The Citizen Observatory: Enabling Next Generation Citizen Science

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Abstract

Background: Citizen science offers an attractive paradigm for addressing some of the complex problems facing society. However, translating the paradigm's potential into meaningful action and sustainable impact remains a formidable challenge. Historically, the citizen science landscape was fractured into silos of activities; nonetheless, it has demonstrably delivered credible results. An innovative concept of the Citizen Observatory offers a tractable means of mitigating many of the recurring issues that historically afflicted citizen science initiatives, thus empowering a new generation of citizen scientists. Citizen Observatories may be regarded as open, standardised software platforms for community-based monitoring of any phenomenon of interest. **Objectives:** This paper seeks to validate a Citizen Observatory in a traditional citizen science context, that of butterfly recording. **Methods/Approach:** A case study was undertaken in a UNESCO-designated Biosphere Reserve. **Results:** A community of citizen scientists successfully recorded various observations concerning butterflies, their feeding behaviours, and their habitat. The resultant dataset was made available to the local government environmental agency. **Conclusions:** The Citizen Observatory model offers a realistic basis for enabling more sustainable participatory science activities. Such developments have implications for non-government organisations, businesses, and local governments.

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Introduction: Why Citizen Science Matters

Contrary to public perception, many well-known scientists, such as Darwin and Franklin, undertook their research personally; as pointed out by Silvertown (2009), the age of professional science is a relatively recent development. Though the recent surge of interest in Citizen Science (CitSci) and similar crowdsourced methodologies is remarkable at first sight, there is a long tradition of public engagement in scientific endeavors – the annual Christmas day bird count organised by the National Audubon Society in North America and running for over 100 years is one such exemplar. Reasons attributed to this growth in interest include an increased awareness of environmental issues, recognition of the potential for CitSci by governments and scientists, coupled with a desire to influence public policy. Many benefits accrue from public participation in science – increased scientific literacy, social capital, and environmental democracy amongst others; one of the most pertinent motivations for such participation is the urgent necessity to confront the paradoxical post-truth attitudes that currently prevail. Establishing *Communities of Scientific Practice* that involve multiple stakeholders from different disciplines but with synergistic objectives offers one approach to countering such attitudes (Bouma, 2018). Recent developments in Information & Communication Technologies (ICT) have proved transformative, representing a paradigm shift in how many CitSci programs are implemented.

Transitioning from traditional paper-based CitSci to one based on mobile technologies is ongoing; nonetheless, the smartphone is easily the platform of choice in CitSci today. However, the net result is one of a fragmented landscape. Apps for all kinds of CitSci increase, but an agreed, standardized vision of how best to support the CitSci community is lacking. This paper considers one model of a shared ICT infrastructure and methodology of CitSci, that of the Citizen Observatory (CO).

At the launch of the smartphone era – the iPhone was launched in 2007, the paper was the default medium for data collection and publication in CitSci. The potential of technology was acknowledged; nonetheless, the twin challenges of accessibility and keeping up with rapid technological change were identified, as was a need for well-designed and standardized methods of data collection (Silvertown, 2009). Previously, the need for public dialogue and engagement with science was recognised (Irwin, 2001). Motivated by these observations, this paper seeks to define what may be termed next generation CitSci. The CO methodology is considered with this context and validated through a small case study in a UNESCO biosphere reserve.

This paper is structured as follows. Limitations of conventional CitSci are first considered. How the CO methodology remedies some fundamental limitations is then outlined. A report on the design and implementation experiences of a prototypical CO platform is immediately presented. A reflection on the entire experience is then provided, after which the paper is concluded.

Literature Review & Problem Definition

It is in the realisation of the potential of CitSci that its most significant impact will be manifested. At the same time, the benefits of empowering local communities are acknowledged; it is ultimately in tackling "wicked problems" in a global context (Ellwood et al., 2017) that is of most relevance. According to Theobald et al. (2015), the growth of CitSci "represents unprecedented opportunity and potential to contend with global changes with local observers". Despite phenomenal progress in remote sensing technologies, CitSci remains a critical and tractable approach for the widespread in-situ monitoring necessary to cover the planet's biosphere at the necessary spatial and temporal resolutions (Pereira et al., 2010).

