable. We propose that long-term data collection can be practical as part of any teaching or outreach program, and we provide guidance on how long-term projects can fit into a teaching and research schedule. While our primary audience is college faculty, our message is appropriate for anyone interested in establishing long-term studies. The benefits of adopting these kinds of projects include experience for students, encouraging public interest in science, increased publication potential for researchers, and increased large-scale data availability, leading to a better understanding of ecological phenomena.

Key Words: *Citizen science; crowdsourcing; volunteer; long-term data.*

○ Introduction

Developing a comprehensive understanding of ecological phenomena often requires documenting patterns through time. Processes of population growth, species interactions, and ecosystem function may take years to play out. Some of our most familiar concepts, such as succession and metapopulations, also require long-term data to fully understand (Franklin, 1989). Documenting the effects of climate change clearly requires long-term data (Walther et al., 2002). Equally important is the use of long-term data to establish management plans and guide environmental policy decisions (Schwartz et al., 2000; Lovett et al., 2007). Furthermore, long-term data sets often find uses far beyond the original goals of the study, as in the discovery of acid rain by scientists monitoring the Hubbard Brooks experimental forest (Likens & Bailey, 2014). Or the data later take on unforeseeable importance, such as a 39-year record of subalpine flowering times becoming an invaluable resource in understanding the complex response of plant communities to climate change (CaraDonna et al., 2014).

Developing a comprehensive understanding of ecological phenomena often requires documenting patterns through time.

Despite the clear value of long-term data, many ecologists approach these projects with trepidation because of perceived financial and logistical obstacles. As a result, most ecological theory is still derived from small-scale, short-term studies that may fail to capture the influence of important sources of variation and patterns that are known to occur at longer time scales (e.g., dampening effects; Barbeta et al., 2013). This problem is being addressed by National Science Foundation–funded initiatives such as Long Term Research in Environmental Biology, the Long Term Ecological Research Network, and the National Ecological Observatory Network (NEON; http://neoninc.org). However, long-term projects cannot solely be the purview of a small number of large programs; the scope of the problem is simply too great to be addressed by only one approach. Long-term data collection needs to become a standard part of ecological research for investigators to move our understanding of complex ecological phenomena forward in all systems.

There are now several excellent examples of long-term data studies made possible by creatively using the existing resources at academic institutions. Students who need to develop technical skills or fulfill research requirements can be recruited for data collection on long-term projects. Class modules can also be developed to incorporate long-term components. These have the added benefit of exposing students to realistic hypothesis-testing and data-collection activities, which is otherwise often absent in science lab courses (Hoopes et al., 2013). Furthermore, the use of students can increase civic attitudes as well as aid in management or restoration goals directly (Bruce et al., 2014).

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Alternatively, the enthusiasm of the general public can be leveraged for the collection and analysis of long-term data (e.g., "citizen science"), facilitating the development of longitudinal studies (Conrad & Hilchey, 2011). Citizen science can be particularly useful for collecting data over very large spatial scales (Dickinson et al., 2010) or by capitalizing on local knowledge (Gallo & Waitt, 2011). Crowdsourcing, the mobilization of a group of people to solve a problem (Doan et al., 2011), is a facet of citizen science that is quickly gaining popularity due to the accessibility of sophisticated (and often free) Internet applications. Crowdsourcing has been widely used, and with great success, across a variety of disciplines, from ecology (e.g., http://www.snapshotserengeti.org; http://crickets.yourwildlife.org/) and microbiology (e.g., the http://humanfoodproject.com/) to biosecurity (e.g., Lyon et al., 2013) and human health impacts (e.g., McCormick, 2012).

The benefit of establishing ongoing projects that rely on students or citizen scientists for long-term data collection is threefold. First, these projects can generate important data on a larger spatial and time scale than most individual projects – large-scale and long-term data are required to gain a full understanding of ecological dynamics in many systems (e.g., Chung et al., 2011). Second, building data-collecting activities into the infrastructure of a curriculum or into a community-based project increases the likelihood that the project will continue to function somewhat independently of any single researcher or lab, increasing the likelihood of producing a well-maintained and useful data set. Lastly, ecological knowledge and appreciation is likely to increase among participants (Thornton & Leahy, 2012; Hoopes et al., 2013). Although data quality is always a concern when transferring the responsibility of data collection and (sometimes) organization to individuals who are not the principal investigators (PIs; Fitzpatrick et al., 2009; Dickinson et al., 2010), the benefits of using students or citizen scientists for long-term data collection can far outweigh the challenges.

