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Community Monitoring of Natural Resource Systems and the Environment

Finn Danielsen,[1] Hajo Eicken,[2] Mikkel Funder,[3] Noor Johnson,[4] Olivia Lee,[2] Ida Theilade,[5] Dimitrios Argyriou,[6] and Neil D. Burgess[7,8]

[1]Nordic Foundation for Development and Ecology (NORDECO), Copenhagen, Denmark; email: fd@nordeco.dk

[2]International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska, USA

[3]Danish Institute for International Studies, Copenhagen, Denmark

[4]National Snow and Ice Data Center, University of Colorado, Boulder, Colorado, USA

[5]Department of Food and Resource Economics, University of Copenhagen, Copenhagen, Denmark

[6]Forest & Peoples Organization, Copenhagen, Denmark

[7]Centre for Macroecology, Evolution and Climate within Globe Institute, Copenhagen, Denmark

[8]UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, United Kingdom

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Abstract

Community monitoring can track environmental phenomena, resource use, and natural resource management processes of concern to community members. It can also contribute to planning and decision-making and empower community members in resource management. While community monitoring that addresses the environmental crisis is growing, it also gathers data on other global challenges: climate change, social welfare, and health. Some environmental community monitoring programs are challenged by limited collective action and community participation, insufficient state responsiveness to data and proposals, and lack of sustainability over time. Additionally, community members monitoring the environment are increasingly harassed and sometimes killed. Community monitoring is more effective with improved data collection, improved data management and sharing, and stronger efforts to meet community information needs, enable conflict resolution, and strengthen self-determination. Other promising areas for development are further incorporating governance issues, embracing integrated approaches at the community level, and establishing stronger links to national and global frameworks.

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1. INTRODUCTION

Human knowledge on the status and trends of natural resources, ecosystem services, and species on Earth is increasing but remains limited, especially in remote areas (1–3). Environmental assessments aim to synthesize and use this limited data (3–6) to inform decision-making and policy development. Due to the limited data available, decisions and policies being taken and developed may be poorly targeted and critical needs may not be addressed. Decision-makers simply cannot know whether sound actions are being taken without robust and representative systems for monitoring natural resource systems and the environment.

Monitoring: tracking of a particular variable or phenomenon over time and identifying trends that require an action

Overall, there are two strands of monitoring data on the environment. The first strand is dominated by scientists and volunteers led by scientists mostly in financially wealthy countries (7–11). These monitoring programs gather data for specific purposes, increasingly using remote sensing data and other technology solutions (12), but with the limitations that they do not cover all situations (13, 14). Increasingly, this monitoring is aided by online platforms, such as the Cornell Lab of Ornithology's eBird (**https://ebird.org/home**), Global Forest Watch

Figure 1

From the Arctic (*a–c*) to the woodlands of Tanzania (*d,e*) and Myanmar (*f*), environmental monitoring programs led by community members have informed decision-making and action on natural resource management. The actions included zoning of land for different uses, local time or area closures, changes in resource extraction methods or gear, and changes in quotas or seasons. (*a*) Fisherman and hunter Lars Olsen, Akunnaaq, Greenland, and (*b*) dog sleds in Qaarsut, Greenland, the Greenland Ministry of Fisheries and Hunting's *Piniakkanik Sumiiffinni Nalunaarsuineq* program. (*c*) Domestic reindeer belonging to herders in Yakutia, the Community Based Monitoring Program of the Republic Indigenous Peoples' Organisation of Sakha Republic, Russia. (*d,e*) Village meeting and community monitors in Tanzania's Iringa District. (*f*) Focus group discussion where villagers are discussing changes in the status of natural resources and agreeing on solutions to problems relating to the resources in Myanmar's Nat Ma Taung National Park. Photos provided by (*a*) F. Danielsen, (*b,c,f*) M. Enghoff, (*d*) T. Blomley, and (*e*) M.K. Poulsen.

(**https://www.globalforestwatch.org**), and iNaturalist (**https://www.inaturalist.org/**), containing status and trends data on different aspects of species and habitats.

Community: a group of people who share a place and an environment or institution

The second strand is community monitoring systems, where community members, often environmentally interested fishermen, hunters, farmers, forest product collectors, and other resource users, gather and use data on natural resource systems and the environment, sometimes in collaboration with scientists (15). Community monitoring systems can be found in all countries and environments (**Figure 1**), but they are often found where there is strong self-interest in the results for management purposes. Both strands of monitoring systems can provide data that can lead to a better understanding of the environment and its management (16).

Nature-based solutions (NbS): actions to protect, sustainably manage, and restore ecosystems that address societal challenges and simultaneously provide human well-being and biodiversity benefits

Convivial conservation: a conservation approach focused at socially and ecologically just conservation and embodying convivial (literally "living with") principles

Community monitoring of the environment has been the subject of several reviews (e.g., 17–23). These reviews suggested that, when properly designed and carefully tailored to local issues, community monitoring can provide quality data cost-effectively and sustainably while building capacity among local constituents and prompting practical and effective management interventions.

Several large quantitative studies have generated major scientific advances in understanding community monitoring. For example, experiments introducing community monitoring to 400 randomly selected communities in six countries have demonstrated that community monitoring measurably reduces resource extraction and increases user satisfaction (24). Another study, based on 25,000 km of foot patrols in 34 tropical forest sites across the three tropical continents by scientists and community members who had attended only primary school, has shown that both groups produce closely similar results on status of and trends in species and natural resources (14, 25). Moreover, at the technical level, there has been rapid development and uptake of user-friendly approaches to storing and sharing data and information in community monitoring programs (26). All these developments have created a need to reexamine community monitoring programs, including their strengths, weaknesses, and future potential.

In recent years, the use of Indigenous and local knowledge for informing decision-making has received increased attention (4). Likewise, new approaches have been proposed to address the escalating biodiversity, climate, and development challenges by protecting ecosystems. These include nature-based solutions (NbS) (27, 28), other effective area-based conservation measures (OECMs) (29), and convivial conservation (30; **https://convivialconservation.com/**). If the new approaches are not to repeat the mistakes of past interventionist-based conservation, causing resource conflicts (31), green grabbing (32), human rights abuses (33), and failed ecosystem protection (34), they will need to involve community members and their knowledge. In fact, their success or otherwise will critically depend on it.

In this article we use the literature on community monitoring of the environment from the past five years to define community monitoring (Section 2), summarize the advantages and shortcomings of community monitoring (Section 3), situate community monitoring of the environment in relation to other applications where community monitoring has been tried (Section 4), explore how community monitoring of the environment can be more effective (Section 5), and discuss how the field is likely to evolve (Section 6).

2. WHAT IS COMMUNITY MONITORING OF THE ENVIRONMENT?

Numerous terms are used to describe different approaches to environmental monitoring with participation of community members (16, 35, 36). In this article, we define community monitoring of natural resource systems and the environment as a process of routinely observing environmental or social phenomena, or both, that is led and undertaken by community members and civil society associations, and can involve external collaboration and support of visiting researchers and government agencies (modified from 22).

