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Extreme citizen science: Lessons learned from initiatives around the globe

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Abstract
The participation of communities living in high conservation value areas is increasingly valued in conservation science and practice, potentially producing multiple positive impacts on both biodiversity and local people. Here, we discuss important steps for implementing a successful extreme citizen science project, based on four case studies from conservation projects with Pantaneiro fishers living in Brazilian Pantanal wetland, Baka hunter-gatherers and Fang farmers in lowland wet forest in Cameroon, Maasai pastoralists in Kenya, and Ju|'hoansi rangers living in the semiarid deserts of Namibia. We highlight the need for a high level of trust between the target communities and project developers, communities' right to choose the data they will be collecting, and researchers' openness to include new tools that were not initially planned. By following these steps, conservation scientists can effectively create bottom-up collaborations with those living on the frontlines of conservation through community-led extreme citizen science.

KEYWORDS
Brazil, Cameroon, community-based conservation, extreme citizen science, Kenya, Namibia, Sapeli

1 | INTRODUCTION

Citizen science is increasingly recognized and valued in community-led conservation initiatives (Pimm et al., 2015). It is seen as a way to support researchers to better explore different dimensions of indigenous peoples and local communities' well-being, customary governance, ecological knowledge, natural resource use, and other types of interaction between people and their environment in scientific and robust ways (McKinley et al., 2017), and at scales and resolutions previously unseen (Kobori et al., 2016). Today, citizen science applications cover a wide range of contexts, including the study of marine and coastal systems (Cigliano et al., 2015), phenological events (Amano et al., 2010), entomology (Brereton et al., 2013), and mammals (Parsons et al., 2018), to mention but a few. As internet and smartphone use becomes more ubiquitous, so too is the development and use of mapping and data collection applications able to support digitally enabled citizen science initiatives in rural and remote regions (Kar et al., 2016; Pejovic & Skarlatidou, 2020).

Citizen science activities and projects may take different forms and shapes. Haklay (2013) describes a four-

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level hierarchy. In the first level (crowdsourcing), people participate as sensors—not knowing how the data contributes to addressing scientific questions. In the second level (distributed intelligence), participants carry out cognitive tasks for data interpretation. In the third level (participatory science), participants contribute to the problem definition and carry out data collection tasks. Finally, in the fourth level (extreme citizen science [ECS]), participants are deeply involved in the research process through co-creation which supports collaboratively identifying the problem, forming the research questions, designing the tools and methods to support data collection, and collecting and analyzing the data.

2 | EXTREME CITIZEN SCIENCE

ECS initiatives draw knowledge from Participatory Rural Appraisal, led by the principle that when marginalized and vulnerable people are enabled and empowered to conduct and present analyses of their realities, projects are more appropriate and more effective in achieving objectives (Chambers, 1981). In this process, ECS initiatives take into account the local needs, practices, and cultures into their design and implementation (Skarlatidou & Haklay, 2021). A set of methods are now in place to support the design and implementation of ECS initiatives which include: (1) free prior and informed consent (FPIC) process, which aims to discuss openly and honestly the potential positive and negative consequences of the initiative; (2) establishment of a community protocol, which formalizes aspects of local management and initiative structure collectively agreed upon by the participating community in an iterative process that continues throughout the lifetime of the intervention; and (3) participatory design and evaluation of local technological interventions (Moustard et al., 2021). Central to ECS projects are a data collection tool which facilitates the engagement of indigenous peoples and local communities with external scientists. It is often important that these tools are designed to be user-friendly regardless of participants' textual or digital literacy (Pejovic & Skarlatidou, 2020).

The design and implementation of ECS with local and indigenous communities in some of the most remote areas of our planet comes with a set of challenges. Although the adoption of general citizen science initiatives is gaining momentum at a global scale (Mills et al., 2019), they are not necessarily immune from reinforcing prejudices against local people (Reid & Sieber, 2020). Therefore, it is fundamental to carefully consider the complex mix of methods and localized knowledge needed to deeply engage local communities in ECS projects equitably and successfully. If conducted in inappropriate ways, ECS can further marginalize indigenous and local communities (Conquest, 2013). Below we present four case studies in which ECS was implemented, discussing the possible challenges one may face (Table 1).

