Citizen science editorial: Towards ecological science for all by all

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1 Introduction

Imagine a global community of people who - as a matter of daily routine - observe wildlife, smell the air, discuss the weather and touch the world around them. As sensors, people have evolved the ability to assess environmental change and one might easily conceive an army of such 'citizen scientists' ready and willing to advance knowledge. Of course, it's not that straightforward. Although volunteers have supported science for decades, the concept of citizen science that has a more holistic consideration of methods, ethics, philosophy and social science is relatively new. We know citizen science can generate large, high quality data sets, but as much as the potential of citizen science has been demonstrated, new challenges and opportunities such as reconnecting people with nature have also been found. No matter the discipline, how best to incorporate citizen science into research in an efficient, cost-effective and ethical way that works for both contributing citizen and professional scientist is still to be fully understood. Indeed, from the perspective of the social sciences, there is the need for citizen science to adapt to a society that demands science to be responsive to rapidly changing concerns.

The Oxford English Dictionary defined citizen science in 2014 (OED, 2020), and combined two early definitions that emphasized i) the responsibility of science to society (Irwin, 1995), and ii) the participatory role of people contributing observations or efforts to scientific endeavours (Bonney, 1996). More recently, Ceccaroni *et al.* (2017) attempted to reconcile these viewpoints to describe citizen science as *work undertaken by civic educators and scientists together with citizen communities to advance science, foster a broad scientific mentality, and/or encourage democratic engagement, which allows society to deal rationally with complex modern problems* (Eitzel *et al.*, 2017). As of 12th December 2020, the citizen science hub SciStarter.com lists 1358 active citizen science projects. Of these, 642 (47.3%) are listed under the topic 'Ecology and Environment'. Indeed, there has been a rapid growth in such projects since the 1940s, and since 1990 there has been a 10% decadal increase (Pocock *et al.*, 2017). This expansion in citizen science has precipitated a range of supporting infrastructure, including typologies (e.g., Danielsen *et al.*, 2009; Wiggins and Crowston, 2011), best practice principles (e.g., ECSA, 2017) and frameworks for implementation (Shirk *et al.*, 2012; Resnik, Elliott and Miller, 2015; Chase and Levine, 2016).

It is because of the growth in citizen science activities across the breadth of ecology and environmental studies, and increasing attention in the social sciences, that the BES launched an open call for papers to this Special Feature on citizen science across six of the BES journals in October 2019. In doing so, the BES sought to assess the contribution of citizen science to ecological knowledge, but also to our understanding of the connection between people and nature. In this Editorial for the Special Feature, we discuss the papers and topics covered and conclude with a brief outlook on ongoing and future developments.

2 Questions and themes covered by papers in the special feature

This Special Feature comprises 20 papers, of which seven are in *Journal of Applied Ecology*, five in *People and Nature*, four in *Journal of Animal Ecology*, two in *Ecological Solutions and Evidence* and one each in *Journal of Ecology* and *Methods in Ecology and Evolution*. Although wide-ranging and varied, as a collection these articles address the two perspectives intended for this Special Feature; the contribution of citizen science to the advancement of ecological knowledge and the contribution of community-based perspectives to citizen science. Amongst these 20 papers are 16 that present original quantitative or qualitative research, a practice-based article (Bonnet *et al.* 2021), a perspective (Palmer *et al.* 2021), a protocol (Garcia *et al.* 2021) and a literature review (Winch *et al.* 2021).

2.1 Quality assurance and control

Seven papers address aspects of *quality assurance and quality control (QA/QC)*. Trust is a critical factor for leveraging partnerships between citizen scientists, project coordinators and decision-makers (Freitag, Meyer and Whiteman, 2016). Although an increasing number of disciplines incorporate citizen science, there remains scepticism of the public as a trusted source of scientific information (Burgess *et al.*, 2017; Tredick *et al.*, 2017) and many projects struggle to meet decision-maker needs (Newman *et al.*, 2016), who frequently require data suitable for reliable inference. Thus, underpinning quality assurance and control is that it is the scientific mode and quality of information that matters, which in the context of citizen science means ensuring that any participation in the data collection by community members may be improved by the development of procedures and protocols to be followed before and during data collection (quality assurance). This is also extended to processes for improving data quality after data collection, or ‘at the back-end’ (quality control).

