THESIS

IS CITIZEN SCIENCE WORTH IT?

ECONOMIC DECISIONS OF NATURAL RESOURCE MANAGERS

Submitted by

Brian M Fauver

Department of Human Dimensions of Natural Resources

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Master's Committee:

Advisor: Brett Bruyere

Gregory Newman
Alan Bright

ABSTRACT

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Citizen science, or public participation in scientific research, is often used by natural resource management agencies for monitoring. Citizen science has been studied for its effects on volunteer education, community engagement, data rigor, and cost savings. This thesis researches the cost savings of citizen science projects by comparing three citizen science projects to equivalent professional projects, and by analyzing the methodology of implementation of three citizen science case studies. It found that the citizen science projects studied are not notably cheaper than their professional counterparts but are lauded for their benefits of education, community engagement, and stewardship. For the case studies, supervised data collection and on-the-job training were found to have higher variable costs, while unsupervised data collection and training prior to data collection was found to have higher fixed costs. The findings of this thesis might aid resource managers in deciding if citizen science is an appropriate monitoring tool for their resource.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Robbie Lasley lives in Denver, Colorado. On his weekends he journeys to the prairie grassland of Fort Collins and volunteers to collect data about grassland plants. This involves getting up early and traipsing around with other volunteers for a full day collecting data at several field sites. Robbie's story is similar to the stories of thousands of other Americans who volunteer their time to help scientists and resource managers conduct research. While it doesn't cost anything for Robbie to collect data, an agency spends a lot of effort in preparing Robbie to collect data. He has to be recruited, trained, and coordinated before starting his data collection. After his data collection is complete, it is analyzed and presented at professional conferences and published in scientific journals. Along the way every year, funding to support the citizen science project to which Robbie contributed must be justified and allocated, possibly through grants and donations. So, who pays for all this? Are the funding and effort worth it? Would it be more affordable to hire professional field technicians?

In Robbie's case, the person who makes these decisions is Leslie McPhie. Leslie works as a biologist for the Fort Collins Natural Areas Program. The onus falls to natural resource management agencies like the Fort Collins Natural Areas Program to take inventory of the current state of our natural resources and to implement ongoing ecological inventories. However, budgets for many public sector natural resources agencies are stagnant while the need for monitoring is increasing. This forces government agencies to reduce their workload, work additional hours for minimal incentive, or pursue innovative options. Leslie chose the innovative route and selected citizen science. For Leslie, this made sense. When Leslie takes out four volunteers to collect data, five people are collecting data, but only one is paid. From an accounting perspective, Leslie quadrupled her production with minimal increased costs. But many natural resource managers hold reservations about citizen science. Is the data valid? How will effective volunteers be recruited? How much will it cost?

Citizen science can be a creative solution that saves natural resource managers time and money while maintaining a rigorous level of monitoring. But before citizen science is heralded as a panacea for natural resource managers, several things need to be thoroughly investigated. While practitioners like Leslie tout benefits of cost effectiveness, educational outreach and community engagement, research is needed to fully verify these claims. If these claims were verified, the result could convince more natural resource managers to adopt citizen science for the benefit of more monitoring data, for the benefit of volunteers, and for the benefit of the natural resource managers themselves.

This thesis will concentrate on the cost effectiveness of citizen science, an act of using volunteers to aid in the research or monitoring process. This thesis is organized into five chapters.

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Manuscript 1: Intentional Implementation of Citizen Science: Economic Decision Making of Natural Resource Managers
- Chapter 4: Manuscript 2: Is Citizen Science Worth It: Perceived Value of Environmental Monitoring Techniques
- Chapter 5: Conclusion

The first manuscript, entitled *Intentional Implementation of Citizen Science: Economic Decision Making of Natural Resource Managers*, compares the budgets of three citizen science case studies. This chapter analyzes two phases of the citizen science process: training volunteer and data collection. Each case study uses a different strategy of these two phases (data collection supervised or unsupervised, and training prior to data collection or concurrent with data collection), leaving three unique combinations to compare to three budgets that display fixed costs and variable costs. Research questions addressed in this chapter were:

1: Does choice of implementation strategies (training and data collection protocols) have an effect on a project's annual fixed costs (costs that do not change with additional volunteers) and annual variable costs (costs that increase per additional volunteer)?

The second manuscript, entitled *Is Citizen Science Worth It: Perceived Value of Environmental Monitoring Techniques*, compares three case studies of citizen science projects against three hypothetical professional monitoring projects. Research questions were:

1: How do costs differ between citizen science and professional monitoring projects?

2: What do natural resource managers identify as the main benefits and concerns of citizen science monitoring projects?

LITERATURE REVIEW

Introduction

Citizen science is the act of participants volunteering in any part of the scientific research process. It can be an excellent management tool that provides useful data, an increase in community engagement, and scientific outreach to targeted audiences (G. Newman et al., 2012). Citizen science projects come in all shapes and sizes, from the very large to the very small. Galaxy Zoo, which has hubs in Oxford, Chicago, Minnesota, and Portsmouth, manages more than 200,000 volunteers from all over the world and collects an immense amount of astronomy data. All volunteer interaction is done virtually, including training, data collection, and analysis. The data Galaxy Zoo collects and analyzes would not be feasible with paid researchers (Raddick, Bracey, & Gay, 2010). Alternatively, the Front Range Pika Project manages 60 volunteers who are trained in person and collect data in mountain landscapes on the American pikas, lagomorphs of the high alpine, for a 10-week period in late summer each year (G. J. Newman, Skarpino, Masching, & Mueller, 2013). The Front Range Pika Project contributes to work already being done by the state wildlife management agency, Colorado Parks and Wildlife, and could theoretically be replaced by paid field technicians.

While the concept of members of the public volunteering for scientific research or monitoring is not new, natural resource managers have adopted it more frequently in recent years. Early citizen science projects include Audubon Society’s Christmas Day bird-count, which has records as early as 1900 (Dickinson, Zuckerberg, & Bonter, 2010). This early data collection has grown into a larger phenomenon in which multitudes of volunteers collect data for thousands of non-governmental agencies studying everything from archeology to astronomy. A recent paper estimates that the number of citizen science projects is now in the thousands, and the number of volunteers collecting data is now over a million (Bonney et al., 2014). With this immense amount of data collected and the growing popularity of participation in citizen science, opportunity has also blossomed for new research studying this phenomenon. So far, research has focused on the benefits that volunteers of citizen science projects enjoy, the cost effectiveness of citizen science, and the community that citizen science creates.

As the world population is steadily moving toward urban centers, citizen science can play a role in reconnecting people to nature (Devictor, Whittaker, & Beltrame, 2010; Miller, 2005). Participants in citizen science projects become engaged in local, place-based, ecological interactions through which scientific investigation invites them to feel wonder and curiosity toward nature. These urban residents find connections to nature that exist within cities through citizen science programs such as Project Budburst, which encourages participants to track phenological changes of local flora (Devictor et al., 2010).

Citizen science is often assumed to be cheap, as the labor cost of field technicians is replaced by or completed with volunteer labor. However, it is hard to evaluate if the costs associated with citizen science outweigh its benefits because of minimal research about the topic. For example, many studies looking at the expense of citizen science replace only the costs of field technicians with free volunteer labor, ignoring additional costs, such as time taken to train volunteers (Cohn, 2008; Schmeller et al., 2009). Other studies calculate costs of citizen science projects using the cost per plot or grid sampled (Gardiner et al., 2012; Tulloch, Possingham, Joseph, Szabo, & Martin, 2013). This can be an effective way to compare the two strategies but cannot be easily compared to other projects that do not study the same species or use similar field methods. Due to the absence of studies that are either adequate in accounting logic or repeatable, it is difficult to determine if citizen science is a less expensive alternative than professional monitoring.

John Dewey, an early American philosopher (1859–1952), argued that a complete democracy requires an educated and a fully informed public, which is accomplished only through communication between citizens, technical experts, and decision-makers (Dewey, 2007). An engaged and educated public relies on and builds relationships with community members and trust between managers and the public (White, 2001). This dynamic not only can take place with existing relationships but can expand into creating new and stronger bonds of trust with the community. This creates so-called “political capital” with members of the public. These trust-based relationships are necessary for managers to build a populace that is fully informed regarding the intricacies of natural resource decisions. With an educated and engaged public, natural resource decisions can become quicker and less controversial (Thompson, Elmendorf, Mcdonough, & Burban, 2005).

As members of the public participate in information collection, they develop a greater capacity for understanding natural resource management decisions which are grounded in connection to nature. White also argues that once people have a participation-based working relationship with community members, this attracts new constituency populations that would otherwise be inaccessible. This cyclical dynamic increases the constituency base, but citizen-science can also be used to foster relationships with entirely new, often disengaged, members of the public: city dwellers. As Mckinley et al. (2013) put it, “The rise of citizen science and participatory research is a contemporary manifestation of an ever-evolving democracy and land ethic” (p. 10). Citizen science increases a manager’s ability to understand and be involved in a community’s ever-expanding relationship with the environment.

Scientific Benefit

Long-term ecological monitoring is known to be valuable. It is useful not only to understand long-term ecological change or disturbance, but also to add to basic ecological theory of communities and populations (Lindenmayer & Likens, 2010b). A great example of the power of long term ecological monitoring is the Japanese Cherry Blossom Festival, which has been tracking phenology of the cherry blossom tree for over a millennium (Primack, Higuchi, & Miller-Rushing, 2009). And while it is increasingly harder for professional researchers to implement or operate a long-term monitoring project due to academic culture, funding cycles, and/or intellectual property issues (Lindenmayer & Likens, 2010a), citizen science projects can fill this need to collect long-term data that is so beneficial for current and future analysis.

Through the nature of citizen science data being collected by amateurs, the data is often believed to be less trusted than professional data. An article in 2008 by Ely summarized thoughts of citizen science practitioners involved in the Citizen Science Toolkit Conference in 2008. Ely found that several citizen science practitioners believe that natural resource managers do not trust data collected by smaller (local) citizen science projects. This results in these projects contributing less data toward scientific publications or management decisions. This study is in contrast to a paper looking at a highly successful larger (nation-wide) citizen science project called eBird. This citizen science project is an online-based repository for bird monitoring. Tens of thousands of volunteers submit data annually. This has provided eBird with an abundance of data about bird migration, data which is later validated in some instances (Bonney et al., 2009). eBird has used this opportunity to create a published approach of data quality/data control that has created trust in its data. This trust has inspired many resource managers and scientists to use eBird data (Bonney et al. 2009). Tulloch, Mustin, Possingham, Szabo, & Wilson (2013) found similar results when studying other citizen science project's study bird migration. They found that between 2005 and 2010 there were 83 instances of citizen science collected data for atlas bird surveys (large scale, multiple species citizen science projects) used in scientific publications, and 93 instances in which data from bird breeding surveys collected by volunteers was used in scientific publications.

Citizen science has been shown to affect policy and management decisions (Conrad & Hilchey, 2011). The Florida LakeWatch program has collected data since 1992. This program collects a wide range of data about the lake, including invasive species, nutrient content, plant life, and chemical makeup. This data can be useful for governmental agencies to keep inventory of Florida lakes internally or on websites like the Florida Atlas of Lakes. The state of Florida, the National Oceanic and Atmospheric Association and the government of the Bahamas have used Florida LakeWatch data (Conrad & Hilchey, 2011). While, there are several successful examples of governmental or peer reviewed publication of citizen science data, scientific rigor of citizen science data remains a popular topic as evidenced by the plethora of articles written about it.