3 | CASE STUDIES

3.1 | Brazil, Pantanal fisheries

This initiative was implemented in the buffer zone of a network of strictly protected areas within the Pantanal wetland, Brazil, in which community access is not allowed. The protected areas were set aside between the 1980s and 1990s and have led to the physical and economic displacement of hundreds of Pantaneiro fisher families (Chiaravalloti, 2019), with managers accusing the local families of overfishing and trespassing the boundaries of the protected areas (Franco et al., 2013). The ECS initiative aimed to give Pantaneiro communities the means to map their traditional territory, utilizing such data to solve local disputes across the region in partnership with the Brazilian NGO Ecoa—Ecologia e Ação and University College London.

The project was implemented in 2014 using the software Sapelli Collector. Although the institution that led the programme had been working with local people for over 20 years, the team of researchers who were leading the project took 4 months to establish with local communities what natural resources they were going to monitor. Local people decided to focus their mapping on fishing locations. Four families were involved in the ECS data collection. Ethnography research on land tenure and identity was held alongside the ECS project by a PhD student from University College London.

Lack of electricity and internet connection obliged the team of researchers to manually download the data directly from the phones and subsequently create the maps using GIS software.

After 2 years of data collection, the project brought an important positive impact. A scientific report based on the data collected using ECS was addressed to the Brazilian Federal Minister of Prosecution and, in 2019, led to the creation of a 5000 km^2 community reserve in the region, giving local people' tenure rights over their traditional fishing territory (Chiaravalloti, 2021).

3.2 | Kenya, Maasai Pastoralists

The initiative was implemented in the buffer zone of the Maasai Mara National Reserve (Sekenani Valley) within

TABLE 1 Main features of the citizen science case studies analyzed in the four different contexts

Guiding questions	Brazil	Cameroon	Kenya	Namibia
Year the initiative has started	2014	2016	2019	2018
Previous experience working with local people	Yes, >20 years	Yes, >7 years	Yes, >2 years	Yes, >2 year
Time spent to co-design and implement data collection tools	~8 months	~3.5 months	2 weeks	~15 months
How many students were involved in the project	1 PhD student and 1 practitioner	1 PhD student	1 postdoc, 1 PhD student, 2 MSc students	2 PhD students, 2 visiting PhD students
Ethnography was part of the implementation?	Yes	No	No	Yes
Any other method was used to collect the information?	Yes, printed maps to collect more data	No	Yes, names of plant species listed on paper	Yes, paper records
How many decisions/ branches in the decision tree?	4–5	8–14	6 and 8	9
How many families/ people collected data?	4 families	Average 5 people per community	Around 10 Maasai warriors (10 families)	14 rangers
Were people paid to collect data?	No	Yes, depending on the specific data point	No	No
How data were downloaded from the phones?	Collected direct from the phones	Uploaded automatically to an online server	Uploaded automatically to an online server	Uploaded automatically to an online server
How data were explained/returned to local people?	Printed maps with all the results	Vocal feedback, distribution of photos and data points shown on offline map	Participants visit Research Centre to visualize the data	Reporting on individual ranger activity over WhatsApp
How long did it take to explain the data to local people?	~2.5 months	3 days	Partner institutions show the data regularly to the community	Continuous feedback
Conservation impact	A 5000 km^2 community reserve was created	Greater engagement with indigenous peoples by conservation NGOs in the region, more effective conservation interventions, better planning of wildlife corridors outside protected areas	Local users conducting new projects using the software	Developed digital skills, better understanding of forest legislation

the Serengeti-Mara savannah ecosystem, where some originally nomadic pastoralist Maasai communities have settled in the buffer zone after displacements due to the creation of the reserve (Rukwaro & Mukono, 2001). The change from a nomadic to a more sedentary lifestyle has impacted the Maasai's relation with the environment (Bussmann et al., 2006), especially accelerating the loss of botanical knowledge, despite traditional plant use remaining essential for traditional medicines, building materials, fodder, weapons, and other commodities (Bussmann et al., 2006). The initiative, started in 2019, is focused on recording plant distribution and knowledge to ensure intergenerational knowledge transfer. It is held through a partnership between Sekenani EnviroTech

Centre, Maasai Mara University, University of Eldoret, and UCL Institute for Global Prosperity.

