Citizen Science Across a Spectrum: Broadening the Impact of Citizen Science and Community Science

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Abstract

Environmental protection as a movement is broadening to both invite and require the participation and energy of everyone, including federal agencies, local governments, activists, and enthusiasts. There is evidence that institutions and agencies are moving towards more inclusive visions of their missions, and citizen scientists and community scientists are motivated to be involved. Citizen science and community science, approaches rooted in non-traditional partnerships and diverse participation, are a strong approaches to science, and they are especially strong approaches to a wide range of outcomes with direct impacts on the protection of the environment, from civic engagement to enforcement action. In this discussion paper, we propose a spectrum of engagement that defines opportunities for citizen science and community science beyond the participation of volunteers in institution-driven or scientist-driven research; we also provide examples of projects and efforts that have led to outcomes for each of the spectrum categories. Citizen science and community science represent a more inclusive version of science and provide a model for embracing truly collaborative environmental protection, as well.

Keywords: citizen science, community science, environmental protection

Introduction

Citizen science and community science are thriving. Millions of people are participating in and starting thousands of projects (Funk et al., 2017; Scistarter.com) that are contributing to scientific, educational, and advocacy outcomes. The impact of citizen science on science is remarkable and still growing; the use of the term 'citizen science' in scientific publications is growing exponentially (McKinley et al., 2015). For example, central claims about bird migration and climate change have been shown to be based in large part on data from citizen science (Cooper et al., 2014).

The contribution of citizen science to science continues to be demonstrated, and we argue that the contributions of citizen science and community science to environmental protection beyond research is unrealized and potentially even more impactful. *Citizen science* is the involvement of the public in scientific research and in its traditional form crowdsources data collection for studies implemented by scientific researchers towards educational or scientific advancements (Bonney et al., 2009b). In *community science*, collaboratively-led scientific investigation and

exploration addresses community defined questions, allowing for engagement in the entirety of the scientific process. Unique in comparison to traditional citizen science driven by researchers or institutions, community science may or may not include partnerships with professional scientists, emphasizes the community's ownership of research and access to resulting data, and orients toward community goals and working together in scalable networks to encourage collaborative learning and civic engagement (Dosemagen and Gehrke, 2016). In community science, an institution does not conduct directed research but instead supports people in communities who are health and environment aware, able to indicate potential concerns, hotspots and/or trends and are able be both engaged in and driving engagement, monitoring and advocacy work.

Both citizen science and community science push for the democratization of science practices and the involvement of diverse communities of people, and these terms are not clearly defined in theory and practice. For example, the United States Environmental Protection Agency (US EPA) literature refers to the term 'citizen science' for both traditional citizen science led by scientists as well as community science, as defined here. Regardless of the terms used, it is our view that both institutionally-driven citizen science and community science are effective at supporting environmental protection, and in fact provide complementary approaches for addressing environmental issues.

Citizen science and community science offer opportunities for impact beyond science and can support progress in environmental protection in multiple complementary ways. Citizen science and community science can further progress in problems for which there is incomplete and contradictory knowledge and incompatible or conflicting perspectives or value positions; "wicked" problems that require the involvement of many stakeholders, like issues of environmental quality and conservation (Bonney et al., 2014; Ellwood et al., 2017). Citizen science and community science can help transition to new approaches to science and knowledge that emphasize dialogue, agency, capacity building, and collaborative learning (Dillon et al., 2016). Projects spanning a range of involvement provide opportunities for change at multiple scales. The degree to which members of the public are involved in science affects the scale and speed at which solutions are found and implemented; Danielson et al. (2010) found that environmental monitoring by scientists tended to result in policy action that was more long-term and at large scale, while environmental monitoring that involved the public resulted in local change much more quickly.

As citizen science and community science grow in participation and impact on science, local, state, tribal, and national governments are beginning to recognize the benefits and power of engaging with those collecting data about their environments. This emerging interest is beginning to enable the use of citizen science and community science in government action and promoting the use of citizen science and community science for action beyond research. However, the nature of these impacts is not well-defined, and the role of citizen science and community science organizations, participants, and governments is not well-established. In what ways can citizen science and community science support progress in environmental protection beyond research? What is the role of citizen science and community science in the changing landscape of environmental protection?