Community monitoring thus differs from monitoring efforts in which there is some community involvement but with science-centered goals that are solely defined by scientists or individuals from outside the local community (37). Our definition of community monitoring does not explicitly address the degree of collaboration among stakeholders or community members and scientists, although various models for collaboration have been identified (**Figure 2**). Community monitoring programs may not always involve community members in defining or cocreating, and iteratively revising, the scope of and goals for the monitoring activity (closely resembling Model 6

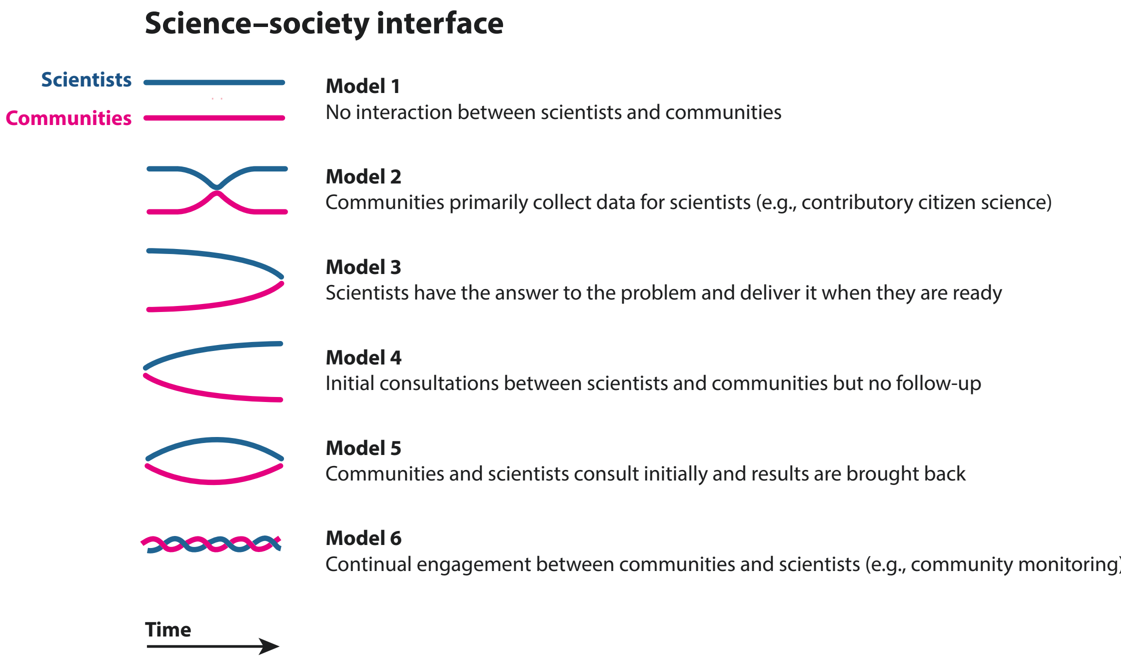

Figure 2

Schematic models of local stakeholder engagement approaches, ranging from no interaction between scientists and communities (Model 1) to continual engagement (Model 6). Models 1 and 3–6 have been adapted from Reference 38, figure 1.

in **Figure 2**), but in community monitoring programs the community members are typically the stakeholders of the monitored phenomena. Even in Model 2, community involvement at the onset and early community engagement are likely to increase the ability of programs to meet community needs and retain community members' interest and participation over time. Our broad definition of community monitoring programs does not seek to categorize levels of participatory approaches, but the related scholarly literature identifies a spectrum of participatory monitoring approaches, highlighting key differences in varying involvement of community members and scientists (14).

Two important aspects of community monitoring include its relationship to citizen science and the potential inclusion of Indigenous knowledge. With respect to the former, community monitoring of the environment is sometimes considered a subset of citizen science (35, 39–42), although as Pocock and colleagues (16, p. 172) wrote, "not all activities falling under this broad description would define themselves as 'citizen science' and it is important to be sensitive to the concerns of those practitioners." Given the mounting societal pressure for more inclusive practices in the field of citizen science, there has been an emergence of relabeling citizen science as community science (43). Further reference to citizen science literature later in the article emphasizes monitoring programs that are consistent with our definition of community monitoring.

Indigenous knowledge: knowledge held by individuals and communities that identify as Indigenous peoples

The second aspect of community monitoring that we highlight is the potential inclusion of Indigenous and local knowledge (44). Community monitoring of the environment may involve Indigenous communities particularly when it includes areas or resources of value to them. In such instances the monitoring often includes Indigenous knowledge (45, 46). Community monitoring may use Indigenous and local knowledge indicators (47) or scientific methods adapted to

Table 1 Approaches to community monitoring of the environment as described in four bodies of literature[a]

	Citizen science literature	Adaptive management literature	Common property literature	Democratic accountability literature
Role of monitoring	Provide information for better scientific knowledge	Provide information on system outcomes to improve system management	Provide information on rule compliance to better target sanctions and to resolve disagreements	Increase transparency of decision-making to hold authorities accountable
Attributes monitored	Species, ecosystems, ecosystem processes	System performance and its relationship to interventions	User behavior, match between user behavior and rules	Authorities, actions of authorities
Monitoring mechanisms	Volunteer monitoring networks, species lists, smartphone apps	User-provided information, specialized monitors, automated sensors	In-person direct and indirect observations, remote sensing data	Citizen scorecards, meetings, audits, community-led drones, sensors, undercover work, exposure of confidential official documents
Anticipated effects	Changes in scientific knowledge, higher citizen participation, more effective data collection tools	Changes in management interventions and system processes	Increased rule compliance	Greater transparency

[a]Modified from Reference 51.

nonspecialists' use (48, 49). Examples of Indigenous and local knowledge indicators are changes in the abundance, size, health, or taste of mammals, birds, fishes, and plants (50).

Ferraro & Agrawal (51) have identified four types of scientific literature that focus on community monitoring of natural resource systems and the environment, and we summarize some of their findings below. In each type of literature there are different perspectives on what is measured and why it is measured (**Table 1**). Information about natural resources and resource use is obtained to improve science (citizen science literature) or to improve natural resource system performance through better management (adaptive management literature). In contrast, information about the actions of members of a community or an organization, and how their actions align with rules governing their behaviors, is obtained to secure and promote user compliance with rules (common pool resource literature). Finally, information about actions of authorities is obtained to increase transparency of decision-making and hold authorities accountable (democratic accountability literature). The first three literatures encompass a large number of publications (e.g., 52), whereas the literature on democratic accountability is relatively limited.

According to Ferraro & Agrawal (51), the ultimate goal of community monitoring typically depends on the role of the decision-makers in natural resource management. In areas where decision-makers act in the public's best interest, community monitoring may improve understanding of the natural resource systems and the environment and lead to better management (51). In areas where decision-makers are not assumed to act in the public's best interest, community monitoring may provide information on rule compliance to better target sanctions, resolve disagreements, and increase transparency of decision-making, thereby promoting user compliance with rules, lowering corruption, and holding authorities accountable.

3. ADVANTAGES AND SHORTCOMINGS OF COMMUNITY MONITORING

3.1. The Importance of Context: Fit and Scale

Any assessment of the benefits and trade-offs of community monitoring must be cognizant of the broader context (53). This context includes the socio-environmental drivers that create the need for a monitoring effort, the decision-making frameworks within which the observations are embedded, and the objectives of a given monitoring program (54) (**Table 1**). We frame our review of advantages and shortcomings by considering two fundamental aspects of community monitoring: fit for purpose and scale.

Fit for purpose (or, fit) is a measure of the alignment between monitoring programs and the specific policy, management, or decision-support goals they are meant to support. Ideally, the functions or roles served by monitoring tie directly to the anticipated outcomes. A high degree of fit implies that the attributes monitored serve as useful proxies of the anticipated outcomes of the monitoring, and that the selected monitoring mechanisms are effective and conform with the particular setting. In the reverse case, a lack of fit of the attributes being monitored preempts desired outcomes (55, 56).

The concept of fit has been effective in the assessment of governance frameworks (57). Cost–benefit analyses of monitoring systems may serve as proxies for fit (58). Sometimes assessments are made of the potential social benefits that can be derived from environmental monitoring systems (e.g., for the Global Ocean Observing System; 59). The aims of such assessments are to develop monitoring systems that tie essential variables to specific applications or agency missions, which in turn map onto societal benefit areas. However, such approaches are not always effective in achieving fit for purpose at the local scale. In taking a largely reductionist approach, they are particularly challenged in meeting the needs of Indigenous communities (60). Community monitoring approaches are especially useful for mitigating lack of fit (61). For example, Rijke and colleagues (62) outline a process that gauges fit for purpose of governance mechanisms in relation to expected outcomes, with iterative refinement maximizing fit, serving also as an illustration of Model 6 in **Figure 2**. This work is particularly relevant in a monitoring context because, rather than considering resources in isolation, it builds on Ostrom's (63) concept of resource systems that draw on ecosystem services.

Scale can encompass both the total area covered by a community monitoring effort (coverage scale) and the spatial and temporal resolutions of observations (sampling scale). It is related to fit because specific applications are often associated with a particular scale defined by community concerns and resource use. Scale is also important in the context of monitoring approaches. With increasing resolution and availability of remote sensing data, from both satellite and drone platforms, how to downscale remote sensing data sets to the community scale is of increasing importance (61, 64).