Most studies approach the issue of data rigor in one of three ways: methods to prevent data error, methods to test data error, and methods to correct data error after the data collection. Two strategies have been shown to most effectively prevent data error: volunteer training and proper data collection tools. In a case study in Canada, students received one hour of training offsite within two weeks prior to data collection and tended to over count important species. This failure of data quality can be attributed to an insufficient and short training (Galloway, Tudor, & Haegen, 2006). In another instance, data collected by volunteers who received eight hours of training was as reliable as data collected by trained professionals (Brandon & Spyreas, 2003). A third example is from Belize. Coral Caye Conservation collects data on reef organisms and biodiversity on the barrier reef of Belize. Their volunteers spend eight days in an intensive training on the Coral Caye Conservation protocols for collecting reef data. As a result, their volunteers can provide data that is on par with the data collected by professionals (Mumby & Harborne, 1995).

Another way to prevent data errors is to ensure that the volunteers and the professionals use the same equipment. A 2001 study determined that deviations in data collected by volunteers from that collected professionals were due to the different equipment each group used to collect the same data (Nicholson, Ryan, & Hodgkins, 2001). The study looked at a citizen science project in Victoria, Canada that collected the turbidity data of several rivers and then compared this data to professional data on the same rivers. The study found that the citizen science data differed significantly from professional data, but the equipment that the citizen scientists used differed from that used by professionals. The citizen scientists used turbidity tubes, a subjective color scale based instrument while the professionals used a turbidity meter, a precise numerical instrument.

Citizen science data can be assessed for accuracy after data collection. A simple way to do this is with a statistical comparison between professional and citizen science data (Cohn, 2008; Crall et al., 2011; Nicholson et al., 2001). Papers that test for data accuracy can be beneficial for other projects attempting to study the same subject as they create a best practices template for other citizen science projects to follow. Ottinger (2009) describes a scenario in which universalized methods to measure air quality led to significant changes to a nearby Shell factory. Ensuring data accuracy of a specific data collection training and procedure helps other projects defend their data. Belt (2010) studied volunteer accuracy when collecting data on the American pika. She found that when volunteers followed a certain data collection protocol, their data was acceptably accurate. Since this study, seven other citizen science projects studying the American pika have adopted the protocols outlined in her study (G. J. Newman et al., 2013).

Community Benefits

The two most commonly researched topics about citizen science other than data collection are a) volunteer education and b) the greater community that is a part of citizen science projects. The benefits of using citizen science participants can be identified by researching volunteer motivation. Bradford and Israel (2004) surveyed 382 volunteers who participated in a sea turtle monitoring project that identified conservation of sea turtles as their primary motivation. A more recent study (Raddick et al., 2010) interviewed 12 participants of a large astronomy citizen science project. They found that each volunteer had several motivations but could identify common themes among all volunteers, such as astronomy, learning, discovery, and community. Both these studies found that participants prioritize helping the project's objectives over other motivations such as personal education or the community of fellow citizen scientists. These two articles illustrate that the volunteers take part in the citizen science process for several reasons, but volunteer education and interest in the subject matter are a priorities.

Education is often measured through an increase in volunteers' scientific literacy. Several papers have found evidence that supports this hypothesis (citizen science projects increase the scientific literacy of participants), and several have found evidence that does not. An early paper discussing volunteer benefits from citizen science found that its participants engaged in scientific thinking (Trumbull, Bonney, Bascom, Cabral, & Trumbull, 2000). The citizen science project studied bird nests and required participants to mail data annually. The data was often accompanied by additional comments from the volunteers. Trumbull et al. (2000) analyzed these comments and found that eighty percent of them engaged in "scientific based thought processes," defined as “actively engaged in thinking about the research process...during project participation.”

Five years later, two papers studied scientific literacy among participants in more depth. Evans, Abrams, and Reitsma (2005) and Brossard, Lewenstein, and Bonney (2005) both found that their respective projects (Neighborhood Nest Watch and The Birdhouse Network) increased participant knowledge of their subject matter (bird biology) but did *not* increase the scientific literacy of participants. Both the projects studied were similar to the project in the original Trumbull et al. (2000). Both were very large bird monitoring project with little personal volunteer-to-scientist interaction.

Volunteer-scientist interaction is significant for scientific literacy, as found by Cronin and Messemer (2013). Cronin and Messemer studied a water quality citizen science project that had 57 adult volunteers. Using a pre/post survey of adult volunteers, they found that the scientific vocabulary of participants increased, as did their understanding of scientific concepts. They offered an explanation that the one-on-one mentorship between project leaders and participants helped the participants increase knowledge of scientific literacy. Ballard and Belsky (2010) found a similar result, that their smaller project increased scientific literacy.

Volunteers interested in environmental topics can also lead to invested public communities. Public engagement in governmental decision making has been found to increase public support of the governmental agency (White, 2001). White found that when the Wisconsin Department of Natural Resources implemented a committee consisting of members of the public to help with decision making of a contentious issue, public opinion of the department increased significantly, as did trust in the department by members of the public. This study did not look at citizen science specifically but was used as a foundation for other papers that did address citizen science. Cheng, Danks, and Allred (2011) called citizen science "multiparty or participatory monitoring," and Thomson et al. (2005) referred to using public volunteers as "citizen planning." These "multiparty or participatory monitors" and "citizen planners" differentiated themselves from citizen science by being included in the project planning phase, data collection phase, and final decision-making process, not just the data collection phase. Both papers found that including volunteers throughout the decision-making process increases public support of natural resource decision-making.

This finding is repeated in papers that specifically refer to citizen science (Fraser, Dougill, Mabee, Reed, & McAlpine, 2006; Petrokofsky et al., 2010; Talwar, Wiek, & Robinson, 2011). These papers all studied so called "bottom-up" citizen science projects, meaning the volunteers who participated in this project were a part of the project's design. Bottom-up citizen science projects are in contrast to top-down citizen science projects, which do not include the volunteers in the decision-making process. That is, a top-down citizen science project has already identified the questions and methods of the project and uses the volunteers only to collect data. Two papers speculated that a data collection only citizen science project could increase public support of a natural resource agency (Cooper, Dickinson, Phillips, & Bonney, 2007; McKinley et al., 2013), but their work was not data based.

Cost Effectiveness

Cost of citizen science is an understudied subject. Only four papers have been widely published to address this subject. Similar to data quality, it is hard to compare citizen science projects that study different species. Four papers (Gardiner et al., 2012; Nerbonne & Nelson, 2008; Schmeller et al., 2009; Tulloch, et al., 2013) have published the cost of their citizen science projects. Two used cost per site for their analysis. For example, Gardiner et al. (2012)

studied a lady beetle citizen science project that used sticky traps to collect data. It found that it cost 31.44$per sticky trap for a citizen scientist to collect the data. It cost the project 40.29$per sticky trap to have the citizen science collect the data and then have the data verified. Gardiner et al. (2012) also found that the cost of traditional science cost 126.62$per sticky card trap was more than three times the cost of a citizen science project. Similarly, Nerbonne and Nelson (2008) surveyed 138 citizen science macroinvertebrate monitoring projects. Of these projects, spending ranged from 1,000$per site to no cost per site and averaged $211.

On the other hand, two papers studied cost per volunteer hour. Both were studying large, continent wide monitoring projects. Tulloch et al. (2013) studied several citizen science projects to compare bird atlas monitoring programs and breeding bird survey projects. Atlas monitoring programs are citizen science projects that collects volunteer data from only specific stratified sites, for no set amount of time, while breeding bird surveys are citizen science projects that collect volunteer data from any location, but only during a set amount of time. They found that bird atlas monitoring programs had mean data collection hours of 186,500, and a mean cost of 10,133,500 USD, or 54.34$per volunteer hour. The breeding bird survey projects surveyed had mean data collection hours of 147,900 and mean costs of 10,014,200USD, or 67.71$per volunteer hour. The second study that looked at cost per volunteer hour was conducted by Schmeller et al. (2009). They took several years' worth of data from the European Monitoring (EuMon) project. The EuMon project is a multi-national scale project that monitors several different species. This study looked at citizen science projects that studied amphibians and reptiles, birds, butterflies, other insects, plants, and mammals (Schmeller et al., 2009). It found that it cost approximately four million euros (approximately 4,370,140USD) to operate 148,690 person-days (one eight-hour day). After, their cost was calculated as 3.67$per volunteer hour.

Schmeller et al. (2009) did not study a professional monitoring project; it did state that to pay a worker for each volunteer hour would have cost 13 million euros (14,238,900$as of 2/26/15), or roughly three times the cost of its citizen science project, EuMon.

The research surrounding citizen science and cost varies greatly by study and method of analysis. Of the four papers, the studies cannot be compared because the methods differed greatly among projects. Gardiner et al. (2012) used sticky card traps to calculate cost while Nerbonne and Nelson (2008) used stream monitoring sites visited to calculate cost. Tulloch et al. (2013) and Schmeller et al. (2009) can be compared to each other as they both analyzed cost per volunteer hour. Tulloch et al. (2013) found costs of two types of large-scale bird citizen science projects of 54.34$per volunteer data collection hour and 67.71$per volunteer data collection hour, respectively. These costs are substantially different from those of Schmeller et al.'s (2009) findings that a large scale multi species citizen science project costs 3.67$per data collection hour. While Schmeller et al. (2009) did not explicitly describe the methods of EuMon, perhaps the training and coordination were less substantial than both the atlas monitoring programs and the breeding bird surveys described by Tulloch (2013) which could explain the difference in cost. As illustrated with these studies, differences in cost between projects can be very high.

However, there is consensus among two studies that professional projects would cost roughly three times the cost of a citizen science project. It is useful to note that both of these comparisons do not change the project methods other than data collection between citizen science and professionals which assumes that professional and citizen science projects are run identically.

Conclusion

Citizen science offers an exciting possibility that could benefit natural resource management agencies through data, community benefits, and cost effectiveness. Citizen science data has been used in publication of scientific journals and governmental decision making processes. Data collected by citizen science projects is often studied for accuracy. Several studies have analyzed citizen science data by comparing it to professional data and looked for outliers within the citizen science data. These studies recommend ensuring equipment and training are adequately rigorous for citizen science data collection needs and implementing a quality assurance/quality control procedure for the data collected.

Several studies have analyzed community benefits of citizen science projects. These papers can conclude that the results are mixed as to how a citizen science project will affect volunteer scientific literacy. Other studies show that citizen science will increase participants' scientific literacy and that citizen science has no effect. However, it is useful to note that the studies that found a relationship between citizen science and participant increase in scientific literacy were all studying smaller sized projects. Other community benefits of citizen science that have been studied include an increased trust in governmental decision making. However, these results require participants to be involved in the selection of subject matter studied and data collection methodologies to find an increase trust of governmental decision making. The effect of citizen science data collection (not selection of subject matter or data collection methodologies) on trust in governmental decision making has not been tested.

However, for all these benefits it is difficult for natural resource managers to anticipate the outcome of any citizen science project because the drawbacks and budgetary costs have not been adequately studied. This creates a challenge for natural resource institutions that consider implementation of citizen science. Cost effectiveness of citizen science has not been studied in depth from a budgetary perspective. From the studies that have looked at citizen science, a few had similar results. The papers that compared professional monitoring projects to citizen science projects found that professional projects cost three times as much as the citizen science projects. But this was the only similarity among the papers. The costs of project varied so wildly that a resource manager would have a difficult time synthesizing any useful information from the papers. If citizen science can be a beneficial tool for natural resource managers, then more work must be done to research cost effectiveness so that managers are not left without this management tool in their toolboxes.

