Citizen Science

A STAP background note

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STAP SCIENTIFIC AND TECHNICAL ADVISORY PANEL
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Summary

The rapid pace of global change requires an "whole-of-society"[i] approach to harness scientific understanding to anticipate, adapt, and innovate in addressing environmental degradation, which his can often be achieved more effectively if done in partnership with those outside professional and scientific circles. Citizen science involves non-professionals and local communities in the design, implementation, monitoring, data collection, analysis, and evaluation of projects to generate scientific information and knowledge.

Citizen science can contribute to delivering global environmental benefits (GEBs), and raise community awareness, improve scientific literacy, promote social learning and behavior change, engender empowerment, and increase the transparency and accountability of environmental decision-making. The inclusion of civil society in Global Environment Facility (GEF) programming can also promote diverse "ways of knowing" by providing pathways to engage Indigenous Peoples, local communities, and Indigenous and local knowledge.

Including citizens in project design at an early stage, incorporating citizen science into knowledge management, and ensuring sufficient training and resources for citizen engagement, can all help to increase the likelihood of achieving benefits for projects and participants. These actions can also reduce some of the challenges, such as difficulties in engaging a sufficient number of diverse citizens, potential disputes about data ownership, questions about data quality, limited institutional capacity, lack of prolonged engagement, and non-recognition of the value of data collected.

[i] The whole-of-society approach entails the robust participation of State and non-State actors, formal and informal institutions, as well as individuals, communities, and other stakeholders, in the design and implementation of solutions.

The GEF has a unique mandate to achieve GEBs. Embracing a whole-of-society approach in GEF-8 provides an impetus to incorporate citizen science in the GEF's programming. A limited analysis indicates some use of citizen science in GEF projects, but because information about citizen science is not collected systematically and terminology is inconsistent, it is difficult to know the full extent of its adoption and what impact this has had on outcomes. However, it is clear that citizen science – if done correctly – has the potential to achieve environmental and socioeconomic co-benefits.

The GEF could take the following actions to encourage greater adoption of citizen science in projects and programs:

(1) Adopt a more consistent definition of citizen science to provide a better shared understanding in the GEF partnership.

(2) Develop criteria to guide the use of citizen science, as the basis for a more systematic review of how citizen science has contributed to project outcomes, what are the barriers to more widespread adoption, and what measures could harness greater citizen participation.

(3) Include "citizen science" as part of the taxonomy of terms in the new strategy for Knowledge Management and Learning.

(4) Ensure sound training and feedback to improve citizen engagement, ownership, and data quality.

(5) Develop and implement sound data quality assurance and quality control protocols along with clear rules for data ownership.

(6) Encourage partnerships between citizen science initiatives, Indigenous Peoples, local communities, research institutions, and government agencies to enable knowledge-sharing, including with the GEF Civil Society Organization (CSO) network.

Introduction

Citizen science, community science, crowdsourcing and participatory monitoring describe diverse practices where non-scientists volunteer to produce scientific data and knowledge. Citizen science provides the opportunity to engage non-scientists in scientific enterprises to deliver global environmental benefits (GEBs) such as improving natural resource management. The practice is not new – scientific projects involving "non-professionals" gathering information date back to the seventeenth century.[1] However, the increasing popularity and geographical expansion of citizen science is shown by the involvement of millions of people globally.[2,3] It is therefore not surprising that numerous governments, regions, and agencies – from the United States of America[ii] to the European Union to United Nations Educational, Scientific and Cultural Organization (UNESCO) – are promoting and facilitating the involvement of citizens to accelerate science, technology, and innovation. This popularity can translate into the equivalent of additional funding for information and knowledge-gathering. For example, the value of in-kind contributions by 1.3–2.3 million biodiversity-related citizen science volunteers were estimated to be up to US$ 2.5 billion in 2015.[4]

Bergerot (2022) defines citizen science as "a scientific project involving a partnership with volunteers, both novices and experts, in the generation of new knowledge."[5] (See Box 1 for an explanation of why the term "citizen science" is used in this paper.) A broad range of practices are used in citizen science. Common to these practices are the collaboration and cooperation of professional scientists and non-scientists in scientific activities, which may extend beyond the boundary of an institution.[6] Citizen science goes beyond public engagement with science and science communication because it involves citizens in the actual production of scientific knowledge, as opposed to informing and educating citizens about its production or results.[7]

Citizen science has contributed to natural resource management and increased resilience to natural hazards through, for example, the monitoring of terrestrial and aquatic ecosystems and meteorological conditions, and crowdsourcing feasible solutions to address environmental challenges.[8] Contributions from citizen science have provided data for monitoring progress towards achieving the Sustainable Development Goals, notably Goal 15 (Life on Land), Goal 11 (Sustainable Cities and Communities), Goal 3(Good Health and Wellbeing), and Goal 6 (Clean Water and Sanitation).[9,10,11] The United Nations Department of Economic and Social Affairs engages citizens and partners from many communities in data collection to help fill critical data gaps through the Collaborative on Citizen Data initiative.[12]

The growth of citizen science in scale and scope over the past few decades can be attributed to several factors, including increased citizen interest in scientific information, enabled by access to the Internet, platforms such as Wikipedia and YouTube, and open access journals.[13] While many documented citizen science projects and associated analyses have historically come from countries in the Global North, a growing number of projects are taking place in the Global South.[14,15,16]

This paper illustrates the benefits and opportunities to the Global Environment Facility (GEF) of enhancing public engagement through citizen science. It starts by describing citizen science typologies, summarizes the benefits of adopting citizen science practices, describes barriers and challenges, and offers some considerations for moving forward. The paper relies on information obtained from peer-reviewed scientific and practitioner (e.g. international and non-governmental organizations) literature and a non-exhaustive review of the use of citizen

[ii] For example, the United States, under the Obama Administration, held several events aimed at accelerating crowdsourcing and citizen science to raise awareness of associated benefits and to motivate more federal agencies and Americans to take advantage of these approaches.

science in GEF projects (through written documentation and personal communication with project and program managers).

Box 1: The term "citizen science" is used throughout this paper because it is most often used in the literature.[17] The word "citizen" was intended by its original proponents to refer to a "citizen of the world" or the general public, rather than the legal meaning of a citizen of a sovereign country.[18] Recently the term has been criticized for being exclusionary, particularly in the United States, because of the struggle of marginalized groups to obtain full rights associated with citizenship. However, changing the name for the practice of engaging "non-professionals" as volunteers (e.g. to "community science") has also been criticized, given the global momentum of activities and organizations formed under the well-recognized term "citizen science".

Citizen science typologies

Several typologies of citizen science have been developed, all of which consider the degree to which non-scientists are involved in a project.[19] Walker et al. (2020)[20] offer a typology of citizen science projects that ranges from co-produced projects designed and implemented collegially by non-scientists and professional scientists to projects that merely harvest data from non-scientists through the *Internet of things* or other platforms, without their active participation in project design and implementation (Figure 1).