The taxonomic bias remains pervasive in the research literature; to remedy this problem, it has been suggested that scientists should develop societal initiatives based on CitSci (see, e.g., Troudet et al., 2017). As the biology, conservation, and ecology domain represent the predominant focus of endeavors by the CitSci community (Kullenberg et al., 2016), a significant body of expertise could be leveraged. The provision of CitSci data may ease multiple competing hypothesis testing, for example, an issue identified as problematic in ecology and evolutionary biology (Betini et al., 2017). Longitudinal CitSci initiatives may also provide a basis for mitigating Shifting Baseline Syndrome (Soga et al., 2018).

Monitoring progress towards achieving the UN Sustainable Development Goals (SDGs) poses significant challenges; crowdsourcing, CitSci is one dimension, has been proposed as a critical element for achieving the SDGs (Flückiger et al., 2016). Though the potential of CitSci in ecological and environmental monitoring is significant (McKinley et al., 2017), CitSci is broadly under-utilised, thus limiting its potential to deliver meaningful impact (Barrie et al., 2019; Hicks et al., 2019; Theobald et al., 2015).

Concerns & Limitations

A disruptive paradigm, CitSci must at once seek both to challenge and complement conventional norms in scientific and policy decision-making. If CitSci is to succeed, certain obstacles, perceptions, and even prejudices must be confronted. Many issues hinder the uptake of CitSci; for this discussion, the effective resolution of four key issues is a prerequisite for increasing the impact of CitSci.

Data Quality

Issues relating to provenance and integrity are recurring themes when the use of CitSci-derived data is discussed. It must be emphasised that within CitSci contexts, data may be of a category depending on the use case - qualitative, quantitative, economic, environmental, and so forth. Transparency, conflicts of interest, and lack of clarity around the methodology for data collection generate legitimate concerns about data collected by amateur scientists (see, e.g. Nature, 2015); in fairness, it should be noted that such issues are also frequently present in the professional community. Indeed, the implicit assumption that data collected by professional scientists represents the baseline through which CitSci data can be reliably compared has been challenged (Specht et al., 2018). In principle, it is reasonable to expect the adoption of protocols and quality control measures such as those that would exist in conventional scientific practice; in reality, the nature of CitSci programs makes quality assurance a problematic proposition to effectively implement consistently.

The debate concerning the credibility of data gathered by the CitSci community is ongoing; research presents contradictory findings. Van der Velde et al. (2017) demonstrated that CitSci could broaden coverage and increase sampling frequency but without compromising data. In contrast, MacKenzie et al. (2017) observed disparity in volunteers' self-assessed and actual species (plant) identification skills, and consequently, their project is now almost entirely reliant on observations from trained staff.

In the case of species identification, a popular task in many CitSci projects, conventional wisdom suggests that citizen scientists are generally competent at identifying higher-order taxonomic categories whilst identifying rarer species is best left to professional taxonomists. Yet, as Chandler et al. (2017a) pointed out, this generalisation does not always hold as an experienced layperson may be more familiar with specific taxa or what is most likely in certain locations. The smartphone has proved transformative for species identification; by searching a local database of high-quality images, species can be quickly identified and subsequently recorded. A photograph offers supporting evidence and allows for subsequent independent validation. Such validation is vital for the sustainability of project outputs as, ultimately, the consequences of unverified data and poor quality-control may lead to inappropriate conservation and policy measures (Vantieghem et al., 2017).

Lack of Support for Open Science

Open Science (Nosek et al., 2015) is an ongoing initiative that seeks to make the results of scientific endeavours accessible to all; open data is one critical dimension that envisages data being made available without copyright or any other restrictions. While it is often assumed that data produced by the CitSci community are freely available, this is often not the case as the community can face hurdles in making their data open and freely available (Fox et al., 2019; Pearce-Higgins et al., 2018). A study by Groom et al. (2017) of datasets in the Global Biodiversity Information Facility (GBIF) (https://www.gbif.org/) indicated that datasets from the volunteer community are amongst the most restrictive in the way they could be used. In many cases, datasets lacked licensing information; as the authors pointed out, this is not a proxy for open data and thus compromised the potential of the data in policy and commercial use cases. Several reasons underpin this situation.

