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The Contributions of Community-Based Monitoring and Traditional Knowledge to Arctic Observing Networks: Reflections on the State of the Field

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ABSTRACT. Community-based monitoring (CBM) in the Arctic is gaining increasing support from a wide range of interested parties, including community members, scientists, government agencies, and funders. Through CBM initiatives, Arctic residents conduct or are involved in ongoing observing and monitoring activities. Arctic Indigenous peoples have been observing the environment for millennia, and CBM often incorporates traditional knowledge, which may be used independently from or in partnership with conventional scientific monitoring methods. Drawing on insights from the first Arctic Observing Summit, we provide an overview of the state of CBM in the Arctic. The CBM approach to monitoring is centered on community needs and interests. It offers fine-grained, local-scale data that are readily accessible to community and municipal decision makers. In spite of these advantages, CBM initiatives remain little documented and are often unconnected to wider networks, with the result that many practitioners lack a clear sense of the field and how best to support its growth and development. CBM initiatives are implemented within legal and governance frameworks that vary significantly both within and among different national contexts. Further documentation of differences and similarities among Arctic communities in relation to observing needs, interests, and legal and institutional capacities will help assess how CBM can contribute to Arctic observing networks. While CBM holds significant potential to meet observing needs of communities, more investment and experimentation are needed to determine how observations and data generated through CBM approaches might effectively inform decision making beyond the community level.

Key words: community-based monitoring; traditional knowledge; observing networks; environmental change; sustainability; knowledge management; natural resource management

RÉSUMÉ. Dans l'Arctique, la surveillance communautaire (SC) reçoit un appui de plus en plus grand de la part de nombreuses parties intéressées, dont les membres de la communauté, les scientifiques, les organismes gouvernementaux et les bailleurs de fonds. Dans le cadre des initiatives de SC, des habitants de l'Arctique effectuent des tâches permanentes d'observation et de surveillance ou participent à de telles tâches. Les peuples indigènes de l'Arctique observent l'environnement depuis des millénaires. Souvent, la SC fait appel aux connaissances traditionnelles, connaissances qui peuvent être employées seules ou conjointement avec les méthodes classiques de surveillance scientifique. Nous nous sommes appuyés sur les connaissances dérivées du premier sommet d'observation de l'Arctique pour donner un aperçu de l'état de la SC dans l'Arctique. La méthode de SC est centrée sur les besoins et les intérêts de la communauté. Elle permet d'obtenir des données à grain fin à l'échelle locale, données qui sont facilement accessibles par la communauté et les preneurs de décisions municipaux. Malgré ces avantages, il existe peu de documentation au sujet des initiatives de SC et souvent, ces initiatives ne sont pas rattachées aux grands réseaux, ce qui fait que bien des intervenants ne comprennent pas clairement ce qui se passe sur le terrain et ne savent pas vraiment comment appuyer la croissance et le développement de la surveillance communautaire. Les initiatives de SC respectent les cadres de référence nécessaires en matière de droit et de gouvernance, et ceux-ci varient considérablement au sein des contextes nationaux. L'enrichissement de la documentation en ce qui a trait aux différences et aux similitudes qui existent entre les communautés de l'Arctique en matière de besoins d'observation, d'intérêts et de capacités juridiques et

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institutionnelles aidera à déterminer en quoi la SC pourra jouer un rôle au sein des réseaux d'observation de l'Arctique. Bien que la SC ait la possibilité de jouer un rôle important dans les besoins d'observation des communautés, il y a lieu de faire plus d'investissements et d'expériences pour déterminer comment les observations et les données découlant des méthodes de SC pourront favoriser la prise de décisions au-delà des communautés.

Mots clés : surveillance communautaire; connaissances traditionnelles; réseaux d'observation; changement environnemental; durabilité; gestion du savoir; gestion des ressources naturelles

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INTRODUCTION

Community-based monitoring (CBM) engages the capacities of residents in ongoing observing and monitoring of the Arctic. CBM has been defined as "a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track, and respond to issues of common community concern" (EMAN, 2003:4). An alternative definition proposed by Danielsen et al. (2014a:15) is "monitoring… undertaken by local stakeholders using their own resources and in relation to aims and objectives that make sense to them." In the Arctic context, resources from outside the community often contribute to formal CBM initiatives. In this article, we define CBM as a process of routinely observing environmental or social phenomena, or both, that is led and undertaken by community members and can involve external collaboration and support of visiting researchers and government agencies. In Arctic Indigenous communities, many CBM initiatives incorporate traditional knowledge (TK), which can be defined as the cumulative and transmitted knowledge, experience, and wisdom of human communities with a long-term attachment to place (Kliskey et al., 2009). Traditional knowledge, sometimes referred to as Indigenous knowledge, is "a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems" (ICC, 2013).

