Studying citizen science through adaptive management and learning feedbacks as mechanisms for improving conservation

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Abstract

Citizen science has generated a growing interest among scientists and community groups, and citizen science programs have been created specifically for conservation. We examined collaborative science, a highly interactive form of citizen science, which we developed within a theoretically informed framework. In this essay, we focused on 2 aspects of our framework: social learning and adaptive management. Social learning, in contrast to individual-based learning, stresses collaborative and generative insight making and is well-suited for adaptive management. Adaptive-management integrates feedback loops that are informed by what is learned and is guided by iterative decision making. Participants engaged in citizen science are able to add to what they are learning through primary data collection, which can result in the real-time information that is often necessary for conservation. Our work is particularly timely because research publications consistently report a lack of established frameworks and evaluation plans to address the extent of conservation outcomes in citizen science. To illustrate how our framework supports conservation through citizen science, we examined how 2 programs enacted our collaborative science framework. Further, we inspected preliminary conservation outcomes of our case-study programs. These programs, despite their recent implementation, are demonstrating promise with regard to positive conservation outcomes. To date, they are independently earning funds to support research, earning buy-in from local partners to engage in experimentation, and, in the absence of leading scientists, are collecting data to test ideas. We argue that this success is due to citizen scientists being organized around local issues and engaging in iterative, collaborative, and adaptive learning.

Introduction

Although citizen science has a rich history in conservation science (Silvertown 2009), it has only recently begun to organize as a distinct field of inquiry (Jordan et al. 2015). This recent organization has resulted in increased efforts to evaluate and test theory about how to improve outcomes of citizen science projects (e.g., Bonney et al. 2014), especially in the face of the changing social and ecological dynamics where projects take place (Gray et al. 2012*a*; Shirk et al. 2012). We suggest that conservation scientists could benefit from ideas and practices only recently being tested within the field of citizen science. This is especially relevant for those who work within a collaborative conservation framework and wish to use citizen science as an approach to meet conservation goals.

We focused on citizen science programs that foster and engage in partnerships with scientists, managers, and the public who gather, analyze, and share scientifically valid, or authentic, data (Jordan et al. 2012a). Citizen science projects result in different outcomes, including data, publications, and funding; conservation action; and learning and skill gains (Shirk et al. 2012). The amount and type of citizen science participation in these activities varies dramatically depending on the project design. Bonney et al. (2009) defined 3 major types or models of citizen science participations: contributory (scientists design the program and include the public in data collection), collaborative (scientists provide opportunities for the public to engage in project design and data collection), and cocreated (partnerships between scientists and the public in which the public is engaged in all steps of the project). The participation of the public in science—especially in collaborative and cocreative projects—represents a paradigm shift in how science is typically done (e.g., Wiggins & Crowston 2011).

Most (e.g., Nicosia et al. 2014) citizen science projects are contributory, wherein individuals are engaged in data collection. Collaborative and cocreated community-embedded projects are of particular interest to conservation biologists because of the potential benefits that may occur when the roles of nonprofessional scientists are increased and stakeholder interests overlap with conservation goals. Furthermore, increased use of citizen science is expected to increase public engagement, through education, and lead to conservation action; however, evidence to support these claims remains sparse, if not contradictory (Conrad & Hilchey 2011).

We examined 2 cases in which an informed (i.e., consistent with scholarly literature in and related to citizen science) approach to integrating citizen science into conservation science has led to successful conservation outcomes. We reviewed these cases to highlight our approach to collaborative science through citizen science, where feedback loops are integrated into a citizen science project in which both scientists and participants iteratively gather new information and learn from each other and about the environmental dynamics of a system. In the case studies, we focused on environmental decision making and conservation outcomes and explored the capacity of the programs to effect community-level change. We devised suggestions as to how citizen science programs can improve the resilience of social–ecological systems (Shirk et al. 2012; Crain et al. 2014).

Background

Much like the collaborative conservation movement, collaborative citizen science seeks to engage stakeholders in problem definition, data collection, and decision-making processes when dealing with a conservation issue. These stakeholders should represent the communities affected by or who are personally invested in the particular conservation issue. These include individuals who are often marginalized in terms of decision making (e.g., scientists, managers, and, in many cases, commercial interests). (See Brick et al. [2001] for a detailed consideration of collaborative conservation.) Among other outcomes, collaborative conservation seeks to close the gap between scientific practice and conservation action through collective dialog and shared setting of objectives (Lauber et al. 2011). Although similar practices are engaged in, especially through cocreated projects in citizen science (see Cooper et al. 2007; Bonney et al. 2009, for examples), the actual data collection is also defined by and shared among stakeholders. Citizen science projects that address conservation priorities through collaboration could be considered a type of collaborative conservation project with nontraditional scientific labor.

