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Research article

Citizen science for water quality monitoring: Data implications of citizen perspectives

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ABSTRACT

Citizen science, where citizens play an active role in the scientific process, is increasingly used to expand the reach and scope of scientific research while also achieving engagement and educational goals. Despite the emergence of studies exploring data outcomes of citizen science, the process and experience of engaging with citizens and citizen-lead groups through participatory science is less explored. This includes how citizen perspectives alter data outcomes, a critical upshot given prevalent mistrust of citizen versus scientist data. This study uses a citizen science campaign investigating watershed impacts on water quality to interrogate the nature and implications of citizen involvement in producing scientifically and societally relevant data. Data representing scientific outcomes are presented alongside a series of vignettes that offer context regarding how, why, and where citizens engaged with the project. From these vignettes, six specific lessons are examined towards understanding how integration of citizen participation alters data outcomes relative to 'professional' science. In particular, elements of participant social identity (e.g., their motivation for participation), and contextual knowledge (e.g., of the research program itself) can shape participation and resulting data outcomes. Such scientific outcomes are particularly relevant given continued concerns regarding the quality of citizen data, which could hinder scientific acceptance of citizen sciences. Importantly, the potential for meaningful engagement with citizen and participants within citizen groups - given significant capacity within the community - represents a substantial and under-realized opportunity.

1. Introduction

1.1. Citizen science in environmental management

Citizen science has become increasingly popular across a variety of scientific disciplines in recent years, as indicated by the appearance of a number of peer-reviewed publications and uptake by academics, governments, non-governmental and community organizations. Most citizen science relates to the practical implementation of citizen participation within the scientific process (Bonney et al., 2009b), where a second definition envisions citizen science as the relationship between citizens and scientific institutions (Irwin, 1995). 'Citizen science' thus describes a wide range of projects (Riesch and Potter, 2013), which are defined by approaches that span crowdsourcing through to explicit involvement and integration of citizens within the scientific process (Wiggins and Crowston, 2011).

Citizen science has become particularly popular within ecology, biology, and environmental monitoring (Devictor et al., 2010; Greenwood, 2007), including the rise of 'citizens-sensor-networks' (Carton and Ache, 2017). This includes water quality monitoring, such as volunteer contributions to watershed health assessments under various programs in the USA following the 1972 Clean Water Act (Jalbert and Kinchy, 2015). Citizen science can dramatically expand data collection and analysis at a fraction of the cost of traditional scientific campaigns (Silvertown, 2009). Citizen science can augment project scope across temporal and spatial scales (McKinley et al., 2015), improve the statistical power

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of data sets (Greenwood, 2007; Schmeller et al., 2009), and facilitate the observation of otherwise difficult to quantify phenomena (Ricciardi et al., 2000). Other cited advantages driving the proliferation of citizen science include education, improving scientific literacy, and engaging with the public. Education is a fundamental motivator for pursuing citizen science, involving the exchange of knowledge regarding the frameworks, assumptions and machinations that constitute the scientific process (Bonney et al., 2009a, 2009b; Couvet et al., 2008; Silvertown, 2009). The 'knowledge deficit' model typifies education within citizen science, where knowledge flows one-way from scientific to community actors (Irwin, 1995). Citizen science within environmental realms can also be implicitly vested with public engagement goals (Conrad and Daoust, 2008; Lasker and Weiss, 2003). These goals echo the dramatic upsurge in concern over environmental issues in the latter half of the 20th century, with a corresponding escalation in opportunities for citizen involvement within environmentally-relevant policy and decision making (Allen, 2004). Goals of increasing environmental awareness, promoting pro-environmental attitudes (Brossard et al., 2005), and reconnecting people to nature (Devictor et al., 2010) are often inherent within environmental citizen sciences (such as water quality monitoring), which have also been used to include citizens in policy-relevant science (Jepson and Canney, 2001, 2003; McKinley et al., 2015).

