Bridging the nature gap: can citizen science reverse the extinction of experience?

Stephanie G Schuttler[1]*, Amanda E Sorensen[2], Rebecca C Jordan[2], Caren Cooper[1,3], and Assaf Shwartz[4]

Opportunities for people to interact with nature have declined over the past century, as many now live in urban areas and spend much of their time indoors. Conservation attitudes and behaviors largely depend on experiences with nature, and this "extinction of experience" (EOE) is a threat to biodiversity conservation. In this paper, we propose that citizen science, an increasingly popular way to integrate public outreach with data collection, can potentially mitigate EOE. Our review of the literature on volunteers' motivations and/or outcomes indicates that nature-based citizen science (NBCS) fosters cognitive and emotional aspects of experiences in nature. Although these experiences can change participants' behaviors and attitudes toward the natural world, this field remains largely unstudied. As such, even though NBCS can complement efforts to increase opportunities for people to interact with nature, further research on the mechanisms that drive this relationship is needed to strengthen our understanding of various outcomes of citizen science.

Front Ecol Environ 2018; 16(7): 405–411, doi: 10.1002/fee.1826

The human appropriation of natural resources has led to an unprecedented crisis, where conservation efforts and government regulations have failed to contain losses of biodiversity (Dirzo *et al.* 2014). A key step in mitigating this crisis is integrating proactive conservation into policies, which requires broad-based support from the public to enable governments to act (Reid *et al.* 2005). Yet many of the same processes that threaten biodiversity, such as urbanization, agricultural intensification, and biotic homogenization, also arguably isolate humans from forming personal connections with the natural world (Pett *et al.* 2016). In 1978, Robert Pyle coined the phrase "extinction of experience" (EOE) to describe this alienation from nature and contended that EOE is one of the greatest causes of the biodiversity crisis (Pyle 1978). Despite greater awareness four decades after its inception, information about the causes and consequences of EOE – and potential solutions to it – remains scarce (Soga and Gaston 2016).

EOE is likely exacerbated by a pervasive, negative cycle that fosters alienation from and indifference toward nature. The main drivers of this cycle are expanding urbanization and subsequent urban lifestyles (Figure 1), which result in losses of natural spaces and fewer experiences in nature (Soga and Gaston 2016). Many people now live in biologically impoverished cities and spend much of their time indoors, with limited opportunities to interact with nature in their daily lives (Turner *et al.* 2004), leading to an overall reduction in the quantity and quality of natural experiences (Figure 1). This reduced availability is especially alarming with regard to young people, as research suggests that an affinity with nature develops through childhood experiences involving direct contact with nature (Chawla 1999).

Reduced availability of nature, along with the rise of urban lifestyles, negatively affects people's affinity toward nature. The likelihood of parents encouraging their children to spend time outdoors is predicted by their own childhood experience (Cheng and Monroe 2010), which then influences their children's motivation to experience nature for themselves. The resulting reduced emotional connectedness is then correlated with reductions in visitation frequency and time spent in nature (Mayer and Frantz 2004). The cycle worsens as urban

In a nutshell:

- Opportunities for people to experience nature have declined over recent decades
- Conservation attitudes and behaviors depend on people's previous experiences of nature, so the loss of human–nature interactions poses a threat to biodiversity conservation
- Although citizen science can affect the behaviors and attitudes of participants, the extent to which it does so is largely unknown
- A review of the literature indicates that participating in nature-based citizen science (NBCS) can increase emotional and cognitive connections to nature
- We advocate for the use of NBCS as a means to mitigate the effects of this lack of engagement with nature, and highlight the mechanisms that drive this process, as well as existing knowledge gaps and challenges

[1]*North Carolina Museum of Natural Sciences, Raleigh, NC *(Stephanie.schuttler@gmail.com); [2]Rutgers University, Department of Human Ecology, New Brunswick, NJ; [3]North Carolina State University, Department of Forestry and Environmental Resources, Raleigh, NC; [4]Technion-Israel Institute of Technology, Human and Biodiversity Research Group, Faculty of Architecture and Town Planning, Haifa, Israel*

