PROJECT REPORT

Vanishing Fireflies: A Citizen-Science Project Promoting Scientific Inquiry and Environmental Stewardship

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Abstract

Fireflies are a unique part of the natural landscape. Urban development and changes in forestry practices have altered the landscape, causing a decline in firefly distribution and abundance. Assessment of firefly abundance through counts of bioluminescence flashes provides an environmental quality indicator that can be easily observed and quantified by citizen scientists. Researchers at Clemson University, collaborating with resources managers, educators, and teachers from local non-profit organizations and schools, have conducted firefly surveys in the state of South Carolina (SC) since 2010. This community-based project begins with the incorporation of scientific inquiry into service-learning to promote sustainability and ultimately environmental stewardship. This paper describes project activities and summarizes the results and observations of the four-year-old program. Lessons learned from this project can be applied to citizen-science projects in other regions to monitor different organisms such as cicadas, dragonflies, and frogs.

Introduction

Citizen-science projects call on individuals to gather data for use by scientists to investigate research questions (Bonney et al. 2009). While these projects can produce large databases, it is possible that their benefits extend further (Trumbull et al. 2000). By engaging citizens in authentic science, some argue that these projects can have an impact on participants' understanding of science content, understanding of the process of science, and attitudes toward science and the environment (Cohn 2008). Although citizen-science projects are growing in popularity, there is little published evidence on the impacts of such projects on the participants (Druschke and Seltzer 2012).

Fireflies (*Coleoptera: Lampyridae*), sometimes called lightning bugs, produce bioluminescence to attract mates or even prey (Barrows et al. 2008; Viviani et al. 2010), and they can be easily observed during the spring and summer (Frick-Ruppert and Rosen 2008; Lloyd 1972). Citizens of all ages exhibit an interest in, and have fond memories of, observing these amazing insects (Ho et al. 2009). Many adult citizens have inquired about the recent rarity of firefly flashes, which are perceived as having been ubiquitous in their childhood. Such interest has provided environmental science educators an opportunity to use fireflies as a charismatic and easily observed educational tool (Faust 2004).

Environmental indicators are used to communicate information about the health of ecosystems and the impacts of human activity to school children, the general public, and government policy makers (Turcu 2013; Conway et al. 2009). These indicators can reflect biological, chemical, and physical aspects of ecosystem health. Fireflies are reliable indicators of environmental health because their abundance is correlated with the availability of healthy habitats (Kazama et al. 2007; Takeda et al. 2006). The habitat of fireflies can be significantly impacted by changes in land use patterns and structures, such as converting forested areas into open lawns, residential gardens, and agricultural fields (Kazama et al. 2007; Jusoh et al. 2010). Indiscriminate use of insecticides in lawns and urban areas can kill many non-target insects, including fireflies. Pollution from commonly used chemicals (e.g., pesticides and fertilizer) and biological pollutants (e.g., pet waste) can also alter the quality of the habitat (Lee et al. 2008; Leong et al. 2007). Strong, bright artificial light can outshine firefly flashes and interfere with mating behavior (Viviani et al. 2010). All these factors work in concert to reduce the quantity and quality of habitat, thus reducing the abundance of fireflies.

Forested land makes up 66 percent of South Carolina's total land area (Conner 1993) and fireflies are commonly observed in the natural areas (Barrows et al. 2008; Frick-Ruppert and Rosen 2008). South Carolina, similar to many states in the U.S.A. and many parts of the world, has experienced significant population and economic growth, which has resulted in a significant loss of natural habitats. For instance, urban areas surrounding the city of Charleston have increased sevenfold in the last 40 years, from 180 km2 in 1973 to 1,300 km2 in 2010, and they are expected to increase to 2,250 km2 by 2030 (Allen and Lu 2003). The population of several coastal counties in South Carolina is approaching one million, a 25 percent increase in the last decade (US Census Bureau 2010). Commercial and residential development and resultant land-use changes undoubtedly modify the landscape and alter the environmental quality of coastal areas (Pouyat et al. 2007). To protect the natural environments in South Carolina while providing for economic growth, sustainability and environmental stewardship have become important concerns to local communities.