INTENTIONAL IMPLEMENTATION OF CITIZEN SCIENCE: ECONOMIC DECISION MAKING OF NATURAL RESOURCE MANAGERS

Citizen science has been studied in depth from several common perspectives including a data quality perspective (both precision and accuracy), an educational and community benefits perspective, and a scientific impacts and outcomes perspective. Yet, not much work has been done from an economic perspective. Costs were compared across three implementation strategies of three citizen science projects: A) training volunteers prior to data collection and supervised data collection; B) training volunteers concurrent with data collection and supervised data collection; and C) training volunteers prior to data collection and unsupervised data collection. We hypothesize that choice of implementation strategy will relate to a project's annual fixed costs (costs that do not change with additional volunteer data collection hours) and annual variable costs (costs that increase per volunteer data collection hour). Fixed and variable costs are important because a project with high fixed costs and low variable costs can increase in size (or "scale up") more cost effectively than a project with low fixed costs and high variable costs. When calculated as a percent of the project's total budget, Strategy A (training prior to data collection and supervised data collection) had the highest fixed costs and lowest variable costs; Strategy B (training concurrent with data collection and supervised data collection) had the lowest fixed costs but the highest variable cost per additional data collection hour; and Strategy C (training prior to data collection and unsupervised data collection) had moderate fixed costs and moderate variable costs. Understanding the effects of implementation strategy on a project's budget is essential when designing and implementing a successful citizen science project.

Introduction

Citizen science can empower volunteers to collect environmental monitoring data that in turn can be used by researchers and natural resource managers. It is often heralded as an excellent management tool that provides useful scientific data, increases community engagement, and educates targeted audiences. Policy benefits include a more engaged public (Devictor et al. 2010; McKinley et al. 2013), a larger community interest in natural resources (Thompson et al. 2005; White 2001), an increased opportunity for adaptive management (Cooper et al. 2007; Couvet et al. 2008), and an almost immediate feedback loop for ecological information and public opinion (Fraser et al. 2006). Volunteers who participate in citizen science projects become engaged in local, place-based scientific investigation which can create a renewed wonder and curiosity toward nature (Braschler et al. 2009), an increased knowledge of the scientific process, and an improved scientific vocabulary (Cronin & Messemer 2013).

Despite such benefits, concerns remain regarding data quality. Studies on citizen science data quality (e.g., accuracy and precision) can be organized into three categories: approaches to prevent data quality errors (Brandon & Spyreas 2003; Crall et al. 2011; Galloway et al. 2006; Mumby & Harborne 1995; Nicholson et al. 2001), approaches to test for and/or detect data quality errors (Cohn 2008; Ottinger 2009), and approaches to account for data quality errors (Bhattacharjee 2005).

While a significant amount of research has been done to alleviate concerns about data quality, little has been done to address other important concerns for citizen science, such as cost. Four studies have examined the cost of citizen science projects: two looking at costs/site and two looking at cost/volunteer hour. Gardiner et al (2012) studied a citizen science lady beetle monitoring project using average cost of plot monitored and found that cost varied from

40.29$per sticky card trap to 31.44$per sticky card trap (2012). Similarly, Nerbonne and Nelson (2008) surveyed 138 citizen science macroinvertebrate monitoring projects and found that costs ranged from 1,000$per site to 0$per site, averaging 211$per site.

From a costs per volunteer hour perspective, a comprehensive analysis of the EuMon (European Monitoring) project was done between 1993 and 2005 (Schmeller et al. 2009). They found that the project cost approximately four million euros (4,370,140$as of 2/26/16) to operate 148,690 person-days; assuming that one person-day is equal to 8 hours, then cost per volunteer hour for this project would amount to $3.67 dollars per volunteer hour. Finally, Tulloch et al. (2013) found that bird atlas monitoring programs had mean cost $54.34 dollars per volunteer data collection hour, while breeding bird survey projects had mean costs of $ 67.71 dollars per data collection hour. These costs between projects vary drastically, most likely due to the project's methods of volunteer management and data collection. These four studies have all analyzed cost as having a continuous linear relationship to data collection hours or data collection plots. This ignores any fixed costs or costs do not increase as the number of plots or hours produced are increased (Samuelson & Nordhaus 2010). This is significant because a project with high fixed costs and low variable costs can increase in size (or scale up) more cost effectively than a project with low fixed costs and high variable costs.

To date, there has not been a method that compares the budgets of citizen science projects across different fields of study using fixed costs and variable costs. To address this gap, we present an approach to compare projects' operational budgets by examining three case studies of citizen science projects in different fields of study. Further, we posit that different implementation strategies (training and data collection protocols) effect a given project's annual fixed costs (costs that do not change with additional volunteer data collection hour) and annual variable costs (costs that increase per volunteer data collection hour).

Methods

In this study we present a unique approach to compare citizen science project budgets across three fields of study: marine biology, botany, and conservation biology. Each case study used different sampling units (points, transects, polygons). We compared project costs per volunteer data collection hour for each case study separated into fixed costs (costs that remain static as hours of data collection increase) and variable costs (costs that change as data collection hours increase [Samuelson and Nordhaus, 2010]). These costs were found using cash-based accounting methods (Dechow 1994). We assumed that all trained volunteers were equally efficient in collecting required data within and across projects. The case studies selected were confined to field-based citizen science projects that involved volunteer training, were managed by project managers that were willing and able to be interviewed and work with our team to reflectively calculate project costs and that were willing to share their annual budget and associated expenses.

Cash-based Accounting

Project coordinators were asked to estimate fixed and variable costs for an average budget year associated with common citizen science process steps through cash-based accounting (Dechow, 1994). Specifically, project coordinators estimated variable and fixed costs associated with each step of the citizen science process (Table 1) through collaborative discussions. Costs were divided into eight steps (e.g., form a team, refine protocols, recruit participants, train participants, collect data, analyze data, retain participants, and disseminate results) following a modified version (adding volunteer retention) of the widely published citizen science toolkit (Bonney et al. 2009; Bonney et al. 2014).

Cash-based accounting was used to reflectively calculate estimated average annual budgets for each of the three citizen science projects categorized by each citizen science process step. Cash-based accounting itemizes expenses that are paid by the project (Dechow, 1994) and excludes equipment or time that is donated to the project. After the estimated fixed and variable costs for each step of the citizen science process were calculated using the estimates provided by project coordinators, graphical budgets were created for each project representing costs per participant data collection hour where fixed costs are shown as dotted lines and the rate at which total costs per volunteer data collection hour (e.g., variable plus fixed costs) rise is shown as solid lines, as described by Samuelson and Nordhaus (2010). The relationship between total project costs and project data collection hours is assumed to be linear. For each project, coordinators identified the desired number of volunteer data collection hours needed to obtain an appropriate sample size for statistical significance necessary to answer project research questions.

Three citizen science projects were opportunistically chosen with different implementation strategies as case studies. In our experience, field-based citizen science implementation strategies vary on two dimensions: (1) *when* trainings are conducted (before or during data collection events) and (2) whether data collection by volunteers is *supervised* or *unsupervised* by coordinators. Other implementation possibilities not considered herein consist of citizen science projects without data collection training and citizen science projects whose participants are supervised remotely. For these purposes, all three case studies represented unique combinations of these two field-based dimensions. Strategy A consisted of training before data collection and supervised data collection, Strategy B had training during data collection with supervised data collection, and Strategy C represented training before data collection with unsupervised data collection. We could not find a field-based example of Strategy D, which has training concurrent with data collection and unsupervised data collection as a field-based citizen science project. The three case studies chosen represent implementation strategies A, B, and C and included the Seattle Aquarium Citizen Science Program, the Fort Collins Natural Areas Department, and the Front Range Pika Project. These projects and their associated relevant variables are shown in Table 1.

Table 1: Comparison of the Three Selected Field Based Citizen Science Case Studies

Project	Implementation Strategy	Training in relation to data collection	Supervised / unsupervised data collection	# of Volunteers	Volunteer to Coordinator Ratio During Data Collection	Annual Operational Budget	Data Collection Hours
Seattle Aquarium Citizen Science Program (SACSP)	A	Before	Supervised	90	9:1	$111,522.00	1750
Fort Collins Natural Areas Department (FCNAD)	B	During	Supervised	12	6:1	$18,798	494
Front Range Pika Project (FRPP)	C	Before	Unsupervised	30-40	2:0*	$57,923	703

*Note: FRPP does not supervise volunteers during data collection

All three projects represent field-based citizen science monitoring projects with a small volunteer base and limited monetary resources. All projects placed thresholds on the maximum amount of data collection required based on the statistical needs of the parent lead organization and were, therefore, not interested in scaling their respective projects larger than their current size to collect greater amounts of data. Each project was analyzed for cost spent per volunteer data collection hour through quantitative accounting techniques (Mariotti & Glackine, 2012) and qualitative interviews (Lindlof & Taylor, 2011) of project coordinators and natural resource managers associated with the projects. Each project's annual operational budget was separated into fixed and variable costs and by process step. We specifically focused on training and data collection as process steps of interest given the importance of these two steps monetarily in citizen science project implementation. These steps tend to consume a large proportion of a project budget and they represented the two factors differentiating each of the three implementation strategies.

Case Studies

Seattle Aquarium Citizen Science Program (Strategy A)

The Seattle Aquarium Citizen Science Program(SACSP) is a citizen science project designed to engage and educate historically underrepresented high school students in the Puget Sound area of Washington State. Operated by the Seattle Aquarium, the project has been operating for 11 years. For budgetary cash-based accounting purposes, we analyzed the 2014 budget. The program trains its student-scientist participants to collect and analyze data while educating them about marine science concepts, plant and animal identification, and field-based research techniques. Participants monitor specie’s presence and habitat trends on local beaches. As identified by project coordinators, SACSP reported annual fixed costs of permanent and seasonal employees, dissemination of project results, and program evaluation. SACSP reported variable costs of permanent and seasonal employees, travel, supplies, teacher and substitute payment, and incentives to retain participants (Table 1). This project is implemented using Strategy A. It requires $111,522 and a volunteer to coordinator ratio of 9:1 to achieve a desired goal of 1,750 hours of data collection. SACSP coordinates 375 citizen scientists. SACSP has additional costs based on educational content provided to students outside the scope of learning the data collection protocols for the monitoring project. Each of the participating student conducts an inquiry driven field study of their own and presents it at a symposium under the guidance of Aquarium staff.

Fort Collins Natural Areas Department (Strategy B)

The Fort Collins Natural Areas Department (FCNAD) project is a citizen science project created and designed to address rare plant monitoring needs for the FCNAD. It has operated since 2006. For budgetary cash-based accounting purposes, we analyzed years 2010-2012 to calculate average annual budget. FCNAD locates and inventories a variety of plants that are rare to northern Colorado. The data collected is shared with the Colorado Natural Heritage Program for conservation status assessments. Volunteers travel with a botanist to natural areas identified as potential habitat and search for a number of rare plants. FCNAD reported annual fixed costs of forming a team and refining protocols, recruiting participants, and disseminating project results. FCNAD reported variable costs of training participants, data collection, and data analysis (Table 1). FCNAD required 494 hours to achieve its monitoring needs. It coordinates 12 volunteers and implements Strategy B to train and collect data with those volunteers. The project costs $18,798 and has a volunteer to coordinator ratio of 6:1 (Table 1).

Front Range Pika Project (Strategy C)

The Front Range Pika Project (FRPP) has been operating since 2010. It sends adult volunteers to study American pika (*Ochotona princeps*) populations throughout the alpine mountains of Colorado. For budgetary cash-based accounting purposes, we analyzed years 2012–2015 to calculate average annual budget. It is a collaboration between two non-profit organizations (Rocky Mountain Wild and the Denver Zoological Foundation), two universities, (the University of Colorado and Colorado State University), and a state agency, Colorado Parks and Wildlife. Volunteers travel unsupervised to potential pika sites and mark if the mammal is present or absent and collect additional data regarding the characteristics of the talus field (rocky alpine sites) at the site. These variables include weather data, old pika sign (urine, scat, or haypiles), and site characteristics (talus depth, size of talus field, size of talus pieces, presence of water). FRPP reported annual fixed costs of staff time, travel, and variable costs of equipment, volunteer events, and staff time (Table 1). FRPP determined that 703 data collection hours would be adequate to meet the project's statistical design. To attain these data collection needs, FRPP manages 30 to 40 volunteers for implementing Strategy C. This implementation strategy costs FRPP a calculated estimated annual budget of $57,923 and requires a volunteer to coordinator ratio of 2:0 (Table 1).