Monitoring of the Arctic did not begin with the introduction of formal scientific monitoring initiatives; Arctic Indigenous peoples have been observing the environment for millennia, and other Arctic residents also routinely observe and respond to change. For example, Inuit hunters use both personal and intergenerational knowledge and observations of sea ice dynamics to facilitate safe hunting practices and identify safe travel routes on the sea ice (Laidler et al., 2009), and Sámi reindeer herders draw on TK of snow and ice conditions to manage winter pasture and grazing (Riseth et al., 2011). CBM is therefore based on the understanding that monitoring is not solely the concern of governments or scientific researchers, but is a process that Arctic residents also have a stake in and engage in for their own purpose and on their own terms.

As an approach to Arctic observing, CBM has many advantages (Danielsen et al., 2009; Huntington, 2011). Limited access and the high cost of infrastructure in remote, northern regions can present challenges for scientists seeking year-round data (Danielsen et al., 2014b). Local residents, especially in Indigenous communities, often possess intimate knowledge about the environment (Ferguson et al., 1998; Gearheard et al., 2011), and have an interest in the sustainability of both biological resources and abiotic features such as sea ice (Oskal et al., 2009). They are capable of applying their skills and capacities to participate in organized and systematic data gathering (Danielsen et al., 2014b).

In spite of the promise of CBM, this approach remains under-represented and poorly understood within wider Arctic monitoring networks (Huntington, 2011). A number of factors contribute to this situation. First, the results of community-based efforts are not always shared widely beyond the community level (Sharpe and Conrad, 2006). Moreover, since national funding networks were originally designed to support the efforts of government and research institutions, community-led CBM initiatives that lack direct connections to these institutions face a relative disadvantage (Pollock and Whitelaw, 2005; Berkes et al., 2007). Third, in our experience, a bias remains in the scientific community against monitoring done by community residents who lack formal training in data collection and analysis. Further, community-based monitoring often embodies a significant contribution from traditional epistemologies. Researchers from outside the community, particularly those unfamiliar with the local context, can find it difficult to understand monitoring based on TK. Community members may prioritize different phenomena for monitoring than visiting researchers would choose, and they often use alternative indicators to assess and understand stasis and change (Huntington, 1998, 2000).

Drawing on the literature and reflections initiated in the context of the 2013 Arctic Observing Summit, we offer an overview of the current state of CBM in the Arctic and reflect on how CBM can be supported to contribute to the design and infrastructure of wider observing systems in the Arctic. CBM was absent from the formal agenda of the first Arctic Observing Summit, held in Vancouver, British Columbia, from 30 April to 2 May 2013, though it was the subject of several white papers contributed by the observing community, including one by the present authors. At the 2014 Arctic Observing Summit in Helsinki, Finland, a dedicated session focused on community-based monitoring approaches, reflecting a strong interest of CBM practitioners in being part of a broader dialogue and network-building process within the larger Arctic observing community.

TRADITIONAL KNOWLEDGE, WESTERN SCIENCE, AND KNOWLEDGE CO-PRODUCTION

Traditional knowledge uses a range of perspectives, from the physical to the allegorical to the spiritual (Kliskey et al., 2009; Lynch and Hammer, 2013), and is adaptive, incorporating multigenerational observations, lessons, and skills, as well as direct experience (ICC, 2013). Like all bodies of knowledge that are applied and used, TK is dynamic and responsive to change (Ellen, 1998; ICC, 2013). Some researchers and Indigenous practitioners prefer the term "Indigenous science" because it emphasizes the dynamic nature of these knowledge systems, the systematic nature of observations they generate, and the fact that science is not a uniquely Western paradigm (Turnbull, 1997; Barsh, 2000; Kliskey et al., 2009; Barrett, 2013).

Here we pay particular attention to CBM in the Indigenous community context, a focus that stems from our experience and interest as researchers and practitioners; however, we recognize that other citizen groups and stakeholders also have the potential to contribute local knowledge to Arctic observing through community-based monitoring. Local knowledge refers to the knowledge of the local residents of a community, often the users of local resources. Unlike TK, it is not necessarily embedded within an explicit belief system (Kliskey et al., 2009).

Individuals and groups with local knowledge and on-the-ground observing capacity in the Arctic include hunters, subsistence and commercial fishers, sports enthusiasts, adventurers, bird watchers and other environmentally interested people. While the term "community" is often interpreted to mean a permanent settlement, it can also refer to these different human collectives or "communities of practice" (Wenger, 1998) that interact with the landscape in various, dynamic ways. Nomadic reindeer herders in the Russian North and the crews of fishing vessels far from home can be part of a CBM approach to monitoring.