Educating researchers at early career stages about initiating and maintaining long-term projects is particularly important, as is helping young researchers identify the kinds of projects that can stimulate a sustainable long-term research program. Promoting collaboration among researchers and the integration of these kinds of projects into curricula could increase the number of successful long-term data-collection projects. However, the goal of initiating and maintaining collections of long-term data is a challenging one, particularly in an era of dwindling financial support for research. Here, we provide a set of guidelines to consider in organizing a long-term research program using student volunteers or citizen scientists, thereby complementing, but not duplicating, recent papers that simply describe particular aspects of academic volunteers or citizen scientists.

○ A Plan for Long-Term Research Projects

Long-term studies vary greatly in their questions, goals, methodologies, amount of required work, and productivity. We considered many ongoing projects and looked for common approaches and problems that may be helpful for an early-career scientist to consider before deciding whether or not to invest energy and funds into such a project. We identified five critical areas to consider.

Identifying Appropriate Projects

While successful long-term projects are similar to short-term projects in many ways (such as the need to be motivated by important questions with testable hypotheses), they also have several unique characteristics. First, projects must be sufficiently interesting to attract students, volunteers/citizen scientists, organizations, or even other scientists. This may require projects that have both short- and long-term implications. For example, interest in local water quality on the Vassar College campus led to a long-term study involving undergraduates, faculty, and interns from the college, state employees from several agencies, and local citizen volunteers. The project provided information about current water quality, as well as changes in water quality through time. Volunteers were motivated by the local, immediate effects of their contributions, as well as by longer-lasting and long-term implications of their work.

Long-term projects require some patience, and PIs need to begin with the understanding that such projects involve a maturation period, both for refining methods and for creating a sufficient database. It is helpful if the short-term results are interesting; many long-term studies are aborted because they develop slowly, as investigators lose interest or are discouraged by the lack of productivity. One approach to minimize this maturation period is to tie short-term, contemporary results to historical or archived data sets, where available. This strategy has been used in NEON's Project BudBurst (http://www.budburst.org) to "extend" past data sets to the present, providing interesting and motivating results to share with participants from the earliest stages of the project. In addition, there are a growing number of resources for connecting local projects to regional or global databases by adopting standardized protocols in local systems (e.g., National Phenological Network, http://www.usanpn.org), which can reduce some of the "trial and error" period inherent in developing new protocols and make results more immediately rewarding. Many of these projects can be modified to fit the scale and expertise level of participants and may be attached to teaching resources (e.g., http://education.teamnetwork.org/) that can help make long-term data-collection projects more feasible for high school and early college instructors.

Establishing Support

One of the major logistical hurdles of developing a long-term project is planning for and securing the required resources needed to keep a project running for an appropriate time. These resources may include money, people, logistical support, special equipment, and access to reliable field sites, all of which could come from a variety of agencies. Thinking through the lifetime needs of the project can help determine whether the project is best conducted by a single investigator or in collaboration with other researchers, departments, or local agencies. Even for projects spearheaded by a single investigator, institutional support in the form of money, equipment, or logistics can often be leveraged to improve the project.

There are many ways to limit research costs (using students from classes, volunteers, etc.), but long-term projects usually require some consistent funding to ensure regular and repeatable sampling and data management. Investigators may be able to tap into institutional endowments to secure funding, in addition to seeking more traditional grants. Although grant extensions and additional funds can sometimes be acquired on single grants, longer-term projects require a more dedicated funding stream than short-term projects. This, in turn, requires additional forethought at the planning stage to estimate the expected duration of the project. Having an idea at the outset of how long the project must run to produce acceptable results is important for resource planning and setting realistic expectations.

For investigators with access to students, finding ways to offer course credit in exchange for helping on a long-term project can help institutionalize the sampling routine and provide a dependable stream of labor and funds. Building projects into the curriculum increases the likelihood of regular sampling and continued institutional support (discussed further below).

Collaborations with other classes or departments within a university, or with government agencies, can provide access to a larger pool of institutional resources. From equipment supply to technical support and data management to website building and public outreach, large organizations often have dedicated staff to offer advice and support for many aspects of a project. For example, many universities now have offices dedicated to undergraduate research. Making use of such resources in both planning and executing projects can greatly reduce the workload on an individual investigator. Further, if the project can involve state and local agencies or organizations, these collaborations can also provide additional resources and expertise that can add stability to a project (Franklin, 1989). Partnerships with state and local agencies might also facilitate the identification of appropriate projects and underutilized grant sources.