3.2. Advantages

In **Table 2**, we summarize examples of advantages and shortcomings of community monitoring of natural resource systems and the environment. We also describe how the advantages and shortcomings are associated with the scale and the fit of the monitoring programs.

One of the key advantages of community monitoring is that it enables acquisition of time- and place-specific information, often about attributes and at temporal and spatial scales, relevant to resource users and managers (61, 65). Community monitoring therefore has the potential to tie directly to the most pressing policy, planning, and decision-making contexts. Community monitoring can ensure a high degree of fit at a scale suitable to community concerns and resource use

Table 2 Examples of advantages and shortcomings of community monitoring of the environment[a]

Advantages	How to maximize the benefit	Scale	Fit	Reference(s)
Acquisition of time- and place-specific information, often about attributes and at temporal and spatial scales, relevant to resource users and managers; potential to tie to the most pressing policy, planning, and decision-making contexts	Incorporate the monitoring activities into the area's natural resource governance processes and into the existing institutions responsible for policy, planning, and decision-making about natural resource use	Positive	Positive	61, 65–68
Potential to contribute to hypothesis development, product validation, and synthesis in large-scale monitoring programs	Promote reward structures in academia for work focused on actionable, solutions-oriented science; ensure sufficient organizational support structures	Positive	Positive	23, 69, 70
Adaptive to address unforeseen situations and hazards, including climate change and threats to food security	Translate economic benefits of hazard risk reduction into refinement of monitoring systems	Positive	Positive	71–73
Enhances local perceptions and actions to engage with the environment, strengthens community ownership and engagement, strengthens the bonds of community members with the resource itself, may provide a mechanism for community empowerment in natural resource management, helps advance sustainable common resource use practices	Establish policies and legal frameworks in support of community monitoring as a means to claim and secure natural resource rights	Neutral	Positive	14, 74–77
Low cost	Encourage use of locally available approaches and tools, draw on cost–benefit analysis to optimize fit	Neutral	Positive	23, 58
May ensure continuity in monitoring time series	Establish good practice and lessons learned from disruptions such as pandemic	Neutral	Neutral	78
Shortcomings	**How to mitigate the shortcoming**	**Scale**	**Fit**	**Reference(s)**
Perceived lack of rigor in collecting data or observations, challenging upscaling, meeting interoperability requirements, and the uptake of findings into decision-making	Convene educational programs and train agency personnel, encourage coproduction approaches to ensure fit	Negative	Negative	23, 61, 66, 79–81
Persecution of community monitors in countries with authoritarian rule	Raise awareness of the important role of community monitors, provide legal assistance	Neutral	Negative	82
Large effort needed for capacity development, institutionalization, and program sustainability at the local level, including retention of community participation	Encourage coproduction and comanagement approaches	Neutral	Neutral	23, 61, 83–85

[a]Each advantage or shortcoming is associated with positive, neutral, or negative impacts on scale and fit for purpose of the monitoring program.

(**Table 2**). Central to this success is the design or evolution of monitoring efforts that emerge out of community priorities and needs (61). Such needs often grow out of problems or issues identified by a particular community well before the same is recognized or acknowledged at higher levels of government or by academia (e.g., 86, 87).

Empowerment: a participatory, developmental process where individuals and groups gain greater control over their lives and over valued natural resources

Major drivers for such needs-based design are often tied to rapid changes at the local scale that render existing resource management policy or practice obsolete. The Greenland Ministry of Fisheries and Hunting's *Piniakkanik Sumiiffinni Nalunaarsuineq* (PISUNA) program (**Figure 1*a*,*b***) tracks and responds to major shifts in marine living resources that outpace existing harvest regulatory frameworks (23). Community-led initiatives with a focus on water resources management often find themselves in similar predicaments because of conflicting uses of an increasingly scarce resource (66–68).

For similar reasons, community monitoring typically has proven adaptive to addressing unforeseen situations or hazards (**Table 2**). The latter extends to slow-onset environmental change and threats to food security that may not be captured by large-scale observing systems beyond the community's reach (e.g., 71–73). In hazard contexts, the financial benefits of community monitoring outweigh the costs of the monitoring action (58). Community hazard monitoring is particularly compelling in regions such as rural Nepal, where river floods cause significant loss of life and property and operational government agencies are challenged to implement effective hazard monitoring systems (58).

These types of economic benefits demonstrated for hazard monitoring extend to other dimensions of community monitoring as well, for example, monitoring the efficacy of desired resource management practices (cf. **Table 1**, Adaptive Management Literature column) and their environmental context. The economic benefits offset the costs of running, in some cases expensive, monitoring programs and helping advance sustainable practices for common resource use (74).

Community monitoring can also be a mechanism to expand the role of community perspectives on and knowledge in natural resource management decisions (**Table 2**). Observations and data that tie to larger-scale management and planning frameworks can help create openings for the entry of local and Indigenous expertise into management regimes that might otherwise be actively or inadvertently suppressing involvement at the local scale. Communities may still face significant odds in gaining a greater voice in governance processes (88; P. Benyi, A. Skarlatidou, D. Argyriou, R. Hall, I. Theilade, et al., manuscript submitted), but the number of cases where some measure of success has been achieved is increasing, illustrated by examples such as the community monitoring initiative in Yakutia, Russia (75) (**Figure 1*c***); tropical forest management in Tanzania and Myanmar (77, 89–91) (**Figure 1*d–f***); and ocean management in Greenland (23, 76) (**Figure 1*a*,*b***; the sidebar titled Empowerment Potential of Community Monitoring).

While the COVID-19 pandemic has had negative, and in some instances devastating, impacts on remote Arctic communities, one positive aspect has been the recognition that Indigenous experts and local residents throughout the Arctic have kept the monitoring programs running. They have stepped in to ensure some level of continuity in monitoring time series (**Table 2**), pointing the way toward further empowerment and capacity building to help grow their role (78).

3.3. Shortcomings

Potential shortcomings of community monitoring are a perceived lack of quality or rigor in collecting data or observations (14, 80) and the amount of effort needed to ensure data quality and interoperability. These issues are directly tied to challenges in upscaling from community-scale monitoring or downscaling from large-scale observing efforts in cases where such information complements community monitoring (**Table 2**). As outlined above, with technological progress

EMPOWERMENT POTENTIAL OF COMMUNITY MONITORING

In the past, limited attention was given to the empowerment potential of programs for community monitoring of the environment (84, 92, 93). To advance understanding, we distinguish four ways that community monitoring can empower community members in natural resource management (14). First, it can lead to cognitive empowerment, such as increased feelings of pride and self-esteem in resource management (15, 94, 95). Second, it can lead to political empowerment via greater local influence on and involvement in decisions about natural resources (24, 96). For example, in Cambodia, community monitors tracking forest resources (90) frequently experience death threats (see the sidebar titled Increasing Harassment of Community Monitors) yet perceive themselves to be successful at stopping illegal logging even though they hold no formal power to enforce rules (97). Third, community monitoring can also lead to social empowerment through, for example, improved local organization for management of natural resources (98). Fourth, community monitoring can lead to economic empowerment, for example, through increasing the local control of resources against encroachment (89, 97).

and availability of sufficient resources, systematic protocols, and sustained engagement, potential data quality issues can be addressed and overcome (see also the sidebar titled Data Quality in Community Monitoring).

Linked to concerns over the quality of the data, community monitoring programs are sometimes not recognized as a valid and legitimate source of knowledge in decision-making (14, 45). Importantly, this can seriously impede the uptake of community members' management proposals into government decision-making processes. There are even examples in which conventional scientists and decision-makers expect community monitoring programs to threaten their own work because they believe the findings from the programs may lead to their loss of power and control over the natural resource management process (80) (**Figure 3**).

An important aspect of ensuring data quality of community monitoring is the ability to recognize risks associated with potentially conflicting aims of monitoring programs that can evolve into a major challenge for otherwise successful programs. For example, observing programs with a primary or prominent educational component may place more emphasis on capacity-sharing than on data collection. Such deterioration in monitoring approaches for fit carries the risk of sacrificing observational rigor for breadth and inclusivity.