Local people had no difficulty in recording the breadth of their ecological knowledge. As soon as the initiative started, local people decided to increase the number of plant species initially established to include all those that they valued medicinally (over 120 species). Data captured with phones equipped with Sapelli Collector were automatically transmitted to an online server (Geokey) where it was stored and made available for visualization through a web mapping interface (Community Maps). To facilitate visualization, participants were invited to visit the Sekenani EnviroTech Centre where they could inspect the collected data directly on Community Maps with the support of a local technician. Currently, local users are conducting new citizen science projects using the same software.

3.3 | Namibia, Ju|'hoansi people

This initiative was implemented in the Nyae Nyae (*N||oq'an!'ae*) Conservancy, a communal conservancy established by the Ju|'hoansi people (one of many indigenous groups in southern Africa more commonly known as "San" or "Bushmen") in 1998 as part of a broader national move postapartheid to ensure that different traditional communities had political and self-determination and could become economically self-sufficient (Barnard, 2007, 2019). The initiative is located in the semiarid deserts of Namibia. The Conservancy Biodiversity Management Plan is based on a hunting quota-setting system, which can be used by local people themselves or sold as "licenses" to professional hunting outlets. To assure local sustainability of the hunting practice, the government employs local people as rangers to monitor animal populations. Recently, however, doubts have been raised over community-based quota-setting practices within the conservancy, especially over the reliability of the figures collected by local people (Damm, 2019; Grobler, 2019).

The ECS initiative started in 2018 and it is focused on building a system of wildlife monitoring through which rangers can feel empowered to use and, at the same time, it can be supported and validated by the government and scientific community. Fourteen rangers participate in the project, and researchers spent 5 months building the structure of the software with them. A PhD student carrying out ethnographic research also participated in the project.

As in the Maasai case study, data were downloaded from phones installed with Sapelli Collector and sent automatically to the GeoKey online server allowing for visualization via the Community Maps integration. Rangers could access online maps, but their feedback and any other communication between participants and researchers took place on WhatsApp. Recent reports show that the project enhanced local people's digital skills and their understanding of forest legislation (Skarlatidou & Haklay, 2021).

3.4 | Cameroon, Baka hunter-gatherers, and Fang farmers

This initiative was implemented around the periphery of the Dja Biosphere Reserve, in the Guineo-Congolian lowland rainforest of southern Cameroon. The reserve was established in 1981. Although Baka hunter-gatherers have been living in this region for thousands of years and farming communities for several hundred years, the majority of the forest estate has been allocated to logging concessions or as wildlife reserves (Megevand et al., 2013). As a consequence, many local communities have been, and continue to be, forcibly evicted from their traditional areas (Clarke, 2019; Samndong & Vatn, 2012). Moreover, national management strategies aiming to reduce illegal wildlife crime and illegal logging neglect rich local knowledge systems, instead prioritizing law enforcement measures through militarization (Pyhälä et al., 2019). The main aim of the ECS initiative is to broaden the reserve's management strategies to recognize local values and collaborate with local knowledge systems to address wildlife crime and conduct ecological monitoring. The project was initiated in 2016, taking between 3 and 4 months for data collection to begin with the seven communities involved.