Successful long-term data collection often requires unimpeded access to one or more sites over a long period. The success of the project may also depend on protecting sites from unintended disturbance. Secure sites are essential for adequate consistency and replication of an experiment and might require negotiations that surpass those associated with shorter-term work. This may involve simply making special arrangements or agreements with a management agency or something as formal as the development of a land trust dedicated to the project. Finding appropriate private land or working with organizations such as the Ecological Continuity Trust (http://www.ecologicalcontinuitytrust.org/) can be an effective way to maintain the availability of and access to long-term sites. Long-term use of sites may also require establishing relationships with local community stakeholders such as farmers, fishermen, local interest groups, or residents; establishing these relationships at the outset of the project is advisable.

Recruiting Assistants

Many long-term projects depend on student or citizen volunteers, paid assistants, or some combination of these. While many of the concerns about data quality and logistics raised in other sections apply equally to these categories of helpers, each also requires unique considerations.

Students. The authors have found it surprisingly easy to recruit student volunteers for long-term research projects. Many students are interested in ecology and want research experience. Announcements in relevant classes or student clubs can attract lots of volunteers, especially if they are signed up on the spot, rather than waiting for them to initiate contact. Student volunteers are easier to recruit if fieldwork occurs in interesting nearby locations, although if funds are available to support student travel, motivated students can be used at more distant sites. Some high schools and colleges now allow students to earn volunteer credits for such work, which helps incentivize students to maintain the high-quality work and focus required for many projects. Although building independent projects for students into the larger project can require more work, it is also a good way to keep students invested in the effort.

Incorporating data-collection activities into a relevant course can ensure regular sampling with an adequate set of hands. However, students that are required to do the work as part of a course are sometimes less motivated to do high-quality work than students who volunteer. Sampling plans implemented as coursework must be flexible enough to accommodate recalcitrant or uninterested students. On the other hand, students tend to be enthusiastic about participating in research if they feel the project is worthwhile. Setting out clear questions and goals for their contribution is imperative for keeping them interested and focused. For long-term projects particularly, it is important to motivate students with an interesting introduction to the research, since they will not necessarily produce interpretable data from their own work – especially early in the project. Giving a lecture on the concepts involved in the study, including videos or pictures of past years' activities, can get them interested and start the training process. This approach is being used successfully on a savanna restoration project in north Florida. It was initiated by managers of the nearby Apalachicola National Forest but is now monitored annually with the help of students enrolled in the General Ecology Lab at Florida State University (T. E. Miller, unpublished data; Table 1). In this study, interest in restoring habitat for a diversity of charismatic carnivorous plants helps drive student enthusiasm.

It is important to note that a project need not be grand or elaborate in order to be worthwhile. Many classic examples of long-term data that have been essential in understanding the effects of climate change were collected at small scales, by a single enthusiast, such as the flowering records kept by Henry David Thoreau (Primack & Miller-Rushing, 2012). Matching the scale of project to the abilities and interests of the students involved can help any age of student produce rigorous and useful data.

Citizen scientists. Citizen scientists are an increasingly recognized resource for addressing many types of ecological questions (Dickinson et al., 2010), especially those that require large geographic scales (Great Sunflower Project, https://www.greatsunflower.org/) or long time scales (Christmas Bird Count, http://birds.audubon.org/christmas-bird-count) or that are focused on ephemeral phenomena (Project BudBurst). Harnessing the energy and enthusiasm of nonexperts allows research to be conducted on scales far exceeding the abilities of scientists. If the proposed project involves the "general public," it is imperative to create simple, straightforward protocols to keep both data quality and participation high. The geographic scale of the project will define some of the parameters for recruitment, training, and participation. For example, local research efforts might involve face-to-face interaction between the investigator and the citizen scientist, whereas national projects are more likely to rely on online tools and interfaces. The project scale will also affect how data collection and quality control are handled. Small projects may simply use pencil-and-paper data sheets checked individually by the PI, whereas larger projects might need to rely on automated quality-control methods and online data-entry interfaces. While building the infrastructure to support a large project can be intimidating, it is not impossible. Many projects have

Table 1. Monitoring the restoration of natural savannas in the Apalachicola National Forest with the help of Florida State University Students (by T. E. Miller).