DATA QUALITY IN COMMUNITY MONITORING

The perception that volunteer-collected data are unreliable may hinder the use of community monitoring results (99). Many studies have compared data from communities with data from scientists (100–103). In Ethiopia, for example, Walker and colleagues (94) compared community members' data on rainfall, river flow, and groundwater levels over 18 months with data from scientists. They found the community monitoring provided high-quality observations and improved both the spatial and the temporal characterization of rainfall, river flow, and groundwater levels. In another example, in New Zealand, Storey and colleagues (99) compared community members' data on stream water quality and biology also over 18 months with data from government sources. They found high correlations ($\geq$0.85) between community members' and scientists' data for most of the variables they tested, although visual assessments of physical habitat appeared challenging for both scientists and volunteers. Tests across a range of ecosystems and sociopolitical settings have demonstrated that community monitoring approaches are capable of providing accurate and precise information independent of scientists (14).

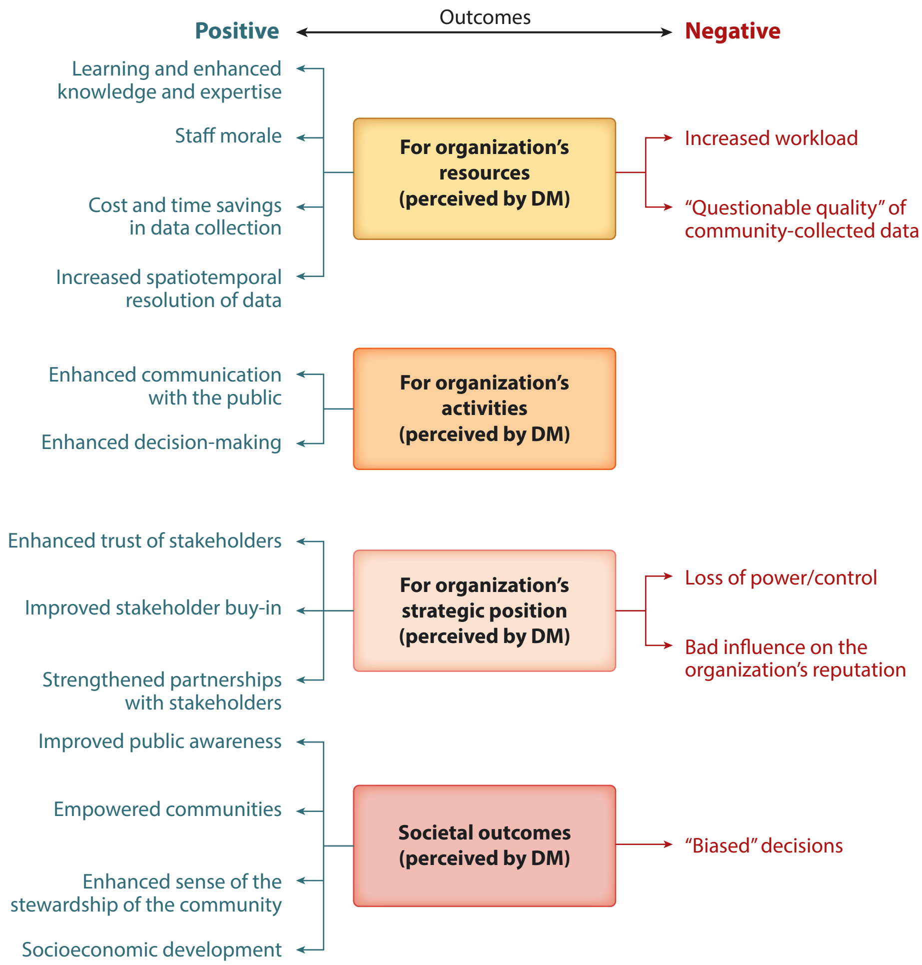

Figure 3

Incentives and barriers for participation in community monitoring programs. Beliefs of decision-makers (DM) about the expected outcomes or consequences of their participation in community monitoring. Although the figure is based on "very limited" (80) cases, it still may be informative. Figure adapted with permission from Reference 80, figure 11 (CC BY-NC-ND 4.0).

On the other hand, however, this potential risk needs to be balanced by consideration of how communities relate to research and monitoring. If communities really are in control of monitoring and research, they must have the ability to understand how data can be used to meet multiple needs and goals for information. Often, a primary concern of communities is how environmental changes will affect future generations; thus, education is often an important objective. Typically, community information needs are holistic, and it is important not to focus on one purpose alone but to allow new goals and purposes to emerge in the community monitoring process (cf. Model 6 in **Figure 2**). If one focuses only on observational rigor, there is a risk that the community will lose interest.

The Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) illustrates this issue. As explained by Reges and colleagues (104, p. 1837), "CoCoRaHS from its infancy was never envisioned to be a national and international monitoring network" but was seen largely as a tool for climate literacy outreach. In the process, however, the high quality of contributor observations was increasingly appreciated and has bolstered the observing network elements of the program.

For the US National Aeronautics and Space Administration's Global Learning and Observations to Benefit the Environment (GLOBE) program, Amos et al. (81) have identified a similar challenge in ensuring acceptance of their community monitoring products by the broader research community. The challenge relates to upscaling a larger patchwork of observations that may not conform to uniform observational standards or meet interoperability requirements. To solve this issue, the program developed specific recommendations to ensure that data quality and program rigor meet the demands of the effort's management and decision-making context (66).

The effort and resources needed to support capacity building, institutionalization, and program sustainability at the local level also pose a challenge to community monitoring (83, 85) (**Table 2**). Key solutions to circumvent these problems are to integrate the community monitoring processes into the existing natural resource governance framework in the particular area, to integrate tasks into the day-to-day activities of the community members, and to reduce the dependency on human, professional, and financial resources that are not locally available (23, 61).

4. OTHER AREAS IN WHICH COMMUNITY MONITORING HAS BEEN TRIED

While community monitoring is gradually becoming an established practice within natural resource management (16, 105), it has also emerged in other fields. In this section, we provide a brief overview of recent applications of community monitoring within climate change adaptation, social welfare, and health. These areas have been selected because (*a*) they constitute critical global issues alongside the environmental crisis; (*b*) they are key to the livelihoods of natural resource users in many settings, thereby providing opportunities for a more coherent approach to monitoring; and (*c*) they offer methods relevant to monitoring of resource governance, which has so far received little attention in practice and in the scientific literature on community monitoring (**Table 1**).

Understanding developments in these fields can inform natural resource monitoring and provide a basis for cross-disciplinary learning and action. One could argue that community monitoring of climatic phenomena and disasters is also about natural resources, but because of the large volume of scientific literature on climate change and disasters, for the purpose of this review we separate these fields. We first summarize recent applications of community monitoring in these fields and key challenges and then discuss selected key features that are relevant to community monitoring in conservation and natural resource management.

4.1. Climate Change Adaptation Monitoring

Community monitoring has long been part of climate change mitigation efforts. For example, for the past decade, community members have been assessing carbon stocks (forest aboveground biomass) in vegetation plots in tropical forests as part of REDD+ (reducing emissions from deforestation and forest degradation, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stocks) efforts (106, 107). Community monitoring is, however, also relevant in the context of adaptation to climate change. This includes (*a*) monitoring climate change impacts on resources, (*b*) monitoring for participatory adaptation planning, and (*c*) monitoring for disaster risk management. Some of these methods are drawn from natural resources monitoring itself, whereas others have developed independently as adaptation and disaster management approaches have emerged.