A collaborative approach to CBM involves both scientific researchers and residents, including TK holders (Getz et al., 1999; Danielsen et al., 2009; Conrad and Hilchey, 2011); this approach has been referred to as "knowledge co-production" (Kofinas et al., 2002; Armitage et al., 2011; UNESCO, 2012). Collaborative projects using this approach have documented Arctic community members' detailed knowledge of key components of their environment, such as sea ice (Laidler, 2006; Mahoney et al., 2009; Fidel et al., 2014), weather patterns (Lynch et al., 2008; Gearheard et al., 2010; Weatherhead et al., 2010; Fidel et al., 2014), and caribou (Ferguson et al., 1998; Russell et al., 2013). These efforts parallel global initiatives, such as those of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), to champion the idea of a "multiple evidence base" that includes Indigenous and local knowledge and natural and social science to conceptualize the interactions between social and ecological systems (Thaman et al., 2013; Tengö et al., 2014).

For example, a study of changes in snow and ice conditions in Sweden drew on TK of Sámi reindeer herders about snow type and pasture, as well as snow density and hardness measurements contributed by scientists (Riseth et al., 2011). The researchers found that TK holders observed a greater range of changes and recognized the significance of some of the observed changes more readily than scientists did. Scientific measurement and models, however, allowed for projection into the future, which was important for adaptation planning and decision making. In another study in Canada, Inuit had observed that the weather during the spring months was more changeable than in the past. Drawing on this observation, meteorologists analyzed weather persistence, the "tendency of a warmer than normal day to be followed by another warmer than normal day" (Weatherhead et al., 2010:525). They found that over the past 20 years, weather persistence in the spring has dropped, a finding that matched Inuit observations (Weatherhead et al., 2010). The researchers involved noted that it was an insight from Inuit knowledge that prompted them to focus on weather persistence and emphasized that combining Indigenous knowledge and formal scientific methods can lead to novel insights.

Western science and TK may be more similar than conventional treatments in the social and natural sciences suggest, with a shared commitment to testing and updating hypotheses on the basis of observed data (Gorelick, 2014). Sociological inquiries have demonstrated the situated and relational nature of all knowledge (Jasanoff, 2004; Yearley, 2005), suggesting that science is just as "local" as TK (Turnbull, 1997). These terms are therefore a shorthand way of referring to particular knowledge traditions that, in spite of their differences, also have much in common (Gorelick, 2014). While we acknowledge that these terms have significant limitations, we adopt them here because they are widely used and familiar within the Arctic research community.

COMMUNITY ENGAGEMENT AND THE UTILIZATION OF COMMUNITY-BASED APPROACHES

Involvement of community residents is a defining characteristic of community-based monitoring. Since Arctic communities are regionally and internally diverse, the term "community-based" does not imply that the entire community is equally involved or invested in monitoring, but rather that the project engages the expertise and ongoing participation of some residents. These participants may be high school or college students, TK holders who are recognized as experts within the community, individuals interested in learning scientific methods and adapting new technologies to meet local needs, and individuals who are active in fishing and hunting activities, among others.

Formal monitoring initiatives that define themselves as "community-based" use different approaches to community engagement. At one end of the spectrum, government or academic researchers or environmental organizations may enlist community members in collecting data or samples for initiatives driven by the information needs of institutions located outside the community. At the other end, residents and local institutions drive the establishment of monitoring initiatives based on information needs within the community. Within this range, community members may be involved in some or all aspects of the initiative, from setting goals and defining methods, to data collection, to analysis and interpretation, to sharing and disseminating the results and using them for decision making (Danielsen et al., 2009; Gofman, 2010).

Robust community engagement is a key factor in the long-term viability of CBM initiatives (Pollock and Whitelaw, 2005; Danielsen et al., 2014b). Researchers seeking to partner or establish monitoring programs with communities are most successful when they have a strong understanding of community needs and expectations (Gearheard and Shirley, 2007), take an open and engaged approach to communication with community members (Pearce et al., 2009), and are flexible and adaptive (Pollock and Whitelaw, 2005). An important first step is familiarity with ethics protocols and practices for working with Indigenous knowledge holders, including intellectual property rights and data stewardship rights and responsibilities (Pulsifer et al., 2012). Factors that impede engagement include high turnover of community observers and local staff affiliated with CBM initiatives, government spending cuts and high turnover of government agency staff, and under-resourcing of initiatives that precludes adequate compensation for community participation (ITK and NRI, 2007; Pearce et al., 2009). These factors may have implications for the longevity of initiatives. One strategy that has been successful in sustaining community engagement is to incorporate monitoring activities into the existing everyday activities of local residents (Danielsen et al., 2014b).

In some cases, communities interested in soliciting outside expertise and scientists eager to partner with communities may be unsure of how to initiate collaborations. Formal institutions that have been established at different scales of governance can play a role in making the connections needed. For example, the Ittaq Heritage and Research Centre was established at the community level in Clyde River, Nunavut, to support community leadership in research. At the regional level in Canada, Inuit Research Advisor positions have been established with support from national research programs, including the Northern Contaminants Program (NCP), ArcticNet, and Nasivvik, to address the questions and concerns that communities and researchers may have about research priorities, projects, and practices. The NCP has established regional contaminant committees that review research proposals and ensure that regional and community concerns are addressed. In addition, national aboriginal organizations, regional governments, and land-claim organizations are part of the NCP management and help to determine research priorities and funding decisions. A specific funding envelope for community-based research and a committee that discusses application of TK as part of the program are some of the further products of this engagement.