Within these typologies, the level of sophistication of the scientific methods used ranges from the simple and inexpensive to the more complex and costly. For example, the methods used to gather data span from recording and reporting the presence or absence of a species, in order to monitor trends in biodiversity, to using sophisticated sensors and other equipment to record local hydrometeorological data that can inform the design and implementation of agricultural practices adapted to a changing climate. The choice of scientific method can have implications for the time and commitment needed to gather and process data. A related dimension of these typologies is whether data collection relies on resources (e.g. equipment) owned by citizen scientists or if these resources are provided by a centralized institution.[21]

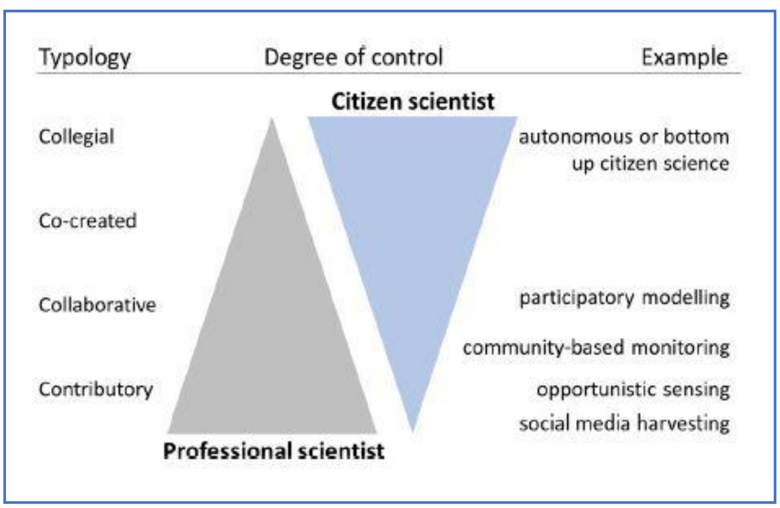

Figure 1. The relative degree of involvement of citizens and professional scientists for different typologies of citizen science (Walker et al., 2020). Categorization varies by context; for example, community-based monitoring and participatory modelling could move up or down the scale. [22]

The typologies can also vary according to their use of different "ways of knowing". Many projects rely on Western science as the dominant way of knowing. However, citizen science can also include Indigenous and local knowledge which can, for example, strengthen ecosystem stewardship.[23]

Several analyses and reviews of citizen science projects indicate that most fall under the "contributory" category where data are crowdsourced or collected via "distributed intelligence"[iii] enabled through Internet connectivity.[24,25,26,27] However, these projects often fail to engage citizens sufficiently, and the potential benefits may not accrue. In contrast, projects that are co-designed and co-executed by professionals and non-professionals, where the latter have a more active role in project design and resource management, are more likely to reap benefits.[28,29]

Benefits of citizen science

Citizen science can help a project achieve its goals, and also benefit the citizens involved, communities, decision makers, and data users, as described in the substantial literature on the subject. This includes several meta-analyses.[30,31,32] The following is a summary of the major benefits that have been documented through analyses of projects, emphasizing those pertaining to the Global South.

1. **Increased depth and breadth of data collection.** The increased capacity provided by citizen scientists can expand the spatial and temporal ranges, and the quantity, of data collected.[33] Citizen science can also accelerate research or enable large-scale projects by harnessing large numbers of participants.[34] Where a time series is short, the increased spatial coverage provided by including non-scientists in data collection can compensate, by adding sites with greater diversity and variability in conditions.[35] An example is the iNaturalist application which crowdsources data on species and organism occurrence to advance biodiversity science and conservation. As of May 2022, iNaturalist surpassed 100 million verifiable observations, mostly from North America and Europe.[36] Another successful example is eBird, to which citizens contribute more than 100 million bird sightings annually, with the annual participation rate increasing by 20%. Data collected from citizen science are also used to monitor Sustainable Development Goal indicator 6.3.2,"Proportion of bodies of water with good ambient water quality". This is facilitated through the Global Environment Monitoring System for Freshwater (GEMS/Water), administered by United Nations Environment Programme (UNEP) using the GEMStat database.[37] These data complement information provided by governments and organizations. Data gathered by citizen scientists were particularly helpful during COVID-19 when project team members were unable to go to the field. For example, as part of the GEF-funded "Citizen science-based action for the conservation of coastal wetlands in Beibu Gulf project in China" the team relied on local volunteers to collect biological data (Figure 2).[38]

[iii] "Distributed intelligence" refers to developing learning and ideas across people, environments, situations, and time. Vishwanath, A., and R. Pea (undated). Distributed Intelligence. The International Society of the Learning Sciences.

Figure 2. Citizen scientists monitor crab populations as part of the GEF-funded Citizen Science-based Beibu Gulf Coastal Wetland Conservation Action. Photo courtesy of the Guangxi Biodiversity Research and Conservation Association.

2. **Empowerment and community capacity-building,** particularly for people who are underserved and underrepresented by "traditional" science.[39,40,41] Citizen science can help in democratizing science and in promoting widespread availability and equitable access to data and information.[42] Acquiring and having access to data helps build "horizontal" bridges between people in different social groups by creating networks and alliances among those involved in data-gathering. "Vertical" bridges can also be built with institutions to increase social accountability and encourage citizens' involvement in decision-making, arming citizens with information to hold decision makers and other actors accountable.[43,44] Contributions to social well-being can come from projects that give people a voice in local environmental decision-making.[45]

   See Box 2 for examples of citizen science taking place in the Amazon that have resulted in empowerment and, in turn, improved resource management. Other examples include community-based monitoring programs that involve Indigenous Peoples in program design, which can build Indigenous capacity and governance, where monitoring feeds into planning and decision-making. This is illustrated by an Indigenous-led, community-based water quality monitoring network involving Yukon First Nations in Canada and Yukon Alaska Tribes coordinated by the Yukon River Inter-Tribal Watershed Council.[46] Indigenous populations in the Congo Basin have been empowered by a citizen science project in which they can track illegal logging and poaching using handheld tracking devices.[47] Other applications, such as Forest Watcher, allow forest managers, Indigenous communities, and law enforcement to report deforestation on the ground and connect this information with data collected through satellite remote sensing.[48]

3. **Increased scientific awareness and knowledge**.[49,50,51] Engaging citizens in monitoring change over time can deepen scientific literacy, knowledge, and understanding of environmental and conservation processes and issues.[52] This can be particularly important where issues and solutions are abstract, intangible, or invisible (e.g. water contamination). A citizen science project in Nepal, for example, which involved students in rainfall data collection to sensitize them to aspects of the genesis of natural hazards (monsoon rains and flooding), led to increased awareness and knowledge and the autonomous development of student-organized science clubs.[53] The evidence also indicates that engaging citizen scientists in iterative, collaborative, and adaptive learning can deepen scientific knowledge and optimize project outcomes by providing new insights and information that may otherwise not have been uncovered.[54]