In many cases, an intermediate organisation has custodianship of the data; though making the data publicly available may align with the organization's mission, practical issues such as leveraging funding and commodification may act against this. Another explanation may be found in the different expectations of scientists and citizens. Data are primary for scientists; for citizens, education is often foremost (Jollymore et al., 2017). By their nature, CitSci projects to date have in the main tended to be short-term rather than longitudinal in scope; thus, the need to deliver a project legacy through ensuring the sustainability of its outputs is not always a strategic objective.

Ad-hoc approach to Citizen Science

Outside of well-known CitSci initiatives, the predominant approaches are generally ad-hoc in nature. This is both a strength and a weakness, a strength in that such approaches promote innovation and demonstrate agility, and a weakness as CitSci initiatives tend to be local and temporally focused. Indeed, the diversity of CitSci projects suggests that there can be no single model that will guarantee a successful outcome; nonetheless, successful initiatives tend to share common traits (Cardoso et al., 2017). In the case of Invasive Alien Species (IAS), it has been recommended that initiatives should seek to "build on and strengthen existing user communities but at the same time, coordinate and aggregate validated CitSci data on IAS to open repositories" (Cardoso et al., 2017). The lack of a coordinated approach hinders the potential and impact of CitSci; how best to deliver effective coordination in practice remains an open and urgent question. One approach is that of a city center that "would create, organise and synthesise centralized repositories of volunteer collected data" and serve as centers for excellence in CitSci (Bonney et al., 2014).

Global Variation of CitSci Adoption

Though the potential of CitSci is widely acknowledged, in practice, there are vast differences in the ability of projects to deliver impact (Newman et al., 2017). A lack of local capacity has been identified as the most significant obstacle to adequate monitoring (Schmeller et al., 2017). This situation leads to an uncomfortable observation that successful CitSci initiatives tend to be linked to well-funded organisations and are mostly restricted to Europe and minority world countries (Chandler et al., 2017b). Therefore, low-income countries of the majority world are at a disadvantage. This situation contributes to significant gaps in datasets from various biodiversity-rich regions; such regions are often remote, underpopulated, and have less network coverage and infrastructure. Remedying this imbalance is essential. CitSci initiatives in majority-world countries exist; for example, Liebenberg et al. (2017) consider interface design for non-literate trackers using the well-known CyberTracker Platform. Nonetheless, building CitSci capacity in the majority world remains imperative.

Conventional Approaches to Citizen Sciences

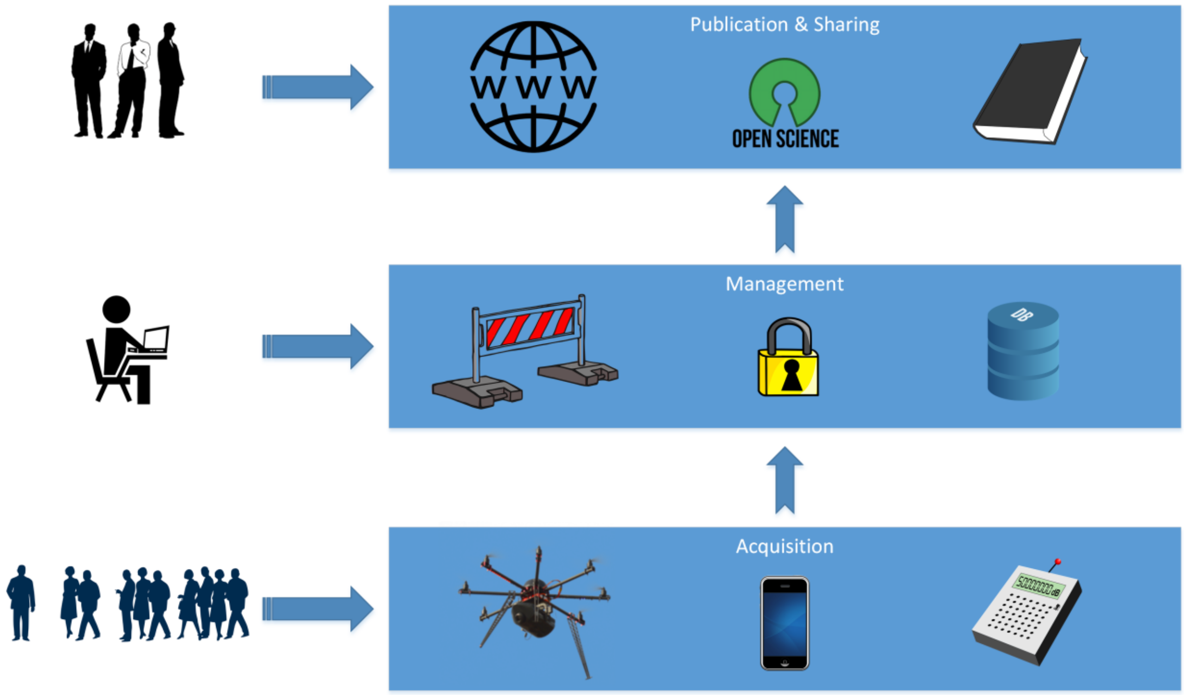
Though some CitSci initiatives are bespoke, many seek to leverage various tools, mainly ICT-based, that are publicly available. To highlight one such tool, iNaturalist (https://www.inaturalist.org/) is archetypical for biodiversity monitoring; it consists of an App for capturing observations in the field, facilitates the sharing of data via GBIF, and is supported by an active social network for discussing observations and developments. As an example, the iNaturalist model has been recommended as a suitable tool for assessing the status of palms, a plant with a high risk of extinction (Gardiner et al., 2016). Zooniverse (https://www.zooniverse.org), a virtual CitSci platform, supports the online classification of data. The Citizen Science Toolkit (http://www.birds.cornell.edu/citscitoolkit/toolkit) offers a compilation of resources to help initiate and manage new projects; CitSci.org (http://www.citsci.org) offers a suite of tools that help with all aspects of the design, implementation, and management of CitSci projects. SciStarter (https://scistarter.com/) is a portal of CitSci projects that is searchable by location and interest; this allows members of the public to sign up for projects.