The papers by Pernat *et al.* (2021) and Bizru *et al.* (2021) are two such studies of quality assurance. Pernat *et al.* (2021) compared trained researcher (or ‘professional’) data to citizen science data on mosquito collections in the German ‘Mückenatlas’, while Bizru *et al.* (2021) compared local peoples’ capacity to determine the reproductive status of female pacas (*Cuniculus paca*). Pernat *et al.* (2021) used data from seven years of surveillance to evaluate what kind of information each method of collection provides. They found that systematic monitoring was superior in terms of mapping diversity, but passive monitoring did a better job detecting invasive species. This suggests that citizens can often do better at detecting novel occurrences than systematic approaches. With a 17-

year long dataset, Bizru *et al.* (2021) found that indigenous knowledge was already highly accurate for pregnancy diagnosis (72.5% correct), which was even better after training (88.2% correct).

Thus, depending on the circumstances, citizen science data may not only complement systematic monitoring but can be superior to it by providing novel insights emerging from extensive local or indigenous knowledge. This has been seen in citizen science before: for example, with Hanny's Voorwerp on the Galaxy Zoo project (Cardamone *et al.*, 2009). It is through insights such as these that blur the boundaries between those who are considered citizen scientists or professionals when either may produce sufficiently high quality data to inform wildlife management. However, such high rates of agreement as found by Bizru *et al.* (2021) may only be seen in about 55% of similar studies on the accuracy of citizen science data (Aceves-Bueno *et al.*, 2017).

The term 'extreme' citizen science, which has emerged in recent years, was borne partly out of internet accessibility, which has led to the development of thousands of web-based or mobile applications to aid the citizen scientists in recording accurate observations. Extreme citizen science involves not only the crowdsourcing of data, but also its analysis (see Haklay, 2013). The 'From Practice' paper by Bonnet *et al.* (2021) presents the Pl@ntNet platform, which was initiated in 2009 and as well as being a platform for participatory research, aggregating and disseminating observations, it allows the identification of plants by automatic visual recognition. Bonnet *et al.* (2021) describe how Pl@ntNet was disseminated to local communities in two different socioeconomic contexts; the Ramières Reserve (France) and the Lewa Conservatory (Kenya). For such a tool to be widely adopted, the key factors they identify reinforce existing research and include good communication (Constant and Roberts, 2017), data quality and validation, recognition of participant expectations (Dickinson *et al.*, 2012). In line with the concept of extreme citizen science this includes adopting an open data policy and ensuring technologies are commensurate with local infrastructure.

The paper by Petersen et al (2021) provides a forensic study of biological recording in Norway and finds classic taxonomic biases towards traditionally recorded and charismatic fauna (e.g., birds), and a non-random skew of observations towards anthropogenic land-uses ('road-side bias'), whether the focus be on any, rare or non-native species. Thus, the study by Petersen et al (2021) provides useful context for the remaining three papers under the theme of quality control which consider how to account for different forms of bias generated through citizen science data related to site selection and observer retention over time (Dambly *et al.* 2021), artificial light conditions (Ditmer *et al.* 2021) and choice of methods in generating less biased SDMs (Steen *et al.* 2021).

With long-term monitoring, there is concern that frequent turnover of observers can affect accuracy (Dickinson, Zuckerberg and Bonter, 2010). Dambly *et al.* (2021) develop a 'virtual ecologist' model to test whether and how opportunistic site selection and uneven observer retention over time affect monitoring of bat roosts. They showed that these issues can result in biased trends, affecting the reliability of monitoring projects. Their findings highlight the value of engaging and retaining citizen science observers, a standardised sampling design, and the collection of metadata. However, from an interdisciplinary perspective, what is termed 'bias' in the natural sciences, may be part of the rich social dimensions that shape the science in particular ways; and it is this social shaping of the citizen science that the papers submitted in to People and Nature are largely concerned with. In particular because they alert us to the human and social dimensions related to why the concerns of citizen science may be particularly compelling to observers, who we might like to engage for extended periods of time.