To answer these questions, we propose a spectrum of engagement in citizen science and community science and outline the ways in which engaged people and governments are pushing and moving toward more inclusive environmental protection. In a time in which the public and agencies need new methods to be stronger environmental and human health advocates and protectors, the following sections explore the many modes of citizen science and community science - the people using these approaches, the methods for citizen science and community science practice, and the role that partnerships play in increasing the impact of work across a spectrum of project outcomes.

Methods

This article comes out of a collaboration by the authors as co-editors of a report by the National

Advisory Council on Environmental Policy and Technology (NACEPT), a federal advisory council for the US EPA. In 2015, NACEPT was tasked with drafting recommendations to the US EPA Administration on the use of citizen science and community science for addressing three particular questions, 1) How can we sustain and improve current US EPA projects, 2) How can US EPA invest in citizen science approaches for the greatest gain, and 3) How can US EPA increase the impact of knowledge and data generated via citizen science (NACEPT, 2016). Twenty-eight members, representatives of tribal, state, and local government, academia, nonprofit and community-based organizations and industry, drafted a core set of thirteen recommendations, which can be found in the report *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA* (NACEPT, 2016). Author Parker is an ORISE Research Fellow hosted by US EPA and co-editor of the NACEPT report and author Dosemagen is a member of NACEPT and Executive Director of the Public Lab nonprofit.

The Council's process involved extensive research into citizen science and community science organizations and practices. The Council began with a set of presentations from citizen science and community science practitioners spanning tribal, federal, state, nonprofit, and academic work, and explored US EPA efforts related to citizen science and community science in air, water, environmental justice, and in the US EPA Regions. The Council also participated in webinars and discussions focused on current efforts in citizen science and community science, data management, and ethical, legal, and social implications. The Council broke into working groups to focus on strategic opportunities, community-driven citizen science (i.e. community science), and data quality and management; each working group conducted interviews of citizen science and community science practitioners and US EPA staff. The working groups developed white papers, after which the main ideas were synthesized and compiled into the final report (NACEPT, 2016).

Incorporating the feedback and contributions of NACEPT members and the wider citizen science and community science fields, the council identified a spectrum of projects, widely varying outcomes and using methods and techniques indicative of projects designed for the ability of people to participate – ranging from a pastor in El Paso, Texas using local knowledge of burials to indicate a cancer cluster to a bucket brigade in Tonawanda, NY providing the first set of data for US EPA enforcement actions. These case studies provide examples for how citizen science and community science can contribute to a wide range of outcomes in environmental protection. Some of these examples relate to US EPA, but most do not - indicating that environmental protection is broadening to include a more diverse range of organizations and participants working towards a range of outcomes.

Trajectory of US EPA citizen science and the broader field

Community science projects are often a response to the perception that local, state, tribal, and federal governments are not responsive to community concerns, and community groups are often frustrated at the inability or unwillingness of federal, tribal, state, and local agencies to assess their data and respond with action. As a result, community science programs and participants are often defined by antagonism towards institutions and governments. However, gradually accumulating examples demonstrate that a combination of approaches — using both traditional research and regulatory roles and innovative efforts by citizen science and community groups — can be very successful in addressing complex issues at multiple levels and promoting positive interactions between individuals, communities, and government.

Since its creation, many have considered the US EPA to be the most powerful voice for environmental protection in the United States. The environmental movement of the 1960s contested widespread environmental pollution and issues such as Dichlorodiphenyltrichloroethane (DDT) and waste dumping; these issues motivated the creation of the US EPA by the Nixon Administration in 1970. The US EPA is tasked with protecting human health and the environment, and was developed to merge environmental research,

monitoring, enforcement and standard setting and set up to tackle increasingly evident environmental pollution (EPA, 2016). However, the ability for the US EPA to accomplish environmental protection on its own is often questioned. Since the 1970s, green groups (e.g. Greenpeace and the Natural Resources Defense Council) and grassroots groups (e.g. those organized around environmental justice and health issues) have drawn attention to and called on US EPA for stronger responses to pressing environmental concerns. Critiquing both US EPA and the environmental movement as a whole, Shellenberger and Nordhaus (2004) noted that the complexity of the environmental issues and systems — such as climate change — were not being adequately addressed by the modern framing of environmental advocacy and protection.