Nonetheless, despite the significant adoption of ICT in the last decade, the problems alluded to above continue to afflict CitSci. Addressing these problems in their totality demands a multi-actor transdisciplinary approach and the development of an open, sustainable model to empower the next generation of citizen scientists.

Methodology - The Citizen Observatory

A Citizen Observatory (CO) (Figure 1) may be described as "the citizens' observations and understanding of environmentally related issues and, in particular, as reporting and commenting on them within a dedicated ICT platform" (Liu et al., 2014). The rationale for COs is to raise environmental awareness whilst promoting and enabling communication between communities, scientists, and decision-makers. Contributors are protected from data management's intricacies, allowing them to focus on what is of interest – data collection, analysis, and collaboration. A CO encapsulates a CitSci approach but with one crucial difference; the CO seeks to enable the collection, management, and publishing of data using a *verifiable scientific methodology* but without the expectation of necessarily contributing to science per se. Instead, the emphasis on COs is often influencing policy definition; see Grainger (2017) for a detailed treatment of the CO. It must be emphasised that a CO does not seek to replace conventional CitSci platforms; rather, it seeks to complement their strengths but to remedy the problems identified earlier. Thus, a CitSci initiative could conceivably incorporate a CO for data collection, management, and publication; online platforms could then be harnessed for participatory data analysis if required. Four key issues that the CO seeks to address are now described.

Figure 1
A Model of a Citizen Observatory



Source: Author's illustration

Data Quality
Projects within COs are, by definition, collaborative and co-creative; in this way, the data needs of various stakeholders – science, policy, and so forth, maybe holistically addressed. As the CO would generally provide a suite of shared services for data management, the focus is directed on the data collection exercise as activities undertaken during collection, as well as the experience of participants, represent the primary determinants of data quality. A careful balancing of data contributors and data consumers is fundamental to the design of monitoring networks, such as envisaged by COs. It is of primary importance that data within the CO corpus is not compromised by the admittance of low quality or rogue data. Training of volunteers is one popular approach to mitigating this concern in conventional CitSci programs; this may be augmented with automated approaches to outlier identification in COs.

Open Data
Making data open requires planning, effort, and understanding the many legal issues relating to data protection. In Europe, the General Data Protection Regulation (GDPR) harmonizes data protection and privacy across the EU, strengthening individuals' rights and awareness about these rights whilst increasing the obligations on organisations, including Non-Governmental Organisations (NGOs). Secondly, an understanding of semantics and metadata is necessary to ensure that data is meaningful to potential end-users. A third issue relates to standardised formats and data licenses. It is unrealistic to expect a deep understanding of these three issues on the part of the general public; thus, a challenge for a CO is in helping communities understand the importance of standardisation of format, license, metadata, and the rules that govern data protection.