At the national level in Canada, Inuit Qaujisarvingat: The Inuit Knowledge Centre, an initiative of Inuit Tapiriit Kanatami, aims to build capacity for Inuit to transition from being subjects of research to leading research based on local goals. Another example is the Alaska Native Science Commission, which was developed to support collaborations between Native communities and researchers and to serve as a clearinghouse and archive for past and ongoing research. These institutions may be useful in helping to build models for collaborative, community-led, integrative CBM initiatives that can contribute information to decision making locally, as well as regionally and nationally (Berkes et al., 2007).

The term "community-based monitoring" has more recognition in Alaska, Canada, and Greenland than it does in other regions. There is also regional and local diversity in the approaches to monitoring used. While TK is important in many parts of the Arctic, in more urban contexts with diverse populations, TK may be less relevant to community monitoring needs. Since currently little information about approaches to CBM that exist across the Arctic is available, it is important to document, analyze, and compare the different approaches used.

Communities around the Arctic are engaged in informal monitoring and observing based on TK and ongoing environmental engagement, and they have their own ways of sharing this knowledge (Mustonen and Lehtinen, 2013). Initiatives to document TK of environmental change and natural resource management practices include the Snowchange Cooperative, based in Finland, and the Eálat program, initiated by the International Centre for Reindeer Husbandry in Norway. Both Snowchange and Eálat document local knowledge and management systems in Indigenous languages that incorporate local cosmologies (Oskal et al., 2009; Mustonen and Lehtinen, 2013; Mustonen and Syrjämäki, 2013). Additional efforts and investments to document local observing traditions and systems more comprehensively, including how monitoring information is shared among residents of a community, would help ensure that future CBM initiatives build on and integrate insights from these existing local observing systems.

TOOLS AND METHODS

CBM initiatives draw on a variety of tools and methods depending on the community context, the data desired, and its intended use. As is the case in other approaches to monitoring, many of the potential limitations of CBM can be overcome by careful planning, explicit consideration of likely biases, thorough training and supervision of participants, and a clear communications plan (Danielsen et al., 2009; Kliskey et al., 2009; Gofman, 2010; Luzar et al., 2011). Planning and budgeting for community consultation and engagement in verification and analysis are also important. Below we review current approaches to data collection, analysis, and integration and suggest areas for further development.

Data Collection

Depending on the aims of the initiative, CBM data collection methods can use quantitative or qualitative approaches, or both. Methods may include scientific field research, photos, journals, drawing, focus groups, and interviews (Gofman, 2010). CBM that draws on TK typically involves eliciting and recording the observations and knowledge of community-identified experts through interviews, oral histories, and documentation of place names. Many communities are working to develop their own oral history archives; this has been a particular focus, for example, of the Snowchange initiative. The documentation and use of Indigenous languages is also an important resource for monitoring. For example, place names in local dialects can reflect landscape stability or change over time; efforts to document toponyms, such as the Yu'pik Environmental Knowledge Project (http://eloka-arctic.org/communities/yupik/), offer a resource for environmental monitoring rooted in local understandings of change.

Traditional knowledge documentation usually includes recording the wider context surrounding these observations through interviews, open-format discussion, semi-structured or structured surveys, or a combination. Traditional knowledge can also be collected by using journals or diaries kept by village monitors, as in the SIKU ice observation project in Alaska, Greenland, and Russia (Krupnik et al., 2010). Selection of observers should be guided by respected and knowledgeable members of the community who understand the purpose of the monitoring initiative. For example, a CBM initiative tracking changes in health and abundance of wildlife might engage active harvesters or active resource users (i.e., high-exposure observers) who have a longstanding familiarity with the territory.

Many Arctic CBM initiatives adapt technologies so they are easy to use, can reliably capture data in a cold environment, and will record data in a way that is responsive to local ways of interacting with the environment. Projects have successfully adapted and integrated field computers and Global Positioning System (GPS) units (Gearheard et al., 2011; Maynard et al., 2011), meteorological equipment (Weatherhead et al., 2010), sea ice monitoring tools (Mahoney et al., 2009), and other technologies (Danielsen et al., 2014b). Some initiatives use existing maps, often generated through Geographic Information Systems (GIS), to identify potential conflicts between industry and Indigenous uses of traditional territory (Tobias, 2009). For example, an International Polar Year (IPY) project conducted by researchers at the Norwegian Polar Institute and the Association of Nenets People Yasavey monitored industrial development on traditional-use lands in the Nenets Autonomous Okrug in Russia (http://ipy-nenets.npolar.no/). While the project was of limited duration, it provides baseline data that can be used for future social and environmental monitoring efforts in the region, and is helping the Nenets to protect their reindeer pasturelands against large-scale industrial development (Dallman et al., 2011).