Results

Based on our cash-based accounting, total costs per volunteer data collection hour for each case study (fixed and variable costs) differ across implementation strategy (Figure 1). Implementation Strategy A (SACSP) had medium fixed and variable costs as a percent of their total budget; Strategy B (FCNAD) had the lowest fixed costs and the highest variable costs as a percent of their total budget; and Strategy C (FRPP) had the highest fixed costs and lowest variable costs as a percent of their total budget (Figure 1). When looking at training and data collection in more detail, Strategy A (SACSP) listed both fixed and variable cost items associated with training, Strategy B (FCNAD) listed only variable cost items associated with training, and Strategy C (FRPP) listed both fixed and variable cost items associated with training. Similarly, Strategy A (SACSP) listed only fixed cost items associated with training, Strategy B

(FCNAD) listed only variable cost items associated with training, and Strategy C (FRPP) listed both fixed and variable cost items associated with training (Table 2).

Table 2: Fixed and Variable Cost Items Associated with Common Citizen Science Process Steps (Modified from the Citizen Science Toolkit; see Bonney et al. 2009; Shirk et al, 2014) Identified by the Three Cases Studies Examined

	Form Team	Refine Protocol	Recruit Participants	Train Participants	Collect Data	Analyze Data	Retain Participants	Share Results
Strategy A (SACSP) Fixed Cost Items	Staff Time	Staff Time	-	Staff Time	-	-	Staff Time	Staff Time
Strategy A (SACSP) Variable Cost Items	-	-	Staff Time	Staff Time	Staff Time	Staff Time	-	-
Strategy B (FCNAD) Fixed Cost Items	-	Staff Time	Staff Time	-	-	-	-	Staff Time
Strategy B (FCNAD) Variable Cost Items	-	-	-	Staff Time	Staff Time	Staff Time	-	-
Strategy C (FRPP) Fixed Cost Items	Staff Time	Staff Time, Travel	Staff Time	Staff Time, Travel	Staff Time	Staff Time	Staff Time, Travel, Catering Fee	
Strategy C (FRPP) Variable Cost Items			Staff Time	Staff Time, Food, Volunteer Manuals	Staff Time, Equipment	Staff Time	Staff Time, Food, Appreciation Gift	

The three case studies had differing variable and fixed costs associated with reaching their desired number of volunteer data collection hours as shown on Figure 1. Both the FRPP and the SACSP project invested a large amount of money into fixed costs; volunteer training contributed a large proportion of these projects' fixed costs. Both of these two projects chose to conduct training prior to data collection (e.g., FRPP chose Strategy C and SACSP chose Strategy A). Both the FCNARP and the SACSP chose an implementation strategy that had volunteers supervised while collecting data (e.g., FCNARP chose Strategy B and SACSP chose Strategy A). Table 3 shows differences in variable costs, fixed costs, and implementation strategy among the three project implementation strategies.

Table 3: Comparisons Across Citizen Science Projects in terms of Variable and Fixed Costs per Data Collection Hour and Implementation Strategy

Project	Strategy	Total Variable	Total Fixed	Training Variable Costs	Training Fixed Costs	Data Collection Variable Costs	Data Collection Fixed Costs
SACSP*	A	$65,718 (59% of total budget)	$45,804 (41% of total budget)	0	$14,541 (32% of total fixed cost)	0	$9,628.50 (21% of total fixed cost)
FCNAD**	B	$18,309 (97% of total budget)	$480 (3% of total budget)	$9,704 (53% of total variable cost)	0	$7,141 (39% of total variable cost)	0
FRPP***	C	$20,147 (35% of total budget)	$31,776 (65% of total budget)	$5,238 (26% of total variable cost)	$8,596 (23% of total fixed cost)	$8,663 (43% of total variable cost)	$2,141 (6% of total fixed cost)

* Note: SACSP = Seattle Aquarium Citizen Science Program
** Note: FCNAD = Fort Collins Natural Areas Department
*** Note: FRPP = Front Range Pika Project

Data Collection

Strategies that used supervised data collection (A and B) had higher percentages of variable costs (59 percent and 97 percent) than the strategy that used unsupervised data collection (C), which had a lower percentage of variable costs (35 percent). Similarly, strategies that used supervised data collection had lower fixed costs: Strategy B's fixed costs were $480 or 3 percent of the project’s total budget; Strategy A's fixed costs were 41 percent of the project’s total budget; and Strategy C's (unsupervised data collection) fixed costs were 65 percent of the project’s total budget.

Strategy A (training prior to data collection) had data collection costs of staff time as a fixed cost. This cost amounted to 14,541$or 32 percent of the total fixed costs for the project. Strategy B (supervised data collection) had data collection costs of staff time which was a variable cost. This cost was $7,141 or 39 percent of the total variable costs for the project. Finally, Strategy C (unsupervised data collection) had data collection fixed costs of staff time ($2,141 or 6 percent of total fixed costs of the project) and training variable costs of staff time and equipment ($8,663 or 43 percent of total variable costs).

Training

Strategies that used a training prior to data collection (A and C) had a higher percentage of fixed costs than the strategies that used a training during data collection (B). Strategy C's fixed costs were $31,776 or 65 percent of the project's total budget, Strategy A's fixed costs were $45,804 or 41 percent of the project's total budget, and Strategy B's fixed costs were $408 or 3 percent of the project's total budget. And inversely, Strategy B, which used training during data collection, had the highest percentage of variable costs compared to its project budget (97 percent), while Strategies A and C had lower percentages of variable costs of 59 percent and 35 percent respectively.

Strategy A (training prior to data collection) had training costs of staff time as a fixed cost. This cost amounted to $14,541 or 32 percent of the total fixed costs for the project. Strategy B (training during data collection) had training costs of staff time as a variable cost. This cost was $9,704 or 53 percent of the total variable costs for the project. Finally, Strategy C (training prior to data collection) had training fixed costs of staff time and travel ($8,596 or 26 percent of total fixed costs of the project) and training variable costs of food, and training manuals ($ 5,238 or 23 percent of total variable costs).

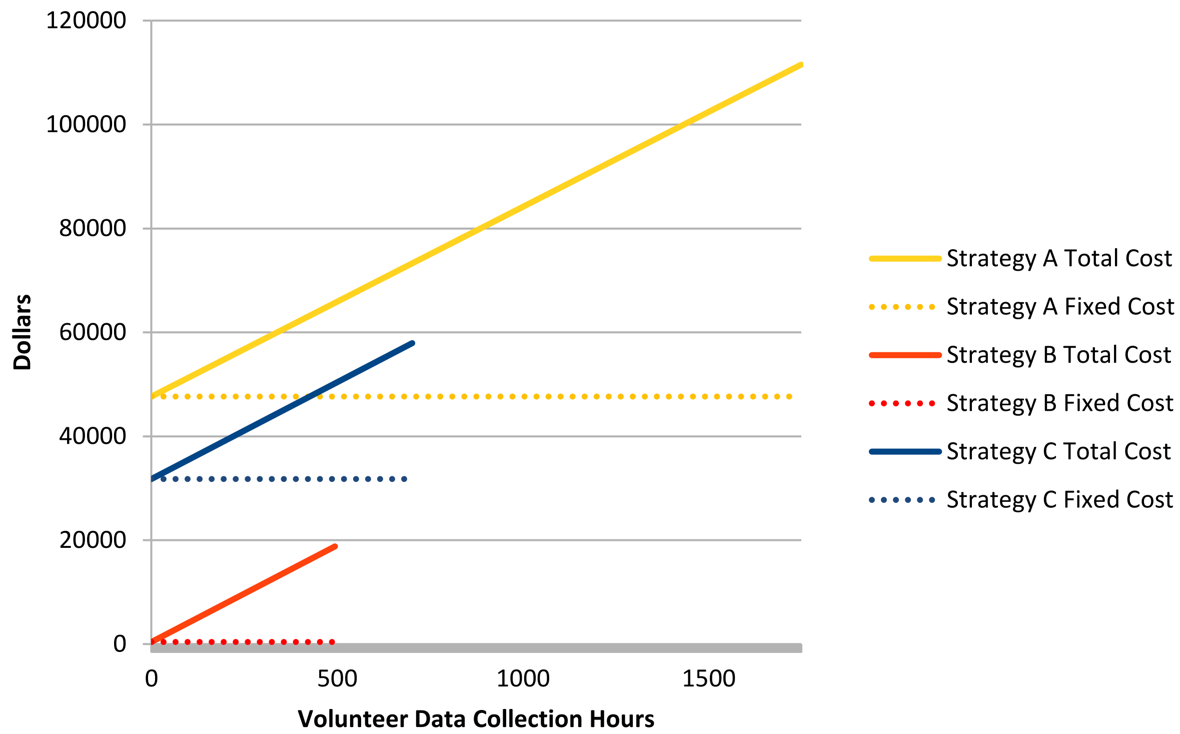

Figure 1: Associated Costs of Three Citizen Science Projects. Initial fixed costs are shown as the y intercept and the rate at which costs rise per volunteer hour represent variable costs.

Strategy A (SANMM) cost $36.52 per data collection hour, Strategy B (FCNAD) cost $35.61 per data collection hour, and Strategy C (FRPP) cost $37.25 per data collection hour. The results indicate that implementation strategy affects costs associated with running various field-based citizen science projects. Training prior to data collection increases the fixed costs of a project but saves money over a longer term compared to training volunteers concurrently with data collection. Similarly, unsupervised data collection saves project money over the long term but can be offset with the more extensive training needed to meet data quality standards, as supervisors will not be present to answer questions or correct incorrect data collection behavior. These differences are due to the cost of staff time. The cost of staff time rises with the amount of time spent in the field collecting data, whereas training prior to data collection only operates a set number of times during the field season regardless of the amount of data collected.

Discussion

This study was built from two major assumptions: first, this study was reflective in nature, in that it started with known annual budget data and retroactively calculated budget backwards to estimate fixed and variable costs for each volunteer data collection hour, and second variable costs were linear. Given the reflective nature of this study, we cannot predict future costs associated with increased volunteer data collection hours for these case studies. In reality, variable costs are not linear but fluctuate up or down with every additional data collection hour (Samuelson and Nordhaus, 2010). But averaging these costs over a year as a linear relationship saves time and mimics previous work by Nerbonne and Nelson (2008) and Tulloch (2013).

We can compare our results to the previous studies looking at citizen science cost per hour by taking the annual operating budget for each project and dividing by the total number of volunteer hours. This gives us Strategy A (SACSP) at $63.73 per data collection hour, Strategy B (FCNAD) at $38.05 per data collection hour, and Strategy C (FRPP) at $82.39 per data collection hour. These are much, more expensive than the EuMon monitoring project, which cost $3.67 per volunteer hour (Nerbonne and Nelson, 2008). But the costs of Strategy A, B, and C are close to the results that Tulloch (2013) found: bird atlas monitoring programs had an average cost $54.34 per volunteer data collection hour, while breeding bird survey projects had an average cost of $67.71 per data collection hour. However, as discussed in the introduction, this style of data analysis ignores fixed costs. A project with high fixed costs and low variable costs can be scaled up in size more cost effectively than a project with low fixed costs and high variable costs.