Program developers have viewed citizen scientists along a spectrum from living instruments for data collection that require appropriate training (i.e., calibration) to ensure accuracy on one end (see McEver et al. 2007) to social-change agents that contribute to the broader process of science and management on the other end (Shirk et al. 2012). Regardless of how participants in these programs have been viewed, citizen science scholarship has recently broadened its focus on the types of common metrics that should be used to understand the outcomes associated with these programs. Although previous work has looked at individual- (e.g., learning: Evans et al. 2005; Jordan et al. 2011; Crall et al. 2012) or program-level outcomes (e.g., Conrad & Hilchey 2011; Tulloch et al. 2013), recent work suggests that the scope be widened to address larger scale social changes that may result from these scientist–public partnerships (e.g., Wiggins & Crowston 2011; Jordan et al. 2012a; Crain et al. 2014). For example, there has been an increased interest among scholars and researchers regarding citizen sciences' contribution to community-level impacts and increasing public representation in scientific decision making (Gray et al. 2012*b*; Mueller et al. 2012). Emerging research involving communities has generated new questions regarding how increased participation and community-level (i.e., social) learning, in aggregate with the generation of new data sets, may contribute to broader social or environmental change (Jordan et al. 2012a).

Theoretical Approach

We specifically chose the adaptive-management framework (Holling 1978) for this project in an effort to structure volunteer projects in a manner that allows for iterative collaborative learning and development. In particular, our approach stresses social learning, in contrast to a more cognitive approach (akin to Buck et al. 2001) in that the information gathered is used in collaborative and intentional learning settings. Learning in this context encourages multiple perspectives toward shared goals. Maarleveld and Dangbegnon (1999) identified learning loops. The primary loop refers to the declarative information-gathering phase, whereas the secondary loop features theory building. Keen et al. (2005) added a third loop that focuses on challenging assumptions and established processes that can be particularly relevant when considering institutional and organizational policy that affects resource conservation and management.

What is important to adaptive management is that both the learning and the data generated are viewed as part of a greater socioecological system with built-in feedback that results in reducing uncertainty and in the system becoming smarter (e.g., Fernandez-Gimenez et al. 2008). Learning can also be a driving force (Jordan et al. 2012*b*), as opposed to being solely an outcome, in citizen science projects. This is because human agents, within the social and ecological systems of which they are a part, can alter their decisions and behaviors in light of anticipated changes and their improved understanding of the environment (Pahl-Wost & Hare 2004; Gray et al. 2015a). Anticipation of future social and ecological states often results in decisions and actions that seek to maximize changes that are deemed favorable and decrease changes that are unfavorable to meet management goals (Gray et al. 2012b).

The iterative or adaptive process also emphasizes the dynamic nature of learning in adaptive management because individuals and groups change their understanding of the external world, which often occurs over time based on external feedbacks (i.e., information from the past influencing the future states of knowledge). Therefore, we suggest that when feedback loops are integrated in a citizen science project through formal adaptive management (i.e., constant system monitoring to reduce uncertainty), then individual participants will have the opportunity to experience efficacy in directing change (i.e., agency). This agency can contribute to conservation outcomes because of the increase in capacity for individuals to enact change.

The link between the social-learning practices and capacity is a sense that effective change is possible based on what is learned, which we term agency (Bandura 1989) Agency can also be thought of as an individual's ability to act on will (Barker 2005). One's agency can be activated through social learning. But, without a sense of efficacy, it is unlikely that one's will to act will be engaged. Bandura (1977) describes self-efficacy as a belief that one's actions will have desired outcomes. In the context of both citizen science and collaborative conservation, agency and feedbacks in mutual learning can affect both individual and community capacity, which can be summed up as the capacity for adaptive change (U.N. Econ. Soc. Coun. 2006). This capacity in both individuals and groups is a critical element to the adaptive-management process and[1] ultimately in decision making for conservation management (e.g., Schusler et al. 2003).