Observer bias may also be influenced by environmental conditions. Ditmer *et al.* (2021) tested whether the incorporation of artificial light at night (ALAN) conditions influenced the detection of American black bears by citizen scientists. Members of the public provided 1315 observations of black bear across Minnesota, USA. Using an occupancy modelling framework, the authors found that when compared to other commonly used metrics of human footprint (e.g., housing density), artificial light conditions did the best job of accounting for spatial bias showing higher rates of detection with elevated illuminance. Thus, bear abundance may be substantially underestimated in more natural conditions. Such spatial bias in volunteer effort associated with urban infrastructure is well established (Geldmann *et al.*, 2016; Tiago, Ceia-Hasse, *et al.*, 2017), but the added interaction of artificial light improves our understanding of detection bias, and can be incorporated into occupancy models to improve estimation and predictions of organisms' distributions and abundances.

Further error may result from methodological choices made during the production of SDMs based upon presence-only data, which is a frequent characteristic of citizen science. Such data generate class imbalances where one class (e.g., absence data) is far more abundant than another (Robinson, Ruiz-Gutierrez and Fink, 2018). Steen *et al.* (2021) compare three choices for mitigating class imbalance; spatial thinning, class balancing and majority-only thinning using eBird data for 102 species. Finding that there was no single best approach across all species, and the considerable differences in SDM performance, the authors recommend a series of factors to be considered on a case-by-case basis to guide how to thin or balance data. Furthermore, because methodological choices determine what a person will do and how they will contribute to the data gathering, it is also important to consider the social dimension when thinking about how to manage a successful and sustainable citizen science programme.

2.2 Species movement and distribution

The involvement of volunteers in recording species observations is one of the most established forms of citizen science (although it may not always have been referred to as such). For example, The Audubon Society sponsored Christmas Bird Count began in 1900 (Bock and Root, 1981) and the UK Butterfly Monitoring Scheme in 1976 (Pollard and Yates, 1994), closely followed by American and European equivalents. Such is the popularity of ornithology in particular, that bird data dominate biodiversity occurrence data on GBIF (Troudet *et al.*, 2017), thanks in part, to the highly successfully citizen science platform eBird (Sullivan *et al.*, 2009).

When combined with conventional monitoring, citizen science data have broadened the opportunity for temporal ecological studies, allowing for the study of phenology and temporal population dynamics. It has been demonstrated to improve our understanding of the phenology of animals (Van Der Kolk, Wallisdevries and Van Vliet, 2016) and plants (van Vliet, Bron and Mulder, 2014) in relation to a changing climate; and of the distribution of invasive species (Crall *et al.*, 2011), amphibians and reptiles (Tiago, Pereira and Capinha, 2017), and migratory birds (Robinson *et al.*, 2020). In the absence of citizen science data, many studies may be limited to fewer species or a more narrow geographic range, or investigated only within a small portion of an annual cycle or an organism's life cycle.

In this collection, the use of eBird data by La Sorte *et al.* (2021) has allowed the associations between vegetation and breeding bird migration to be tracked across the entire annual cycle, rather than just focusing on a small portion of the cycle, and across a broad spatial extent. The use of citizen science data has also allowed habitat tracking to be investigated across a large number of species, whilst previous tracking studies have been limited in the number of species they have been able to investigate simultaneously. Similarly, citizen science data from Project FeederWatch allowed Latimer and Zuckerberg (2021) to identify temporal population dynamics of North American birds. The authors used the repeat observation data from this scheme to develop dynamic occupancy models, which explicitly model differences in the recording and detection processes. The recent development and expansion of hierarchical modelling techniques such as these have facilitated a boom in the usability of citizen science data.

The combined use of citizen science data from multiple sources or programmes will facilitate greater flexibility and increased scope in the questions that can be answered. For example, Williams *et al.* (2021) combine data on purple martin occurrence from eBird, abundance from the Breeding Bird Survey, and demographic parameters from Project MartinWatch to investigate the relationship between habitat suitability and species demography. This study highlights how citizen science projects may also record more than just the observations of a species' presence by asking observers to record data on fecundity such as number of eggs and fledglings per nest.

Technologies such as camera traps offer new ways for citizen scientists to collect and contribute conventional data (e.g., species presence) in a more planned and systematic way. This is because traps can be left in fixed locations on site, and over more defined survey periods. Twining *et al.* (2021) use such data in a study of red and grey squirrel, and pine marten distribution at 332 sites distributed across Northern Ireland. Camera trap data were used to build species occupancy models and demonstrated that the recovery of pine marten was strongly, and positively associated with red squirrel populations, with grey squirrel having the opposite relation. Expanding on the data to develop a model of habitat suitability the authors also warn that grey squirrel populations are likely to persist in urban areas. With clear policy and ecosystem management implications, this study demonstrates eloquently how careful set-up, handling and verification of citizen science data through the use of camera traps can lead to real impacts for natural conservation (see also Santangeli *et al.*, 2020).