The combination of civic concerns and the value of fireflies as an educational tool led to the development of Clemson University's Vanishing Firefly Project in 2010. Firefly surveys have been promoted worldwide as citizen-science projects (Ho et al. 2009; Masaki 2011). The Clemson Vanishing Firefly Project has four primary project goals: (1) Science Inquiry—Engage citizens in scientific practices to understand the impacts of urbanization on environmental quality; (2) Service-Learning—Increase the skill of citizens in making critical, scientific, and informed decisions through community and service activities; (3) Sustainability—Protect natural habitats through effective land and resource management practices; (4) Stewardship—Provide opportunities for citizens to participate in environmental and sustainability studies and activities. This paper summarizes activities carried out since 2010, the impacts on participant understanding of scientific inquiry and attitudes toward science and the environment, and the difficulties encountered during the organization of the project.

Project Activities

The Clemson Vanishing Firefly Project, which began in 2010, is a collaborative effort by researchers from Clemson University, land and resource managers from Hobcaw Barony Nature Reserve, educators from Hobcaw Barony Discovery Center, teachers from local schools, and leaders of local nonprofit organizations. Researchers from Clemson University focus on research about environmental quality and firefly biology and lead the field investigations and data analysis. Land and resource managers manage the 12 study sites in Hobcaw Barony and provide historical and geographic information on the study sites. Teachers and educators serve as mentors to the students and other participants during the service-learning experience. The Hobcaw Barony Discovery Center and Baruch Institute of Coastal Ecology and Forest Science provide long-term opportunities to participants who are interested in continuing the research and who volunteer to work at the Hobcaw Barony. All parties work together in promoting and advertising the Clemson Vanishing Firefly Project to local communities.

The Clemson Vanishing Firefly Project was composed of two service-learning activities each year: (1) a Firefly Field Day and (2) a South Carolina Statewide Firefly Survey. Both activities occurred in May or early June during the peak season

FIGURE 1. Aerial view of the 12 study sites at Hobcaw Barony, Georgetown, SC. (1) Managed forest burned in 2009; (2) Natural forest; (3) Clear-cut recovery area; (4) Managed forest; (5) Salt marsh; (6) Hurricane damage recovery area; (7) Active logging area; (8) Natural forest; (9) Natural forest; (10) Open and abandoned housing area; (11) Forest thinning area; and (12) Low density housing area

of firefly activity in coastal South Carolina. The Firefly Field Day was conducted at Hobcaw Barony, a 17,500-acre wildlife refuge and a member of the National Estuarine Research Reserve System. Twelve sites on Hobcaw Barony representing different land uses and forest management practices were selected as survey sites during the Firefly Field Day (Figure 1). Activities during the field day included a half-day program that included a one-hour orientation with classroom instruction, a two-hour daytime field survey and sample collection, and a two-hour nighttime firefly abundance assessment. During the orientation and classroom instruction, experts in entomology, forestry, and soil science provided some brief background information on firefly biology, methods for firefly counting and identification, methods for soil and litter sampling, general field safety, environmental impacts from coastal developments, and importance of sustainability.