It is worth noting that the largest determinant of cost for a great majority of project steps (recruiting participants, training participants, collecting data, etc.) was staff time (see Table 2). As such, our results could also be analyzed using staff time as a substitute for cost. This would eliminate many project and study matter specific costs, such as data collection equipment (which varies based on data collection object of study). If this parameter is used, our results are largely the same; the project implementing Strategy A (training prior to data collection and supervised data collection), which had the highest fixed costs and lowest variable costs, also had the highest amount of fixed staff time and the lowest amount of variable staff time. Strategy B (training concurrently with data collection and supervised data collection), which had the lowest fixed costs but the highest variable costs, also had the lowest fixed staff time and the highest variable staff time. And finally, Strategy C (training prior to data collection and unsupervised data collection), which had moderate fixed costs and moderate variable costs, also had moderate fixed costs and moderate variable costs. It is quite possible that staff time is a better metric to compare across projects because it eliminates project-specific costs (like equipment), as well as differences in salary for project coordinators.

Project cost is certainly not the only outcome from different implementation strategies. For example, it is possible that trainings prior to data collection can increase data quality by maintaining consistent participant knowledge throughout data collection activities, whereas training volunteers concurrently with data collection could have participant data quality slowly increase in precision and accuracy as participants continue to gain knowledge. However, trainings prior to data collection also run the risk of participants forgetting critical information between trainings and data collection activities. Projects that use supervised data collection could ensure collection of more precise and accurate data given greater accessibility to project trainers for participants for questions about data collection method or quality assurance/quality control. Activities that are done as a group may increase the sense of community experienced by volunteers. Trainings prior to data collection and supervised data collection will often have more group interaction than trainings concurrent with data collection and unsupervised data collection. Projects that expect volunteers to collect data without supervision often have difficulty creating a robust and motivated volunteer community due to lack of volunteer interaction. While volunteers who are trained prior to data collection and who collect data unsupervised may be well versed in data quality, their scientific literacy may not increase due to a lack of one-on-one mentorship (Cronin & Messemer, 2013). The project leaders of FCNAD had discussed that this one-on-one mentorship kept their volunteer retention rate extremely high compared to other citizen science projects they have conducted. These are all possibilities to be addressed in further studies and are speculative at this time. Additional research is needed to more fully address these possible linkages.

The three implementation strategies evaluated in these case studies create many opportunities for further research. More research is needed to evaluate more case studies across topic, and implementation strategies to further assess the patterns found in this study. Further analysis could experimentally change the implementation strategy of a given citizen science project to attempt to elucidate different budgetary outcomes. Additionally, projects within the same topic that have chosen different implementation strategies could be compared. The choice of implementation strategy could be studied for its effect on data quality, volunteer community, volunteer education, and project costs. Furthermore, we did not study implementation Strategy

D, (training concurrent with data collection and unsupervised data collection), or any other possible implementation strategy.

Conclusion

Training among the three case studies had a large effect on fixed and variable costs. Projects that implemented training prior to collecting data (FRPP, SACSP) had much higher fixed costs, and lower variable costs. Conversely, the project that trained its volunteers concurrently with data collection (FCNAD) had lower fixed costs, but higher variable costs. Projects that implemented supervised data collection (SACSP, FCNAD) had lower fixed costs and higher variable costs. The project that implemented unsupervised data collection (FRPP) had higher fixed costs and lower variable costs. By examining these three citizen science project case studies, we can identify budgetary consequences of an implementation strategy, which should be discussed before creating, designing, or starting a project. These case studies illustrate that trainings prior to data collection and unsupervised data collection are more cost effective the more time spent on data collection. Trainings concurrent with data collection and supervised data collection are more cost effective the less time spent on data collection. However, these results can vary when applied to a specific project based on equipment needed and the project object of study. We recommend that projects calculate their respective costs of operating these four implementation strategies for a more accurate projected budget.

IS CITIZEN SCIENCE WORTH IT: PERCEIVED VALUE OF ENVIRONMENTAL MONITORING TECHNIQUES

While some studies have compared individual citizen science projects to professional monitoring projects, this paper is unique in that it divides fixed costs (annual costs that remain constant regardless of number of data collection hours spent) and variable costs (costs that increase incrementally as the number of data collection hours rises) as a way to compare the professional monitoring approach to the citizen science approach. Additionally, this study uses this analysis to compare three case studies. Each object of study – rare plants, the American pika, and archaeological artifacts – can be monitored using professional field technicians or citizen scientists. These two strategies were compared by budgets and the perceived benefits by natural resource managers. Each professional monitoring approach was found to cost the natural resource agency more than a citizen science approach. However, the difference in cost between the citizen science approach and the professional monitoring approach was nominal in comparison to the projects' budgets. While the topics addressed by citizen science are diverse, cost of an object of study (e.g., water quality, invasive plants, bird monitoring) is more closely linked to a project's cost than to its method of implementation (i.e., citizen science or professional monitoring). Natural resource managers commented that the benefits of citizen science come with higher investment and risk due to the uncertainty of the final product and the need for strong relationships with volunteers. This work will inform natural resource managers of citizen science benefits and drawbacks from an economic perspective.

Introduction

Budgets are stagnant for many natural resource agencies, including national and smaller municipal agencies. This creates a dilemma for agencies whose responsibility for stewardship remains the same, while pressures and demands on the natural resource are increasing, such as invasive species, climate change, and increased visitor use. However, there has not been much research that supports this claim, other than the logical nature of the statement.

However, an often discussed drawback of citizen science is the validity of the data collected. The literature discussing scientific rigor of citizen science can be categorized into two groups: research studying large nationwide citizen science projects, and research studying smaller community-based citizen science projects. The larger nationwide citizen science projects, such as eBird, a website to which tens of thousands of people contribute data annually, have produced an immense amount of research about bird migration, research that has been studied and determined to be valid and reliable (Bonney et al., 2009). eBird has a well-documented approach of data quality and data control which encourages trust in the data accuracy and precision (Bonney et al., 2009). As a result, the success of eBird has inspired trust in many other citizen science projects about bird observation and migration patterns. Tulloch et al. (2013) found that other large-scale citizen science bird projects had success in getting their data published in peer reviewed journals. Between 2005 and 2010, 83 instances of data about atlas bird surveys were collected by citizen science (large-scale, multiple species citizen science projects) and 93 instances of citizen science collected breeding bird surveys (large-scale, ongoing citizen science projects) were used for scientific publications.

While large nationwide citizen science projects are often used to aid natural resource managers with management decisions, natural resource managers are slower to trust data quality of smaller, more localized citizen science projects (Ely, 2008). The biggest difference between the large nationwide citizen science projects and the smaller localized citizen science projects is the quantity of local projects. It is hard to make any ubiquitous statements about the vast number of local citizen science projects studying an incredible diversity of topics. Many smaller citizen science projects struggle to contribute their data toward management decisions or research journals (Ely, 2008).

Citizen science is often presented as a low cost alternative that provides a similar monitoring benefit of baseline information that could be achieved via paid staff. Four studies address the cost of citizen science projects. Gardiner, Alley and Brown (2012) studied a citizen science beetle monitoring project, using average cost of plot monitored. They compared verified citizen science (i.e., volunteer data are checked by researchers) to direct citizen science (i.e., volunteer data are not verified by researchers). The study found that verified citizen science cost $40.29 per trap, and direct citizen science cost $31.44 per trap. Another study that looked at cost per data collection plot was Nerbonne and Nelson (2008), which surveyed 138 citizen science macro-invertebrate monitoring projects. Of these projects, spending ranged from $1,000 per site to $0 per data collection site, and averaged $211. A very large, comprehensive analysis of the EuMon (European Monitoring) project was conducted between 1993 and 2005. The EuMon is a multinational scale project that monitors several species. This study considered citizen science projects that addressed amphibians, reptiles, birds, butterflies, other insects, plants, and mammals (Schmeller et al., 2009). It found that it cost approximately four million euros (approximately 4,370,140) to facilitate 148,690 person-days (this variable was undefined). If we assume that one person-day is equal to eight hours, then the cost per volunteer hour is $3.67. Finally, Tulloch, Possingham, and Joseph (2013) calculated the average cost of two methods for citizen science bird surveying over several years, compared using data collection hours. They found that bird atlas monitoring programs had mean data collection hours of 186,500, and a mean cost of $10,133,500, or $54.34 per volunteer hour. The breeding bird survey projects surveyed had mean data collection hours of 147,900, and mean costs of $10,014,200, or $67.71 per data collection hour. These costs between projects vary drastically, most likely due to the project's methods of volunteer management and data collection.

In two projects that compared the costs of citizen science against the costs of professional monitoring, Gardiner et al. (2012) found that the cost of professionals was $126.62 per sticky card trap, more than three times the cost of a citizen science project. Schmeller et al. (2009) did not include a professional monitoring aspect, though the authors stated that to pay a worker for each volunteer hour it would have cost 13 million euros (approximately $14,238,900), or roughly three times the cost of the EuMon citizen science project. While project costs may differ greatly, these papers have a consensus that professional monitors cost considerably more than citizen science monitors.

Besides data collection and cost, citizen science can result in other benefits. In 2000, Trumbull, Bonney and Bascom (2000) analyzed letters from 700 participants of a nest-based citizen science bird observation project. These unsolicited letters were sent to the project coordinators along with their yearly data. They found that 80 percent of the letters included scientific-based thought processes, a term defined by Bonney et al. (2000) as “actively engaged in thinking about the research process...during project participation.” The article used these findings to demonstrate that citizen science increases knowledge of the scientific process, or scientific literacy.

Five years later, two other articles found data that contradicted Trumbull et al. (2000). Evans, Abrams, and Reitsma (2005) and Brossard, Lewenstein, and Bonney (2005) both found that their projects (Neighborhood Nest Watch and The Birdhouse Network, respectively) increased participant knowledge of their subject matter (i.e., bird biology) but did *not* increase overall scientific literacy of participants. These studies were followed by two papers that found data supporting claims made by Trumbull et al. (2000). Ballard and Belsky (2010) and Cronin and Messemer (2013) found that their projects *did* increase scientific literacy. Conin and Messemer offered an explanation: the one-on-one mentorship aspect of their program between project leaders and participants helped participants increase knowledge of scientific literacy. Ballard and Belksy did not explain why their project increased scientific literacy, but it could be that they also benefited from one-on-one mentorship by project leaders.

The literature review for this study failed to result in a single article that both compares citizen science costs versus professional costs and uses fixed and variable costs to further analyze each project. This study uses three case studies to compare the citizen science monitoring costs to the costs of the professional monitoring approach and to discuss common concerns and benefits of citizen science. This study examines two questions:

1) How do costs differ between citizen science and professional monitoring projects?

2) What do natural resource managers identify as the main benefits and concerns of citizen science monitoring projects?

Methods

Three Colorado-based citizen science projects were studied, as shown in Table 4.. Each project was run by or is in close partnership with a natural resource management agency. Two of the projects (Front Range Pika Project and City of Fort Collins Natural Areas Department) are still operational, while the third (Scott Miller Archaeological Survey) no longer exists.

Table 4: Citizen Science Projects of Interest

Name of Project	Object of Study	Location	Natural Resource Agency
Front Range Pika Project	American Pika	Denver, CO	Colorado Parks and Wildlife
City of Fort Collins Natural Areas Department	Rare Plants	Fort Collins, CO	City of Fort Collins Natural Areas
Scott Miller Archaeological Survey	Archaeology	Monta Vista Fish and Wildlife Refuge, CO	United States Fish and Wildlife Service

The Front Range Pika Project (FRPP) collects data about the high alpine American pika (*Ochotona princeps*), specifically presence/absence and habitat data. The project has an average of 40 volunteers annually. Volunteers trained in early August collect data during August and September. Field sites are in remote often hard to reach high altitude locations; one site can take a full day to complete. The project is a partnership led by the state wildlife management agency, Colorado Parks and Wildlife. It has been operating for five years.

The City of Fort Collins Natural Areas Department (FCNAD) inventories the rare and endangered plants that exist within city-owned natural areas. FCNAD uses only citizen science to collect this data, in lieu of professional technicians. It has been operating for nine years. In this project, small groups of 6 to 10 volunteers go with a project coordinator to inventory rare and endangered plants on open space land. This citizen science project was compared to similar professional plant surveys operated by the FCNAD.