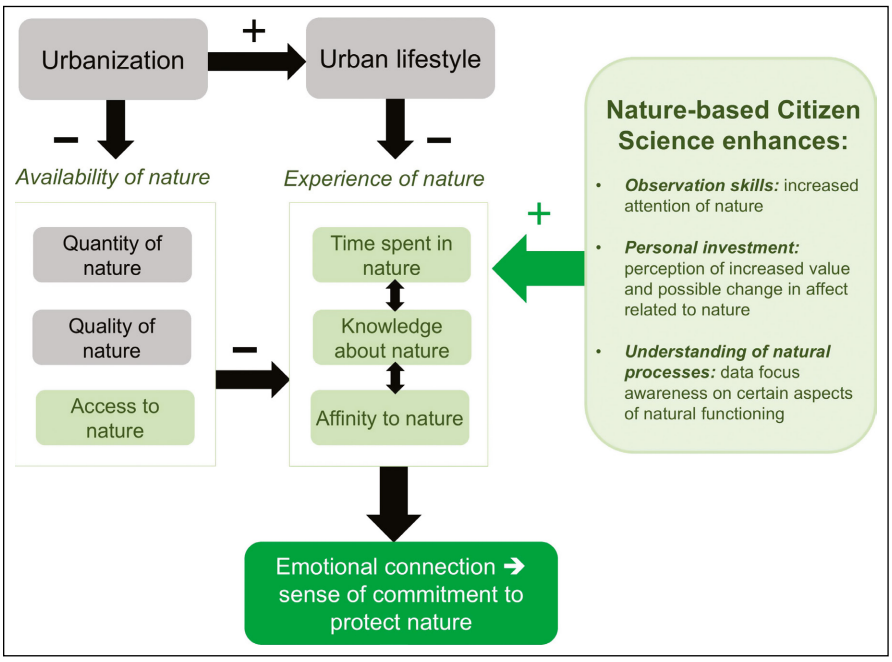

Figure 1. Proposed model of how nature-based citizen science (NBCS) can reduce the extinction of experience (EOE). Expanding urbanization reduces the availability and experience of nature in people's daily lives, which collectively leads to the EOE phenomenon. The emphasis of parents encouraging their children to spend time outdoors depends on their own nature-based experiences during childhood, and this influences their children's motivation to experience nature. EOE in turn encourages an urban lifestyle, thereby continuing the pervasive cycle, which reduces emotional connections between people and nature, and subsequently the commitments to protect nature. The impacts of NBCS (represented in light green) have the potential to disrupt this negative cycle by increasing access to, time spent in, and knowledge about nature, important components for increasing the availability of nature experiences and for creating experiences in nature. Ultimately, this can increase emotional connections to nature and a commitment to protect nature.

lifestyles increasingly become the norm with each passing generation, and the biologically impoverished environment encountered by children raised in urban environments establishes the baseline against which future degradation is assessed (Miller 2005). These "shifting baselines" (Pauly and Christensen 1995) lead to reduced expectations for the conservation of biodiversity, as people are not aware of what has been lost.

How can EOE be reversed? Improving the availability of and public knowledge about nature is often presented as a solution (Cosquer *et al.* 2012), but this is not enough. EOE stems from a cultural decline in emotional connection with nature, driven by adults who experience nature less themselves and shape children's experiences, attitudes, and values. Increasing the availability of nature in cities and encouraging people to go outside is an essential first step, but an individual's connection to the natural world may be reduced to such an extent that nature may not even be noticed (Shwartz *et al.* 2014). Rather, individuals need to learn how to take the time to notice elements of nature in order to develop an appreciation (Coldwell and Evans 2017). We propose that nature-based citizen science (NBCS) may be one means of reducing or even reversing the effects of EOE by volunteers' direct experiences in natural systems, the knowledge they gain from these experiences, and their meaningful engagement with the natural world through the contribution of data collection.

Citizen science and EOE

Citizen science is "a method of integrating public outreach and scientific data collection locally, regionally, and across large geographical scales" (Cooper *et al.* 2007). Beyond its scientific benefits, NBCS can enhance ecological knowledge and promote new relationships between people and nature, ultimately influencing their environmental behaviors and attitudes (Overdevest *et al.* 2004; Lewandowski and Oberhauser 2017). For NBCS to truly affect EOE, however, it must extend to people who lack an affinity with nature.