While implementing the project, it was understood that some financial compensation for the time spent in data collection was important. However, to limit the influence of payments in the decision of participation, community priorities were first established without mention of the ECS project, and these priorities in conjunction with local leadership presided over project design, the FPIC process ensuring genuine motivation. It was only once these stages were completed and discussions moved to the community protocol stage that the modalities and expectations for community management of participation were discussed and questions of remuneration were publicly raised and decided on by participants.

As with the previous two case studies, the downloaded data taken with Sapelli Collector were automatically transferred to GeoKey and visualization was enabled through Community Maps. Offline maps were consulted by local people through local facilitators, and non-sensitive photos were fed back.

As of August 2020 (approximately 4 years since the project inception), community wildlife data has contributed to 36 arrest incidents (sometimes of multiple perpetrators) and 19 seizures without arrests of traffickers. Additionally, community supplied data on wildlife sightings enabled conservation managers to better plan wildlife corridors between protected areas, empowering project participants in the process (Hoyte, 2021).

4 | HOW TO IMPLEMENT AN ECS PROJECT?

Different realities may bring different challenges to ECS projects. However, as presented in the case studies, despite the historical, ecological, political, and economic differences of different socioecological systems, the following important steps may facilitate project implementation over a wide range of contexts (Table 1, Figure 1):

4.1 | Trust between researchers and local people

The first aspect highlighted is the need to gain a reasonable level of trust between researchers and local people before initiating the ECS project. Conservation challenges, such as disputes over use of resources within strictly protected areas (e.g., the Pantanal, Cameroon, and Kenya case studies) normally involve power plays (Brittain et al., 2020). Researchers in conservation often fail to acknowledge and clearly understand these aspects before implementing an initiative, risking the reinforcement of harmful power games and perpetuating historical injustices (Dressler et al., 2010; Neumann, 2004). It is crucial to be guided by such locally trusted gatekeepers to take account of possible conflicts, disputes, historical, physical, or economic displacement or similar grievances, and local power dynamics before implementing an ECS initiative. In all case studies, community trust was gained through engaging with local people, either directly or through existing relationships with partners, for a certain amount of time before initiating the ECS project, varying from 2 years in Namibia and Kenya to 7 and 20 years in Cameroon and Brazil, respectively. Also, in two initiatives (Namibia and Brazil), researchers used participant observation as the basis for an ethnographic enquiry, they acquired linguistic and cultural competence while living in the community for between 1 and 2 years. Ethnography research involves getting close to people and making them feel comfortable with the presence of the researchers who become a "fly on the wall," allowing observation about their lives unbiased by external judgment or other effects (Bernard, 2006). While these research projects were not initially related to the implementation of the ECS initiative, the long duration and close contact with local people provided researchers with opportunities to develop an enhanced knowledge of local social-ecological dynamics, as well as an understanding of local concerns, values and community organization, facilitating the effective implementation of ECS initiatives (Drury et al., 2011).

4.2 | Community-led decisions

Another important common aspect is local people's ability to guide the initiatives. A truly ECS project is based on communities' right to choose their monitoring target and participating in design sessions. Local peoples'

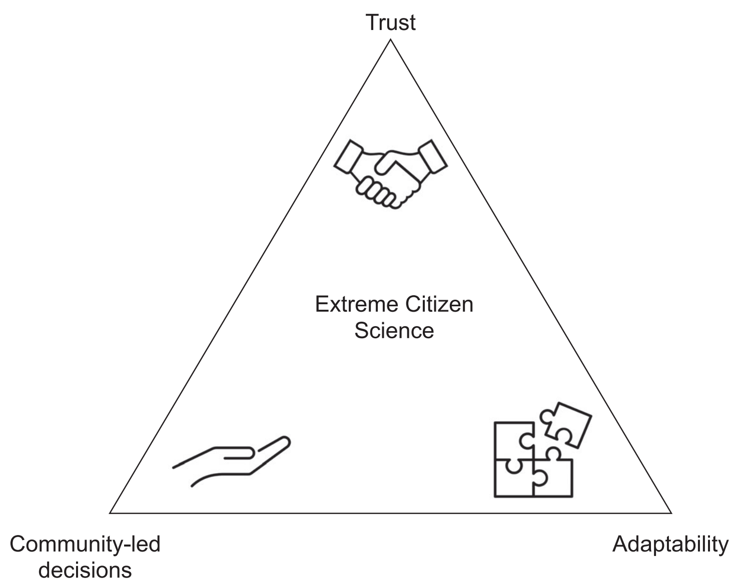

FIGURE 1 Three important drivers that increase the chance of success in the implementation and execution of extreme citizen science