The uniqueness of each project makes data publishing a formidable challenge. In the case of ecology data, GBIF and Darwin Core are obvious candidates when publishing datasets in standardised open formats; WaterML might be the preference in a water-monitoring project. Several initiatives seeking to harmonise data and metadata management in the CitSci domain are ongoing, for example, the Citizen Science Association (https://www.citizenscience.org/). The degree to which COs enable citizen scientists to address the omnipresent issues of standards compliance and licensing of data via, for example, Creative Commons licenses will probably be the critical determinants of whether COs will be adopted and utilised going forward.

Coordination
COs offer a focal point making coordination and orchestration of projects possible. Projects may be clustered around several dimensions, for example, a single geographic area like a river catchment; alternatively, they may focus on monitoring a particular phenomenon, for example, the presence of frogs, across a wide geographic space over extended periods, thus supporting longitudinal studies. COs are an apt solution where there is a requirement for a cluster of diverse projects that are best delivered via a common ICT infrastructure.

Inclusivity
COs may be deployed and configured quickly to deliver agile citizen-enabled data collection solutions. There is a need for WWW and wireless connectivity, but this need not be 24/7. Infrastructure limitations can be circumvented with careful planning; mobile broadband networks are only available to 67% of the global rural population (ITU, 2016), but other issues, including literacy, will invariably arise. Integration with established networks such as GEOBON - Group on Earth Observations Biodiversity Observation Network (https://geobon.org/) or DataONE - Data Observation Network for Earth (https://www.dataone.org/) offers options for leveraging state-of-the-art facilities for sharing data.

Role of a Citizens' Observatory
COs do not seek to replace existing platforms; rather, they seek to complement and augment them. Furthermore, COs do not proscribe the adoption of specific technologies; for example, COs do not advocate Cloud computing as distinct from any other technical solution. Design choices are the prerogatives of those working with domain experts who understand the intricates of the domain, the pragmatic constraints in which the CO must operate, and the profile of those who will both produce and consume the data. COs demand that all data be augmented with an appropriate suite of metadata such that its genesis and provenance be determinable, allowing for its publication for subsequent consumption through compliance with appropriate international standards.

To illustrate one interpretation of how a CO might operate in practice, a case study is now presented that reports on the authors' initial experiences of collaborating with a local community to design and deploy a CO.

Results - Prototyping a Citizen Observatory in a UNESCO Biosphere
The World Network of Biosphere Reserves (WNBR) comprises 714 biosphere reserves in 129 countries. Biosphere designation, the prerogative of UNESCO, demands active community engagement in the management of the biosphere, envisaging such

engagement as a prerequisite for sustainability; thus, biosphere communities represent prospective highly-motivated citizen scientist groups and potential end-users for COs. Remote location, sparse communities, and ecological diversity pose many challenges but make biospheres ideal locations for prototyping COs.

To demonstrate the viability of the CO concept, a pilot case study was designed and undertaken in Penparcau, a suburb of Aberystwyth, within the Dyfi biosphere in mid-Wales. The objective was to enable local communities to influence Land Management Plans (LMPs); such plans significantly affect local wildlife conservation. Following consultation with stakeholders that included the Welsh Government, the West Wales Biodiversity Information Centre (WWBIC), the Conservation Officer from Ceredigion County Council (CCC), a local NGO, and the Penparcau Community Forum, citizens were tasked with recording a suite of observations of butterfly and larval food plants. Butterflies are good environmental indicators with knowledge of their distribution and abundance helping to inform local land management.

Traditionally, butterflies are surveyed by a strict walking of a transect; however, without adequate training, this type of surveying risks alienating potential participants, reducing participation, and, therefore, the associated volume of data collected. Surveys of butterfly populations using CitSci have been documented in the literature (see, e.g. Lewandowski et al., 2017; Schultz et al., 2017). In terms of Apps, iRecord Butterflies (https://butterfly-conservation.org/8803/irecord-butterflies.html) is an exemplar and the preferred App of the Butterfly Conservation - an organisation that runs three of the world's largest butterfly and moth recording schemes.