In the last twenty years, a transformation has begun outside of traditional institutions and is changing the environmental movement and the work of government agencies. This transformation is having a direct and lasting influence on how environmental advocacy and protection is accomplished. Environmental protection is broadening; individuals and communities are more motivated to engage, and agencies are moving toward more inclusive visions of government. The increasing prevalence of open data, civic media, citizen science and community science point to one central conclusion - in addressing our increasingly complex environments, the power lies in the participation of many.

There is increasing evidence that US EPA recognizes that responsiveness to citizen science and community science needs additional attention. Advisory councils have taken on these issues, often under the direction or with the support of US EPA. In 2012, the National Advisory Council for Environmental Policy and Technology (NACEPT) recommended that US EPA Administrator Lisa Jackson address environmental justice issues and support vulnerable populations in collecting data on environmental health concerns. In 2017, the National Environmental Justice Advisory Council (NEJAC) provided US EPA with recommendations that center on the important role of building trust between government staff and communities in order to support community monitoring. In 2015, the US EPA charged the National Advisory Council for Environmental Policy and Technology with developing advice and recommendations on how to integrate citizen science into the work of US EPA. This work culminated in two reports to US EPA advocating for proactive integration of citizen science and community science into all aspects of US EPA work: *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA* and *Information to Action: Strengthening EPA Citizen Science Partnerships for Environmental Protection* (NACEPT, 2016; NACEPT, 2018).

Within the US EPA itself a number of events have communicated increasing legitimacy of citizen science and community science in the federal space. In July 2015, US EPA held a Community Air Monitoring Training, inviting 30 community members representing local organizations from across the United States to discuss best practices for using Next Generation Air Monitoring technology. In June 2016, US EPA's New England Region hosted an Open Space meeting for US EPA and state employees, nongovernmental organizations, and community groups to discuss opportunities and barriers for environmental citizen science and community science.

Historically, US EPA support for citizen science and community science was focused mainly on volunteer water monitoring programs with funding and organizational support from US EPA's Office of Water. More recently, programs throughout US EPA's programs and regions communicate an increased interest and legitimacy of public involvement in US EPA research and policy. This includes projects driven by US EPA and its scientists as well as collaborative partnerships with community organizations. In New Jersey, US EPA scientists worked with the Ironbound Community Corporation to better understand air quality in Newark, including sensor technology and study design support. In California, US EPA participates in the Identifying Violations Affecting Neighborhoods (IVAN) network and is working to support the network in developing performance measures. In the Northwest region, US EPA works extensively with community groups to use US EPA tools such as the Environmental Justice Screening and Mapping Tool (EJSCREEN), the Community-Focused Exposure and Risk Screening Tool

(C-FERST), the Community-Line Source Model (C-LINE), and EnviroAtlas.

Moreover, citizen science is gaining popularity and acceptance across the United States federal government. In September 2015, US President Barack Obama's Science Advisor John Holdren (2015) issued a policy memo encouraging federal agencies to use citizen science and crowdsourcing approaches. The memo outlines principles for the use of these approaches, including the "fitness for use" of citizen science data, openness, and public participation. In addition, Congress passed legislation – signed by President Obama in January 2016 – encouraging the use of citizen science by federal agencies. Although these federal policies initially focus on institutional citizen science, the gradual movement towards embracing these principles – especially a shift in agency culture towards the acceptance of citizen science data – will open opportunities for both citizen science and community science.

Spectrum of Engagement

A primary motivation for many involved in citizen science and community science is the potential for change. Modified from the Wilson Center report *Clearing the Path: Citizen Science and Public Decision Making in the United States* (McElfish et al., 2016), the National Advisory Council for Policy and Technology adopted a spectrum of engagement to describe the range of ways that citizen science and community science data can be used to impact environmental protection. This spectrum, described in *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA*, demonstrates the potential for citizen science and community science to transform not only environmental research, but all aspects of environmental protection from civic engagement to environmental regulations. Citizen science and community science support research and can also provide a holistic approach for engaging with complex issues that cannot be solved through

Figure 1. The spectrum of engagement describes the range of ways that citizen science and community science data can be used to impact environmental protection. Case studies for each category of citizen science data use demonstrate how citizen science and community science can support all aspects of environmental protection from civic engagement to environmental regulations.

science alone. More and more, people are finding opportunities to engage in scientific processes towards actionable goals.