The objective of the daytime survey was to provide hands-on experiences to participants about the methodology and principles of environmental and forest research. All participants were asked to inspect all 12 survey sites. They learned about the impacts of forest management practices, land use patterns, and natural disasters (e.g., hurricanes) on vegetation and the soil carbon cycle in forests. In addition, they participated in a soil carbon study (Figure 2) by collecting soil and litter samples in three selected field sites (sites 1, 4, and 9 listed in Figure 1), representing burned, actively managed, and natural forests. This exercise, which required participants to measure and interpret their data, illustrates the amount of anthropogenic disturbance in each forest ecosystem (Dale et al. 2002). The nighttime survey was intended to assess firefly abundance and provided a unique opportunity for the participants to learn first-hand the biology and ecology of fireflies in the field, as well as to observe the amazing bioluminescence display of fireflies. Participants revisited the 12 field sites after dark in vans provided and driven by staff of the Hobcaw Barony Discovery Center and Clemson University. A data sheet was given to each participant for recording his/her observations. At each site, the participants were then asked to count the number of fireflies in front of their windows within a one-minute period. The participants were also asked to identify the firefly species based on flashing patterns, as discussed in the classroom instruction, when they were able to do so. At the end of the survey, researchers collected all data sheets and summarized the results at a debriefing session.

Participants of the South Carolina Statewide Firefly Survey were asked to collect data on firefly abundance observed on one night in May or early June and submit their observations through the project's web page. The method of collecting the data was similar to the one used in the Firefly Field Day—each participant counted the number of fireflies across his/her field of vision within a one-minute period. Background information, study objectives, and a detailed sampling procedure were posted on the web page. The web page also included pre-set options for land use selection, which included farm, forest, home lawn and garden, marsh edge, wood-bordering lawn and garden, and other. The result of the statewide survey, presented as GIS–marked locations on a map, was posted on the Vanishing Firefly Project web page and disseminated to local newspapers.

In 2013, the field day and statewide survey were both conducted on June 1. In addition to the field day, researchers conducted several one- to two-hour workshops with school and community groups. Participants for the statewide survey were recruited through local and statewide media, and their ages ranged from eight to 76 years of age. While more than 1,000 participants uploaded firefly count data to our website or through our smartphone app, the findings reported in this paper focus on the 26 participants who attended either

FIGURE 2. The two high school students on the right worked with two senior participants on litter collections during a daytime survey

a workshop or the field day prior to their participation in the firefly field survey.

Participants attended workshops sometime during the month prior to the day of the firefly field survey date. Workshop attendees were asked to complete an initial questionnaire. The questionnaire asked for demographic information and the participant's knowledge of firefly biology, understanding of the process of science, and attitudes toward science and the environment. During the workshop, participants engaged in discussion and activities related to firefly biology, methods for firefly counting and identification, methods for soil and litter sampling, general field safety, environmental impacts from coastal developments, and the importance of sustainability. Following their firefly field survey, participants were asked to complete a second questionnaire online. Many of the items on this questionnaire were identical to items on the first one.

Project Findings

Data collection and analysis by the Clemson Vanishing Firefly Project are ongoing; therefore, we do not report the results of firefly counts in this paper. In brief, firefly abundance assessments during the Firefly Field Day suggest at least three *Photinus* species were observed at Hobcaw Barony. Results also indicate high between-year and between-site variations in firefly abundance at the 12 sites. Data from the South Carolina Statewide Firefly Survey suggest great differences in firefly abundance among locations and land use pattern, even within a single city. The observation that certain urban parks or reserves provide refuge and habitats for the firefly populations is an encouraging sign in the conservation of these insects. In the 2011 South Carolina Statewide survey, 42 percent of participants observed no fireflies, 32 percent reported one to 10, 14 percent reported 11 to 49, and 12 percent observed more than 50 fireflies in a minute. Most of the participants chose lawn and garden land use patterns, indicating that most participants reside in urban or suburban environments.

Questionnaire responses indicated some changes in understanding of the process of science from before the workshop to after the firefly field survey (Table 1). While participants agreed that the scientific method is used in all research studies, they better understood that there is no single correct approach to scientific research. They better understood that scientists have their own biases and perceptions, and also that those scientific ideas can be changed.

Participants also responded to several open-ended questions about the process of science, such as "What does it mean to study something scientifically?" A 1–7 scoring scheme was used to code responses on the degree of scientific literacy (Brossard et al. 2006). The scores on both the initial and the final questionnaires showed that most of the participants' responses described hypothesis testing, use of controls, and conclusions based on data.