Box 2: Citizen science in the Amazon

The Science Panel for the Amazon (SPA) was established to make clear the scientific, economic, and moral case for conservation and to address widespread deforestation, forest degradation, and wildfires, which have intensified in recent years. Sponsored by the United Nations Sustainable Development Solutions Network with support from the Gordon and Betty Moore Foundation and the GEF, in 2021 the SPA released its Amazon Assessment Report. This includes several examples where citizen science has played an important role in supporting conservation activities while also empowering citizens:

1) "Citizen science as a tool for fisheries monitoring using the Ictio App in the Madeira River Basin": Prior to this project, the only entity that generated and held fisheries data in Rondônia was a hydroelectric dam concession holder, which limited the access of fisherfolk and government agencies to data and inhibited their participation in decision-making. However, local scientists and fisherfolk agreed to test and implement citizen science approaches and the Ictio App to ensure that both State decision makers and fishers could generate and effectively access fisheries data. As a result, community members were empowered to monitor and co-manage fisheries, by uniting modes of formal and traditional governance, and to use their own data to address potential impacts of the two hydroelectric projects operating in the Madeira Basin.

2) The Citizen Science for the Amazon Network (Amazon Basin-wide) is a collaboration among more than 30 partners from different backgrounds, countries, and interests, to increase the understanding of Amazonian migratory fish and foster sustainable fisheries management across the entire Amazon Basin.[55] Using low-cost, user-friendly digital tools and transparent knowledge-sharing agreements, network partners and more than 70 citizen scientist groups (e.g. fisherfolk, Indigenous Peoples and local communities, students) have generated and shared more than 55,000 observations of over 20 migratory and food fish species across the Basin using the Ictio App and shared database.

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4. **Increased opportunities for adaptive management and behavior change through social learning.**[iv,56,57,58] Learning about socioecological systems through citizen science provides collective knowledge which can lead to behavior change, reorganization, and adaptation.[59] For example, flood risk management depends on awareness, preparedness, and the capacity to cope with a flood event. Social learning through citizen science can lead to participatory governance of flood risk management.[60,61] Citizen science can also support participants in learning about and adopting new solutions – such as those aimed at climate resilience, protecting biodiversity, and land management – which are often needed for transitioning to environmentally sustainable solutions.[62] For example, in Colombia, participation in water research in a rural Andean watershed led to sharing of experience and best practices among community members for riparian vegetation management, water re-use, filtration systems for potable water, and septic system maintenance.[63]

5. **Opening opportunities to broaden ways of knowing by including Indigenous, traditional, and local knowledge**.[64,65,66] This knowledge and non-Western ways of knowing can and foster acceptance by communities of proposed project measures, and also increase overall confidence in the data and results.[67]

[iv] Social – or in this case, citizen – learning refers to a collaborative learning process where new behaviours can be acquired by observing and working with others. Here, individuals can gain collective knowledge that increases their capacity for positive behavior change and adaptation.

These benefits are more likely to occur if those holding this knowledge are involved in project design through a collegial approach.[68] For example, non-literate trackers in the Congo used their knowledge of animal behavior to collect data using a Smartphone Icon User Interface that alerted health officials to outbreaks of Ebola in wild animal populations well in advance of these posing risks to human beings. Trackers also played a role in curtailing the poaching of large mammals to improve conservation efforts.[69] (See Box 2 for additional examples.)

The benefits of citizen science can accrue through intentional and thoughtful design and planning. Experience shows that citizens should be engaged early in project development using a collegial approach to build trusting partnerships and a shared vision. Expectations should be realistic and clear, and open lines of communication created and maintained. Further, capacity-building activities need to be included, data-gathering designs should be responsive to citizen capacity, and health and safety standards should be established and followed.[70] (See Box 3 Good practices for engaging citizen scientists.) In addition, citizen science networks can be built jointly with civil society organizations (CSOs), using multiple sources of funding to ensure that the viability of citizen engagement is not tied to a discrete project. The GEF CSO Network is ideal for this type of effort because it is already well-established, and its global membership engages with a diverse array of talented and experienced professionals and organizations well placed to expand citizen science efforts.

The benefits of citizen science can continue beyond project completion by embedding citizen science activities within local and national institutions. An example is the Custodians of Rare and Endangered Wildflowers (CREW) program, a citizen science initiative that involves the South African public in the surveying and monitoring of plants, which has helped in locating endemic plants requiring conservation. This project has contributed to conservation assessments, land-use decision-making, and prioritization of the expansion of protected areas.[71] The program has actively engaged citizens for 20 years and continues to provide valuable data and inform decision-making because of its integration into the South African National Biodiversity Institute (SANBI), following initial funding from the Critical Ecosystem Partnership Fund (CEPF), supported by the GEF.

If, on the other hand, support for citizen science is not sustained, the data may continue to have utility for some time, but likely not indefinitely. For example, data derived in part from citizen science for the Protea Atlas Project on sugar bush flowers in Southern Africa were used as a primary source for spatial planning and climate modelling for 20 years after funding was terminated. The same is true for the Southern African FrogMAP and Bird Atlas[72] projects, where funding was terminated but the data continued to be used by researchers and policymakers. In both these cases, the data reflect historical rather than current species distributions.[73] Fortunately, a follow-up to the Bird Atlas Project called SABAP2 has recently been initiated.

Box 3. Good practices for engaging citizen scientists

General principles have been developed to guide citizen science practices – by, for example, the European Citizen Science Association[74] – which articulate the possible roles played by citizens, the distribution of benefits, and legal and ethical considerations.[75]

Based on the available evidence, best practices to achieve optimal, long-term benefits when engaging in citizen science cover a range of subjects, including how to set up a project; how to attract, motivate, and retain participants; how to store and manage data; and how to influence policy. Guidance for project development and implementation may take many forms – for example, training manuals, case studies, best practice examples, and how-to guides.[76] Guidance may also refer to different aspects of citizen science projects such as ethics, data collection, data analysis and management, scientific methods, and obtaining funding.[77]

Depending on the project, different guidelines may be consulted. Rather than provide an exhaustive list of guidelines, which are context and project specific, it is more helpful to enumerate key principles that should underline any project using citizen science-based data. The European Citizen Science Association, led by the Natural History Museum London with input from many members of the Association, developed 10 key principles that form the basis of good practice in citizen science, as quoted below.[78]

1. **Citizen science projects actively involve citizens in scientific endeavor that generates new knowledge or understanding**. Citizens may act as contributors, collaborators, or as project leaders and have a meaningful role in the project.