Case Studies

Community Engagement

At their cores, citizen science and community science are tools for engaging all parts of society in complex environmental problems, mobilizing diverse individuals for change, and building populations equipped to advocate for their own health and environments.

In El Paso, Texas, Father Pablo Matta of Westway's Imaculado Corazón de María Catholic Church noticed a pattern in increasing deaths from cancer, and voiced his concerns to the local community. His initial advocacy led to members and organizers of the Westway community in Texas to use community-based participatory research methods to document evidence of a cancer cluster (Staudt et al., 2015).

Education

Citizen science and community science are valuable tools for informal and formal education, especially environmental and science literacy. Many citizen science and community science projects include education as a key goal (Bonney et al., 2009a). In particular, many community science projects build community education and capacity, which in turn can lead to broader impacts over time.

In the Ironbound community of Newark, New Jersey, US EPA partnered with community organizations – including the Ironbound Community Corporation – to conduct local air monitoring. US EPA designed air monitors, including protocols for where the instruments should be located and how to maintain and operate them, and provided resources for data management and quality assurance. Community members collected data on nitrous oxide and fine particulate matter and learned to understand local environmental conditions, which allowed them to identify neighborhood trends and make local decisions. This project facilitated education in the community and build community capacity for environmental monitoring (EPA, 2015; NACEPT, 2016).

Condition Indicator

Citizen science and community science data can play an important role as indicators of environmental conditions, which can raise public awareness of environmental concerns and motivate further action. Projects that indicate the environmental conditions can include or motivate a media campaign, cross-sector stakeholder involvement, a request for further study or involvement by a government agency (such as US EPA) or a research institution.

In Philadelphia, the Center in the Park's Senior Environment Corps supports older adults in playing active, visible roles in education and advocacy; for example, volunteers were able to identify high incidence of *E. coli* in Monoshone Creek, which motivated response from the Philadelphia Water Department, the Pennsylvania Department of Environmental Protection, and the US EPA and led ultimately to an emergency contract from the Philadelphia Water Department (Siegal, 2016; NACEPT, 2016).

In Kansas City, Kansas, a community air monitoring project looked at emissions from diesel switch yard locomotives and their effect on community health. The project documented excessive levels of elemental carbon (EC) in local neighborhoods with the potential for extreme cardiovascular and respiratory health risks. Local coverage of the results motivated dialog between a local Good Neighbor Committee and BNSF Railway about strategies for emissions reductions (Diesel Health Project, 2015; NACEPT, 2016).

In Southeast Alaska, the Southeast Alaska Tribal Ocean Research (SEATOR) program supports research on the impacts of climate change on the marine environments conducted by tribes, especially in relation to paralytic shellfish poisoning from harmful algal blooms. The program fills a gap in Alaska state agency monitoring of paralytic shellfish poisoning by monitoring subsistence and recreational shellfish. Data are provided to NOAA's SoundToxin database and the Phytoplankton Monitoring Network and provide for forecasting and early warning (SEATOR, 2015; NACEPT, 2016).

Research

Within the field of citizen science, there is a rich tradition of citizen science approaches for

research; however, this progress has happened largely in research conducted by academic and non-governmental organizations. Recently, local, state, tribal, and national governments are recognizing the ability for citizen science and community science to support science normally conducted completely within institutional walls. Citizen science and community science have a great deal of possible uses for expanding baseline knowledge and supporting research and management decisions (Converse et al., 2016). Projects with a research focus can create baseline datasets, identify trends and hotspots in health and ecological change over time, and fill research gaps.

In the Mill/Otter Creek watershed in the Delaware Estuary Coastal Zone, the Friends of the Silver Lake Nature Center tests sites in the watershed for pH, dissolved oxygen, nutrients such as phosphates and nitrates, identifies aquatic organisms, and maps stormwater drainage outfalls; the data are shared with Delaware Riverkeeper, Pennsylvania Department of Environmental Protection, Pennsylvania Fish and Boat Commission, health departments, and Stroud Water Research Center (NACEPT, 2016).

The Friends of the Shenandoah River operate a water quality analysis laboratory with Virginia Department of Environmental Quality Level III accreditation, and operate a network of volunteer water quality monitors that collect data on nutrients, water chemistry, water physical characteristics, bacteria, and benthic factors. These data are used by the Virginia Department of Environmental Quality for reports to US EPA, listing impaired streams, delisting non impaired stream segments, and inform the community about exposure and risk at recreational areas and in drinking water (NACEPT, 2016).