Indigenous views have sometimes been critical of the role of technology in monitoring initiatives, particularly in monitoring animal populations: both Inuit and Sámi have raised concerns about some techniques used in wildlife monitoring and the impacts of certain technologies such as radio collars for bear monitoring (Mustonen and Syrjämäki, 2013) and other methods (ITK, 2009). A review of technologies used and their impact on animals conducted in cooperation with the Indigenous knowledge holders would help to reduce potential conflicts.

Data Interpretation and Analysis

Within communities, informal monitoring and observing play a significant role in daily life, providing information that is critical to safe travel and successful hunting and harvesting activities. In these approaches, analysis is also conducted informally as community members process what they have observed by discussing their observations with others. More formal monitoring initiatives require a thoughtful approach to planning how different kinds of knowledge can be involved in different stages of a project, including the data analysis phase. Efforts to identify methods for linking Indigenous and scientific knowledge production approaches should be a priority of future work in this field (Gill et al., 2011; Culp et al., 2012; Russell et al., 2013).

In formal CBM initiatives, data are often analyzed using quantitative and qualitative analytical methods and techniques, including statistical analysis and thematic identification and coding. Quality assurance and quality control of data require an established and documented procedure for data entry, error checking, error correction, and data verification. The procedure necessarily involves observers, community coordinators, and scientists working as a team (Alessa et al., 2013).

Program Design and Scale

Data and information generated by monitoring initiatives are an important resource for decision makers; however, the ability to represent CBM data within larger data repositories depends on careful attention to the way they are collected. The methods used for collecting local and TK will often determine whether or not the raw or synthesized knowledge can contribute to larger regional, national, pan-Arctic, and global data sets and assessments. Taking the time during the monitoring design phase to consider how methods relate to sharing and use of data at a larger scale may increase the project's long-term impact.

The Inuvialuit Settlement Region Community-Based Monitoring Program is an example of a CBM initiative that is being designed with attention to scale (ISR-CBMP; http://www.jointsecretariat.ca/ISR-CBMP; Knopp et al., 2013). This emerging initiative specifically seeks to develop a networked approach to monitoring that will allow local interests to shape the parameters of what is monitored and how the information is used and shared. The six communities involved will identify priorities for monitoring in dialogue with relevant co-management institutions, and data collection will involve expertise from TK experts as well as quantitative methods. The regional Inuvialuit Joint Secretariat will manage the data, placing a high priority on ensuring a flow of information to and among communities. A hierarchy of data users has been identified for future access, with communities retaining highest priority followed by co-management committees and finally third parties, such as government, academia, and industry (Knopp et al., 2013).

Another initiative, the Bering Sea Sub-Network (BSSN), was designed to provide insights about pan-Arctic processes through systematic collection of community-based environmental observations (Gofman and Smith, 2009). It comprises a "structured network" of eight communities in Russia and Alaska, whose members contribute their observations through a survey administered twice a year by trained community research assistants to capture information for the preceding two seasons. Data management and application were important parts of the project design. A steering committee, made up of one member from each community, advises the research team on sensitive issues and helps determine what data from the community can be released to the general public. This network and its successor, the Community-based Observing Network for Adaptation and Security (CONAS), have generated both aggregate reports and community-specific reports that can be used by different kinds of decision-making bodies at different scales (Gofman and Smith, 2009; Fidel et al., 2014).

DATA AND KNOWLEDGE MANAGEMENT

Like all monitoring programs, CBM initiatives generate significant amounts of data and information. Effective data management in initiatives that involve TK and respond to locally identified environmental management challenges requires both sensitivity and technical skill. Traditional knowledge documentation often removes this knowledge from the context in which it was developed, raising questions about the feasibility and desirability of knowledge integration (Agrawal, 2002). Data must be managed in a culturally sensitive way that promotes sharing when appropriate while ensuring that knowledge holders and communities retain control of their knowledge and data.

The management of data from TK occurs at the intersection of numerous norms and legal regimes that sometimes conflict (Hammer et al., 2013): these include cultural norms and traditional law, as well as Western legal regimes, specifically intellectual property law (Mauro and Hardison, 2000; Anaya, 2004; Cottier and Panizzon, 2004). Movements and trends in scientific data management, such as the "open data" movement, are not always appropriate for TK (IASC, 2013). Normative and legal frameworks related to data sharing may serve the interests of Indigenous peoples or superimpose incompatible requirements (Mauro and Hardison, 2000; Young-Ing, 2008; Capistrano and Charles, 2012).

