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NATURE NAVIGATOR: A REVIEW OF CITIZEN SCIENCE AS A TOOL FOR MONITORING AND DISCOVERING BIODIVERSITY

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ABSTRACT

Informing individuals on the importance of the natural environment and biodiversity within is the cornerstone to how the natural world can be protected from the growing public who are disconnected from green spaces. In a detached society, citizen science instils appreciation and understanding of the importance of nature, endangered species, and degraded habitats. A comprehensive literature review shows that citizen science has greatly extended the range and area of environmental monitoring and biodiversity discovery due to long-term research that is unrivalled by professional scientific research on both spatial and temporal scales, and at reduced costs. Previous concerns of poor data generated from citizen science with respect to misidentification and bias are outweighed by the extensive sample sizes produced and reviews by trained scientists. The considerable amount of results that citizen science generates would be unobtainable by scientists alone, who would then be incapable of delivering the necessary data required on which policy decisions are made. Citizen science projects not only generate data, but also educate and empower the public to preserve and enhance the natural environment for biodiversity to flourish.

INTRODUCTION

Amidst unfamiliar environmental transitions following anthropogenic (human) activities and climate change, large-scale monitoring, which is the act of recording data on system state variables (Yoccoz et al., 2001), with the intention of deducing spatial or temporal changes of species displacement is universally important for biodiversity conservation (Couvet et al., 2008; Dobson, 2005; Tulloch et al., 2013). The general public is more aware of the issues faced by nature and the environment today compared to before the millennium (Theobald et al., 2015). A notable example is rainforest deforestation and the loss of its species prior to discovery, which is now regarded as common knowledge, leading to the enhanced concern citizens have for protecting nature in their local communities (Novacek, 2008; Theobald et al., 2015). Public awareness has grown about the impact that daily routines have on the environment following increased media attention on environmental degradation and climate change. Policy implementation has also increased public's awareness of the benefits of reducing a wasteful lifestyle (Donnelly et al., 2013; Everett & Priestley, 2015); for example, the 5p plastic bag charge (effective since 2011) leading to a 22% decrease in plastic bag waste along UK coastlines since 2015 (Marine Conservation Society, 2016). Through these initiatives, the broader public has become more involved in monitoring and discovering biodiversity and citizen science has risen in popularity over recent decades (Novacek, 2008).

Citizen Science is the voluntary engagement in scientific research where citizens actively collect and analyse data in collaboration with professional scientists (Follett & Strezov, 2015; Gordienko, 2013). Although the term 'citizen science' is fairly modern - first published in 1994 by Alan Irwin (Irwin et al., 1994) - data collection by volunteers has been utilised in a number of scientific disciplines, from natural history to astronomy, since records began. Some of these records, such as locust outbreaks in China, date back 1,910 years (Dickinson et al., 2010; Follett & Strezov, 2015). However, the majority of records come from the 17th century, which emphasises this long-standing method of monitoring and discovering biodiversity as a serviceable tool for ecology (Dickinson et al., 2010; Donnelly et al., 2013; Novacek, 2008).

The discovery and monitoring of biodiversity are urgently required on an international scale as global temperatures increase alongside human population growth and the degradation of habitats following anthropogenic activities (Cooper et al., 2007; Dickinson et al., 2010; Theobald et al., 2015). However, to gather information quickly enough to assess and prevent biodiversity loss, a shift in focus from site-scale data collection by qualified scientists to regional-scale collection is necessary. For this to be cost effective (Silvertown, 2009), and implemented over a large geographical area and a prolonged period, the utilisation of citizen science is required, and has become a mainstay of research aimed at biodiversity conservation. This allows citizen science to present data to supplement data gathered by professional scientists (Couvet et al., 2008; Dickinson et al., 2010; Donnelly et al., 2013; Silvertown et al., 2013; Theobald et al., 2015; Tulloch et al., 2013).