The Apalachicola National Forest is a large tract of long-leaf and slash pine forest near the campus of Florida State University in the panhandle of Florida. This area has been managed by the U.S. Forest Service after being decimated by logging at the turn of the twentieth century. Frequent fires are an important management feature of this habitat and are required for keeping their characteristically wide-spaced canopy and diverse herbaceous undergrowth. The U.S. Forest Service is interested in developing repeatable techniques to restore the diversity of undergrowth but often does not have the funds to monitor the recovery of the community after they implement a treatment.
We were approached by a U.S. Forest Service biologist for help monitoring the restoration of an open grassy savanna that had been partially fertilized and planted with slash pine some 30 years ago. The Forest Service was going to remove the slash pine, with the goal of eventually restoring the open savanna vegetation. The plan was for us to set up permanent plots before the trees were removed, then to re-census the plots annually to document the recovery of the herbaceous understory and compare it to a nearby, naturally occurring savanna.
The project is now in its fifth year and is re-censused each fall by 15–20 junior and senior biology students as part of the coursework for an ecology lab. Each year, the students census permanent quadrats in both the treatment area and the natural savanna. They experience the unique long-leaf pine and wiregrass ecosystem and learn about basic ecological fieldwork techniques, plant taxonomy, and restoration science. More importantly, we use this project to encourage the students to think about the meaning of concepts such as "restoration," "recovery," "succession," and "natural." For example, when has a site has been sufficiently "restored" to call the project successful?
As with other long-term projects, this project stumbled for the first two years for a number of reasons. The plots were initially not well marked and were difficult to find, we did not have sufficient personnel with botanical training or easy-to-use keys, and we did not have a consistent system in place to deal with unknown species. The tree removal treatment was also unintentionally delayed for two years due to dealings between the U.S. Forest Service and the timber contractor. These complications caused frustrations for the students, who were initially simply not very interested in participating in this project. However, we now have the plots well marked, we have a system of voucher specimens and adequate identification keys in place, and we often bring graduate students with local botanical knowledge along on the trip, all of which have improved both the quality of data and student morale. The accumulation of class data over the first 5 years and the creation of stronger course material related to conservation and restoration have been especially important for improving the student's opinion of the project. We expect this project to run at least 10 more years, but the rate of recovery may determine the ultimate time-scale of the project.

benefited from partnerships with organizations that can provide these tools or have made use of increasingly user-friendly, web-based tools. A suite of such project-building tools, technology resources, and detailed information about designing each step of a citizen science project is available at http://citizenscience.org.

Citizen science can be inexpensive but often requires collaboration and creative resource use. For example, the Great Sunflower Project has less than one full-time employee but benefits from resources available within a university. Likewise, the NEON education division has approximately 2.5 employees dedicated to Project BudBurst, including management, content development, and basic tech support. In addition, Project BudBurst benefits from having access to the NEON cyber infrastructure, graphic support, and other staff and resources that contribute to the effort. Finally, external partners, such as the Chicago Botanic Garden and the U.S. Fish and Wildlife National Refuge System, provide additional expertise; collectively, this is a significant dedication of resources. As with using student and other volunteers, there is an ongoing and constant need to recruit, train, and try to retain people for the duration of the project. For citizen science projects, a significant amount of planning should be dedicated to generating and maintaining citizens' interest in contributing to the project.

As more successful citizen-science projects mature, there are more case studies to learn from in designing new projects. There is also a growing literature about effective strategies for recruiting and working with citizen scientists (e.g., Gardiner et al., 2012; Gura, 2013; Reynolds & Lowman, 2013; Tulloch et al., 2013), including an entire issue of *Frontiers in Ecology and the Environment*.

In all cases, sending periodic e-mails to a list of all current and past participants about the progress of the study and recognizing their contribution helps maintain ongoing interest in the project and in citizen science in general. It is also an excellent way to continue to bring experienced volunteers back to help with the research when more volunteers are needed.

Collecting the Data

Collecting high-quality data, with minimal noise and bias, is critical in any study but can be particularly problematic for long-term studies involving students and volunteers. Even simple projects require careful thought about training. One issue in many long-term ecology projects is designing data-collection tasks with realistic expectations for the worker's field skills and natural-history knowledge. For example, it is often not reasonable to expect short-term participants to learn extensive species-identification skills. For technical tasks, it is useful to have more experienced workers lead small groups of less experienced workers, with each person specializing in a smaller number of species or tasks. This approach is used for an annual census of vegetation on St. George

Island, Florida, where teams of three or four are led by a trained botanist who teaches the rest of the team to identify particular species (Figure 1; Miller et al., 2010). When very few experienced workers are available, having them rove between groups to ensure accuracy may be the most beneficial role. Both retaining experienced volunteers and ensuring overlap between crews in order to maintain essential expertise can aid in a project's success.

Likewise, ensuring standardized methods between workers is very important. Sometimes it helps to create a guide for learning specific tasks. For example, in a project that requires estimating percent area damaged on leaves, assistants were given laminated cards illustrating different levels of damage, which could be taken into the field for reference (Figure 2). For multiweek censuses, team members completed a brief retraining and check of interobserver consistency in which small teams independently collected data from the same sample, then discussed differences and came to consensus (S. Halpern, unpublished data).