1. Monitoring climate change impacts on resources. Adapting to climate change requires understanding the ways in which resources for human production and consumption are affected and change. Methods developed for this purpose are not new to the field of natural resource monitoring and are often drawn from the field itself. Examples include the use of mobile phone apps to document range shifts of plant and marine species (108, 109) and rapid surveys of coastal reef change (110). Several programs in water management are equally relevant in this context (111). For example, a voluntary groundwater monitoring program in Canada provides information on water level changes (112), and community rainfall monitors in Mexico contributed to local government catchment conservation (113).
2. Monitoring for participatory adaptation planning. Other methods focus on linking community monitoring directly to adaptation and agricultural planning (114). For example, a project in Ghana established collaborative fora in which farmers, meteorologists, and local planners combine community observations of seasonal change and meteorological data to plan farming calendars and agricultural service provision as a means to address seasonal unpredictability (115). Efforts to employ community monitoring to track the effectiveness of adaptation measures are also emerging (116). Using the FAO SHARP (Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists) tool, farmers and pastoralists self-evaluate their resilience. This evaluation includes quantitative scoring of their adaptive capacity, which can be aggregated and used by national governments to report adaptation progress under the 2016 Paris Agreement (117).
3. Monitoring for disaster risk management. Community monitoring has been a prominent feature in recent approaches to disaster risk management (118, 119). Methods range from simple community monitoring of flood levels (120) to more comprehensive early warning systems in which communities monitor human and animal health as indicators of famine, develop risk and hazard maps, and disseminate information and warnings through social media and radio announcements (73). As these systems expand in scope, some aim to evolve into broader online environmental observatories whereby community members can monitor environmental hazards and compile knowledge on suitable responses (119, 121).

4.2. Social Welfare Monitoring

Community monitoring has been recently applied within various efforts to promote social welfare, including poverty reduction (122), food security (72), child welfare (123), and education (124). Two key applications are

1. Monitoring social welfare outcomes and trends. Participatory methodologies are applied in studies and evaluations of social welfare interventions, particularly in relation to poverty measures (125, 126). Institutionalized monitoring is less well developed in this regard but is emerging. For example, a community-based poverty monitoring system in the Philippines feeds data into local government planning through a collaborative process of validation and analysis (122). Elsewhere, methods and indicators are being developed toward applying community-level data collection in national-level monitoring of poverty reduction and other UN Sustainable Development Goals (SDGs) (127, 128).
2. Monitoring the performance and accountability of public service delivery. Methods that allow communities to monitor and assess the quality and social accountability of public service delivery have emerged (123, 129; cf. **Table 1**, Democratic Accountability Literature column). Community scorecards (also called citizen scorecards) are particularly widespread.

In Kenya, these have been used to assess whether public institutions deliver on promises and plans within areas such as poverty reduction, schooling, and security (130, 131). Other methods include community audits, in which users are given access to examine the accounts and reporting of public institutions to assess their validity and compare them with received benefits, and grievance redress mechanisms, which allow users to contest and document false claims by public institutions and politicians (129, 132, 133).

4.3. Health Monitoring

Although health services have a long tradition of direct street-level engagement with community members, community monitoring is relatively recent (134, 135). Some overlap with natural resource monitoring exists; for example, harmful algal bloom monitoring has a direct implication for safe human consumption of shellfish and other marine species (136). Applications of community monitoring within the health field include

1. Monitoring disease patterns and trends. The COVID-19 pandemic prompted efforts to apply digital methods to rapidly and safely obtain sizeable data sets on virus trends and community members' behavior (137). For example, a US study employed mobile phone apps through which community members self-reported on their health condition, social behavior, and mental challenges such as depression (138). Efforts to undertake longer-term monitoring of, for example, malaria through mobile phones are also underway (139).
2. Monitoring health service provision. This includes community report cards and scorecards similar to those discussed above (140–142). In several West African countries, community treatment observatories monitor HIV treatment effectiveness and community access to health services. The data are analyzed in multistakeholder fora and used to advocate for improvements vis-à-vis public authorities and politicians (143).
3. Monitoring emerging health issues. Community members are well positioned to monitor health issues that emerge locally or are under the radar of public authorities, including the impacts of environmental change on physical and mental health (144). In Spain, communities monitored invasive mosquito species that are potential disease vectors (145). In India and Indonesia, a project developed qualitative journey maps to identify, track, and visualize everyday health issues in urban communities (146).

4.4. Challenges Reported in Other Areas Where Community Monitoring Has Been Tried

Despite the diversity of methods and contexts of community monitoring in different fields, some overall experiences are recurrent. Three commonly noted challenges for community monitoring in these fields are described below.

First, although in some instances community monitoring is fit for a specific problem at a specific time (e.g., short-term monitoring of hazardous effluents from a factory) and thus not all monitoring programs are meant for the long term, it is regularly considered a challenge in community monitoring programs that the longer-term sustainability of mechanisms and methods is not secured. While some systems have been institutionalized and incorporated into local and national mechanisms, a number are short-term, one-off projects funded by donors as pilot projects or driven by short-term external research and not by the community members (111, 144, 147) (see also Section 3).

Second, collective action and community participation are often assumed but they are by no means a given, and the evidence for actual benefits to community members from monitoring is

LINKS FROM COMMUNITY MONITORING TO DECISION-MAKING

Some studies of community monitoring programs suggest that far more interventions result from community monitoring than from conventional monitoring programs (14). Other studies have found that community monitoring programs were ineffective at leading to decisions beyond the local level (66). Wehn & Almomani (80) reviewed 10 examples of community monitoring programs to explore the perceived outcomes of the programs and the hindering factors from the perspective of decision-makers. In most of the programs, the decision-makers' expectations of community monitoring were similar to expectations of any other new approach to be taken up by government agencies: New approaches require sufficient staff, time, funding, and expertise, and uptake is easier if the decision-makers themselves are involved in the design, having ownership in the process (149–152) (see also **Figure 3**).

limited (111, 129) (see also the sidebar titled Empowerment Potential of Community Monitoring). Problems of representation and elite capture are also a challenge (132, 140).

Third, responsiveness of national governments to data and proposals generated from community monitoring has been a challenge in some settings as a result of institutional path dependency or reluctance to relinquish authority to lower levels (129, 132, 148). These challenges echo those found for community monitoring for natural resource management described in **Table 2** and in the sidebar titled Links from Community Monitoring to Decision-Making, suggesting there is scope for learning across the sectors.

4.5. What Community Monitoring of the Environment Can Learn from Other Fields

Community monitoring of the environment can learn from other fields, particularly in three key areas: monitoring public performance and accountability in environmental governance, monitoring community benefits from conservation, and institutionalizing community monitoring.

4.5.1. Monitoring public performance and accountability in environmental governance. Most community monitoring programs for natural resource management have focused on monitoring resource trends and use. These programs have been the subject of studies within the adaptive management and citizen science literatures (**Table 1**). So far, relatively limited attention has been given to monitoring how resource use and conservation are governed and how communities can contribute to this monitoring effort (see also Section 2). Two important aspects of this are how and to what extent governments and public authorities comply with their obligations and commitments as stipulated in national and international legal frameworks, agreements, and policies on the environment. Here, community monitoring of the environment can benefit from three methods used in performance and accountability monitoring within the social welfare and health sectors discussed above.

1. The community scorecard method from the social welfare and health sectors can be used to assess the perceived conservation efficacy of public wildlife and forestry agencies (130, 131). This may highlight points of contention but also serves as an indicator of public acceptance of such agencies and their approaches to conservation, thereby facilitating a more informed basis for dialogue and policy.
2. In extension of this, social audit methods could help enhance transparency of how public agencies in the natural resource sectors allocate funds and staffing. This could be done, for

INCREASING HARASSMENT OF COMMUNITY MONITORS

Records of persecution of community members for defending their lands and the environment have been increasing, particularly since 2010 (see **Figure 4*b***). An unknown proportion of the killed community members were killed while monitoring the environment and the status of the natural resources. Between 2002 and 2020, more than 2,200 people were killed in 57 countries, mostly in countries with authoritarian rule (82, 154–156) (**Figure 4**). In 2020 alone, 227 lethal attacks (about four people a week) were recorded, making it the most dangerous year on record for environmental defenders (157). Seventy percent of attacked defenders were working to protect the world's forests from deforestation and industrial development (158). Over one-third of the fatal attacks targeted Indigenous people even though Indigenous communities make up only 5% of the world's population. Transparency platforms like Global Forest Watch enable everyone with access to the Internet to view forest loss occurring in near real-time, but they may create risks for community monitors on the ground who are investigating deforestation events on their land. Zeng et al. (159) found higher rates of homicides in areas where otherwise limited resources (e.g., freshwater, land, forests) are more plentiful, suggesting a potential overlap between ecosystems where community monitoring has great potential and those areas where killings are taking place.

example, by providing trained community volunteers regularized access to public accounts and work plans as has been done in other sectors in India (133).