participation allows researchers to understand the modifications needed in the interface of the software so that it is best suited to the local context and local priorities. Building on community concerns that already exist rather than imposing an outsiders' agenda ensures that initiatives are more likely to be in the interests of local people (Bennett et al., 2017). It encourages more effective participation, greater confidence in the group or community's ability to manage their local environment, and independence from outsiders (Smith et al., 2009). For instance, in the Brazil case study, it took 6 months for the researcher to define with local communities what natural resources they were going to monitor, reducing the initial number that was drafted from 12 to only 3. In Kenya, by contrast local communities decided to increase the number of plant species to include all those that they valued medicinally (over 120 species). If facilitators are genuinely committed to local leadership, community-led initiatives' ultimate goal must be to become self-sufficient (Büscher & Fletcher, 2019).

4.3 | Adaptability

As presented in all four cases studies, researchers facilitating ECS projects often have to be adaptable to address specific additional requirements including learning how to use GIS software to return the data to local communities, restructuring the interface design after data collection has begun (e.g., Brazil case study), accompanying participants to check the online maps at places with internet access, or adding new tools or methods (e.g., Kenya case study). Adaptive approaches should be a key component of all conservation initiatives seeking genuine local collaboration and/or leadership (Ribot & Peluso, 2009; Westgate et al., 2013). Community-based tools have to adapt to specific features of rural or isolated socio-ecological systems, such as nomadic behavior, unpredictability of natural resource distribution and abundance, and the different ontologies and epistemologies that underlie local decision-making and values (Conquest, 2013; Levin et al., 2013). In such contexts, approaches aiming to capture community ecological relations must be also able to adapt to the different realities. For instance, payments, as a motivational incentive, may challenge the voluntary nature of citizen science participation (as in the case of Cameroon); however, the socioeconomic realities and expectations of each site should always be prioritized and may require payments or incentives (Haklay et al., 2020).

5 | CONCLUSION

ECS initiatives have an important potential to instigate a paradigm shift in the conservation agenda. Recent developments and availability of geospatial information and communication technology tools have expanded the capacity of citizens to record, analyze and share data important for conservation in ways that were not previously possible. Our exploration of four ECS initiatives implemented in Brazil and Sub-Saharan Africa reveals how ECS initiatives can contribute to developing partnerships and conservation skills among local people, identify new areas of high conservation value, provide biodiversity monitoring, contribute to improving law enforcement, collect evidence of corruption, document traditional ecological knowledge, uncover the boundaries of traditional territories among others, which go hand-in-hand with the empowerment of communities and re-orientation of conservation projects toward local concerns and equity (Dawson et al., 2021). However, when designing and running such initiatives, the team's shared understanding of local socio-ecological contexts and concerns is key. It is also important to identify different solutions for the range of issues in regard to data collection. These can range from using nondigital methods such as paper forms to complement digital processes to establishing relationships with outside individuals and organizations to facilitate access to the internet for uploading data, downloading updates and data, and communicating results, or for technical support. By following these steps, conservation scientists can change local power dynamics which is a vital first step in developing genuine community-based conservation approaches.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Rafael Morais Chiaravalloti and Artemis Skarlatidou contributed to document conceptualization, writing, and revision. Simon Hoyte, Marcos Moreu Badia, Muki Haklay, and Jerome Lewis all contributed to the writing and revision.

DATA AVAILABILITY STATEMENT

All data cited are open access.

ETHICS STATEMENT

Research was in accordance ESI university and local guidance.

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