THE EVOLUTION OF CITIZEN SCIENCE

The use of citizen science increased dramatically following the establishment and improvement of the internet and technology (Dickinson et al., 2010; Silvertown, 2009; Theobald et al., 2015). For example, the development of trackers and widely available Global Positioning Systems (GPS) to monitor species allowed easy and reliable recordings of species distribution by anyone with a smartphone (Dickinson et al., 2010; Donnelly et al., 2013). The internet provides widely available identification guides and the use of apps to take photographs to confirm species presence, to be later verified by professionals (Dickinson et al., 2010; Donnelly et al., 2013; Losey et al., 2013) (Figure 1). One example of this is the Dragon Finder

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Froglife app, which enables the public to record where they have sighted adult reptiles and amphibians, contributing information on species presence and abundance -including their eggs, larvae, and animal calls - as well as submit information on dead or diseased animals (Dragon Finder, 2016) to help track deadly diseases across the UK and forecast possible threats to populations. GPS location marking is also used to assess the environmental conditions associated with organisms' presence and where species hotspots occur in relation to biotic and abiotic factors. This helps assess the dynamics of biodiversity in space and time, apparent with the Mediterranean Jellyrisk app (Dickinson et al., 2010; Marambio et al., 2016).

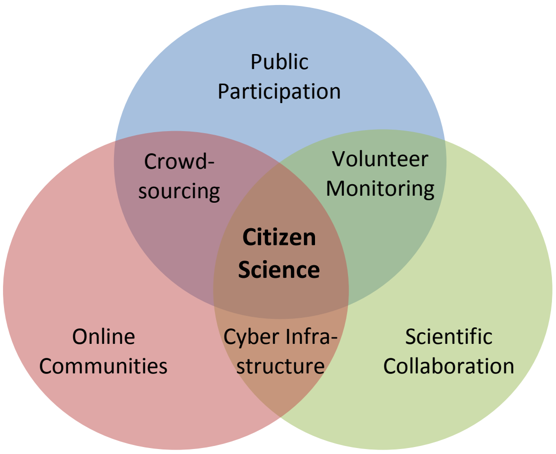

Figure 1: Venn diagram depicting the three basic components of modern citizen science and the importance of the interdisciplinary collaboration between them to generate results. Recreated from Engels, 2015.

Through technology, citizen science is not restricted to field work. Office work is important to detect possible errors, improve methodologies, and directly monitor species. For example, InstantWILD is a citizen science project that identifies camera trap photographs from remote locations in Sri Lanka, Kenya, and Mongolia (Silvertown et al., 2013). These practices ensure accurate data collection and reinforce fieldwork, thus reaching out to a range of individuals with different interests and abilities around the world, particularly those who live in urban areas which are more disconnected from nature.

Following technological advances, citizen science has grown more recently from the research and innovation funding program, European Union Horizon 2020 (EU H2020), which invested markedly into citizen science to generate guides, apps and outreach events (Bonney et al., 2016; Gordienko, 2013). This has driven the development of citizen science from 'scientists using citizens as data collectors' to 'citizens as scientists' (Conrad & Hilchey, 2010), which has allowed both the management and monitoring of biodiversity and in turn facilitated the positive growth of citizen science to better develop projects and gather accurate data (Bonney et al., 2016).

Investment of time, money, and resources has also enabled volunteers to gather reliable data using experienced local coordinators to train new and existing volunteers, such as the project iSpot which involves 90 natural history societies. In its first two years, the project made 66,000 observations and the discovery of two insect species not previously recorded in the UK. Furthermore, nearly 400 species with a conservation listing were classed as either rare on the UK Red List or a Biodiversity Action Plan species, hence threatened by extinction. iSpot has also enabled the discovery of an endemic species in Africa, that was previously believed to be extinct, thanks to volunteers actively supporting species monitoring and discovery (Silvertown et al., 2013; Beubien & Hamann, 2011; Donnelly et al., 2013; Novacek, 2008). These expansions following investment have provided valuable assets to biodiversity conservation, as well as instilled knowledge and appreciation for the environment (Couvet et al., 2008; Dickinson et al., 2010; Earthwatch Institute, 2012; Silvertown et al., 2013).

Despite funding from a number of sources, government cutbacks continue (Conrad and Hilchey, 2011), and there remains the requirement for data collection for the implementation of regulations and conservation of species. This has led to the increased and beneficial use of amateur environmentalists, such as 1500 volunteers across England providing fundamental conservation data on red squirrel (Sciurus vulgaris) sightings (Red Squirrel Survival Trust et al., 2011). Citizen science helps track large-scale environmental change, which is now regarded as highly important in North America and Europe (Couvet et al., 2008; Donnelly et al., 2013) to foresee how changes in the environment can impact biodiversity. This would otherwise be unachievable due to lack of funds (Theobald et al., 2015).