1.2. Mistrust of citizen data - barriers to citizen science

Despite the potential for citizen science, empirical works based on citizen engagement with data collection are at present underreported within the scientific literature, with concerns regarding data quality the most invoked barrier (Catlin-Groves, 2012). Citizen inexperience about how to best collect scientific data can indeed bias or skew data, hindering data quality and reliability (Flanagin and Metzger, 2008). Thus, the challenge of understanding how non-professionals operate within scientific programs, including the resultant effect on data quality, has necessitated development of citizen science frameworks and best practices for practitioners (for example: Bonney et al., 2009b; Conrad and Daoust, 2008; Silvertown, 2009). Such frameworks generally constrain experimental conditions to minimize the potential for citizens to bias or improperly collect data. Subsequent to this, a range of approaches for comparing and validating citizen data have been reported, including replication, expert review for identification and screening of outlier data (Bonter and Cooper, 2012; Wiggins et al., 2011), as well as statistical tactics for validating hydrologic data (Walker et al., 2016).

Citizen data has and can mirror the quality of professionally collected data, a finding reported in numerous recent studies (for example Danielsen et al., 2014; Delaney et al., 2008; Smith et al., 2013; Sullivan et al., 2014). Such examples are facilitated by the continued development of frameworks for identifying sampling bias, errors in detection, measurement and identification, and spatial clustering (Bird et al., 2014; Munson et al., 2010). Recent iterations of citizen science thus emphasize their scientific rigor, and that they be subject to the same assumptions and expectations as conventional science (McKinley et al., 2015). Despite evidence that citizen data can rival professional data, and a growing understanding of what constitutes 'good' citizen science, surveys of scientist perceptions show that concerns regarding data quality remain a significant barrier for trusting scientific conclusions derived from citizen science data (Riesch and Potter, 2013). Perhaps as a consequence of this, many citizen science projects are reported outside of peer-review (Conrad and Hilchey, 2011). This mistrust is particularly concerning for policy-relevant science such as environmental research, where apprehension regarding data quality can impede the use of findings derived from citizen data in high-level policy and decision-making (Conrad and Hilchey, 2011; Jalbert and Kinchy, 2015).

1.3. Citizen science from citizen perspectives – why participate?

Scholars have also generally failed to investigate citizen science from the perspective of citizens. Instead, the tendency is to report only those case studies deemed 'successful' based on data and data quality (Riesch and Potter, 2013). Studies exploring perspectives beyond data results include those investigating participant learning outcomes (Crall et al., 2013; Cronje et al., 2011; Jordan et al., 2011; Trumbull et al., 2000), the motivations behind and experience of participants (Alender, 2016; Raddick et al., 2009), and the public-expert relationship (Cornwell and Campbell, 2012). Studies have also scrutinized whether participation increases knowledge metrics related to the topic and/or the scientific process, a critical outcome reflecting the importance of educational goals in many citizen science programs. These conclude generally that participation in citizen science does not always improve either scientific or subject-based knowledge, nor does it necessarily result in the adoption of pro-environmental attitudes (Brossard et al., 2005; Cronje et al., 2011; Druschke and Seltzer, 2012). Further studies also question whether citizen science is an effective means of engaging citizens, such as within environmental policies or management controversies (Druschke and Seltzer, 2012).

Hindering the meaningful delivery of goals embedded in citizen science is the absence of two-way dialogue between scientists and citizen participants. Instead, transfer of information from scientist to citizen tends to be uni-directional, with the common assumption by scientific actors that communication be predicated on the public's 'knowledge deficit' (Jensen and Holliman, 2009; Riesch and Potter, 2013). This one-way knowledge flow impedes meaningful integration of contextual, traditional and local knowledges, a commonly cited benefit that has been absent from much citizen science reported to date (Couvet et al., 2008; McKinley et al., 2015). In general, significantly less focus has been made to elements outside of data outcomes, including social identity, questions of political power, and empowering citizen voices as a basic premise of environmental justice and democracy (Jalbert and Kinchy, 2015). The focus on scientific outcomes (i.e., data) has also resulted in less opportunity to voice concerns, and consider the roles and experiences of both participants and scientist advisors (Riesch and Potter, 2013). This also includes little discussion regarding how citizen perspectives alter how and why they participate within citizen science programs, and how this in tern impacts data outcomes. Additionally, despite numerous implementations of citizen science programs within water management, there are few discussions of best practices, frameworks, and lessons-learned regarding citizen participation specifically within hydrological sciences (Breuer et al., 2015; Buytaert et al., 2014). Such understandings are critical if citizen science is to be successfully applied and compared to scientist-lead evaluations of water quality (for example, Fulazzaky, 2009).