2. **Citizen science projects have a genuine science outcome.** For example, answering a research question or informing conservation action, management decisions or environmental policy.

3. **Both the professional scientist and the citizen scientists benefit from taking part.** Benefits may include the publication of research outputs, learning opportunities, personal enjoyment, social benefits, satisfaction through contributing to scientific evidence e.g. to address local, national, and international issues, and through that, the potential to influence policy.

4. **Citizen scientists may, if they wish, participate in multiple stages of the scientific process.** This may include developing the research question, designing the method, gathering, and analyzing data, and communicating the results.

5. **Citizen scientists receive feedback from the project.** For example, how their data are being used and what the research, policy or societal outcomes are.

6. **Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for.** However, unlike traditional research approaches, citizen science provides opportunity for greater public engagement and democratization of science.

7. **Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format.** Data sharing may occur during or after the project unless there are security or privacy concerns that prevent this.

8. **Citizen scientists are acknowledged in project results and publications.**

9. **Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.**

10. **The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.**

Citizen science and the GEF

The GEF has embraced a whole-of-society approach to achieve its objective of addressing global environmental challenges (biodiversity loss, climate change, pollution, and strains on land and ocean health).[79] To meet global sustainability and climate goals, the GEF-8 strategy (2022–2026) highlights the importance of contributions from local innovation, civil society actions, and coalitions.[80] The whole-of-society approach was emphasized at the Seventh GEF Assembly in Vancouver, Canada, and through engagement with youth and civil society including with the GEF CSO Network. The GEF subsequently sponsored youth participation at the Twenty-eighth Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) climate summit in November–December 2023 in Dubai, through Youth Ambassadors for Climate.[v] The GEF has stressed its intention of continuing to engage youth in its activities. Embracing citizen science and intentionally incorporating its practices in GEF programming could help to facilitate and expand the GEF's whole-of-society approach. Importantly, citizen science can contribute to achieving GEBs in all the GEF focal areas and Integrated Programs (see Box 4).

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Box 4: Citizen science across GEF focal areas

Biodiversity conservation: Citizen science has been used to report and monitor species occurrence and distribution, including invasive alien species (IAS), for conservation purposes. It has made substantial contributions to both local and large-scale, international biodiversity monitoring,[81] including for single animal or plant species, birds, bees, and butterflies.[82] Biodiversity monitoring can help achieve the objective of the GEF biodiversity focal area and support the goals of the Kunming-Montreal Global Biodiversity Framework, where Parties and relevant organizations are invited to support community-based monitoring and information systems. Citizens are welcomed to contribute to the implementation of the monitoring framework.[83] Citizen science is already taking place in GEF biodiversity projects. For example, a GEF Small Grants Programme project is applying citizen science to monitor coral bleaching and hawksbill sea turtle populations in the Red Sea. This data will support the Royal Marine Conservation Society of Jordan (JREDS) in monitoring the status of Aqaba's coral reefs and hawksbill sea turtles, and establish baseline data, contributing to more informed management decisions.

Sustainable forest management and climate mitigation: Citizen scientists have been actively engaged in climate mitigation projects for the monitoring, reporting, and verification (MRV) of carbon sequestration as part of REDD+ (reducing emissions from deforestation and forest degradation in developing countries). This has been through gathering in situ field data, which are often used in conjunction with satellite remote sensing data, useful for detailed measurement of changes in carbon stocks.[84] An example of community-based forest monitoring for REDD+ MRV is in the Ankasa Conservation Area in Ghana where locals collected forest condition data of relevance to REDD+ implementation.[85] Community-based forest monitoring can support the sustainable forest management activities of the GEF's climate change mitigation portfolio and the Critical Forest Biomes Integrated Program.

Climate change adaptation: People are at the center of climate change adaptation. The knowledge and experience of local people, obtained via citizen science activities, can help in designing and implementing climate change adaptation solutions. For example, the Transforming Climate Knowledge with and for Society (TRACKS) program in north-eastern Bangladesh included a research component where citizen scientists collected rainfall data to better understand how changing rainfall patterns affect local livelihoods.[86] These types of applications of citizen science can support projects under the GEF Least Developed Countries Fund (LDCF) and Special Climate Change Fund (SCCF).

[v] See GEF press release (30 October 2023).

Land degradation/restoration: Citizen science can help address data gaps on soil health and productivity, providing information for reducing land degradation and for restoration solutions.[87] For example, the "Ishiara Citizen Science (iCitSci) Bamboo Micro-Pilot project" in Kenya applied citizen science in establishing sustainable bamboo agroecological farming to restore degraded riparian areas, and which created income for participants.[88] On a global scale, the "On-Farm Experimentation" project involving over 30,000 farmers in more than 30 countries engages farmers in collectively solving problems with maintaining yields in a changing climate.[89] Innovative solutions are fostered through the sharing and dissemination of on-the-ground information through a decentralized and inclusive research model. One of the outputs is the development of a decision-support system for fruit production value chains in Africa that has brought together diverse stakeholders for co-learning solutions to manage fruit crops.[90]

Water quality testing and monitoring: Citizen science has been widely used for water quality monitoring.[91] A collaboration involving local citizens and university researchers in Lebanon to assess groundwater quality generated physical and chemical water quality data from the citizen scientists that were comparable to those from the university researchers.[92] Citizen-supported water quality monitoring can be applied in GEF projects under the International Waters portfolio as well as the Clean and Healthy Ocean Integrated Program to reduce land-based sources of pollution. It could also be applied to the GEF Chemicals and Waste activities addressing the pollution of water bodies by harmful chemicals (e.g. pesticides).

Citizen science can also lead to "incidental co-benefits", i.e. environmental and socioeconomic benefits outside of the GEF's mandate, which are not essential to achieving durable GEBs but which increase the overall impact of GEF investment.[93]

Citizen science can be part of community engagement and support for local livelihoods. For example, a GEF Small Grants Programme (SGP) project in Belize[vi] involved citizen scientists recording data on birds in forested areas using the eBird application. The project's success has been largely attributed to the sense of co-ownership among volunteers who were involved in designing the project and who later used the data to promote nature tourism, thereby providing income opportunities that otherwise would not have accrued.[94] As part of the GEF-funded Global Wildlife Program, a project in Panama[vii] has improved protection for jaguars, while also reducing loss of livestock from predation by engaging farmers and other citizens in monitoring jaguars and building enclosures for livestock. Long-term monitoring of jaguars using cameras that citizen scientists also help to install (Figure 3) has led to a growing understanding of, and familiarity with, jaguars, which has translated into fewer jaguar deaths due to hunting.[95]

[vi] SGP Project No: BZE/SGP/OP6/Y5/CORE/IWBE/2019/06: Strengthening Community Conservation Values in the Maya Forest Corridor Through Avian Citizen Science

[vii] GEF TF Medium Size Project ID: 10285: Conservation of wildcats and prey species through public-private partnerships and human-jaguar conflict management in Panama.