Biodiversity extends to diversity within species (UNEP, 1994) and so it is that Aavik *et al.* (2021) took a citizen-science approach to study the distribution in morph frequencies of flower styles in populations of the heterostylous grassland plant cowslip across Estonia. A citizen-science campaign 'Eesti otsib nurmenukke' ('Estonia is looking for cowslips') engaged participants from 1700 localities across Estonia. Analysis of the data indicated deviations from equal morph ratios in areas with high human population density and greater habitat fragmentation, with a higher likelihood for inbreeding and fitness declines (Leigh *et al.*, 2019), a finding which builds on earlier evidence from a much more geographically restricted study (Van Rossum and Triest, 2006). In conclusion, citizen science contributed to monitoring of species movement and distribution through the engagement and mobilization of technologies and people who could monitor these over a wider spatial and temporal range, in comparison to a traditional study. The broadened spatial and temporal range of data collection, also has the potential for allowing for new insights and associations, and indeed raises that potential for citizen science to play a significant role in long-term monitoring.

2.3 Long-term monitoring

Detecting environmental change at multiple spatial and temporal scales through biotic and abiotic monitoring is not only important for science and scientists, it is fundamentally important for policy-makers and environmental managers because it provides the basis for longer term planning and resource allocation (Parr *et al.*, 2002; Peters *et al.*, 2014). To successfully detect environmental change at multiple scales requires long term efforts to disentangle change from background noise

(Magurran *et al.*, 2010). Citizen science has been posed as a possible solution to this given its potential to generate data at spatial and temporal scales not achievable by conventional means (Thornhill *et al.*, 2016; Pocock *et al.*, 2018).

Alongside funding shortfalls, a limiting factor to long-term monitoring is the successful engagement of volunteers, which may be limited by the amount of survey effort required (Weiser *et al.*, 2019). It may, therefore, be sensible to optimise monitoring to maximise volunteer retention, as well as ecological and economic efficiencies. What then would be the minimum amount of monitoring required to detect robust trends in, for example, woodland bird populations? This is an aspect explored by Prowse *et al.* (2021), who resample 16 years of monitoring data to simulate different levels of monitoring effort. They find that rather than reducing the number of sites surveyed, trend detection would be retained most effectively by revisiting biennially but that would in turn, risk long-term engagement. A compromise might be met by reducing the number of sites visited annually but retaining the spatial extent, however, this may compromise the ability of a monitoring programme to detect early warning signals, particularly in rare or declining species. Thus, social dimensions, traditionally seen as aspects to be controlled within scientific research, become aspects that critically inform both the success of the data collection and the outcomes of the research.

Garcia *et al.* (2021) explicitly focus on the potential for citizen science monitoring to detect early-warning signals in plant populations within the 'Adopt-a-Plant' program in Northeast Spain. Participants in the Adopt-a-Plant program survey fixed representative areas to a robust protocol that is customised to each of the species concerned to inform metrics that are compatible with the Essential Biodiversity Variables (EBVs). As well as providing an in depth account of the protocol, which may provide a framework to be adapted to other regions, the authors analyse 242 populations of 150 taxa monitored over 3-10 years. The findings point to generally stable populations, but small localised populations are more vulnerable, in accordance with the wider literature (Matthies *et al.*, 2004). It is this capacity for citizen science data to contribute to the understanding of small localized trends that stabilizes its stand-alone role in the scientific effort, which has its own merits beyond being a complementary form of scientific investigation.

Citizen science is also an approach that places non-scientists, but other types of experts and communities at the centre of the scientific endeavour. Billaud *et al.* (2021) engage more than 1000 French farmers over a period of seven years to disentangle the effect of farm practices upon invertebrate diversity from natural variations. Varied relationships are found between farming practices and the five invertebrate groups investigated. For example, flying taxa are negatively impacted by pesticide use and mineral fertilization, but the effect upon other groups is mixed. The authors recognise the potential benefit of monitoring being sustained by farmers, which may have the additional benefit of contributing to conservation through an increased awareness of biodiversity, and the role of biodiversity for farming.