Furthermore, research into some citizen science projects has shown that the amount of time volunteers donate is equivalent to 11-42% of the annual US National Science Foundation budget (~ $0.7-2.5 billion) (Theobald et al., 2015). Yet, citizen science does not merely save money through free labour. Some projects require volunteers to pay fees. This leads to citizen science actively improving knowledge on biodiversity, supporting conservation techniques, and funding more specific scientific research. A notable example is Cornell's Project FeederWatch which raises $3,000,000 annually (Dickinson et al., 2010) to track and measure range movements of 100 winter bird species in order to produce the most accurate population maps and identify long-term trends in bird distribution and abundance, all of which cannot be detected by any other method (Project FeederWatch, 2016).

A range of citizen science projects have flourished over the last decade, such as with Open Air Laboratories (OPAL), spanning various objectives with a focus on both the extensive collection of scientific data and research, as well as public engagement and outreach as a priority to encourage all ages, backgrounds, and abilities to become hands on with nature (Figure 2) (Lakeman-Fraser et al., 2016; Imperial College London, 2016). This allows not only benefits to the monitoring and discovery of the present day natural environment, but also invests in the scientists of the future by inspiring future generations.

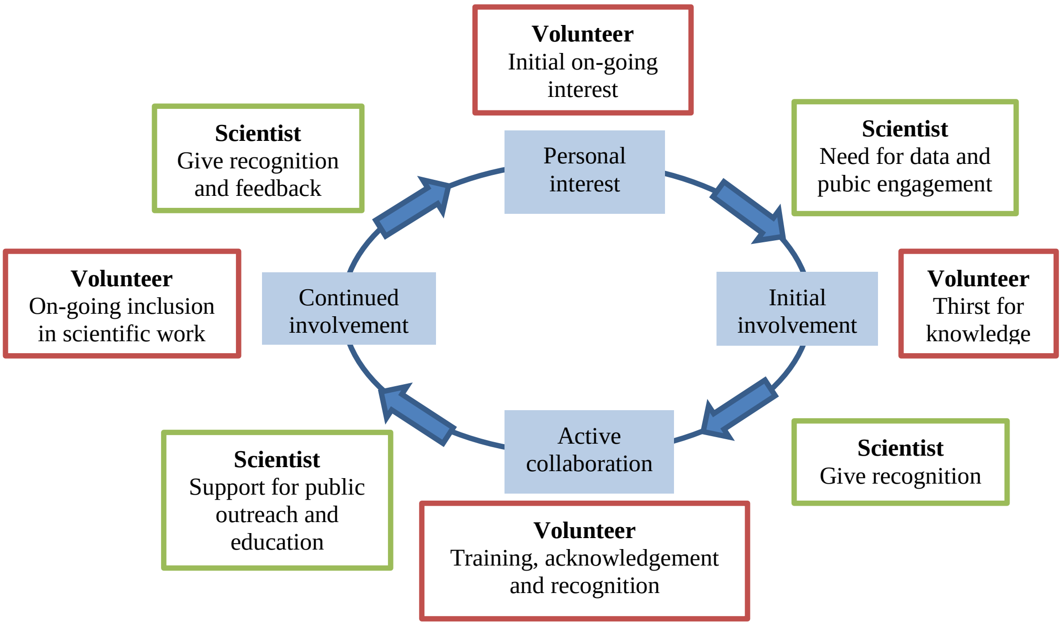

Figure 2: This model represents the continued involvement of volunteers through outreach and public engagement from scientists to ensure an active collaboration continues. Adapted from Engels, 2015.

IS CITIZEN SCIENCE A VALID METHOD OF RESEARCH?

Although the use of citizen science has increased (Pocock et al., 2015), there has been considerable controversy and debate on its use as a feasible form of data collection due to the applicability of the monitoring practices carried out by untrained individuals and flexible design of the data recording (Donnelly et al., 2013). Establishing a citizen science project that is attractive to the general public is important to ensure amateur naturalists have an interest in investigating biodiversity and, therefore, carry out a conscientious effort to gather accurate data (Anderson, 2001; Couvet et al., 2008; Szabo et al., 2012). A review of scientific literature reveals that one major criticism is the approach of attractive and flexible citizen science projects. It has been debated that studies often have undirected 'convenience sampling' recorded along roads or trails and are, therefore, not representative of the population (Anderson, 2001; Szabo et al., 2012). Volunteers who can choose study sites through 'convenience sampling' appear to oversample. For example, birdwatchers at locations for 'good' bird watching are more likely to report rare bird species that are actively sought, compared to more common species, or occasions when no birds are sighted. Hence, this builds a misrepresented dataset and produces misleading conclusions leading to spatial bias.