Understanding what motivates individuals to participate in NBCS can help broaden the reach of programs to social groups that are less connected to nature; at the same time, understanding the outcomes of participation enables us to evaluate how effective NBCS programs are at influencing volunteers' affective and cognitive connections with nature. Through a review of current and past literature, our goal here was to synthesize the motivations and outcomes of participants in various NBCS programs as a way to examine the links between NBCS and the mitigation of EOE.

Literature review of NBCS

To evaluate the extent to which NBCS participants' motivations or outcomes were studied in NBCS-related literature, we reviewed (1) a database of 888 peer-reviewed studies on citizen-science theory and methods (Follett and Strezov 2015), and (2) 87 papers published between January 2014 and August 2017 that were identified from a search we conducted in the Web of Science database using the terms "citizen science" and "nature". Follet and Strezov (2015) categorized studies using criteria relating to project development and outcomes. We excluded studies in the categories of validation, general reviews of the citizen-science field, or investigation (ie articles focused on scientific research goals), as they did not contain empirical evidence on participants' motivations and outcomes; we only reviewed studies categorized as project (describing a citizen-science study), methodology, motivation/affect, action (projects with a civic agenda), conservation (projects with a conservation purpose), virtual, and education (n = 289). Of the remaining studies and the 87 studies generated from our search (total n = 376), those that did not include NBCS research and/or did

not report participant motivations or outcomes were also excluded from our analysis. Whenever there was doubt about a paper, we tended to include it. Excluded papers were examined by two additional coauthors to achieve consensus. We defined nature broadly and included studies on such topics as astronomy and those involving only virtual, indirect contact with nature. Studies that included only anecdotal statements of participant outcomes were rejected, as were two papers written in German. The resulting 65 studies were reviewed by two coauthors and included in the final analysis if participant motivations and/or outcomes were quantified. We recorded each quantifiable motivation/outcome and grouped them into one of the seven categories described in Phillips *et al.* (2014), with one additional category (Table 1).

Motivations for and outcomes of participating in NBCS

Less than 7% (n = 26) of the studies we reviewed included data on the motivations (n = 4), outcomes (n = 13), or both (n = 9) of volunteers participating in NBCS programs (WebTable 1). The most common motivations reported fell within the categories "interest in science and the environment" (n = 11), "behavior and stewardship" (n = 10), "knowledge of the nature of science" (n = 7), and "well-being" (n = 7) (Figure 2). The most common outcomes studied were in the categories "behavior and stewardship" (n = 19), "knowledge of the nature of science" (n = 17), and "skills of science inquiry" (n = 13) (Figure 2).

Fewer than one-half of the studies (n = 10) included a statistical evaluation of the participants' outcomes in a before–after framework, with only five including control groups. Studies frequently included multiple outcomes. Nine studies reported at least one statistically significant increase in an outcome measured (eg an increase in knowledge), whereas six reported outcomes where no changes were observed, and only one reported two outcomes that resulted in significant reductions in the construct measured (Figure 3). Outcome categories with the most statistically significant positive changes included "knowledge of the nature of science" (n = 8) and "behavior and stewardship" (n = 5).

The role NBCS can play in creating or enhancing relationships with nature

The greening of cities, which creates more opportunities for people to interact with nature, has been suggested as a key step in mitigating EOE, but this alone may be insufficient, given that many people today have reduced access to and interest in experiencing nature. For instance, visitors to public gardens in Paris, France, failed to notice an experimental increase in the diversity of birds, flowering plants, butterflies, and other pollinators (Shwartz *et al.* 2014). Actions that can engage and attract individuals in meaningful nature experiences are necessary to reverse EOE effects and the resulting public indifference toward conservation. Important factors that play a role in forming such strong relationships with nature include the quantity, quality, and knowledge of, as well as access to and time spent in, nature (Figure 1). Through our review of NBCS, we found evidence that such programs can create or enhance relationships between the public and nature, resulting in positive changes in people's environmental behaviors and attitudes. Below, we highlight specific mechanisms by which NBCS can affect the cognitive and emotional experiences of participants, and how these mechanisms can lead to greater overall support for the environment achieved by traditional experiences to nature (Hungerford and Volk 1990).