Questionnaire responses indicated that participant attitudes toward science and the environment changed little as a result of the firefly field survey (Table 2). However, there were significant differences in responses to the item "Humans have a large impact on their environment," and differences approached significance on the item focused on participant interest in protecting the environment.

While surveys of fireflies and participants have been informative, there have been other lessons learned as a result of this project. The firefly counts used in data analysis could be higher than actual observations. There is always doubt concerning the reliability and repeatability of data collected by volunteers (Cheung and Chow 2011; Fogleman and Curran 2008). Despite the introduction and training, firefly identification using flash patterns was difficult for most participants. Double counting of the same firefly was the most common problem for non-experienced participants, since fireflies move around while flashing. It is difficult to track its flying path in the dark, particularly in areas with large numbers of fireflies. Based on the individual recording sheets, participants sometimes recorded higher numbers than the technical staff, and

TABLE 1. Results of questionnaire measuring participant understanding of the process of science

LIKERT ITEM	INITIAL QUESTIONNAIRE MEAN (SD)	FINAL QUESTIONNAIRE MEAN (SD)	P VALUE
The scientific method is used in all scientific research studies.	3.6 (1.2)	3.5 (1.1)	0.74
No experiment can fail if the scientific method is followed.	2.6 (1.1)	2.1 (0.9)	0.01*
Conducting an experiment is difficult.	2.9 (1.0)	2.9 (1.1)	0.84
The results of an experiment will be the same each time it is conducted.	2.2 (0.9)	1.9 (0.5)	0.03*
Once a study is completed, the answer to the research question will be known.	2.4 (1.0)	2.1 (0.6)	0.13
Scientists stay objective as they work.	3.6 (0.9)	3.1 (0.8)	0.04*
Scientific ideas can be changed.	4.0 (1.0)	4.3 (0.5)	0.05*
I only counted a few fireflies so the data are not useful.	1.7 (0.9)	1.5 (0.5)	0.26

An (*) asterisk indicates a statistically significant difference.

younger students recorded higher numbers than adults. Unfortunately, the number of participants in each group (i.e., technical staff, adults, and students) was too small to statistically verify these observations.

Students and adults appeared to have different attitudes towards this service-learning exercise. Students were primarily interested in field activities such as firefly counts and vegetation and soil sample collection and less interested in the introduction and group discussions. In contrast, adults expressed strong interest during the introduction in understanding the causes of firefly occurrence and disappearance. Despite the differences in behavior, both groups were excited and enjoyed the experience of observing fireflies during the nighttime surveys.

Conclusions and Implications

The findings indicate that the project had a small impact on participants' understanding of the process of science. There were significant differences on several of the Likert items addressing the nature of science from initial to final administration. The initial to final comparison for the items related to attitudes toward science and the environment showed almost no differences. It is possible that citizens interested in a workshop and field survey related to fireflies already have an interest in science and protecting the environment. Our future directions include encouraging participation for school-aged citizens as well as having participants engage with the project for a longer period of time. In order to impact the citizens who participate in the project, citizen-science projects should encourage collaboration with scientists versus merely collecting data for scientists. In order for participants to feel like collaborators, this project will begin to encourage all participants (whether on-site during a field day or off-site doing the statewide survey) to participate in long-term data collection for two to four weeks. At the end of the data collection period, participants will be invited back (either in person or online) to view a visualization of the long-term firefly count data as well as other data such as land use

TABLE 2. Results of questionnaire measuring attitudes toward science and the environment.