Management Decisions

Citizen science and community science projects can support remediation, restoration, and enactment of community solutions to environmental problems. The Canton Creek Snorkel Survey monitors the abundance and distribution of salmonids in the Canton Creek Watershed and expects to provide long-term baseline data, and this effort promotes the management and restoration of this watershed. In the Washington DC region, a grassroots environmental group implements a fermentation composting method (Bokashi composting) for church functions and church members at three Episcopal Korean churches in Maryland and Virginia (NACEPT, 2016).

Regulatory Decisions

In recent years, citizen science and community science are beginning to complement traditional regulatory and enforcement processes. While uncommon, there are a number of examples of citizen science and community science informing regulatory and enforcement action.

Communities surrounding the United Bulk Terminals in Plaquemines, Louisiana were concerned about ongoing environmental issues like coal dust. The Clean Gulf Commerce Coalition demonstrated systematic problems from faulty equipment through aerial imagery, leading to a consent decree and fines from the Louisiana Department of Environmental Quality and a lawsuit resulting in stricter pollution prevention terms, additional fines for wetland restoration, and corrections to facilities and operations (U.S. District Court for the Eastern District of Louisiana, 2015; NACEPT, 2016).

Regulatory Standard Setting

Communities surrounding the Iron King Mine and Humboldt Smelter Superfund Sites were concerned about arsenic and lead in vegetables from their home gardens. Through the project Gardenroots, the communities and a University of Arizona researcher worked together to investigate arsenic exposure and risk. The study revealed that local public water exceeded the arsenic drinking water standard, resulting in a notice of violation to the municipal water supplier (Ramirez-Andreotta, 2014; NACEPT, 2016).

Colorado River Watch brings together 140 groups monitoring 650 locations for water quality, including chemical, macroinvertebrate, and physical habitat assessment. Data are used for many purposes, including standard development and setting, use assessment, impaired stream listing/delisting, development and monitoring of total maximum daily loads, and nonpoint source project monitoring. These data are more comprehensive, both temporally and spatially, than those

from any other data provider that can be used in regulatory standard setting hearings (NACEPT, 2016).

Enforcement

In Tonawanda, New York, community members were concerned about the health impacts of local industry. They collected local air samples that indicated extremely high levels of benzene. A year-long follow-up study by the New York State Department of Environmental Conservation confirmed this result. This work resulted in US EPA enforcement action, a criminal trial, the conviction of the environmental control manager for Tonawanda Coke, and ultimately, 68% and 86% reductions of benzene as measured by local air monitors (NACEPT, 2016; James-Creedon, 2016).

Conclusion

The case studies presented here provide models for how citizen science and community science can support a range of outcomes, from community engagement and education to regulations and enforcement. Many times, the motivation and energy behind those outcomes are a result of individuals' and communities' motivation for change. To support the full spectrum of engagement in environmental protection, institutions should support early involvement by communities – including problem identification and goal setting by the people asking the questions – at both a partnership and policy level. Institutions should consider how they can bolster the capacity of community science projects through focusing funding and technical support resources towards project goals and community skill building. Opportunities for true co-design should be identified and implemented with community members. Policies that create clear standards can bridge current gaps between citizen science and community science and institutions (Ottinger, 2009), which would support a range of citizen science and community science projects and allow for more action across the spectrum of engagement.

As environmentalism and environmental protection change, new approaches to collaboration are essential to tackle complex problems. Citizen science and community science invite the participation of everyone into work traditionally reserved for professionals. Similarly, environmental protection needs the action of a diverse crowd that includes activists, researchers, and enthusiasts in addition to the work of government agencies. Research is just one way that citizen scientists and activists can participate in solving environmental issues; citizen science and community science can support environmental protection through a full spectrum of activities, including supporting civic engagement, education, condition indicating, management, regulations, regulatory standard setting, and enforcement. The spectrum of engagement outlines a variety of ways that citizen science and community science can complement traditional work in environmental protection. Citizen science and community science provide ways to bring together diverse groups towards common goals, and these approaches to environmental work are changing how communities engage with their own environment and health and the way that government and institutions interact with the public.

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