Enhancing cognitive connections to nature

The majority of the statistically significant outcomes were in the "knowledge" category, with eight studies demonstrating

Table 1. Definitions of categories for the motivations and outcomes reported from 26 peer-reviewed nature-based citizen-science papers

Category	Definition
Interest in science and the environment	Interest in pursuing science and environmental topics, careers, issues, activities, such as going outside; interested in and/or are attracted to the aesthetics of a species and/or system
Behavior and stewardship	Attitude change, behavior change (or intended behavior change) resulting from participation, such as place-based and global stewardship, new participation, and community or civic action
Knowledge of the nature of science	Knowledge and/or awareness of the nature of science; understanding of the scientific process and how science is conducted by researchers; knowledge and/or awareness of the species, study system, or nature; direct access to/communication with scientist(s)
Well-being*	Participation contributes to science and/or conservation; provides opportunities for participants with similar interests to socialize; provides a sense of satisfaction, enjoyment, and/or health benefits
Curiosity about science**	Desire to engage in a citizen-science program; motivation to pursue science and environmental goals, such as STEM careers and citizen-science project activities
Skills of science inquiry	Procedural skills, such as asking questions; designing studies; collecting, analyzing, and interpreting data; experimentation; argumentation; communication; critical technology use; synthesis; thinking
Self-efficacy	The extent to which a learner has confidence in his/her ability to participate in science or to successfully perform stewardship behaviors

Notes: Categories were selected from Phillips *et al.* (2014) with a few text additions to definitions. *Represents a new category created in this study; **represents the "motivation" category in Phillips *et al.* (2014), renamed to avoid confusion with motivations reported in this study.

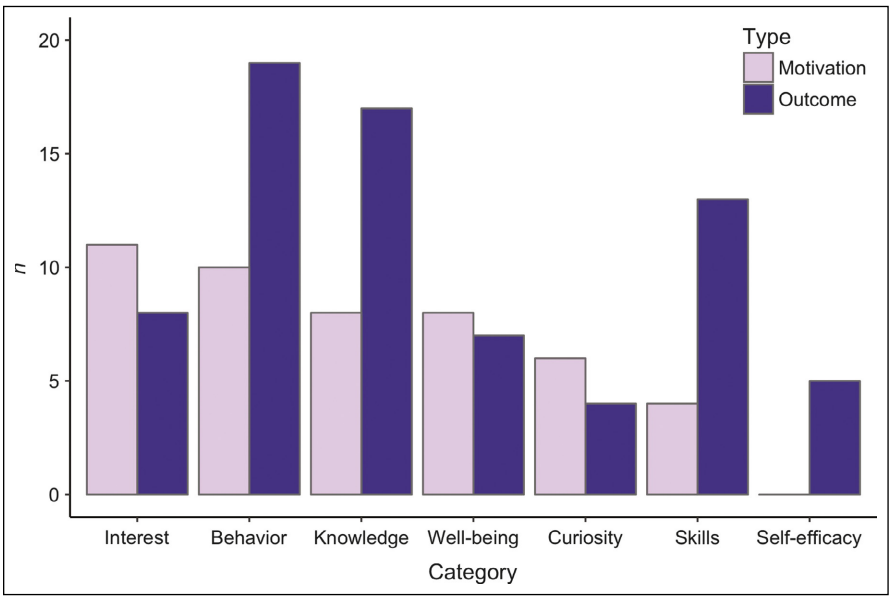

Figure 2. Numbers of papers in which the motivations and outcomes of participants in NBCS programs were examined and sorted according to category; because some papers reported multiple motivations and outcomes, the collective number of motivations and outcomes exceeds the number of papers ($n = 26$).

increases in participants' knowledge, awareness, and/or understanding of the nature of science or the study system/species of the program. For example, in the Great Pollinator Project in the northeastern US, knowledge combined with observations increased volunteers' appreciation for bees and the natural world (Toomey and Domroese 2013), while in India, volunteers' newly gained knowledge from surveys increased their concern for wildlife and the environment generally (Johnson *et al.* 2014). As a precursor to attitude and behavioral changes, participants can become more supportive of conservation practices by extending knowledge learned beyond the scope of the project. For instance, volunteers in the French National Museum of Natural History's Garden Butterflies Watch program used the knowledge they gained from that experience to make gardens more hospitable to biodiversity (Cosquer *et al.* 2012), while participants in the Smithsonian Migratory Bird Center's Neighborhood Nestwatch program extended their knowledge of bird biology from feeder observations to other features on their own properties (Evans *et al.* 2005). Knowledge gains and behavioral changes were observed even without recommendations, suggesting the importance of experiential learning; for example, volunteers in the University of Washington's Coastal Observation and Seabird Survey Team (COASST) began to clean beach sites during surveys, even though this activity was not part of the official program (Haywood *et al.* 2016).