3. Under the right conditions, social audits could also be linked to and employed in emerging community monitoring efforts that examine whether government-sanctioned resource extraction activities such as logging or mining comply with environmental regulations and commitments (153). Clearly, in some settings such methods may involve risks for community members; whether these methods are feasible and whether members can remain anonymous would need to be carefully assessed (see the sidebar titled Increasing Harassment of Community Monitors).

More generally, application of these methods in environmental monitoring should as much as possible be linked to and accompanied by independent grievance redress mechanisms, such as local or national ombudsmen, public inquiries, or civil society platforms, to ensure alternative arenas for applying the results of monitoring if they are ignored by government authorities.

4.5.2. Monitoring community benefits from conservation. Conservation has long promised benefits for local communities, not least in developing countries where changing variants of community-based conservation have emphasized economic benefits and ecosystem services as incentives for community conservation (160). Most recently, the growing attention on NbS (161) and OECMs (162) has highlighted the potential importance of Indigenous territories and community lands in addressing not only biodiversity loss but also climate resilience and adaptation by humans and local development (163–165).

Ironically, however, little attention has been given to how these promised benefits for communities can be monitored on a continuous basis. While there have been numerous studies of community benefits from conservation, these are typically conventional researcher-led studies or externally driven short-term project monitoring for the benefit of donor-required project reporting (166). Community monitoring of the environment must expand to also monitor how and to what extent communities really benefit from conservation. This is critical not only from a human development perspective but also for conservation success, as it can help mitigate conflicts by documenting community benefits and acting on situations where promised benefits do not materialize (167, 168). Three overall areas need monitoring:

1. The actual ecosystem services provided to communities at the user end. For example, the extent to which forest conservation leads to improved household water security is monitored by combining community water monitoring methods (169) with household scorecard monitoring methods from the social welfare and health sectors (141).
2. The economic benefits from conservation. For example, household benefits from sustainably harvested nontimber forest products are monitored by using methods from participatory poverty and impact assessments (126, 130).
3. The rights of communities in conservation, including land and water rights and procedural rights such as representation and participation in leadership in conservation decision-making (84). For example, the International Working Group on Indigenous Affairs has developed tools whereby Indigenous communities can assess whether their rights, including land rights, are sustained (**https://indigenousnavigator.org/news**).

Experience from community monitoring in adaptation, social welfare, and health shows that such methods need not be complicated or time-consuming and can consist of, for example, annual exercises carried out by communities themselves.

4.5.3. Institutionalizing community monitoring. As discussed in Sections 3.3 and 4.4, community monitoring sometimes suffers from a lack of institutionalization and linking to broader institutional frameworks. While the problem is not unique to environmental monitoring, three approaches from other fields could benefit environmental monitoring in this respect.

1. Community observatories and their emergence in disaster risk management and health sectors. Community observatories provide a potential means of integrating monitoring data for analysis and action by community stakeholders (119, 143). Where digital solutions are practically feasible, such observatories can furthermore enhance individual access to monitoring data (121), thereby improving transparency of, for example, ecosystem health and community benefits from conservation schemes. An example of a community observatory is the integrated forest monitoring observatory that monitors forest loss in Cambodia using satellite images combined with community groundtruthing websites (170).
2. Linking community monitoring data to planning and decision-making in local governments. The significance of local governments for successful conservation governance is increasingly recognized, including in otherwise large-scale efforts such as REDD+ initiatives (171, 172). The linking of participatory poverty monitoring to local government planning and decision-making in the Philippines is an example that could be adapted for conservation and natural resource management (122; see also 14, 23).
3. Linking community monitoring to national and international frameworks. Emerging approaches that feed into such processes have been proposed and piloted in relation to the Paris Agreement (117) and the UN SDGs (127, 128). Such approaches can help inform similar approaches within conservation, for example, proposals to link community monitoring to the Convention on Biological Diversity (173; F. Danielsen, N. Ali, H.T. Andrianandrasana, A. Baquero, U. Basilius, et al., manuscript submitted).

5. HOW COMMUNITY MONITORING CAN BE MORE EFFECTIVE

How do you increase the effectiveness of community monitoring of natural resource systems and the environment and make this approach more widely used? Because of the range of different community monitoring programs, increased effectiveness could be achieved, for example, by improving approaches to data collection, improving or adopting new tools for data management, or creating clearer pathways for data to be used and applied to decision-making. Perhaps the best way to demonstrate effectiveness of community monitoring is to show that involving community members in monitoring leads to better outcomes for resource management and other types of decision-making (see Reference 14 for examples). In this section, we discuss efforts to standardize data collection and to increase the use of digital tools for improving data management and sharing in community monitoring. We also discuss approaches to integrating monitoring with land and resource management through Indigenous Guardians programs as an example of how communities can be more engaged in and committed to involvement in monitoring.

5.1. Improving Data Collection and Standardization Through Coordination

Greater standardization of data collection protocols would allow data to be shared, compared, and potentially integrated for monitoring larger regions (23, 174). This could have benefits to programs in terms of increasing the acceptance and perception of the validity of the data by the broader scientific community. It could also allow programs to support one another with refining collection protocols and by potentially sharing costs for the development of digital data management tools.

One way that programs are supporting standardization of data collection is by developing or adopting mobile apps that make it easier for community members to enter data and have the data processed and uploaded without the need for an intermediary (26, 175–177). So far, efforts to coordinate data collection across multiple community monitoring programs for the purpose of sharing data have been extremely limited (or perhaps nonexistent); however, this has been discussed as a goal of some networking efforts (178, 179). One challenge to these efforts has been a lack of incentive on the part of the programs themselves, which often focus on more local needs for data.

Support from outside the community level could facilitate better organizing and collaboration that may eventually result in standardization efforts. This approach is visible in efforts such as the European Union–funded Integrated Arctic Observation System (INTAROS) project (75, 174, 178), the National Science Foundation–funded Exchange for Local Observations and Knowledge of the Arctic (ELOKA) (180), and Alaska's Landscape Conservation Cooperatives (181), all of which have convened workshops to support better communication and coordination of community monitoring programs.

In Alaska, the Harmful Algal Bloom Network (136) coordinates federal and state agencies, universities, shellfish farmers and associations, and tribes to monitor coastal algal blooms with a focus on human health impacts. Indigenous Guardians programs in North America, which often incorporate monitoring programs as part of a larger tribal or Indigenous conservation effort, have made efforts to coordinate with each other. For example, the Northern Indigenous Stewardship Network (182) focuses on building connections and facilitating information-sharing among Indigenous Guardians and environmental stewardship programs across northern Canada. Because they offer the opportunity to build trust-based relationships, these sustained networks that engage the same members over time are likely to have greater success with coordinating collection protocols as well as data sharing.

5.2. Improving Data Management and Sharing

Many community monitoring programs are adopting digital tools and technologies to support data management and sharing. These tools offer the potential to greatly expand the reach of the programs by facilitating broader access to and discoverability of data (183), by integrating different types of data (and thus enhancing the value of local observations to different end users), and by automating some aspects of data processing to make data more immediately usable (26). They also may make it easier for community members to collect data by automating data entry and logging location information automatically.

In spite of the significant potential for digital tools to increase the effectiveness of data collection and management, there are also risks associated with their widespread adoption (184). Good practices for community monitoring require recognition of community ownership of data and ongoing efforts to ensure that the community maintains control over data generated through the program (185). When Indigenous community members are involved, these practices are rooted in the UN Declaration on the Rights of Indigenous Peoples and the Principle of Free, Prior and Informed Consent (FPIC) (186, 187).

Indigenous peoples also have the right to data sovereignty based on treaty agreements and international law. Indigenous data sovereignty recognizes the rights of Indigenous peoples to maintain control of information by, for, or about their people, lands, waters, and territories (188). To that end, the International Indigenous Data Sovereignty Interest Group within the Research Data Alliance has developed Indigenous data guidelines that set a minimum of requirements for Indigenous-designed data approaches and standards that include the Indigenous rights to data governance and decision-making. The CARE (Collective benefit, Authority to control, Responsibility, and Ethics) principles for Indigenous data governance outline obligations for researchers, governments, funders, and data stewards in the collection, ownership, and dissemination of Indigenous data (189). Furthermore, digital tools make it easier to share information broadly but risk making it more difficult for communities to maintain control over data, including potentially sensitive data.