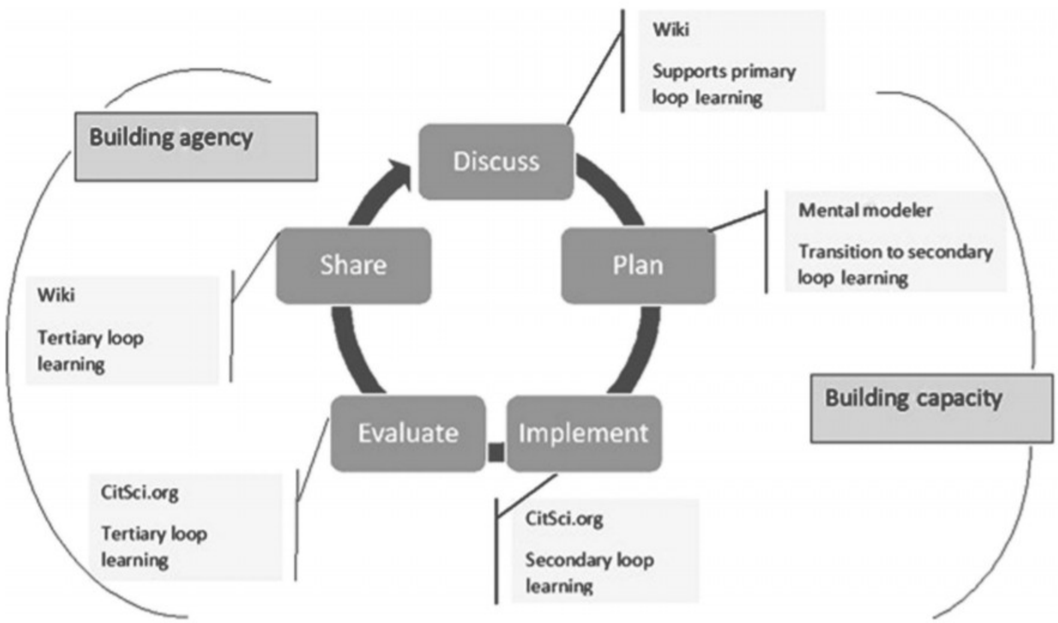

Figure 1. An illustration of how the phases of adaptive management are integrated into the collaborative-science approach and associated tools (i.e., the collaborative wiki, the mental modeler software, and citsci.org). The right side of the diagram can be thought of as steps to build capacity, and the left side contains steps to build agency.

In such decision-making contexts, we posit that the social context of learning not only improves current discourse on complex conservation problems, but also explicitly feeds back into the system to create a more stable or perhaps adaptive state (Walker et al. 2002) (Fig. 1). In combination, the adaptive-management approach and its associated social learning can provide capacity and agency, which in turn can theoretically enhance system resilience (Carpenter et al. 2001). In the context of conservation, this integration can be beneficial because resilient systems are more likely to cope with evolving stressors (i.e., threats to biodiversity and ecological integrity) that can affect stability and the preference for social–ecological states (Gray et al. 2015a). This means the community would be better able to deal with slow or sudden shocks to coupled environmental and social systems (Henly-Shepard et al. 2015).

Specific Tools

We considered 2 cases of collaborative conservation through citizen science. These cases are part of CollaborativeScience.org, a program supported by the National Science Foundation under the title Sustaining Ecological Communities through Citizen Science and Online Collaboration. This program focuses on developing cyberinfrastructure to promote conservation-based and cocreated citizen science. The Virginia Master Naturalist (VMN) organization was targeted for the design of this project because the participants are self-selected enthusiasts of natural resource conservation and are required to participate in citizen science, environmental stewardship, or environmental education service projects to remain certified in the program (www.virginiamasternaturalist.org). We chose to work with VMNs because they already had a strong interest in conservation and because we wanted to examine a program in which individual motivations were being addressed (Clary & Snyder 1999) and that encouraged volunteer satisfaction and retention (Stukas et al. 2009).

The VMN program is a Virginia (U.S.A.) state-sponsored natural resource volunteer organization in which participants are taught about natural resource management and basic ecological science. Volunteers in this program have the opportunity to collect information and data in support of resource managers. The data to be collected are identified collaboratively with professional natural resource management agencies. VMNs ($N = 533$) considered the motivation factors including desire to learn (87%), connect with nature (74%), meet others with shared interests (48%), and “give back” to the community (45%) as most important to their continued participation in the program (T. B. Frensley, personal communication). Based on these data, we developed the Collaborative Science program to provide additional learning opportunities and field-based endeavors.