Figure 3. Ricardo Moreno, head of the GEF-supported project, Conservation of wildcats and prey species through public-private partnerships and human-jaguar conflict management in Panama, working with citizen scientist Elsie Quintero (also a farmer and teacher) to set up a camera trap on a farm to monitor jaguars as part of the project. Photo courtesy of Ginger Deason.

Citizen science can make more efficient use of resources, for example where the acquisition of, and access to, data and research outputs involves crowdsourcing.[96] Lessons learned from analyzing cases from Zooniverse, a large, online citizen science platform, indicates that crowdsourcing data can increase efficiencies in project data collection and the achievement of project goals by harnessing the involvement of numerous volunteers. However, it is important to note that, depending on system design, crowdsourcing can also inadvertently lower volunteer engagement, create exclusionary practices, and reduce opportunities for serendipitous discovery.[97]

Challenges to implementing citizen science

Applying good practices (see Box 3) can increase the likelihood and range of benefits from citizen science. However, even when good practices are followed, there remain challenges to successful implementation. These include:

1. **Low levels of citizen participation.** Increasing citizen engagement requires dedicating time and resources to involve citizens; centering projects on community needs and ways of knowing; targeting recruitment efforts to increase the diversity of participants; and incentivizing citizens to participate. Lack of information about citizen science opportunities and or incentives can result in low participation rates. This tends to be more common in low-income countries but can be addressed through developing and applying various context-specific recruitment strategies, such as online questionnaires and face-to-face interviews.[98,99] In cases where citizens do participate, it can be challenging to ensure their continued involvement. Several steps can be taken to encourage participation and minimize exclusion, such as reducing barriers posed by using expensive or sophisticated technologies (which can lead to a trade-off with the type and quality of data collected).[100] Evidence indicates that people tend to be more engaged when they receive clear guidelines within a well-defined time frame.[101] Prolonged institutional support is also a key factor in ensuring continued participation, as well as developing a more collegial approach

2. **Lack of diversity among participants**. Greater diversity can benefit projects by revealing new and different viewpoints on research questions, interpretations, and method development.[102] However, achieving diverse participation can be challenging. Self-selection which favors those who have achieved higher education, who have sufficient economic resources to afford the equipment and time to participate, and who live in areas of political stability, can lead to underrepresentation of those who do not have these characteristics, particularly people from marginalized and Indigenous populations. Biased participation can result in biased outlooks.[103] Involving citizens from a diversity of backgrounds in designing and implementing projects can facilitate greater participation and viewpoints, which can help align project goals and outcomes more effectively with community needs.[104]

3. **Lack of clarity on data ownership.** There can be tensions around who owns and has access to the data and information collected by citizens, which can lead to conflicts between the institution leading the project and citizen scientists.[105] Data accessibility for all stakeholders and partners requires a clear data and information ownership and sharing protocol embedded in a knowledge management strategy, with roles, responsibilities, and ownership clearly delineated.

4. **Poor data quality.** Data quality can be a concern, notably the validity of data collected and biases in data collected with gaps in space and time.[106] However, studies have shown that citizens do contribute valuable and valid data and information. Steps can be taken to improve data quality, including through training and feedback through peer review, and validation by experts.[107,108,109,110] Standardized protocols and quality control measures can help enhance data quality and confidence in results.

5. **Institutional and financial barriers.** These include limited institutional capacity, lack of prolonged funding, and lack of institutional buy-in demonstrated through a lack of recognition of the value of data collected – all of which can limit the success of citizen science initiatives.[111, 112] Institutions supporting citizen science projects require capacity and funding to train and sustain the engagement of participants, as well as to validate data, etc. – and such sustained funding is not always available. Institutions can support the use of citizen science by signalling their trust in citizen-collected data, which in turn can be fostered by adopting protocols for data collection and management. Such support has been exhibited by numerous institutions in high-income countries but could be strengthened in institutions working in the Global South.

Citizen science can also have drawbacks for the participants. For example, they may feel overburdened by the need to participate in data collection,[113] or disappointed when projects do not show immediate results. Citizens excluded from the participatory process owing to, for example, a lack of technological know-how can feel disempowered. There could also be conflicts because data are not accepted or believed. Furthermore, health and safety risks could arise when conducting certain types of data-gathering (e.g. monitoring rivers during floods or examining the quality of contaminated or unsafe water).

Harnessing the benefits of citizen science in GEF programming

To realize the potential benefits from the more widespread use of citizen science, the GEF could consider the following actions:

1. Adopt a consistent definition of what citizen science means but be flexible about how much citizen involvement is expected to occur in practice – to develop a shared understanding, rather than create a hard and fast rule.

2. Develop criteria as a guide to where citizen science could be beneficial. The criteria could consider where engaging with Indigenous Peoples and local communities could provide knowledge to help with project design and implementation.

3. Include "citizen science" as part of the taxonomy of terms in the new Knowledge Management and Learning strategy (pathway 3 is about empowerment and exchange to achieve more scaling and durability from GEF investments through greater flow and ownership of knowledge and learning among partners).[114]

4. Adopt a protocol to guide training and feedback for project participants who are making use of citizen science to improve citizen engagement and sense of ownership, and data quality, and to inspire confidence in results. Communicating the outcomes from citizen science to those individuals and communities who were engaged in collecting data will help them understand the practical value of their work and feel appreciated.

5. Support the adoption and implementation of robust data quality assurance and validation protocols for citizen-generated data to increase overall confidence in data quality. Be clear about data ownership and access rights for all parties engaged to avoid potential tension or conflicts. Whenever possible, support the sharing of data and information through open access data policies; encourage the use of free and open access software and apps to collect and share information; and support widespread access.

6. Encourage partnerships among citizen science initiatives, Indigenous Peoples, local communities, research institutions, and government agencies to facilitate knowledge-sharing. Engage through existing efforts by the GEF CSO Network and connect with other initiatives and communities of practice where citizen science is represented – such as the World Water Quality Alliance, or knowledge platforms that specifically cater to citizen science, such as the MICS: measuring the impact of citizen science website.