Prowse et al. (2021) question the social and political acceptability of adapting long-monitoring strategies. Indeed, the goal of any monitoring plan is a subjective decision that should be made by a wide variety of stakeholders under the guidance of social scientists (Hauser, Pople and Possingham, 2006). The three papers regarding long-term monitoring in this special feature (Billaud et al. 2021; Garcia et al. 2021; Prowse et al. 2021) further contribute to this discussion. Each reviews a successful approach but poses challenging questions for anyone designing a new monitoring plan resourced by volunteers. What resolution of information is required within the protocol, spatially, or temporally for it to be effective? And, what are the requirements of the decision-makers that will use the data? Perhaps more so, they point to questions about drivers of participation, which is the central focus of the next selection of papers.

2.4 Focusing on the social dimensions of citizen science

The use of the term citizen science suggests that by including citizens or communities, or individuals, in addressing scientific questions that it is by its very nature, a social or a psychological endeavour. The next set of papers focus on the question of what motivates individuals to take part in a citizen science project. This is a critical question that must be addressed if citizen science is to serve the dual purpose of generating trustworthy information at an appropriate spatial and temporal resolution, as well as societal transformation (Bela *et al.*, 2016). Yet, citizen science research has only recently begun to consider what motivates participants to take part and stay engaged (e.g., Geoghegan *et al.*, 2016), and the extent to which citizen science might enhance public understanding of science or engender behaviour change (Bonney *et al.*, 2016).

Winch *et al.* (2021) make a substantial contribution to this area of research firstly, with a systematic review of more than 1000 papers regarding volunteer participation. From a large set of reasons for participating, they find that the most important factor is to design projects that align to the motivations of the participants. More intriguingly they go on to compare and contrast the demographics and motivations of those volunteers who are a part of the UK-based NatureVolunteers community, to projects being advertised by conservation organisations. They do this to identify how such organisations might tailor their projects to appeal more readily to prospective volunteers. The NatureVolunteers community is typically younger, and more interested in physical activity, skills use and habitat restoration than the conventional communities involved in environmental volunteering. Addressing these mismatches may broaden the appeal of conservation projects, including citizen science, and diversify the volunteer base. However, as they and other authors identify, the motivations of volunteers are often diverse and meeting scientific goals are only likely to be a priority for a minority of groups. Efforts to understand the social, as well as the political and contextual nature of participation, may help us better understand both why some groups are well represented in citizen science, and why some groups (and spatial areas including Asia and Latin Americas) still remain underrepresented.

One way to address such mismatches could be to co-design projects with participants to embed their values and opinions (Bela *et al.*, 2016). MacLeod and Scott (2021) report how the NZGBS reporting process has been adapted in response to three surveys that focused on different communication channels. An impressive 15,844 responses were received and as a result, the team were able to diversify and refine their communication strategy to ensure that the participant feedback loop was more complete, and that the results of the NZGBS were better disseminated to a larger, and more diverse community of participants. Ensuring that this happens has been frequently cited as an important factor for long-term engagement in citizen science (Sullivan *et al.*, 2014; Geoghegan *et al.*, 2016). However, despite efforts to embed community values in the co-design of the NZGBS project, the authors acknowledge the complexities of co-production, and the success as largely one of promoting the organizations' goals of good governance rather than making “a real-world difference in engagement”.

While understanding what motivates volunteers to participate in citizen science, one might also wonder what the less tangible or societal benefits there are for conservation are (see, for example Billaud *et al.* 2021). There are many ways to understand what these societal benefits may be – from building social cohesion through addressing environmental problems, or providing active forms of education and involvement in local or global issues. Most of the contributions in the special issue however, focused on the interests related to the role of psychological or individual behaviour change. Santori *et al.* (2021) for example analyse behaviour change in 148 participants in the Australian turtle mapping project TurtleSAT. Unexpectedly, behaviour and attitude changes were not related to observation rate, and were unlikely to be altered by participation. If scalable to other projects, this finding adds important context for the often witnessed long tail of participation i.e. relatively few volunteers generate the majority of the information (e.g. August *et al.*, 2019), and that even minimal participation may have tangible conservation outcomes.