It is difficult to carefully consider all the potential uses of data once it is released to the public, and communities are concerned that data be used for purposes that support (rather than disrupt) their ongoing livelihoods and their stewardship of natural resources (190). The existing data-centric approach represented in the FAIR (findable, accessible, interoperable, reusable) guiding principles for scientific data management and stewardship forms a framework that uses metadata to safeguard the reusability of Indigenous data (189). Digital data management tools offer solutions such as password protection and creating enhanced access to data for community members and limiting public access. These techniques are not infallible, however, so the adoption of digital tools does require a greater focus on a thoughtful and ongoing process to ensure that data are managed ethically and in accordance with community goals (191).

Inequities in digital access limit the effectiveness of digital tools for community data management. Remote communities may have limited or irregular access to the Internet, or it may be prohibitively expensive to connect. Hardware such as computers and mobile phones are also expensive and require ongoing investments and replacement over time. Solutions such as creating offline versions of apps are partial remedies; they do not address underlying inequities in access to digital tools. Another issue with digital solutions is that the software often requires large investments to develop, upgrade, and maintain. Development of software applications for community data management should also be done with significant consultation and feedback from community users, which requires time and resources. In short, although digital tools can increase effectiveness of data collection and sharing in various ways, these approaches can also be expensive and add complexity to data management.

5.3. Improving Data Application and Use in Support of Self-Determination

While community monitoring may appeal to scientists and conservationists as a way to produce valuable data in a decentralized, crowdsourced and sometimes cost-effective way, deepening community commitment requires demonstrating the usefulness of community monitoring in meeting community information needs and, ultimately, supporting greater self-determination. Somewhat ironically, community monitoring is a tool that can both support neoliberal governance—the withdrawal of state commitments to collecting high-quality environmental data and information in favor of a do-it-yourself approach to monitoring—and increase local sovereignty or empower community knowledge and voices in decision-making (66). These two goals are not necessarily contradictory, but without significant funding from the state and other entities, community monitoring programs struggle to sustain themselves (84) (**Table 2**; Section 3.3).

Monitoring programs that incorporate direct information-sharing pathways with decision-making bodies such as comanagement boards may result in greater use of monitoring data (14, 178). Programs that recognize Indigenous sovereignty and support Indigenous governance, such as the Indigenous Guardians model, use monitoring data to support Indigenous nation-building and self-determination (192). Monitoring is just one component of these programs, which also include other explicit goals such as supporting employment and engagement with land-based activities as well as secondary benefits such as teaching Indigenous languages and addressing intergenerational trauma (193). Although these programs are being implemented within governance and funding arrangements that privilege state control above Indigenous sovereignty (192), Indigenous Guardians programs offer a model that embeds community monitoring within a larger project that ostensibly is about supporting self-determination. This approach, though in need of further study, has the potential to generate stronger support at the community level because of clear and direct links to supporting greater control over environmental decision-making and governance.

6. HOW THE FIELD OF COMMUNITY MONITORING IS LIKELY TO EVOLVE

How is the field of community monitoring for natural resource management likely to evolve? On the one hand, some developments may reduce the relevance and importance of community monitoring. These include the emergence of several approaches that can potentially substitute some aspects of community monitoring: (*a*) sophisticated automated sensors that can detect, for example, the presence of vocal birds in a particular area (194, 195); (*b*) emergence of big data, such as Google traffic, which can track, for example, changing patterns in human–tick (*Ixodes ricinus*) encounters (196); (*c*) routine collection of information that can serve as proxy for data community members can collect (197); and (*d*) emergence of machine learning and artificial intelligence that may enable more systematic projections of changes in natural resources and the environment (198, 199).

Likewise, the proportion of the world's population that lives in rural areas and depends on the natural ecosystems for their livelihoods is decreasing (3, 200), although during times of conflicts services derived from the natural ecosystems remain critically important, particularly to marginalized communities. Moreover, in countries with authoritarian rule it is becoming increasingly dangerous for community members to defend the environment and the land (**Figure 4**; the sidebar titled Increasing Harassment of Community Monitors).

On the other hand, there are also significant developments that may increase the relevance and importance of community monitoring. These include the economic and educational gap between the powerful elite living in the towns and cities and the world's rural communities (202, 203). Likewise, an awareness of the value of functional ecosystems, and the opportunities that Indigenous communities and small-scale resource users now have for being heard through, for example, the use of community monitoring tools, is increasing (105, 204). Moreover, international agreements increasingly emphasize that decisions on natural resource management should take into consideration both Indigenous and local knowledge and scientific knowledge (for example, the

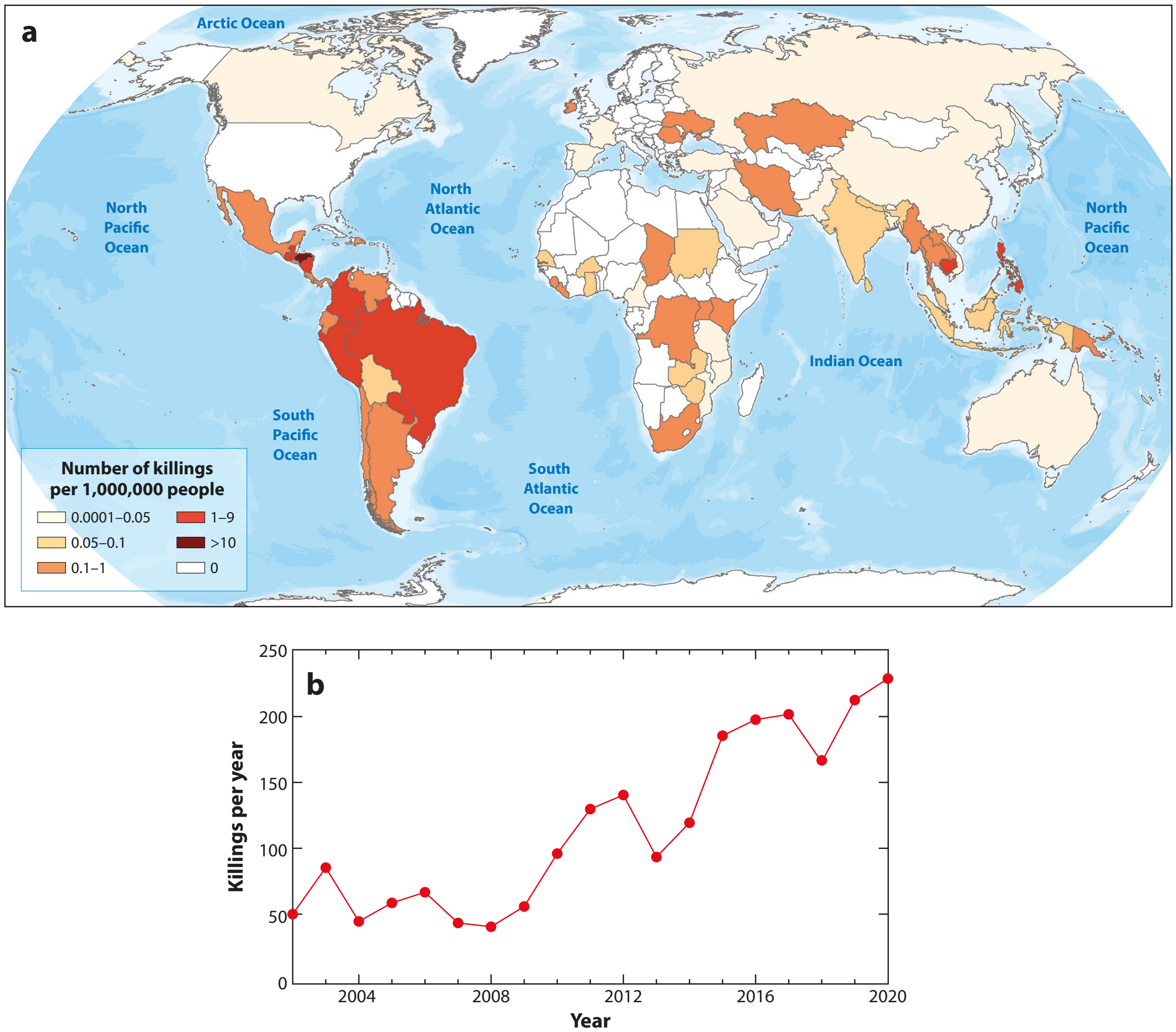

Figure 4

Community members reportedly killed between 2002 and 2020 for defending their lands and the environment. (*a*) Geographical distribution of the killings of community members. (*b*) The number of community members killed per year. The figures are likely underestimates, because many murders go unreported, particularly in rural areas. Data from Global Witness (157, 201). Basemap reproduced from Esri. Data set can be found in **Supplemental Table 1**.