References

[1] Haklay, M. (2015). Citizen Science and Policy: A European Perspective. Washington, DC: Woodrow Wilson International Center for Scholars.
[2] Cooper CB *et al*. (2021). Inclusion in citizen science: the conundrum of rebranding. *Science* 372(6549:1386-1388).
[3] Bonney R., *et al.* (2009). Public participation in scientific research: defining the field and assessing its potential for informal science education. A CAISE Inquiry Group Report. Washington D.C.: Centre for Advancement of Informal Science Education (CAISE).
[4] Theobald E.J. *et al.* (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biol Conserv* 181: 236-244.
[5] Bergerot, B. (2022). The citizen science paradox. *Land* 11(8): 1151.
[6] Haklay, M. (2015). Citizen Science and Policy: A European Perspective. Washington, DC: Woodrow Wilson International Center for Scholars.
[7] Sauermann, H. *et al.* (2020). Citizen science and sustainability transitions. *Res Policy* 49: 103978.
[8] Koffler S. *et al.* (2021). A buzz for sustainability and conservation: the growing potential of citizen science studies on bees. *Sustainability* 13: 959.
[9] Fraisl, D., Campbell, J., See, L., Wehn, U., Wardlaw, J., Gold, M., Moorthy, I., Arias, R., Piera, J., Oliver, J.L., *et al.* (2020). Mapping citizen science contributions to the UN sustainable development goals. *Sustain. Sci.* 15: 1735-1751.
[10] Fritz, S., *et al.* (2019). Citizen science and the United Nations Sustainable Development Goals. *Nat. Sustain*. 2:922–930.
[11] Koffler S. *et al.* (2021). A buzz for sustainability and conservation: the growing potential of citizen science studies on bees. *Sustainability* 13: 959.
[12] The Collaborative on Citizen Data is a multi-stakeholder collaboration of countries and regional and international agencies with the goal of filling critical data gaps, especially of marginalized groups, and improving citizen participation in government decision-making to promote fairness, inclusiveness and transparency, as one avenue to promote its 2030 Agenda.
[13] Haklay, M. (2015). Citizen Science and Policy: A European Perspective. Washington, DC: Woodrow Wilson International Center for Scholars.
[14] Pocock M.J.O. *et al.* (2018). Developing the global potential of citizen science: assessing opportunities that benefit people, society, and the environment in East Africa. *J Applied Ecol* 56: 274-281.
[15] Koffler S. *et al.* (2021). A buzz for sustainability and conservation: the growing potential of citizen science studies on bees. *Sustainability* 13: 959.
[16] (CREW: Custodians of Rare & Endangered Wild Flowers); the Southern African Bird Atlas (https://SABAP2.birdmap.africa), and the Protea Atlas Project.
[17] Haklay, M. (2015). Citizen Science and Policy: A European Perspective. Washington, DC: Woodrow Wilson International Center for Scholars.
[18] Haklay, M. *et al.* (2021). Contours of citizen science: a vignette study. *Royal Society Open Science* 8.
[19] Bonney R., *et al.* (2009). Public participation in scientific research: defining the field and assessing its potential for informal science education. A CAISE Inquiry Group Report. Washington D.C.: Centre for Advancement of Informal Science Education (CAISE).
[20] Walker, D.W., Smigaj, M. and M. Tani. (2020). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. *WIREs Water:* 8:e1488.
[21] Walker, D.W., Smigaj, M. and M. Tani. (2020). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. WIREs Water: 8:e1488.
[22] Adapted from Shirk, J. L., H. L. Ballard, C. C. Wilderman, T. Phillips, A. Wiggins, R. Jordan, E. McCallie, M. Minarchek, B. V. Lewenstein, M. E. Krasny, and R. Bonney. 2012. Public participation in scientific research: a framework for deliberate design. Ecology and Society 17(2): 29. http://dx.doi.org/10.5751/ES-04705-170229
[23] Tengö M *et al.* 2021. Creating synergies between citizen science and Indigenous and Local Knowledge. *BioSci* 71: 503-518.
[24] Ngo KA, Altmann CS, and F. Klan (2023). How the general public appraises contributory citizen science: factors that affect participation. Citizen Science: Theory and Practice. 8(3): 1-15.
[25] Carlson T., and A. Cohen (2018). Linking community-based monitoring to water policy: Perceptions of citizen scientists. *J Environ Manag* 219: 168-177.
[26] Stepenuck, K.F., and L.T. Green (2015). Individual- and community-level impacts of volunteer environmental monitoring: a synthesis of peer-reviewed literature. *Ecol & Soc* 20: 19.
[27] Land-Zandstra, A., Agnello, G., and G. Selman. (2021). Participants in citizen science. The Science of Citizen Science. Springer.
[28] Land-Zandstra, A., Agnello, G., and G. Selman. (2021). Participants in citizen science. The Science of Citizen Science. Springer.
[29] Roche J., *et al.* (2020). Citizen science, education, and learning: challenges and opportunities. *Front Sociol* 5.
[30] Walker, D.W., Smigaj, M. and M. Tani. (2020). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. *WIREs Water:* 8:e1488.
[31] Pocock M.J.O. *et al.* (2018). Developing the global potential of citizen science: assessing opportunities that benefit people, society, and the environment in East Africa. *J Applied Ecol* 56: 274-281.
[32] Hicks, A., Barclay, J., Chilvers, J., Armijos, M. T., Oven, K., Simmons, P., & Haklay, M. (2019). Global mapping of citizen science projects for disaster risk reduction. *Frontiers in Earth Science,* 7: 226.
[33]Walker, D.W., Smigaj, M. and M. Tani. (2020). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. *WIREs Water:* 8:e1488.
[34] Sauermann, H., *et al.* (2020). Citizen science and sustainability transitions. *Res Policy* 49: 103978.
[35] Bergerot, B. (2022). The citizen science paradox. *Land* 11(8): 1151.
[35] Cooper C.B., *et al.* (2021). Inclusion in citizen science: the conundrum of rebranding. *Science* 372 (6549:1386-1388).
[36] https://www.inaturalist.org/blog/66531-we-ve-passed-100-000-000-verifiable-observations-on-inaturalist
[37] https://www.unep.org/explore-topics/water/what-we-do/world-water-quality-alliance-wwqa-partnership-effort/citizen
[38] Xiaoyun Tang, Guangxi Biodversity Research and Conservation Authority, personal communication.
[39] Couvet, D., *et al.,* (2008). Enhancing citizen contributions to biodiversity science and public policy. *Interdiscip. Sci. Rev*. 33, 95–103.
[40] Ballard, H.L.; Robinson, L.D.; Young, A.N.; Pauly, G.B.; Higgins, L.M.; Johnson, R.F.; Tweddle, J.C. (2017). Contributions to conservation outcomes by natural history museum-led citizen science: Examining evidence and next steps. *Biol. Conserv.* 208: 87–97.
[41] McKinley, D.C., *et al.* (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biol. Conserv.* 208: 15–28.