Nonetheless, the collection of data in convenient areas along roadsides cannot be regarded purely as 'convenience sampling', as roads have a huge impact on wildlife number and distribution related to the disruption of migration pathways and leading to human-wildlife conflicts following collisions (Lee et al., 2006). For example, the citizen science project Road Watch in the Pass engages the public to report their sightings of wildlife along a 44 km highway through Crowsnest Pass in southwestern Alberta, in Canada. This project is instrumental in assessing the effects of road extension and, where wildlife mortality is of concern, for improvement and development of wildlife crossings, and for future highway mitigation and design options (Lee et al., 2006).

Similarly, 'convenience sampling' can produce temporal bias at certain times of the year. Summer months may be over-represented when the weather is favourable, and weekends are often when volunteers have free time to carry out citizen science projects (Donnelly et al., 2013), which can lead to misrepresentation of species presence for migratory bird arrival dates (Sparks et al., 2008). Temporal bias due to volunteers conducting data collection at periods of time when the target species is not present can also lead to dilution of reporting rates (Szabo et al., 2012; Dickinson et al., 2010). Nonetheless, 'convenience sampling' and their associated biases can be tackled by reducing the freedom of choice of where and when the volunteers can record data. OPAL surveys in the UK such as Polli:Nation, a nationwide survey of habitats and pollinators carried out in 260 schools, (Imperial College London, 2016) emphasises that citizen science projects can be designed to be carried out as part of the school curriculum, enabling data collection all year round and during the week, addressing concerns of bias as well as making learning fun with outdoor education and providing a rigorous amount of data.

Although the reduction in the freedom of volunteers may help address bias, it could theoretically reduce the attractiveness of helping in citizen science projects. More regimented methodology may mean volunteers feel overwhelmed and deterred from participating. Work undertaken by National Audubon (USA) on the Christmas Bird Count, initiated in 1900, has generated over 63 million bird counts from tens of thousands of volunteers, emphasising the need to ensure that the monitoring and detection of biodiversity remains an attractive approach to gathering important and extensive biodiversity monitoring data (Silvertown, 2009).

Further concerns of citizens as scientists are species sampling bias which can produce a poor representation of biodiversity of certain taxa. Popular species, such as butterflies, shellfish, and birds are more likely to be monitored compared to beetles: citizen science may neglect some taxa that professional scientists would not ignore. Although citizen science does not build an accurate representation of biodiversity as a whole, it is flexible to be used to monitor an extensive range of taxa and environments (Devictor et al., 2010; Theobald et al., 2015).

While citizen science has temporal and spatial sampling methods which are (at times) regarded as biased, these biases are consistent in professional science, such as observer bias. Nonetheless, due to extensive data sets, sampling error is reduced in citizen science (Dickinson et al., 2010; Theobald et al., 2015). Even though some scientists' reservations of citizen science are that it is too simplistic, producing 'noisy' and biased data (Anderson, 2001; Donnelly et al., 2013; Szabo et al., 2012), in many cases, citizen science is the only way to gather information on species distribution across an extensive geographic range. This is exemplified by Evolution MegaLab, a project that engaged thousands of volunteers across fifteen European countries to explore the evolutionary changes of brown-lipped banded snails (Cepaea nemoralis) driven by climate change (Silvertown et al., 2011). To ensure minimal analysis errors, appropriate and careful planning of the projects, as well as education, guides, and workshops by specialists carrying out research are necessary. Large sample sizes collected from long-term standardised protocols with high temporal and spatial resolution reduces error due to the high statistical power (Devictor et al., 2010; Donnelly et al., 2013). Appropriate statistical tools can then assess data quality and heterogeneity to ensure reliability (Couvert et al., 2008; Devictor et al., 2010; Dickinson et al., 2010; Szabo et al., 2012).