NBCS facilitates direct interactions between scientists and the community, increasing cognitive gains as professionals and participants share what they know and their experiences. Among participants of Citizen Sky, a program of the American Association of Variable Star Observers, attitudinal changes and literacy in science were related solely to volunteers' participation in social components of the program (Price and Lee 2013). Data collection immerses volunteers in the details of scientific research, and learning how the data they collected fit into the "bigger picture" often changes their perception of the natural world (Figure 4; Cosquer *et al.* 2012; Haywood *et al.* 2016). In Citizen Sky, a combination of project result updates and a community member forum allowed for open dialogue between volunteers and experts, as volunteers were treated as scientific equals (Mankowski *et al.* 2011). Surprisingly, however, statistically significant decreases in the self-reported "knowledge of the nature of science" and "skills of science inquiry" categories were detected among participants in this program, but these results most likely reflected participants' evaluation of their own scientific capabilities rather than actual declines; interviews revealed that as participants became more involved in the project, they also became more aware of how much they did not know (Price and Lee 2013), while other studies that assessed general scientific concepts found no differences between pre and post surveys among participants (Brossard *et al.* 2005; Jordan *et al.* 2016). Overall, many measured or observed knowledge gains resulting from participation in NBCS programs were content-specific, indicating the need for more research on the ability of NBCS to promote scientific literacy in general.

Engaging with natural systems

The outcomes and motivations reported in this review suggest that NBCS can encourage and inspire participants to engage with natural systems, thereby increasing their time spent in nature. A common motivator among participants was awareness of their contribution to research. In some cases, this left volunteers with a sense of satisfaction and provided reasons for them to be outside (Figure 3; Koss and Kingsley 2010; Hobbs and White 2016). For example, one-third of COASST interviewees reported a deeper level of understanding of data collection processes, leading to more frequent site surveys and the adoption of additional survey sites (Haywood *et al.* 2016). Several volunteers in Garden BirdWatch, an initiative of the British Trust for Ornithology, stated that their participation "justified" their hobby of birdwatching and made them feel less guilty when doing so (Hobbs and White 2012).

NBCS may also incentivize individuals to spend more time outside by "gamifying" nature through achievements, restoring opportunities to experience nature lost through traditional means. Using a nature app contributed to longer park visits, and closer and more focused observations among participants (Preece *et al.* 2014), whereas participants in Citizen Sky

reported having a sense of community through online forums, which motivated users to continue the work (Price and Lee 2013). Although technology often competes with nature as a source of recreation, many NBCS programs have developed online guidebooks, websites, and apps (eg iNaturalist, eMammal, eBird, Project BudBurst) that can deliver thousands of images, sounds, and written information to help people learn about and interact with nature.

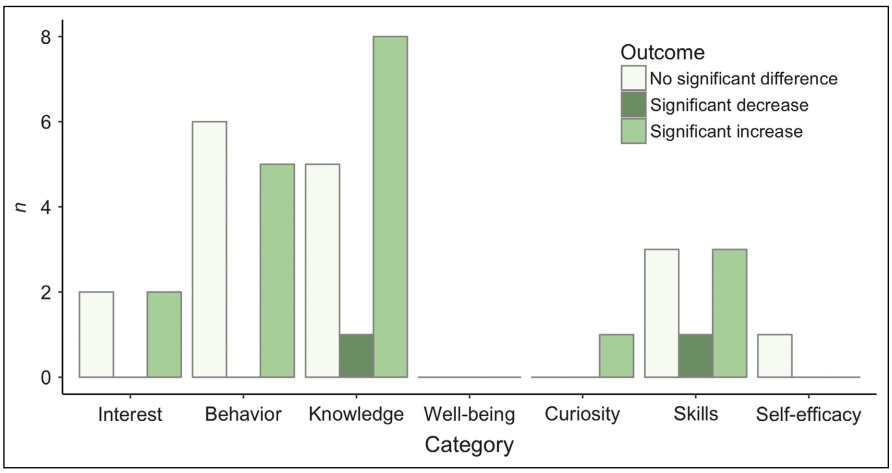

Figure 3. The number of outcomes reported in studies that were subject to statistical tests in a before-and-after experimental framework (n = 10) and the categories of the outcomes measured.