[42] De Sherbinin A., *et al.* The critical importance of citizen science data. *Frontiers in Climate* 3: 650760.
[43] Newman G., *et al.* (2017). Leveraging the power of place in citizen science for effective conservation decision making. *Biol Conserv* 208:55-64.
[44] Walker, D.W., Smigaj, M. and M. Tani. (2020). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. WIREs Water: 8:e1488.
[45] Ronney R, Phillips, T., Ballard, HL, Enck, JW. (2015). Can citizen science enhance public understanding of science? *Public Understanding of Science* 25(1).
[46] Wilson, N.J. *et al.,* (2018). Community-based monitoring as the practice of Indigenous governance: A case study of Indigenous-led water quality monitoring in the Yukon River Basin. *J Environ Management* 210: 290-298.
[47] Rowland, K., (2012). Citizen science goes 'extreme.' *Science Nature News.*
[48] Peterson, R. and L. Forest Watcher Brings Data Straight to Environmental Defenders. World Resources Institute.
[49] Bonney, R. *et al.,* (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience* 59: 977–984
[50] Pérez-Belmont P, Alvarado J, Vázquez-Salvador N, Rodíguez E, Valiente E, Días J. (2019). Water quality monitoring in the Xochimilco peri-urban wetland: experiences engaging in citizen science. *Freshwater Sci* 38: 342-31.
[51] Araya, Yoseph (2020). Using Citizen Science to Raise Public Awareness and Engagement with Water Issues. In: Maurice, Patricia A. ed. Encyclopedia of Water: Science, Technology and Society. John Wiley & Sons Inc.
[52] Roche J, Bell L, Galväo *et al.* (2020). Citizen science, education, and learning: challenges and opportunities. *Front Sociol* 5.
[53] Paul, J.D., *et al.* (2020). Applying citizen science for sustainable development: rainfall monitoring in Western Nepal. *Frontiers Water* 2: 581375.
[54] Jordan, R., *et al.* (2015). Studying citizen science through adaptive management and learning feedbacks as mechanisms for improving conservation. *Conserv Biol* 30: 487-495.
[55] Eyng, V., Gomes, M.C., Câmpera, L., and A. Hercos. (2022). Engagement in a citizen science project in the Amazon Basin. Engagement in a citizen science project in the Amazon Basin. Citizen Science: Theory and Practice, 7(1): 28, pp. 1–14.
[56] Jordan, R.C., Ballard, H.L., and T.B. Phillips (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Front Ecol Environ* 10: 307-309.
[57] Evers, M., Jonoski, A., Almoradie, A., and L. Lange. (2016). Collaborative decision making in sustainable flood risk management: A sociotechnical approach and tools for participatory governance. *Environmental Science & Policy* 55: 335–344.
[58]Bonney R., *et al.* (2009). Public participation in scientific research: defining the field and assessing its potential for informal science education. A CAISE Inquiry Group Report. Washington D.C.: Centre for Advancement of Informal Science Education (CAISE).
[59] Jordan, R.C., Ballard, H.L., and T.B. Phillips (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Front Ecol Environ* 10: 307-309.
[60] Evers M, Jonoski, A, Almoradie, A, Lange L. (2016). Collaborative decision making in sustainable flood risk management: A socio-technical approach and tools for participatory governance. *Environ Sci Policy* 55 (Part 2): 3335-344.
[61] Kongo, V.M., Kosgei, J.R., Jewitt, G.P.W., and S.A. Lorentz (2010). Establishment of a catchment monitoring network through a participatory approach in a rural community in South Africa. *Hydrol Earth Sys Sci* 14: 2507-2525.
[62] Sauermann, H. *et al.* (2020). Citizen science and sustainability transitions. *Res Policy* 49: 103978.
[62] Cooper C.B., *et al.* (2021). Inclusion in citizen science: the conundrum of rebranding. *Science* 372 (6549:1386-1388).
[63] Walker, D.A., Smigaj, M., and M. Tani (2020). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. *WIREs Water* citing Garcia, C. R., & Brown, S. (2009). Assessing water use and quality through youth participatory research in a rural Andean watershed. *Journal of Environmental Management*, 90(10), 3040–3047.
[64] Hicks, A., Barclay, J., Chilvers, J., Armijos, M.T., Oven, K., Simmons, P., and M. Haklay (2019). Global mapping of citizen science projects for disaster risk reduction. *Front Earth Sci* 7.; Evers M, Jonoski, A, Almoradie, A, Lange L. (2016). Collaborative decision making in sustainable flood risk management: A socio-technical approach and tools for participatory governance. *Environ Sci Policy* 55 (Part 2): 3335-344.
[65] Bennett, E.M., *et al.* (2021). Facing the challenges of using place-based social-ecological research to support ecosystem service governance at multiple scales. *Ecosystems People* 17:574-589.
[66] Schröter M., *et al.* (2017). Citizen science for assessing ecosystem services: status, challenges and opportunities. *Ecosys Serv* 28: 80-94.
[67] Wilson, N.J., *et al.* (2018). Community-based monitoring as the practice of Indigenous governance: A case study of Indigenous-led water quality monitoring in the Yukon River Basin. *J Environ Management* 210: 290-298.
[68] Tengö, M., *et al.* (2021). Creating synergies between citizen science and Indigenous and local knowledge. BioScience 71: 503-581.
[69] Liebenberg, L., *et al.* (2017). Smartphone Icon User Interface design for non-literate trackers and its implications for an inclusive citizen science. *Biol Cionserv* 208: 155-162.
[70] Alexandre C., *et al.* (2023). Creating shared value(s) from On-Farm Experimentation: ten key lessons learned from the development of SoYield digital solution in Africa. *Agronomy for Sustainable Development* 43:38.
[71] Custodians of Rare and Endangered Wildflowers (CREW) programme. SANBI. Accessed 15 January 2024.
[72] Harrison, J.A., Underhill, L.G. & Barnard, P. (2008). The seminal legacy of the Southern African Bird Atlas Project. *South African Journal of Science* 102: 82–84.
[73] Personal communication with Dr. John Donaldson, STAP Panel Member for Biodiversity and former Chief Director: Biodiversity Research, Assessment and Monitoring for the South African National Biodiversity Institute (SANBI). *13 December, 2023.*
[74] CSA. (2015). Ten Principles of Citizen Science.
[75] In addition to articulating best practices, national governments have sought to encourage citizen science activities in support of their broader policy objectives. For example, the United States National Advisory Council for Environmental Policy and Technology (NACEPT) urged the United States Environmental Protection Agency (EPA) to embrace citizen science and capacity-building initiatives that advance the Agency's mission and included 13 specific recommendations in support of this goal National Advisory Council for Environmental Policy and Technology (NACEPT) (2016). Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA. EPA 219-R-16-001. Washington, DC. https://www.epa.gov/participatory-science/nacept-2016-report-environmental-protection-belongs-public-vision-citizen