Supplemental Material >

Aarhus Convention and the International Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean; 205, 206). The Indigenous Guardians model, which is expanding across Northern America, New Zealand, and Australia, identifies ways to strengthen tribal and Indigenous sovereignty by observing and monitoring natural resources (192). As these programs mature, important lessons will emerge for how community monitoring programs can more successfully support community involvement in natural resource governance.

Robust multicountry studies have shown that the measurable effect size of community monitoring on reductions in resource extraction is comparable to the effect size of the establishment of protected areas and of payments for environmental services programs (51). Nevertheless, whether community monitoring for natural resource management will further develop and be more widely used in the coming years is impossible to foresee (207, 208). Our review of the recent literature, however, suggests that community monitoring for natural resource management has particular potential to further develop in three areas:

1. Learning from and linking to governance monitoring. Community monitoring for natural resource management could benefit from employing and expanding the social accountability monitoring methods within the social welfare and health sectors. As discussed above (Section 4.5), although scorecard methods have been used in some natural resource management settings, the attention to governance issues has been limited and rarely integrated into community monitoring itself (209). This could include community monitoring of (*a*) the efficacy and transparency of government agencies in conservation, (*b*) delivery of promised benefits from community-based conservation programs, (*c*) protection of community rights to land and other natural resources, (*d*) community members' participation in conservation decision-making, and (*e*) threats, incrimination, arrests, and abuses of environmental and human rights defenders. Similar methods could be used by community members to monitor community-level governance.
2. Embracing integrated approaches at the community level. The proliferation of community monitoring within a range of fields contains a risk of building parallel mechanisms and replicating silo thinking at community levels. While different disciplines require different methods, the resulting data, analysis, and decision-making would benefit from being integrated to a greater degree at the community level (144). For example, the data from monitoring environmental, social, and health trends could be compiled in community observatories, allowing for cross-cutting analysis and response (119).
3. Linking to national and international frameworks. The numerous country commitments to global agreements, which require progress reporting and documentation, are an obvious entry point. Community monitoring methods that can feed into such processes have been proposed and piloted in relation to the Paris Agreement (117), the Convention on Biological Diversity (173), and the UN SDGs (127, 128). However, the notion that community monitoring is relevant beyond the local level is hampered by lack of awareness and skepticism, sometimes among proponents of community monitoring themselves (210). A greater emphasis on cross-disciplinary learning and joint methods development is needed to explore and document the potential of community monitoring in this respect. Here, programs such as the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) and community-based REDD+ and forest restoration initiatives (211) that integrate remote sensing and surface-based observations to support local-scale decision-making and management may serve as catalysts (69, 79).

SUMMARY POINTS

1. In community monitoring programs, community members lead the design, the data collection, and the data interpretation, although external researchers, government agencies, and civil society associations may be involved in providing support and assistance.
2. Community monitoring can track phenomena of concern to community members at fine temporal and spatial scales, contribute to planning and decision-making, and lead to empowerment of community members in resource management.

3. Some community monitoring programs have been challenged by lack of long-term sustainability, limited collective action and community participation, and insufficient state responsiveness to data and proposals.
4. There is great potential to learn from other fields in terms of monitoring public performance and accountability in environmental governance, monitoring community benefits from conservation, and institutionalizing community monitoring.
5. Community monitoring can be made more effective with improved approaches for data collection, data management and sharing, and application in support of self-determination.
6. Data frameworks such as the CARE and FAIR principles coupled with an FPIC approach are the minimum requirements to promote Indigenous rights, governance and sovereignty over the collection, ownership, and dissemination of Indigenous data.
7. Community members defending the environment are increasingly persecuted by government agencies and corporations, particularly in countries with authoritarian rule.
8. Promising areas for future development of community monitoring for natural resource management are incorporating governance issues into monitoring, embracing integrated approaches at the community level, and establishing stronger links to national and global frameworks.

FUTURE ISSUES

1. Community members, scientists, and government staff often represent different world views and they have different perspectives on conservation and sustainable development. There is a need to better understand how to obtain, use, and combine data from different people with varying beliefs, epistemologies, rationalities, and cosmologies in mutually beneficial ways. One example is that scientists typically prefer data in their most disaggregated form, whereas decision-makers need a synthesis that describes the bigger picture, what the data show about the topic of interest, how strong the evidence is, and therefore what needs to be done, by whom and when.
2. There is need for cross-disciplinary learning and the development of joint methods to further explore and document the potential contribution of community monitoring to national and international frameworks such as the Paris Agreement, the Convention on Biological Diversity, and the UN Sustainable Development Goals. Policy makers, UN agencies, and national statistics offices should address the data gaps that exist in the global frameworks by incorporating community monitoring data, programs, and institutions into the official statistics and policy processes. There is a need for promoting and protecting local knowledge and agendas, not for transforming local knowledge to fit global agendas.
3. Government decision-makers should be encouraged to do more to ensure that legal frameworks, government staff time, and funding are in place that support the use of community monitoring of the environment for planning and decision-making on natural resource management.

4. Education and training reform of the next generation of public resource managers, scientists, and staff of nongovernmental organizations is needed so they become able to facilitate, implement, and operationalize fairer and more inclusive participatory approaches to natural resource management in practice.
5. Governments and nongovernmental organizations should promote community members' use of advanced technologies such as sensors, artificial intelligence, and digital platforms for community monitoring of the environment. Often, the conservation nongovernmental organizations have large budgets for trail cameras, drones, night visions, and the like. Only rarely are advanced technologies for environmental monitoring put into the hands of community monitors.
6. Environmental human rights defenders play an important role in upholding, implementing, and advancing environmental rule of law. Legal protection of environmental human rights defenders requires attention in line with Sustainable Development Goal 16 (peace, justice, and strong institutions). It is important that UN agencies, national governments, nongovernmental organizations, the private sector, and the general public understand the vital role of environmental human rights defenders in protecting environment.

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RELATED RESOURCES

PMMP (Particip. Monit. Manag. Partnersh.). 2015. *Manaus Letter: recommendations for the Participatory Monitoring of Biodiversity*. Developed by 220 participants from 18 countries by invitation of the CBD Secretariat at the International Seminar on Participatory Monitoring of Biodiversity for the Management of Natural Resources 2014. Manaus, Brazil, Sep. 22–26, 2014. 9 pp. **http://dx.doi.org/10.25607/OBP-965**. Guidelines for practitioners who organize, or develop capacity in, community monitoring of natural resource systems and the environment.

Community Based Monitoring Library: **https://mkp28.wixsite.com/cbm-best-practice**. Community monitoring library with information about seven Arctic community monitoring and citizen science programs, the manuals they use, and the key lessons learned as described by the organizers of the programs.

Prey Lang Community Network: **www.preylang.net** and **https://vimeo.com/154774156**. A network of more than 100 villages whose members patrol Prey Lang forest in Cambodia on a voluntary basis. They document illegal logging with a smartphone app, intercept illegal logging, seize chainsaws and other logging equipment, and petition the government to enforce the forest law.

PISUNA-net Local Observations database: **https://eloka-arctic.org/pisuna-net/en** and **http://www.pisuna.org/**. Digital platforms for a community monitoring program, building on Indigenous and local knowledge. PISUNA-net is a searchable database of observations by fishermen and hunters and their recommendations on natural resource management interventions in West Greenland.

Monitoring Matters Network Publications: **http://www.monitoringmatters.org/publications.htm**. List of publications on community monitoring of environment and natural resources.

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