Increasing access to nature

NBCS can increase access to nature by developing skill sets necessary to view communities in a different way. Although NBCS typically does not improve the quality of nature (with the exception of restoration-oriented projects), it can inspire and train individuals to notice nature around them (Figure 4), sometimes through specialized equipment that allows participants to observe nature that would otherwise be inaccessible to them. For example, volunteers in three programs tracked animals using radiotelemetry equipment or camera traps, which allowed participants to see wildlife up-close (Figure 4; Toomey and Domroese 2013; Forrester *et al.* 2016; Hobbs and White 2016). Four studies reported that participation in NBCS also increased access to nature via exposure to other NBCS programs; for instance, over 60% of COASST volunteers subsequently participated in regional or national programs they learned about from other COASST participants (Haywood *et al.* 2016). In a study on urban hedgehogs, volunteers said they were interested in other environmental activities of which they were unaware prior to participation in an NBCS program (Hobbs and White 2016).

Establishing emotional connections to nature

To combat EOE, individuals need to develop environmental empathy, a construct that moves beyond concern to a deeper identification with environmental entities (eg the ecosystem or species within the ecosystem; Sobel 1996). Such empathy involves not only a certain level of cognitive awareness but also emotional connections with moral underpinnings. Müller *et al.* (2009) found emotional affinity toward nature, not merely spending time in natural settings, contributed greatly to pro-environmental commitment. We found some supporting evidence for this in our study. Six papers included in our review measured outcomes that did not fit into the categories proposed by Phillips *et al.* (2014), and consequently were placed in a "well-being" category to reflect the feelings of satisfaction and enjoyment that volunteers developed from their contributions to science or through socializing with like-minded individuals (Figure 4). For instance, the Marine Conservation Society's Seasearch volunteers reported positive feelings, emotionally and mentally, stemming from a sense of achievement from preserving and improving their local marine protected area (Koss and Kingsley 2010), and COASST volunteers developed a deepened sense of place from regular participation, which led to a strong sense of belonging and ownership of the site (Haywood *et al.* 2016). This sense of ownership may be associated not only with a stronger sense of place, but also with community building, confidence, and subsequent agency in enacting positive conservation outcomes, creating a positive feedback loop that triggers future conservation behaviors.

Can we preach beyond the choir?

To mitigate and ultimately reverse the EOE phenomenon, it is important to reach beyond people already interested in nature, yet we found "interest in science and the environment" to be the most common motivating factor for participation in NBCS. Our results suggest some potential for motivation in NBCS through other interests, as participants also reported social reasons or the desire to "give back". Based on the results of the studies reviewed here, it is difficult to assess the ability of NBCS to attract non-traditional participants because many programs recruited volunteers who were already interested in nature from outdoor groups and even nature-related careers. In most studies, volunteers were educated (>60% with an undergraduate degree or higher from those that reported education, n = 16), and some studies reported no changes in knowledge or attitude due to the pre-existing, relatively high level of knowledge about nature among NBCS volunteers.

Given that strong connections with nature develop primarily in childhood, NBCS would be most effective in reversing EOE by working with schools or youth programs, yet we found only one study implemented in classrooms (Zárybnická *et al.* 2017). Other studies reported parents participating with children (Evans *et al.* 2005; Cosquer *et al.* 2012; Sickler *et al.* 2014),

Figure 4. NBCS programs offer participants opportunities to (a and b) observe nature more closely, (c) socialize with like-minded individuals, and (d) use technology to observe nature in new ways.

and in some programs educator participants stated they would incorporate NBCS into their youth groups (Johnson *et al.* 2014; Merenlender *et al.* 2016). However, the extent to which NBCS can influence connections with nature among the young has yet to be explored fully. Zárybnická *et al.* (2017) found statistically significant knowledge gains by students about birds, and other studies outside of this review reported that NBCS messages were often conveyed to local communities through presentations and media coverage (Eastman *et al.* 2014). The major advantage of working in schools is that participant selection bias is reduced or even removed, as experiences in nature are offered to diverse communities. Unfortunately, in the studies we reviewed, most participants were well above the age of 30 (n = 18), and of studies that included race (n = 3), participants were reported to be overwhelmingly Caucasian (>80%).