An analysis of iRecord, and other Apps designed for ecological monitoring, indicated that none enabled the collection of that particular dataset on butterflies and their larval food plants necessary to influence local land planning in the biosphere. This situation of pre-existing Apps not quite meeting the needs of local operating conditions, it is suspected, is an unfortunate but recurring theme in many CitSci initiatives; maximizing the use of pre-existing, often open-source, solutions are desirable, but structures are needed that discover suitable Apps seamless and transparent. Furthermore, Apps should be available under appropriate open licensing conditions such that they can be modified in response to local data requirements. A future strategic objective for COs must be the identification of pragmatic solutions to this problem.

An initial version of the *Penparcau Butterfly Survey App* was created using services provided by the COBWEB CO platform (Higgins et al., 2018). This App was iteratively developed in response to feedback and a deeper understanding of local requirements. The first iteration focused on recording larval food plants. Table 1 outlines the tasks and questions that the observer was asked to respond to. The subsequent iteration of the App-enabled the opportunistic recording of butterflies that, invariably, would be found near such food plants; see Table 2 for the additional questions asked in this release. A final release of the App invited the completion of some questions relating to the habitat itself; Table 3 outlines these questions. The survey was completed by members of the local Penparcau Community Forum (https://penparcau.cymru/) over three months, in cooperation with, and under the guidance of, a local ecologist working with the West Wales Biodiversity Information Centre (WWBIC). She subsequently logged the resultant dataset with the Local Environmental Records Centre (LERC).

Table 1
The first element of the "Penparcau Butterfly Survey" focused on larval plants

Task	Question	Modalities	Comment
1	What plant have you seen?	○ Grasses ○ Nettle ○ Ivy ○ Holly ○ Garlic Mustard /Hedge Garlic ○ Bird's Foot trefoil ○ Ladys Smock ○ Thistle ○ Burdock ○ Clover ○ Alder buckthorn ○ Dock or Sorrel ○ Other	If "Grasses", the option to complete T1.1, that is, classify the type of grass, is then requested. If "Other", the option of specifying the plant is given via T1.3. For any option selected, apart from "Grasses", completion of T1.2 is requested.
1.1	What type of grass?	○ Mown/grazed ○ Short ○ Very green grass ○ Rough ○ Maybe grazed ○ Tousled ○ Overgrown ○ Lots of wildflowers ○ Meadow	
1.2	Does the plant have any flowers?	○ A few (1-10) ○ Some (10-15) ○ Lots (> 50)	
1.3	Do you know what plant it is?		If known, the name of the plant is specified via the soft keyboard on the mobile device.
2	How confident are you that it is thus plant	○ Confident ○ Ok ○ Not confident	For all plants identified, the option of specifying a confidence indicator is given.
3	Take a photo of the plant you have seen.		A photo of the plant will allow subsequent independent verification.
4	How big an area does the plant cover?	○ Less than 1m² (Bath towel) ○ Between 1 to 5 m² (Picnic blanket size) ○ More than 5 m² (larger than picnic blanket)	An estimate of plant abundance is requested.
5	Was there a butterfly within 5 meters of the plant?		The presence of a butterfly will trigger a further series of tasks.

Source: Author's work

Table 2
Once a larval plant has been recorded, augmenting the observation with one on butterflies, should one be in the vicinity of the plant, is then available.

Task	Question	Modalities	Explanation
1	Can you take a photo of the butterfly?		It will be automatically timestamped and geotagged on successfully taking a photograph, and the subsequent tasks will be completed.
2	What kind of butterfly did you see?	○ Brimstone ○ Clouded Yellow ○ Comma ○ Common Blue ○ Gatekeeper ○ Green-veined White ○ Meadow Brown ○ Orange Tip ○ Painted lady ○ Peacock ○ Red Admiral ○ Ringlet ○ Small Tortoiseshell ○ Small White ○ Specked Wood ○ Small Copper ○ Wall ○ Large Skipper ○ Other Butterfly	If "other butterfly" is selected, T2.1 is triggered.
2.1	Do you know what kind of butterfly it is?		If known, the option of specifying it via a textbox/soft keyboard is offered.
2.2	How confident are you that it was this kind of butterfly?	○ Confident ○ OK ○ Not Confident	A self-assessed metric of confidence in the observation, noting that the photo may be subsequently used for independent validation.
3	What was the butterfly doing?	○ Resting ○ Feeding ○ Flying ○ Other	A standard typology of possible behaviors is offered for selection.