Ethics protocols have been developed to guide research practices in and with Indigenous communities in a number of contexts. These protocols include guidelines specific to particular Indigenous groups within a single nation state, such as those created by and for Canadian Inuit communities (ITK and NRI, 1998, 2007). Similarly, in the Sámi context, multiple ethics codes are in use in different countries. The Code of Research Ethics adopted by the Alaska Native Science Commission is intended to apply to all research occurring with, by, and for federally recognized tribes in Alaska (ANSC, n.d.). Canada's OCAP (Ownership, Control, Access and Possession) principles are national in scope and apply to First Nations communities; these principles uphold the sovereignty and stewardship of First Nations knowledge holders over their own knowledge and data, which include the right to determine how these are managed and with whom they may be shared at all times (First Nations Centre, 2007). The Tkarihwaié:ri Code of Ethical Conduct is an example of an international code of conduct to "ensure respect for the cultural and intellectual heritage of Indigenous and local communities relevant to the conservation and use of biological diversity" (UNCBD, 2011). While they share some common themes, such as the rights of communities to control how knowledge will be used, with whom it will be shared, and how it will be stored over time, these codes are specific to their institutional and community contexts.

These various legal regimes and ethics protocols can be confusing for both communities and researchers. In regions where protocols for community or TK data protection are absent, it may be unclear who has the authority to use or share data generated through community-based initiatives. Researchers seeking to partner with Arctic Indigenous communities on CBM initiatives should seek guidance from regional and local governments and institutions on established protocols for research collaboration. At a minimum, all parties should agree upon protocols for information sharing and data storage in the planning stages of a project, before any data are collected.

There are also technical considerations for the protection of sensitive data. Solutions may include systems with multiple access roles, data encryption, protection of sensitive locations, and removing personally identifiable information to retain anonymity, though the latter can be difficult to achieve in small communities. Many of these solutions require in-depth knowledge of computing and information services, reflecting a growing need for third parties who can work sensitively with communities to pioneer new protocols. The Exchange for Local Observations and Knowledge of the Arctic (ELOKA; www.eloka-arctic.org) is one such initiative: researchers and systems experts work with local communities to think through and develop approaches to TK data management that are context-specific, helping to ensure that community requirements for protection of sensitive data are met effectively (Pulsifer et al., 2012). One example of a knowledge management product, implemented by ELOKA in collaboration with the Inuit Circumpolar Council and other partners, is the Atlas of Community-Based Monitoring in a Changing Arctic (www.arcticcbm.org), an online inventory of CBM and TK initiatives. The atlas is a tool for networking and visibility of CBM initiatives and helps to connect them to the broader Arctic observing community.

In addition to cultural and legal issues, challenges related to technology infrastructure also shape how CBM and TK are managed. Access to technology remains a problem for northern communities, and Internet speed is considerably slower in higher latitudes than in lower latitudes of Arctic nations because of infrastructural inequities. These considerations need to be reflected in the development of plans for storing and sharing data.

Technical considerations related to interoperability that are specific to CBM and TK also must be considered. Interoperability has been defined as "circulation of data across diverse technical platforms, organizational environments, disciplines and institutions" (Millerand and Bowker, 2009:150). Interoperability issues occur at three levels: 1) data storage format, which includes issues in exchanging different formats and the use of different character sets (e.g., syllabics); 2) data structure, which includes how the data are organized (in flat files or relational databases, for example); and 3) data semantics and "semantic interoperability." The last issue relates to the fact that data sets are in fact references to larger systems of meaning and understanding (Sillitoe, 1998; Wellen and Sieber, 2013) and is perhaps the most difficult aspect of data management to address.

A final area to consider is the need for long-term preservation to ensure that data can continue to be accessed over time. Specifically, there is a need to ensure that the individuals and communities that share the results of CBM and TK documentation projects have continued access to the materials. Such access can become an issue when funding needed to maintain either a physical or digital repository is not secured.

SHARING, APPLICATION AND USE OF DATA

The ultimate goal of all Arctic monitoring initiatives is to apply and use the monitoring data, yet these outcomes remain difficult to assess. The use of data relates in part to how widely data are shared, what format they are shared in, and their perceived relevance to critical decision-making issues and challenges. Community-based monitoring is more locally embedded than other types of monitoring, which suggests that the data and information generated through these initiatives are more likely to be applied in decision making at a local scale. At the same time, its community-centered nature also means that sharing data and information across scales at the regional or national levels can be more challenging.

Research suggests that higher levels of community engagement in monitoring lead to use of the information in local environmental management and decision making (Brook et al., 2009; Conrad and Hilchey, 2011). A recent study compared how much time it takes to make a policy decision based on monitoring results in scientist-driven monitoring programs versus community-based monitoring (Danielsen et al., 2010). The authors found that monitoring activities involving local residents often lead to policy changes within one year of the data acquisition and analysis, compared to three to nine years for scientist-executed monitoring programs. Additionally, while scientist-executed monitoring programs motivate decisions on regional, national, and international levels, they have little impact at a community scale. The authors concluded that increasing the degree of local participation in monitoring efforts enhances management responses at the local scale. Another study found that for the same recurrent government investment, community-based biodiversity monitoring resulted in more conservation management actions than conventional research methods (Danielsen et al., 2007).