Although citizen science can contribute valuable information, some projections and conclusions on biased data from volunteers can be incorrect (Donnelly et al., 2013; Szabo et al., 2012). There are often uncertainties on the quality of data gathered from non-professionals and questions as to whether volunteers have followed project protocols. A study detecting Hemiptera densities has also shown that trained volunteers were unable to achieve the same level of accuracy as professional biologists at detecting organisms (Dickinson et al., 2010); therefore, citizen science projects may not be appropriate for some fields of ecology that need more qualified individuals to carry out monitoring on organisms that require expertise to identify or locate. Yet, citizen science projects with outreach events such as the BioBlitzes (identifies as many species as possible within 24 hours in a given area) tackle these concerns due to the sheer volume of data that can be generated in a short space of time on a variety of species (Imperial College London, 2016). This can result following celebrity backing to advertise the citizen science projects, as with Joanna Lumley and Sir David Attenborough backing the Big Butterfly Count (Butterfly Conservation, 2010), due to a large number of volunteers who may not otherwise be interested in the environment or engaged with a nature project.

CITIZEN SCIENCE AS A FUTURE INVESTMENT

Volunteered surveys and atlases, which are relatively inexpensive to create, can produce important information to develop conservation and management initiatives. They aid in the identification of areas that may need more extensive and focused ecological research or implementation of conservation regulations (Devictor et al., 2010; Donnelly et al., 2013; Couvet et al., 2008; Szabo et al., 2012). Atlases have previously detected early changes in species populations to help produce more focussed monitoring schemes for scientific experts to later investigate whether climatic factors are involved in species dispersal; identify species of concern; or identify poaching areas (Conrad & Hilchey, 2011). Through the use of citizen science, Szabo et al. (2011) identified between 35 and 50 species of woodland birds in Australia that underwent local extinctions, as well as other rapidly reducing populations, which would not have been identified by site-scale monitoring.

Citizen science can help researchers answer questions about climate change impact on biodiversity, due to the numerous monitoring sites necessary to differentiate change in shifts of species range, reproduction, and migration on a continental and global level (Couvert et al., 2008; Dickinson et al., 2010). Citizen science is now producing results that are progressively regarded as credible science for policy development and are published in peer-reviewed journals (Couvet et al., 2008; Devictor et al., 2010; Donnelly et al., 2013; Silvertown, 2009; Theobald et al., 2015). Increasingly, scientific literature recognises the importance of citizen science for changes in biodiversity distribution associated with the challenges of environmental degradation and climate change (Devictor et al., 2010; Follett & Strezov, 2015; Szabo et al., 2012). Following habitat loss and fragmentation, citizen science has identified that there is a reduction in species occurrence and an increase in abundance variability, particularly for habitat specialists (Devictor et al., 2010; Dickinson et al., 2010). This is illustrated by Thomas and Lennon (1999) who used citizen science data to compare two British bird breeding atlases and discovered a northern range shift for 59 southerly species. This demonstrates that citizen science is crucial to documenting the poleward range shifts for a number of taxa worldwide, and provides some of the strongest evidence of climate change impact on biodiversity (Dickinson et al., 2010).

Additionally, citizen science can formulate new questions from new data on species and habitats, as well as establish where there are problems with invasive species or declining endemic populations that may otherwise be overlooked by smaller-scale professional scientific research (Couvet et al., 2008; Dickinson et al., 2010; Donnelly et al., 2013; Novacek, 2008; Tulloch et al., 2013). This distinction is exemplified in the US Lost Ladybug Project, which led to the identification of rare and invasive species, as well as organisms that are declining in their native habitats (Dickinson et al., 2010; Donnelly et al., 2013; Losey et al., 2013). This project identified the nine-spotted lady beetle (*Coccinella novemnotata*) which originally thrived in North America but which has dramatically declined over two decades due to habitat degradation and invasive species. Citizen science facilitated progress in this research that would otherwise be unattainable. Trained specialists were few in numbers to adequately survey the range of the rare lady beetles, therefore, the utilisation of citizen science enabled this species to be tracked across thousands of locations compared to specialists who were struggling to monitor less than one hundred sites. Although specialists may be more likely to find an organism in any given site, this is balanced by the larger number of observations recorded by citizen scientists (Losey et al., 2013).