Source: Author's work

Table 3
The option of answering some questions on the prevailing habitat is then available.

Task	Question	Modalities	Explanation
1	Would you like to record more information that would be useful?	○ Yes ○ No	Noting that time may be at a premium for the observer, the option of recording some additional information is offered. If "No", data is saved, and the App terminates.
2	How would you describe the habitat the plant was found in?	○ Woodland ○ Paths and Hedgerows ○ Farmland ○ Gorse ○ Grassland ○ Water ○ Urban	
2.1	Type of woodland?	○ High (Flowers, shrubs, etc.) ○ Medium (Bracken) ○ Low (Bare earth)	
2.2	Type of Farming?	○ Crops ○ Grazing for animals ○ Grassland	
2.3	Type of Grassland	○ Mown/Grazed ○ Rough ○ Overgrown (meadow/wildflowers)	

Source: Author's work

Discussion and Conclusion

Relations to previous findings

A key motivation for COs is to remedy the fragmentation of CitSci initiatives and reduce the need for ad-hoc developments. Environmental monitoring is the predominant domain of CitSci endeavors, as testified by a courtesy examination of the research literature. Though only a point example in butterfly monitoring, it can be reasonably conjectured that many CitSci campaigns in the broad environment domain could be recast as citizen observatory initiatives, with all the potential benefits that would unfold.

Learning is synonymous with CitSci; likewise, the need for volunteer training is a recurring theme in the literature. There can be little doubt that in migrating to a CO platform, the volunteer population's technological literacy would need to exceed a certain threshold. What is less considered is the need for education and training at all levels, including the sponsorship or organisational levels. In treating citizen scientists as mere data collectors, a disservice is occurring, and an opportunity is being missed. To maximize their work's impact, citizen scientists need to understand an eclectic range of issues ranging from ethics to data licensing. Likewise, those initiating campaigns need to ensure that the participants are well-schooled in the project's objectives and that they see data collection as just one essential step in a complete process.

Concluding Remarks

COs offer a model through which a new generation of CitSci and community-based monitoring initiatives may be enabled in communities worldwide. The vision for COs goes well beyond addressing the limitations of conventional CitSci approaches. The overall goal must be to deliver one cornerstone for sustainable global monitoring initiatives; the success of such initiatives depends on developing coherent, standardised, and decision-relevant systems (Rosenstock et al., 2017). Such a development has a particular resonance for biodiversity and conservation, given the importance of CitSci in these activities (see e.g. Isaac et al., 2014), and maximizes the use cases for CitSci by communities, scientists, and policymakers. Experience from the Dyfi Biosphere suggests that the CO model is valid and that the technologies are in place for its practical realization. Nonetheless, the human element, including training and usability dimensions, and the role of the CO within the context of pre-existing CitSci initiatives, merit further research.

Looking forward: a more strategic contribution may be manifested both in enabling more longitudinal studies by the CitSci community and enabling initiatives in geographical regions that, until now, have not had the resources to engage in community-enabled participatory monitoring programs. Furthermore, COs offer government agencies opportunities to facilitate community inclusion in policy definition as well as opening commercial opportunities through the development of disruptive and innovative business models.

Research limitations and future research directions

This study is small-scale and exploratory. It demonstrates proof of concept; however, citizen involvement outside of data collection was limited. Moreover, an automated protocol for publishing and sharing data is needed. Such developments demand the involvement of those organisations charged with repository maintenance. In the medium term, seamless publication of citizen-derived data is unlikely; however, publishing data compliant to an internal standard is tractable.

In the longer term, a key challenge is to ensure that the CO model continues to evolve. Thus, as has been acknowledged elsewhere, there is a need for open, user-friendly platforms that are reusable and reconfigurable (De Wilde et al., 2020). While the focus to date has been on the citizen and the scientist, other stakeholders must be considered. Such stakeholders include the local communities and local government agencies. Globally, the potential of COs as enablers of sustainability and local democracy merits detailed investigation.

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