Although this may not be obvious to your workers, the data recorder is one of the most important roles. This person must be extremely responsible, with the ability to pay careful attention to details. Being able to keep entries in order and groups on task, while calling attention to anomalies, is essential.

Figure 1. A team of volunteers surveys a long-term vegetation census plot on St. George Island, Florida.

Figure 2. A diagram of four levels of herbivore damage on leaves, used as a reference guide by novice volunteers in a long-term field survey.

Finally, the attention span of volunteers is usually lower than that of the PI. Bringing extra workers allows the crew to have time off for recreation, relaxation, or their own exploration helps, as does planning for diversions (such as frisbee and ice cream) during the fieldwork. Keeping the work enjoyable also helps with the reenlistment of volunteers for the next sample period.

Data Management

Organizing field-collected data into files ready for analysis is a challenging part of any study, but long-term studies pose some unique challenges. In particular, data and metadata files must be highly organized, yet sufficiently simple and flexible to accept each new wave of data. Without careful documentation from the beginning, information will be lost over time. Planning ahead for how the data will be analyzed can help minimize the amount of reorganizing that has to be done. Metadata are especially important for long-term studies because of the turnover of individuals involved in data collection and entry. It is important to keep explicit notes on every variable recorded, explanations of shorthand codes used, as well as information about when data were collected, checked, edited, and used in analyses. Also, the original data and backups need to be kept in a secure manner, while keeping up with changing technology for electronic databases. Deciding how the data will be kept and who will have access to the files for data entry, quality control and analysis should be done early to protect the integrity of the files and to minimize mistakes. The issues associated with data management require adherence to "best practices"; several organizations now provide flexible guidance appropriate for different projects (Whitlock, 2011; Strasser et al., 2015).

Data entry and quality control can be daunting components of long-term projects. It may be possible to use digital data recorders in the field for speed, but these require careful training of volunteers. For some projects, it may be useful to involve participants in data entry, but appropriate precautions should be taken. These include methods for ensuring consistent and accurate data entry, such as reading back data in pairs or establishing a set menu of options for qualitative data. Participating in data entry and analysis can help undergraduates and volunteers understand more of the steps involved in completing a research project and can help workers feel more invested in the outcome.

Finally, consideration must be given to how and when data will be made available to both participants and the general public. These data sets are often useful to people outside of the team generating the data. For these reasons, we encourage researchers to plan to provide public access to the data on an ongoing and updated basis, as well as to publish interesting findings as soon as possible. Many organizations that provide public access to their data offer guidelines on how and when the data can be used (for an example, see http://www.piscoweb.org/data/data-sharing-policy). Developing a coherent policy about the use of your data and your strategy for dissemination can help formalize the goals and expectations you have for a long-term project. Once again, thinking through the lifetime of the project – from conception to publication(s) – is the best way to design a project with the highest chance to succeed.

○ Conclusion

The research challenges for college faculty – and research opportunities for teachers at other levels – have changed over the past decade. There is greater pressure from academic administrations for college faculty to be productive and involve undergraduate students in research, while research and teaching funds seem to be on the decline. Meanwhile, many of the major questions in ecology now involve larger spatial and longer temporal scales, especially as we come to grips with anthropogenic changes in land use and climate. Responding to these challenges may require creativity and new approaches.

We encourage all college faculty, but especially early-career faculty, to consider initiating long-term studies that involve classes or the other interested groups. We encourage faculty at all levels, especially those in secondary education, to identify opportunities for their students to be involved in such research. Such studies are extremely valuable, for both the research and the participants, but they are rarely undertaken because of perceived logistical, financial, and manpower constraints. While such studies are challenging, we contend that the perceived challenges can be overcome with adequate information and planning – yielding important data that cannot be gathered any other way.

In this article, we have tried to draw from past studies to provide guidance on initiating and maintaining productive long-term studies. The considerations outlined above provide a framework for thinking through the logistics of such a project and highlight some of the "best practice" methods honed by the authors through a process of trial and error in establishing their own successful projects. While each question and system will be idiosyncratic, these five areas of concern are common to all long-term projects: picking the right project, establishing support, recruiting assistants, collecting data, and managing data. With well-designed sampling schemes, resilience in the face of adversity, and persistence as results slowly accumulate, any investigator can add a long-term component to their research program and reap the benefits of a unique data set, an ongoing source of publications, and a more complete understanding of an ecological system. At the same time, they can provide unique and important experiences for students and volunteers. We encourage investigators at all stages of their careers and working in all types of institutions to consider establishing long-term projects as part of their research programs to increase the availability of these essential data.

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