The conservation goals driving the Collaborative Science project developers were initially identified by participants and managers. Individuals participating in Collaborative Science are given a space to collaborate online (see collaborativescience.org). This online environment is intended to help geographically dispersed individuals who share a common interest to work together on a local project that can be connected to regional issues and experts. In the online environment, users access instruction about ecosystems, ecosystem management, adaptive management, and a modeling tool that allows users to explore different management scenarios (Gray et al. 2013).

A challenge in engaging volunteers with Collaborative Science is that individuals need a common and impartial space to integrate goals and research tools. This space must also allow individuals to share a common language toward meeting specific goals. We, therefore, chose to use shared mental modeling through a semiquantitative form of concept mapping that would allow for multiple ideas to be discussed and debated in a common environment to facilitate social learning (Henley-Shepard et al. 2015). Instruction for volunteers covers semiquantitative fuzzy-logic cognitive mapping through Mental Modeler (www.mentalmodeler.org) (Gray et al. 2013) and the web-based CitSci.org platform (www.citsci.org) (Newman et al. 2011). Volunteers are encouraged to develop an adaptive-management plan. Each stage of the adaptive-management plan (discuss, plan, implement, evaluate, and share) is listed on separate tabs and features a discussion forum, question prompts, and a collaborative wiki space for volunteers to share ideas. In addition, the discuss page has space for individuals to create and discuss their models, and the implement tab contains the CitSci.org project implementation tools and information, which enables individuals to create project data sheets, upload observations, view data, and share features (e.g., identification guides, tutorials, maps, etc.). Finally, the share page compiles the information into each wiki to create an executive summary of the project relevant to stakeholders (Fig. 1). The online environment is different in its current form on the project website.

Throughout the training, participants can contact project personnel who provide feedback as the group defines their conservation questions to be addressed in the project. Project personnel can help contact experts. With this information, groups can update and share their models online through an ongoing and iterative process of project design. Although projects are ongoing, discussions with 4 project members support the notion that social learning is occurring in the same manner as in previous collaborative modeling studies (Henley-Shepard et al. 2015). When probed about the claims they made, each of the four participants mentioned other participants as sources of information and expertise that existed outside their personal understanding (i.e., primary loop learning). When asked to describe project design, all 4 mentioned their models as collaboration of ideas that can be supported with data (i.e., creating theoretical conjectures or double-loop learning, which is consistent with Biggs et al. [2011]). Two of the 4 participants also mentioned assumptions that remained to be tested in their projects (i.e., challenging assumptions and establishing a process, which is consistent with triple-loop learning). Based on these preliminary data sources, social learning was a major factor that contributed to learning about the conservation issue and developing data-collection protocols that sought to validate this collective knowledge.

When we tested the software, we found that motivation to engage with these computational modeling tools was low. Drawing formally from motivation frameworks for citizen science (Bonney et al. 2009) and from survey data taken from Collaborative Science participants (N = 23) (T. B. Frensley et al., personal communication), volunteers were motivated to participate in the Collaborative Science program because of an interest in the environment (74% of 23 participants ranked it among top 3 motivating factors), citizen science (61%), and natural resource management (57%). Interest in science in general (30%), protecting a specific natural resource (43%), and curiosity (9%) were less-mentioned motivating factors. Prior to this survey, we hypothesized that individuals would be strongly motivated by science in general and not by any particular environmental issue (participants had 40 h of classroom and field training in general natural resources). Based on this information, initial discussions (3 in total) were facilitated either in person or via a webinar by collaborative scientists. In the words of a recent volunteer, this helped “frame the variables that need to be considered prior to data collection.” More importantly, for program design, this facilitation, when completed, resulted in very little volunteer attrition in more recent projects.

We used our Collaborative Science approach when working with another group of volunteers in Baltimore, Maryland (U.S.A.), who were engaged with the Take Back the Block citizen science program, a program originally designed by scientists to help identify the presence or absence of adults and larvae of an invasive mosquito species to better understand the relationship between mosquito habitat, mosquito populations, and public health. Although the approach was similar to that of the VMN projects, volunteers in Baltimore completed all tasks with pen and paper. We chose to review the practices and outcomes of Take Back the Block because these individuals represent an independent group for which the program was not designed specifically. This group is not particularly motivated by conservation; rather, they were motivated by social ramifications associated with the conservation outcomes. Out of 16 participants, science (26%), fun (32%), community building (21%), learning (16%), and financial benefits (5%) (i.e., participant support costs and professional development) were listed as top motivators.