Filling in knowledge gaps

We found evidence that NBCS can affect participants in meaningful ways and influence their connections to nature. Nine studies in our review detected statistically significant increases in volunteers' knowledge, attitudes, and environmental behaviors, important factors for breaking the EOE cycle. All 13 studies on outcomes found at least one positive change, and participant statements exemplified the profound impacts that NBCS has on volunteers' lives. Despite these promising findings, very few studies (n = 26) formally evaluated participants' motivations for and/or outcomes from volunteering, and only 10 of these employed experimental frameworks facilitating the identification of cause-and-effect; moreover, only a single study measured impacts on children, the most important demographic for reversing EOE. Questions remain regarding NBCS effectiveness in reaching non-traditional audiences, how long or how many times a volunteer must participate for connections to nature to form, whether attitudinal and behavioral changes endure, and what the most influential elements of NBCS are for people to create lasting connections to nature. Our review suggests that we are at the initial stages of understanding the true potential of NBCS programs in mitigating EOE. We recommend all NBCS programs include evaluation opportunities to investigate the effects of engagement in NBCS on participants' attitudes toward and interactions with nature, as highlighted above. Experimental studies of NBCS can also help us to more fully understand the transformational role that NBCS can play in reversing EOE.

Acknowledgements

We thank R Follett and V Strezov for sharing their database of studies used in this review, and A Land-Zandstra for detailed comments and suggestions. This work was conducted with funding from the US National Science Foundation (grant #1319293).

References

Brossard D, Lewenstein B, and Bonney R. 2005. Scientific knowledge and attitude change: the impact of a citizen science project. *Int J Sci Educ* **27**: 1099–21.

Chawla L. 1999. Life paths into effective environmental action. *J Environ Educ* **31**: 15–26.

Cheng JC-H and Monroe MC. 2012. Connection to nature. *Environ Behav* **44**: 31–49.

Coldwell DF and Evans KL. 2017. Contrasting effects of visiting urban green-space and the countryside on biodiversity knowledge and conservation support. *PLoS ONE* **12**: e0174376.

Cooper CB, Dickinson J, Phillips T, *et al.* 2007. Citizen science as a tool for conservation in residential ecosystems. *Ecol Soc* **12**: art11.

Cosquer A, Raymond R, and Prevot-Julliard A-C. 2012. Observations of everyday biodiversity: a new perspective for conservation? *Ecol Soc* **17**: 82–96.

Dirzo R, Young HS, Galetti M, *et al.* 2014. Defaunation in the Anthropocene. *Science* **345**: 401.

Eastman L, Hidalgo-Ruz V, Macaya-Caquilpán V, *et al.* 2014. The potential for young citizen scientist projects: a case study of Chilean schoolchildren collecting data on marine litter. *J Integr Coastal Zone Manage* **14**: 569–79.

Evans C, Abrams E, Reitsma R, *et al.* 2005. The Neighborhood Nestwatch program: participant outcomes of a citizen-science ecological research project. *Conserv Biol* **19**: 589–94.

Follett R and Strezov V. 2015. An analysis of citizen science based research: usage and publication patterns. *PLoS ONE* **10**: e0143687.

Forrester TD, Baker M, Costello R, *et al.* 2016. Creating advocates for mammal conservation through citizen science. *Biol Conserv* **208**: 98–105.

Haywood BK, Parrish JK, and Dolliver J. 2016. Place-based and data-rich citizen science as a precursor for conservation action. *Conserv Biol* **30**: 476–86.

Hobbs SJ and White PCL. 2012. Motivations and barriers in relation to community participation in biodiversity recording. *J Nat Conserv* **20**: 364–73.

Hobbs SJ and White PCL. 2016. Achieving positive social outcomes through participatory urban wildlife conservation projects. *Wildlife Res* **42**: 607–17.