While these studies present strong evidence that CBM approaches lead to application and use of data at the local level, the links between local initiatives and information needs at other levels of scale (regional, national, global) remain largely underdeveloped. CBM methods, including documentation of TK through qualitative methods such as interviews, can be difficult to translate into data formats that can be aggregated or shared in ways that are relevant for non-local use. Sensitivities related to data ownership and sharing of TK may also prevent data sharing. Additionally, even when community members want to share their data and results, they often lack the resources and capacity to disseminate them through conventional scientific conference presentations and publications. It is therefore important for program designers to consider both the data sharing goals of communities and the requirements of potential data users to help ensure that data are collected in a format compatible with data-sharing infrastructures and that community participation is adequately resourced.

SUSTAINABILITY AND CAPACITY BUILDING

A critical aspect of establishing a successful CBM initiative is sustainability. Since monitoring programs by their very nature require long-term plans and sustained work, long-term funds must be committed in order for any program to succeed. In practice, however, it is rare for CBM initiatives to find or secure long-term funding. Funding agencies almost without exception fund only projects with timelines of a few months to a few years. Multiyear funding can be conditional or dependent on available funds, and renewal of projects beyond the initial multiyear commitment is rare. Communities that do manage to maintain monitoring programs over time often have to piece together funding from various sources, which may result in gaps in data collection. A lack of sustained funding can endanger not only long-term data collection, but also the preservation and maintenance of data already collected.

National and regional funding programs and networks play an important role in supporting monitoring initiatives. Interest in CBM among funding communities is growing; in Canada, programs such as the Northern Contaminants Program and ArcticNet have funded community-based projects, while in the United States, the Inter-Agency Arctic Research Policy Committee identified engagement of Indigenous knowledge holders and communities in monitoring as one of its priorities for Arctic funding for 2013–2017. In recent years, some agencies have committed significant funds to CBM and TK programs and initiatives. The National Science Foundation has made commitments to the BSSN and ELOKA; Environment Canada provided pilot funding for the Canadian Community Monitoring Network (CCMN); and the Government of Canada supported the Circumpolar Flaw Lead Study during the IPY, which included a focus on TK and the links between "two ways of knowing" about flaw leads and the marine ecosystem (Pulsifer et al., 2012).

While these are positive developments and welcome investments, a challenge shared with other observing networks has been the short-term rather than sustained nature of funding through initiatives such as the International Polar Year. There is a need for funding streams that provide long-term, multiyear, renewable funding mechanisms for CBM programs. Meanwhile, there is also a challenge of unequal opportunity; for example, communities in the Russian Arctic have few funding sources from which to initiate community-based monitoring.

The short-term and sporadic nature of many CBM initiatives has a direct impact on community interest and motivation. Participatory and bottom-up approaches are intended to give local residents significant control over monitoring and engage them for the long term; these efforts are disrupted if a project is cut short or fails for lack of funding. In such instances, residents can feel frustrated and disheartened, which leads to waning interest and motivation.

Other factors also affect the interest and engagement of community practitioners. In community-led CBM initiatives that involve TK, the inter-generational transmission of knowledge and skills is integral to continuity of observing systems. Supporting efforts to pass on TK is therefore significant to sustainability in these contexts. In formal CBM initiatives, community members should receive appropriate training, equipment, and infrastructure and other support in order to carry out monitoring efforts (Gofman, 2010). Residents that gain new knowledge and skills from participating in CBM efforts understand and can teach others about the nature and importance of their monitoring results and can help make these results available to local decision makers (EMAN, 2003). Having a sense of ownership of the initiative motivates CBM observers and workers to maintain and develop it, thus leading to stability and sustainability.

Local residents involved in CBM initiatives are not the only ones who require capacity building for the long-term success of CBM; partnering scientists, funders, and government workers also need to develop new skills, capacities, and knowledge areas. Issues of personnel turnover plague government agencies as well as community initiatives; CBM projects suffer when government staff who have developed trust with communities are replaced. Partnerships are strongest and most successful when they build on relationships over time and when non-local partners have familiarity with the social and ecological fabric of the community involved (Gearheard and Shirley, 2007; Pearce et al., 2009).

CBM programs that participate in larger networks have the benefit of sharing information that is of local interest (community-to-community sharing). By linking to other monitoring and scientific research initiatives, community members gain a sense of being part of a wider collective. They also gain access to new ideas and resources that can improve techniques and lead to new discoveries. Being part of a larger network can therefore help sustain energy, interest, and excitement at the community level.