The Scott Miller Archaeological Inventory (SMAI) surveyed archaeological artifacts in southwestern Colorado. SMAI was operated by the United States Fish and Wildlife Service (USFWS) on the Monte Vista Wildlife Refuge. Citizen scientists for SMAI combed the area in a systematic manner searching for archaeological artifacts. This was a smaller group of around 15. The USFWS used citizen science to collect this data rather than professional technicians. It operated for only one year, which fulfilled the required data collection of the National Heritage

Act. This citizen science project was compared to previous professional archaeological inventories operated by USFWS.

Data collection was conducted through a sequential mixed method design. This included quantitative data to calculate the costs of the monitoring projects, as well as qualitative, reflexive interviews to understand the thoughts of natural resource managers. This sequential method of data collection helped reveal a cost per data collection hour for both citizen science projects and the comparable professional monitoring approach. This also provided insights into the thoughts of managers and their beliefs about the positive benefits and drawbacks of citizen science and professional monitoring.

Quantitative Accounting

Through discussion with representatives of each citizen science project, total fixed costs and variable costs were recorded for the project, using the citizen science toolkit published by the Cornell Laboratory of Ornithology (Bonney et al., 2014) as a guideline. These costs were applied to the professional monitoring approach as well. Table 5 outlines these steps and their related costs.

Table 5: The Citizen Science Process with Related Costs (Bonney et al., 2014)

Process Steps	**Fixed Costs**	**Variable Costs**	**Reasoning**
Form a Team	Staff time	n/a	Cost of forming a team will not increase as the hours of data collection rise.
Refine Protocols	Staff time	n/a	Cost of refining protocols will not increase as the hours of data collection rise.
Recruit Participants	n/a	Advertising, staff time	As the hours of data collection rise, the project needs more volunteers. This requires more advertising and staff time.

Process Steps	Fixed Costs	Variable Costs	Reasoning
Train Participants	Online training	Staff travel, training food, staff time, volunteer training kit	As hours of data collection rise, the project needs to train more volunteers. The cost of maintaining online training will not increase, but the cost of operating more in person trainings will. These costs can include staff travel, staff time, training food, volunteer training kits, etc.
Collect Data	Staff time for unsupervised data collection	Equipment, staff time for supervised data collection, staff travel	If the project staff do not supervise the data collection, then cost will remain constant as more hours of data collection are spent. But the project will need to increase spending if the data collection is supervised. Additionally, the project will increase spending on equipment, and staff travel.
Analyze Data	n/a	Staff time	As hours of data collection rise, project needs will have more data to analyze. This will result in increased staff time.
Retain Participants	Celebration venue	Celebration food, volunteer appreciation gifts	As the hours of data collection rise, the project needs more volunteers. This will increase the cost of retaining volunteers, such as celebration food and volunteer appreciation gifts. For these three projects, the cost of venue would not increase as hours of data collection increase.
Disseminate Results	Staff time	n/a	Cost of disseminating results will not increase as the hours of data collection rise.

Cash based accounting (which includes only project expenses that are paid for) was used to calculate budgets of all professional and citizen science projects during each of the phase of the citizen science process (see Dechow, 1994). After the costs for each part of the process were calculated for both the citizen science and professional approach, graphs were produced for each project's budget, representing costs over time related to the fixed costs and variable costs. Each citizen science project was compared to the professional monitoring project.

Interviews

Natural resource managers were interviewed about benefits and drawbacks of both citizen science and professional field technicians for monitoring. Graphs of each approach and for each project were used as a discussion aid. Each interview followed a semi-structured guide: 1) the graphical budget of both the citizen science project and the professional approach was described to the project managers, 2) managers were asked about the benefits and drawbacks of citizen science and/or paid professional approaches, depending on which methods they use, and 3) managers were asked if they would implement their chosen approach even if it were the more expensive option. The questions were conducted in a reflexive approach, meaning each question was adapted by each previous response. In this way, the interviewer is encouraged to react to the responses given to create an evolving conversation. The interviews followed the respondent interview method, which seeks an opinion rather than information on a historical occurrence (Lindlof & Taylor, 2011). All the interviews were transcribed and then studied for common themes or codes. These codes were further developed into narratives if codes were seen in multiple interview transcriptions.

Results

For each of the three projects, the cost of professional monitoring was similar to the citizen science cost. The largest difference was between the FRPP professional monitoring and citizen science project, in which the professional approach was $1,131 more costly (within a total budget of $60,000 or a 1-2% savings). All three professional projects had higher variable costs than their citizen science counterparts.

Table 6: Project Professional and Citizen Science Expenses

Project	Total Project Cost	Dollars Saved by Citizen Science	Variable Costs (Cost per Data Collection Hour)	Fixed Costs (Costs That Do Not Fluctuate with Additional Data Collection Hours)
Front Range Pika Project	Citizen Science: $59,391 Professional: $60,522	$1,131 (2% difference)	Citizen Science: $61 Professional: $124	Citizen Science: $37,289 Professional: $17,500

Scott Miller Archaeological Inventory	Citizen Science: $18,840 Professional: $19,129	$739 (4% difference)	Citizen Science: $28 Professional: $47	Citizen Science: $125 Professional: $143
Fort Collins Natural Areas Rare Plant	Citizen Science: $8,995 Professional: $9,643	$648 (7% difference)	Citizen Science: $17 Professional: $26	Citizen Science: $508 Professional: $660

The FRPP citizen science monitoring cost is $1,131 less (about 2%) than an equivalent professional monitoring project. The total cost of the FRPP *citizen science* project was $59,391, and reported the costs of staff time, travel, equipment, volunteer trainings and celebrations. The total cost of a *professional* pika monitoring project was $60,522, including data collection, equipment, data analysis, and manager time. These differences in expenses led to the FRPP citizen science project having a higher fixed cost ($37,289) than the pika professional monitoring fixed cost ($17,500). Conversely, the citizen science project had much lower variable costs ($61) compared to the professional monitoring variable costs ($124). See Figure 2 for total costs of the FRPP citizen science and the professional pika monitoring project 1.

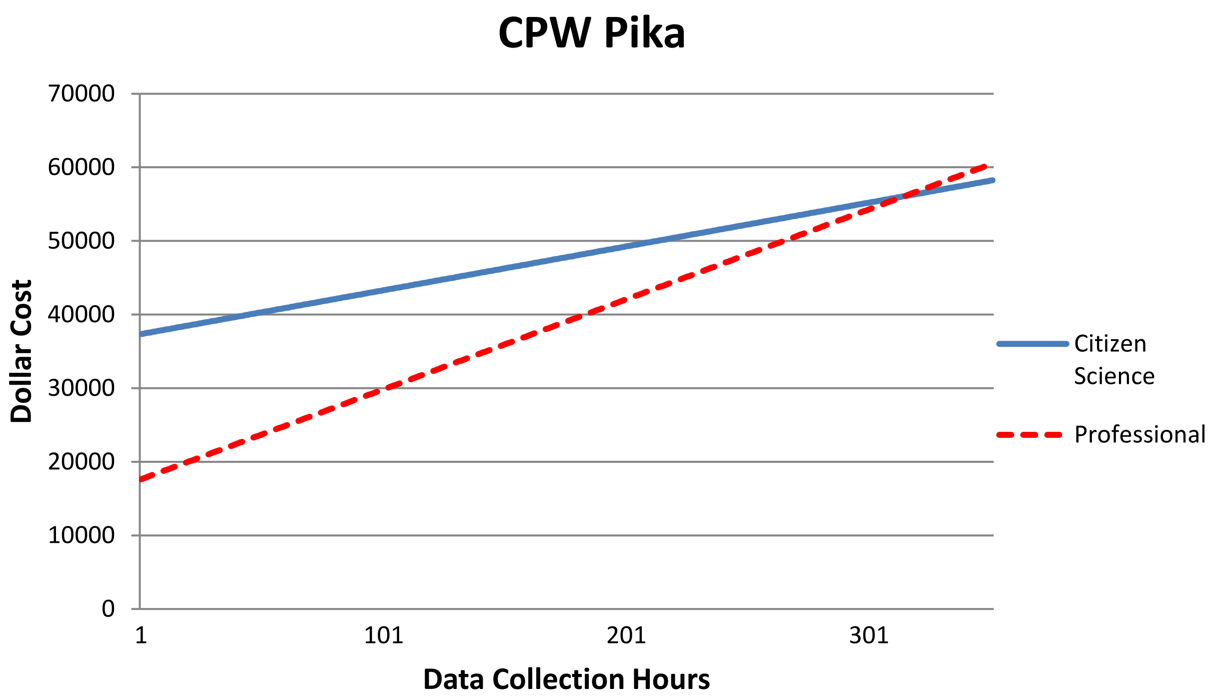

Figure 2: The American Pika: Citizen Science and Professional Monitoring Costs

The FCNAD citizen science project cost the city agency $648 less (about 6%) than an equivalent professional monitoring project. The total cost of the FCNAD citizen science project was $8,995. This project reported costs of planning, volunteer recruitment, volunteer trainings, data collection, data analysis, and disseminating results. The total cost of a professional rare plant monitoring project was estimated at $9643. These similar expenses lead to the FCNAD citizen science project having a fixed cost of $508, and the professional project having a fixed cost of $660. The citizen science project had lower variable costs per data collection hour ($17) than the professional monitoring variable costs per data collection hour ($26). See Figure 3 for total costs of the FCNARP citizen science and the professional rare plant monitoring project 2.

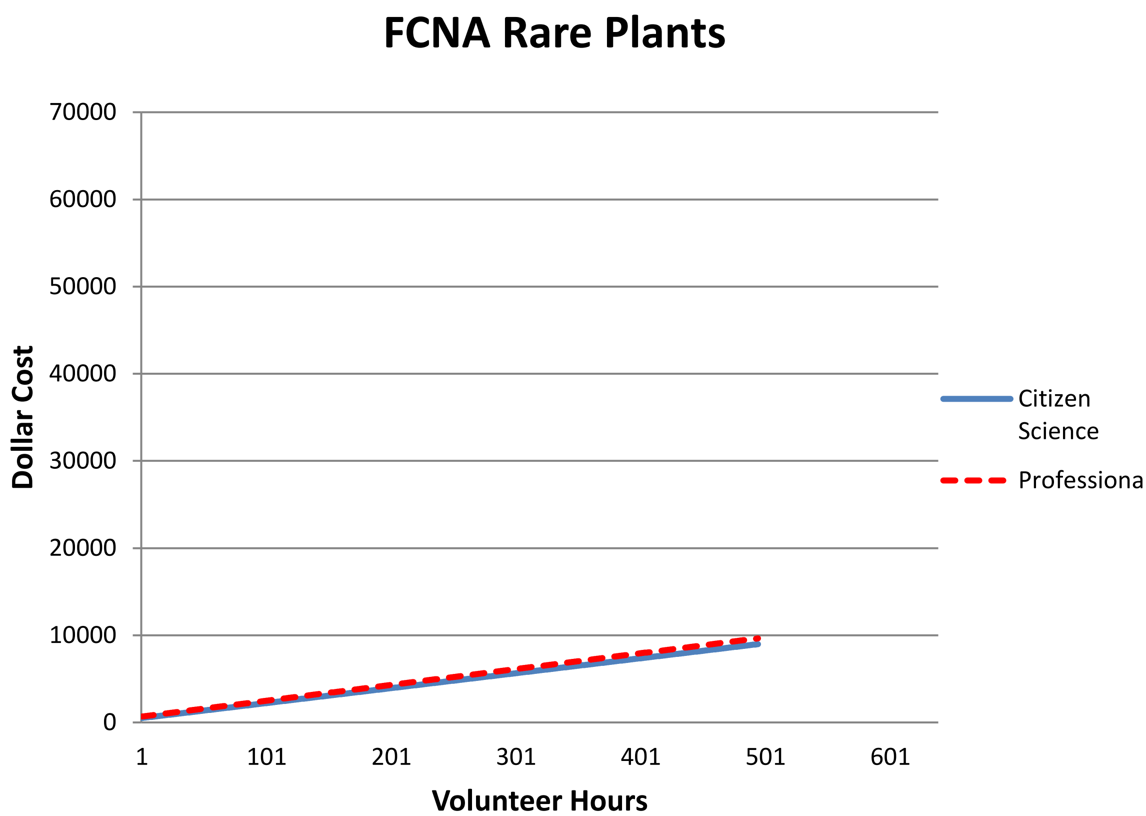

Figure 3: Rare Plants of Fort Collins: Citizen Science and Professional Monitoring Costs

The SMAI cost the agency $739.38 less (approximately 3.5%) than an equivalent professional monitoring project. The SMAI citizen science project cost $18,839.70 and reported costs of data collection, equipment, data analysis, and a project coordinator's time. An equivalent professional monitoring project was estimated at $19,129.08. The SMAI citizen science project had a lower fixed cost ($125.00) than the professional monitoring fixed cost ($143.09). Additionally, the citizen science project had lower variable costs ($27.50) than the professional monitoring variable costs ($47.46). While these numbers are large in relation to each other, they are hard to distinguish on the graph because they are both so small. Figure 4 shows the total costs for the SMAI citizen science project and the professional archaeological monitoring.