Virginia Master Naturalists

The training included an online and asynchronous program focused on sharing information about conservation ecology and using models in scientific reasoning, elementary statistics, and the Mental Modeler software tool. We also provided an overview of the adaptive-management process. This content was given as a series of voiceover videos, each accompanied by worksheets from a modified adaptive-management handbook, and a short quiz to allow participants to test themselves. The adaptive-management section encouraged the participant to think about the current and desired states of the resource in question and to create and test a potential management plan that allowed for subsequent project evaluation and results sharing.

In-person training included work with the Mental Modeler software focusing on the discuss and plan portions of the adaptive-management process and work with CitSci.org on the implement portion of the plan. Outside of the training, individuals were encouraged to use the discussion forums with question prompts and the collaborative wiki space to enter ideas. Mental Modeler is a cognitive-mapping software package designed to allow individuals to create a qualitative conceptual model about an issue of concern and then develop plausible scenarios based on strength and extent of different relationships in consideration of different outcomes or management regimes. Using this software enables individuals to work together or alone to document current ideas and revise.

After individuals generate plausible explanations using their conceptual models, they can seek evidence to support or refute their ideas. In this manner, the models generated by volunteers are embedded in the CitSci.org data management and visualization platform to be used in the implementation phase. CitSci.org is used through a web application, where citizen scientists can structure empirical plans. Data are submitted through customizable data sheets tailored by project managers and volunteers. All data are listed by location enabling spatial analyses. In addition, participants can enter information or photos about their projects so that others visiting the site can learn about their projects. Additionally, charts to visualize trends in the analyze phase are also available. (See Fig. 1 to see how interactions with the tools described above are contextualized within our broad approach.) Finally, individuals can use the wiki to share results.

Two VMN projects have resulted in positive conservation actions on the part of volunteers. (See Gray et al. [2015b] for data on social learning in these projects.) We report on these 2 projects because they have been in place for over a year.

In the first project, 7 VMN volunteers were interested in conservation and management of a Nature Conservancy (TNC)-owned property that contained a rare, fire-mediated pine savannah habitat and the endangered Red Cockaded Woodpecker (*Leuconotopicus borealis*). These participants worked with a TNC land manager to establish research questions and to create a data plan to test different management regimes through the establishment of enclosed experimental plots. Once data are gathered, a specific model will be presented to TNC; thereby bridging a boundary between citizen concerns and a conservation nongovernmental organization.

In the second project, 16 volunteers were concerned about a lack of riparian buffer in agriculture areas surrounding a wetland of interest. Therefore, with permission from land owners and using their model, they gathered evidence about the presence and abundance of coliform bacteria from sites where riparian buffers did and did not exist. After sharing these data, the Soil Conservation District awarded this team of volunteers $200,000 for site remediation (Gray et al. 2015b).

Finally, although data collection is still ongoing, before and after the collaborative planning process, participating individuals increased their confidence of self-reported strategies to fix a natural resource problem (Wald–Wolfowitz test, $N = 23$, $Z = 2.43$, $P = 0.015$). This increase in confidence in their strategies or self-efficacy could enhance the likelihood that these participants will continue their efforts to improve conservation and management practices. Future plans involve improving understanding of the link between individual motivations, activities, and a sense of agency for change (Table 1).

Table 1. A comparison between the Virginia Master Naturalist program and Take Back the Block in terms of the 5 phases in the approaches of adaptive management and collaborative science.

Collaborative science and adaptive management	*Virginia Master Naturalists*	*Take Back the Block*
Discuss and assess needs	within-chapter identification of place-based issues of concern	community-based call for focus groups
Plan and conduct mental modeling	integrating ideas from all individuals, allowing for expert and manager input, and culminating in scenario development	in-group discussion of broader impacts of data collection and decisions about taking on scientist data-gathering protocols
Implement	data collection	data collection
Evaluate	data analysis and mental-model revision	analyzed data presentation, additional data gathered, and ideas revised
Share	report and executive summary shared with decision makers	discussions and undertaking small action projects

Take Back the Block

Take Back the Block is the Collaborative Science project in which participants engaged in the adaptive management and social learning aspects of our approach. Due to limited resources, however, these individuals did not use the tools online. This National Science Foundation-funded project engages West Baltimore, Maryland, volunteers in mapping mosquito habitat and describing mosquito nuisance (rating scale of annoyance). Participants were given a packet in early spring with the materials for data collection throughout the summer. In the packet were directions for all data-collection protocols, data sheets, mailing envelopes, and a sealed participant survey. A short presurvey was administered during the signup process to begin the citizen science program. It was during this time that participants engaged in the discuss-and-plan phases of the project.