LIKERT ITEM	INITIAL QUESTIONNAIRE MEAN (SD)	FINAL QUESTIONNAIRE MEAN (SD)	P VALUE
Decisions about the environment should be made based on science.	4.0 (0.8)	3.8 (1.0)	0.13
Science is useful for solving problems of everyday life.	4.4 (0.6)	4.4 (0.7)	0.60
I am interested in science.	4.4 (0.8)	4.5 (0.7)	0.80
Science can make our lives healthier, easier, and more comfortable.	4.4 (0.6)	4.2 (0.7)	0.13
I usually understand what I read and hear about science.	3.9 (0.7)	4.0 (0.7)	0.58
I enjoy talking to other people about science.	4.0 (1.0)	4.1 (0.7)	0.54
It is not important to know science to get a good job.	2.5 (1.0)	2.3 (0.9)	0.48
I am interested in protecting our environment.	4.4 (0.7)	4.6 (0.5)	0.07
Humans have a large impact on their environment.	4.2 (0.7)	4.8 (0.5)	0.01*
It is important for me to share my views on the environment with others.	3.9 (0.8)	3.9 (0.9)	0.91

An (*) asterisk indicates a statistically significant difference.

patterns, soil and litter quality, and other environmental indicators. Participants in the callback meeting at Hobcaw Barony will participate in a discussion of the results, while participants online will be asked to consider questions intended to guide their thinking about the results. Being more engaged in the project and contributing more to data collection and discussion of the results might lead to more gains in content knowledge, understanding of science processes, and attitudes toward science and the environment.

The Vanishing Firefly Project is in the final stages of integrating mobile device technology. Participants attending the Firefly Field Day will begin collecting data using a newly developed mobile phone app to record the distribution and abundance of fireflies. This mobile phone app will make data collection more efficient and will encourage the general public to participate (Teacher et al. 2013; Johnson and Johnson 2013).

While our preliminary results on the impact of the project on participants are encouraging, we need to develop a more rigorous data collection plan. Specifically, we want to investigate the impact the project has on the participants' knowledge of fireflies, their understanding of the process of science, their attitudes toward science and scientists, and their attitudes toward the environment and conservation. After their participation in the project, a long-term post-activity survey will also gauge participants' engagement in community service, participation in sustainability and environmental stewardship activities, scientific literacy, and career goals (depending on their age). Through surveys, field observations, and interviews we will have a better understanding of the benefits and limitations of citizen-scientist programs.

Our initial comparison revealed that firefly abundance data collected by participants were different from those collected by experts. There are two ways to address this issue. First, the participants need more training in the method of assessing firefly abundance and identification. Web-based simulations have been successful in other citizen-science projects (Mulder et al. 2010). We will develop online simulations of firefly flashing patterns to better train our participants in identification. We will also develop different field days or training modules that are more suited to the different learning behaviors of adults and children.

The Clemson Vanishing Firefly Project is a citizen-science project that begins with scientific inquiry incorporated into service-learning to promote sustainability and ultimately environmental stewardship. The Clemson Vanishing Firefly Project provides an opportunity for citizen scientists of all ages to answer an important *science inquiry* question—Are the fireflies disappearing?—through volunteerism, training, and collection of scientific data *(service-learning)*. The goal of the Clemson Vanishing Firefly Project is to educate and prepare citizens to integrate *sustainability* and environmental *stewardship* into their future activities. In addition, this service-learning experience may motivate young participants to improve their scientific literacy and may encourage enrollment in post-secondary science programs and possibly even a career in environmental sciences. Since 2010, the project has engaged over 1,200 citizens in its annual Firefly Field Day and South Carolina Statewide Firefly Survey. The participants have received in-person or online training and information on firefly biology, environmental science, scientific methodology, and environmental sustainability. The soil characteristic survey and firefly abundance assessment have given participants hands-on experience in scientific research. The participants have collected valuable data; however, a more rigorous training program must be developed to increase the reliability of abundance and identification data from the participants. Adults and children have different behavior and attitudes toward the original program; therefore, different programs aimed at different age groups will be developed. A long-term survey will be developed to accurately assess the engagement of the participants in sustainability- and stewardship-related activities. If the Clemson Vanishing Firefly Project is successful in educating and engaging the citizens of South Carolina using the charismatic firefly, we hope it will lead to the integration of environmental sustainability and stewardship into the activities and the decision-making process of local communities.

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