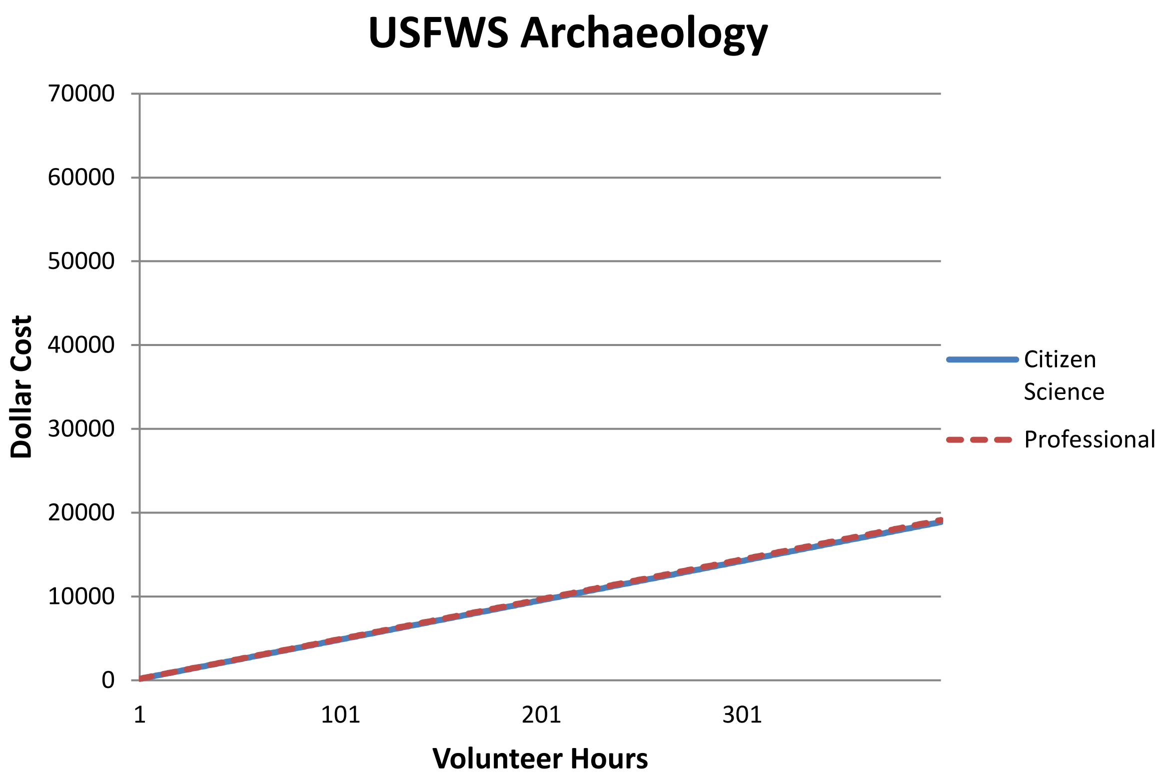

Figure 4: Archaeological Artifacts: Citizen Science and Professional Monitoring Costs

Interview Results

Asking the natural resource managers of each of the three programs to compare and contrast professional field technician and citizen scientist approaches resulted in three main themes: data quality, community and educational benefits, and resource investment needed for citizen science.

Data Quality

Data quality was discussed during each of the three interviews, with each project taking a different perspective on how to achieve the highest data quality. For FCNAD, the natural resource manager believed that the citizen science project collects data at a higher quality and consistency than hiring outside contractors. Here, the manager discusses the project’s high volunteer retention rate and its effect on data quality:

> The consistency I get with my volunteers. I have the same hardcore group of 5-15. I know what kind of product I will get out of those volunteers.

Conversely, the Colorado Parks and Wildlife (CPW) natural resource manager believed that the pika monitoring project receives higher data quality with professional field technicians than with citizen scientists:

> I can be selective on the people that I am hiring. Whereas with a volunteer, if they can help, they're going to help whether you think that they're really equipped to do the job or not. Trust in the data. And that they can get the job done.

The USFWS archaeological project took a middling stance, stating,

> There are citizens that are volunteer or retired archaeologists so conceivably you could get (professional data) you just aren't paying them. And so theoretically the data quality would be just as high.

Both the archaeology project and the pika project emphasized using citizen scientists as generalists in data collection and relying on professionals for more specialized data collection purposes. Both natural resource managers said that citizen scientists are reliable when collecting simple data, but as the data becomes more complicated to collect, citizen scientists become less reliable. As an example, pika citizen scientists were found to collect accurate data when recording presence/absence data but inaccurate data when recording number of individuals (Moyer-Horner, Smith, and Belt, 2012).

Community Education, Community-Based Science

Community engagement and volunteer education was ubiquitously discussed as a positive outcome from citizen science. The archaeology manager states,

> The pluses for the citizens is that you are getting community involvement and buy-in and they are maybe learning things, well undoubtedly they are learning things… Local community interest in anything happening on the refuge, anything positive anyway is really hard to come to by.

This statement identifies the benefits that a citizen science project can have for the volunteers, through education, and for the managers, through community building. While SMAI used an existing volunteer community, *Friends of the USFWS*, the citizen science project was an effective way to engage this group. The plant manager noticed,

> They (the volunteers) see the benefit in learning it and they get real excited about it, whereas the seasonal doesn't seem to share that as much… Whereas many of my volunteers are retired, they have already done that. Now it is all about learning, and the joy of learning.

Here, the manager identified that the citizen science benefits of education can have a positive effect not only of volunteer retention, but of volunteer engagement and excitement while collecting data. And the pika manager said succinctly,

> If you have a simple project, that you can have people that haven't done a lot of wildlife, just want to get out into the field, it's a good opportunity to educate them on wildlife and species conservation or biology.

All three managers recognized the benefit that bringing in a community of volunteers does for the volunteers, for the agency, and – in the case of SACSP – the data quality.

Resource Investment

All three natural resource managers expressed that implementing and managing a citizen science project was a much larger investment of their personal time and emotion than either contracting or directly hiring. This was reflected in the results of the project: the natural resource managers time increased with citizen science projects and decreased with professional projects. However, non-manager field technician time increased with professional projects, keeping the difference in staff time cost to a minimum. The archaeology manager summarized this concept with the following:

> And I think too, you know I found that it was really important to me that the people had a good time and are learning and enjoying themselves. And know they are appreciated. And so there is an emotional investment of the project, but also the people. I want them to really like this. I want them to like being out there, I want them to like archeology. That is really important to me.

This emotional investment can serve as a beneficial motivation or a drawback. The pika manager stated,

> So it can be more effort than what you are getting out of it. So in my profession I have to think about which projects could potentially be a citizen science project and which ones couldn't… I think projects need to be selective.

This drawback of more energy and time needed for success can be especially risky for natural resource managers who are already time strapped. However, this large time investment can serve as a great inspiration for managers.

> Being with volunteers. I think because they are so excited about learning, it makes me more excited about teaching them, as explained by the leader of the FCNARP project.

Discussion

For all three citizen science projects, minimal money was saved. The largest amount of money saved by the FCNAD project was less than $5,000, or around 5% of the total professional budget. While citizen science has often been lauded for it cost effectiveness, in these three case studies while it was cheaper than a professional project, it was not considered cheap “enough” to make a substantive change in the economic thought processes of the natural resource managers. As natural resource agencies continue to have limited funds and as citizen science becomes increasingly perceived as a viable tool for collecting data, citizen science projects would theoretically increase in number. While we cannot compare these projects to other studies without knowing their fixed and variable costs, it is worth noting that Gardiner et al. (2013) found that traditional science or professionals would have cost their project three times the amount that citizen science cost. Without a significant economic incentive to develop a citizen science project, the risk of using an unproven and/or uncertain method of collecting data to replace traditional professional monitoring is too high.

Data quality was considered by each natural resource manager but was only a drawback for the natural resource manager of the professional pika monitoring. The natural resource manager of the SMAI study thought that citizen scientists could collect accurate data in certain circumstances, and the FCNAD manager believed that the citizen scientists collected more precise data for the SMAI project than professionals would have. These findings are converse to the conclusions posited by Ely in 2008. Ely suggested that data quality was enough of a deterrent that natural resource managers were generally not using citizen science projects for management decisions. Perhaps there has been enough increased awareness and acceptance of citizen science within the scientific community that some natural resource managers trust citizen science collected data or maybe these natural resource managers were biased due to their close interaction with citizen science projects.

All managers reported increased levels of excitement from volunteers, just as Braschler, Mahood, Karenyi, Gaston, and Chown (2009) found as one result of their study. Representatives of each citizen project identified the education and community-building benefits of citizen science. A volunteer base that is educated about a particular species or ecosystem is an engaged volunteer base. So, while citizen science projects might not provide a meaningful economic incentive and might raise questions about data quality, they grant a unique strategy for natural resource managers to engage an active community around natural resources, like McKinley et al. (2012) suggested in their paper. Additionally, the benefits gained from an engaged volunteer community from increased manager and community interactions are similar to Fraser, Dougill, Mabee, Reed, and McAlpine (2006) findings. These benefits of education and community building were stated several times by each natural resource manager, further cementing the idea that these benefits can have repercussions that outweigh simple monitoring projects.

A volunteer community interested in place-specific resource stewardship can mean a significant emotional investment from the citizen science organizer. This finding was not discussed in the literature and is unique to this study. As Cronin and Messemer (2013) discussed the impact of the leader's interaction with the community members, the community members have an equivalent impact on the leader. The emotional and educational benefit gained by participants is echoed back to the volunteer coordinator by way of emotional investment. While this emotional investment was not measured or quantified in this chapter, it gives prospective citizen science coordinators part encouragement and part warning. Are all these benefits worth investing in without the economic incentive? Is the perception of data quality loss too much of a drawback? While citizen science remains a powerful tool in the toolbox of natural resource managers, it is certainly no panacea, and its drawbacks should be seriously considered.

AFTERWORD

In 2012, the Cornell Lab of Ornithology held a citizen science conference called *Public Participation in Scientific Research* (the name of citizen science at the time) and invited anyone practicing citizen science. Around 90 citizen science practitioners attended and the Citizen Science Association was created. Three years later, the Citizen Science Association sponsored a similar conference. Over 3,000 citizen science practitioners attended. This dramatic increase in participation led to researchers studying data validation, volunteer education, and citizen science communities. As more natural resource management agencies use citizen science, in part because of potential money-saving benefits, there is little evidence to document or understand those financial benefits.