[76] García, F.S., *et al.* (2021). Finding What You Need: A Guide to Citizen Science Guidelines. In: Vohland, K., *et al.* The Science of Citizen Science. Springer, Cham.
[77] García, F.S., *et al.* (2021). Finding What You Need: A Guide to Citizen Science Guidelines. In: Vohland, K., *et al.* The Science of Citizen Science. Springer, Cham.
[78] ECSA: Ten principles of citizen science. OSF webpage. *Accessed on 15 January 2024.*
[79] The Global Environment Facility. *Accessed 15 January 2024.*
[80] GEF programming directions. GEF/R.08/29/Rev.01
[81] Chandler, M., See, L., Copas, K., Bonde, A. M., López, B. C., Danielsen, F., and E. Turak (2017). Contribution of citizen science towards international biodiversity monitoring. *Biological conservation* 213: 280-294.
[82] Damnyag, L., Bampoh, A.A., and Y. Mohammed. (2023). Community-based forest monitoring for REDD+ MRV in the Ankasa Conservation Area, Ghana. *International Forestry Review* 25(3): 300-309.
[83] See CBD/COP/DEC/15/5 Agenda item 9B Decision adopted by the COP to the Convention of the CBD. Monitoring framework for the Kunming-Montreal Global Biodiversity Framework.
[84] UNFCCC. REDD+ methodological guidance. *Accessed on 15 January 2024.*
[85] Damnyag, L., Bampoh, A.A., and Y. Mohammed. (2023). Community-based forest monitoring for REDD+ MRV in the Ankasa Conservation Area, Ghana. *International Forestry Review* 25(3): 300-309.
[86] Bremer, S., Haque, M. M., Aziz, S. B., and S. Kvamme. (2019). 'My new routine': Assessing the impact of citizen science on climate adaptation in Bangladesh. *Environmental Science & Policy*, 94, 245-257.
[87] Head, J.S., Crockatt, M.E., Didarali, Z., Woodward, M.J. and B.A. Emmett BA. (2020). The Role of Citizen Science in Meeting SDG Targets around Soil Health. *Sustainability.* 12(24):10254.
[88] Young Kenyans aim to establish sustainable bamboo agroecological farming with the help of citizen science. *Accessed 15 January 2024.*
[89] Lacoste, M., *et al.,* (2022). On-Farm Experimentation to transform global agriculture. *Nature Food* 3: 11-18.
[90] This is a type of citizen science that uses an App to share info. Alexandre C., *et al.* (2023). Creating shared value(s) from On-Farm Experimentation: ten key lessons learned from the development of SoYield digital solution in Africa. *Agronomy for Sustainable Development* 43:38.
[91] Ramirez, S.B., Meerveld, I., and J. Seibert (2023). Citizen science approaches for water quality measurements. *Science of the Total Environment* 897:165436.; Schölvinck A-FM, Scholten, W., and P.J.M.Diederen (2022) Improve water quality through meaningful, not just any, citizen science. *PLOS Water* 1(12): e0000065.
[92] Baalbaki, R., Ahmad, S.H., Kays, W., Talhouk, S.N., Saliba, N.A., and M. Al-Hindi (2019). Citizen science in Lebanon—a case study for groundwater quality monitoring. *R. Soc. open sci.* 6: 181871.
[93] GEF STAP. (2023). Incorporating co-benefits in the design of GEF projects. Washington, DC.
[94] Personal communication with Mr. Leonel Requena, SGP Country Office Contact for Belize on October 23, 2023.
[95] Ricardo Moreno and Natalia Young, Yaguara Panama, Personal Communication, November 10, 2023. See https://www.unep.org/news-and-stories/story/panama-cattle-rancher-leads-way-resolving-human-jaguar-conflict
[96] Franzoni, C. and H. Sauermann (2013). Crowd science: the organization of scientific research in open collaborative projects *Res. Policy*, 43(1):1-20.
[97] Trouille, L., Lintott, C.J., and L.F. Fortson. (2019). Citizen science frontiers: Efficiency, engagement, and serendipitous discover with human-machine systems. *PNAS* 116 (6) 1902-1909.
[98] Pocock M.J.O. *et al.* (2018). Developing the global potential of citizen science: assessing opportunities that benefit people, society, and the environment in East Africa. *J Applied Ecol* 56: 274-281.
[99] Requier, F., *et al.* Citizen science in developing countries: how to improve volunteer participation. *Front Ecol Environ* 18: 101-108.
[100] Sauermann, H., *et al.* (2020). Citizen science and sustainability transitions. *Res Policy* 49: 103978.
[101] Hyder, K., Wright, S., Kirby, M., and J. Brant. (2017). The role of citizen science in monitoring small-scale pollution events. *Marine Pollut. Bull.,* 120 (1–2): 51-57.
[102] Paleco, C., *et al.* (2021). Inclusiveness and diversity in citizen science. The Science of Citizen Science. 262-381. Springer.
[103] Benyei, P., *et al.* (2023). Challenges, strategies, and impacts of doing citizen science with marginalised and Indigenous communities: reflections from project coordinators. Citizen Science: Theory and Practice. 8: 21.
[104] Lowry, C.S., and K.F. Stepenuck (2021). Is citizen science dead? *Environ. Sci. Technol.* 55: 4194-4196.
[105] Christine, D.I. and M. Thinyane (2021). Citizen science as a data-based practice: a consideration of data justice. *Patterns* 3: 100575. Sauermann, H. *et al.* (2020). Citizen science and sustainability transitions. *Res Policy* 49: 103978. Cooper C.B., *et al.* (2021). Inclusion in citizen science: the conundrum of rebranding. *Science* 372 (6549:1386-1388).
[106] Sandahl, A and Tøttrup, A.P. (2020). Marine Citizen Science: Recent Developments and Future Recommendations. Citizen Science: Theory and Practice, 5(1): 24:1–11.
[107] Fritz, S., *et al.* (2019). Citizen science and the United Nations Sustainable Development Goals. *Nat. Sustain*. 2:922–930.
[108] Palmer, J. R. B. *et al.* (2017). Citizen science provides a reliable and scalable tool to track disease-carrying mosquitoes. *Nat. Commun*. 8(916).
[109] Callaghan, C.T. *et al.* 2019. Improving big citizen science data: moving beyond haphazard sampling. PLOS *Biology* 17:e3000357.
[110] Quinlivan, L., Chapman, D.V., and T. Sullivan (2020). Validating citizen Science monitoring of ambient wáter quality for the United Nations sustainable development goals. *Sci Total Environ.* 10:699:134255.
[111] Pocock M.J.O. *et al.* (2018). Developing the global potential of citizen science: assessing opportunities that benefit people, society, and the environment in East Africa. *J Applied Ecol* 56: 274-281.
[112] Pateman, R., Tuhkanen, H., and S. Cinderby. (2021). Citizen science and the sustainable development goals in low and middle income country cities. *Sustainability* 13: 9534.
[113] Poolman, M., and N. Van de Giesen (2006). Participation: Rhetoric and reality. The importance of understanding stakeholders based on a case study in Upper East Ghana. *Int J Water Res Develop* 22: 561-573.
[114] Global Environment Facility Strategy for Knowledge Management and Learning (2023). GEF/C.64/07.