The data collected by participants during the implementation phase throughout the summer were emergence of the first mosquito of the season, mosquito habitats in their monitoring area, and monthly occurrence of mosquito nuisance and presence. Participants were asked to periodically mail in their information throughout the summer. At the end of the summer, when mosquito populations begin to diminish, participants took a postsurvey to follow up on their experiences in the program. During the winter months, participants were asked to join in discussions about evaluating the data from the project, revising ideas, and sharing the information with other community members and interested scientists. The explanations, models, and citsci.org entries were made by project staff in response to ideas given by individuals. (See Table 1 for a comparison of both cases.)

As part of our project evaluation, we asked a number of individuals who were actively engaged in citizen science (before and after the project), individuals who had received passive information about mosquito problems, and naive individuals about their beliefs regarding what they learned and of what they as individuals are capable. We also asked about their trust in municipal capacity to enact that change. These questions were asked via paper and pencil survey handed to residents in the case of naïve individuals or mailed to individuals given passive information or to the citizen scientists signed up with the project. When rating ideas on a Likert scale from 1 to 5, we found an increase in social responsibility to effect change in citizen scientists only and post project participation (paired *t* test, $N = 16$ pairs, $P < 0.001$). Levels of social responsibility in the 2 remaining groups were similar to those of the preproject citizen scientists (paired *t* test, $N = 16$ pairs, $P > 0.100$ for 2 comparisons: passive knowledge *vs*. citizen scientists and naïve *vs*. citizen scientists). Although citizen scientists reported greater mosquito knowledge (verified by a short quiz) following participation, they also reported a lower but not statistically significant sense of trust in the municipality. Despite this, a small number of participants from this case ($N = 5$) were created and are undertaking a study of a garbage control and art project in 2 neighborhoods. What remains to be seen is if the latter encourages, discourages, or has no effect on individual will to take action when it comes to advocating for change based on the final data set.

Discussion

These examples from citizen science programs highlight how data collection, citizen participation, and resource management were improved through an example of collaborative citizen science termed collaborative science. Early conservation outcomes support the notion that such citizen science projects are also consistent with the aims of collaborative conservation. Furthermore, these initial and preliminary data support the notion that participation in collaborative citizen science may encourage self-efficacy and motivation (post hoc surveys indicated that all individuals described above said they wanted to return to the project). This likely contribution to agency may be critical to community capacity and ultimately socioecological change (e.g., in terms of playing different roles to enhance community capacity [Folke et al. 2003] or of strategic or even transformative agency, where critical resources are invested to enact specific change [Westley et al. 2013]).

As more evidence to support the claim that these citizen science groups act as agents for social change emerges, strategic elements of collaborative science may be transferrable to other citizen science and conservation groups and contexts. It is our view that engaging participants as both learners and decision makers in a social–ecological system may help increase the capacity for natural resource management and conservation. At a meta level, by both sharing and consuming data on the practices of our citizen scientists, we found an opportunity for us as scholars to improve our programs and to grow as scholars that was akin to triple-loop learning.

Following the ideas described in our case, and if we accept that the ecological system of interest to the citizen science project is nested within a broader socioenvironmental system, then there are implications for changing social–ecological resilience with a project like Collaborative Science. The mechanism for this increase in resilience stems from allowing the group of learners to act as a self-identified community, where information is gained and uncertainty about system dynamics is diminished (Gray et al. 2015b).

We acknowledge, however, that such effects of learning need to be measured before definitive statements can be made and suggest that learning be measured along with changes in both social and ecological states.

Theoretically, socioecological resilience could be enhanced by engaging not only immediate stakeholders, but also extended members of the community (e.g., elders, children, new comers, etc.) in a manner similar to civic ecology (defined here as a means of learning about and improving social–ecological relations within that community and across generations [Tidball & Krasney 2012]). Measures to document such resiliency, however, are yet to be developed (although guiding perspectives exist [e.g., Gunderson & Holling 2002; Walker et al. 2002; Carpenter et al. 2005]). In an effort to test and possibly share our model of collaborative science, future directions include establishing more projects and developing robust measures of agency and long-term change in both social and ecological communities that are attributable to citizen science projects.

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