Citizen science is a very positive discipline. As more and more citizen science projects have been created and conferences with more attendees to share lessons learned have been hosted, this has revealed many additional success stories. But, focusing only on the successes does not tell the whole story. The majority of citizen science practitioners are on a tight monetary and time budget. Before creating a successful citizen science project, practitioners should consider if a) citizen science is the correct choice given other data collection alternatives, and b) the most beneficial way to go about their citizen science project given their particular data collection needs.

To answer the first question (is citizen science the correct choice given other data collection alternatives), many natural resource managers need to know the cost of the citizen science project in question. Cost of citizen science has not been adequately studied to assist natural resource managers in deciding this question. In the literature review, I compared research about citizen science data, volunteer education, citizen science community benefits, and cost of citizen science. There have been four papers researching cost of citizen science, but they have all been very broad, exploratory-based hypotheses. This leaves an opportunity to respond to the papers published and explore more specific hypotheses.

The first manuscript: *Intentional Implementation of Citizen Science: Economic Decision Making of Natural Resource Managers* replicates the work done by Gardiner et al. (2012), looking at three smaller citizen science projects. I had two major findings:

1. The citizen science case studies were not remarkably cheaper than professional monitoring projects.
2. The citizen science case studies required more time and emotional investment than the professional monitoring projects.

These findings encourage more in depth research about costs of a citizen science project. These findings guided my second chapter: *Is Citizen Science Worth It: Perceived Value of Environmental Monitoring Techniques*, which looked at determinants of cost in further depth. This second manuscript also had two findings:

1. For these citizen science case studies, training beforehand is a higher percentage of total project fixed cost and on-the-job training is a higher percentage of total project variable cost.
2. For these citizen science case studies, unsupervised data collection is a higher percentage of total project fixed cost, and supervised data collection is a higher percentage of total project variable cost.

These findings show how the cost of these citizen science projects are influenced by implementation strategy (volunteer training and data collection). Findings from both chapters will hopefully aid natural resource managers in decision making when considering citizen science as an approach to data collection.

REFERENCES

Ballard, H. L., & Belsky, J. M. (2010). Participatory action research and environmental learning: implications for resilient forests and communities. *Environmental Education Research*, *16*(5-6), 611–627. http://doi.org/10.1080/13504622.2010.505440

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, *59*(11), 977–984. http://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Citizen science. Next steps for citizen science. *Science (New York, N.Y.)*, *343*(6178), 1436–7. http://doi.org/10.1126/science.1251554

Brandon, A., & Spyreas, G. (2003). Can volunteers provide reliable data for forest vegetation surveys? *Natural Areas …*, *23*(3), 254–261. Retrieved from http://plsa.inhs.uiuc.edu/publications/Brandon_et_al.pdf

Braschler, B., Mahood, K., Karenyi, N., Gaston, K. J., Chown, S.L. (2009). Realizing a synergy between research and education: how participation in ant monitoring helps raise biodiversity awareness in a resource-poor country. *Journal of Insect Conservation, 14, 19-30.*

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099–1121. http://doi.org/10.1080/09500690500069483

Cheng, A. S., Danks, C., & Allred, S. R. (2011). The role of social and policy learning in changing forest governance: An examination of community-based forestry initiatives in the U.S. *Forest Policy and Economics*, *13*(2), 89–96. http://doi.org/10.1016/j.forpol.2010.09.005

Cohn, J. (2008). Citizen science: Can volunteers do real research? *BioScience*, *58*(3), 192–197. Retrieved from http://www.bioone.org/doi/pdf/10.1641/B580303

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental Monitoring and Assessment*, *176*(1-4), 273–91. http://doi.org/10.1007/s10661-010-1582-5

Cooper, C. B., Dickinson, J., Phillips, T., & Bonney, R. (2007). Citizen Science as a Tool for Conservation in Residential Ecosystems, *12*(2).

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. a., Graham, J., & Waller, D. M. (2011). Assessing citizen science data quality: an invasive species case study. *Conservation Letters*, *4*(6), 433–442. http://doi.org/10.1111/j.1755-263X.2011.00196.x

Cronin, D., & Messemer, J. (2013). Elevating Adult Civic Science Literacy Through a Renewed Citizen Science Paradigm. *Adult Learning*, *24*(4), 143–150. http://doi.org/10.1177/1045159513499550.

Dechow, P.M., (1993). Accounting earnings and cash flows as measures of firm performance the role of accounting accruals. *Journal of Accounting and Economics, 18, 3-42*.

Devictor, V., Whittaker, R. J., & Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. *Diversity and Distributions*, *16*(3), 354–362. http://doi.org/10.1111/j.1472-4642.2009.00615.x

Dewey, J. (2007). *Experience and education*. Kappa Delta Pi. Retrieved from http://books.google.com/books?hl=en&lr=&id=JhjPK4FKpCcC&oi=fnd&pg=PA14&dq=EXPERIENCE+%26+EDUCATION&ots=D8AH4lHAH8&sig=4I4pK1zDnvBefY7P-2HKgp2KtCk

Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen Science as an Ecological Research Tool: Challenges and Benefits. *Annual Review of Ecology, Evolution, and Systematics*, *41*(1), 149–172. http://doi.org/10.1146/annurev-ecolsys-102209-144636

Ely, E. (2008). Volunteer Monitoring & the Democratization of Science. *National Newsletter of Volunteer Watershed Monitoring*, *19*(1), 1–24.

Evans, C., Abrams, E., & Reitsma, R. (2005). The Neighborhood Nestwatch Program: Participant Outcomes of a Citizen- Science Ecological Research Project. *Conservation Biology*, *19*(3), 589–594. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1523-1739.2005.00s01.x/full

Fraser, E. D. G., Dougill, A. J., Mabee, W. E., Reed, M., & McAlpine, P. (2006). Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. *Journal of Environmental Management*, *78*(2), 114–27. http://doi.org/10.1016/j.jenvman.2005.04.009

Galloway, A. W. E., Tudor, M. T., & Haegen, W. M. Vander. (2006). The Reliability of Citizen Science: A Case Study of Oregon White Oak Stand Surveys. *Wildlife Society Bulletin*, *34*(5), 1425–1429. http://doi.org/10.2193/0091-7648(2006)34[1425:TROCSA]2.0.CO;2

Gardiner, M. M., Allee, L. L., Brown, P. M. J., Losey, J. E., Roy, H. E., & Smyth, R. R. (2012). Lessons from lady beetles: Accuracy of monitoring data from US and UK citizenscience programs. *Frontiers in Ecology and the Environment*, *10*(9), 471–476. http://doi.org/10.1890/110185

Lindenmayer, D. B., & Likens, G. E. (2010a). Changes in Culture Needed to Facilitate Monitoring. In *Effective Ecological Monitoring2* (pp. 148–153).

Lindenmayer, D. B., & Likens, G. E. (2010b). Some of the Ecological Values and Uses of Long-Term Datasets. In *Effective Ecological Monitoring* (pp. 3–8).

Lindlof, T., Taylor, B., (2011). Qualitative Communication Research Methods. *Sage Publications Inc.*

McKinley, D. C., Briggs, R. D., & Bartuska, A. M. (2013). When peer-reviewed publications are not enough! Delivering Science for natural resource management (Reprinted from Forest Policy and Economics, vol 21, pg 1). *Forest Policy and Economics*, *37*, 9–19. http://doi.org/10.1016/j.forpol.2013.09.004

Miller, J. R. (2005). Biodiversity conservation and the extinction of experience. *Trends in Ecology & Evolution*, *20*(8), 430–4. http://doi.org/10.1016/j.tree.2005.05.013

Moyer-Horner, L., Smith, M. M., Belt, J. (2012). Citizen science and observer variability during American pika surveys. *Journal of Wildlife Management*, 76, 1472-1479.

Mumby, P., & Harborne, A. (1995). A critical assessment of data derived from Coral Cay Conservation volunteers. *Bulletin of Marine …*, *56*(3), 737–751. Retrieved from http://www.ingentaconnect.com/content/umrsmas/bullmar/1995/00000056/00000003/art00002

Nerbonne, J. F., & Nelson, K. C. (2008). Volunteer Macroinvertebrate Monitoring: Tensions Among Group Goals, Data Quality, and Outcomes. *Environmental Management*, *42*, 470–479.

Newman, G. J., Skarpino, R., Masching, A., & Mueller, M. (2013). Front Range Pika Project. Retrieved June 12, 2013, from http://www.pikapartners.org/cwis438/websites/FRPP/Home.php?WebSiteID=18

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment*, *10*(6), 298–304. http://doi.org/10.1890/110294

Nicholson, E., Ryan, J., & Hodgkins, D. (2001). Community Data – where does the value lie? Assessing confidence limits of community collected water quality data. Keywords, *3002*(1999).

Ottinger, G. (2009). Buckets of Resistance: Standards and the Effectiveness of Citizen Science. *Science, Technology & Human Values*, *35*(2), 244–270. http://doi.org/10.1177/0162243909337121

Petrokofsky, G., Brown, N. D., Hemery, G. E., Woodward, S., Wilson, E., Weatherall, A., … Arnold, J. E. M. (2010). A participatory process for identifying and prioritizing policy-relevant research questions in natural resource management: A case study from the UK forestry sector. *Forestry*, *83*(4), 357–367. http://doi.org/10.1093/forestry/cpq018

Primack, R. B., Higuchi, H., & Miller-Rushing, A. J. (2009). The impact of climate change on cherry trees and other species in Japan. *Biological Conservation*, *142*(9), 1943–1949. http://doi.org/10.1016/j.biocon.2009.03.016

Raddick, M., Bracey, G., & Gay, P. (2010). Galaxy zoo: Exploring the motivations of citizen science volunteers. *Astronomy Education …*. Retrieved from http://link.aip.org/link/?AERSCZ/9/010103/1

Schmeller, D. S., Henry, P.-Y., Julliard, R., Gruber, B., Clobert, J., Dziock, F., … Henle, K. (2009). Advantages of volunteer-based biodiversity monitoring in Europe. *Conservation Biology: The Journal of the Society for Conservation Biology*, *23*(2), 307–16. http://doi.org/10.1111/j.1523-1739.2008.01125.x

Talwar, S., Wiek, A., & Robinson, J. (2011). User engagement in sustainability research. *Science and Public Policy*, *38*(5), 379–390. http://doi.org/10.3152/030234211X12960315267615

Thompson, J. R., Elmendorf, W. F., Mcdonough, M. H., & Burban, L. L. (2005). Participation and Conflict: Lessons Learned From Community Forestry. *Journal of Forestry*.

Trumbull, D. J., Bonney, R., Bascom, D., Cabral, A., & Trumbull, D. J. (2000). Thinking Scientifically during Participation in a Citizen-Science Project. *Inc. Sci Ed*, *84*, 265–275. http://doi.org/10.1002/(sici)1098-237x(200003)84:2<265::aid-sce7>3.0.co;2-5

Tulloch, A. I. T., Mustin, K., Possingham, H. P., Szabo, J. K., & Wilson, K. a. (2013). To boldly go where no volunteer has gone before: predicting volunteer activity to prioritize surveys at the landscape scale. *Diversity and Distributions*, *19*(4), 465–480. http://doi.org/10.1111/j.1472-4642.2012.00947.x

Tulloch, A. I. T., Possingham, H. P., Joseph, L. N., Szabo, J., & Martin, T. G. (2013). Realising the full potential of citizen science monitoring programs. *Biological Conservation*. http://doi.org/10.1016/j.biocon.2013.05.025

White, S. S. (2001). Public participation and organizational change in Wisconsin land use management. *Land Use Policy*, *18*(4), 341–350. http://doi.org/10.1016/S0264-8377(01)00027-8