An under-researched area of citizen science, and more widely environmental stewardship, is the emotional bond between a person and a place, termed 'place attachment' (PAT). Haywood *et al.* (2021) delineate a revised three-dimensional model of PAT for citizen science (after Raymond, Brown and Weber, 2010) and apply it to the COASST program. The three dimensions comprise personal, community and natural environment components, with seven major constructs across them. Through the analysis of interviewee responses, Haywood *et al.* (2021) demonstrate that the participants exhibit PAT in all three dimensions and show how the PAT profile of an individual may change over time, with important implications for sustained engagement. These findings also reflect the difficult to measure, but undoubtedly important, motivations for citizen science (Tiago, Gouveia, *et al.*, 2017). However, the authors highlight that more research is needed to investigate whether the unique PAT profile of participants is a function of personal, social, or programmatic variables pre- and post-program participation.

2.5 A role for regulation in citizen science?

In recent years there has been an increasing focus on ethics within citizen science, both in the engagement of volunteers (Resnik, Elliott and Miller, 2015), the contribution and status of social knowledge, and, although perhaps less so, the ethical treatment of wildlife. The latter reflects the setting of the ground around environmental ethics in scientific research, and the potential shaping of citizen science by other regulatory forces, in this case animal welfare policies (e.g. Drinkwater, Robinson and Hart, 2019). This regulatory context in turn is being shaped by an increasing public concern for animal welfare (McMahon *et al.*, 2012) and in 2019 *Citizen Science: Theory and Practice* presented a special issue on ethical issues in citizen science (Rasmussen and Cooper, 2019). In this Special Feature, Palmer *et al.* (2021) ask 'What (is the role) for regulation?' in particular, for those wildlife-focused citizen science projects that disturb animals, such as involving mark-recapture methods or trapping. The authors provide a comprehensive and thoughtful overview of UK legislation pertaining to animal research and citizen science and offer three key discussion points: 1) Take stock of wildlife-focussed citizen science, 2) Assess the state of formal regulations, and 3) Consider the integration of informal regulations. The paper opens out its perspective on the need for citizen science to engage with the political, social and historical regulatory frameworks that shape society as well as science.

3 Future prospects

There have been huge developments in the application of citizen science, and we are now moving beyond its use simply to observe or model where species occur. Citizen science data are now being used to study species demographics, phenology, and biodiversity change to name just a few applications, as well as the behaviour of both participant and subject. All the evidence, of which this Special Feature provides an excellent snapshot, points towards further growth and expansion of the field with goals to engage more people from diverse backgrounds, generate better and more research, expand into new topic areas and to become more democratic; giving the participant a voice.

However, one of the limitations of this special issue is that many of the theoretical and conceptual assumptions about citizen science have not yet been addressed. What does it mean for example to include a diversity of participants in citizen science, if citizen science remains unwilling to be shaped by the real challenges that this may offer the natural sciences? What different roles can citizen science play across the broad temporal and spatial scales that these studies have identified, and to what extent can citizen science play in elevating local or indigenous knowledge in the scientific endeavour, potentially transforming our understanding of what science can do and how it can contribute to solving our contemporary environmental problems?

From this Special Feature, care could be considered a golden thread necessary to maximise the citizen science opportunity. Care extends to every aspect of the journey of a citizen science project from inception to dissemination. The use of citizen science should be carefully considered and not all projects are suitable for public engagement (Pocock *et al.*, 2014). Thereafter, the design of projects must consider many facets including procedures for minimising and mitigating errors, the spatial and temporal resolution of data required, how that data will be handled and how best to communicate the results. These ideas are not new for ecosystem monitoring (Vos, Meelis and Ter Keurs, 2000), but in a field so dependent on volunteer effort like citizen science, they take on extra gravitas. Indeed, the emerging knowledge areas shift the focus away from data acquisition to the complex but fundamental world of the participant. Care here extends to understanding the audience at a granular level, their attachment to place and their expectations. Several papers provide new insights into participant motivations, and others have adapted elements of their projects to increase engagement to good effect. Furthermore, there is potential for the general public to gain a greater understanding of and hence build greater trust in science overall. Indeed, there are many contributions to best practice amongst the collection.

In conclusion, the future of citizen science remains very promising. As an interdisciplinary scientific community we are beginning to understand how it operates and are in the process of formalizing the approach in an ethical way. Challenges remain in each of the themes highlighted here, as well as opportunities for refinement. For ecological research, citizen science can assist from a local to international scale, and can focus not only on species occurrences, but on a wide range of ecosystem components. And, just as technology provides so much support to citizen science, as that technology continues to advance, so too will the capacity of citizen science to deliver.

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