Hungerford HR and Volk TL. 1990. Changing learner behavior through environmental education. *J Environ Educ* **21**: 8–21.

Johnson MF, Hannah C, Acton L, *et al.* 2014. Network environmentalism: citizen scientists as agents for environmental advocacy. *Global Environ Chang* **29**: 235–45.

Jordan R, Gray S, Sorensen A, *et al.* 2016. Studying citizen science through adaptive management and learning feedbacks as mechanisms for improving conservation. *Conserv Biol* **30**: 487–95.

Koss RS and Kingsley JY. 2010. Volunteer health and emotional well-being in marine protected areas. *Ocean Coast Manage* **53**: 447–53.

Lewandowski EJ and Oberhauser KS. 2017. Butterfly citizen scientists in the United States increase their engagement in conservation. *Biol Conserv* **208**: 106–12.

Mankowski TA, Slater SJ, and Slater TF. 2011. An interpretive study of meanings citizen scientists make when participating in Galaxy Zoo. *Contemp Issues Educ Res* **4**: 25–42.

Mayer FS and Frantz CM. 2004. The connectedness to nature scale: a measure of individuals' feeling in community with nature. *J Environ Psychol* **24**: 503–15.

Merenlender AM, Crall AW, Drill S, *et al.* 2016. Evaluating environmental education, citizen science, and stewardship through naturalist programs. *Conserv Biol* **30**: 1255–65.

Miller JR. 2005. Biodiversity conservation and the extinction of experience. *Trends Ecol Evol* **20**: 430–34.

Müller M, Kals E, and Pansa R. 2009. Adolescents' emotional affinity toward nature: a cross-sectional study. *J Develop Proc* **4**: 59–69.

Overdevest C, Orr CH, and Stepenuck K. 2004. Volunteer stream monitoring and local participation in natural resource issues. *Hum Ecol Rev* **11**: 177–85.

Pauly D and Christensen V. 1995. Primary production required to sustain global fisheries. *Nature* **375**: 255.

Pett TJ, Shwartz A, Irvine KN, *et al.* 2016. Unpacking the people–biodiversity paradox: a conceptual framework. *BioScience* **66**: 576–83.

Phillips TB, Ferguson M, Minarchek M, *et al.* 2014. User's guide for evaluating learning outcomes in citizen science. Ithaca, NY: Cornell Lab of Ornithology.

Preece J, Grace K, Boston C, *et al.* 2014. Crowdsourcing design and citizen science data using a tabletop in a nature preserve. In: Rospigliosi A and Greener S (Eds). The Proceedings of the European Conference on Social Media – ECSM 2014. Reading, UK: Academic Conferences and Publishing International Ltd.

Price CA and Lee H-S. 2013. Changes in participants' scientific attitudes and epistemological beliefs during an astronomical citizen science project. *J Res Sci Teach* **50**: 773–801.

Pyle RM. 1978. The extinction of experience. *Horticulture* **56**: 64–67.

Reid WV, Mooney HA, Cropper A, *et al.* 2005. Millennium Ecosystem Assessment. Ecosystems and human well-being: synthesis. Washington, DC: Island Press.

Sickler J, Cherry TM, Allee L, *et al.* 2014. Scientific value and educational goals: balancing priorities and increasing adult engagement in a citizen science project. *Appl Environ Educ Commun* **13**: 109–19.

Shwartz A, Turbé A, Simon L, *et al.* 2014. Enhancing urban biodiversity and its influence on city-dwellers: an experiment. *Biol Conserv* **171**: 82–90.

Sobel D. 1996. Beyond ecophobia: reclaiming the heart of nature education. Great Barrington, MA: The Orion Society.

Soga M and Gaston KJ. 2016. Extinction of experience: the loss of human–nature interactions. *Front Ecol Environ* **14**: 94–101.

Toomey AH and Domroese MC. 2013. Can citizen science lead to positive conservation attitudes and behaviors? *Hum Ecol Rev* **20**: 50–62.

Turner WR, Nakamura T, and Dinetti M. 2004. Global urbanization and the separation of humans from nature. *BioScience* **54**: 585–90.

Zárybnická M, Sklenicka P, and Tryjanowski P. 2017. A webcast of bird nesting as a state-of-the-art citizen science. *PLoS Biol* **15**: e2001132.

Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1826/suppinfo