As demonstrated, citizen science can directly influence biodiversity conservation following long-term monitoring. The Alberta PlantWatch programme, a notable example of this, illustrates that citizen science tracking the timing of spring plant development over two decades has established that rising spring temperatures have negatively affected common plants (Beaubien and Hamann 2011; Donnelly et al., 2013). This finding was primarily achieved due to long-term participants that developed knowledge over their time collecting data, but was only found to be marginally less variable compared to short-term volunteers (Beaubien & Hamann 2011). Therefore, despite concerns, this exemplifies the reliability of non-scientific volunteers to monitor biodiversity and identify causes of concern in relation to disrupted biodiversity. Furthermore, the implementation of citizen science ensures that environmental problems and the loss of biodiversity remains relevant in the public's eyes and helps to generate local solutions to global issues with education (Theobald et al., 2015).

A CASE STUDY

Securing Biodiversity through Citizen Science

The expansion of citizen science projects not only continue to benefit biodiversity and the natural environment through the monitoring and discovery of new species; citizen science also enables indicator and keystone species to be identified to actively improve biodiversity and enhance wildlife corridors. This is achieved through the creation of 'wild garden' areas in school grounds, private gardens, and community areas. Such initiatives are particularly beneficial alongside school curriculum, as with Polli:Nation. A chalk bank for butterflies was created within the grounds of Dorothy Stringer High School in Brighton, Sussex. A one-hundred metre (2m x 6m) species-poor grassland area was selected for development to create a raised grass bank (following re-profiling). A variety of trees were planted, areas of meadow wildflower seeds sown by school pupils, and the area has been managed through light strimming (Butterfly Conservation, unknown; Polli:Nation, 2015).

The previous species-poor area within the school grounds has now been transformed into a wildlife garden, increasingly proving to be particularly beneficial for butterflies. Common Blue (*Polyommatus icarus*) and Meadow Brown (*Maniola jurtina*) were identified to have colonised the area in 2006 when mowing was first terminated. Small Copper (*Lycaena phlaeas*) and Essex Skipper (*Thymelicus lineola*) in 2008 were identified following the wild garden completion in 2007; and the arrival of Brown Argus (*Aricia agestis*), Gatekeeper (*Pyronia tithonus*), and the smallest UK species of Small Blue (*Cupido minimus*) in 2009 which have also been identified to lay eggs in the area (Butterfly Conservation, unknown; Polli:Nation, 2015). This project proves that citizen science projects can directly improve biodiversity.

The pupils carried out various monitoring of invertebrate and plant surveys over the site, as well as micro-climate measurements in relation to plant growth, and spider and beetle distribution. This citizen science project has led to an increase of 12 to 107 species over two years as well as 311 invertebrate species recorded. The creation of this Local Biodiversity Hotspot through citizen science has allowed data to be collated in surveys to provide to citizen science projects such as the Urban Butterfly project, and also enabled a range of projects involving arts education and environmental education. It inspired local educational institutions to adopt similar approaches (Butterfly Conservation, unknown; Polli:Nation, 2015) leading to the creation of wildlife corridors and enhancing biodiversity on a local and regional level.

CONCLUSION

Citizen science participants have extended the range and area of professional ecologist's achievements and have assisted environmental research at unrivalled spatial and temporal scales. Increasingly, citizen scientists have provided time and effort to make a real difference to research by collecting and analysing data. Citizen scientists are proving to be a valuable scientific body capable of locating, tracking and recording species presence and abundance, despite concerns of bias and trade-offs. The considerable amount of long-term research and results that citizen science generates would be unobtainable by professional scientists alone, who would be incapable of delivering the necessary data required for policy decisions (Couvet et al., 2008; Theobald et al., 2015). Future citizen science projects that are meticulously planned and guided by experts to ensure volunteers are productive and concise to avoid poor data collection, bias, and erroneous conclusions will aid ecology on a national and an international level. The resources citizen science can offer to biodiversity research can instil new perspectives, answer and formulate more questions, strengthen the environmental conservation efforts, and tackle new and on-going challenges the environment faces, as well as empower the next generation. These are not only achieved by covering a larger expanse of area in a shorter time frame with reduced costs, but through the education of the general public. By empowering them with knowledge and understanding, citizen scientists can contribute to conservation frameworks at the local level and affect global outcomes.

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