One model of network building and information sharing that has shown promise in both the North American and Eurasian contexts involves bringing together communities from different regions to focus on a shared area of interest, such as sea ice (Gearheard et al., 2013) or reindeer herding. Chukchi and Eastern Sámi reindeer herders have been involved in Snowchange conferences and community workshops over the past decade to exchange views on herding, weather change, and the role of motorization in herding (Mustonen and Mustonen, 2010, 2011). A similar initiative allowed Eastern Sámi living along the Ponoi River in Russia to exchange views on salmon co-management with the Eastern Skolt Sámi who live on the Näätämö River in Finland (Feodoroff and Mustonen, 2013).

Ultimately, sustainability depends on making the information generated from monitoring programs available to individuals who need it to make informed decisions. From this perspective, sharing and using the information generated by CBM initiatives becomes integral to the ongoing success of these programs. Individual community programs may not have the capacity to summarize and synthesize data to share with decision makers beyond the community level, which suggests an important role for networks and regional CBM initiatives in linking community observing needs to larger information-sharing and funding platforms.

DISCUSSION AND CONCLUSION

Community-based monitoring has considerable potential to engage the capacities and knowledge of Arctic residents, including TK holders, in support of a robust international

Arctic observing system. In spite of this potential, CBM also has limitations that need to be considered when determining what approach to monitoring will work best in any given context. Some monitoring needs, such as monitoring across large spatial scales without settlements, or in particular environments (deepwater marine ecosystems, ice caps, and mountaintops) where Arctic residents do not routinely travel, cannot be met by CBM alone. The establishment of community-based initiatives should not replace the involvement of government and academic scientists in long-term monitoring, which is essential for sustainable Arctic science.

CBM also has challenges and biases, some that are common to all long-term monitoring and some that are unique. The routine observations of Arctic residents are shaped by their particular engagements with the environment, which means that they may be more attentive to certain phenomena than to others; this focus varies by individual and community, but it can make data collection across a number of communities challenging. Another challenge is lack of experience and training in formal data collection methods. While projects may include methods training for community collaborators, it can be difficult to ensure that a sufficient level of skill is attained, particularly if training is conducted in a short, workshop format. This skill deficit can result in problems with data collection that need to be addressed later, slowing progress and creating gaps in data. Lack of sustained funding, staffing changes, or dwindling interest on the part of community members can also lead to data gaps (Conrad and Hilchey, 2011).

Another issue is that CBM data are not always used to inform decision making. In some cases, some scientists and decision makers may have concerns about the accuracy of data collected through CBM approaches (Conrad and Daoust, 2008). Perhaps more frequently, data are not used for lack of ties to wider networks or integration into existing natural resource governance systems that would offer a clear mechanism for uptake by decision makers. Mapping out these connections during the program design phase can help ensure that data are translated into useful formats and delivered to interested parties.

CBM initiatives, particularly those that aim to make data accessible and applicable, can require significant logistical support from outside the community, which can be difficult to sustain financially at the program level over the long term. One solution to this problem lies in the establishment of organizations that can provide centralized services for diverse CBM projects. ELOKA, which offers data management support for community-based initiatives, is one example.

Many of the elements that contribute to the success of environmental monitoring programs in general are applicable to CBM and, if adopted, can help avoid these pitfalls. For example, Lovett et al. (2007:258) identify "seven habits of highly successful monitoring programs": designing the program around clear and compelling questions; including space for review and adaptation in the program design; choosing measurements carefully; maintaining quality and consistency of data; planning for long-term data storage and accessibility; continually examining, interpreting, and presenting the monitoring data; and including monitoring within an integrated research program. All of these habits are relevant to CBM programs.

Successful implementation of community-based monitoring programs requires ongoing partnerships between local communities and individuals and institutions outside the community, including academic or government scientists. These partnerships take time to develop and require considerable flexibility, creativity, and commitment from all parties involved. A collaborative or co-production approach uses TK and insights from community members alongside methods from social and natural sciences. Co-production has resulted in novel insights informed by Indigenous systems of monitoring, as well as in data that can be used quickly and easily by decision makers at various levels. More research and documentation of collaborative approaches to CBM will yield new insights that can strengthen the field. There is also a need to ensure that more formal CBM programs build on the ongoing monitoring within communities that is based on TK.

In its current state, CBM is not yet living up to its potential. Significant work remains to build networks among initiatives, build capacity for CBM in communities and regions where it remains underdeveloped, refine methods, and develop protocols for sharing data more widely. Investment and support are needed for developing new tools (e.g., for data management), training local residents to implement monitoring programs and interpret their results, and creating opportunities to exchange best practices, new research, and innovations in this field. Each of these elements will require robust, sustained funding and committed engagement from the Arctic observing community. An important first step is to identify relevant institutions and organizations interested in CBM and to develop stronger linkages among them that will facilitate networking and outreach.

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